Tree Rings Affected by Solar Cycle and North Atlantic Oscillation

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Silver fir forests in the mountainous regions of Central and Southern Europe are crucial natural ecosystems, providing environmental, economic, and ecological benefits. Despite their ecological significance, the response of these forests to climate change across Europe remains insufficiently understood compared to different European regions. This study investigates how natural phenomena—solar activity and the North Atlantic Oscillation (NAO)—influence silver fir growth, providing innovative insights into the direct and indirect effects of solar activity on forest ecosystems, an aspect previously unexplored from this perspective, to improve forest management and resilience. Solar activity, characterized by an 11-year cycle, affects the amount of solar energy reaching Earth's surface, influencing tree growth over time. NAO, a weather pattern oscillating between positive and negative phases, brings diverse weather conditions to various parts of Europe. Together, these natural forces play a key role in shaping climate and forest ecosystems. The research analysed tree rings from silver firs across the 16th meridian, spanning forests in Czechia, Croatia, and Italy. Tree rings serve as natural growth records, reflecting the environmental conditions in which trees grow. This study investigated how variations in temperature, rainfall, solar activity, and NAO together phases impact tree growth over time. Results revealed that the influence of solar activity and NAO varies significantly by region. In Czechia, increased solar activity is associated with higher tree-ring growth, while in Croatia, it reduces growth. In southern Italy, solar activity shows no significant impact. The NAO exerts region-specific effects: it negatively impacts tree-ring growth in Czechia and Croatia, while moderately enhancing growth in southern Italy. Seasonal weather patterns play a crucial role. Warmer temperatures in early spring generally encourage growth, while hot and dry summers can reduce it, particularly in northern regions. In southern Italy, tree growth shows fewer fluctuations. This regional variability highlights the differing vulnerabilities of forests to climatic changes, depending on local conditions and the interaction of solar activity and NAO. The findings demonstrate the importance of understanding how these natural forces influence forests. By identifying cyclical patterns in climate and tree growth, the study provides valuable tools for predicting future changes in forest ecosystems. For example, understanding how solar activity and NAO interact can help anticipate periods of stress or growth, allowing forestry managers to prepare more effectively for potential challenges such as droughts, storms, or extreme weather events. This research brings valuable knowledge across multiple fields by uncovering the influence of solar activity on Earth, while also shedding light on how growth fluctuations are driven by recurring environmental cycles. Enhanced understanding of these cyclical dynamics could provide critical early warnings of major disturbances, often triggered by weather imbalances. Such disruptions can lead to catastrophic events with devastating consequences for European forestry. Furthermore, this knowledge can be applied to other sectors impacted by climate change, such as agriculture, where these fluctuations also significantly influence economic outcomes. Improved understanding of these

climate dynamics can lead to better forest management and a more sustainable approach to preserving Europe's vital forest ecosystems for future generations.

Keywords: *Abies alba* Mill. Tree-rings Solar cycle North Atlantic oscillation Precipitation Temperature

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