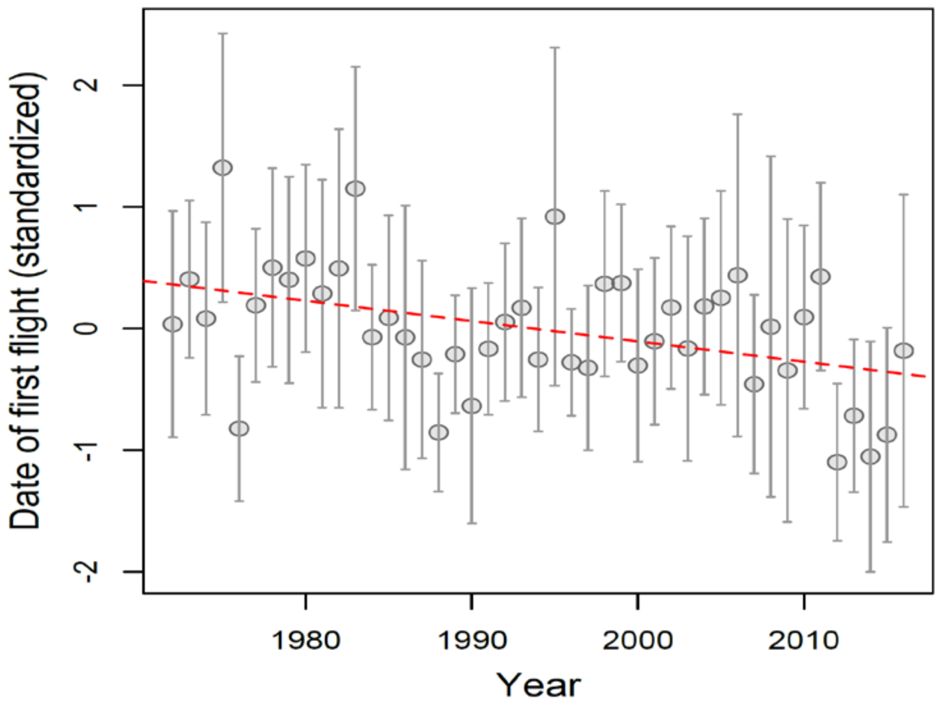
SPRING FLIGHT OF CENTRAL VALLEY BUTTERFLIES

Over the past 45 years, common butterfly species have been appearing in the Central Valley earlier in the spring.

Painted lady (*Vanessa cardui*) Photo: Jim Ellis

Figure 1. Date of First Spring Flight of Central Valley Butterflies



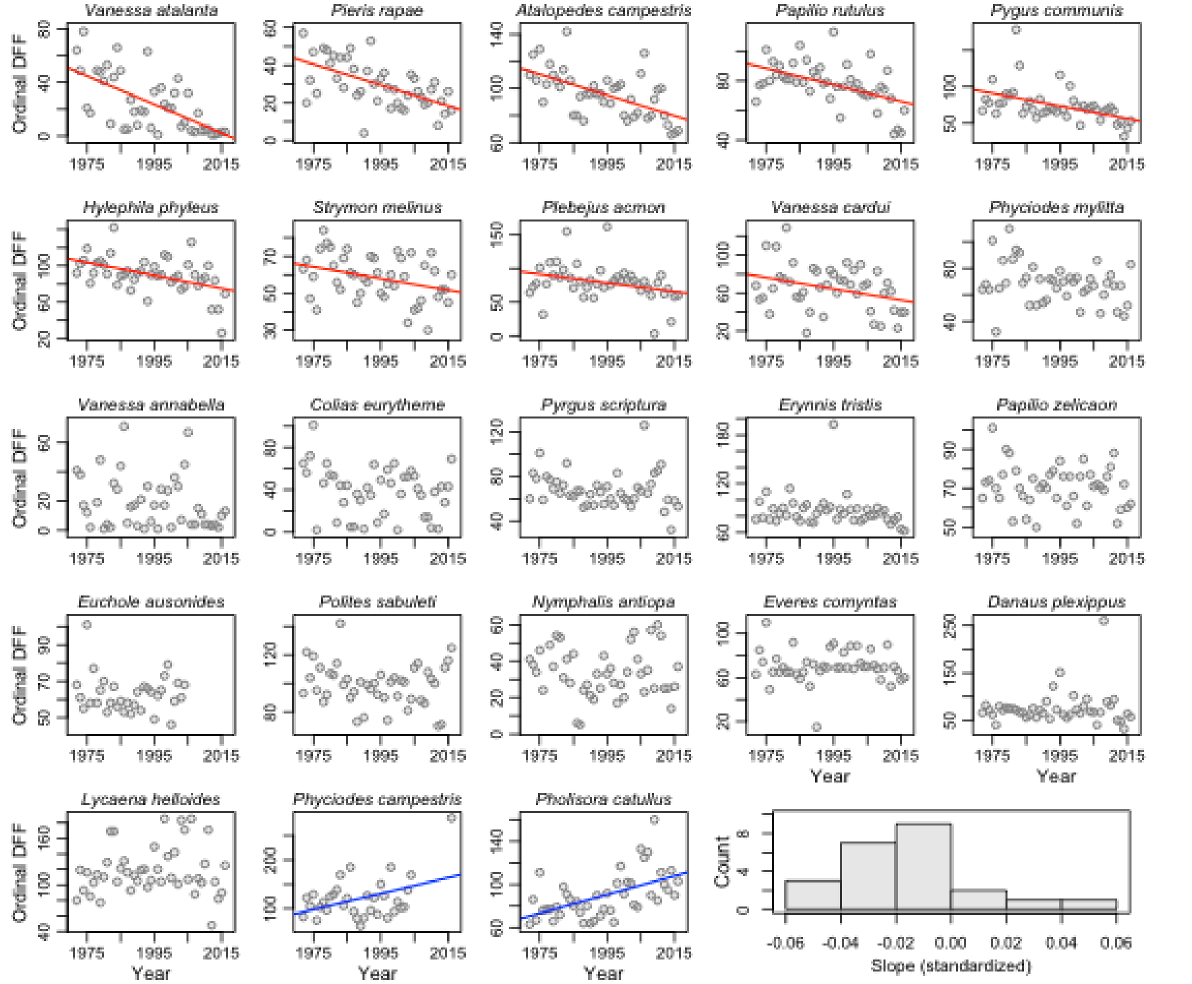
Source: Forister and Shapiro (2003), updated 2017

What does the indicator show?

Over the past 45 years, the average date of first flight (DFF) of a suite of 23 butterfly species in the Central Valley of California has been shifting towards an earlier date in the spring. The DFF refers to the date that the first adult of a species is observed in the field in a given calendar year. In Figure 1, the value shown for each year is the aggregate of DFFs across the 23 species, calculated as described in the *Technical Considerations* section below. The higher the value on the graph, the later the DFF.

Figure 2 presents graphs showing DFF (untransformed) by year for each butterfly species, starting with the species showing stronger trends towards earlier emergence, and ending with the species showing trends towards later emergence. Values plotted are days since the start of the calendar year (also known as "ordinal" dates). Lines on plots indicate that the trend is significant (at $P < 0.05$): red lines are used for species emerging earlier, and blue lines for those emerging later. The histogram in the lower right shows the distribution of slopes of DFF values against years for the different species, calculated using z-scores (see *Technical Considerations*).

Figure 2. Date of first spring flight for 23 butterfly species



Source: Forister and Shapiro (2003), updated 2017

Nine species each independently show significant trends towards earlier emergence, while only two species show significant trends for later emergence. Across the nine species with significantly earlier emergence, the average slope is -0.67 day per year. This means that on average these species have emerged earlier in the spring by roughly one month over the 45 years of observations. The slopes of the two later-emerging species are 1.64 and 0.87 days per year, respectively. As shown in the histogram in Figure 2, slopes of DFF values against years have shifted toward negative values, indicating overall earlier emergence across species, consistent with the pattern shown in Figure 1.

Why is this indicator important?

This indicator tracks the response of common butterfly species as a way of studying biological shifts consistent with the impacts of a changing climate. Plants and animals reproduce, grow, and survive within specific ranges of climatic and environmental conditions. Changes in these conditions beyond a species' tolerances can elicit a change in phenology — that is, a change in the timing of seasonal life-cycle events, such as leaf unfolding, flowering, bird migration, egg-laying and the appearance of butterflies. Studies that have investigated the relationship between phenology and changes in climate conditions have largely been conducted in higher, temperate latitudes, where minor climatic changes can have large impacts on species that are often at the limits of their geographic ranges. By contrast, species from lower latitudes, where the climate is highly variable (including areas of California that have a Mediterranean climate), and where there are large fluctuations in temperature and precipitation, might be expected to be less sensitive to such variability.

The shifting phenology of these 23 butterfly species is correlated with the hotter and drier conditions in the region in recent decades (Forister and Shapiro, 2003) (see *Annual air temperature* and *Precipitation* indicators). The data supporting this indicator suggest that Central Valley butterflies not only are responding to changing climate conditions, but also that their responses have been similar to those of butterflies from higher-latitude climates. These findings complement similar studies from Europe and demonstrate the apparently ubiquitous phenological response of spring butterflies to warming and drying conditions (e.g., Roy and Sparks, 2000; Peñuelas et al., 2002). It is also worth noting that the Central Valley has undergone intense land conversion, both to urban development and to agriculture (Forister et al., 2016). Thus, the data indicate that the phenological impacts of climate change are not restricted to northern latitudes or to areas with pristine ecological conditions.

What factors influence this indicator?

Climatic conditions have a significant impact on the phenology of butterflies. Butterflies in the temperate latitudes enter a dormant state during the winter months; in the spring, temperature cues cause them to hatch, resume feeding, or emerge from pupae as adults (Dennis, 1993; Shapiro, 2007). As climatic conditions during key times of the year have changed, the timing of butterfly life-history events has undergone a corresponding change. The butterfly species monitored overwinter (i.e., spend the winter) in different life-history stages as: eggs (1 species); larvae (8 species); pupae (9 species); and adults (3 species). Two of the species emigrate in the spring from distant overwintering sites.

Statistical analyses were conducted to determine the association between DFF and different weather variables: total precipitation, average daily maximum temperature and average daily minimum temperature in the winter and spring of the year in question, and in the summer and fall of the previous year. Winter conditions — specifically winter precipitation, average winter daily maximum temperature, and average winter daily minimum temperature — were found to have the strongest associations with the date of first flight (Forister and Shapiro, 2003).

Other factors may impact the phenological observations described here, such as nectar and host plant availability. Plant resources may in turn be affected by habitat conversion, though it is not clear how these factors could lead to the earlier emergence of a fauna in a specific area. Finally, the impacts that a shifting insect phenology may have on other species at higher and lower trophic levels, including larval hosts and predators, are also unknown.

Technical Considerations

Data Characteristics

The data described here consist of the date of first spring adult flight (DFF) for 23 butterfly species. These were first reported by Forister and Shapiro (2003). Fourteen years of data have been added to that original data set. The primary result remains unchanged by the updated data: an overall shift towards earlier emergence, with more dramatic shifts in a subset of species.

The values for Figure 1 were derived as follows:

- Calendar dates were first converted into days since the start of the year, also known as "ordinal" dates.
- The ordinal dates of first flight (DFF values) were transformed into z-scores separately for each species. To do this, the mean and standard deviation of DFF values across years were calculated. The difference between each DFF value and the mean was then found, and that result divided by the standard deviation to produce a z-score corresponding to the number of standard deviations a value is from the long-term average DFFs for that species. For example, a z-score of -1 indicates a DFF that is one standard deviation earlier than the average for that species, and a value of 1 indicates a DFF that is one standard deviation later than average.
- The mean of the z-scores across the 23 species for each year is shown in Figure 1, along with the standard deviation of the z-score values.
- The red line in Figure 1 is fit to the mean z-score values across years. It shows that the mean values have decreased over time, and corresponds to an overall trend towards earlier emergence that is significant ($F_{1,43} = 8.92$, $P = 0.0046$).

The study area is located in the Central Valley portions (below 65 meters elevation) of three Northern California counties: Yolo, Sacramento, and Solano. Three permanent field sites in these counties are visited by an investigator at two-week intervals during “good butterfly weather.” Most of the observations (> 90%) of DFF come from these permanent sites; however, in a given year, if a butterfly is first observed to be flying at a location within the three counties, but outside the permanent sites, that observation is included as well.

Weather data were obtained from the University of California/National Oceanic and Atmospheric Administration climate station in Davis, California, a World Meteorological Organization station centrally located among the study sites. Weather variables are not independent, and some were excluded as redundant before use in multiple regressions or other analyses.

Strengths and Limitations of the Data

Since the data are collected and compiled entirely by one observer (Arthur Shapiro of University of California at Davis), any biases in data collection should be consistent across years. This would not be true in studies which involve multiple workers — with variable levels of training — across years.

The primary limitation of the data stems from the fact that DFF is only one aspect of a potentially multi-faceted suite of population-level dynamics. For example, if the spring phenology of a species shifts, does this affect the total flight window? Does it affect peak or total abundance throughout the season? The picture becomes even more complex when one considers the general declines in low-elevation butterfly populations in the region that have been reported by Forister et al. (2010). If populations are in overall decline, with lower densities of individuals throughout the year, this could lower detection probabilities. This is true particularly early in the season for multivoltine species (i.e., species that produce more than one generation in a season, where the first generation tends to be smaller). Lower detection probabilities could appear as later phenological emergence (i.e., a “backwards” shift in time as is shown for *P. catullus* in the bottom right of the second figure). These issues are addressed in more detail in Forister et al. (2011). For further discussion of relevant biological complexities, see Shapiro et al. (2003) and Thorne et al. (2006).

For more information, contact:

University of Nevada, Reno

Matthew L. Forister
Department of Biology
University of Nevada Reno
Mail Stop 314
Reno, NV 89557
(775) 784-4053
mforister@unr.edu

CENTER FOR POPULATION BIOLOGY

Arthur Shapiro
Department of Evolution and Biology
University of California Davis
6347 Storer Hall
Davis, CA 95616
(916) 752-2176
amshapiro@ucdavis.edu

References:

Dennis RLH (1993). *Butterflies and Climate Change.* Manchester, NY: Manchester University Press.

Forister ML, Cousens B, Harrison JG, Anderson K, Thorne JH, et al. (2016). Increasing neonicotinoid use and the declining butterfly fauna of lowland California. *Biology Letters* **12**(8)**:** 20160475.

Forister ML, Jahner JP, Casner KL, Wilson JS and Shapiro AM (2011). The race is not to the swift: long-term data reveals pervasive declines in California's low-elevation butterfly fauna. *Ecology* **92**(12): 2222-2235.

Forister ML, McCall AC, Sanders NJ, Fordyce JA, Thorne JH, et al. (2010). Compounded effects of climate change and habitat alteration shift patterns of butterfly diversity. *Proceedings of the National Academy of Sciences* **107**(5): 2088-2092.

Forister ML and Shapiro AM (2003). Climatic trends and advancing spring flight of butterflies in lowland California. *Global Change Biology* **9**(7): 1130-1135.

Peñuelas J, Filella I, and Comas P (2002). Changed plant and animal life cycles from 1952 to 2000 in the Mediterranean region. *Global Change Biology* **8**(6): 531-544.

Roy DB and Sparks TH (2000). Phenology of British butterflies and climate change. *Global Change Biology* **6**(4): 407-416.

Shapiro A (2007). *Field Guide to Butterflies of the San Francisco Bay and Sacramento Valley Regions.* Berkeley, CA: University of California Press.

Shapiro A, Van Buskirk R, Kareofelas G and Patterson W (2003). Phenofaunistics: Seasonality as a Property of Butterfly Faunas. In: *Butterflies: Ecology and Evolution Taking Flight.* Boggs CL, Watt WB and Ehrlich PR (Eds.). Chicago: University of Chicago Press. pp. 111-147.

Thorne J, O'Brien J, Forister M and Shapiro A (2006). Building phenological models from presence/absence data for a butterfly fauna. *Ecological Applications* **16**(5): 1842-1853.