Vegetation response components to drought regime attributes in the Mediterranean Basin

Matilde Torrassa*[1,2,3], Mara Baudena[3,4], Edoardo Cremonese[2], Maria J. Santos[5]

[1]University of Genova, Italy; [2]CIMA Research Foundation, Italy; [3]National Research Council, Institute of Atmospheric Sciences and Climate (CNR-ISAC), Italy; [4]National Biodiversity Future Center, Italy; [5] University of Zurich, Switzerland

***email:** matilde.torrassa@cimafoundation.org

Introduction

Climate models project **increasing frequency and intensity of droughts** in the Mediterranean Basin, increasing the threat to ecosystems. Mediterranean ecosystems, being **water-limited**, although adapted to water scarcity, may be particularly vulnerable to **extreme droughts**[1]. Understanding the impacts of different **drought attributes and regimes** on ecosystems is particularly relevant under changing drought and climate conditions[2]. Ecosystem resilience concept has been applied since its first introduction[3] yet using a variety of different definitions and metrics[2].

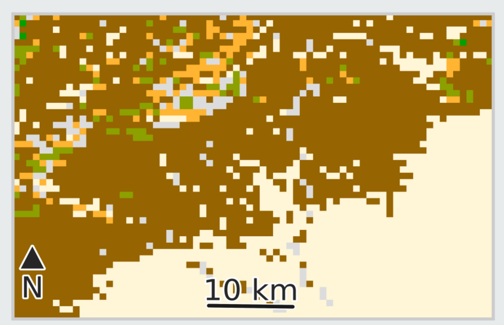
Research Question:

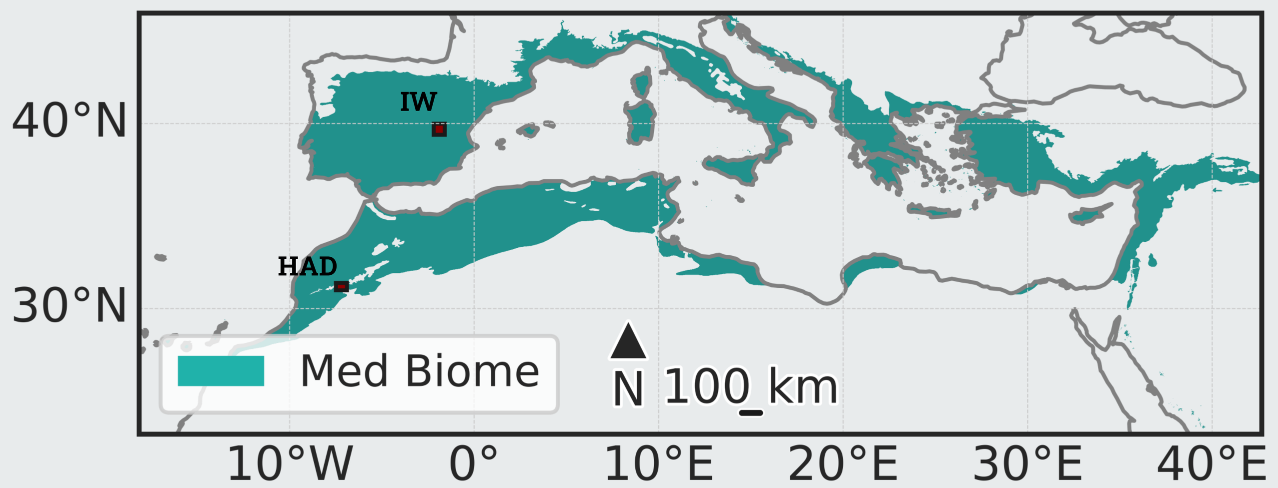
- *Which are the most suited metrics to describe ecosystem resilience to drought in the Mediterranean Basin?*
- *How are different drought regimes influencing Mediterranean ecosystem resilience in the Mediterranean Basin?*

Study Sites

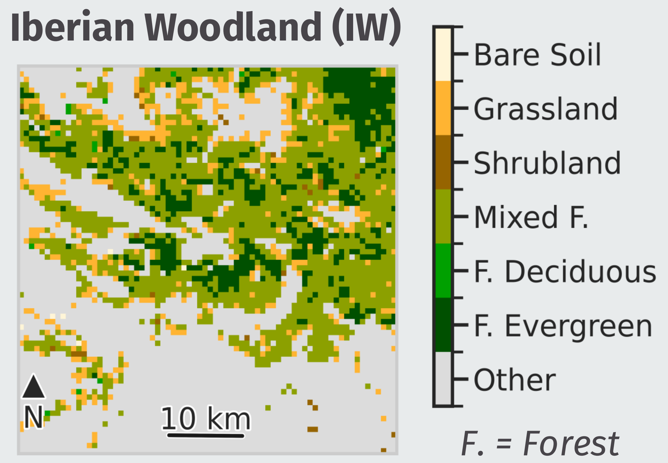
We examined the 2001-2018 timeseries of droughts and vegetation productivity for two different sites, where the impacts of droughts on ecosystems have been previously studied: a **High Atlas Dryland** in Morocco[4] and an **Iberian Woodland** in Spain[5]. These sites are located in different ecoregions and differ in terms of vegetation composition, climate, and aridity. Therefore, an analysis of drought and vegetation response to it in these locations can be relevant to select metrics suitable for application to the entire Mediterranean Biome.

High Atlas Dryland (HAD)





Iberian Woodland (IW)



F. = Forest

Drought and Vegetation Indices

Drought indices:

Standardized Precipitation-Evapotranspiration Index (*SPEI*) at different aggregation time scales, with data retrieved from the CHELSA database[6,7].

- *SPEI3*
- *SPEI6*
- *SPEI12*

Vegetation indices:

Vegetation spectral indices (*VI*) as proxies of vegetation productivity, from the MODIS multispectral sensor:

- Normalized Difference Vegetation Index (*NDVI*)
- Enhanced Vegetation Index (*EVI*)
- Near-infrared Reflectance of Vegetation (*NIRV*)
- Kernel NDVI (*kNDVI*)

We estimated the correlation between SPEIs and VIs and identified the combination that could best capture a response of vegetation to droughts. Before undergoing the correlation test, the vegetation indices were detrended (seasonal and long-term trend). The maximum correlation in both sites occurred for *SPEI12-NDVI* and *SPEI12-kNDVI*. The same result was found sub-setting over single plant functional types. Thus, we selected the ***SPEI12-kNDVI* combination**. *kNDVI* was chosen over *NDVI* since it has been previously proven more resistant to saturation, bias and complex phenological cycles[8].

	High Atlas Dryland			Iberian Woodland		
	SPEI3	SPEI6	SPEI12	SPEI3	SPEI6	SPEI12
NDVI	0.23	0.4	0.47	0.33	0.46	0.54
EVI	0.21	0.38	0.46	0.2	0.29	0.4
NIRV	0.18	0.34	0.44	0.2	0.28	0.38
kNDVI	0.24	0.41	0.47	0.33	0.46	0.54

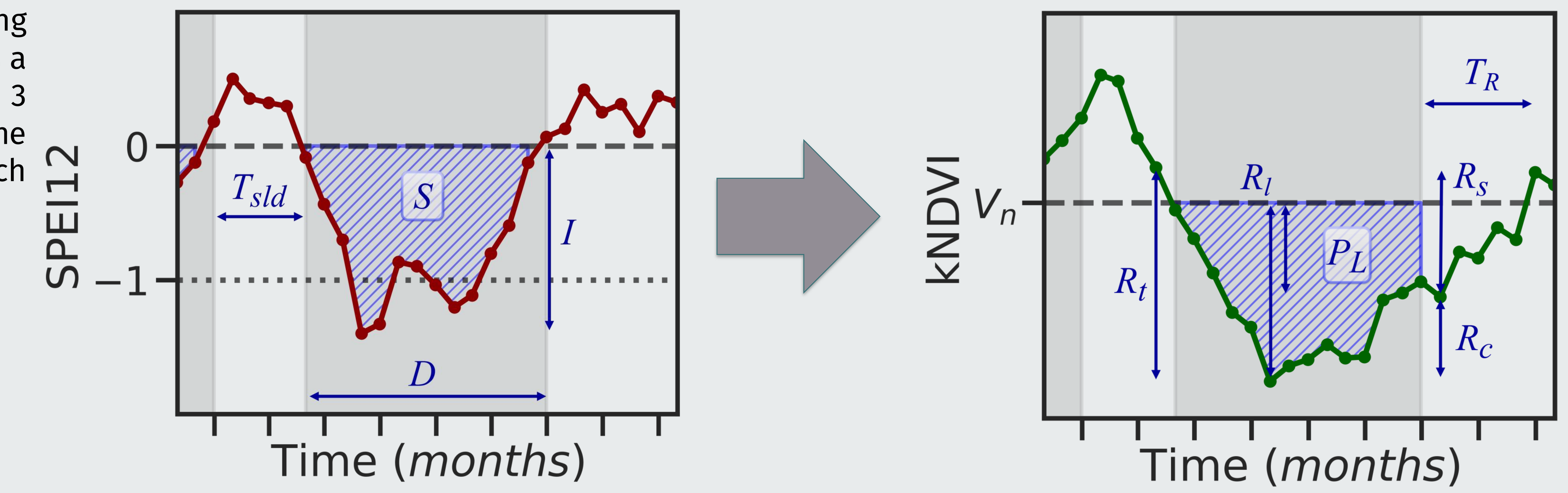
Pearson Correlation Coefficient (scale: −0.50, −0.25, 0.00, 0.25, 0.50)

Drought Attributes and Vegetation Response Components

We employed an **event-based approach** to detect droughts[9]: using *SPEI12*, we defined a **drought event** as a period where *SPEI<0* with at least 3 months of *SPEI<-1* and estimated the **drought regime attributes** for each event:

- **Duration**, *D*
- **Intensity**, *I*
- **Severity**, *S*
- **Time since last drought**, T_{sld}

Due to the high correlation between *S* with either *D* and *I*, it was not included in the vegetation response analyses.



We analyzed the relationship between drought regime attributes and vegetation response components, starting with a **linear regression analysis**.

For each drought event, we evaluated several ecosystem resilience metrics[10,11,12] as **vegetation response components** using the kNDVI timeseries:

- **Productivity Loss**, P_L
- **Resistance**, R_t
- **Recovery**, R_c
- **Resilience**, R_l
- **Resilience**, R_s
- **Time to recover**, T_R

References

[1] Knapp et al. (2023), *Functional Ecology*

[2] Dakos et al. (2022), *Environmental Research Letters*

[3] Holling (1973), *Annual review of ecology and systematics*

[4] Vermeer at al. (2025), *Environmental and Sustainability Indicators*

[5] Moreno-de-las-Heras et al. (2023), *Science of the Total Environment*

[6] Karger et al. (2017), *Scientific Data*

[7] Brun et al. (2022), *Earth System Science Data*

[8] Camps-Valls et al. (2021), *Science Adnvances*

[9] Dayal et al. (2018), *Journal of Hydrologic Engineering*

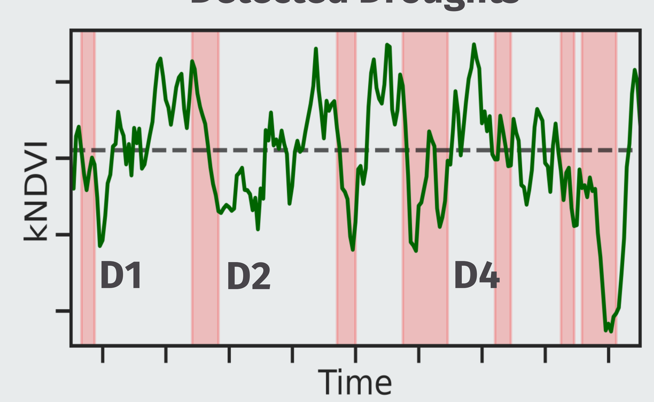
[10] Lloret et al. (2011), *Oikos*

[11] Isbell et al. (2015), *Nature*

[12] Sturm et al. (2022), *Global Change Biology*

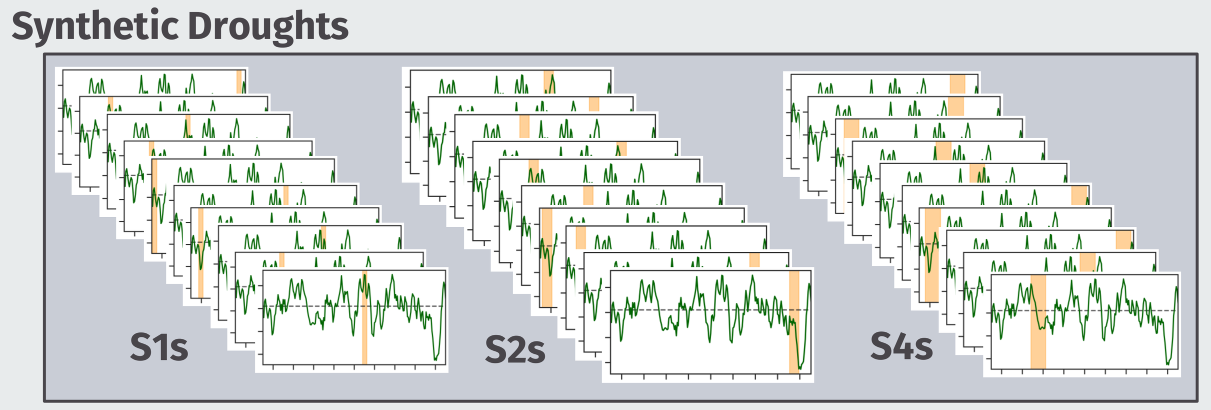
Synthetic Droughts Experiment

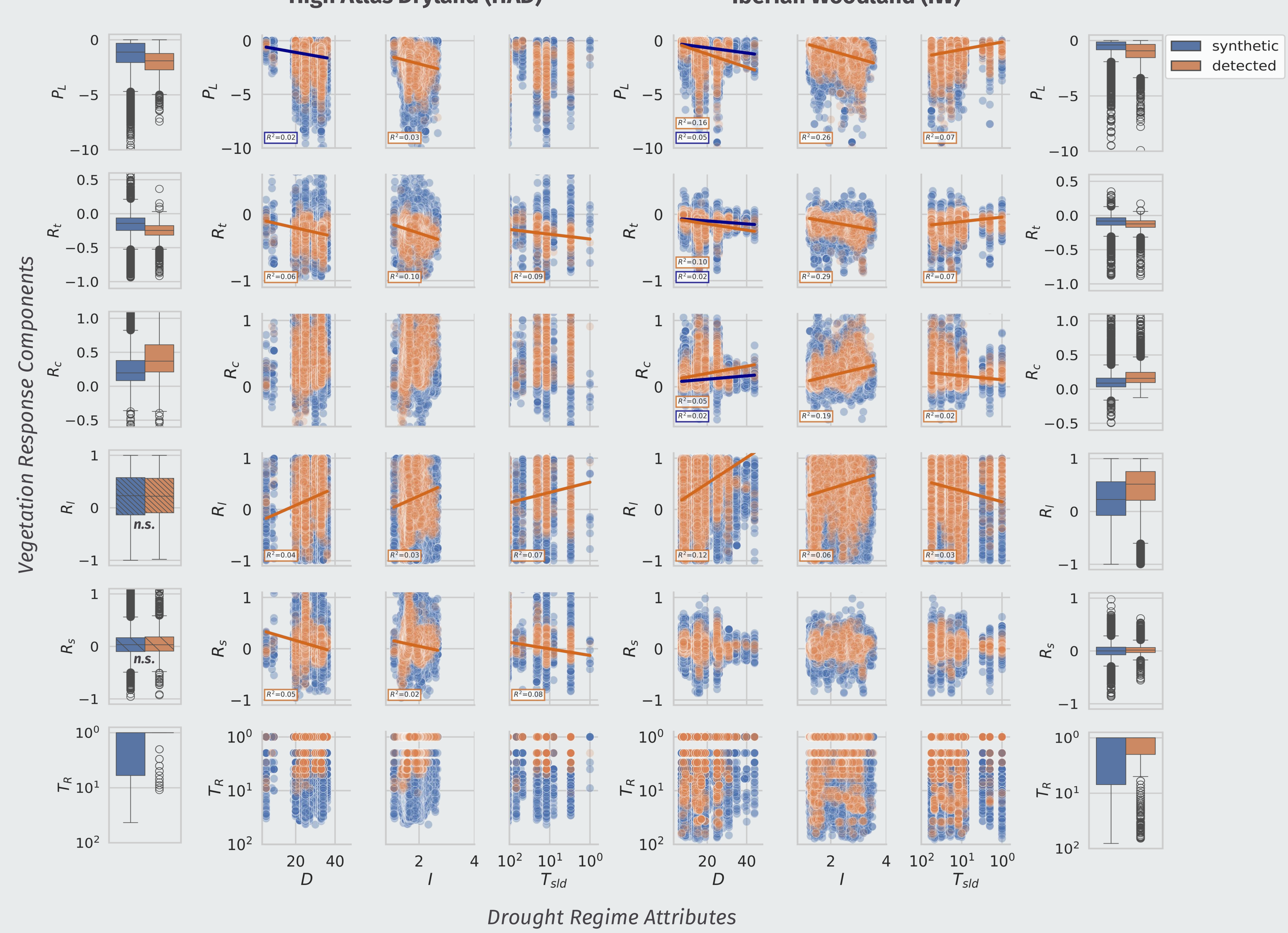
Detected Droughts



To detect the significance of the different vegetation response components, we employed a synthetic drought experiment: each **detected drought** event (*D1, D2…*) was replicated 10 times, generating 10 **synthetic droughts** events (*S1s, S2s…*) with the original drought attributes and a random starting date of the event. Vegetation response components were then estimated for the detected and the synthetic droughts.

Synthetic Droughts





Boxplots: In both sites, the Productivity Loss, Resistance and Recovery distribution for detected droughts exhibited a significant difference compared to the distribution estimated for synthetic droughts: P_L and R_t exhibited lower values, and R_c larger values, meaning a larger impact of the detected droughts. The two Resilience metrics distribution were statistically different only in the Iberian Woodland site, with a larger difference for the R_l distribution.

Scatterplots & Linear Regression: The relationship between vegetation response components and drought regime attributes was generally stronger in the Iberian Woodland site. In this site, **Intensity resulted the drought attribute with the strongest relationship** (largest R^2) **with Productivity Loss** (negative), **Resistance** (negative), **and Recovery** (positive). The absence of a substantial signal at the HAD site might be due to milder drought events during the period considered. Alternatively, it may be indicative of a lack of response in dryland vegetation, due to persistent aridity. Time to Recover did not exhibit any significant relationship in both sites. Conversely, the second formulation of Resilience (R_s) exhibited only weak relationships, albeit in the HAD site.