



## Is anthropogenic pressure limiting the climate-induced upward shift of the subalpine forest line in the French Northern Alps?

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The forest line is a key feature of mountain landscapes around the world. Currently, most forest lines in the Northern Hemisphere are rising due to the combined effects of land-use and climate changes. This upward shift has led to major changes in the functions and services provided by the adjacent socio-ecosystems (e.g. carbon sequestration, biodiversity hosting, services to people...). However, it has not been elucidated how the recent forest-line upward shift fits into the longer context of land abandonment (occurring since the beginning of the 19<sup>th</sup> century in France), and how it is currently responding to the accelerating global warming. To answer this question, we assessed the elevation change of the forest line over the French northern Alps since the forest minimum (mid-19<sup>th</sup> century in France) using old and current land cover maps.

Three digitalised maps: the État-Major map, BD Forêt® v1.0 and BD Forêt® v2.0 were used to display forest cover at three dates: 1859, 1994 and 2007, respectively. These maps were standardized and combined with a digital elevation model to estimate the average elevation of the subalpine forest lines for 178 municipalities across the French departments of the Northern Alps: Haute-Savoie, Savoie and Isère. We compared forest-line elevations between dates and municipalities to explore temporal and spatial patterns.

The forest line in the French Northern Alps has risen by an average of  $152 \pm 18$  m from its ancient position ( $1879 \pm 21$  m a.s.l. in 1859) to its current position ( $2032 \pm 12$  m in 1994). However, no general upward shift was observed during the most recent period from 1994 to 2007, as the forest-line position was  $2013 \pm 13$  m in 2007. In the Haute-Savoie department, a downward shift of  $69 \pm 12$  m was even observed, while forest lines in Isère and Savoie were stable. Forest-lines upward shift in the French Northern Alps has been driven by agricultural abandonment, mountain land restoration and global warming since the period of the forest minimum (around 1860). However, it is noteworthy that forest line dynamics are no longer influenced by these factors nowadays and do not follow the acceleration of temperature increase. The current recession of the forest lines may be attributed to anthropogenic pressure related to the tourism activity. This new anthropogenic pressure corresponds to the development of alpine ski resorts and the increase in the human population in Haute-Savoie since 1925, and later in the other departments.

This large-scale spatial and temporal study shows how global and regional factors interact in the

long-term to shape mountain landscapes, in particular the ecotone between subalpine forest and alpine grassland. Today, the dynamics of this ecotone is still linked to the contradictory tensions that divide our societies (conservation vs. exploitation). This is why we advocate the cautious management of alpine forest line ecotones, which could contribute to carbon sequestration and biodiversity conservation, provided they are not subjected to excessive human pressure (tourism and grazing).