6.3. The phenology of butterflies in Sierra Nevada

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Abstract

The phenological study of butterfly communities of Sierra Nevada shows that most of the species delay their adult emergence at the sites situated at highest elevations. The species with later emergence periods (summer species) show greater synchronization over their elevational distributions than early species (spring species) do. A very clear relation has been observed between mean phenological delay over the elevational gradient studied. The results show that warm springs and, more specifically, higher temperatures in the month of May trigger early emergence of Apollo adults in Sierra Nevada.

Aims and methodology

Butterfly censuses

The sampling method consisted of visually counting the adult butterfly individuals along transects where all the butterflies were counted within an imaginary box of 2.5 m on each side and 5 m in front of and above the observer [5]. This is an internationally accepted method and is used in other similar programmes in different places around the world. The annual number of transects varied according to the year, between 8 and 22, and their length varied from 300 to 3272 m (mean: 1589.5 m). The transects were repeated a minimum of twice monthly and a maximum of once weekly. The samplings were made from 700 to 3100 m.a.s.l..

Butterfly phenology

Weighted mean date, for each year and for each species, was calculated as *mean date*: (Σ Number of butterflies per visit × Date)/Annual total number of butterflies of that species counted in that year and at that site [6]. Species that are not univoltine in the study area were not considered, nor were those that presented difficulties for field identification, or those that had overwintering adults, migratory species or tree-living species. From this information and from its regression against elevation of each study site, the phenological lag was inferred (expressed as days/km).

Climate data

To compare the effects of temperature on the phenological lag, data from the network of multiparametric stations in Sierra Nevada were used. The data corresponded to the stations of Encinar (1700 m.a.s.l.), Rambla de Guadix (600 m.a.s.l.), Embarcadero (1550 m.a.s.l.), Piedra de los Soldados (2150 m.a.s.l.), and Aljibe de Montenegro (975 m.a.s.l.).

For the effects of the climatology on the phenology of *Parnassius apollo*, a multiple regression analysis was performed. Mean date of adult emergence was used as dependent variable and mean temperatures and accumulated precipitation of April and June (monthly values and an average for three months) were used as predictions variables.

The Black-veined White (*Aporia crataegi*).

Results

Elevational gradient

The analyses included between 6 and 14 species/year, according to the criteria established. Only 6 species were analysed over the three study years. The proportion of species that showed a significant elevational delay or earliness was 83.3% in 2012, 71.4% in 2013, and 83.3% in 2014. In the year 2012, it was found that 5 of the 6 species showed a significant elevational delay in phenology. In 2013, 9 species showed a phenological delay along the same gradient, while 5 showed phenological earliness in relation to elevation. Finally, in 2014, 10 species showed a significant elevational delay in phenology while 2 showed the reverse trend. A common patern to all the years was that the species showing the greatest phenological delays were those with the earliest adult emergence (Figure 1). The phenological study of the 5 species of butterflies with a significant phenological response to elevation during the three study years revealed fluctuations between years (2012: 24.2 days of delay/km of ascent, 2013: 29.2 days of delay/km of ascent, and 2014: 27.4 days of delay/km of ascent). These oscillations were related to the mean temperature in March, April, May, and June (r_s= 0.99; $p<0.001$, Figure 2). The species included in this analysis showed different ecological profiles, although all of them have a mountain character: *Aporia crataegi* (mean elevation 2012-2014: 1746 m.a.s.l.), *Melanargia lachesis* (mean elevation 2012-2014: 1804 m.a.s.l.), *Hyponephele lycaon* (mean elevation 2012-2014: 2055 m.a.s.l.), *Lycaena alciphron* (mean elevation 2012-2014:2.055 m.a.s.l.), and *Parnassius apollo* (mean elevation 2012-2014: 2336 m.a.s.l.).

A specific case: the Apollo butterfly of Sierra Nevada

The results from the analyses of 6 years of data for *Parnassius apollo nevadensis* show that the day of the year on which the greatest number of adults emerged was subject to fluctuations from year to year, but the differences between sites situated at different elevations remained constant between years (Figure 3). The mean temperature of the month of May determines the earliness or delay in the weighted mean flight date of the Apollo butterfly at the site with the most complete data series, at Laguna Seca (r_s = 0.95; $p<0.001$, Figures 4 and 5). In this way, the warmest temperatures during May encouraged phenological earliness among adult Apollo butterflies at Laguna Seca, while cooler temperatures in the same month favoured a delay.

Discussion and conclusions

Elevational gradients in butterfly phenology in Sierra Nevada

The monitoring of butterflies in Sierra Nevada during the last 3 years has revealed that most of the species showed a significant elevational delay in phenology, although this response was not constant either among species or between years. The results show a mean delay of 26.93 days/km for 5 butterfly species with different ecological profiles and with significant trends from 2013 to 2014. Given that the temperature descends at a rate of 6ºC per km of ascent in elevation, the results imply that for 1ºC of increase in temperature, the phenology of a species will be 4.48 days early. Climate change prediction forecasts an increase from now to the end of the century of between 2 and 6ºC for maximum temperatures and 1 and 4ºC for minimum temperatures (Chapter 1), in the year 2100 the emergence of these insects could be approximately 6.7 to 22.4 days earlier.

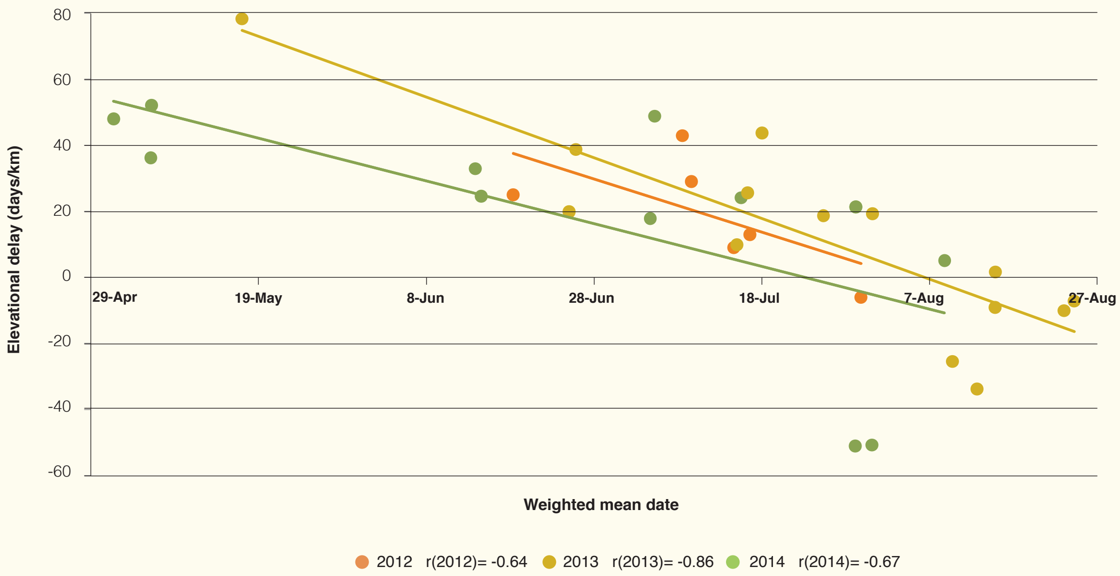
Despite the limitation of the time series available, a close relation has been established between the occurrence of warm springs (March-June) and the synchronization of adult emergence over the elevational gradients. This suggests that the climate warming at the local scale minimizes the differences in the phenophases of poikilotherms such as butterflies over the elevational gradient.

The specific case of the Apollo butterfly in Sierra Nevada

The mean elevational delay for Apollo butterfly populations in Sierra Nevada during the last 3 years was 45.2 days/km. The patterns observed at the site of Laguna Seca established a close relation between the warm months of May and phenological earliness but also indicated the reverse process. May is a key month for the Apollo butterfly in Sierra Nevada, since during this period the larvae of the 5th instar conclude their development and exponentially increase their size and weight (unpubl. data). The more hours per day provided by climatic conditions for the larvae to remain active, the greater will be their growth rate and the earlier they will pupate. This in turn can trigger early emergence of adults. In addition, during the series of years analysed, the May temperatures correlated positively with means of previous months (Feb-May, r_s= 0.81; $p<0.05$), this favouring larval activity and acceleration of larval growth and development.

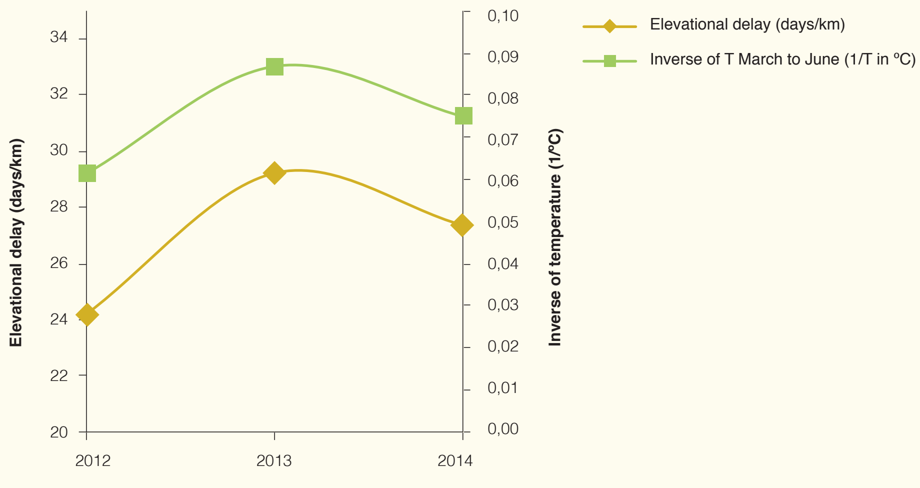
The data presented here provide evidence from two different standpoints (temporal and elevational gradients) concerning what are and what will be the repercussions of climate change on the populations of this key element in the insect communities of the Mediterranean high mountain.

Figure 1



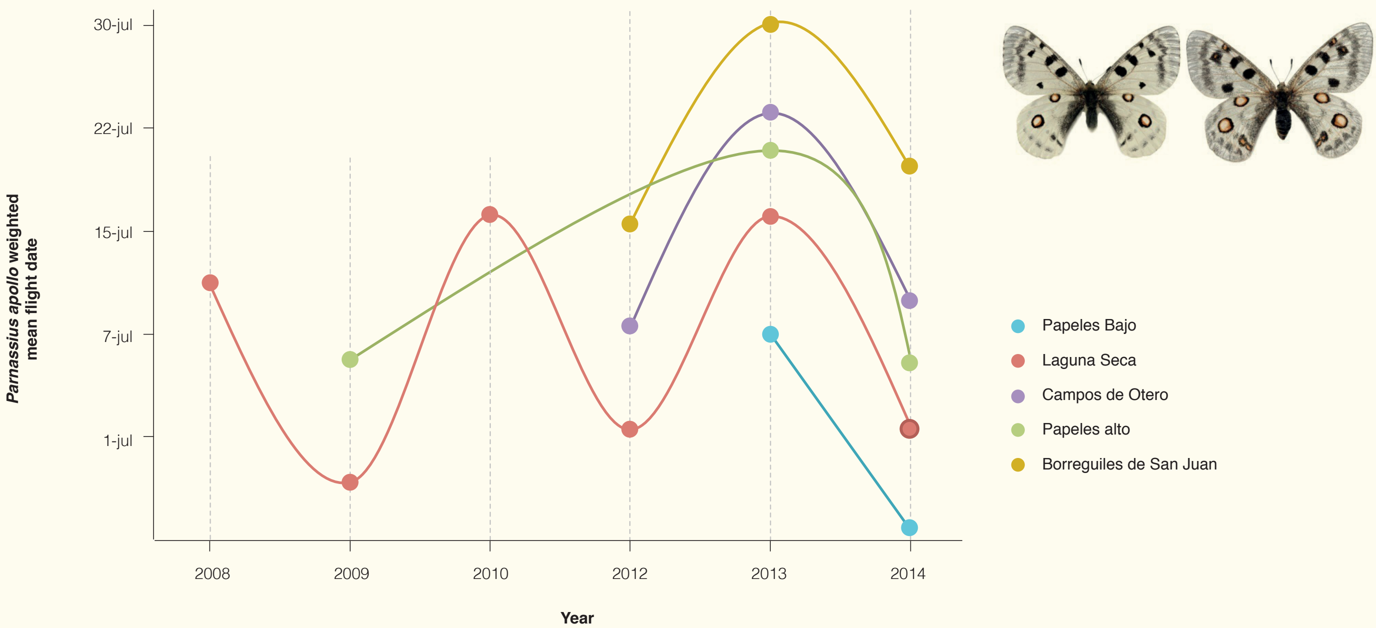
Linear regression of elevational delay and overall mean date. Each point represents one species and one year.

Figure 2



Mean elevational delay for 5 species (*P. apollo, M. lachesis, A. crataegi, H. lycaon, and L. alciphron*) of 2012 to 2014 and the inverse of the mean temperature of March to June (recorded at 5 weather stations located at between 600 and 2150 m.a.s.l.).

Figure 3

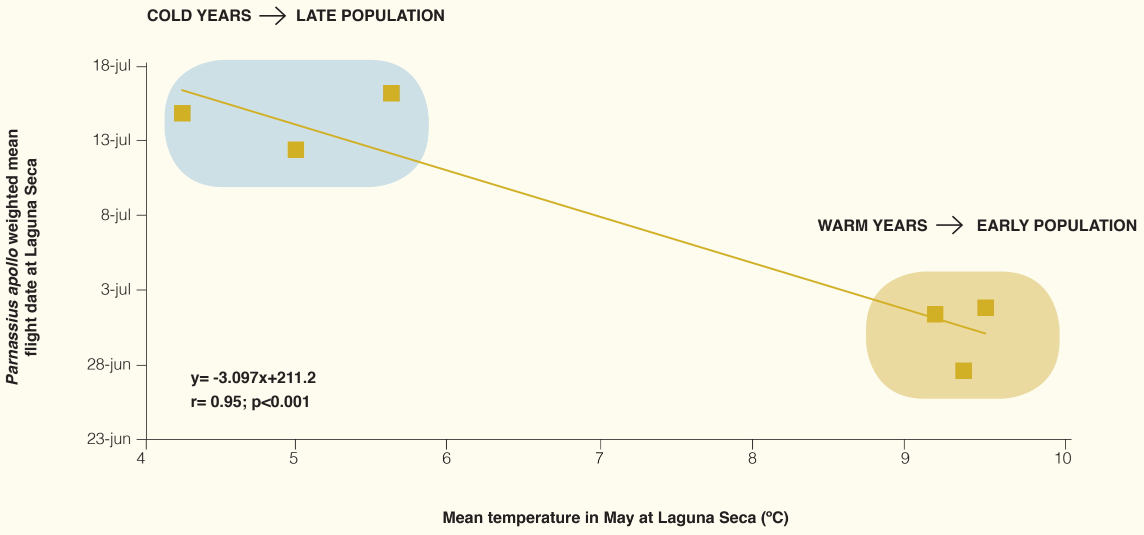


Parnassius apollo weighted mean flight date at different localities in 2008 (1 site), 2009 (2 sites), 2010 (1 site), 2012 (3 sites), 2013 (5 sites.), and 2014 (5 sites).

Figure 4

Parnassius apollo weighted mean flight date and mean temperatures in May at Laguna Seca.

Figure 5



Linear regression of the day of *Parnassius apollo* weighted mean flight date and mean temperature values for May at Laguna Seca.

Recently emerged *Parnassius apollo* with Laguna Seca (2280 m.a.s.l.) in the background.