5.1. High-mountain plant communities: GLORIA

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Abstract

The main findings are presented for the monitoring of vegetation in the high summits of Sierra Nevada over the last 11 years within the project GLORIA (*Global Observation Research Initiative in Alpine Environments*). The results show changes in the cover of the taxa that are more pronounced in certain orientations and/or elevations. The plant cover increases more at southern orientation and lower elevations (<3000 m a.s.l.), while a decline has been found on the eastern orientation. A replacement has been detected in the communities, with the loss of taxa such as *Luzula hispanica* and *Poa minor nevadensis*, which are often linked to conditions of greater moisture, indicating a change in water availability. Results from the whole of Europe in the period 2001-2008 indicates that cool-climate plants disappear from the high mountains, while those adapted to heat prosper. However, a later review for Sierra Nevada appears to indicate a reversal in this trend.

Aims and methodology

Four summits corresponding to an elevational gradient of 2700-3300 m.a.s.l. were chosen. At each summit, the sampling of the vegetation was structured in two parts:

1. Detailed sampling in 16 permanent quadrats of 1x1 m, delimited by plots of 3x3 m laid out in the four cardinal directions. In these, the species composition and cover of each component were recorded (plants, bare soil, rock, etc.). Also, the frequency of appearance of each biotic and abiotic component considered was registered.

2. Sampling was conducted in 8 sections of the summit area. The sections were delimited by the main directions and two lines at 5 and 10 m of difference in level from the central point of the summit, situated in the highest area.

For each section, the composition in taxa and its corresponding cover were estimated according to a scale of qualitative abundance based on the representativeness (dominant, common, widespread, rare, very rare, or locally present). Also, representativeness was estimated, expressed in percentages of different types of surfaces [1].

- Thermicity index (S): Σ(elevation range) ($species_i$) x cover ($species_i$)/Σcover ($species_i$). The range is assigned with the chorology described in the standard floras. This index gives an idea of the plasticity of the species of the community to live at different elevations. High values indicate the presence of species that have broad elevational survival ranges.
- Thermophilization index: calculated as the difference between the previous one at different samplings.

Results

The temperature difference between the summit situated at a lower elevation and the highest (549 m of difference) was 4.42ºC.
The lowest temperatures in winter and summer are located at the sites oriented towards the north and towards the west.

Richness: In total, 102 taxa were recorded, of which 34 are endemic to Sierra Nevada and another 16 are Betic endemisms. These belong to 29 botanical families, notably Asteraceae (n=17), Poaceae (n=15), Brassicaceae (n=11), Caryophyllaceae (n=10), and Lamiaceae (n=6). The proportion of endemic species rises with elevation from 23% in the lowest summits to 67% in the highest [2].

Cover: an increase was detected in the cover with respect to the year 2001. This was especially noticeable at the sites oriented towards the south, while the opposite pattern was appreciable in the localities oriented towards the east. The cover has increased at sites situated below 3000 m.a.s.l., although it has descended slightly at the higher sites (>3000 m.a.s.l.) (Figure 1).

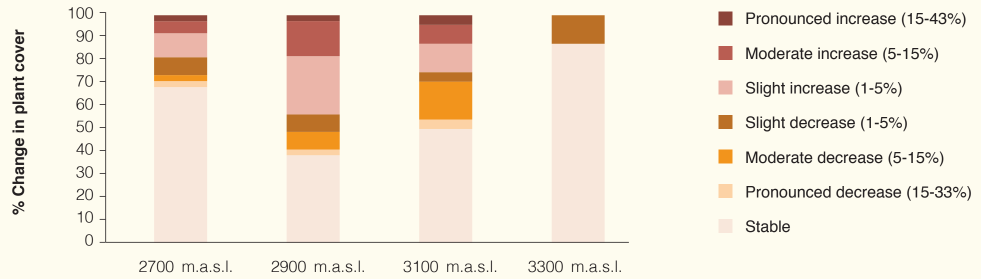
Diversity: at all the spatial scales studied (1x1 m, 3x3 m, and the scale of the summit), a negative relation was found between species richness and elevation, and a positive relation between species richness and mean soil temperature [2].

In terms of change over time, there were no major changes in the community composition at the highest elevations. However, at the lower elevations, 6 taxa were lost. For all the sites studied, 13 disappearances were recorded and 5 species that had not previously recorded were found.

Elevational migrations to the summit were recorded for some species (*Plantago radicata* subsp. *granatensis, Pilosella castellana,* and *Eryngium glaciale*). In parallel, a negative trend was appreciated in the size of the distribution area, which is especially acute in *Lepidium stylatum*, *Viola crassiuscula*, and *Saxifraga nevadensis*.

The thermophilization index (IT): the positive trend of the IT detected in the period 2001-2008 was reversed in the period 2008-2012 (Figure 2). This index provided the composition of the community in terms of diversity and coverage of plant species adapted to cooler or warmer climate conditions. The results for the period 2001-2012 show a general decline in the thermophilization of the summit areas of Sierra Nevada.

Figure 1



Changes in coverage of the plant taxa studied for the period 2001 to 2012.

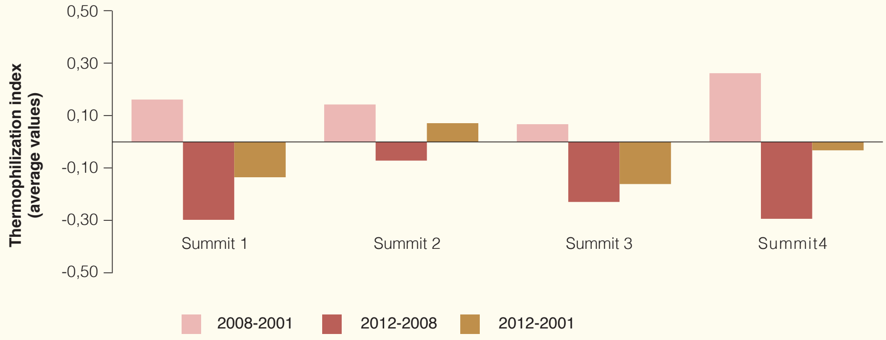
Discussion and conclusions

The last decades have been the warmest since instrumental measurements began to be recorded. This warming is causing major changes in the mountain areas of Europe, which translate in the reduction of areas with alpine conditions. The results of the GLORIA project indicate marked changes in high-mountain vegetation, implying mainly disappearances of some species and the appearance of others, elevational migrations, and changes in the plant cover [3]. At some sites studied in Sierra Nevada, 13 species have disappeared in 11 years at the same time as 5 taxa have been recorded for the first time there. Especially pronounced is the reduction in the distribution area of *Lepidium stylatum*, *Viola crassiuscula*, and *Saxifraga nevadensis*. Other species show a clear ascending trend (e.g. *Plantago radicata* subsp. *granatensis*, *Pilosella castellana*, and *Eryngium glaciale*). These changes agree with those reported at other points of Europe, where species of *Saxifraga* are also becoming rare (in Northern Europe over the last 80 years) or *Pilosella* (which has ascended in elevation in the southern Alps) [4].

At the continent scale of Europe, in the period 2001-2008, the plants best adapted to cold environments became rare, whereas those adapted to warmth prospered. Alpine plant species in 13 northern and temperate European mountain systems have moved an average of 2.7 m higher in only 7 years, and 2.5 m higher in Mediterranean mountains [3]. The ascent of the more thermophilous plants [4] has led to greater species richness in the northern and temperate summits (3.9 species on average), but in the Mediterranean mountains increases in the species at the summits have reportedly been surpassed by the loss of cryophilous species, resulting in a net loss averaging 1.4 species [3]. These observations have proved independent of elevation and latitude, as they occur both at the tree line as well as in the summits and from Scotland to Crete. However, at the scale of Sierra Nevada, this trend appears to have reversed in the period 2008-2012. The results found could be showing the adaptive capacity of certain plants under global warming.

Long-term monitoring would establish the trends in the elevational dynamics of extinction-colonization and expansion-retraction. The interpretation of the results found in Sierra Nevada in a broader geographic context is fundamental in order to establish common patterns in different high-mountains.

Figure 2



Comparison of the Thermophilization index (TI) between the monitoring periods, expressed in terms of average value by summit and time periods (years).

Festuca pseudoeskia at the site of Cúpula.