Comparison of oak phenology between a drought year (WY 2014–2015) and an El Niño year (WY 2015–2016) at Pepperwood Preserve, Sonoma County, CA

Wendy Herniman, *California Naturalist*
Michelle Halbur & Lisa Micheli, *Dwight Center for Conservation Science at Pepperwood*

Abstract

Plant phenology (the timing of plant life cycles) is one of the most sensitive indicators of shifts in climate patterns. The importance of climate change has been highlighted by California's recent 4-year drought from 2012–2015. Climate models suggest that Northern California will become increasingly arid, with summer temperatures increasing by 6–8° F by end-of-century, and an increased probability of extreme events such as drought and flooding (Flint and Flint 2012). Since 2013, citizen scientists at Pepperwood Preserve (many of whom are certified California Naturalists) have been tracking the effects of climate on California native plant life cycles through the National Phenology Network and the California Phenology Project. Here, we compare the phenology of four oak species—Blue oak (*Quercus douglasii*), California black oak (*Q. kelloggii*), Coast live oak (*Q. agrifolia*), and Oregon oak (*Q. garryana*)—in a drought year (WY 2014–2015, 24.4" rain) and an El Niño year (WY 2015–2016, 31.3" rain). We also compare phenophase onset date with growing degree days and cumulative precipitation. We found that in 2015 all four oak species had an earlier onset of breaking leaf buds, flowers and flower buds, and fruits compared to 2016 (with the exception of Blue oaks fruiting at the same time and Coast live oaks fruiting later). Long-term monitoring of these oaks will inform how climate change may impact their phenology and thereby affect the critical habitat, food, and biodiversity oaks provide in California.

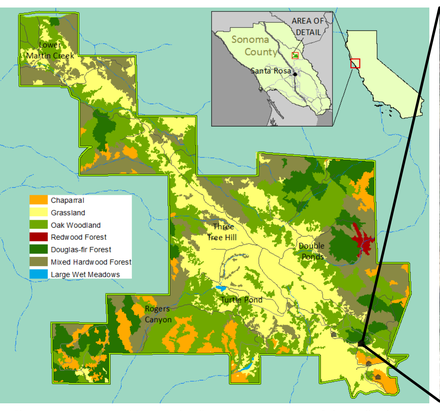


Figure 1a – Pepperwood Preserve locality and vegetation map. Oak woodlands cover approximately 918 acres of the 3200-acre preserve or 43% of the land.

Figure 1b – Oak phenology monitoring site including Blue oak (QUDO), California black oak (QUKE), Coast live oak (QUAG), and Oregon oak (QUGA). Epling's oak (QUEP), a hybrid between Blue and Oregon oak, was not included in this study.

Materials & Methods

Phenology Monitoring

As part of the California Phenology Project and using the National Phenology Network's (NPN) protocols, citizen scientists at Pepperwood have monitored the phenology of five oak species (Figure 1b) since August 2014. Species monitored include: Blue oak (*Quercus douglasii*; n=2), California black oak (*Q. kelloggii*; n=1), Coast live oak (*Q. agrifolia*; n=3), Oregon oak (*Q. garryana*; n=3), and the hybrid Epling's oak (*Q.* x *eplingii*; n=1), which was not included in this analysis.

Trees were monitored weekly for a variety of phenological phases (phenophases) including, but not limited to, the onset of breaking leaf buds, flowers (including flower buds) and fruiting. Data was entered into the NPN's publically accessible online database called Nature's Notebook.

Climate Data

Climate data were collected at Pepperwood in an open grassland approximately 0.3 miles southwest of the oak monitoring site. Air temperature and precipitation data were recorded at 15-minute intervals by Campbell Scientific probes HMP45C and TE525, respectively, and were logged on a CR3000.

Data Analysis

Growing degree days (GDD), a metric used primarily by the agricultural industry to predict plant and pest phenology, involves calculating the number of days that precede the onset day with a temperature above a metabolic threshold of 10° C. We calculated GDD with a start date of December 1, based on climate modelers utilizing Dec/Jan/Feb for generating average winter minimum temperatures. Cumulative precipitation represents the amount of precipitation that has occurred since the start of the respective water year, which begins on October 1.

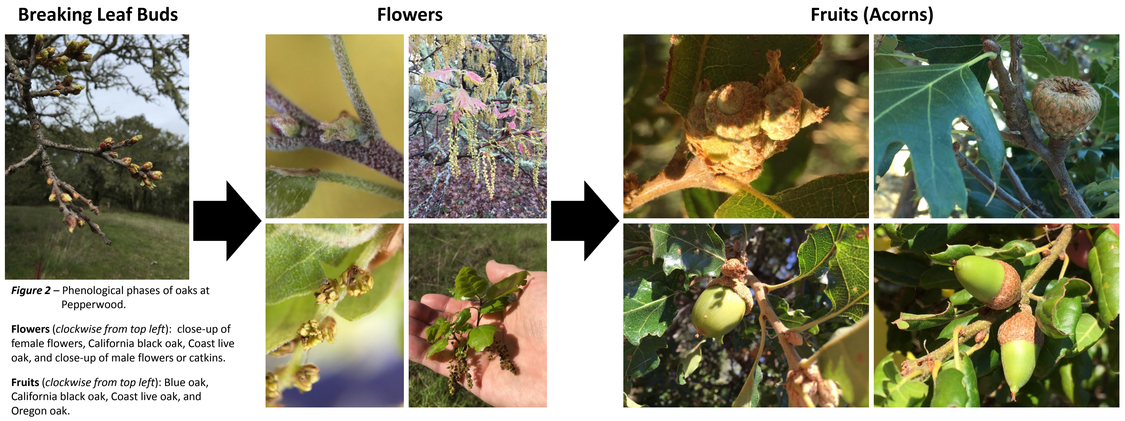


Figure 2 – Phenological phases of oaks at Pepperwood.

Flowers (*clockwise from top left*): close-up of female flowers, California black oak, Coast live oak, and close-up of male flowers or catkins.

Fruits (*clockwise from top left*): Blue oak, California black oak, Coast live oak, and Oregon oak.

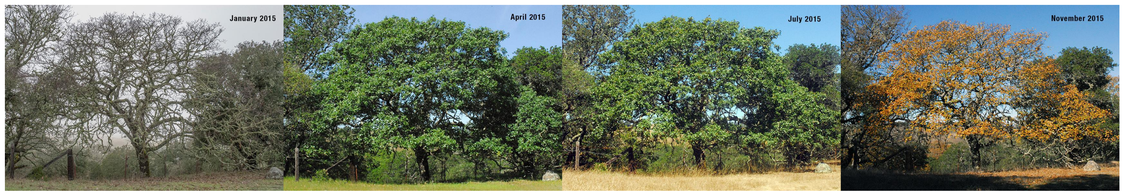
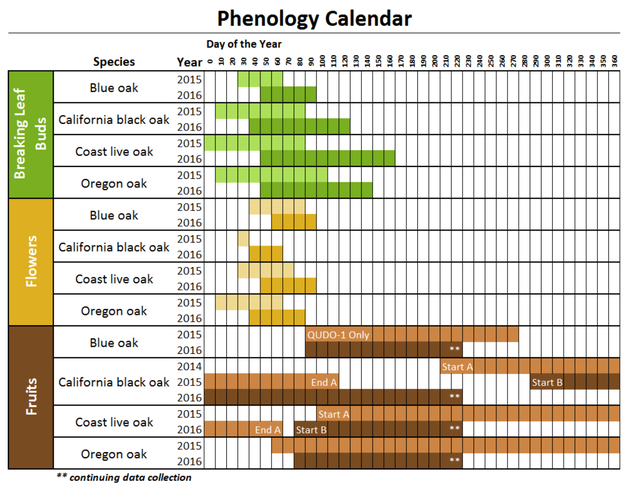


Figure 3 – Leaf phenology transition through the 2015 calendar year for California black oak QUKE-1 (Figure 1b) - photographs by Gary Morgret

Variability of Phenophase Onset Date and Growing Degree Days Among Individual Oregon Oaks

Figure 4 – Phenophase onset dates for three individual Oregon oak trees including the first date of observed breaking leaf buds (indicated by the green arrows), flowers (yellow arrows), and fruits (brown arrows) in 2015 and 2016. Individual phenological variation among trees is evident among each other and between years.

Phenology Calendar



***** continuing data collection***

Figure 5 – Onset dates and durations of breaking leaf buds (first flush of growth only), flowering and fruiting phenophases.

Growing Degree Days at Onset (average when n>1)

	Breaking Leaf Buds			Flowers			Fruits		
Species	**2015**	**2016**	**Difference**	**2015**	**2016**	**Difference**	**2015**	**2016**	**Difference**
Blue oak	50	30	20	64	36	28	100	54	46
California black oak	28	18	10	42	18	24	n/a	n/a	
Coast live oak	43	23	20	56	30	26	183	58	125
Oregon oak	40	26	14	49	31	18	82	48	34

Cumulative Precipitation at Onset (inches)

	Breaking Leaf Buds			Flowers			Fruits		
Species	**2015**	**2016**	**Difference**	**2015**	**2016**	**Difference**	**2015**	**2016**	**Difference**
Blue oak	21.1	19.2	1.9	22.4	19.5	2.9	22.5	28.8	-6.3
California black oak	18.6	17.4	1.2	18.6	17.4	1.2	n/a	n/a	
Coast live oak	20.6	18.9	1.7	21.1	19.1	2.0	24.0	29.0	-5.0
Oregon oak	19.9	18.9	1.0	20.7	21.5	-0.8	22.5	28.7	-6.2

Figure 6 – Onset dates and durations of breaking leaf buds, flowering and fruiting phenophases for WY 2014–15 (listed here as 2015) and WY 2015–16 (listed here as 2016). The differences are 2015 compared to 2016. Negative precipitation values indicate that the amount of cumulative rainfall at onset was greater in 2016 compared to 2015.

Results

Phenophase Onset Date

All four oak species exhibited earlier onset dates in WY 2014–15 (hereafter 2015) compared to WY 2015–16 (hereafter 2016) for the breaking leaf bud and flowering phenophases (Figure 5). The average onset of breaking leaf buds occurred 22 days earlier (range 3–34 days) in 2015 than in 2016. Flowers also formed earlier (average 16 days, range 5–43 days) in 2015 compared to 2016.

Fruiting had a similar trend in California black oak and Oregon oak, which were respectively 78 days (n=1) and an average of 11 days (ranged from -2 to 21 days) earlier in 2015. Coast live oaks exhibited an opposite trend and fruited later in 2015 (average 92 days, range 10–173 days) (Figure 5). The two Blue oak trees we observed had very different fruiting cycles in WY 2014–15; QUDO-1 fruited from April–September 2015 whereas QUDO-2 fruited from August 2014 through February 2015. However, both trees were observed fruiting on the same day (April 1, Day 92) in 2016 (Figure 5).

Phenophase Duration

The average duration of breaking leaf buds (first flush of growth only) was 17 days less in 2015 (43 days, range 19-79 days) compared to 2016 (60 days, range 9-111 days). The average duration of flowering was similar between 2015 (23 days, range 7-49 days) and 2016 (22 days, range 5-37 days). However, the one California black oak tree we monitored had a particularly short flowering duration in 2015 of 8 days compared to 21 days in 2016 (Figure 5). We were unable to calculate differences in fruiting periods between 2015 and 2016 since most oaks were continuing to develop fruits at the time of poster production.

Growing Degree Days & Cumulative Precipitation

WY 2014–15 had warmer temperatures in December and January which led to a greater accumulation of GDD earlier in the year compared to WY 2015–16 (Figures 4 & 6). For all species and phenophase onset dates, GDD was higher in WY 2014–15 (Figure 6). Even though WY 2014–15 was a drought year with below average rainfall, there was greater cumulative precipitation earlier in the year compared to WY 2015–16. This led to a greater accumulation of precipitation at the onset dates of breaking leaf buds and flowers for all species (with the exception of the Oregon oak flowering onset date) (Figure 6). Phenophases that begin later in the year—flowering and fruiting—had greater cumulative precipitation in 2016 from spring rains compared to 2015.

Discussion

As temperatures in the San Francisco Bay Region increase an anticipated 6-8° F by end-of-century, oak phenology will most likely shift to starting earlier in the growing season. This response was observed in the breaking leaf bud and flowering phenophases for all four oak species we monitored in 2015, which had an elevated number of Growing Degree Days prior to onset compared to 2016. This is consistent with the literature on oak phenology where the date of oak leaf bud burst has been shown to advance by 1-3 days per °C (Kuster et al. 2014). Changes to breaking leaf bud dates also have a direct effect on photosynthate availability for growth and development (Lechowicz 1995) and may impact flower and fruit production, forest canopy, and habitat structure.

Phenophase duration was relatively shorter for breaking leaf buds in 2015 whereas flowering duration was consistent among sample years, with the exception of the single California black oak we monitored that had flowers for only 8 days in 2015 – a 62% reduction compared to 2016. Shortened flowering durations may impact fruit maturation and abundance and could thereby affect forest regeneration and species that depend on oaks for food and shelter.

Cumulative precipitation was relatively greater at the time of onset for breaking leaf buds and flowers in WY 2014–15 compared to WY 2015–16. This was due to a greater amount of precipitation occurring earlier in the year even though WY 2014–15 was a drought year compared to WY 2015–16. Experimentally reduced precipitation in autumn months has been shown to have no effect on oak leaf, flower, or fruit development. However, decreased spring precipitation has been shown to negatively affect leaf development and female fruit (acorn) maturation (Misson et al. 2010). By continuing to monitor these oak species at Pepperwood we will be able to observe the response of fruit development and abundance to precipitation. We will also be able to document the effects of climate change on the health of our oak forests and inform our land management practices to support this diverse and critical ecosystem.

Acknowledgements

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