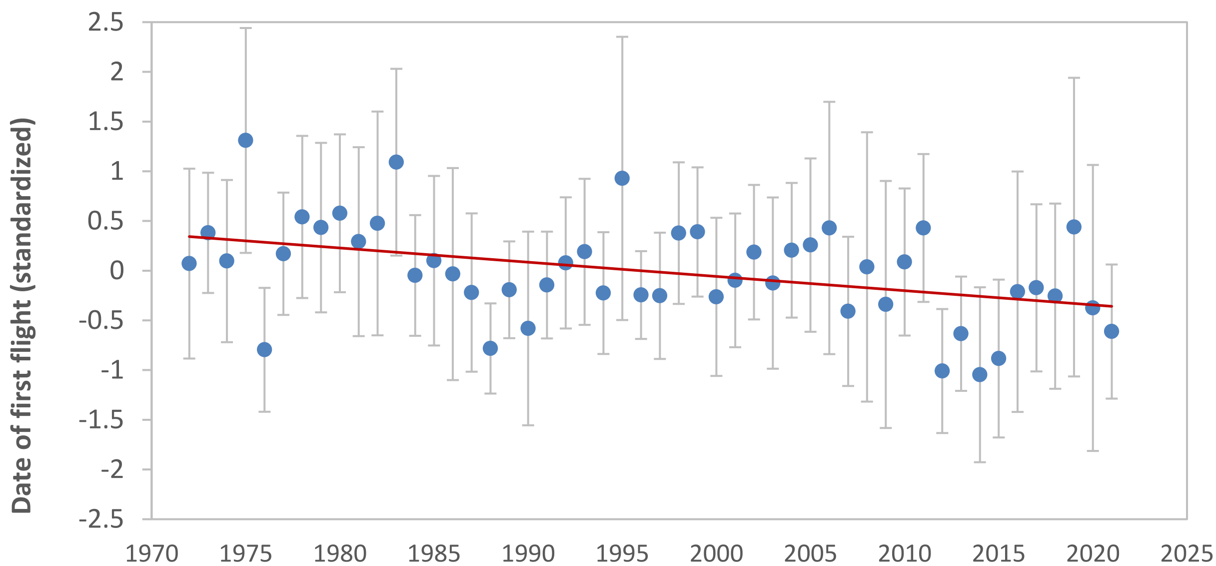
Spring flight of Central Valley butterflies

Over the past 50 years, common butterfly species have been appearing in the Central Valley earlier in the spring.

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



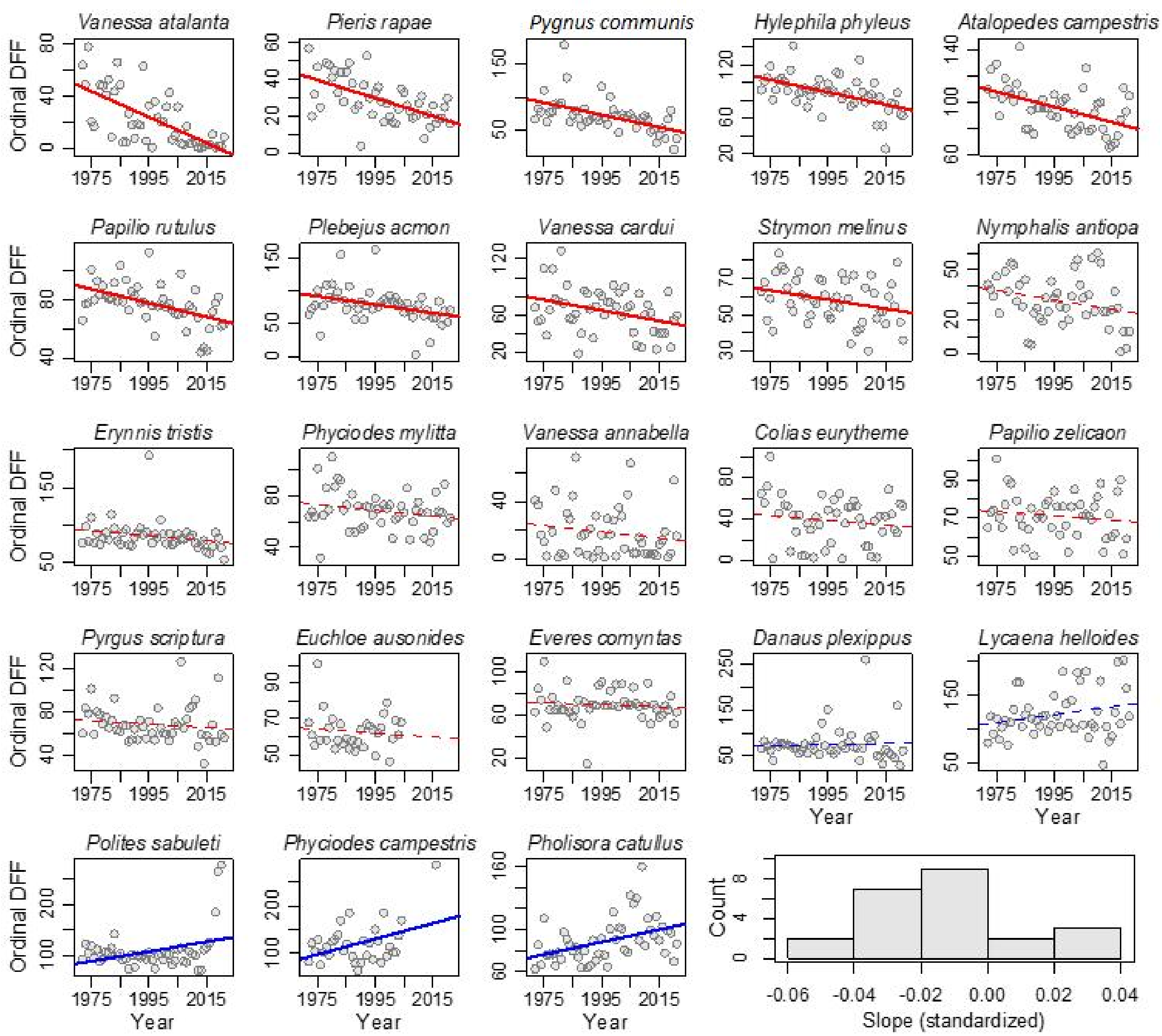
Source: Forister and Shapiro (2003), updated 2021 (see text for explanation)

What is the indicator showing?

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

Over the past 50 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 (Figure 1). The DFF refers to the date that the first adult of a species is observed in the field in a given calendar year. Change in DFF tracks shifts in the phenology (the timing of seasonal life cycle events) in the emergence of butterflies in the Central Valley. 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. A negative value indicates a DFF that is earlier than the average; a positive value, later than the average. The red line in the graph indicates the overall trend towards earlier emergence (Forister and Shapiro, 2003, updated data available from UCD, 2021).

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



Source: Forister and Shapiro 2003 (updated 2021)

**Ordinal DFF are days since the start of the calendar year*

Bold lines are drawn on plots if individual trends are significant in simple linear models with DFF predicted by year, at *P* < 0.05; dashed lines indicate *P* > 0.05. Red for species emerging earlier, and blue for species emerging later.

Figure 2 presents graphs showing DFF by year for each butterfly species, starting with species showing stronger trends towards earlier emergence, and ending with species showing trends towards later emergence. Across the nine species with individually significant responses for earlier emergence, the average slope is -0.62 days per year, which means that the spring phenology of these species is advancing by approximately 6 days per decade. As shown in the histogram in the lower right of the figure, the distribution of slope values across species (generated from analyses of z-scores) is significantly shifted towards the negative, indicating earlier emergence across species (one-sample t test = -2.70, P = 0.013), consistent with the pattern shown in Figure 1.

Why is this indicator important?

This indicator demonstrates the utility of common butterfly species for 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. Species may respond when these conditions change beyond tolerances by moving to more favorable habitats (often poleward or to higher elevations), sometimes changing in morphology such as body size or wing color, or altering phenologicaly with respect to the timing of events such as migration, egg-laying or emergence (Hill et al., 2021; Root et al., 2003). Many studies have investigated the relationship between phenology and changes in climate conditions. These studies, however, have largely been from higher, temperate latitudes, where minor climatic changes can have large impacts on species that are often at the limits of their ranges (Chambers et al., 2013; Parmesan, 2006; Root et al., 2003; Walther et al., 2002).

The shifting phenology of these 23 butterfly species is correlated with the hotter and drier conditions in the region in recent decades (Forister et al., 2018; Forister and Shapiro, 2003; Halsch et al., 2021) (see *Annual air temperature*, *Precipitation* and *Drought* indicators). The data supporting this indicator suggest that Central Valley butterflies are not only responding to changing climate conditions, but also that their responses have been similar to butterflies from higher-latitude climates. This indicator complements similar studies from Austria, Switzerland, the United Kingdom and other European countries and demonstrates the apparently ubiquitous phenological response of spring butterflies to warming and drying conditions (e.g., Altermatt, 2012; Hill et al., 2021; Peñuelas et al., 2002; Roy and Sparks, 2000). 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 pristine ecological conditions. Continued monitoring of phenological changes adds to the growing body of data that elucidate butterfly responses to changing temperature and precipitation linked to climate change, that are occurring alongside changing land use, increasing pesticide use, and other stressors (Chmura et al., 2019).

Changes in the seasonal timing among species that interact—for example, between butterflies and their plant food sources, or between prey and predators—could disrupt population dynamics and species abundance across trophic levels (Weiskopf et al., 2020). Declining populations of butterflies and other insects have been reported globally, underscoring the urgency to better understand how changes in climate, habitat degradation, pollution, and other stressors interact to affect insect populations (Halsch et al., 2021).

Dates of first flight are presented as an indicator of climate change, primarily because they have a history of being used in this context in global change research. However, the date of first flight is of course only one aspect of the biology of a butterfly population. Population densities in the northern Central Valley of California are declining in response to shifting land use, increased use of pesticides, and climate change (Casner et al., 2014; Forister et al., 2016). More recently, severe declines have been observed in areas not immediately adjacent to intense agricultural development and urbanization. During and after the mega-drought years of 2011 to 2015, butterfly populations in the Sierra Nevada Mountains reached historic lows that rival the declines previously seen in the Central Valley (Halsch et al., 2021).

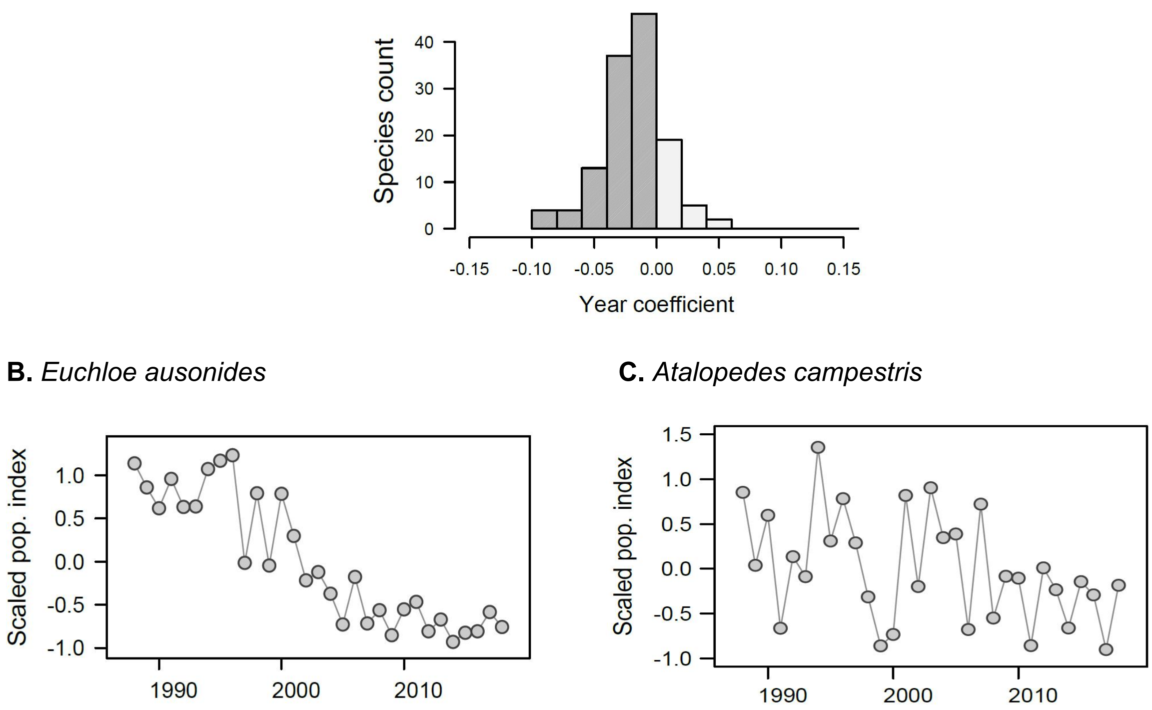
Widespread butterfly declines have been detected across the western US: specifically, Forister et al. (2021) estimated 1.6% fewer butterflies are being observed per year across all western states (95% Bayesian credible intervals around that value ranged from 3.4% decrease to 0.2% increase). That result is based on 72 sites (with 10 or more years of data) monitored by community scientists organized by the North American Butterfly Association (NABA). Changes in the total numbers of butterflies at those sites were modeled as a function of a range of climate and landscape factors, and the most powerful predictors were indices of climate change. In particular, locations where fall months had warmed the most (in maximum daily temperatures) were the locations where annual reductions in total butterfly densities were most pronounced (Forister et al. 2021).

Consistent with the broader trend throughout the western United States, a majority of species in the Northern California data set that includes the butterfly species tracked by this indicator have been seen less frequently over time; the results are summarized in Figure 3A. This data set consists of observations from ten study sites that include large urban and agricultural areas from the Bay Area to the Sierra Nevada Mountains, and the population changes reflect both the effects of habitat loss or degradation and climate change. Annual changes in the probability of being observed (which is used as an index of population density) for two species are shown in Figure 3B and C.

The biological mechanisms linking fall warming to butterfly declines have yet to be thoroughly explored, but likely involve physiological stress on host and nectar plants as well as interference with overwintering stages of the butterflies. Although much has yet to be learned, it is worth nothing that the NABA community scientist program is based on a single day of observations during the middle of summer (in some cases sites are visited more than once, but most are visited once, typically in July). The efficiency of this program highlights the power of crowdsourced biological data for tracking climate effects, especially when used as a complement to the expert-derived data as described in this indicator report.

Figure 3. Declining Northern California butterfly populations

A. Summary of magnitude of change across species*



Source: Forister et al., 2021

**Based on data for ten sites across northern California monitored every other week during the butterfly flight season for between 33 and 49 years, depending on the site. See Forister et al. (2011) and Forister et al. (2021) for additional details on data and methods.*

A. Values summarized are year coefficients (from binomial regression models) that reflect upward or downward population trends; negative values, shown in dark gray, correspond to the majority of species with negative annual coefficients (one species with a large positive value is excluded for ease of visualization). **B and C**. Annual values for two exemplar species: *Euchloe ausonides* (B) and *Atalopedes campestris* (C); y axis values are z-standardized probabilities of being observed in each year (1988-2018).

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, to resume activity, or to 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 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 over-wintering sites. Statistical analyses to determine the association between DFF and twelve different weather variables show winter conditions—specifically winter precipitation, average winter daily maximum temperature, and average winter daily minimum temperature—have the strongest associations with DFF (Forister and Shapiro, 2003). Between 2011 and 2015 (during the drought years), DFFs advanced at the low-elevation locations in the Central Valley, as well as at higher-elevation sites in the Sierra Nevada (Forister et al., 2018). However, dates of last flights remained close to the long-term average at low elevation sites, while advancing at higher elevations, thereby compressing the length of the flight window.

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 obvious how these factors could lead to the earlier emergence of a fauna. 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). The primary result remains unchanged by the updated data: an overall shift towards earlier emergence, with more dramatic shifts in a subset of species. Information about ongoing monitoring of study sites can be found at Monitoring Western Butterflies and Art Shapiro's butterfly site; data are available upon request.

The study area is located in the Central Valley portions (below 65 meter 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 those permanent sites; however, if a butterfly was observed in a given year to be flying first at a location within the three counties but outside of the permanent sites, that observation was included as well.

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 DFF 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.

Strengths and limitations of the data

Since the data are collected and compiled entirely by one observer (Arthur Shapiro), 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 considering 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); and for further discussion of relevant biological complexities, see Shapiro et al. (2003) and Thorne et al. (2006).

OEHHA acknowledges the expert contribution of the following to this report:

University of Nevada, Reno

Matthew L. Forister
Department of Biology
University of Nevada Reno
(775) 784-4053
mforister@unr.edu

CENTER FOR POPULATION BIOLOGY

Arthur Shapiro
Department of Evolution and Biology
University of California Davis
(916) 752-2176
amshapiro@ucdavis.edu

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