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From Leaves to Forests: How to Map Stress in Plants due to Climate Change

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Abstract:

This study aims to develop a map-based storytelling approach to illustrate the changes in forest ecosystems over the years as a response to tree stress induced by increasing biotic and abiotic conditions linked to climate change. Climate change is driven by positive feedback loops that amplify warming trends, complicating efforts in mitigating its impacts (Ripple et al., 2023). Forests face significant challenges adapting to changing environments due to their slow regeneration rates and long-life spans (Lindner et al., 2010). Over the past few decades, the Mediterranean region has seen a faster-than-average temperature increase, accompanied by variable precipitation rates (Castly et al., 2015), leading to increased drought frequency and intensity. These changes increase the forests' vulnerability to interconnected disturbances such as pest outbreaks and extreme weather events. The advancements in sensing techniques have allowed transformative solutions to integrate with local traditional forest monitoring methods. This approach holds promising, cost-effective, scalable forest management practices in addressing Sustainable Development Goal #15: Life of Land to ensure future generations can enjoy the benefits of forest ecosystems.

This research focuses on assessing how trees on different elevation levels respond to biotic and abiotic stress in the Vinschgau / Val Venosta region in South Tyrol, Italy, based on the monitoring activities of the last 10 years. Different tree properties can be used to monitor stress responses. In traditional monitoring, ground measurements are usually based on the tree stem data such as tree circumference, tree ring growth and sap flow (Jacobs et al., 2021). Proximal sensing, which allows assessment on individual tree levels, provides calculations of vegetation indexes based on leaf properties reflecting water and nutrients stress response. Indexes such as the Photochemical Reflectance Index (PRI) is a measure sensitive to heat dissipation under water stress conditions in leaves via the de-epoxidation process of the xanthophyll cycle (D'Odorico et al., 2021). PRI can signal drought stress before visible signs appear. Integrating both data sources can improve foresters' ability to monitor better and respond to tree drought stress efficiently.

Cartographic methods are vital for visualizing and addressing this unconventional interdisciplinary challenge of assessing tree stress, thereby facilitating improved forest management. Innovative sensing solutions combined with historical ground tree data use changes in tree growth to understand responses to tree stress. This study employs a map-based storytelling approach that allows foresters to discern the relationship between specific site data and broader local area trends across different temporal scales and vertical elevations, effectively conveying the impacts of climatic effects. Map-based storytelling may effectively translate complex ecological data into engaging visual narratives that allow stakeholders to visualize the temporal and spatial dynamics of forest health and stress factors. We will explore the use of Space Time Cubes, by exploiting the in-situ information based on sensors (sap flow and dendrometers) to create radial maps of the trees. The trees have specific coordinates that can be plotted to create g spatial maps. In addition, we will combine the spectral information from drones to identify stress signals and link them to the ratio of growing and stress (Fig. 1).

This approach is particularly beneficial for domain experts and informed audiences, such as environmental scientists, policymakers, and conservation organizations, who can leverage these detailed visualizations to make data-driven decisions and implement targeted interventions. A usability study, based on an ad-hoc questionnaire and demo case, will be conducted with a group of foresters to evaluate their efficiency, effectiveness, and satisfaction from using the story map. This research contributes on dual levels: firstly, by designing visual approaches tailored for site-specific data, enabling the narration of local environmental changes; and secondly, by bridging the gap between scientific understanding and societal awareness at a broader level.

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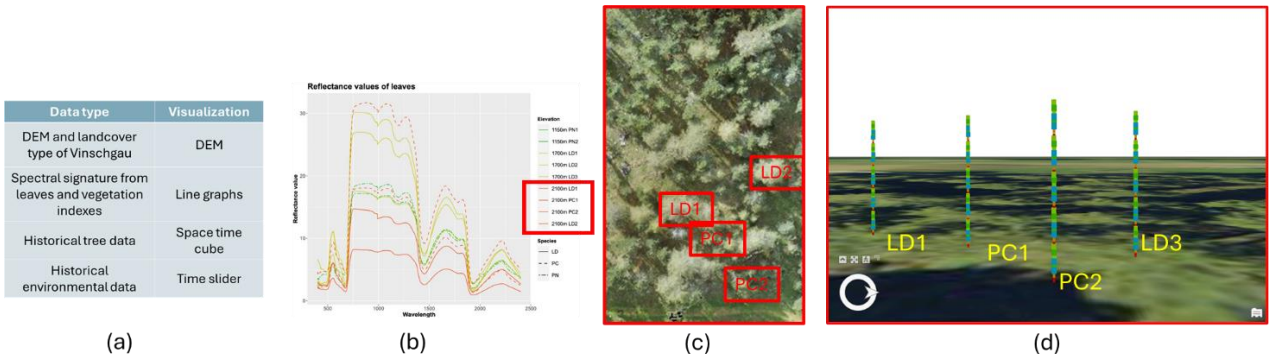

Fig. 1 Map-based storytelling concept of Val Mazia Forest, Italy with (a) source of data, (b) spectral representation of collected tree leaves, (c) UAV-based orthomosaic and tree species identification with (d) space time cubes representing annual dendrometer measurements. Red square color – Area of Interest 5, 2200 m.a.s.l.

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