



Predisposing factors to Landsat based greening trends in the Italian forestline ecotones

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In Europe, alpine treelines are shifting upward under the combined influence of climate and land-use change. In the Mediterranean basin, historical human pressure has significantly lowered treeline elevations, and these legacy effects continue to shape their present-day trajectories. Such legacies are expected to contribute to the contrasting patterns observed between the Alps and the Apennines, the two main Italian mountain ranges. Because treeline ecotones are key for mountain biodiversity and ecosystem services, consistent monitoring is crucial. Satellite remote sensing—especially multi-decadal time series of vegetation indices (VIs)— offers a promising avenue to study forest dynamics and treeline shift. Here, we present a semi-automatic and reproducible method to delineate the uppermost forestlines and to identify significant hotspots of change. We then evaluate the main topographic, climatic, and anthropogenic factors predisposing to treeline dynamics according to the long-term increase of VIs. We integrated national and international open-source datasets within a semi-automatic workflow to detect uppermost forestlines based on vertical distances between forest pixels and their relative highest peaks. We assessed greening along a forestline buffer representing the treeline ecotone using a 40-year Landsat NDVI time series (1984–2023). Trend significance was tested with contextual Mann–Kendall statistics, while Theil–Sen slopes quantified the magnitude of change. Finally, we used Random Forest models to investigate the relative importance of predisposing factors. Highest forestline elevations occur in the Alps, where larger elevation ranges and the dominance of conifers appear to be associated with upward shifts. In contrast, Apennine treelines are mainly formed by European beech; its heavier seeds likely limit upslope encroachment, favouring gap infilling processes over treeline upward shift. Overall, this study contributes a standardized framework for mapping forestlines and analysing the predisposing factors of greening dynamics. The approach is transferable to other mountain regions, supporting comparisons across space and time.