5.7. Shifts in the elevational ranges of insects in Sierra Nevada: evidence of climate change

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Abstract

Climate change can cause massive disruptions in biological systems due to, among other things, changes in distribution ranges of the species, phenology, and interactions with other species. Mountain areas are excellent scenarios to detect these changes because they encompass both upper and lower limits of species distribution. The present study provides evidence for distribution changes of three different groups of insects: Coleoptera, Lepidoptera and Hymenoptera. For the sampled species, it appears that in the last two decades, there has been an elevational shift in the distribution of species, with upper and lower elevational limits moving upwards.

Aims and methodology

1. Coleoptera

To assess distributional shifts of Coleopteran species over time we selected dung beetles (Scarabaeoidea) as they are a group of species with a broad distribution in Sierra Nevada. To do that, we compared past species distributions (1981/1982) with those recorded during a more recent study (2006/2007). In both periods, dung beetles were sampled at 100 m intervals along an elevational gradient in a total of 18 sites. Climatic condition were also recorded for each time period in order to assess whether the changes detected in the species distribution were related to the differences in the climate between the two periods. Changes in mean elevation as well as changes in the upper and lower elevational limits were calculated for each species (see [27] for more details).

2. Lepidoptera and Hymenoptera

For butterflies, we assessed changes in the upper elevational limit of *Parnassius apollo nevadensis* by comparing observational data obtained by the author (AT) during the 1970s and data from the literature with current data.

For Hymenoptera, information about the distribution of two ant species (*Proformica longiseta* and *Formica fusca/lemani*) is provided. The taxonomical status of *Formica fusca* and *F. lemani* is still unresolved so data from the two species are presented together [28]. Historical distribution data are obtained from one publication [29] and a doctoral thesis [30]. The current distribution data come from surveys carry out in 2007 in several localities previously surveyed during the doctoral thesis [30]. Other current data are obtained from occasional surveys at the highest elevations in Sierra Nevada during the last 10 year and until 2013 (Table 1).

Table 1

Locality	Elevation (m.a.s.l.)	Aspect	1979-1981	2007-2013	Elevational ascent
Valle de Siete Lagunas	2946	south	-	*F. fusca/lemani*	200 m
Laguna de Río Seco	3030	south	-	-	0 m
Laguna de Aguas Verdes	3070	south	-	-	0 m
Laguna Larga	2780	north	-	-	0 m
Ventisquero Morón	2809	north	-	*P. longiseta*	100 m
Laguna de la Mosca	2910	north	-	-	0 m
Cabecera del San Juan	2950	north	*P. longiseta*	*P. longiseta*	0 m
Collado Juego Bolos	3000	north	*F. fusca/lemani*	*F. fusca/lemani*	0 m
Los Panderones (Veleta)	3050	north	-	*P. longiseta*	100/150 m
Corral del Veleta	3100	north	-	-	0 m

Historical and current data on the presence/absence of formicids in cacuminal areas of Sierra Nevada.

Results

1. Coleoptera

The results shown that temperature increased significantly between the study periods at low and middle elevations (1.3 °C) but not at higher elevations (0.8 °C). Moreover, the distribution of dung beetle species exhibited important changes between time periods. Most species showed an increase in their mean elevation (89% of species, Figure 1). Changes in mean elevation were related to shifts at the lower elevational limit but not to shifts at the upper limit.

Changes in species elevational distribution were slightly higher than those predicted by changes in climate between study periods (Figure 2). However, differences between observed and predicted elevational changes were not statistically significant, suggesting that species are tracking changes in climate.

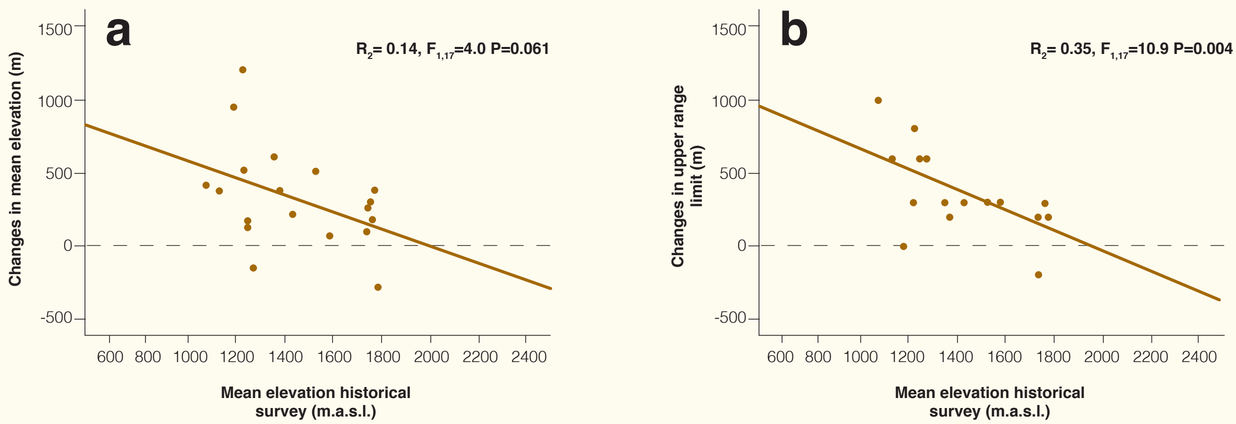
Most dung beetle species found in both time periods showed increases in their upper limit (17 out of 19 species). Shifts at the upper limit were negatively correlated with the mean elevation of the species during the historical period (Figure 2). Lower limits also moved uphill for most of the species (16 species) except for three species that moved downhill. Contractions at the lower limit and expansions at the upper limit were both consistent with changes in climate.

2. Lepidoptera and Hymenoptera

The historical data on the *Parnassius apollo nevadensis* show that this butterfly in 1971 (24 July) was very abundant in the access to Ragua Pass on both sides of the road some 2 km before reaching the pass (1950 m.a.s.l.). Sabariego de la Plaza and Aragonés de Inés [30] indicated that the San Juan Pass (2500 m.a.s.l.) marked the upper elevational limit for this species. Currently, this species reaches its population maximum around 2300 m.a.s.l. on the northern slope and around 2600 m.a.s.l. on the southern slope. Some specimens can be seen flying at 3000 m.a.s.l. on the southern slope, but there is no evidence that they reproduce at that elevation despite the presence of the host plant, however, we have not searched for larvae at those sites. The lower elevational limit can be situated currently at 1850 m.a.s.l. on the northern slope and at around 2200 m.a.s.l. on the southern one. These data indicate a rise in the upper limit of the species of around 400 m.

With respect to ants, the historical data reflect that *Proformica longiseta* and *Formica fusca/lemani* are the two formicid species that reach the highest elevations in Sierra Nevada. The rest of the formicid species usually have their upper limits some 300 to 400 m below these two species. The highest elevation that these two ants can reach in Sierra Nevada varies depending on the slope and the microclimate. In general, the historical data (during 1978) situated the upper limit of *Formica fusca/lemani* at 2900 m.a.s.l. at the head of the San Juan Valley (associated with the borders of the wet pasture-like areas *borreguiles* [29]) and at

Figure 1



Relationship of changes in a) the mean elevation and b) the upper limit of dung beetle species between survey periods against the mean elevation of the species during the historical period.

3000 m.a.s.l. at Laguna de la Caldera and Collado de Juego de Bolos [30]. While *Proformica longiseta*, more xerophilous than the other species, appears up to 2950 m. However, data for this species on the southern slope set the precise elevational limit below 2950 m.a.s.l., although the information is not as detailed. Historically two isolated populations of *P. longiseta* were known at the western slope of Puntal de Juego de Bolos (3050 m.a.s.l.) and near the Laguna de la Caldera (3060 m.a.s.l.), both populations are still currently present.

Populations of *Formica lemani* are currently present up to 3100 m.a.s.l. and for *Proformica longiseta* a population is present at 3140 m.a.s.l.. Thus, in the last 30 years both ant species have colonized certain points that were uninhabited in the 1970s, although this colonization is not uniform through the mountain range (Table 1). In conclusion, a general elevational ascent has been detected, this being as large as 200 m on the southern slope.

Figure 2

Average observed changes in dung beetle elevational distribution (mean elevation, upper and lower limits) and those predicted based on changes in climate (differences between observed and predicted changes were not significant).

› Discussion and conclusions

In Sierra Nevada, an elevational shift was found in the distribution of the insect species analysed, reflected in the elevational ascents in the upper and lower distribution limits. During this period of change, temperature also rose, especially in the low and middle zones of the mountain. Therefore, it appears to be highly likely that this response of the terrestrial insect species was triggered at least partially by global warming, resulting in the colonization of new climatically suitable areas at higher elevations.

This response is consistent with that observed in other regions for different groups of organisms, from plants to mammals [e.g. 31].

Species tolerance to the rising temperatures also appears to be the cause of lower limit contractions, although other factors such as habitat alterations or resource availability cannot be ruled out.