METHODOLOGY FOR ESTIMATING COMPOSITION IN MIXED FOREST STANDS FROM PHENOLOGICAL ANALYSIS OF SENTINEL-1 AND SENTINEL-2 TIME SERIES

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INTRODUCTION:

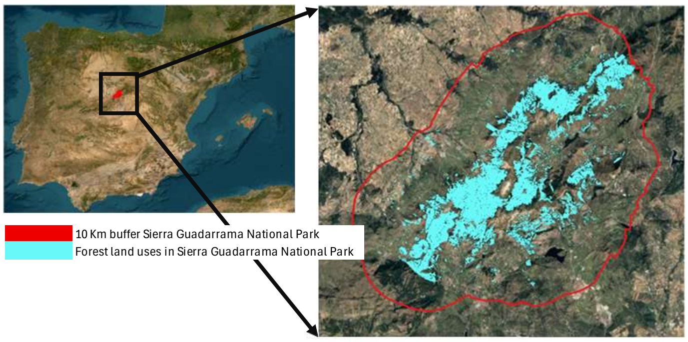
Context and challenge → Mixed forests (broadleaved and coniferous trees) show complex phenological dynamics. Sustainable management requires effective tools for capturing structural and temporal variability.
Relevance of Remote Sensing → Satellite-based spectral indices (Sentinel-2) and SAR metrics (Sentinel-1) are valuable tools. These data series effectively monitor phenological changes throughout the growing season.
Study objective → Estimate phenological parameters in pure forest stands (broadleaved and coniferous). Extrapolate derived phenological patterns to characterize floristic composition in mixed stands.
Working hypothesis → Phenological differences among species can be detected with satellite data and serve as indicators of species composition.

MATERIALS:

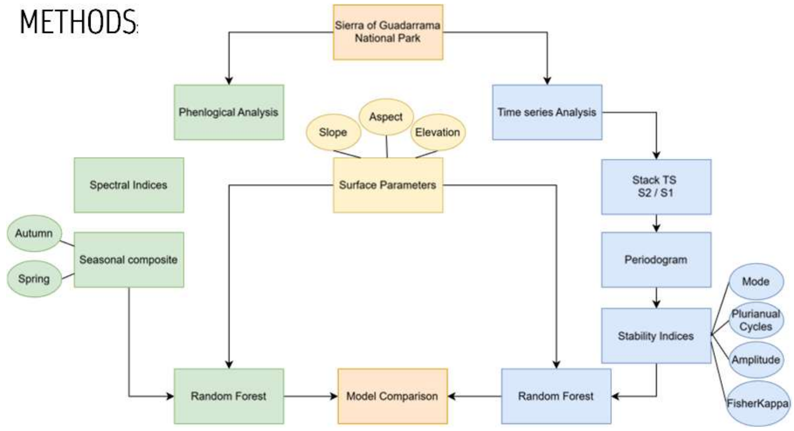
- Time series of spectral indices such as NDVI (Normalized Difference Vegetation Index), fAPAR (fraction of Absorbed Photosynthetically Active Radiation) and LAI (Leaf Area Index), all derived from Sentinel-2 at 10m.
- Sentinel-1 derived metrics
- Plots from the Fourth National Forest Inventory (IFN-4)
- Spanish Forest Map of Spain at 1:25,000 scale (MFE25)

STUDY AREA:

The Sierra de Guadarrama, which includes the National Park and its Protection Zone, has been selected as a pilot area for this study.



METHODS:

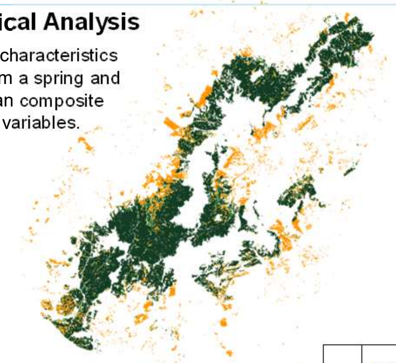


RESULTS

Conifer probability (p)	Forest formation
0.75 ≤ p ≤ 1	Conifers
0.6< p ≤ 0.75	Mixed with conifer dominance
0.4 < p ≤ 0.6	Mixed with conifer dominance
0.25 < p ≤ 0.4	Mixed with broadleaf dominance
0 ≤ p ≤ 0.25	Broadleaf

Phenological Analysis

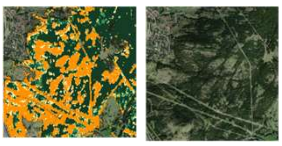
The vector of characteristics was made from a spring and autumn median composite and topologic variables.



Accuracy	0.9599
Kappa	0.9194

True label	Predicted: Broadleaf	Predicted: Conifers
Broadleaf	31	2
Conifers	1	33

Some open conifer stands are **misclassified** as broadleaf

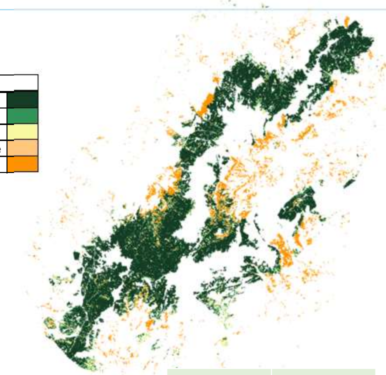


Overestimated broadleaf class; non-vegetated areas misclassified as **broadleaf**.

The **boundary** between broadleaved and coniferous stands is **very clearly defined.**

Time Series Analysis

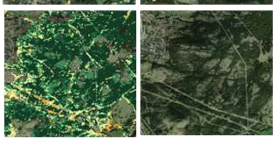
The feature vector was constructed based on time series analysis through periodogram decomposition, and includes descriptors such as amplitude, temporal stability, dominant periodicity, noise, and the presence of pluriannual cycles across spectral bands and derived indices.



Accuracy	0.9696
Kappa	0.9366

True label	Predicted: Broadleaf	Predicted: Conifers
Broadleaf	50	0
Conifers	4	78

Open conifer stands are classified as **conifer**.



Overestimated broadleaf class; non-vegetated areas misclassified as **mixed**.

The boundary between coniferous and broadleaved stands undergoes a transitional gradient.

CONCLUSIONS:

- The TSA provides more detailed insights than phenological analysis.
- It is essential to create a new class for shrubs and grasslands to eliminate misclassified broadleaf areas.
- Sampling of both pure and mixed stands is essential to accurately characterize their phenology and enable effective differentiation.
- The heterogeneity of forested landscapes complicates the extraction of spectrally pure pixels representing individual species, limiting the accuracy of remote sensing-based analyses.
- Time series analysis captures both cyclical patterns and differences in amplitude and stability, enabling more precise segmentation of pure conifer stands from pure broadleaf stands

REFERENCES:

Recuero, L., Litago, J., Pinzón, J. E., Huesca, M., Moyano, M. C., & Palacios-Orueta, A. (2019). Mapping periodic patterns of global vegetation based on spectral analysis of NDVI time series. *Remote Sensing*, *11*(21), 2497.

Hermosilla, T., Wulder, M. A., White, J. C., & Coops, N. C. (2022). Land cover classification in an era of big and open data: Optimizing localized implementation and training data selection to improve mapping outcomes. *Remote Sensing of Environment*, *268*, 112780.