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Methods of leaf phenological monitoring to support management of resilient beech forest: networking activity between Life AForClimate and LIFEGENMON project.

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INTRODUCTION

Forest populations are generally characterized by good level of **phenotypic plasticity, an useful trait for survival, especially in relation to climate change**, which requires plastic responses in relatively short term. Phenological monitoring is therefore considered a valuable tool to study the effect of climate change on species and provenances, to define their resilience and to modelling their distribution range in the near future. Traditional monitoring of foliar phenology concerns in situ observations on single trees, while remote sensing techniques allow to analyse inter-annual variations in vegetation on a geographical wider scale. Traditional methods provide timely monitoring, but they require continuous inspections during the growing season. Remote monitoring is less expensive, nonetheless, even in case of high temporal resolution satellites, the possible presence of clouds could compromise the data acquisition.

The **Life AForClimate** project provides for the monitoring of leaf phenology in two **beech stands** in central Apennines and compares in situ and remote methods in different sectors. Additionally, within the networking activity with the **LIFEGENMON** project, where foliar phenology is a part of forest genetic monitoring, another beech stand from Slovenia was included.

Main aims are to improve the efficiency of the remote survey (data quality, objectivity of the monitoring, economic sustainability)

MATERIAL AND METHODS

Leaf phenology has been monitored, with weekly in-situ observations during spring on 80 dominant trees per site in AForClimate and on 250 or 500 trees per site in 2018 and 2019, respectively in the LIFEGENMON project. Synthetic phenological scale, with 5 scores (1: closed buds; 5: leaves completely extended) for the bud flush has been adopted. Moreover, leaf phenology has been monitored using the SAR (Synthetic Aperture Radar) remote sensing system (Sentinel-1). To estimate the phenophase transition DOY from the backscatter trend we compared two approaches: (i) an automated approach using the OLS-CUSUM test (Ploberger and Krämer, 1992), and (ii) a human-based approach by the visual interpretation of the time series plots.

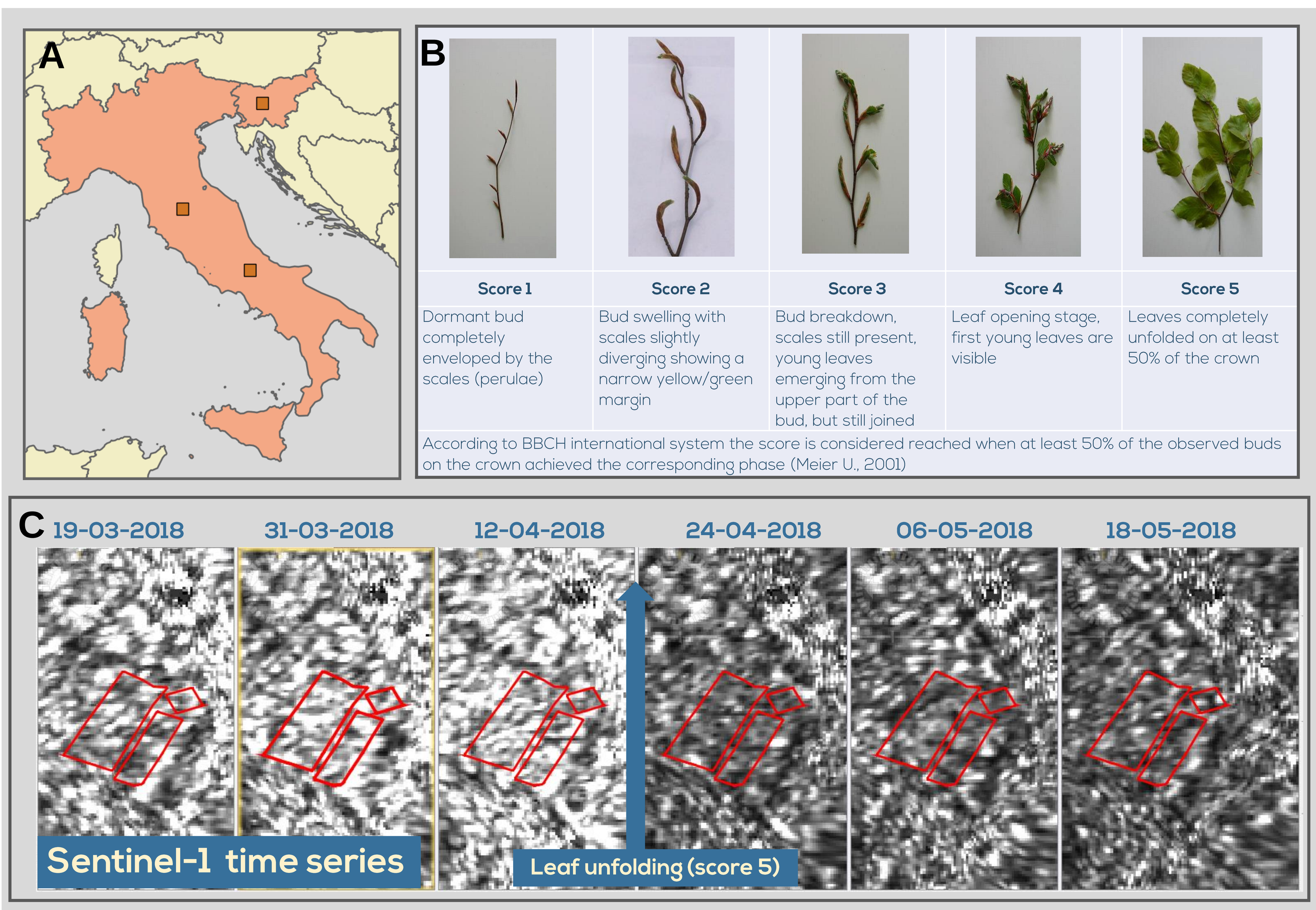

FIGURE 1: A) Study sites (Italy and Slovenia). B) Scoring system adopted for bud break monitoring on *Fagus sylvatica*. C) Sentinel-1 time series of the Gamma backscatter against one observed leaf unfording date.

Acknowledgments

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AFORCLIMATE

RESULTS

The results show that a significant decreasing in the backscatter trend corresponds to the observed spring phenology. Specifically, a regular pattern is visible and all observed phenophases occur in correspondence with a specific portion of the time series trend. Results showed a statistically significant different length of the vegetative spring period, spanning from dormant buds, up to leaves completely unfolded, between sites. Through Synthetic Aperture Radar estimation, this study demonstrates that leaf-out can be monitored with an extreme accuracy with a geometric resolution of 10 m. The phenophase score 4 and 5 estimation showed the best performance (RMSE < of 4 days).

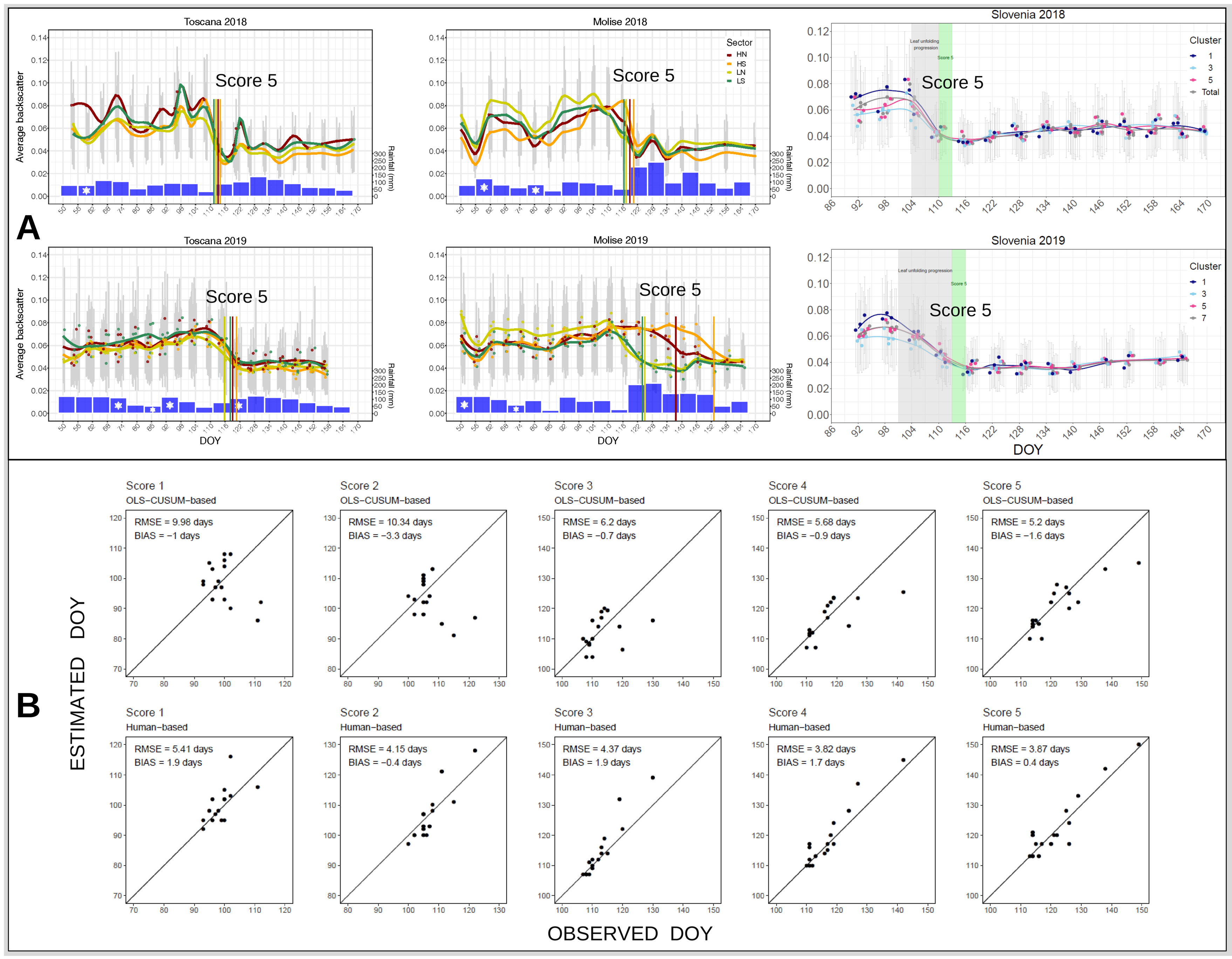

FIGURE 2: A) Smoothed backscatter pattern against observed score 5 DOYs. B) Observed versus remote sensing estimated DOY for all the scores with the two approaches used in this study. On the figures the Root Mean Squared Error (RMSE) and BIAS are reported.

CONCLUSIONS

This study demonstrates that Sentinel-1 is an operational tool to support remote spring phenology monitoring. Specifically, the scores 4 (leaf opening) and 5 (leaf complete unfolding) can be monitored with extreme accuracy (RMSE > 4 days), scores 3 (bud breakdown) and 2 (bud swelling) can be monitored with a slightly lower accuracy (4 to 5 days). Only the score 1 (bud dormancy) showed an error higher than 5 days. In any case, these results are coherent with the mean revisiting periods of the Sentinel-1 system (6 days). This result was confirmed for the two consecutive years of observation in both sites.

This radar approach fixes the cloud problem typical of multispectral approach and very frequent in phenophase change periods in Mediterranean climate regime. In beech forests, γ° backscatter values from VH GHRD Sentinel-1 images showed to identify correctly the leaf-out phases within an operative time resolution of about 4-5 days. Specifically, values of γ° backscatter around -13.6 dB indicated a leaf-on status, while values around -11.5 indicates a leaf-off status. Nonetheless, this approach can be applied to other deciduous species after a proper calibration.

These results promote the proposed remote sensing approach as a very useful tool to monitor growing season starting in remote areas, helping to reduce in situ observations. It also allows for historical reconstruction of phenological activity in areas with no past field observations.

The remote sensing monitoring approach developed in this study can detect the spring phenology in stand with at least a surface of 0.5 ha. Therefore, for a more temporally and geographically detailed scale a direct observation is needed, such as the *in situ* approach reported in this study.

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