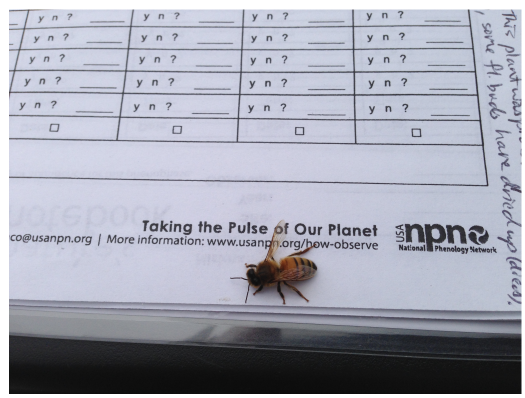
National Park Service
U.S. Department of the Interior

Redwood National & State Parks California Phenology Project Summary Report (2011-2015)



ON THIS PAGE
Left-hand photos: Student interns and volunteers learning to observe silky beach pea (*Lathyrus littoralis*) phenophases at the KVC monitoring location [Credits: Kevin Linowski]
Top right: Phenological monitoring workshop led by Susan Mazer (CPP; UCSB) with an exemplary rhododendron (*Rhododendron* sp.) and NPS interpretive rangers (Steven Krause & Jim Wheeler)
Bottom right: Phenological monitoring datasheet [Credit: Elizabeth Tina Wu]

ON THE COVER
Top right: Pacific rhododendron (*Rhododendron macrophyllum*) [Credit: Stassia Samuels]
First row: Pacific trillium (*Trillium ovatum*) [Credits: Brian Haggerty; David Hoffman; Steven Krause]
Second row: Silky beach pea (*L. littoralis*) [Credits: S. Krause; B. Haggerty]
Third row: Coyotebrush (*Baccharis pilularis*) [Credits: Jerry Kirkhart; Crystal Anderson; C. Anderson]

Redwood National & State Parks
California Phenology Project
Summary Report (2011-2015)

October 2015

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INTRODUCTION

Phenology

Phenology is the study of the timing of biological events—in particular, seasonal occurrences and key transitions in growth and reproduction. For example, at Redwood National & State Parks (REDW), we have monitored several species to track when plants leaf out in early spring, begin blooming, and eventually set fruit in summer or fall. Phenological cycles characterize all species, as demonstrated by life cycles, animal migrations, mass insect emergences, algal blooms, mushroom seasons, etc. Apart from the phenology of individual species, there are phenological aspects to many interspecific interactions, such as the synchrony of early spring flowers with pollinator emergence, the arrival of migratory birds and whales during peak productivity in polar regions, and almost all human activities that depend on the seasons (*e.g.*, traditional hunting and gathering of wild foods, nomadic pastoralism, modern regulation of hunting seasons, hay fever/allergy season, flu season, fleas on pets, gardening, eco-tourism, etc.).

Phenology is both a fascinating biological phenomenon and a topic of practical concern. In conservation work, it is essential to understand the seasonal cycles of species of interest (*i.e.*, their basic biology, including phenology, along with ecological relationships, habitat, threats, etc.) in order to preserve them. In agriculture, the timing of phenological events in domesticated plants and animals may be manipulated to increase their economic value and productivity (*e.g.*, breeding plants to produce fruits relatively early or late in the season, or artificially illuminating chickens to prolong egg-laying), and must be accounted for when aiming to control their predators and pollinators.

With climate change becoming more and more evident, many aspects of life are increasingly affected. Many plant species have been observed to flower earlier than their historical averages. Because of the interconnected nature of life, these "phenological shifts" can have consequences for other species. For instance, if a specialized pollinator emerges after the plant it depends on has already flowered, this "phenological mismatch" could lead to that pollinator species going extinct.

Project Background

In 2010, the California Phenology Project (CPP) was formed as a partnership between the National Park Service (NPS) Pacific West Region, the USA National Phenology Network (USA-NPN), and the University of California, Santa Barbara (UCSB), with funding from the NPS Climate Change Response Program (CCRP). The goals of the CPP are to: a) help develop phenological monitoring programs in California's National Parks, the University of California's Natural Reserve System, and other private and public lands; b) promote public education and engage "citizen scientists" in phenological monitoring; and c) support long-term phenological monitoring and contribute to the USA-NPN database, thereby facilitating research on the link between phenology and climate change, and informing adaptive management of California's natural resources.

The CPP and Redwood National & State Parks (REDW) collaborated to establish the phenological monitoring program at REDW. The CPP advised REDW and provided phenological monitoring resources, including "California Phenology Project (CPP) plant Phenological Monitoring Protocol" (Matthews et al, 2014. NRSS publication 2014/763) and "Phenological Monitoring Guide: Redwood National Park" (Appendix E of Matthews et al., 2014). In June 2011, three phenological monitoring locations were established at REDW, and data collection commenced for six plant species.

Report Goals

This report summarizes activities of the phenological monitoring program at Redwood National & State Parks (REDW) from 2011-2015. The objectives of this report are to: a) provide a project summary; b) present phenological data, in terms of both preliminary results and monitoring effort; and c) discuss the future of the REDW phenology program.

Emphasis will be given to more recent developments (*i.e.*, since the previous report in 2013) and achievements to date. For details about the establishment of this project, please refer to Matthews et al. (2014). And for more information about the pilot phase (2011-2013), refer to the "California Phenology Project (CPP): Report on Pilot Phase Activities" (Matthews et al., 2013, NRSS publication 2013/743; pages 37-39).

Phenological data will be presented here in the form of preliminary results and to summarize the monitoring effort (*i.e.*, program participation) at REDW. The preliminary results are just that—hints at what may be real phenological patterns, which must be confirmed by longer term data collection and rigorous statistical analyses. Data entry has not caught up with monitoring effort, but will be completed and brought up-to-date in the coming weeks. Continued phenological monitoring is necessary to substantiate phenological findings, and to detect future phenological trends. Detailed data analysis and statistical tests are beyond the scope of this report, but recently published research by Dr. Susan Mazer includes the statistical analyses of phenological data collected at several CPP locations, including data for coyotebrush (*Baccharis pilularis*) at REDW (please refer to Mazer *et al*. 2015).

METHODS

Phenological monitoring at Redwood National & State Parks (REDW) follows guidelines created by the USA National Phenology Network (USA-NPN) and the California Phenology Project (CPP). Detailed protocols can be found in Matthews et al. (2014).

Study Design

Plant Species

Six plant species were originally selected for phenological monitoring at Redwood National & State Parks; four species have been retained for continued monitoring. Phenological monitoring began at REDW in 2011, and included the following six species: coyotebrush (*Baccharis pilularis*), common cowparsnip (*Heracleum maximum*, formerly *H. lanatum*), silky beach pea (*Lathyrus littoralis*), Pacific rhododendron (*Rhododendron macryophyllum*), Pacific trillium (*Trillium ovatum*), and red elderberry (*Sambucus racemosa*). Common cowparsnip and red elderberry were monitored for three years (2011-2013), but were discontinued for logistical reasons (the long distance to monitoring sites, the high travel cost, and the lack of available volunteers). Coyotebrush, silky beach pea, Pacific rhododendron, and Pacific trillium have each been monitored for all 5 years (2011-2015) of the study so far, and coyotebrush and Pacific rhododendron are still being monitored (as of fall 2015).

For species information and photos of phenophases (*i.e.*, developmental stages), please refer to the "Phenological Monitoring Guide: Redwood National Park" (section III, pages 5-12) or the project website (https://www.usanpn.org/cpp/taxonomy/term/4).

Coyotebrush is monitored at two study locations, KVC (outside the Kuchel Visitor Center) and CBO (around the Crescent Beach Overlook), which are in the northern and southern sections (respectively) of Redwood National & State Parks. Silky beach pea is also monitored at KVC. Pacific rhododendron and Pacific trillium are monitored at LBJ (along the trail at Lady Bird Johnson Grove). Common cowparsnip and red elderberry were monitored at CBO.

Study Area

Three study locations were established in 2011 at Redwood National & State Parks for phenological monitoring (Figure 1). The KVC monitoring location is the area surrounding the Kuchel Visitor Center, which is near the southern "entrance" of the park. KVC is characterized by coastal dune habitat, and coyotebrush and silky beach pea are monitored there. The LBJ monitoring location is the trail at Lady Bird Johnson Grove, which is in an upland area in the southern section of the park. LBJ represents old-growth redwood forest, where Pacific rhododendron and Pacific trillium are monitored. The CBO monitoring location is the vicinity of the Crescent Beach Overlook, which is in the northern section of the park. CBO is predominantly coastal bluff habitat, and originally included three study species (coyotebrush, common cowparsnip, and red elderberry), but coyotebrush is the only species still monitored there.

For more study area information and additional maps, please refer to the "Phenological Monitoring Guide: Redwood National Park" (section IV, pages 13-18) or the project website (https://www.usanpn.org/cpp/REDW/maps).

Figure 1. Phenological monitoring locations at Redwood National & State Parks

* Credit: Joshua Van Buskirk (NPS-REDW Cartographic Technician)

Phenological Monitoring

The mapped and labeled plants of each species were observed throughout the growing season to record their phenological status (*i.e.*, their growth and progression through life cycle events). Phenological data were then entered into the National Phenology Database (NPDb) and curated by the USA National Phenology Network (USA-NPN). The goals of phenological monitoring at Redwood National & State Parks (REDW) were: a) to contribute to the long-term, large-scale dataset archived on USA-NPN servers and available for downloading; b) to enable the detection of phenological shifts over time and space (*e.g.*, earlier flowering times) and their possible causes (esp. climate change); and thus c) to inform scientists, natural resource managers, and the general public of the link between the phenology of charismatic and ecologically important plant species at REDW.

Monitoring Protocol

REDW phenology observers (NPS staff, student interns, and citizen science volunteers) visited each monitoring location to record the phenological development of the study species. During each visit, observers recorded which phenophase(s) (*i.e.*, growth stage &/or key reproductive development) were exhibited by each plant, and when sufficiently familiar with these phenophases, they would also record “phenophase intensity” (*i.e.*, quantitative measurements). Observers would check on all pre-selected plants of each study species at a given monitoring location. These selected plants (individuals or patches, in the case of silky beach pea) were the same plants observed during each visit and monitored each year.

Phenology observers would record the phenological status of plants at each location one per week (at a minimum), but two or more times a week when staff or interns were available. For each study species at REDW, phenological monitoring aimed to span the entire course of its “phenologically active” period, defined as the period during which transitions between phenophases were most likely to occur (*e.g.*, early spring to mid-summer for Pacific trillium). In practice, this was accomplished for some plant species in some years, and was dependent on observer availability.

For more information about phenological monitoring, please refer to the “California Phenology Project (CPP) plant Phenological Monitoring Protocol” (Matthews et al. 2014, section 3.1, pages 11-12; section 5.3, pages 17-18) and the “Phenological Monitoring Guide: Redwood National Park” (Matthews et al. 2013, sections V-VI, pages 19-20).

Data Entry & the USA-NPN Database (NPDb)

REDW phenological data was submitted to the National Phenology Database (NPDb), which is curated by the USA National Phenology Network (USA-NPN). Data entry was done using “Nature’s Notebook” (the USA-NPN online interface for recording phenological observations). It is best for data entry to be done by the observer who recorded the observations, in relatively prompt fashion, in order to minimize confusion concerning whether data have been uploaded.

For details on data entry, please refer to the "California Phenology Project (CPP) Plant Phenological Monitoring Protocol" (Matthews et al. 2014, NRSS publication 2014/763; section 6, pages 19-20) and the "Phenological Monitoring Guide: Redwood National Park" (sections V-VI, pages 19-20).

The National Phenology Database (NPDb) provides access to phenological observations of many species, at many locations nationwide, and from various phenology projects, including historical, contemporary, and ongoing research. The NPDb is thus a species-rich, large-scale, and long-term phenological dataset.

Phenological Summaries

Phenological data can be extracted from the National Phenology Database (NPDb) for further research using its Data Download tool. The USA-NPN website also includes features for summarization and preliminary analysis of phenological data, and also provides access to download data for more analyses. I used the Phenology Visualization Tool (USA-NPN website) to generate phenological summaries, to characterize annual phenological cycles from year to year, and to detect possible phenological shifts). The phenological summaries include "pheno-calendars" that illustrate seasonal changes in phenological activity (*i.e.*, all yes/no datapoints for each phenophase over the course of the entire year or monitoring period) for each study species in each year monitored. These summaries can also demonstrate potential inter-annual trends in phenological activity.

For more details and additional analytical methods, please refer to the "California Phenology Project (CPP) Plant Phenological Monitoring Protocol" (Matthews et al. 2014, NRSS publication 2014/763; section 7, page 21).

Climatic Data

In order to compare phenological trends with climate patterns, I compiled climatic data from the study period (2011-2015) for Redwood National & State Parks (REDW). I obtained climatic data from the PRISM Climate Group, which incorporates data from many sources, applies quality control measures, and uses sophisticated modeling techniques to generate dynamic datasets, at multiple spatio-temporal resolutions, for climate patterns of the historical past to present (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, accessed 1 October 2015). Climate data were extracted from the PRISM database for REDW's Kuchel Visitor Center (*i.e.*, the KVC monitoring location), which I selected as a representative location for the study area.

From the PRISM climatic dataset (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu/explorer/, dataset created 1 October 2015), I extracted total precipitation and mean temperature (T_{min}, T_{mean}, T_{max}) for each month from January 2011 to August 2015. I also obtained "30-year normals" for precipitation and temperature, which are the mean values of monthly and annual climatic conditions over the most recent three decades (*i.e.*, 1981-2010), and thus represent historical conditions (prism.oregonstate.edu/normals/). I then calculated precipitation and temperature "departures" (*i.e.*, deviations) from the 30-year normal, in order to compare recent climate with historical conditions (cf. Mazer *et al*. 2015). Climatic departures from the "normal" can be used to infer whether, for example, a given month was drier than the historical average for that month during the last three decades (*i.e.*, a negative deviation) or, for another example, whether a given year was hotter than "normal" compared to the last three decades (*i.e.*, a positive deviation).

RESULTS

Annual Climate Summary

From the PRISM Climate Group (Oregon State University, http://prism.oregonstate.edu, dataset created 1 October 2015), I obtained climatic data from 2011-2015 at Redwood National & State Parks (Kuchel Visitor Center). Annual precipitation at REDW has fluctuated greatly between 2011-2015 (Table **1**), with some years receiving more precipitation than "normal" (*i.e.*, compared to the average from 1981-2010), and other years receiving less (Table **2**). Temperatures at REDW have also varied over the years between 2011-2015 (Table **3**), with some years experiencing lower temperatures than "normal" (*i.e.*, compared to the averages from 1981-2010), and other years being warmer than "normal" (Table **4**).

Table 1. Summary of monthly precipitation (PPT, mm) from 2011-2015 and "30-year normal" precipitation (*i.e.*, average PPT from 1981-2010) at Redwood National & State Parks (Kuchel Visitor Center; 124.092 W, 41.287 N). The KVC monitoring location was selected to provide representative climate data for REDW, and data were downloaded from the PRISM database (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, dataset created 1 October 2015).

	Year					30-yr normals
	2011	2012	2013	2014	2015	(1981-2010)
January	82.66	265.18	104.26	66.82	61.16	219.21
February	136.48	107.91	53.27	240.06	185.82	190.38
March	376.45	419.79	97.07	249.59	119.64	183.96
April	170.18	184.12	78.27	66.80	72.95	117.98
May	52.33	38.62	61.07	51.77	2.76	71.65
June	44.43	85.39	25.96	20.73	6.22	33.93
July	7.32	25.73	0.00	0.11	2.29	5.99
August	2.09	3.19	0.52	0.04	15.00	8.26
September	7.19	0.33	120.49	85.03		17.97
October	115.93	117.05	1.14	194.93		80.72
November	146.83	285.64	63.34	138.23		195.64
December	98.40	344.83	34.14	315.49		263.21
Annual Total	1240.29	1877.78	639.53	1429.60		1388.91

Table 2. Departures from "30-year normal" precipitation (ΔPPT, mm) at Redwood National & State Parks (Kuchel Visitor Center; 124.092 W, 41.287 N). Departures are comparisons between recent precipitation (recorded in a given year) and historical precipitation (averaged from 1981-2010).

	Year				
	2011	2012	2013	2014	2015
January	-136.55	45.97	-114.95	-152.39	-158.05
February	-53.90	-82.47	-137.11	49.68	-4.56
March	192.49	235.83	-86.89	65.63	-64.32
April	52.20	66.14	-39.71	-51.18	-45.03
May	-19.32	-33.03	-10.58	-19.88	-68.89
June	10.50	51.46	-7.97	-13.20	-27.71
July	1.33	19.74	-5.99	-5.88	-3.70
August	-6.17	-5.07	-7.74	-8.22	6.74
September	-10.78	-17.64	102.52	67.06	
October	35.21	36.33	-79.58	114.21	
November	-48.81	90.00	-132.30	-57.41	
December	-164.81	81.62	-229.07	52.28	
Overall annual departure*	-148.62	488.87	-749.38	40.69	-365.52
Summary of difference**	2011 was drier than normal	2012 was wetter than normal	2013 was much drier than normal	2014 was slightly wetter than normal	2015 is currently drier than normal

* Overall departure for 2015 is a comparison of total precipitation from January-August 2015 with the 30-yr normals' monthly PPT from the same timeframe.

** The summary of difference is that between recent conditions and historical 30-year normals.

Table 3. Summary of monthly temperature (Tmin, Tmean, Tmax; °C) from 2011-2015 and "30-year normal" temperature (*i.e.*, average Temp from 1981-2010) at Redwood National & State Parks (Kuchel Visitor Center; 124.092 W, 41.287 N). The KVC monitoring location was selected to provide representative climate data for REDW, and data was downloaded from the PRISM database (PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, dataset created 1 October 2015).

	Year 2011			2012			2013			2014			2015			30-yr normals (1981-2010)		
	T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}	T_{min}	T_{mean}	T_{max}
January	5.2	9.1	13.1	6.2	9.8	13.4	3.1	6.9	10.7	5.3	9.8	14.4	7.0	10.9	14.8	6.0	9.2	12.4
February	3.6	7.6	11.6	5.6	9.2	12.9	3.1	7.5	11.9	6.7	9.8	12.9	8.2	12.0	15.8	6.0	9.3	12.7
March	6.6	9.2	11.9	4.9	7.8	10.7	5.4	8.9	12.4	7.5	11.2	14.8	7.7	11.7	15.7	6.2	9.6	13.1
April	5.8	8.9	12.0	7.2	9.8	12.5	6.7	10.2	13.8	7.1	10.9	14.7	6.0	10.1	14.2	6.5	10.1	13.7
May	7.1	10.4	13.7	7.0	10.6	14.2	8.1	11.6	15.2	9.6	13.0	16.4	8.8	11.7	14.6	8.2	11.5	14.9
June	9.9	13.0	16.0	8.8	12.0	15.2	9.9	13.5	17.0	9.6	13.5	17.3	10.9	14.2	17.4	9.5	12.9	16.2
July	10.6	14.0	17.4	10.8	13.3	15.8	10.9	13.9	16.8	11.7	15.0	18.2	11.9	15.7	19.5	10.4	13.7	16.9
August	11.2	14.4	17.7	10.8	13.5	16.1	11.3	14.4	17.4	12.0	14.9	17.8	12.1	15.6	19.1	10.8	14.1	17.4
September	11.1	15.5	19.9	8.3	11.5	14.7	11.1	14.6	18.0	11.3	15.2	18.9				9.8	13.6	17.5
October	11.0	14.8	18.5	8.9	12.5	16.1	6.5	10.8	15.1	11.0	14.6	18.0				8.2	12.2	16.2
November	2.8	8.0	13.3	8.4	11.4	14.3	5.8	10.2	14.7	9.0	12.3	15.4				7.0	10.4	13.9
December	6.1	10.4	14.8	5.5	8.1	10.7	2.6	6.9	11.2	9.0	11.5	13.9				5.8	8.9	12.0
Annual Average	7.6	11.3	15.0	7.7	10.8	13.9	7.0	10.8	14.5	9.2	12.6	16.1				7.9	11.3	14.7

Table 4. Departures from "30-year normal" temperatures (ΔTmin, ΔTmean, ΔTmax; °C) at Redwood National & State Parks (Kuchel Visitor Center; 124.092 W, 41.287 N). Departures are comparisons between recent temperatures (recorded in a given year) and historical temperatures (averaged from 1981-2010).

	Year														
	2011			2012			2013			2014			2015		
	ΔT_{min}	ΔT_{mean}	ΔT_{max}	ΔT_{min}	ΔT_{mean}	ΔT_{max}	ΔT_{min}	ΔT_{mean}	ΔT_{max}	ΔT_{min}	ΔT_{mean}	ΔT_{max}	ΔT_{min}	ΔT_{mean}	ΔT_{max}
January	-0.8	-0.1	0.7	0.2	0.6	1.0	-2.9	-2.3	-1.7	-0.7	0.6	2.0	1.0	1.7	2.4
February	-2.4	-1.7	-1.1	-0.4	-0.1	0.2	-2.9	-1.8	-0.8	0.7	0.5	0.2	2.2	2.7	3.1
March	0.4	-0.4	-1.2	-1.3	-1.8	-2.4	-0.8	-0.7	-0.7	1.3	1.6	1.7	1.5	2.1	2.6
April	-0.7	-1.2	-1.7	0.7	-0.3	-1.2	0.2	0.1	0.1	0.6	0.8	1.0	-0.5	0.0	0.5
May	-1.1	-1.1	-1.2	-1.2	-0.9	-0.7	-0.1	0.1	0.3	1.4	1.5	1.5	0.6	0.2	-0.3
June	0.4	0.1	-0.2	-0.7	-0.9	-1.0	0.4	0.6	0.8	0.1	0.6	1.1	1.4	1.3	1.2
July	0.2	0.3	0.5	0.4	-0.4	-1.1	0.5	0.2	-0.1	1.3	1.3	1.3	1.5	2.0	2.6
August	0.4	0.3	0.3	0.0	-0.6	-1.3	0.5	0.3	0.0	1.2	0.8	0.4	1.3	1.5	1.7
September	1.3	1.9	2.4	-1.5	-2.1	-2.8	1.3	1.0	0.5	1.5	1.6	1.4			
October	2.8	2.6	2.3	0.7	0.3	-0.1	-1.7	-1.4	-1.1	2.8	2.4	1.8			
November	-4.2	-2.4	-0.6	1.4	1.0	0.4	-1.2	-0.2	0.8	2.0	1.9	1.5			
December	0.3	1.5	2.8	-0.3	-0.8	-1.3	-3.2	-2.0	-0.8	3.2	2.6	1.9			
Overall annual departure*	-0.3	0.0	0.3	-0.2	-0.5	-0.8	-0.9	-0.5	-0.2	1.3	1.3	1.4	1.1	1.4	1.7
Summary of difference**	2011 was similar, but with a slightly larger temperature range			2012 was cooler overall			2013 was cooler overall			2014 was warmer overall			2015 is currently warmer overall		

* Overall departure for 2015 is a comparison of average temperature from January-August 2015 with the 30-yr normals' monthly temperatures from the same timeframe.

** The summary of difference is that between recent conditions and historical 30-year normals.

Phenophase Activity

The phenological status of selected plants has been observed for five consecutive years (2011-2015) at all three monitoring locations (KVC, LBJ, and CBO) of the California Phenology Project at Redwood National & State Parks. Four plant species (*Baccharis pilularis*: BAPI; *Lathyrus littoralis*: LALI; *Rhododendron macrophyllum*: RHMA; and *Trillium ovatum*: TROV) have been monitored for the entire study period, whereas two species (*Heracleum lanatum*: HELA and *Sambucus racemosa*: SARA) were monitored for only the first three years. At the time of data analysis for this report, there were 87,074 records from Redwood National & State Parks available via the National Phenology Network's Phenology Visualization Tool (Table **7**).

Coyotebrush (*Baccharis pilularis*)

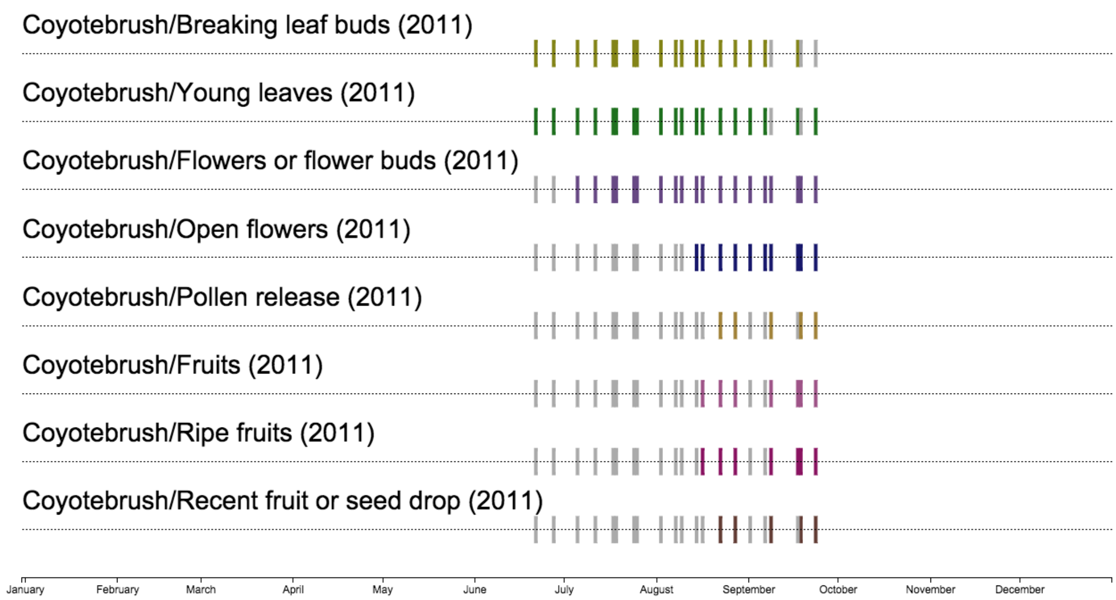
Coyotebrush (*Baccharis pilularis*) has been monitored for all five years (2011-2015) at two locations (near the Kuchel Visitor Center and the Crescent Beach Overlook) (Figure 2; colored vertical bands indicate dates on which observers recorded that the focal phenophase was visible; gray vertical bands indicate dates when observers definitively did not see the focal phenophase.). During the first year (2011), when project development was still underway, observers captured the date of onset of all reproductive phenophases, but not the termination date of its reproductive season (Figure 2A). Unfortunately, there was a hiatus in the phenological data collection in 2013 (Figure 2A and C). Coyotebrush was well monitored during 2012 and 2014, and the 2015 data collection is promising as well (Figure 2A B, D, & E). As of this report-writing, coyotebrush was the best-represented species in the REDW dataset, with 18,292 records available via the NPN's Phenology Visualization Tool.

While this species' phenological cycle seems to have varied over the years (Figure 2), most phenophases have not demonstrated a clear shift in time. Pollen release*, however, seems to be starting and finishing earlier in the fall in 2014 relative to 2012 (Figure 3). Coyotebrush is a dioecious plant, so if male flowers mature significantly earlier than female flowers, there may ultimately be a "phenological mismatch" between the sexes—there would be a shrinking window of time when pollination could successfully occur, which could negatively affect total seed production.

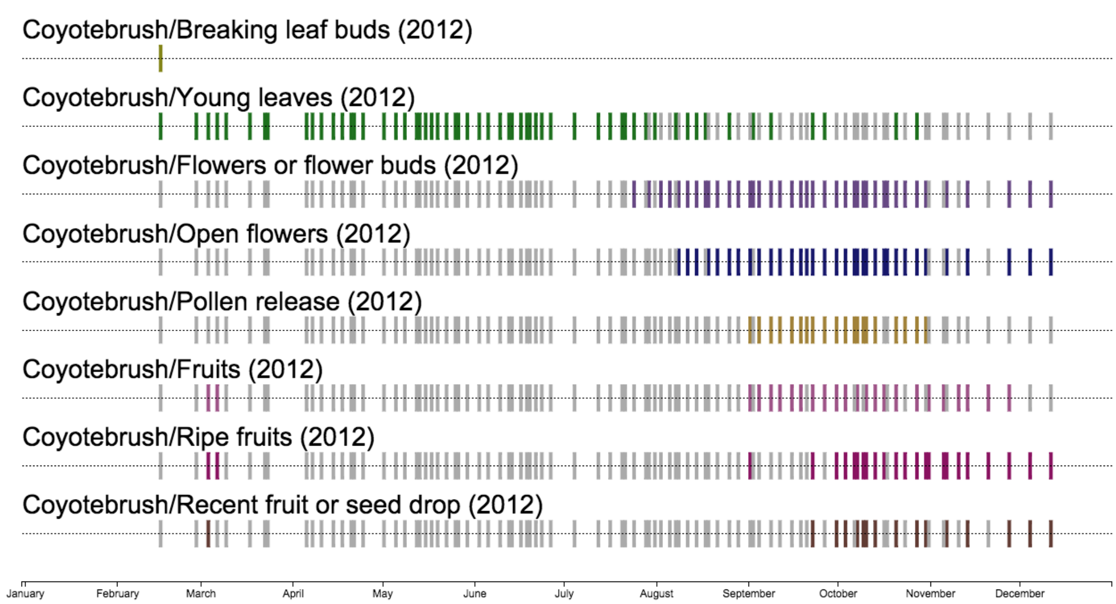
* This trend (*i.e.*, early pollen release) is based primarily on 2012 and 2014 data (Figure2B and D). It will be interesting to observe when pollen release ends this fall (Figure2E), and to re-analyze this trend.

Figure 2. Phenophase activity for coyotebrush (*Baccharis pilularis*) from 2011-2015. Timing of the appearance of targeted phenophases throughout the period of monitoring in successive years is indicated by colored vertical bands. A) 2011; B) 2012; C) 2013; D) 2014; E) 2015. In these figures, colored vertical bands indicate dates when observers recorded that the focal phenophase was visible; gray vertical bands indicate dates when observers definitively did not see the focal phenophase.

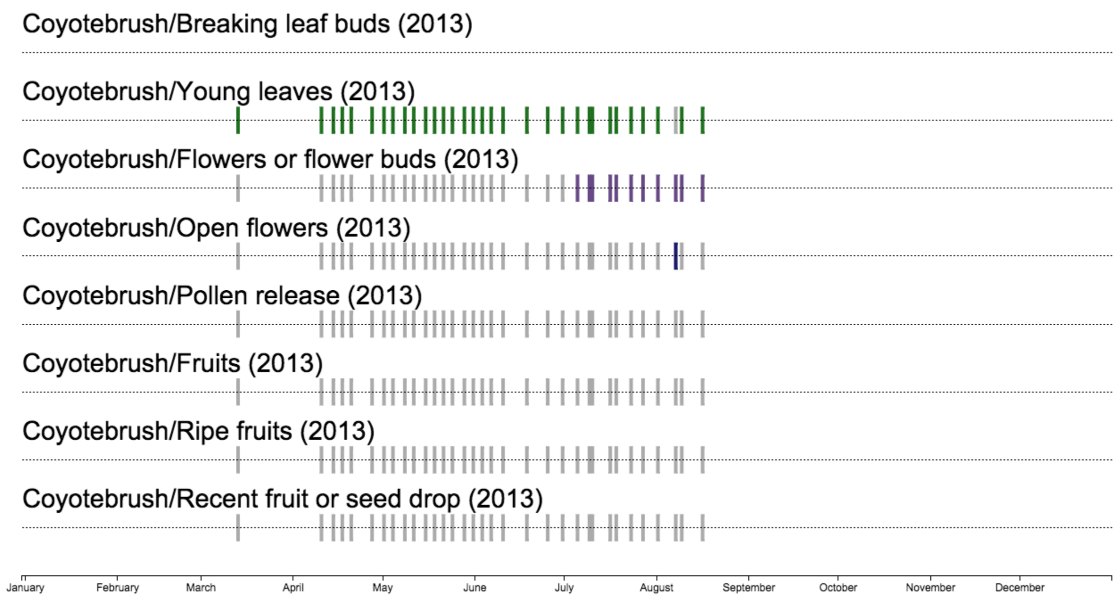
2A



2B



2C



Coyotebrush/Breaking leaf buds (2013)
Coyotebrush/Young leaves (2013)
Coyotebrush/Flowers or flower buds (2013)
Coyotebrush/Open flowers (2013)
Coyotebrush/Pollen release (2013)
Coyotebrush/Fruits (2013)
Coyotebrush/Ripe fruits (2013)
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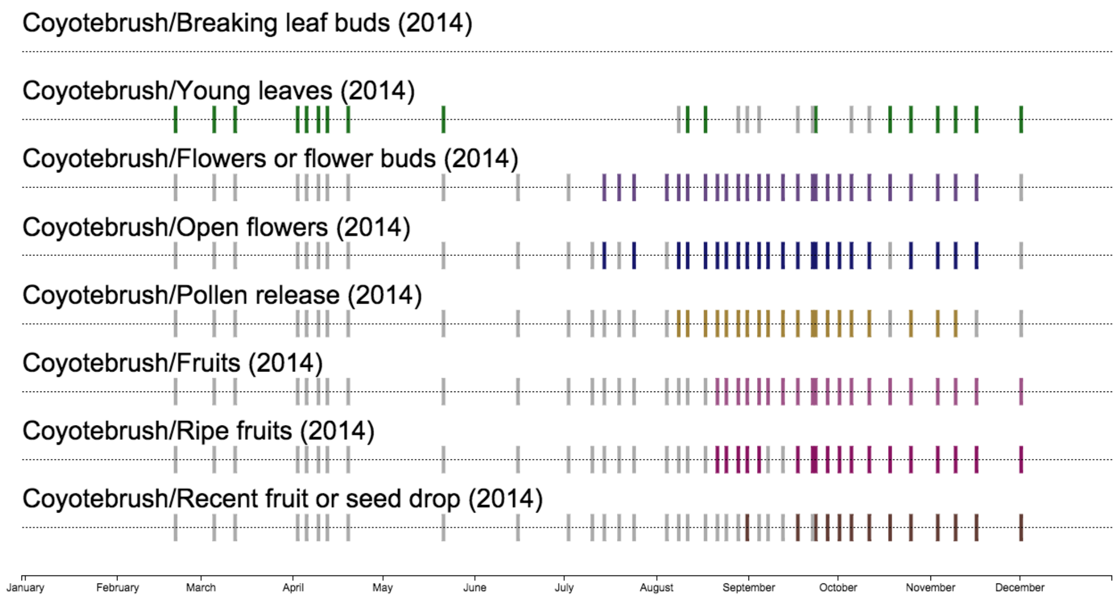

Coyotebrush/Breaking leaf buds (2014)
Coyotebrush/Young leaves (2014)
Coyotebrush/Flowers or flower buds (2014)
Coyotebrush/Open flowers (2014)
Coyotebrush/Pollen release (2014)
Coyotebrush/Fruits (2014)
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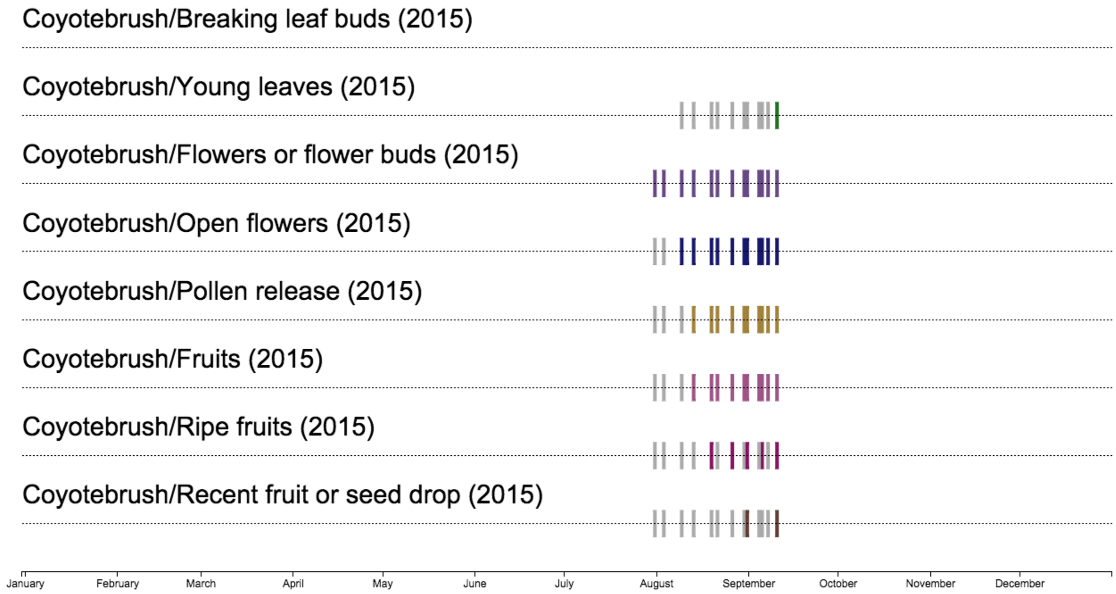


* These figures are based on data pooled from both monitoring locations (CBO and KVC) at Redwood National & State Parks.

** 2015 data collection is still ongoing—**Figure 2**E reflects data through September 11, 2015.

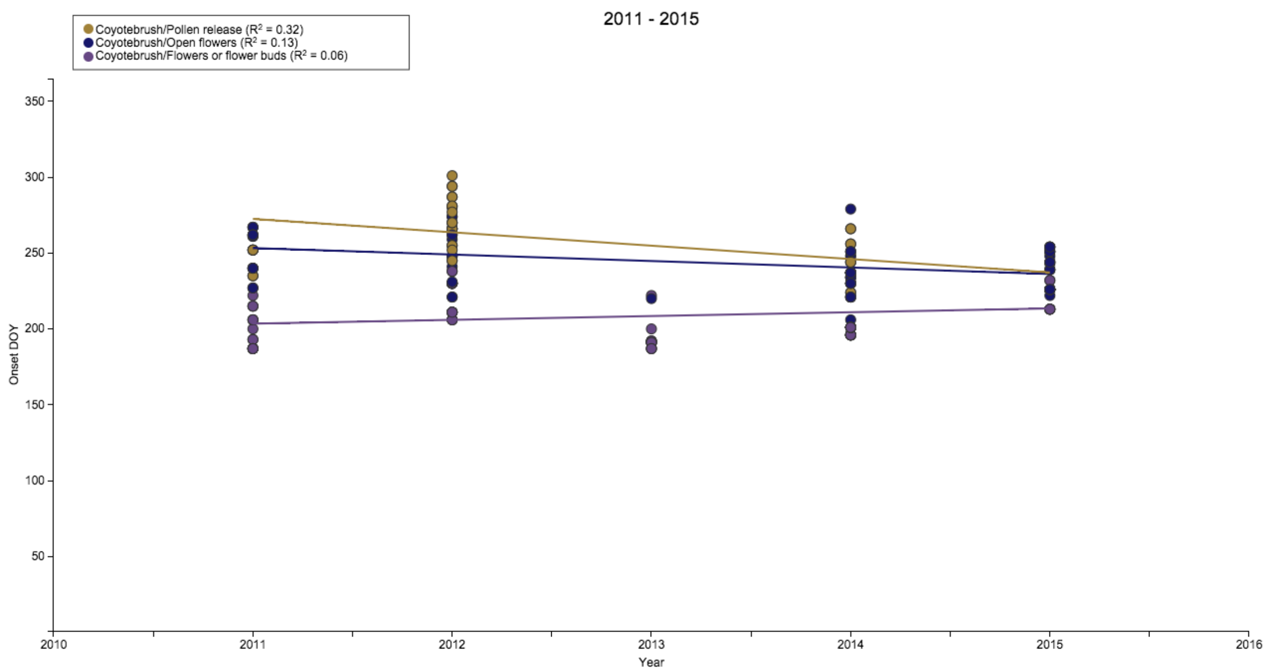


Figure 3. Interannual trends in phenophase activity for coyotebrush (*Baccharis pilularis*) from 2011-2015. Pollen release may be starting and ending earlier in fall**.** The y-axis indicates the day of year (DOY) on which individual plants were observed to exhibit a given phenophase. This figure includes data from both monitoring locations (CBO and KVC) at REDW. 2015 data collection is still ongoing—this figure reflects data through September 11, 2015. It will be interesting to observe when pollen release ends this fall.

Silky beach pea (*Lathyrus littoralis*)

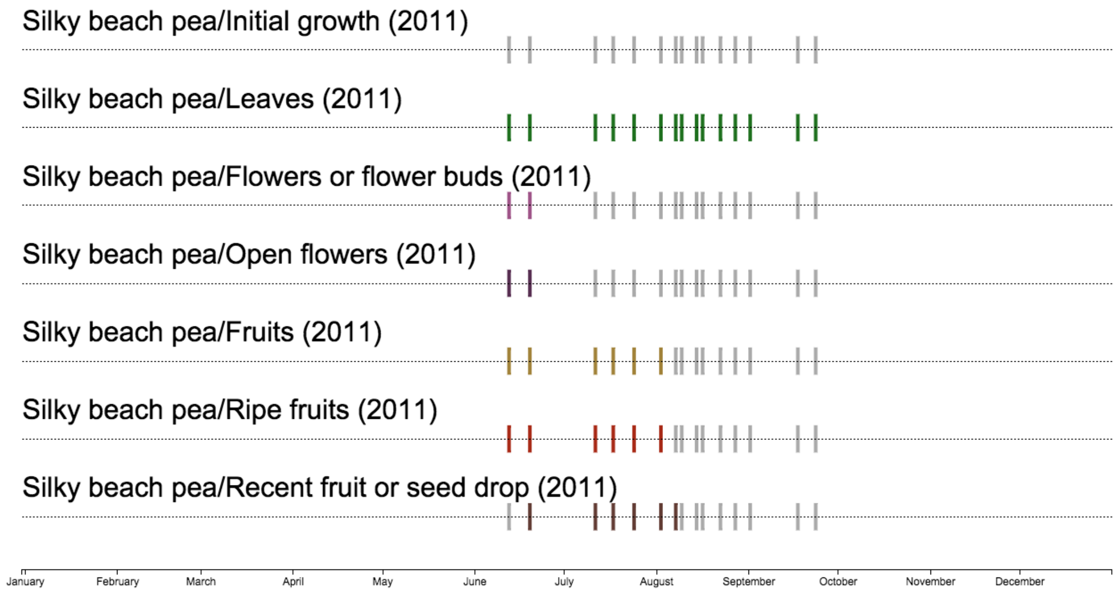
Silky beach pea (*Lathyrus littoralis*) has been monitored for all five years (2011-2015) at the KVC study location (outside the Kuchel Visitor Center) (Figure 4). Data collection did not commence early enough in 2011 to record “initial growth” and the onset of other phenophases (Figure 4A). However, phenological monitoring was fairly continuous in all subsequent years (Figure 4B-E), although the silky beach pea sample size fluctuated over the years, due to study design changes (see METHODS). At the time of this report, silky beach pea was the second-most well-represented species in the REDW dataset, with 16,592 records available via the NPN’s Phenology Visualization Tool.

Silky beach pea reproduction seems to be shifting earlier in the spring (Figure 4 & Figure 5). Significant temporal trends were detected for flower bud formation, blooming time, and fruit development (Figure 5); these phenophases appeared earlier in the year as the five-year monitoring period progressed. This may not impact this species’ reproductive success, since silky beach peas reproduce both sexually and asexually. In fact, I observed in 2014 that these silky beach pea plants experienced complete seed parasitism (due to insect larvae in developing seed pods), and this may well have occurred in other years too.

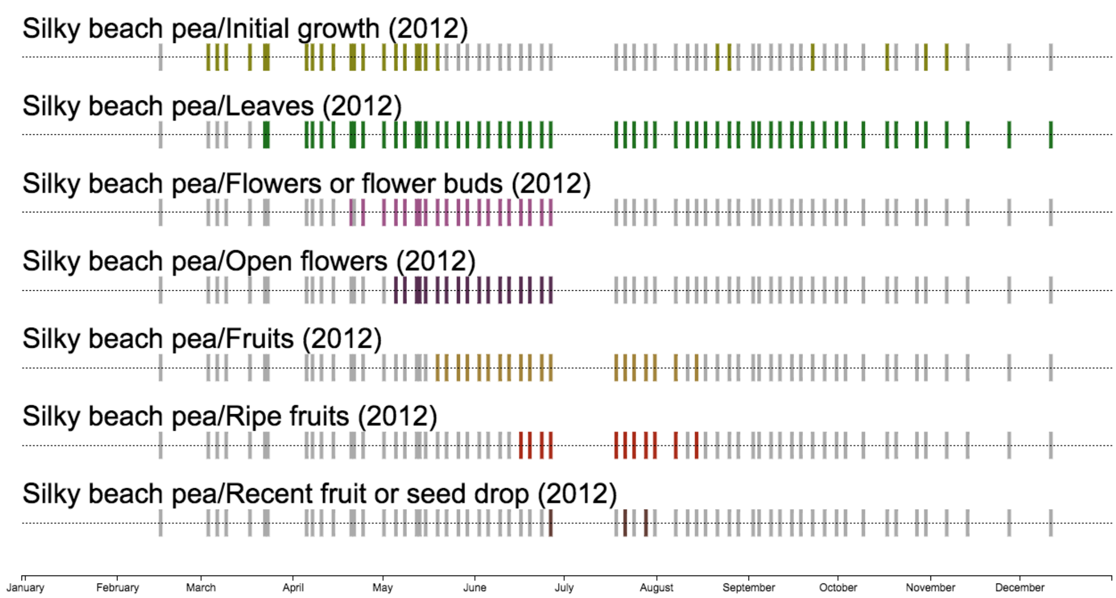
However, there may be ecological consequences (*i.e.*, effects on other species) caused by phenological shifts of silky beach peas. As one of the earliest, relatively abundant, and productive (providing both nectar and pollen) flowers in northern California coastal dune habitats, the silky beach pea is an important resource for the bee species that pollinate it. The phenology of bees (*e.g.*, the silver bee, *Habropoda miserabilis*, which is also being monitored and recorded in the NPN database) seems to be shifting too—unless the silky beach peas and their pollinators continue to track climate in similar ways, there may develop a phenological mismatch, with dire consequences for one or both partner species.

Figure 4. Phenophase activity for silky beach pea (*Lathyrus littoralis*) from 2011-2015. Timing of the appearance of targeted phenophases throughout the period of monitoring in successive years is indicated by colored vertical bands. A) 2011; B) 2012; C) 2013; D) 2014; E) 2015. In these figures, colored vertical bands indicate dates when observers recorded that the focal phenophase was visible; gray vertical bands indicate dates when observers definitively did not see the focal phenophase.

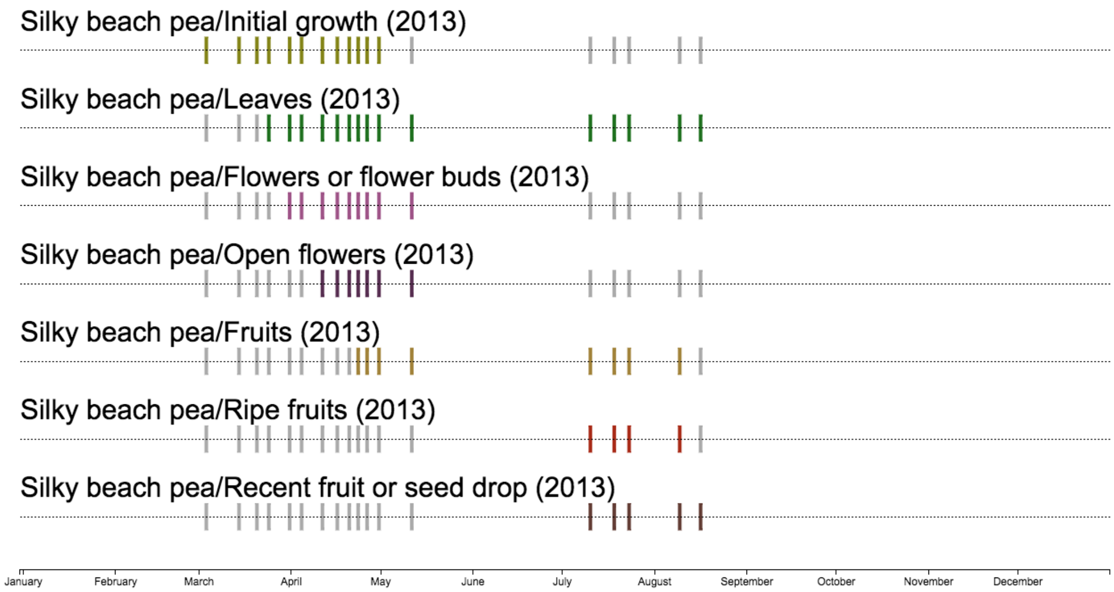
4A



4B



4C


Silky beach pea/Initial growth (2013)
Silky beach pea/Leaves (2013)
Silky beach pea/Flowers or flower buds (2013)
Silky beach pea/Open flowers (2013)
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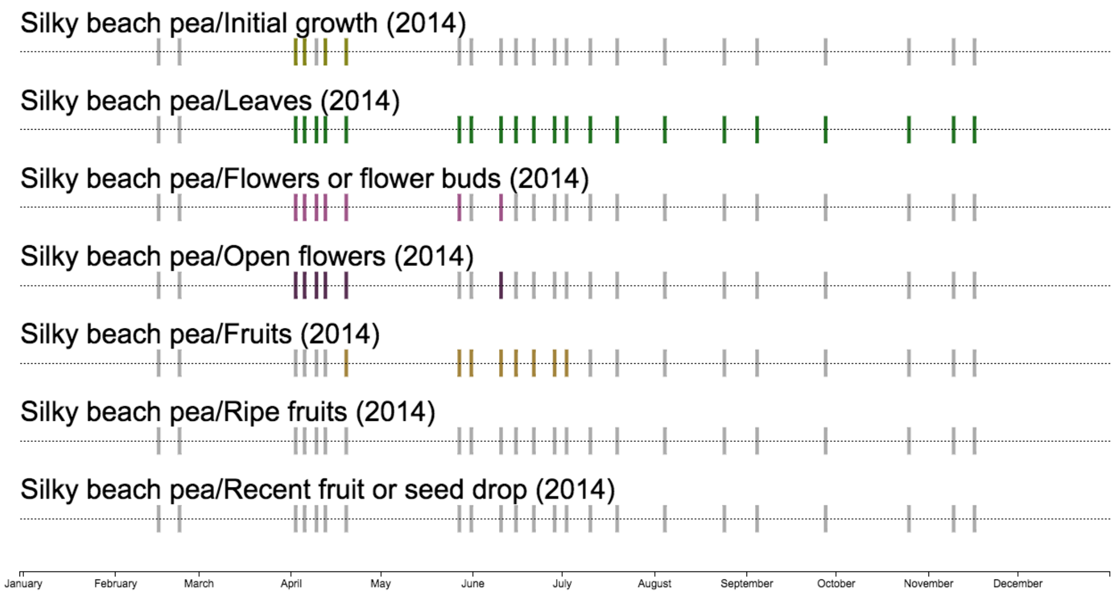
Silky beach pea/Initial growth (2014)
Silky beach pea/Leaves (2014)
Silky beach pea/Flowers or flower buds (2014)
Silky beach pea/Open flowers (2014)
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Silky beach pea/Ripe fruits (2014)
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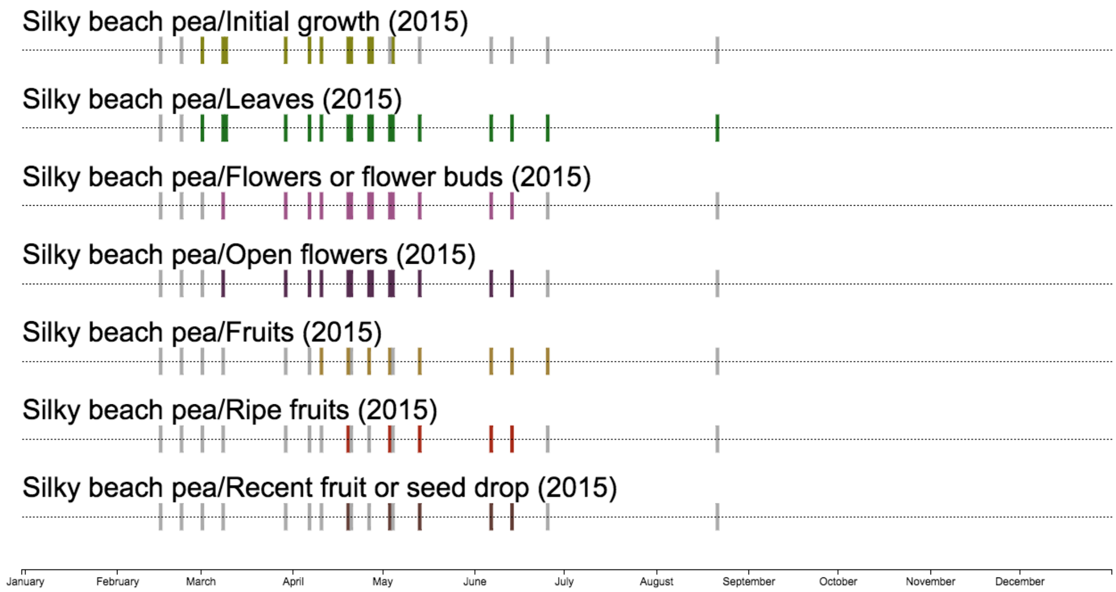

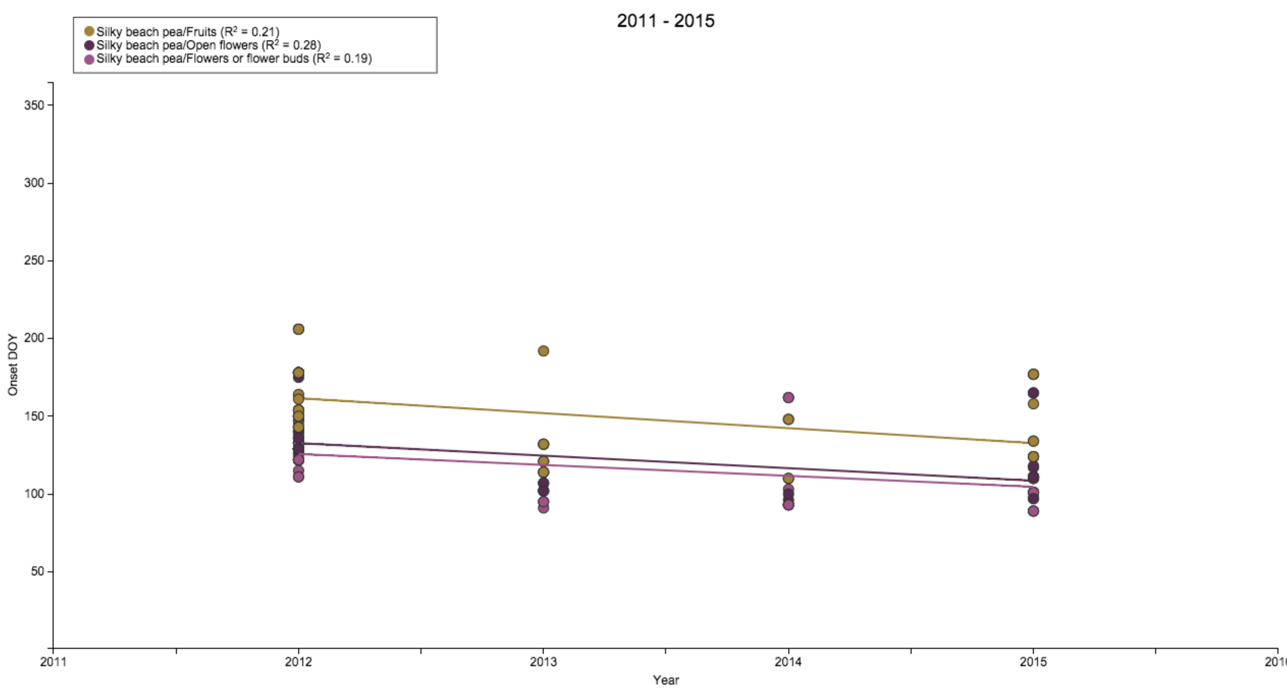

Figure 5. Trends in phenophase activity for silky beach pea (*Lathyrus littoralis*) from 2011-2015. Flower bud formation, bloom time, and fruit development may all be shifting towards earlier onset dates in spring. The y-axis indicates the day of year (DOY) on which individual plants were observed to exhibit a given phenophase.

* For quality assurance purposes, only onset dates that are preceded by negative records are included in the visualization.

Pacific rhododendron (*Rhododendron macrophyllum*)

Pacific rhododendron (*Rhododendron macrophyllum*) has been monitored for all five years (2011-2015) at the LBJ study location (Lady Bird Johnson Grove) (Figure 6). Understandably, phenological monitoring did not begin early enough in the first year (2011) to capture the beginnings of early phenophases, since project development was still underway (Figure 6A). Unfortunately, there was a hiatus in the phenological data collection during the summer of 2013 (Figure 6C). However, Pacific rhododendron was well monitored during 2012 and 2014 (Figure 6B & D). The 2015 data collection is promising too, but this data has not been entered yet (but will be ASAP!). Also, some data from 2012 and 2013 still needs to be entered (but that should not change these preliminary results significantly). At the time of data analysis for this report, Pacific rhododendron was third-best represented in the REDW dataset, with 16,256 records available via the NPN's Phenology Visualization Tool.

Pacific rhododendron seems to be flowering* earlier (Figure 6 & Figure 7). As discussed with silky beach peas (see previous section), there is potential for a phenological mismatch to develop, if Pacific rhododendrons and their pollinator animals diverge in phenological shifts. Pacific rhododendrons likely provide a large proportion of resources for pollinators in the redwood forest (which hosts relatively few flowering plants, that are usually diminutive in size and bloom in early spring), and the Pacific rhododendrons at this site (LBJ) seem to be late-bloomers (the LBJ rhodies always seem to be the last to bloom in the Park!). So, these plants may represent an important resource for pollinators at a time when other floral resources are less available.

* This trend (*i.e.*, early open flowers) is mostly based on 2012 and 2014 data (Figure 6B & D). It is necessary to incorporate this year's data, and re-analyze this trend.

Figure 6. Phenophase activity for Pacific Rhododendron (*Rhododendron macrophyllum*) from 2011-2015. Timing of the appearance of targeted phenophases throughout the period of monitoring in successive years is indicated by colored vertical bands. A) 2011; B) 2012; C) 2013; D) 2014; E) 2015. In these figures, colored vertical bands indicate dates when observers recorded that the focal phenophase was visible; gray vertical bands indicate dates when observers definitively did not see the focal phenophase.

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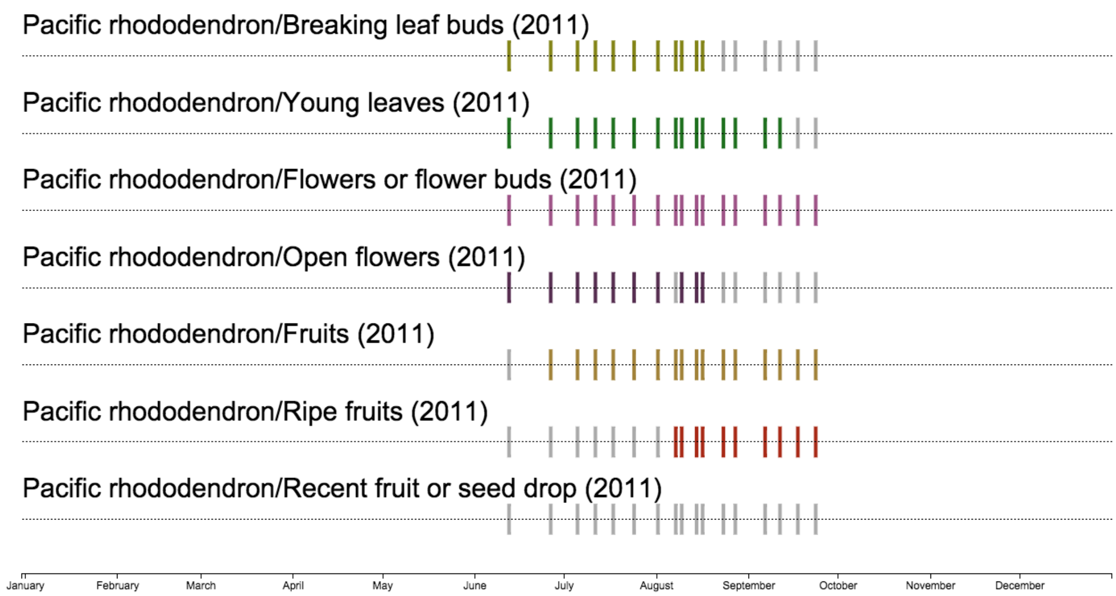
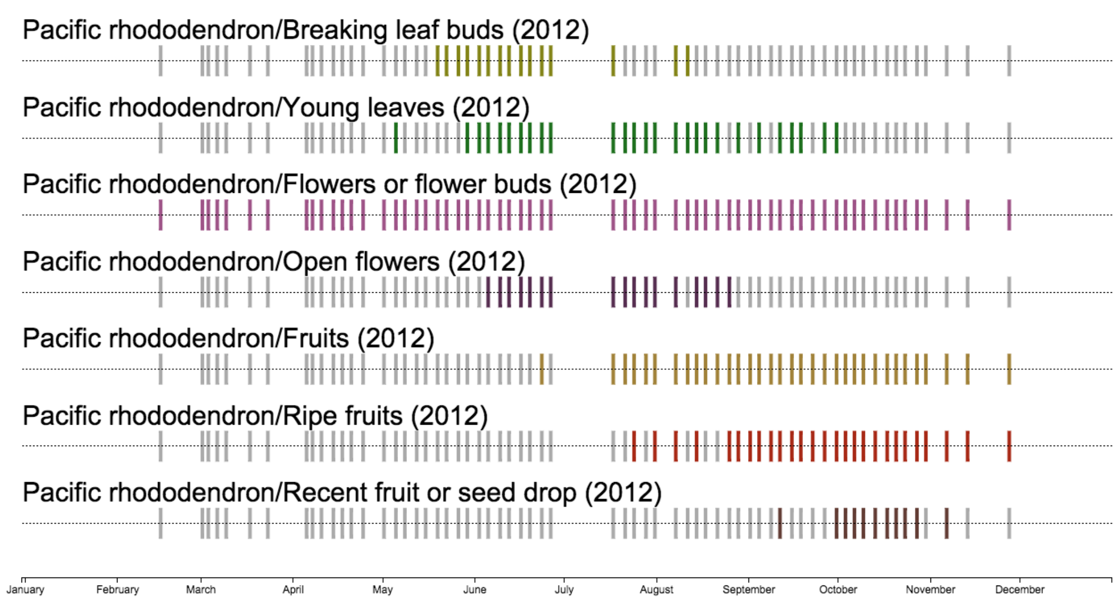


6B



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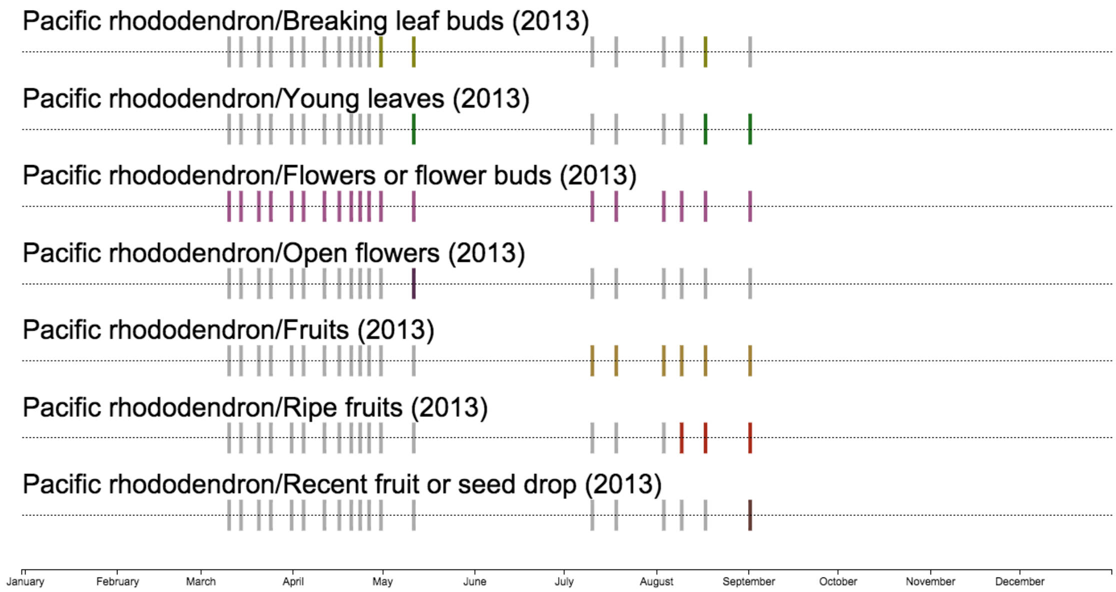
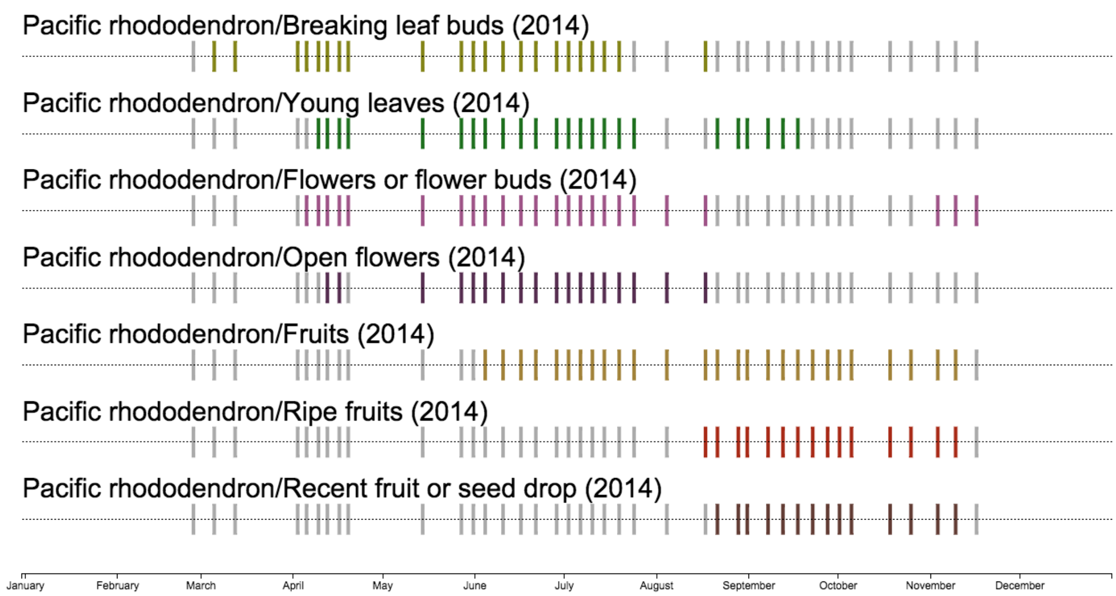


6D



* These figures are based on a fairly comprehensive but still incomplete dataset—some data (approximately 1/3) from 2012 (spring and fall) and 2013 (July-September) has not yet been entered into the NPN database (Nature's Notebook).
** 2015 data collection is ongoing (since June) and needs to be entered into the NPN database.

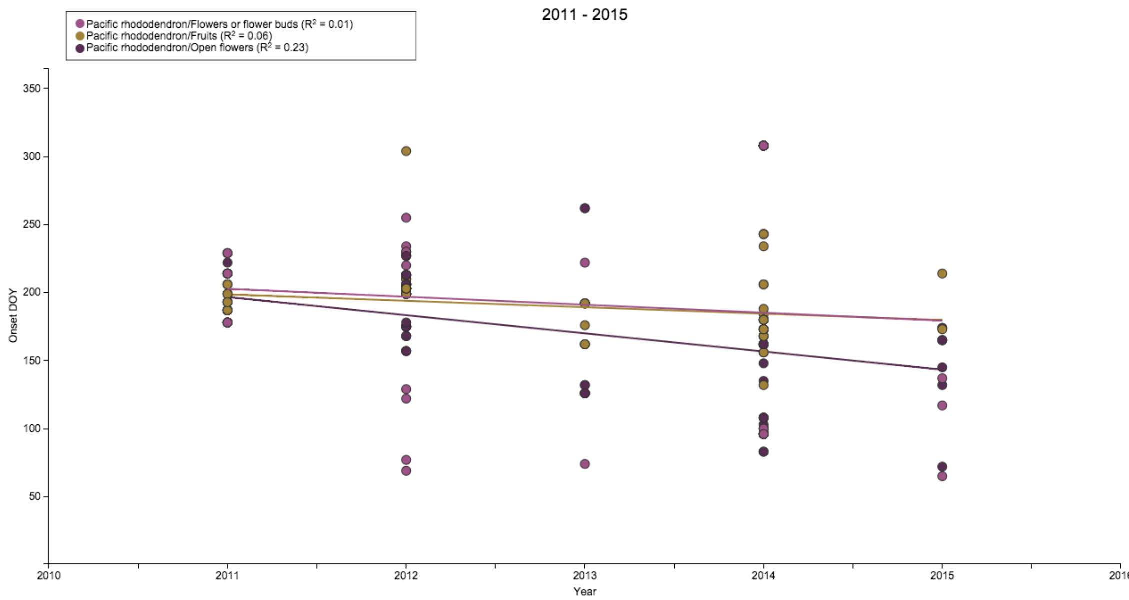


Figure 7. Trends in phenophase activity for Pacific rhododendron (*Rhododendron macrophyllum*) from 2011-2014. Bloom time ("open flowers") may be occurring earlier in the year. The y-axis indicates the day of year (DOY) on which individual plants were observed to exhibit a given phenophase.

* This figure is based on a fairly comprehensive but still incomplete dataset—some data (approximately 1/3) from 2012 (spring and fall) and 2013 (July-September) has not yet been entered into the NPN database (Nature's Notebook).
** 2015 data collection is ongoing (since June) and needs to be entered into the NPN database.
*** For quality assurance purposes, only onset dates that are preceded by negative records are included in the visualization.

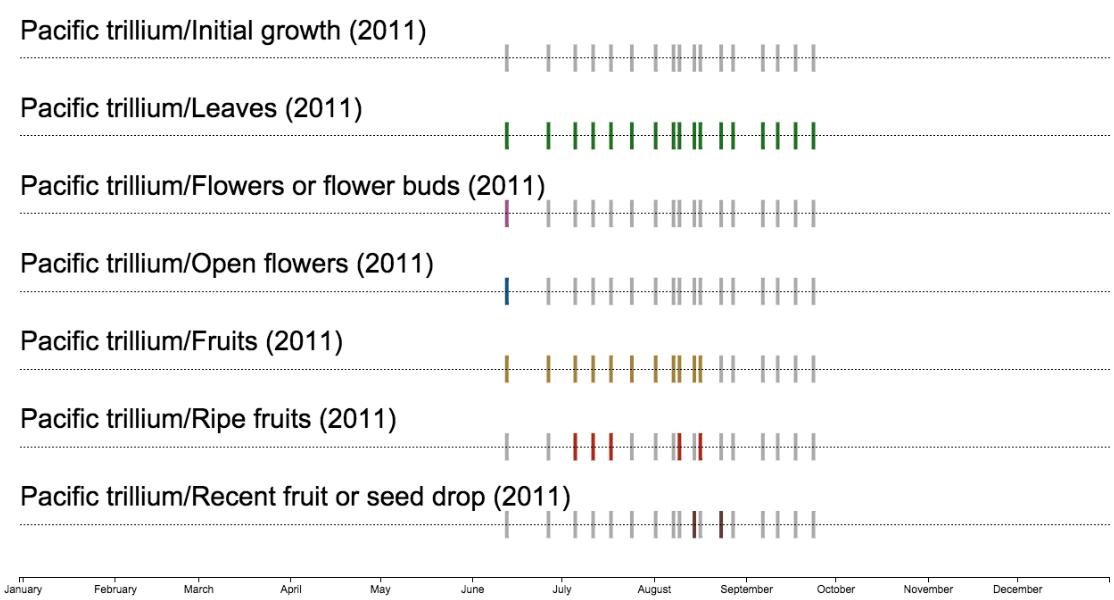
Pacific trillium (*Trillium ovatum*)

Pacific trillium (*Trillium ovatum*) has been monitored for all five years (2011-2015) at the LBJ study location (Lady Bird Johnson Grove) (Figure 8). Understandably, phenological monitoring did not start early enough in the first year (2011) to capture the beginnings of early phenophases, since project development was still underway (Figure 8A). Phenological data collection commenced earlier in subsequent years, but Pacific trillium still began growing before data collection got underway in 2014 (Figure 8D). However, Pacific trillium was well monitored during 2012, 2013, and 2015 (Figure 8B, C & E), although data collection was often stymied by anthropogenic impacts (*i.e.*, visitors would illegally pick the trillium flowers and/or trample the plants). As of this report, Pacific trillium was fourth-best represented in the REDW dataset, with 15,792 records available via the NPN's Phenology Visualization Tool.

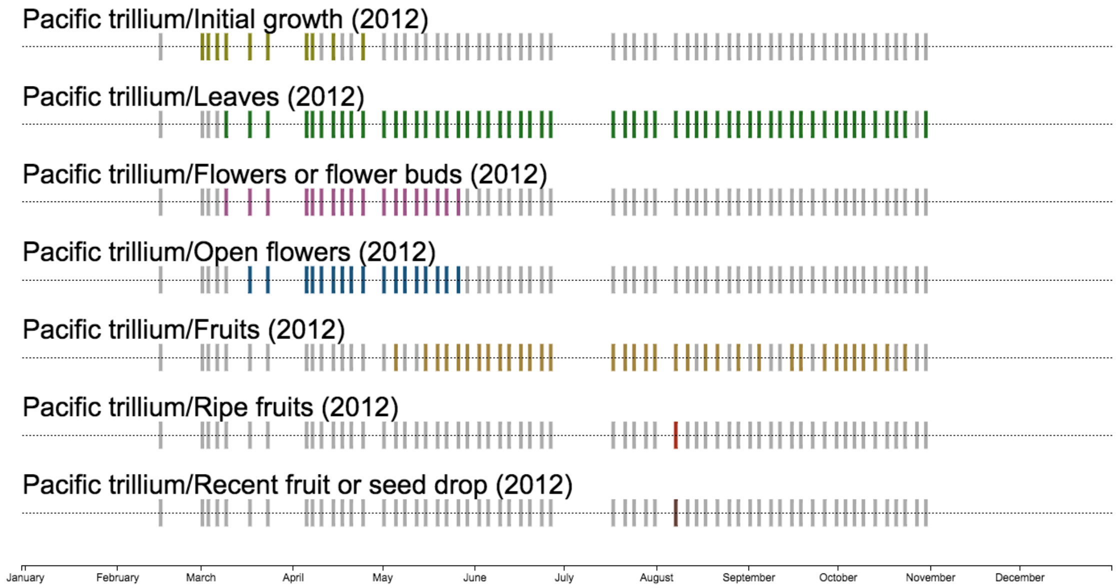
Pacific trillium reproduction seems to be shifting earlier in the spring (Figure 8 & Figure 9). Significant trends were detected for flower bud formation, blooming time, and fruit development (Figure 9). This could have ramifications for pollinators and seed dispersers. Even though ripe fruits were rarely observed (because: a) flowers are often picked, thus precluding any fruit development; b) fruit developmental success is low; c) ripe fruits are quickly removed by ants… myrmecochory!), it is probable that earlier initiation of fruit development could lead to ripe fruits earlier.

Figure 8. Phenophase activity for Pacific trillium (*Trillium ovatum*) from 2011-2015. Timing of the appearance of targeted phenophases throughout the period of monitoring in successive years is indicated by colored vertical bands. A) 2011; B) 2012; C) 2013; D) 2014; E) 2015. In these figures, colored vertical bands indicate dates when observers recorded that the focal phenophase was visible; gray vertical bands indicate dates when observers definitively did not see the focal phenophase.

8A



8B


Pacific trillium/Initial growth (2012)
Pacific trillium/Leaves (2012)
Pacific trillium/Flowers or flower buds (2012)
Pacific trillium/Open flowers (2012)
Pacific trillium/Fruits (2012)
Pacific trillium/Ripe fruits (2012)
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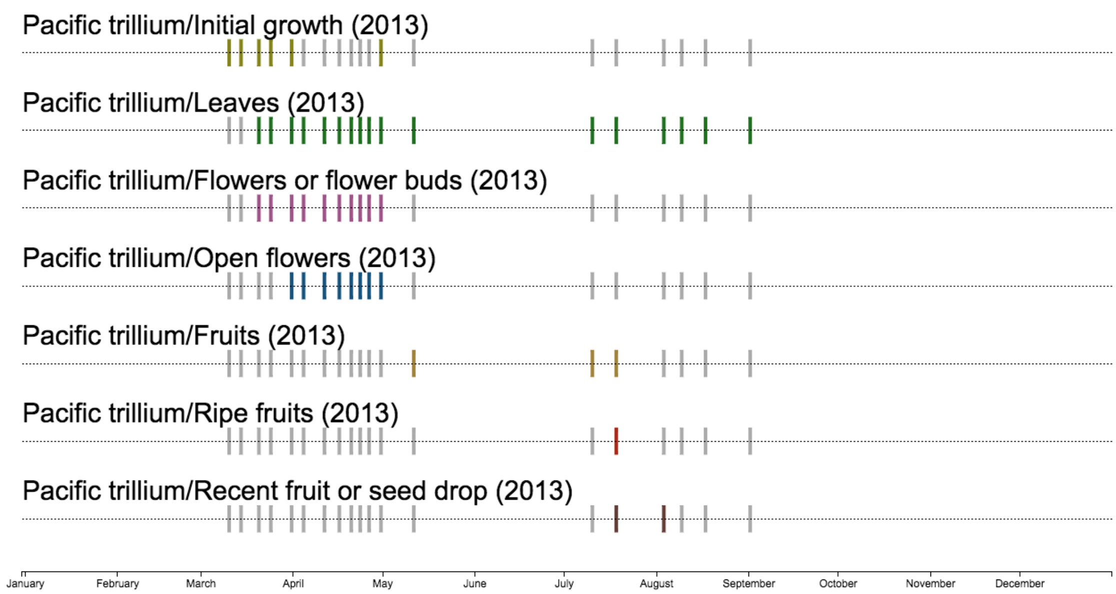
Pacific trillium/Initial growth (2013)
Pacific trillium/Leaves (2013)
Pacific trillium/Flowers or flower buds (2013)
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Pacific trillium/Fruits (2013)
Pacific trillium/Ripe fruits (2013)
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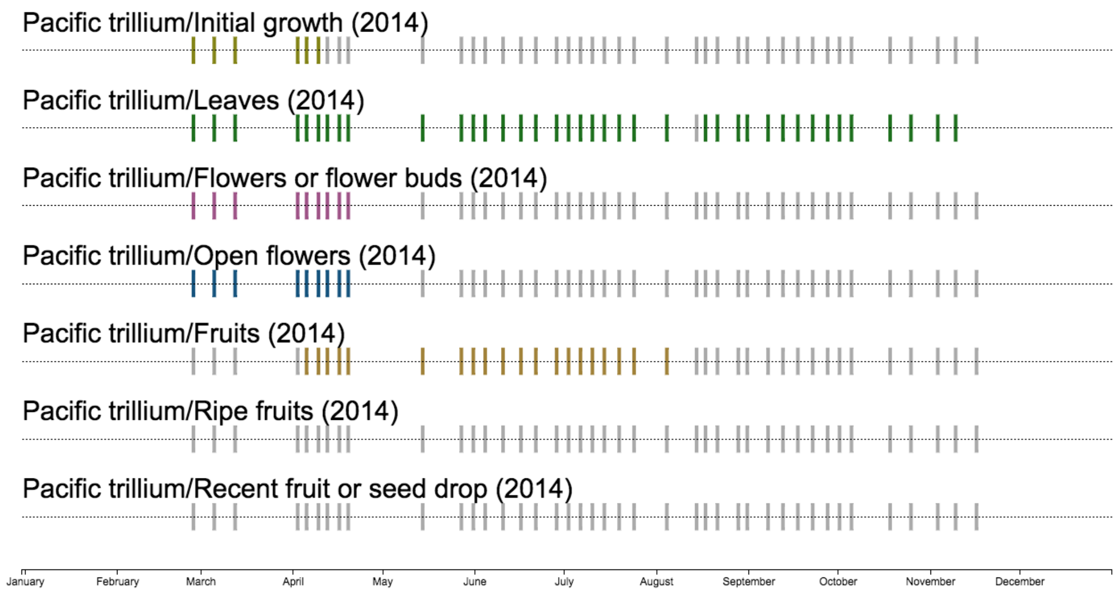
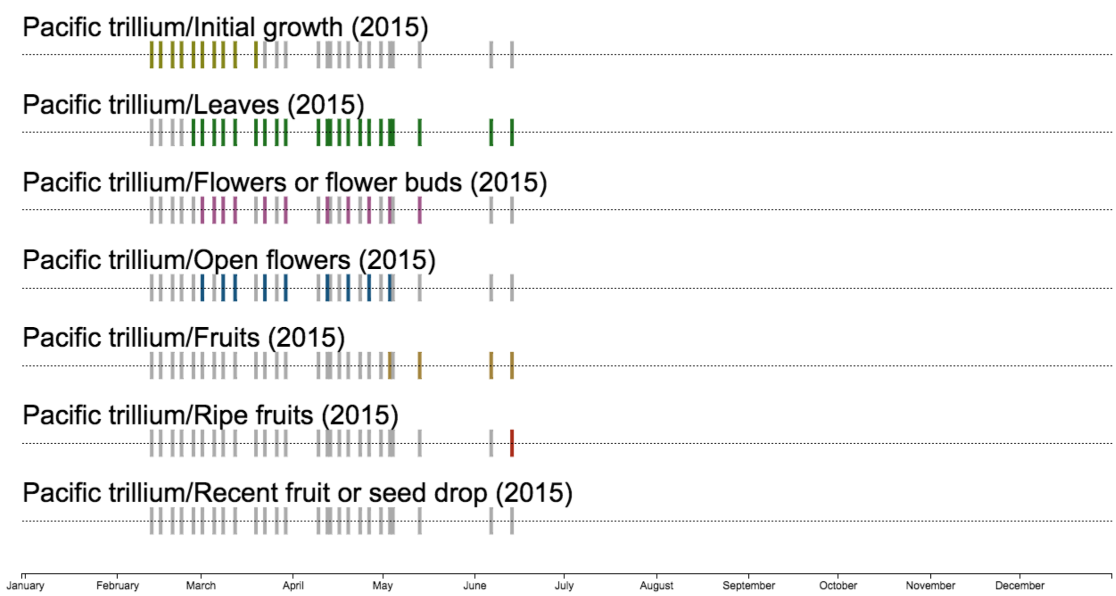


8E



* These figures are based on a fairly comprehensive but still incomplete dataset—some data (approximately 1/3) from 2012 (spring and fall) and 2013 (July-September) has not yet been entered into the NPN database (Nature's Notebook).

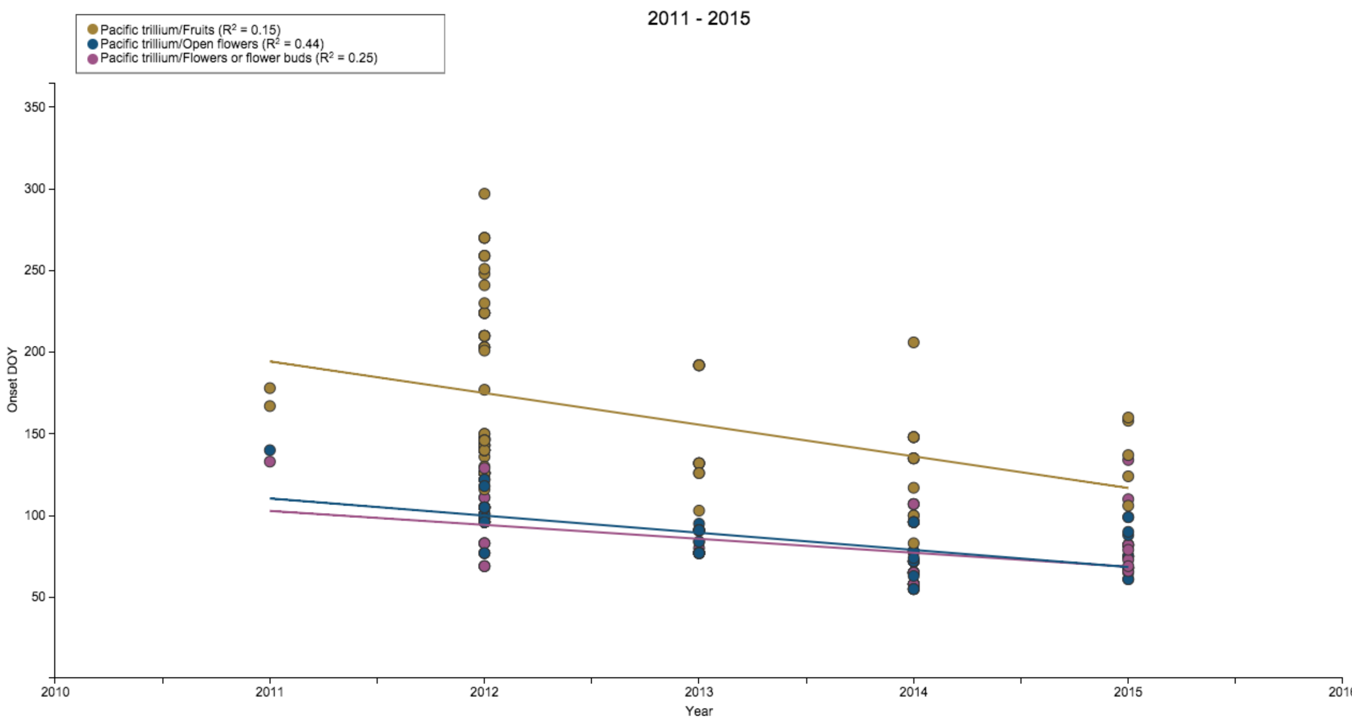


Figure 9. Trends in phenophase activity for Pacific trillium (*Trillium ovatum*) from 2011-2015. The y-axis indicates the day of year (DOY) on which individual plants were observed to exhibit a given phenophase. Flower bud formation, bloom time, and fruit development may all be shifting earlier in spring.

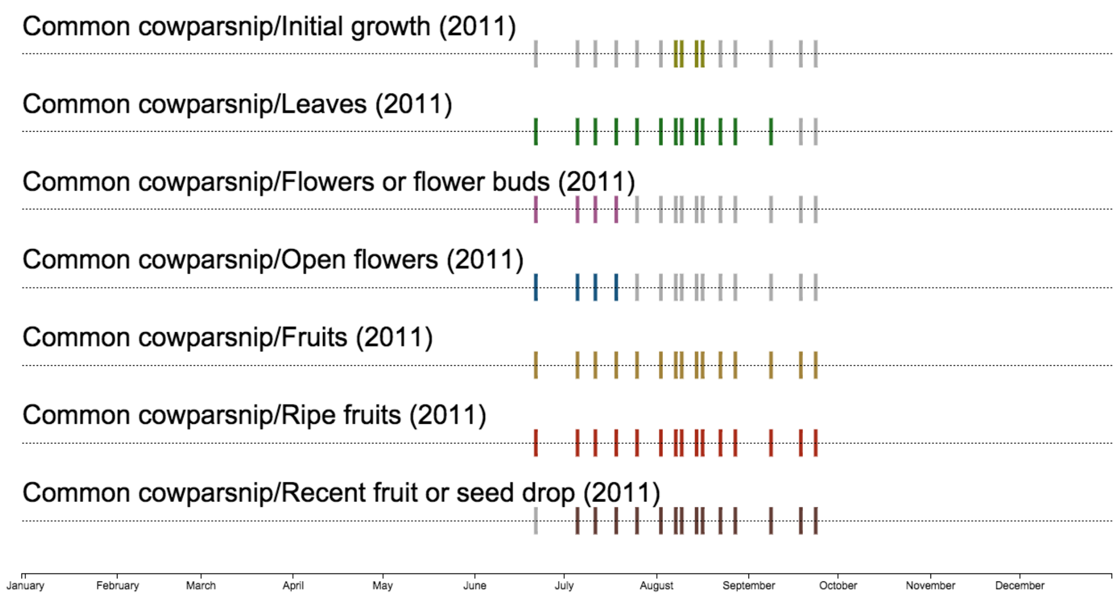
* This figure is based on a fairly comprehensive but still incomplete dataset—some data (approximately 1/3) from 2012 (spring and fall) and 2013 (July-September) has not yet been entered into the NPN database (Nature's Notebook).
** For quality assurance purposes, only onset dates that are preceded by negative records are included in the visualization.

<u>Common cowparsnip (*Heracleum maximum*, formerly *H. lanatum*)</u>

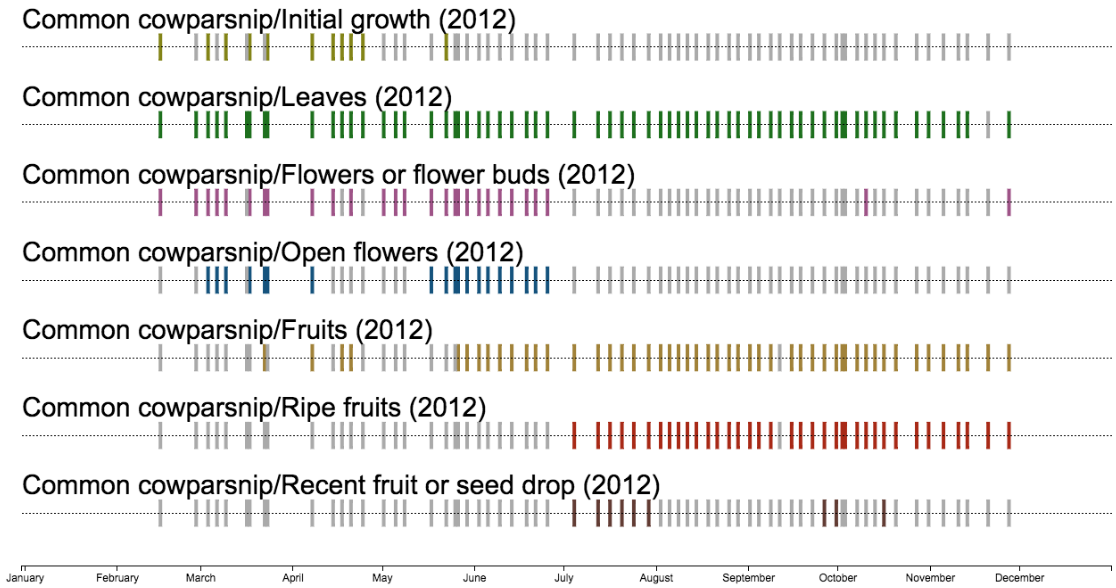
Common cowparsnip (*Heracleum maximum*, formerly *H. lanatum*) was monitored for only the first three years (2011-2013) of the CPP-REDW project, at the CBO study location (near Crescent Beach Overlook) (Figure 10). Understandably, phenological monitoring did not start early enough in the first year (2011) to capture the beginnings of early phenophases, since project development was still underway (Figure 10A). More unfortunately, data collection ceased after three years due to logistical reasons (*i.e.*, a) study plants were often accidentally mowed; b) lack of citizen scientists who could travel to this northernmost study site). While phenological monitoring was fairly comprehensive in 2012 and 2013, most data from 2013 (April-August) has not yet been entered (but will be ASAP!). At the time of this report, common cowparsnip comprised 12,568 records available via the NPN's Phenology Visualization Tool.

Figure 10. Phenophase activity for Common cowparsnip (*Heracleum maximum*) from 2011-2013. Timing of the appearance of targeted phenophases throughout the period of monitoring in successive years is indicated by colored vertical bands. A) 2011; B) 2012; C) 2013; D) 2014; E) 2015. In these figures, colored vertical bands indicate dates when observers recorded that the focal phenophase was visible; gray vertical bands indicate dates when observers definitively did not see the focal phenophase.

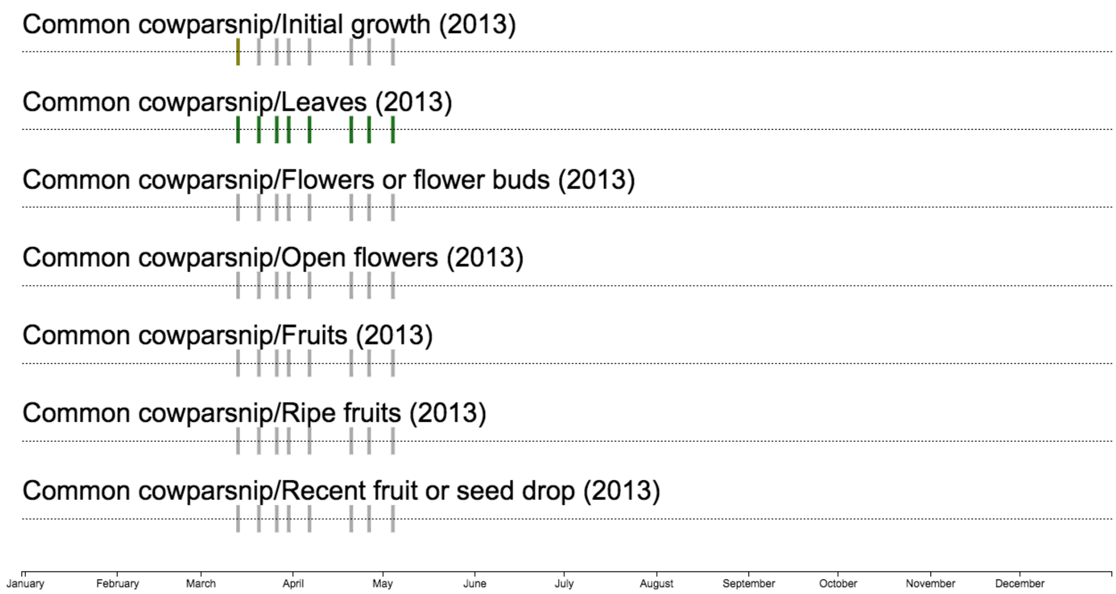
10A



10B



10C



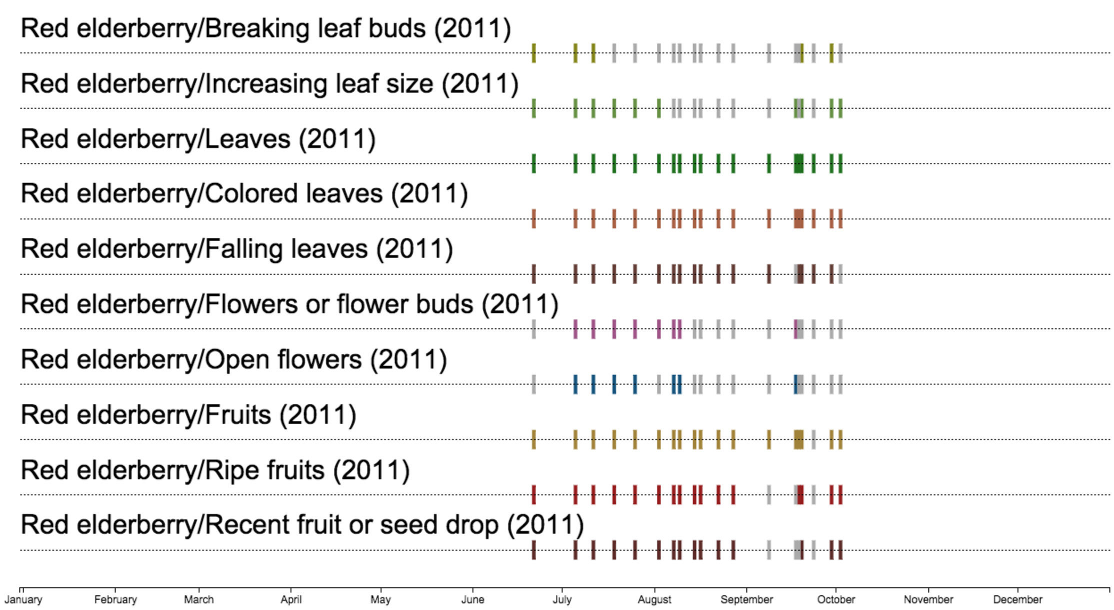
* These figures are based on a relatively short-term and also incomplete dataset—most data from 2013 (April-August) has not yet been entered into the NPN database (Nature's Notebook).

Red elderberry (*Sambucus racemosa*)

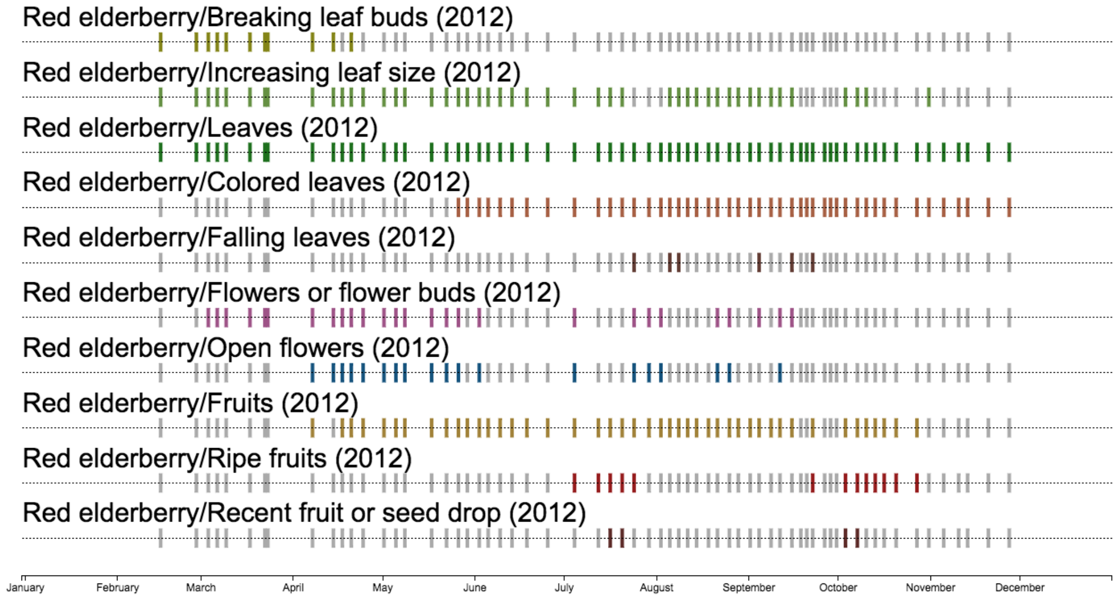
Red elderberry (*Sambucus racemosa*) was monitored for only the first three years (2011-2013) of the CPP-REDW project, at the CBO study location (near Crescent Beach Overlook) (Figure 11). Phenological monitoring did not commence early enough in the first year (2011) to capture the beginnings of early phenophases because project development was still underway (Figure 11A). More unfortunately, monitoring was discontinued after three years due to logistical reasons (*i.e.*, lack of humanpower to travel to this northernmost monitoring location, especially considering the long phenological season of red elderberry). While data collection was thorough in 2012 and 2013, most data from 2013 (April-August) has not yet been entered (but will be ASAP!). At the time of this report, red elderberry was the least well-represented in the REDW dataset, with 7,574 records available via the NPN's Phenology Visualization Tool.

Figure 11. Phenophase activity for Red elderberry (*Sambucus racemosa*) from 2011-2013. Timing of the appearance of targeted phenophases throughout the period of monitoring in successive years is indicated by colored vertical bands. A) 2011; B) 2012; C) 2013; D) 2014; E) 2015. In these figures, colored vertical bands indicate dates when observers recorded that the focal phenophase was visible; gray vertical bands indicate dates when observers definitively did not see the focal phenophase.

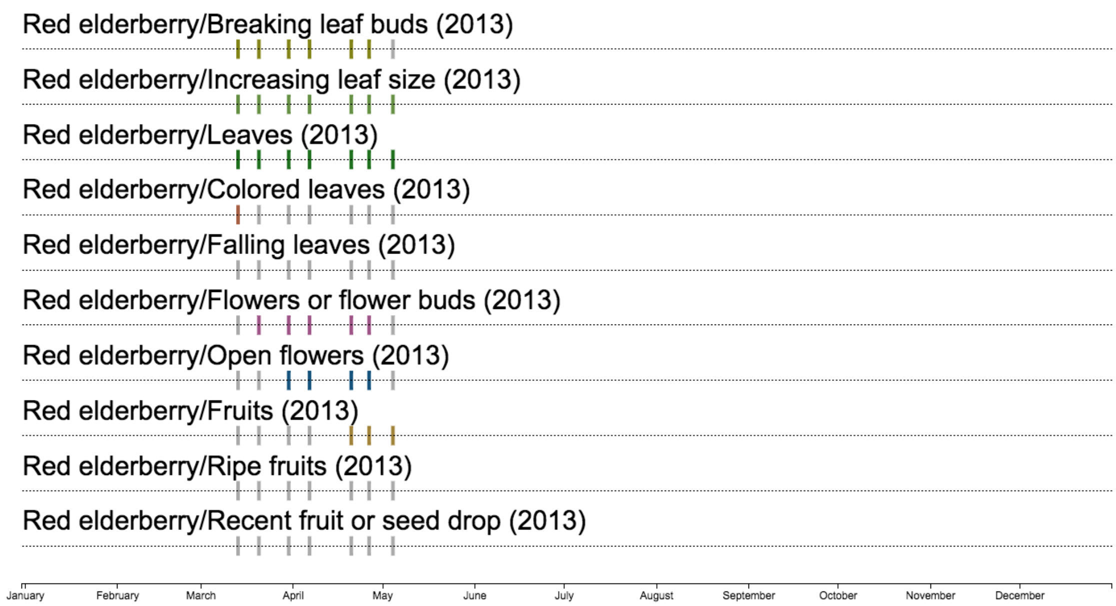
11A



11B



11C



* These figures are based on a relatively short-term and also incomplete dataset—most data from 2013 (April-August) has not yet been entered into the NPN database (Nature's Notebook).

Monitoring Effort

Redwood National & State Parks' phenological monitoring program has gone through varying phases of growth and development in its first five years (2011-2015). The project includes six plant species at three monitoring locations that have experienced different levels of monitoring effort over the years.

Six plant species were selected in 2011 for phenological observation at Redwood National & State Parks—these study species were coyotebrush (*Baccharis pilularis*), common cowparsnip (*Heracleum maximum*, formerly *H. lanatum*), silky beach pea (*Lathyrus littoralis*), Pacific rhododendron (*Rhododendron macrophyllum*), red elderberry (*Sambucus racemosa*), and Pacific trillium (*Trillium ovatum*) (Table 5). All species were monitored for the first three years (2011-2013). In 2014-2015, data collection continued for four species (coyotebrush, silky beach pea, Pacific rhododendron, and Pacific trillium), but common cowparsnip and red elderberry were no longer monitored due to logistical reasons.

Common cowparsnip and red elderberry were at the CBO monitoring location (area of Crescent Beach Overlook), which is just south of Crescent City (by a few miles) and is the northernmost phenological study location of Redwood National & State Parks (approximately 40 miles north of the southern entrance to the park). In the first year (2011), logistical support (in the form of a government vehicle, for which gas was funded) was available for a volunteer to travel from the park office to CBO for phenological monitoring of all study species there (coyotebrush, common cowparsnip, and red elderberry). And then, throughout 2012 and 2013, we were fortunate to have a dedicated volunteer from Crescent City who continued phenological monitoring of the three study species at CBO. However, the majority of our volunteer base comes from Humboldt State University (in Arcata) and nearby (the Humboldt Bay area of Arcata, Eureka, and McKinleyville), which is south of Redwood National & State Parks (approximately 30 miles or 45 minutes) and thus farther from the CBO monitoring location (approximately 70 miles or 1¾ hours). Because of the much greater distance (typically 140 miles round-trip, 3½ hours total, and associated driving costs) required to monitor these species, common cowparsnip and red elderberry were no longer monitored in subsequent years (2014-2015). Additionally, red elderberry has a fairly long phenological monitoring season (early spring to late fall), which also contributed to the difficulty of maintaining data collection. Meanwhile, many common cowparsnip plants were accidentally mowed (by park maintenance, because they were located too close to the side of the road) which, besides directly impacting phenological monitoring, was also discouraging to both phenology staff and citizen scientists.

Coyotebrush is still monitored at the CBO study location. From 2014-2015, funding (from the NPS-CCRP) was available to support a phenology internship. Internship funding was prioritized for coyotebrush monitoring there, because CBO (along with KVC) is the northernmost study site for coyotebrush in California. The California Phenology Project has coordinated coyotebrush monitoring at several study areas along the California coast (including at GOGA and SAMO), in order to compare phenological development at different latitudes. We have also just recruited and trained a new volunteer from Crescent City who will help monitor coyotebrush at CBO through the rest of its phenological season this year.

REDW-CPP should continue to be proactive about volunteer recruitment and retention for coyotebrush at the CBO monitoring location.

Table 5. Plant species, phenological monitoring, and monitoring effort (*i.e.*, sample sizes) at Redwood National & State Parks from 2011-2015

	Year				
	2011	2012	2013	2014	2015
Number of species monitored	6	6	6	4	4
Total number of individual plants (or patches):					
coyotebrush (*Baccharis pilularis*)	18	18	18	26	25
silky beach pea (*Lathyrus littoralis*)	32 indvls	32 indvls	6 patches	4 patches	10 patches
Pacific rhododendron (*Rhododendron macrophyllum*)	18	18	18	18	18
Pacific trillium (*Trillium ovatum*)	23	23	23	15	20
common cowparsnip (*Heracleum maximum*)	21	21	21	*	*
red elderberry (*Sambucus racemosa*)	9	9	9	*	*

* Common cowparsnip and red elderberry were monitored for only three years (2011-2013).

Three monitoring locations were established in 2011 at Redwood National & State Parks—these were KVC, LBJ, and CBO (Table **6**). KVC is the area outside the Kuchel Visitor Center, which is located near the southern end of the park. The KVC monitoring location is comprised of coastal dune habitat, and coyotebrush and silky beach pea are monitored there. LBJ is the trail in Lady Bird Johnson Grove, which is located in the southern area of the park. The LBJ monitoring location is in old-growth redwood forest, where Pacific rhododendron and Pacific trillium are monitored. CBO is the area around the Crescent Beach Overlook, which is located in the northern section of the park. The CBO monitoring location represents coastal bluff habitat, and originally included three study species (coyotebrush, common cowparsnip, and red elderberry). Only coyotebrush is currently being monitored at CBO. At the other monitoring locations (KVC and LBJ), phenological data collection has continued for all study species.

Table 6. Monitoring locations, phenological monitoring, and monitoring effort (*i.e.*, phenophase records) at Redwood National & State Parks from 2011-2015

	Year					
	2011	2012	2013	2014	2015*	Total
Number of active monitoring locations	3	3	3	3	3	
Total number of phenophase records from each monitoring location:						
KVC (outside the Kuchel Visitor Center)	4210	15633	1001	2464	1464	24772
LBJ (along trail at Lady Bird Johnson Grove)	4519	14207	3339	7829	2154	32048
CBO (vicinity of Crescent Beach Overlook)	5088	18789	2821	2723	833	30254

* Phenological monitoring of coyotebrush (at KVC and CBO) and Pacific rhododendron (at LBJ) is still continuing. These numbers represent data collected and entered as of September 21, 2015.

Phenological monitoring at Redwood National & State Parks has taken place since 2011 (Table **7**). Four plant species (coyotebrush, silky beach pea, Pacific rhododendron, and Pacific trillium) have been monitored every year, whereas two species (common cowparsnip and red elderberry) were observed for only the first three years.

Monitoring effort has fluctuated over the years, due to many factors. Human resources (staff, interns, and volunteers) are the most important component in citizen science programs. This variation among years is reflected in the 2013 low point (a total of only 7,161 phenophase records were contributed to the NPN database) and in the higher rate of observation in 2014 (13,026 phenophase records).

Logistics (travel time, distance, and cost) have also been a big factor influencing the frequency and regularity of phenological monitoring at REDW. This has affected volunteer recruitment/retention and internship availability, and is the primary reason for the (perhaps temporary) termination of phenological monitoring of common cowparsnip and red elderberry at CBO. Project morale has also played a role in monitoring effort. This is evidenced by the high point (48,629 phenophase records) of 2012, which was the first full year of the project. In a citizen science program, steps must be taken to minimize volunteer fatigue and promote volunteer enthusiasm (and thus participation and retention).

Table 7. Phenological monitoring, plant species, and monitoring effort (*i.e.*, phenophase records) at Redwood National & State Parks from 2011-2015

	Year					
	2011	2012	2013	2014	2015*	Total
Total number of phenophase records per year	13817	48629	7161	13016	4451	87074
Number of phenophase records for each species:						
coyotebrush	2160	8320	1701	4522	1589	18292
silky beach pea	3130	11403	686	665	708	16592
Pacific rhododendron**	2141	7214	2016	4710	175	16256
Pacific trillium**	2378	6993	1323	3119	1979	15792
common cowparsnip***	2513	9139	916	N/A	N/A	12568
red elderberry***	1495	5560	519	N/A	N/A	7574

* Phenological monitoring of coyotebrush and Pacific rhododendron is still continuing. These numbers represent data collected and entered as of September 21, 2015.

** Data entry for Pacific trillium and rhododendron in 2012 and 2013 is somewhat incomplete. These numbers represent data entered as of September 21, 2015.

*** Common cowparsnip and red elderberry were monitored for only three years (2011-2013). Data entry for cowparsnip and elderberry in 2013 is also rather incomplete. These numbers represent data entered as of September 21, 2015.

DISCUSSION

Results Interpretation

Climate Patterns

During the study period (2011-2015), precipitation and temperatures fluctuated above and below "normal" (*i.e.*, in comparison to climatic averages from 1981-2010) at Redwood National & State Parks (with REDW's Kuchel Visitor Center selected as a representative climatic location) (Table 1,Table 2,Table 3,Table 4).

• 2011: The annual average temperature was similar to the 30-year (1981-2010) average temperature, but monthly temperatures deviated from 30-year normal monthly temperatures (*e.g.*, $Temp_{min}$ for November 2011 was 4.2 °C colder than normal) (Table 4). This year was also somewhat drier (14.862 cm less precipitation) than normal (Table 2).

• 2012: Overall temperatures ($Temp_{min}$, $Temp_{mean}$, $Temp_{max}$) were slightly cooler than normal (the 2012 annual average was 0.5 °C lower than normal) (Table 4). This year also received more rainfall (48.887 cm) than normal, and was the wettest year of the study period (2011-2014; excluding 2015, but it seems very unlikely that 2015 will be wetter) (Table 2).

• 2013: Overall temperatures were again slightly cooler (annual average was also 0.5 °C lower than normal) (Table 4). Meanwhile, this year was much drier (74.938 cm less precipitation) than normal (Table 2), and 2013 has been the driest year of the study period (2011-2014; excluding 2015, but see below).

• 2014: Overall temperatures were warmer than normal ($Temp_{min}$ and $Temp_{mean}$ were both 1.3 °C higher than normal) (Table 4). This year was slightly wetter (4.069 cm more precipitation) than normal (Table 2).

• 2015 (through August): This has been the hottest and possibly driest year during the study period so far (Table 2 & Table 4). Every month (especially February) has been warmer than the 30-year monthly normal, such that the January-August 2015 average temperature was 1.4 °C warmer than normal for that timeframe (Table 4). Every month except August has also been drier than the 30-year monthly normal (with a cumulative deficit of 36.552 cm less precipitation than normal for that timeframe) (Table 2), and it is possible that 2015 could finish as dry as 2013.

Plant Phenology

Coyotebrush (*Baccharis pilularis*)

Redwood National & State Parks (REDW) is responsible for the two northern-most monitoring locations (CBO and KVC) for coyotebrush (*Baccharis pilularis*) in the California Phenology Project (CPP). Coyotebrush is a priority species for CPP, because it is widely distributed and its biogeographic range encompasses a large latitudinal gradient (the entire California coast, along with proximal parts of Oregon and Baja California, Mexico) (David Bogler 2013. *Baccharis*, in Jepson Flora Project (eds.)). Coyotebrush is also a dioecious species, meaning that male and female reproductive parts are on separate plant individuals. Phenological research on coyotebrush is thus driven by questions such as: a) how might phenological shifts develop along a latitudinal gradient; and b) could phenological mismatches occur between male and female floral development and maturation?

CPP-REDW has contributed significantly to answering those questions. Coyotebrush is the most extensively monitored plant species at REDW, with the greatest number of individuals (25 plants) currently being observed at two monitoring locations (KVC and CBO), and boasting the highest number of phenophase records among the species monitored at REDW (18,292 records as of September 21, 2015) (Table **5** &Table **7**). Unfortunately, there was a lapse in the phenological monitoring of coyotebrush in fall 2013 (Figure3C). However, some phenological trends for coyotebrush can still be detected, especially when examining the phenological onset dates during years with the largest datasets (*i.e.*, 2012, 2014, and 2015 so far) (Table **7**).

At REDW, coyotebrush began fruiting at the beginning of September in 2012, which was slightly cooler than normal and the wettest year of the study period, but commenced earlier (mid-August) in 2014 and 2015, which were warmer and drier years (Figure 2B, D, and E; Table 2 &Table 4). For a discussion of the phenological responses of coyotebrush to winter temperatures and precipitation across its range, please see Mazer *et al*. (2015; pages 8-10 and Table 2 (1st line), Figure 2, and Table 3).

Phenological monitoring of coyotebrush at REDW should: a) continue to be prioritized, because REDW hosts the northern-most monitoring locations for this plant species; and b) be given particular attention, to counteract the logistic challenges of this species and the CBO monitoring location. Coyotebrush is tricky species to monitor, due to the subtleties of identifying female phenophases. REDW's northern-most monitoring location (CBO, Crescent Beach Overlook) is difficult, because that location is the farthest from the majority of our volunteer base. Fortunately, REDW-CPP had a dedicated volunteer from Crescent City for two years, was able to fund interns to collect data during volunteer gaps, and recently recruited a new volunteer from Crescent City to continue the phenological monitoring of coyotebrush at CBO. REDW-CPP should continue to be proactive about volunteer recruitment and retention for coyotebrush at the CBO monitoring location.

Silky beach pea (*Lathyrus littoralis*)

Phenological monitoring of silky beach pea at REDW has been uneven. This species was initially (2011-2012) monitored at the individual plant level, but then switched over to a patch protocol (2013-onwards), thus reducing the sample size (Table **5**). The silky beach pea sample size was increase by establishing new patches in 2015, but this perhaps should have been done in 2013. Also, phenological monitoring did not begin early enough in 2014 to detect the onset of its targeted phenophases (Figure 4D), monitoring was continuous and frequent in all other years (2012, 2013, & 2015) of the study (Figure 4B, C, &E).

Silky beach pea (*Lathryus littoralis*) plants at REDW (KVC monitoring location) seem to be progressing through life cycle stages earlier in the spring (Figure 4 & Figure 5). Compared to 2012, reproductive phenophases (flower bud formation, blooming period, and fruit development) all began earlier in 2013 and then even earlier in 2015 (Figure 4B, C, & E). 2012 and 2013 were both slightly cool years, but 2012 was the wettest year while 2013 was the driest year of the study period (Table 2 &Table 4). 2015 has also been very dry, and is the warmest year of the study period so far (Table 2 &Table 4). This phenological shift is likely to have been influenced by local climate conditions (*i.e.*, earlier reproduction seems to correspond with warmer and/or drier conditions) and conforms to the common pattern in which early spring flowering plants are particularly susceptible to this kind of phenological shift.

Earlier reproduction may not necessarily impact the silky beach pea's fitness (*i.e.*, reproductive success), since this species reproduces both sexually and asexually. However, other species (especially pollinators) may be negatively affected by this phenological shift. Silky beach peas are one of the earliest, relatively abundant, and productive (providing both nectar and pollen) flowering plants in northern California coastal dune habitats, and thus an important resource for pollinator species of bees. If a phenological mismatch develops between silky beach peas and their pollinators, there may be dire consequences for one or both partner species.

Pacific rhododendron (*Rhododendron macryophyllum*)

Data collection and data entry for Pacific rhododendron (*Rhododendron macrophyllum*) at REDW (LBJ monitoring location) has fluctuated over the years (Table **7**). Phenological monitoring was fairly comprehensive in 2012 and 2014 (Figure 6 B & D), but there was a lapse in 2013 during early summer (Figure 6 C), which is a phenologically active time for rhododendrons. Monitoring effort has also surpassed data entry, such that a significant amount of data from 2012 and 2013 still needs to be entered. This is a reminder that CPP-REDW should practice better data management, because delaying data entry increases the risk of datasheets becoming forgotten, misplaced, or totally lost.

The rhododendron phenological datasets from 2012 and 2014 are the most robust (Table **7**; Figure 6 B & D) and provide the most interesting point of comparison, since these years represent contrasting climate—2012 was slightly cooler than normal and the wettest year of the study period, whereas 2014 was warmer and the driest year so far (Table **2** & Table **4**). Rhododendrons commenced flowering in early June and fruiting in late June in 2012, while both phenophases began earlier in 2014 (FL: April/May; FR: early June) (Figure 6 B & D).

Phenological shifts such as the earlier onset of flowering can have ecological consequences. If Pacific rhododendrons and their pollinators diverge phenologically as a result of different responses to climatic conditions, then a phenological mismatch may be generated. Rhododendron flowers likely provide a large proportion of available resources for pollinators during late spring (or early summertime) in the redwood forest (which hosts relatively few flowering plants, most of which are diminutive in size and bloom in early spring). As such, *Rhododendron* may provide an important resource for pollinators at a time when other floral resources are less available—so a change in the timing of this resource availability could negatively affect pollinators which could, in turn, also negatively affect rhododendron reproduction.

Pacific trillium (*Trillium ovatum*)

Pacific trillium (*Trillium ovatum*) plants at REDW (LBJ monitoring location) seem to emerge (*i.e.*, shoot emergence aboveground and leaf development) and to flower earlier in response to interannual increases in temperature (Figure 8 & Figure 9). In 2012 and 2013, which were slightly cooler years, with particularly cooler months during "trillium season" (*i.e.*, January/February through spring) (Table 4), leaf formation and flowering did not occur until mid-March (Figure 8 B & C). In 2014 and 2015, which were much warmer overall, and during "trillium season" (Table 4), these same phenophases began earlier—leaves and flowers were present by the beginning of March in 2014 (they surprised REDW observers before data collection began), and leaves and flowers appeared in late February and early March, respectively, in 2015 (Figure 8D & E).

As suggested for silky beach peas (*Lathyrus littoralis*) and Pacific rhododendron (*Rhododendron macrophyllum*), a phenological shift such as early flowering can affect pollinators. In the case of Pacific trillium, this species also has an ecological relationship with seed dispersers—ants that are attracted to the specialized trillium fruits and assist in seed dispersal. So if early flowering leads to early fruiting, this may somehow affect trillium seed dispersal and, potentially, germination success.

A major logistical problem for Pacific trillium in this project is that the flowers tend to be picked by visitors. Trilliums are charismatic plants with highly attractive flowers and its monitoring location (Lady Bird Johnson Grove) is the most popular trail at Redwood National & State Parks. Visitors often pick trillium flowers (which is illegal) and/or accidentally trample the plants. Steps should be taken to mitigate this problem, including outreach/education efforts (*e.g.*, signs) informing visitors that: a) these plants are part of a scientific study; b) removing the flower completely destroys that plant's reproductive potential for the year; c) going off-trail damages habitat; and d) it is illegal to damage plants in the park. This could also be turned into an educational opportunity, in which the signs include a brief description of the CPP-REDW project and some websites for learning more about phenology.

Common cowparsnip (*Heracleum maximum*, formerly *H. lanatum*) & Red elderberry (*Sambucus racemosa*)

Common cowparsnip (*Heracleum maximum*, formerly *H. lanatum*) and red elderberry (*Sambucus racemosa*) were initially included in phenological monitoring (2011-2013), but are no longer part of the CPP-REDW project (Table **5**) due to logistical difficulties in reaching their locations. The duration over which these species were monitored (2.5 years) was not long enough to detect phenological trends, but at least some lessons were learned about the limitations of monitoring distant sites at REDW (see RESULTS section).

Education & Outreach

Citizen Scientists, Students, & Interns

Phenological monitoring at Redwood National & State Parks (REDW) has benefitted greatly from citizen scientist participation, including 25 students, volunteers, and interns. In turn, the California Phenology Project provided invaluable research experience for college students pursuing science majors, along with experience working in a national park. To that end, REDW has partnered with Humboldt State University (HSU), so that students can earn course credit (ENVS 482: Internship or BIOL 499: Directed Study) for helping with phenological monitoring. The ENVS 482 Internship is also supported by the Save-the-Redwoods League (SRL). Additional seasonal internships have been supported at REDW by the California Phenology Project (CPP), with funding from the National Park Service (NPS) Climate Change Response Program (CCRP).

Park Interpretation

The REDW phenology program is currently led by park staff (the Plant Ecologist) in the Vegetation Management Division, but has previously involved and hopes to reconnect with the park's Interpretation Division. A 2-year internship was jointly funded by both Divisions and was very productive. This intern (Steven Krause) collected copious phenological data, created photographic guides (*i.e.*, on-the-ground, first-person perspectives that are extremely useful) that facilitated locating each study plant at all three monitoring locations, and wrote an excellent article about the project, which was published on the front page of the park's Visitor Guide for two years, thus teaching countless visitors about phenology and climate change. In addition, he encountered many curious visitors while conducting data collection—he was actually approached by many more visitors than normal, since they were so curious about the ranger with the clipboard (Steven Krause, *personal communication*)—and so included phenological education and greater engagement in his interpretation work.

Presentations & Workshops

The California Phenology Project (CPP) and Redwood National & State Parks (REDW) have hosted three workshops to train participants and teach the public about phenology and climate change, in hopes of recruiting volunteers for phenological monitoring. These workshops were led by Susan Mazer (CPP director; UCSB-PSP):

• " The *California Phenology Project* at Redwood State and National Parks: monitoring the effects of climate change on the seasonal cycles of native plants species in Redwood National Park – introduction, on-line tools, protocols, and field practice," June 2011, 1 full-day training workshop at Redwood State and National Parks

• "The *California Phenology Project*: monitoring the effects of climate change on the seasonal cycles of California plants," March 2012, two 3-hour workshops (at Crescent City and in Arcata), Redwood State and National Parks

• " *The California Phenology Project:* Tracking phenological activity and its link to climate change at Redwood," April 2014, a 2-hour workshop in Arcata (US-FWS office).

In November 2014, Stassia Samuels (NPS plant ecologist) and Elizabeth Wu (CPP intern) gave a presentation at the Arcata Marsh visitor center. This presentation (indirectly) led to A LOT of volunteers (*i.e.*, 13 students in spring 2015, including a few who continued through summer and fall 2015!).

Lessons Learned & Recommendations

My main recommendations for the Redwood National & State Parks (REDW) phenology program concern: a) continuity and continuation of phenological monitoring; and b) quality of data collected. Input from other REDW-CPP project members (staff and volunteers alike) and suggestions from other NPS-CPP projects have also been incorporated into the following comments.

Phenological monitoring requires careful observation of plant morphology and development in order to identify key phenophase characteristics accurately and with confidence. It is helpful for citizen scientists to have prior knowledge of botany, though not required. In any case, one must be able to pay attention to details, and all observers should be trained well in phenological observation methods. This training should be done in the field, and "refresher" trainings should be given at multiple points during the field season, in order to: a) ensure that data are being collected correctly; b) instruct observers about new phenophases that are appearing for the first time; and c) maintain volunteer interest and engagement. QA/QC methods also need to be implemented, to double-check the accuracy of phenological data.

As mentioned in the Results and Discussion sections of this report, there have been various gaps in phenological monitoring at REDW. For phenological data to be robust, plants must be frequently observed in order to narrow down the timeframe in which a phenophase begins or ends. Regular monitoring must be prioritized, and I suggest that the volunteer coordinator:

a) sets up a realistic but frequent monitoring schedule (ideally, each individual plant would be observed and its phenological status recorded twice per week during phenologically active times for the species);

b) recruits enough observers that back-ups are available;

c) is ready to step in and help with data collection as needed (*e.g.*, during spring break and final exams week, if all the volunteers are students); and

d) provides and maintains an accessible, on-line calendar (such as google calendar or google docs) in which volunteers can schedule their monitoring plan and view those of others in order to determine where and when monitoring must be scheduled. Ideally, these calendars will also provide a way in which volunteers can indicate that they have completed their planned monitoring and data entry.

Phenological monitoring should also begin before any phenophase activity begins, in order to capture the full phenological development (*i.e.*, growing season) of a plant. To that end, the phenological supervisor should anticipate the "phenological season" and plan ahead with the monitoring program. If new species are added to a park's set of monitored plants, during the first year of monitoring, the species should be observed year-round in order to identify periods when it may undergo any new phenological transition. These periods must be identified and made note of so that the phenological monitoring schedule for these species will be sufficiently frequent during these periods that the day of year in which each targeted phenophase appears can be identified.

The future of the REDW phenology program depends upon staffing, citizen scientists, collaboration, and funding. More outreach is needed, and special attention should be given to volunteer recruitment for the CBO monitoring location. Volunteer recruitment, participation, and retention should all be promoted. REDW-CPP should maintain partnerships with Humboldt State University (HSU) and the Save-the-Redwoods League (SRL), since course credit and paid internships have been very successful ways to engage student volunteers. REDW-CPP should also explore other avenues of volunteer recruitment, such as the HSU Botany Club, College of the Redwoods (CR) (*e.g.*, our newest volunteer for CBO is a student at CR's Crescent City campus), and the California Native Plant Society (North Coast Chapter).

For this to be achieved, REDW-CPP needs more support for human resources and funding. This is needed for the NPS staff member who overseas the program (and has many other responsibilities and is thus over-extended), and for supporting staff (*e.g.*, an intern) to help with volunteer coordination (recruitment, scheduling, training, checking in, double-checking data entry), data management, study site maintenance, etc. Funding is needed for this internship position, and travel costs must also be funded.

While this project is valuable, interesting and engaging, it has been difficult to manage with existing park staff. While park interpretive staff were initially engaged, they have redirected their staff time to other projects and are no longer able to support the CPP, leaving program management entirely to the vegetation management staff. Unfortunately, the vegetation management staff at REDW is small and most of its resources are dedicated to restoration activities. The initial plan for staffing the project hinged on a network of student volunteers and a steady coordinator for those volunteers, however it has been difficult to find a volunteer who is able to coordinate the whole program. The time commitment required to recruit, train and supervise a cadre of volunteers to collect the data and enter it into the database each year exceeds the time available to the vegetation management staff.

ACKNOWLEDGEMENTS & APPRECIATION

The Redwood National & State Parks (REDW) phenological monitoring program would not exist if not for the foresight and guidance of Angela Evenden (CCESU), Susan Mazer (UCSB; CPP) and Stassia Samuels (NPS). The National Park Service (NPS) Climate Change Response Program (CCRP) and USA National Phenology Network (USA-NPN) were also instrumental in the establishment of this project.

The REDW phenology project completely depends upon a team of amazing volunteers and interns: Joseph (Joe) Best, Juan (John) Chavez, Bennett Collings, Robby Dipaolo, Shawna Faulkner, Kyle Fisher, Audrey Kelly, Steven Krause, Jennifer Lenstrom, Kevin Linowski, Amelia (Mia) Litz, Rebecca Manion, Jonathan Munguia, Elvia Angelica Munoz, Lily Pastel, Candace Reynolds, Elizabeth Rodriguez, Mika Samoy, Patree Scheid, April Shacklefor, Jake Skrbina, Thomas (Tommy) Thompson, Emelie Traub, Hannah Waterhouse, and Elizabeth Tina Wu. Many students hail from Humboldt State University (HSU), where they have been taught well by professors and lab instructors in HSU's College of Natural Sciences. We are especially grateful to professors Alison Purcell O'Dowd, Jeff Kane, and Erik Jules for providing course credit for HSU students participating in REDW phenological monitoring.

Funding support has been key for the REDW phenology program. The National Park Service (NPS) Climate Change Response Program (CCRP) provided funding that aided in the establishment of the project and supported substantial year-long internships. The Save-the-Redwoods League (SRL) provided funding for additional semester-long internships.

Thank you all!

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