

Lake color trends in European mountain regions

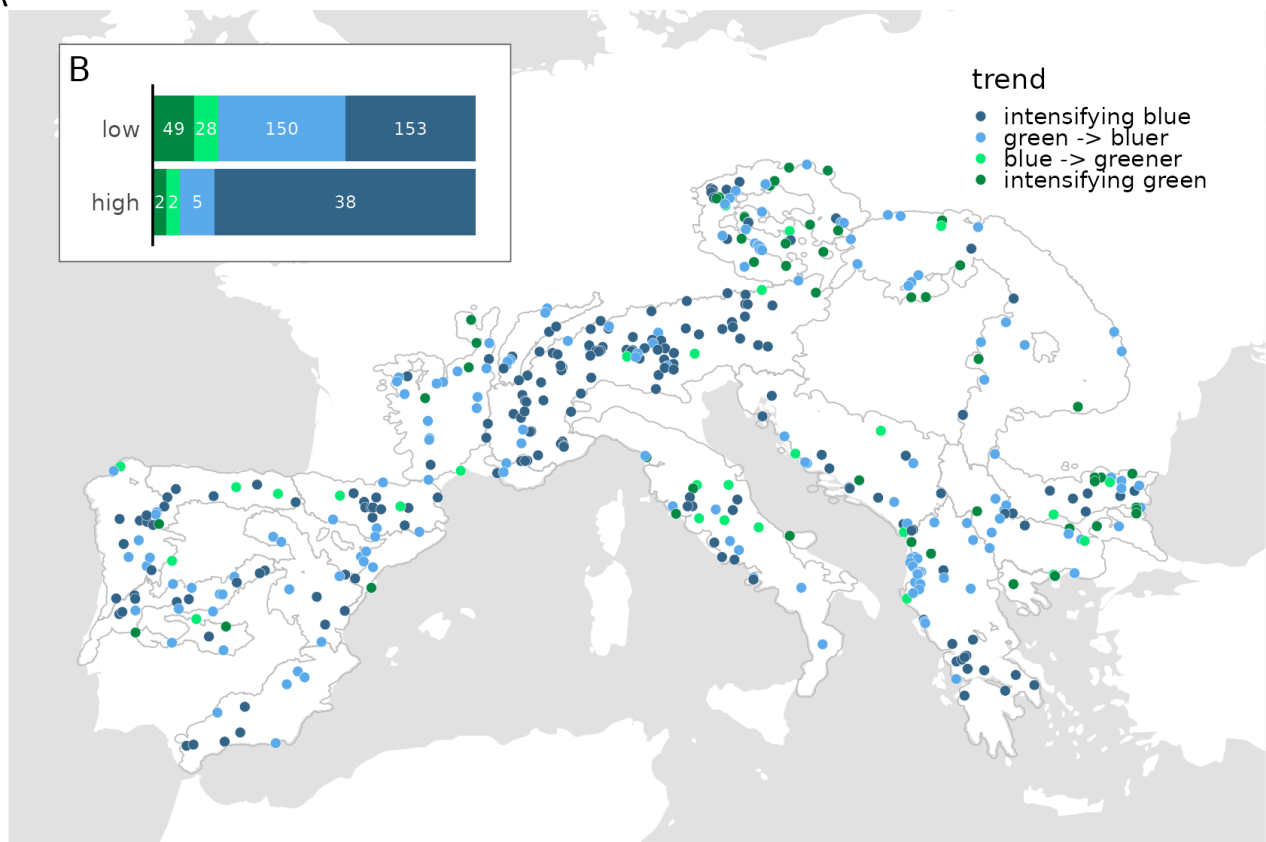
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High-elevation lakes represent important ecosystems that deliver essential services for humans and the environment. They are expected to undergo significant transformations in response to climate change and, owing to their remoteness, represent good indicators of climate change. Although common responses on global scales can be observed for some lake physical parameters such as ice cover and water temperature, biological processes exhibit more complex interactions and less clear change patterns. In this context, lake color represents a relevant indicator of lake's health and can be easily measured both in situ and remotely. Although several studies have examined lake color changes in relation to climate change in mountain lakes within the US, no such study has been conducted in European mountain regions. Utilizing satellite remote sensing, our objective was to determine lake color and its temporal evolution in mountain areas in Europe and identify potential explanatory drivers. Taking advantage of the Landsat image archive and the Google Earth Engine cloud processing tool, we sampled lake color in close to 2000 lakes in the 1984-2022 period. The yearly color time series of each lake was then computed, in the July-August-September period, from which the lake color average and trend were derived. Most high-elevation lakes were found to be blue and showed either a blueing trend or no trend at all. Through an exploratory statistical analysis based on morphometric and climatic variables, depth was found to be the most significant driver of both lake color and its trend, with shallow lakes displaying more green colors and greening trends. While temperature and precipitation seemed to affect average color, establishing a connection between climate trends and lake color trends proved challenging. These findings highlight the complexity of lake biological processes in response to climate change, and the very likely influence of anthropogenic activities within the lake basin and its surroundings. Although no widespread greening of high-elevation lakes was observed, further efforts in lake monitoring remain important to enhance our understanding of their response to global change.

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Lake color trends, divided into four classes based on the initial color (blue or green) and the trend direction (blueing or greening). (A) Spatial distribution. Gray lines delimit the region of interest. (B) Number of lakes per trend class at low and high elevation.