Monitoring Climatic Anomalies and Vegetation Functioning in Italian Protected Areas through Satellite and Climatic Indices

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INTRODUCTION

The increasing frequency of climatic anomalies, such as extreme drought events and high temperatures, affects habitat diversity and functioning, contributing to biodiversity loss. Correlations between satellite-based vegetation indices and climatic data, such as drought indices, can help detect the relationship between vegetation dynamics and water availability, allowing for the identification of the spatial and temporal impact of extreme climatic events on specific ecosystems. As part of the "**DigitAP**" project, which aims to support the monitoring of Italian protected areas through advanced technological tools, this study seeks to investigate the influence of climate on vegetation. Specifically, the objective is to understand the correlation between drought indices and vegetation health, considering different land cover types. The analysis takes into account the prolonged effects of drought through the monthly integration of the SPEI index and the potential delay in vegetation response to drought events, as captured by remote sensing indices.

METHODS

SPEI
Hydrological data: BIGBANG model (ISPRA),
Spatial resolution: 1km,
Time period: 1953-2023

SPEI aggregation: SPEI01, SPEI03, SPEI06, SPEI09,SPEI12
1. Resampling SPEI
Nearest Neighbor method**,** 1km → 500m,
2. Calculation of Frequency, Duration and Intensity of drought (SPEI01<-1)

NDVI
Satellite data: MODIS (SR, MOD09GA)
Spatial resolution: 500m,
Time period: 2000-2023

1. **Mask of** cloud, shadow, snow and cirrus,
2. **Aggregation** at monthly means,
3. Assessment of NDVI **anomaly** in growing season

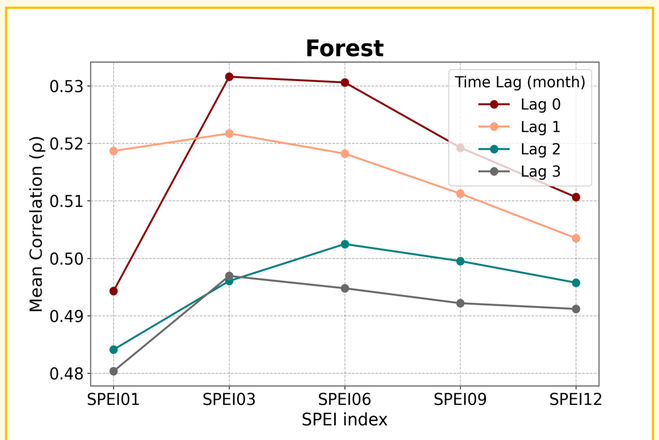
$$NDVI_{Anomaly} = \frac{NDVIi - \mu NDVI}{\sigma NDVI}$$

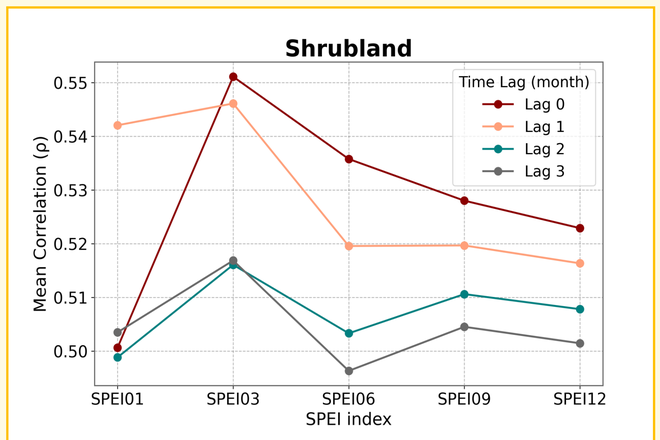
Land Cover
LC Data: Corine Land Cover (Copernicus),
Spatial resolution: *100m*
Time period: CLC 2000 + CLC 2006, + CLC 2012+CLC 2018

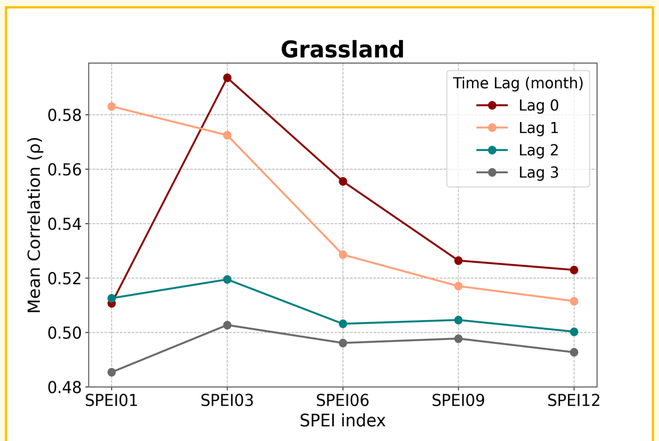
1. **Filtering Stable Natural area,**
2. **Mixed Model Effect Test** with NDVI value to assess *Forest*, *Shrubland* and *Grassland* difference;
3. **Resampling** from 100m to 500m, with 80% homogeneity threshold

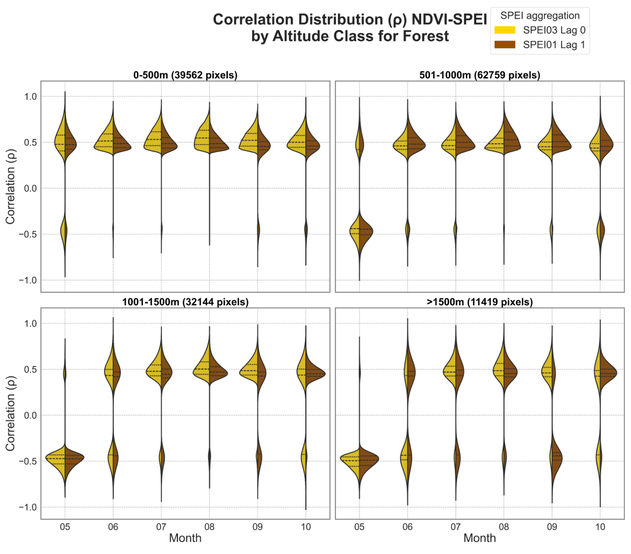
Spearman Correlation (ρ) (*p*-value < 0.05)
Filtering by Land Cover classes : **Forest, Shrubland, Grassland**. With **temporal lag** of 0,1,2,3 months

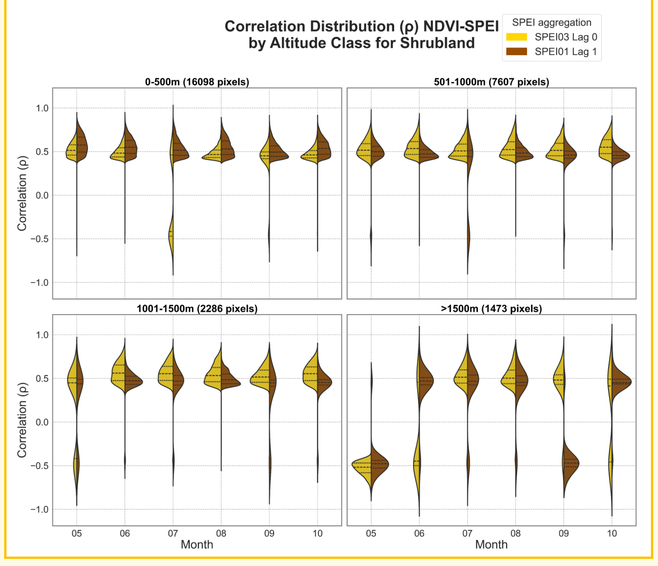
RESULTS

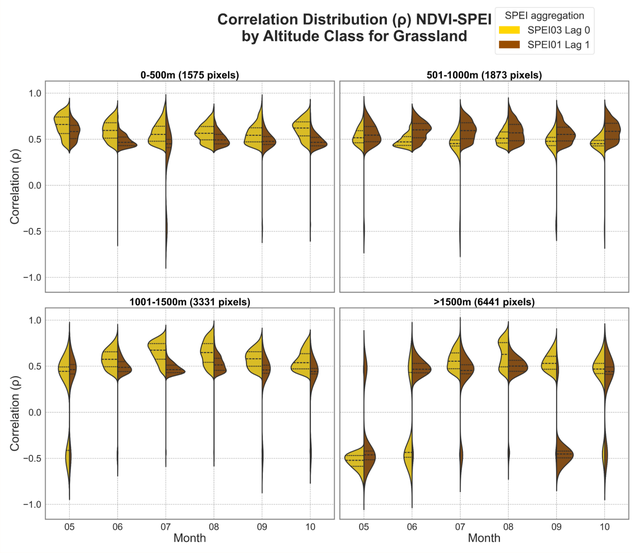












Line-plots In all three land cover types, the highest mean correlation is observed for **SPEI03 with Lag0**, indicating that the 3-month integrated SPEI has the strongest relationship with NDVI without any temporal delay. A one-month lag also shows particularly high mean values for both SPEI01 and SPEI03, especially for the grassland cover class. The correlation values generally decrease as the integration period increases,

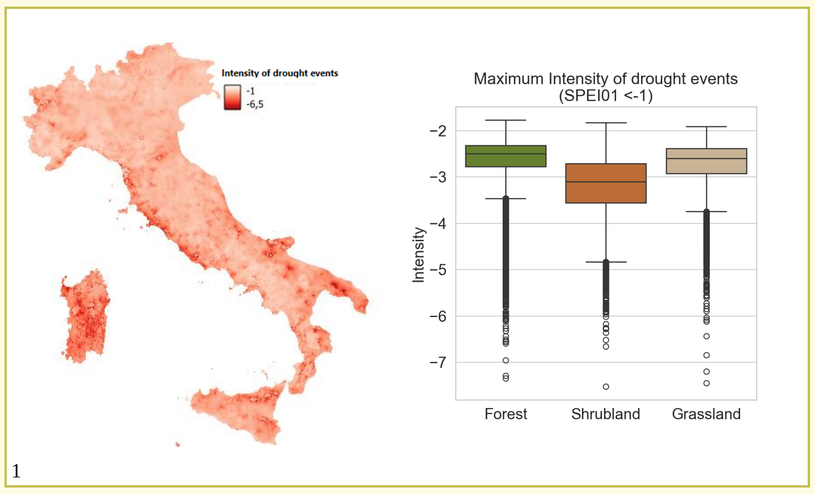
Violin plots The correlation between **NDVI and SPEI** at two integration type and lags (SPEI03 Lag 0 and SPEI01 Lag 1) across different land cover types (Forest, Shrubland, Grassland) and altitude classes shows the following trends:

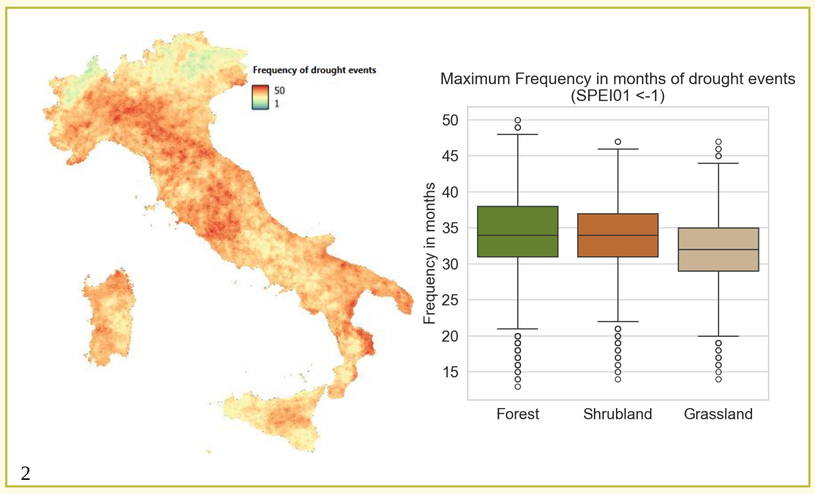
- **SPEI aggregation and Lag:**
SPEI03 (Lag0) generally exhibits higher correlations than SPEI01 (Lag1), suggesting that **NDVI responds more strongly to medium-term drought conditions.** This highlights the importance of water availability accumulated over three months in influencing vegetation health.

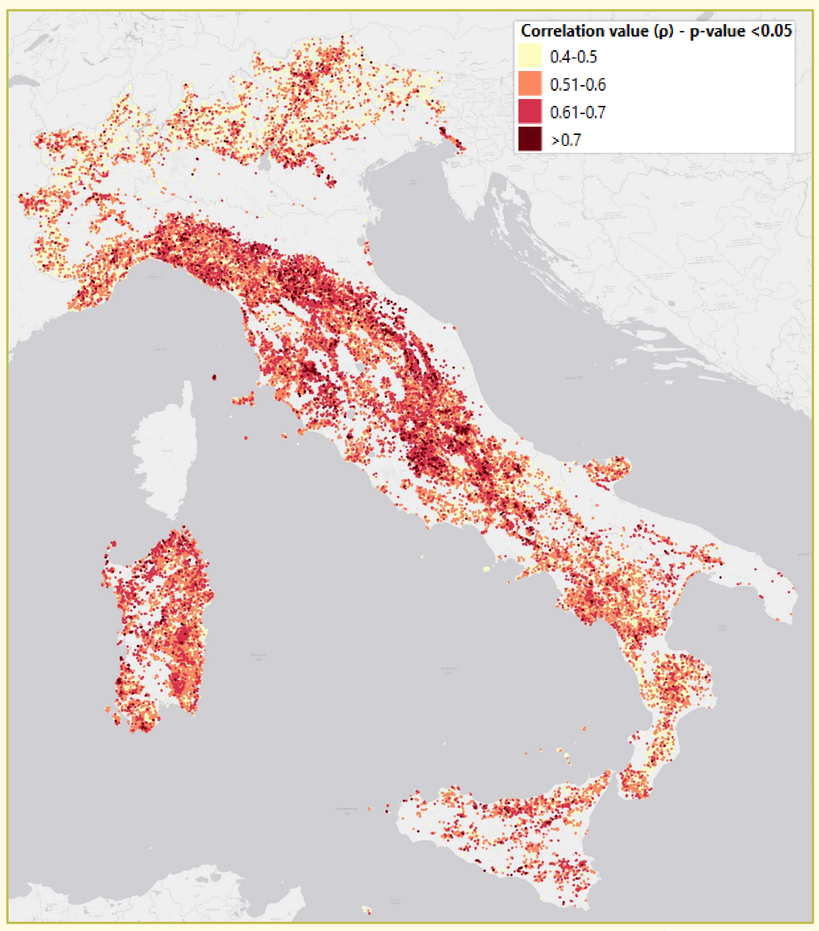
- **Influence of Altitude and Land Cover**:
Low Altitudes (0-500 m): Forest and grassland show a similar response, reacting immediately to prolonged drought conditions (SPEI03, Lag0). Grassland exhibits the highest mean correlation values. Shrubland, however, shows higher correlations for SPEI01 Lag 1, with a delayed vegetation response of about one month.

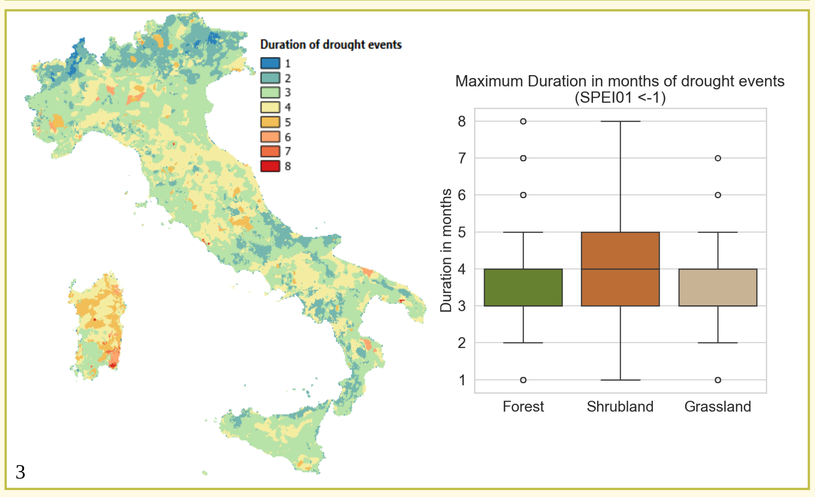
Medium to High Altitudes (500-1500 m): For forest, the pattern shows less continuity, and the correlation is concentrated mainly during the peak of the growing season. Shrubland and grassland show a linear correlation pattern with SPEI. Shrubland responds immediately to SPEI03, while grassland initially shows a one-month delay in its response to drought index. However, as elevation increases, grasslands become more sensitive to prolonged drought conditions (SPEI03 Lag 0).

Higher Elevations (>1500 m): Correlation patterns become more variable, particularly at the beginning and end of the growing season.









Maps and Boxplots

1. Intensity:
All three land cover types (Forest, Shrubland, and Grassland) exhibit similar distributions, with a median intensity around **-2.5 to -3.0**. The high number of **outliers** suggests that many areas experience particularly severe drought events, with some extreme cases reaching below **-6.0**.

2. Frequency:
Forests and shrublands show similar distributions, with a median frequency of approximately **35 months** over the study period. **Grasslands** have a slightly lower frequency but remain within the range of **30-35 months**. The presence of **outliers** indicates that some areas have experienced drought events nearly **50 times**, highlighting **hotspots of recurrent dry conditions.**

3. Duration:
Shrublands experience the **longest drought events** on average, with a median duration of **4-5 months**. **Forests and grasslands** show slightly shorter durations, with a **median of 3 months**.
Variability is highest in shrublands, where some locations record **extreme events** lasting up to **8 months**.

Correlation Map

The **spatial distribution of pixels** where a **positive correlation** between **NDVI and SPEI (01/03)** coincides with a **negative average NDVI anomaly** during the vegetation season from **2000 to 2023** reveals distinct regional patterns: **Less significant correlations** are primarily distributed **along the Alpine mountain range** and, more generally, **across northern Italy**. The **highest density of correlations**, including values exceeding **0.6**, is observed **in central Italy and Sardinia**. Overall, **the entire territory exhibits a strong correlation between NDVI and SPEI**, highlighting the significant influence of drought conditions on vegetation health across Italy.

DISCUSSION

This analysis, made on a 23 years period, provide a picture of how Italian vegetation responds to drought events, highlighting the crucial role **of water availability**, as measured by the SPEI index, in determining NDVI variability. The highest correlation observed between NDVI and SPEI03 at Lag 0 suggests that, despite their heterogeneity, Italian vegetation systems share a strong dependence on water reserves accumulated over the short to medium term (three months). However, **differences emerge in vegetation responses at different altitudes**. At medium and high elevations, correlation patterns become more variable, partly due to the shorter phenological window during which vegetation reaches peak activity and the microclimatic variability characteristic of mountain environments. From an ecological perspective, this suggests that even relatively short drought periods can have significant impacts, particularly on highly sensitive ecosystems such as grasslands. At the same time, delayed responses observed in certain land cover types (e.g., shrublands) or at specific altitudes indicate the existence of adaptation mechanisms related to phenology, soil characteristics, and water-use strategies. Analyses of drought intensity, frequency, and duration reveal that large areas of Italy experience recurrent drought periods, with certain hotspots characterized by extreme events or prolonged drought conditions. Finally, the spatial distribution of positive NDVI-SPEI correlations, associated with negative NDVI anomalies, reflects differences in climatic and phenological dynamics.

Implications for Management and Future Perspectives
The proposed approach, which integrates satellite data and drought indices at a national scale, will be further enhanced with additional information, such as climatic variables, alternative drought indices, and ground-based data. This will help develop a comprehensive knowledge framework to identify particularly vulnerable areas and facilitate the planning of interventions aimed at mitigating the impact of climate change on biodiversity and ecosystem functionality within protected areas.

WORK IN PROGRESS

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