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From wood anatomy to satellites: new frontiers for the upscaling of climate change in the Alpine tundra

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Tree ring growth is strictly bound to annual environmental conditions. Therefore, dendrochronology represents a solid tool for investigating the relationship between the whole plant growth and climate at high temporal resolution, especially in the context of ongoing climate change.

The temperature increase in the Alpine and Arctic ecosystems has been proven to enhance shrub growth contributing to the Arctic/Alpine greening, while the effects of the interaction between temperature and other climatic variables (*e.g.* precipitation/snowfall regime) on the shrub growth have often been neglected.

With the aim of parsing the relationships between the annual growth of *Vaccinium myrtillus* L., a key species in the Alpine tundra, temperature, precipitation, snowfall regime (*i.e.*, in terms of temperature-based snowfall, known as snow water equivalent) and their interaction, we analyzed the xylem rings of 100 cross sections of underground bilberry stem, collected along a 500 meters altitude gradient above the tree line and corresponding over a period of 20 years (1995-2015). Furthermore, aiming at linking different ecological scales, we have adopted an ecological upscaling approach. With reference to the area and the period considered, we calculated NDVI using satellite images, and we studied the relationships between this vegetation index, climate, and the anatomical parameters.

Our results showed that both number (*i.e.* ramet age) and mean width of the rings were negatively affected by altitude. The mean annual temperature and snowfall showed significant interaction effects on mean ring width and xylem mean lumen area. Cold years (*i.e.* low mean annual temperature) and abundant snowfall led to a reduction in the mean ring width, while the snowfall regime did not affect annual ring width in warm years. Xylem mean lumen area was affected by precipitation only in cold years. The mean growth season NDVI increased significantly in the time span considered and showed a positive relationship with the average age of the bilberry community. The interaction between rainfall and average temperature of the vegetative season influenced the NDVI: a negative relationship between vegetation index and rainfall was observed in cooler vegetative seasons, while the relationship was specular in the case of higher

temperatures.

These results suggest that future scenarios should not overlook the precipitation regime effect by virtue of its possible role in snowpack permanence and drought during the growth season. In this light the shrub expansion could also be curbed by the change of precipitation regime and the increased frequency of extreme climate events (*e.g.,* shift of snowfall regime and intensification of heat waves). Moreover, our findings confirmed the potential use of the remote sensing tool for the understanding of the response of dwarf shrub communities to climate change also for long-term monitoring of these plant communities.