

## 3.2. Analysis of the palaeolimnological indicators in the lakes of Sierra Nevada

Pérez-Martínez, C.  
University of Granada

Río Seco lake



### Abstract

The siliceous remains of diatoms and the fossil chlorophyll-*a* were analysed from the last 150 years in six lakes of Sierra Nevada. The chlorophyll-*a* values from all the lakes increased over the 20th century. The magnitude of the experimental variations in the diatom community over the last 150 years proved appreciably different between lakes, with Río Seco y Borreguil lakes showing the most notable differences.

The changes observed in the lakes appear to be related to effects (direct and indirect) of the higher temperatures recorded for this period. In addition to this regional response, local responses were found to be determined by the particularities of each lake.

## > Aims and methodology

The goal of this work is to study various paleolimnological indicators in several lakes of Sierra Nevada, especially useful to quantify the biomass production of these ecosystems. The temporal evolution of chlorophyll and its relationship with temperature are analysed. The morphological and limnological characteristics of the six lakes analysed are shown in Figure 1.

**Siliceous remains of diatoms.** The sediment samples were acid digested and the siliceous remains were mounted in slides with Naphrax for counting [6]. A minimum of 300 diatom frustules were identified and enumerated in

each interval, using a light microscope at 1000x and differential interference contrast (DIC).

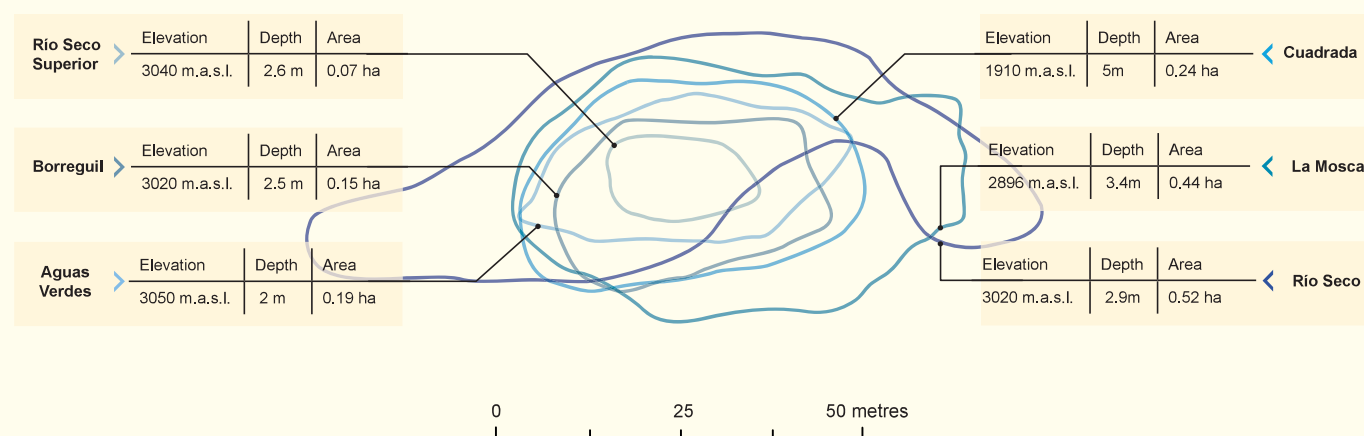
**Chlorophyll-*a* analysis.** The concentration of fossil chlorophyll-*a* (chlorophyll-*a* + derivatives) which were preserved in the sediments was inferred by the VRS technique (Visible Reflectance Spectroscopy) [7].

**Gathering and treatment of climatic data.** The temperature series was taken from station 3195 of Madrid (Retiro Park) since, despite being relatively far away, it offers one of the longest series available (since 1869) and has

a good correlation with other shorter data series from the study zone, such as Armilla and Padul, and also with the climate series created by the Sierra Nevada Global Change Observatory. The precipitation series best correlating with the latter was that of the station of the San Fernando de Cádiz Military Base (since 1841).

**Data analysis.** A Principal Component Analysis (PCA) was performed with the relative abundance data of different diatom species. These data were correlated with the chlorophyll values in each lake.

Figure 1



Schematic representation of the lakes studied. The outline of the lakes and main features are represented.

## > Results

The variations experienced by the diatom community over the last 150 years substantially differed between lakes. Río Seco and Borreguil presented the most notable variations, followed by Aguas Verdes and Mosca, and finally Cuadrada and Río Seco Superior. Regarding the changes in the species composition it should be noted the increase in alkalophilous species and the decline in acidophilous ones as well as in epiphytes and tytoplanktonic species.

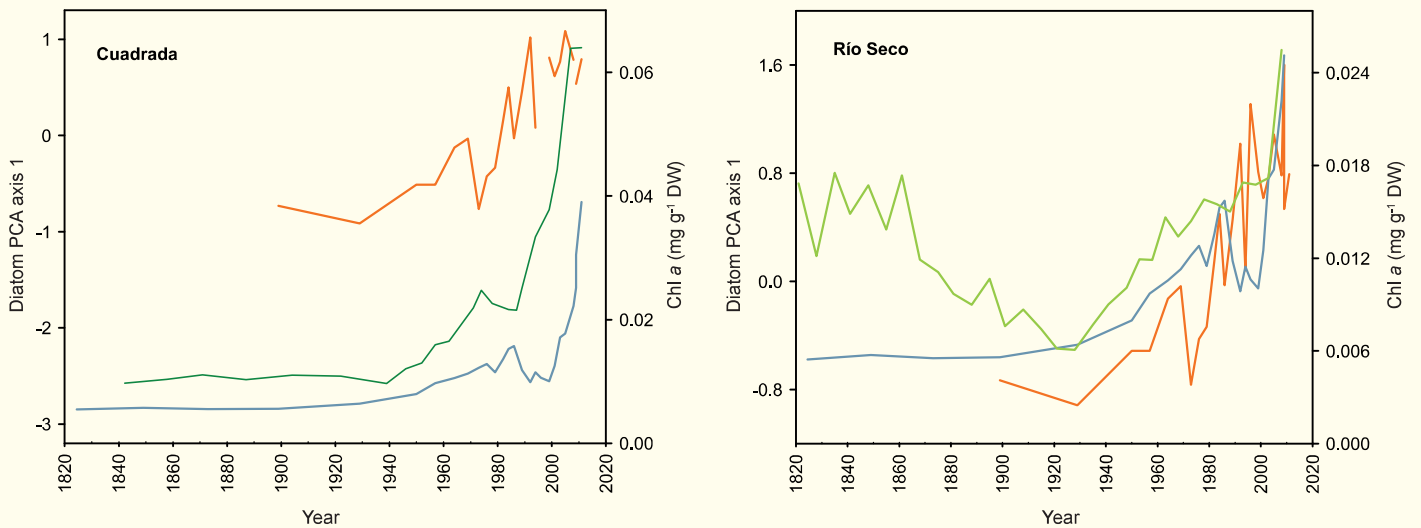
The values of chlorophyll-*a* in all the lakes show

an increase over the 20th century, beginning in the first half of the century in Cuadrada and Río Seco Superior, and in the second half of the century in the other lakes (Figure 2).

The variable that summarizes the changes in the diatom community over time. Axis 1 factor scores of the principal component analysis (PCA) performed on the relative abundance of the diatom species is correlated with the chlorophyll values in each of the lakes (all  $p < 0.01$ ). With respect to the relation of these two variables to the available climate data,

the six lakes rendered significant correlations between the chlorophyll-*a* values and the mean annual temperature values (all  $p < 0.01$ ), while the precipitation had a significant correlation only for Borreguil Lake. In addition, the changes undergone by the diatom community (PCA axis 1) showed a significant correlation with the mean temperature values for each of the lakes (all  $p < 0.001$ ) except in Río Seco Superior Lake, although the relation with precipitation was significant only for Río Seco Lake.

Figure 2



Changes in the composition of the diatom community (blue), time course of the values for chlorophyll-*a* (green) and for mean annual temperature (anomalies with respect to the period 1961-90, red) in Río Seco and Cuadrada lakes.

## > Discussion and conclusions

The increase in chlorophyll-*a* and the variations detected in the diatom community in the six lakes indicate that these systems have significantly changed in their limnological variables over the last 150 years. The robust relation of chlorophyll-*a* and the changes in the diatoms with temperature suggest a significant effect of rising temperatures on these aquatic ecosystems. The primary production of the system, represented by the chlorophyll-*a* values, responds to the direct rise in water temperature and furthermore to the indirect effects derived from the lengthening of the ice-free growing season [8]. Diatoms can reflect the climatic variability in different ways: direct effect of temperature, shift in thermal stability, or changes in water quality and habitat alterations [9]. Thus, the decline in tytoplanktonic species can be attributed to the greater thermal stability of the water column together with the diminished flow of

water entering and leaving, as well as the mean depth of the lakes [10]. On the other hand, the increase in the pH derived from the temperature increase of the decline in acidophilous species and of the increase in alkalophilous species. Finally, the longer ice-free periods, higher temperatures and lower precipitation mainly since the 1980s account for the decrease in the water level of the lakes, as well as the lower degree of moisture in the alpine meadows. Under these conditions, the epiphytic diatom species could have less survival probability in these habitats. These factors would explain the differences in the magnitude of the response of the diatom community in the lakes in such a way that the lakes with the greatest surface area of surrounding meadows and the highest relation of meadows surface area to lake surface area (Río Seco and Borreguil lakes) presented more evident changes than those having a smaller meadows area and fewer changes in terms of

water level (Agua Verdes and Mosca lakes) and those lakes without surrounding meadows (Cuadrada and Río Seco Superior lakes).

In short, the six lakes analysed showed significant changes in the diatom community and in the chlorophyll-*a* values during the last 150 years which appear to be related to the temperature increase recorded in this period. In addition to this response, which can be considered regional, local responses were found, determined by the particularities of each lake, such as the presence and size of the surrounding meadows, the morphometric characteristics of the lakes and their altitude.