Poster ID: 3.12578: I The Future of Mountain Forests

Mountain Pine (*Pinus uncinata*) Growth in Andorra: A First Empirical Evaluation

M. Domènech[1], B. Claramunt[2], G. Grande[1], M. Niell[1]
(1) Andorra Research and Innovation, Av. Rocafort, 21-23 Ed. Molí, AD600 Sant Julià de Lòria, AD.
(2) Centre de Recerca Ecològica i Aplicacions Forestal de Catalunya, Edifici C Facultat de Ciències i Biociències, 08193 Bellaterra, Barcelona, ES

1. Introduction

The forest communities of the Pyrenees are strongly influenced by a broad climatic gradient, making the region well suited to assess how climate change affects high-mountain ecosystems and their species. Mountain pine (*Pinus uncinata*) is the characteristic species of the Pyrenean subalpine belt, and its climate sensitivity plays a key role in forest health. In combination with land abandonment, climate warming is driving unprecedented densification in both mature and recently established high-mountain forests, where summer drought has become a major factor shaping tree-ring formation (1–5).

In this study, we monitor annual growth and seasonal phenology of cambium across stands of differing maturity along the full altitudinal gradient of the species, in relation to temperature and precipitation dynamics.

2. Methods

Experimental design: For the first time, a comprehensive monitoring of mountain pine growth was conducted in Andorra from 2018 to 2023. Forest growth was monitored using digital dendrometers (n = 18) across different mountain pine habitats spanning the specie's altitudinal gradient, in areas with different socio-climatic legacies—from mature stands to recent generated stands. Temperatures were recorded daily for each studied tree, and precipitation was also recorded.

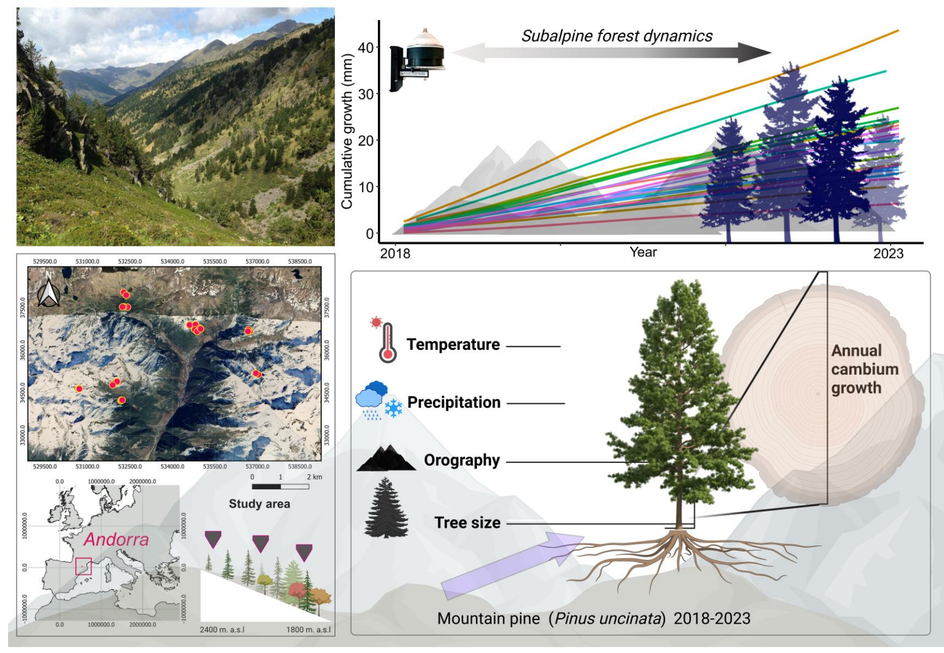

Figure 1. *Conceptual illustration of the experimental design*

3. Results

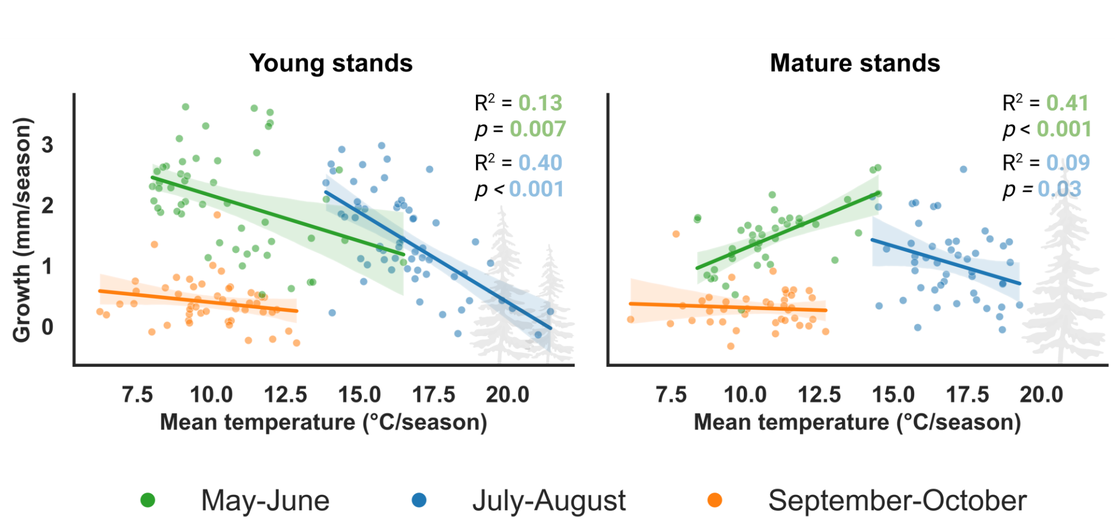

Figure 2. *Seasonal tree growth vs mean seasonal temperature (2018–2023) in young and mature Pinus uncinata stands*

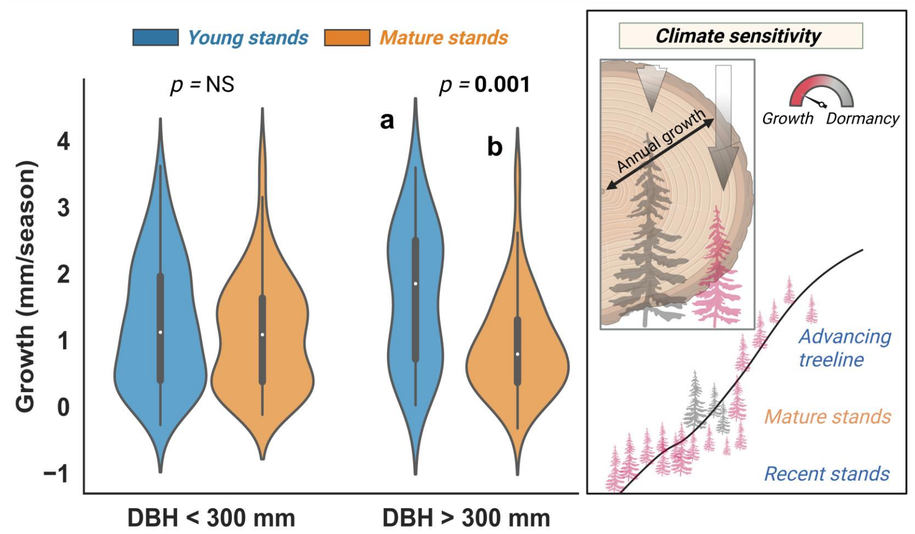

Figure 3. *Seasonal tree growth distributions by tree size (DBH) (2018–2023) in young and mature Pinus uncinata stands. Differences between groups were assessed using the Mann–Whitney U test (Wilcoxon rank-sum)*

From 2018 to 2023, we analyzed the seasonal dynamics of tree growth in young and mature stands of mountain pine in the Andorran Pyrenees (Fig. 2). Among the variables analyzed, seasonal temperature emerged as a key factor driving both the phenology and growth dynamics of mountain pines. Young and mature stands showed contrasting climate sensitivities of seasonal growth. In May–June, growth in young stands decreased as temperature increased, whereas mature stands exhibited the opposite response, with significantly higher growth at warmer temperatures; quantitatively, a +1 °C increase corresponded to slopes of approximately –150 µm·season^{-1} in young stands and +200 µm·season^{-1} in mature stands. During the July–August period, when seasonal temperatures peaked, both young and mature stands showed a growth decline with increasing temperature; a +1 °C increase corresponded to a mean reduction of ~200 µm·season^{-1} in young stands and ~145 µm·season^{-1} in mature stands. In the late growth period (September–October), growth variation in either stand was not explained by temperature (Fig. 2).

By examining the distributions of seasonal tree growth in young and mature stands, we found no differences among smaller trees; for individuals with DBH < 300 mm, young and mature stands showed similar growth (Fig. 3). In contrast, for larger trees (DBH ≥ 300 mm), the distributions clearly diverged, with smaller (and presumably younger) trees growing faster (median ≈ 2 mm·season^{-1}) than larger ones (< 1 mm·season^{-1}).

Considering additional environmental drivers, we found patterns consistent with stand-specific growth responses (Fig. 4). Young and mature stands exhibited a similar linear dependency of growth on temperature. However, young stands showed a stronger linear dependency than mature stands on site-specific traits such as precipitation and altitude. Moreover, altitude was strongly related to precipitation in both stand types, while it was also closely associated with temperature in young stands.

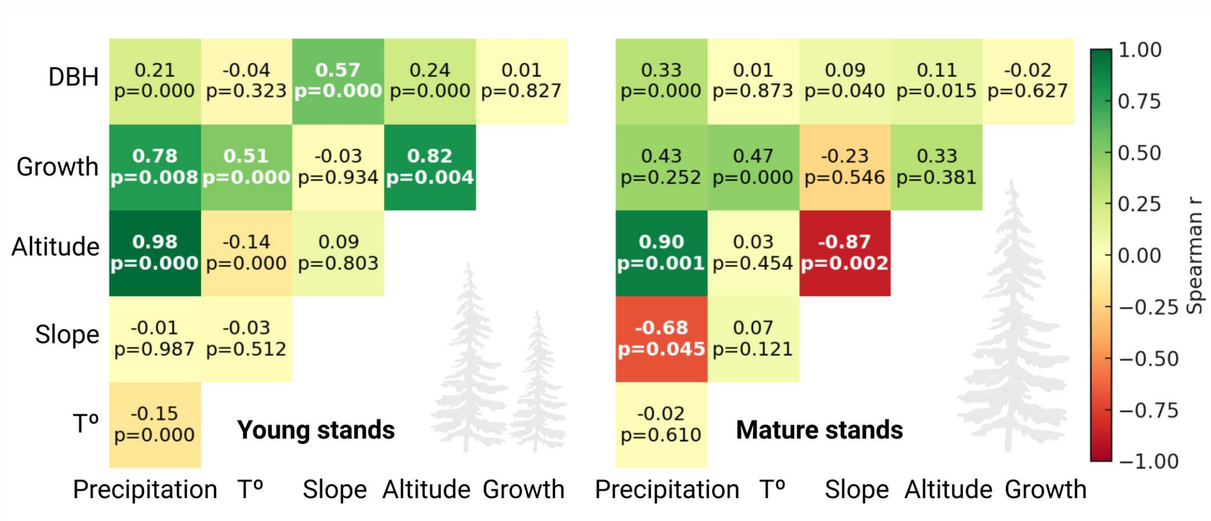

Figure 4. *Correlation matrix based on Spearman's rank correlation between growth and stand-specific variables.*

4. Conclusion

Taken together, our results reveal that Pyrenean tree growth shows different climatic sensitivities depending on stand maturity, under the influence of variables that are expected to shift with ongoing climate change. According to our findings, the growth of young stands does not behave as expected: climate change negatively affects these stands throughout the whole growth period, not only in summer. As a result, young stand's growth is constrained and discloses more physiological stress signs. In contrast, mature stand's growth exhibit the expected behavior and are therefore less affected by temperature increase.

Among all variables studied, site-specific temperature had the most prominent impact on growth dynamics at the monitored sites. Nevertheless, high-altitude forests and higher precipitation appeared to enhance tree growth despite the adverse influence of temperature.

More precisely, age and size heterogeneity are essential for enabling sustainable forest responses to climate change, given the low climatic sensitivity of large trees in mature stands. Overall, advancing treelines and recently established forests are unlikely to sustain growth and may undergo forest health issues. Prolonged periods of limited growth in young stands will compromise their health and may ultimately lead to further mortality events. The stands most likely to be affected are those recently established at lower altitudes, where precipitation is less prominent.

Addressing this challenge requires multifunctional forest management strategies designed to safeguard growth in young forests for ensuring healthy and sustainable forest under climate change during the next decades.

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