Pasture resilience: phenological patterns and potential critical thresholds in the face of climate change

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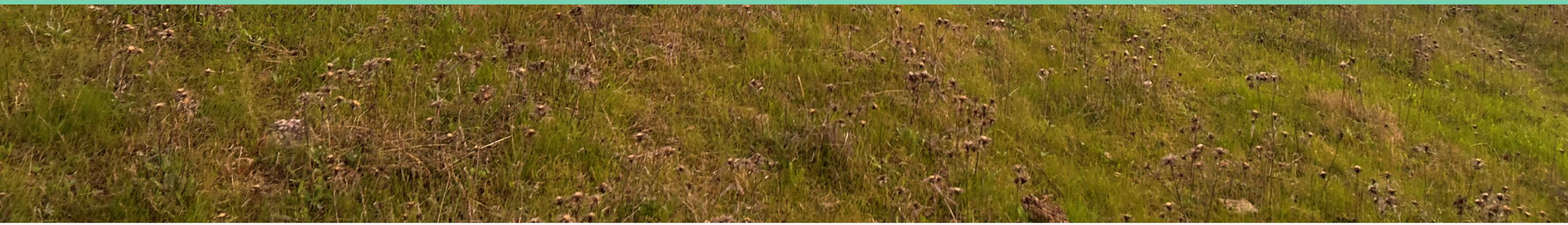

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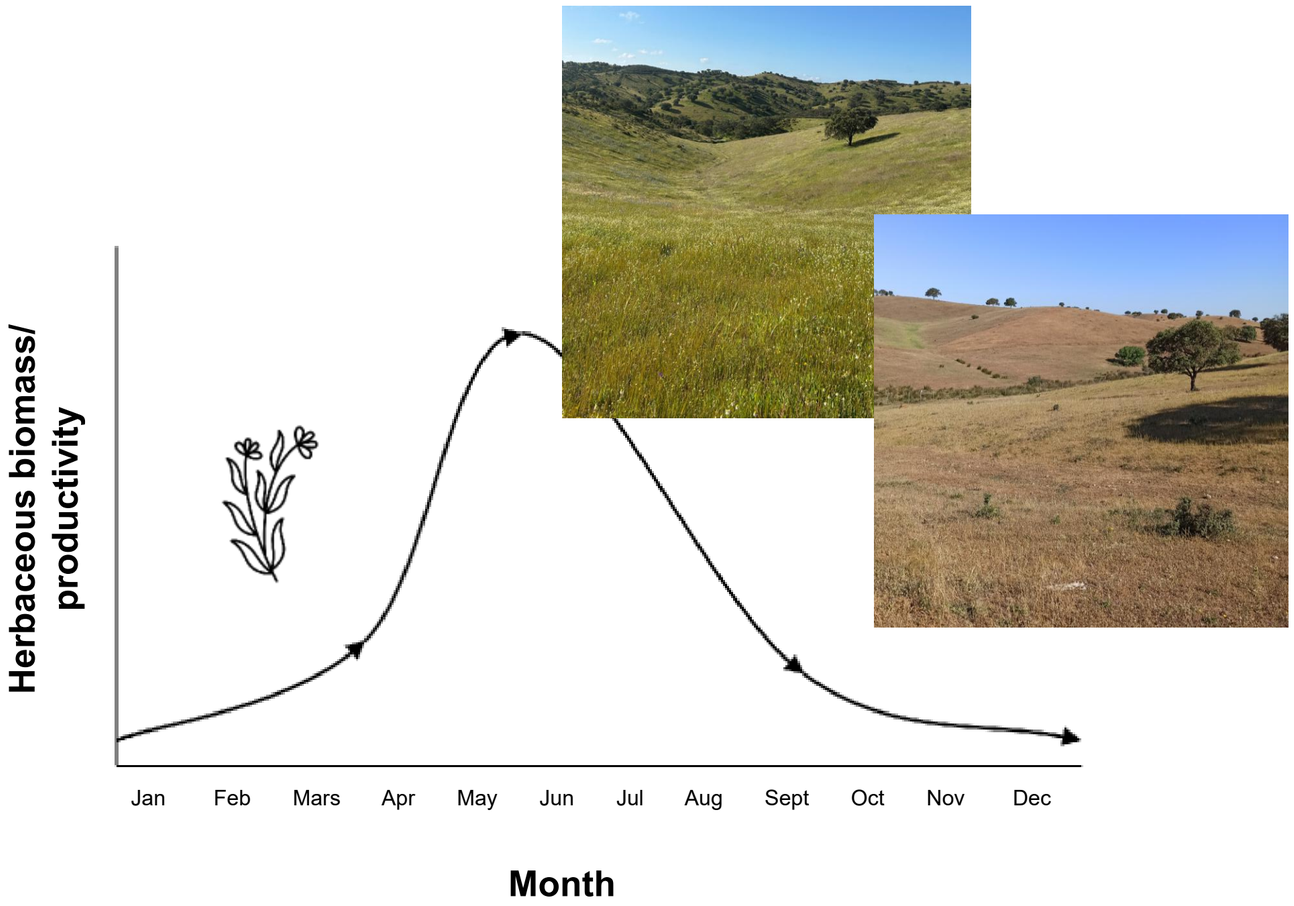
Timings of biological events

Why phenology matters



Pastures follow a bell-shaped **seasonal growth curve** driven by **inter-** and **intra-annual climate variability**

Climate change is altering **biological timings** and **functioning**

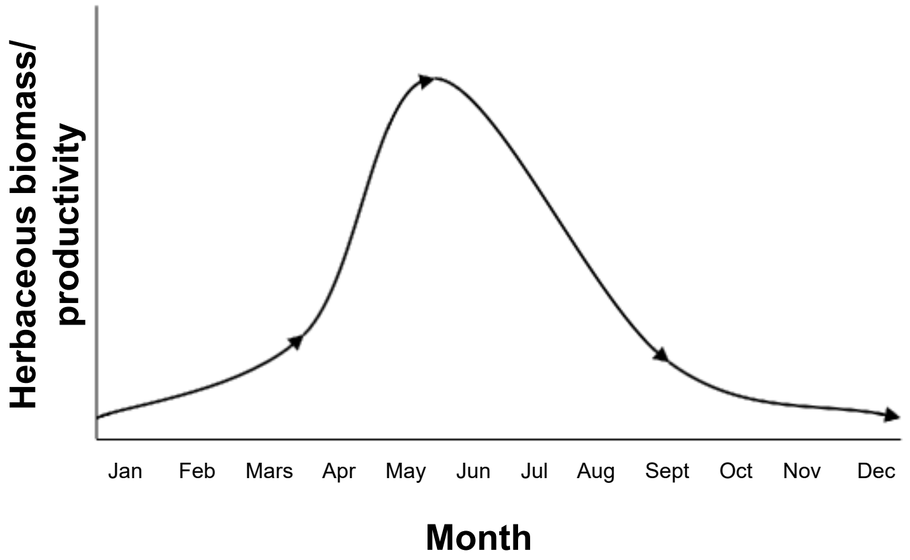
With impacts on **productivity** and **other ecosystem services** such as carbon storage

Need to understand how pasture functioning responds to environmental drivers to assess if ecological functions are maintained under different conditions

The issues

Pasture phenology is influenced by:

- Macroclimate (temperature, precipitation);
- Microclimate (topography, solar radiation);
- Soil (physical and chemical properties);
- Management (grazing, sowing, mowing);
- Biotic interactions (competition).



Highly complex temporal and spatial patterns

How to properly detect the effect of climate so we can anticipate climate change's impacts?

Field sampling?

- Limited spatial coverage
- Resource and time-intensive

Remote sensing?

- High resolution datasets are recent, no long time-series available

Our questions

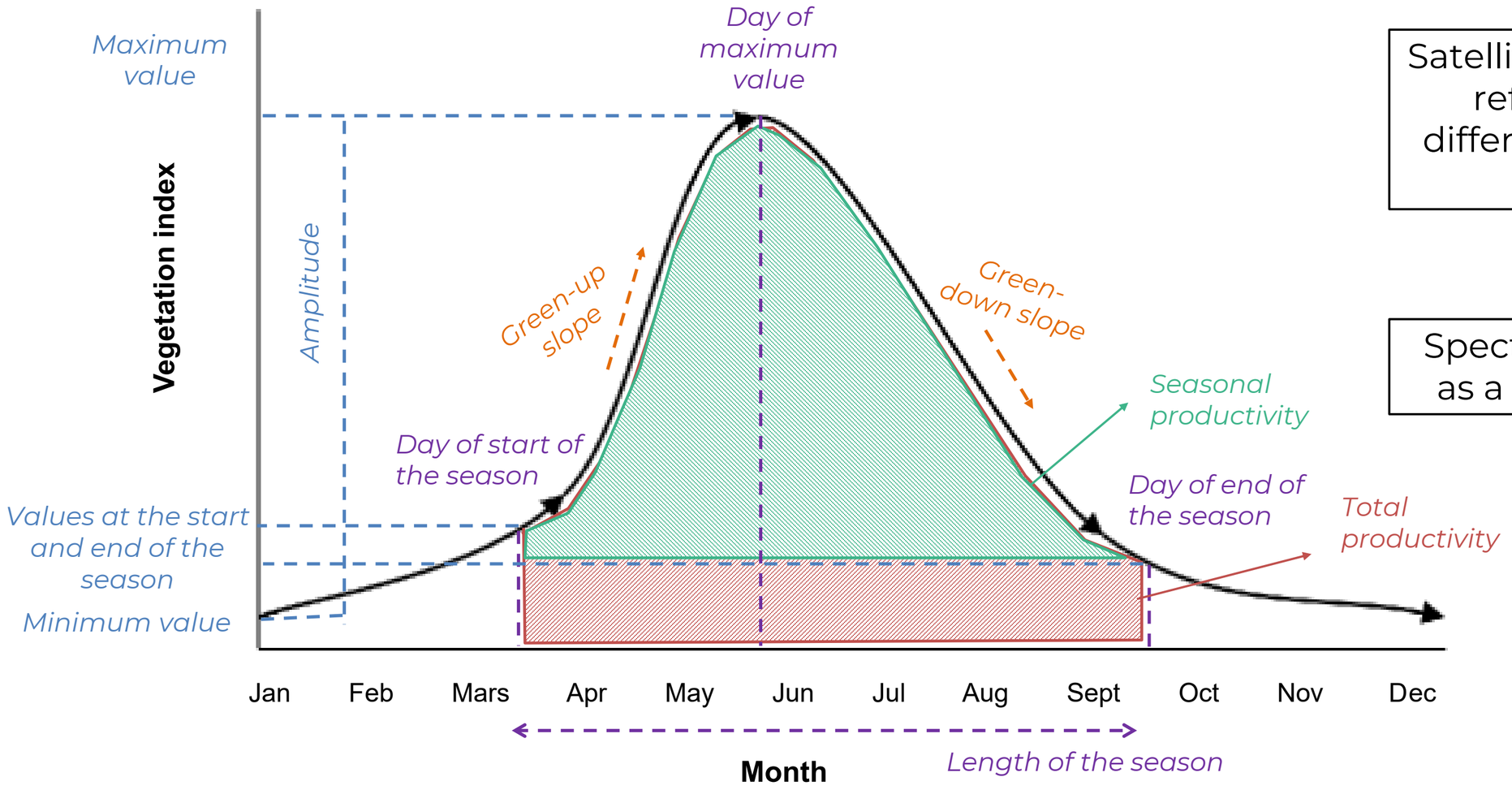
Taking advantage of recent **high-resolution remote sensing** data, and

Using a **space-for-time** approach

1. **Can we discriminate between pastures along a spatial climate gradient based on differences and similarities in their yearly phenology?**

2. **If so, what environmental factors are driving this zonation?**

High-resolution phenology and productivity



REMOTE SENSING

Solar radiation is absorbed and reflected back by plants

⇩

Satellite sensors capture the reflected radiation in different wavelengths (e.g. infra-red)

⇩

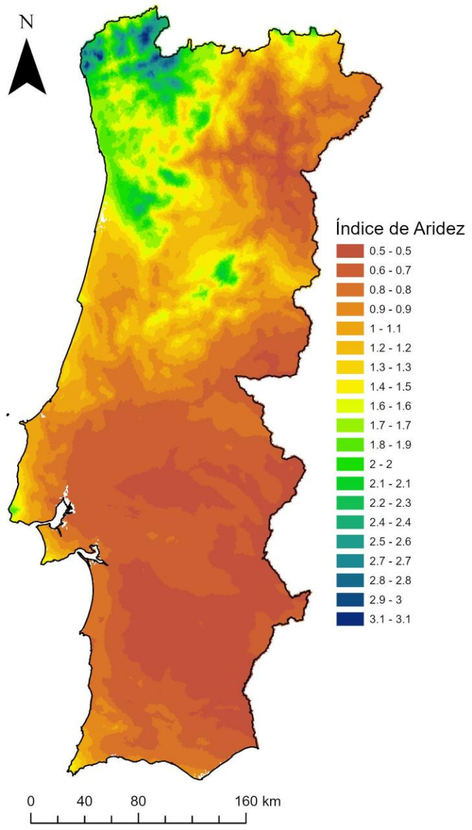
Spectral **vegetation index** as a proxy of productivity

(e.g., NDVI, EVI, PPI)

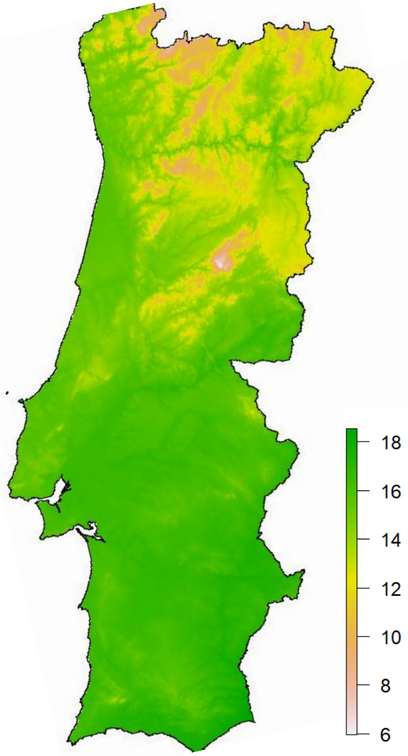
Data: CHELSA Bioclimate variables, Karger et al., 2017

Unraveling phenology patterns

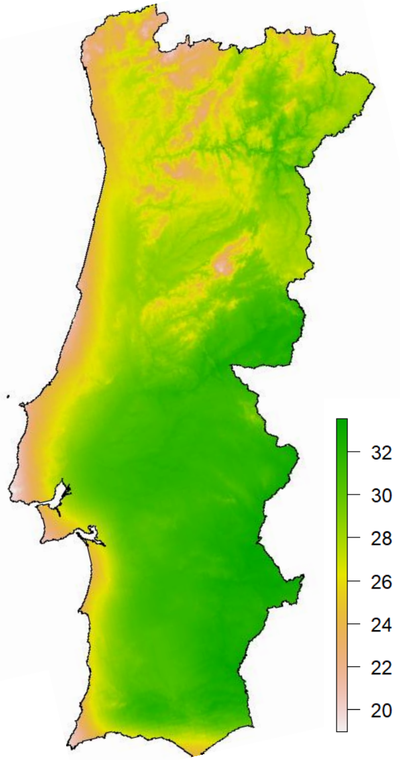
A large-scale climate gradient



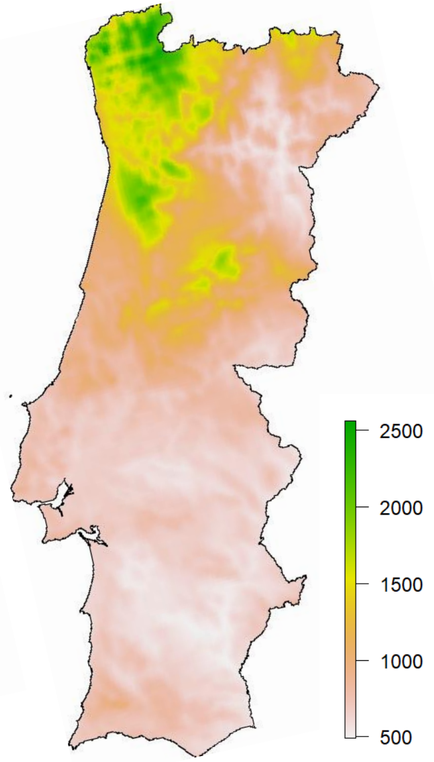
Aridity index



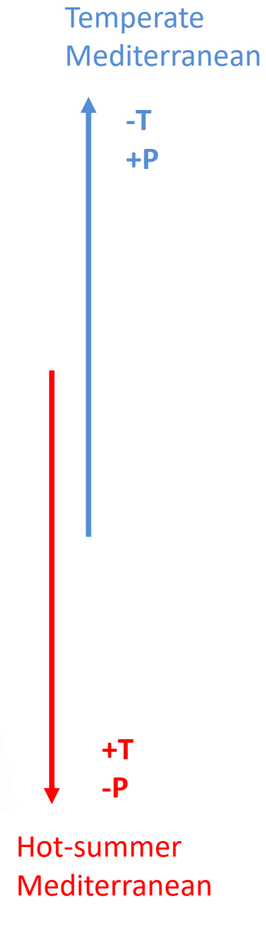
Mean annual daily mean air temperatures averaged over 1 year (C°)



Mean daily maximum air temperature of the warmest month (C°)



Accumulated precipitation amount over 1 year ($kg.m^{-2}.year^{-1}$)



Unraveling phenology patterns

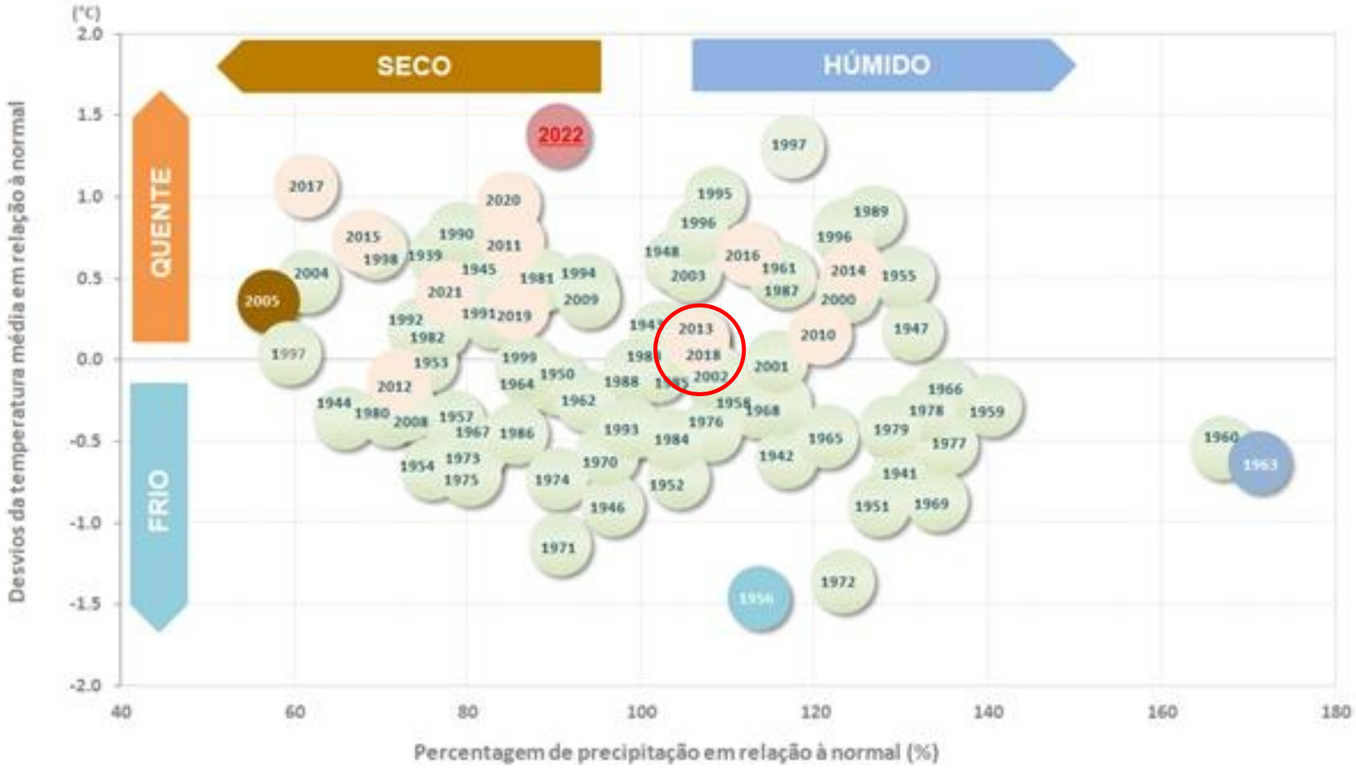
Data: phenology and environment

HR-VPP - high-resolution vegetation phenology parameters from SENTINEL-2

10x10m
5-day revisit time
Plant Phenology Index (PPI) → 13 parameters, 2017 to current time (seasonal productivity, start of the season, length of the season, green-up rate, etc.)

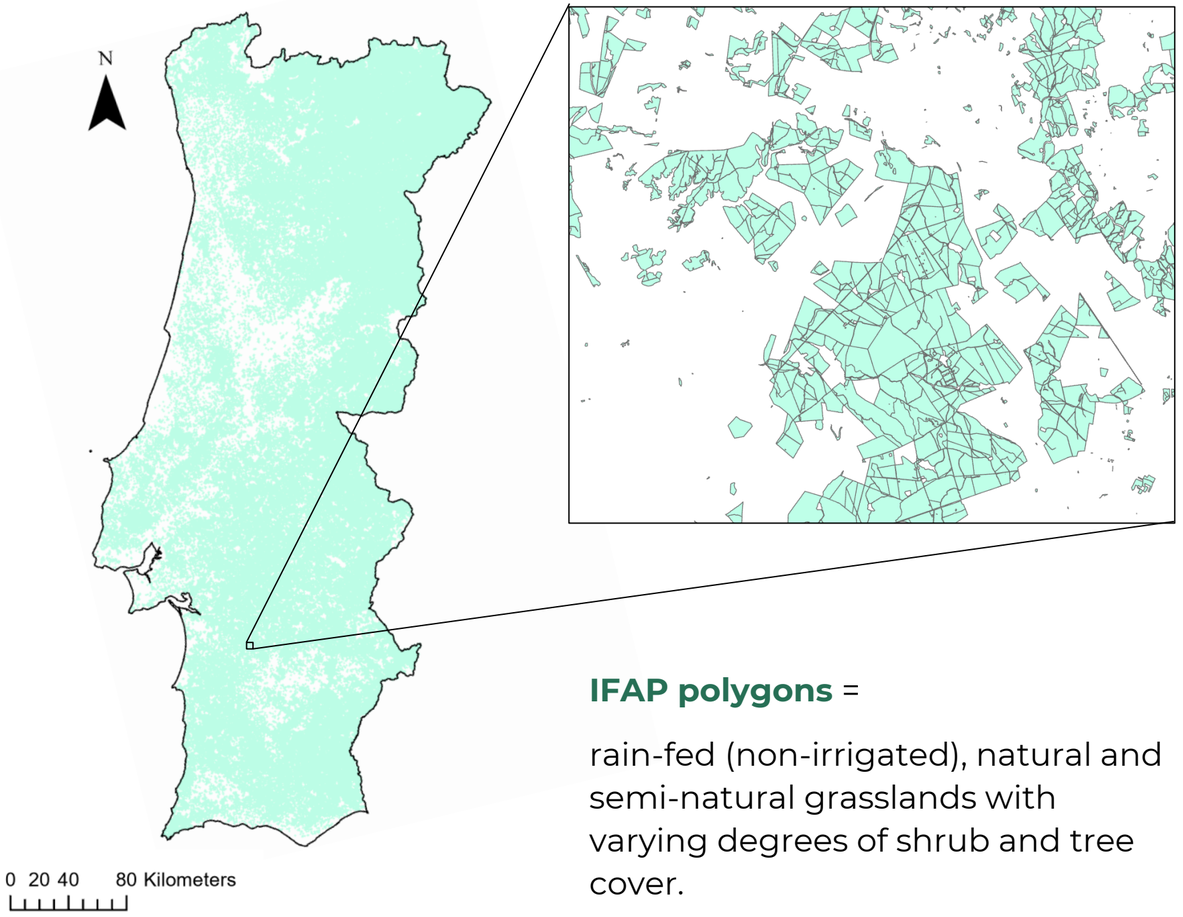
Predictor variables

Topography (elevation, psr, slope)
Bioclimate (temperature, precipitation, aridity, ...)
Soil properties (physical and chemical)
Demographics (human population density, ...)



Unraveling phenology patterns

Data: permanent pastures



IFAP polygons =

rain-fed (non-irrigated), natural and semi-natural grasslands with varying degrees of shrub and tree cover.

All variables extracted for pasture polygons as **mean values**

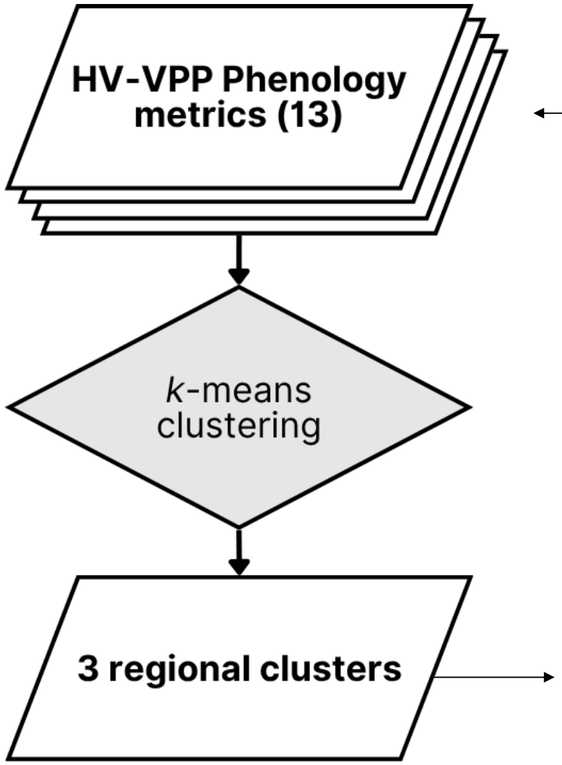
3 land-uses :

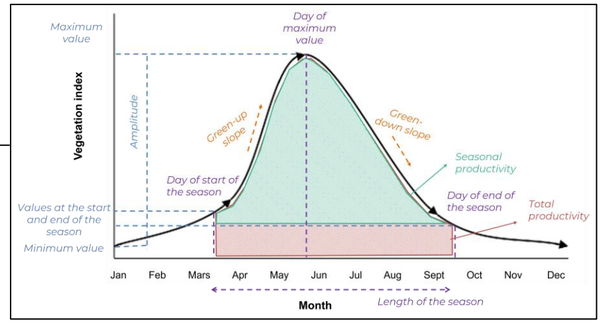
- “Permanent pastures” (N=342 288);
- “Permanent pastures with shrubs” (N=491 217); and
- “Permanent pastures under the cover of *Quercus* spp.” (N=24 142)

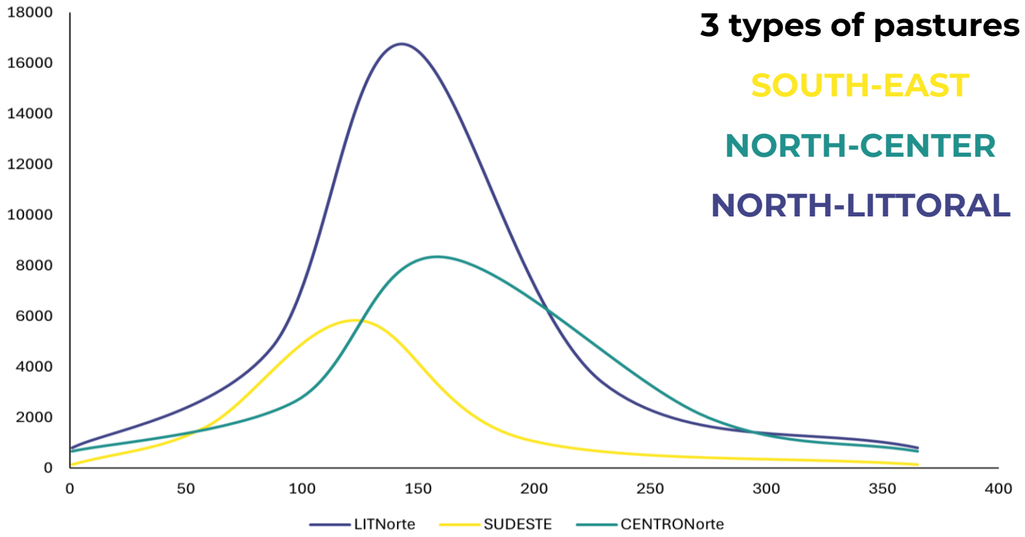
Total: 857 647 “farms”

Unraveling phenology patterns

Clustering analysis – *k*-means





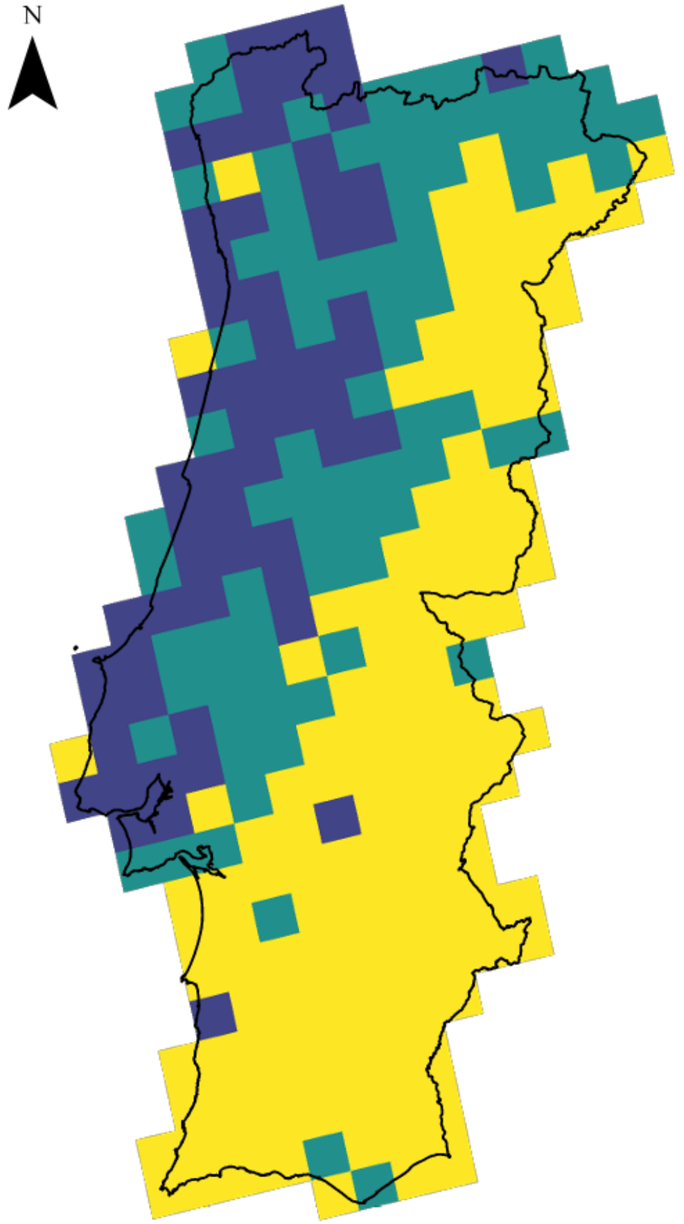


3 types of pastures

SOUTH-EAST

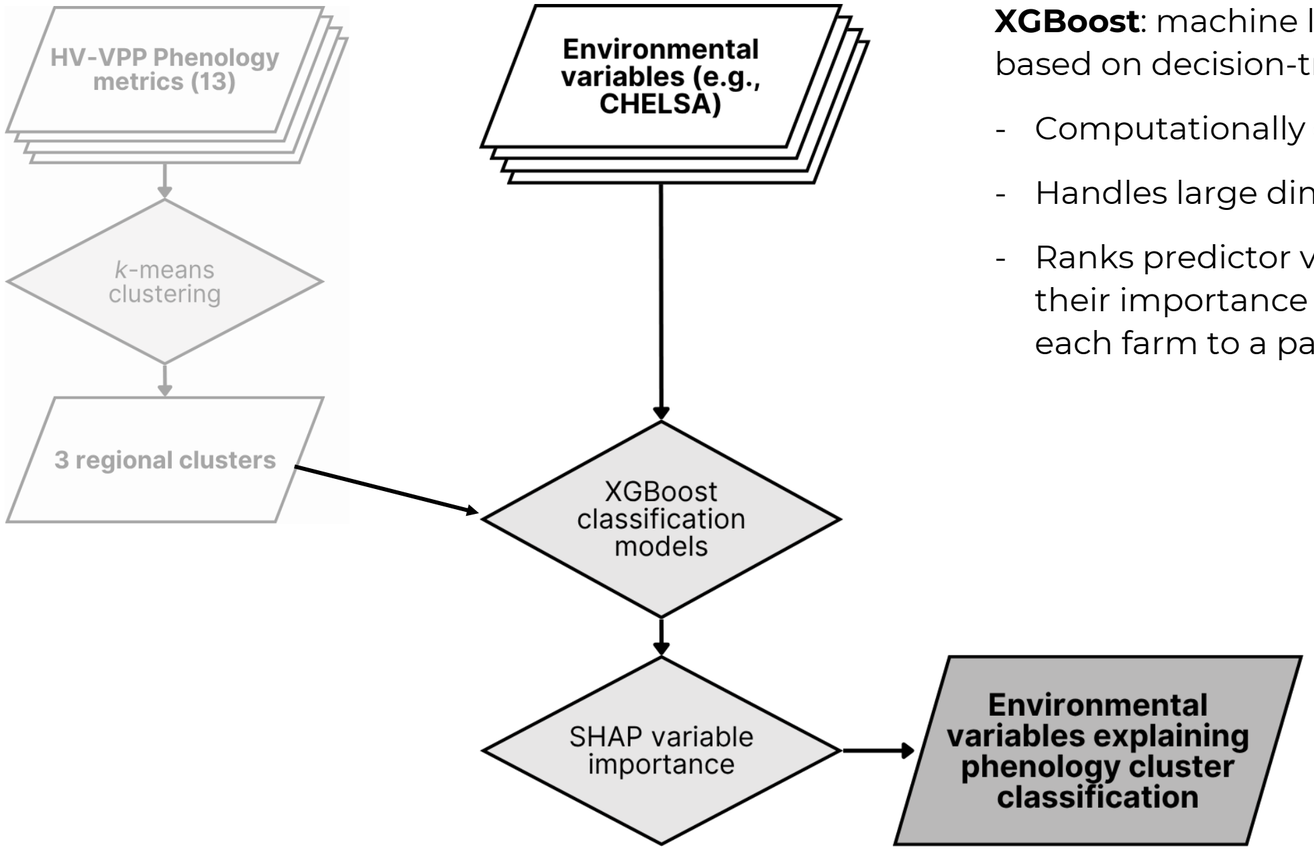
NORTH-CENTER

NORTH-LITTORAL



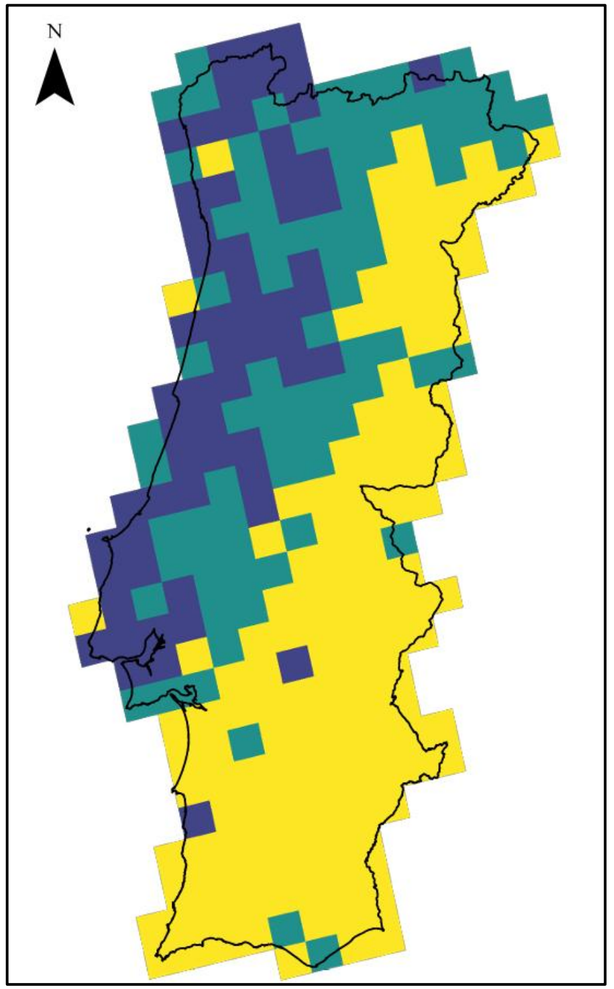
Unraveling phenology patterns

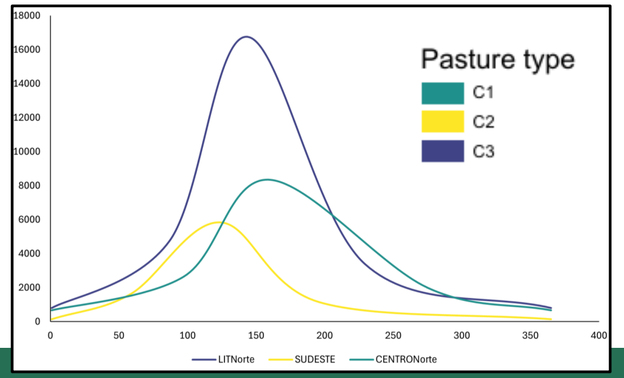
Machine learning model



XGBoost: machine learning algorithm based on decision-trees

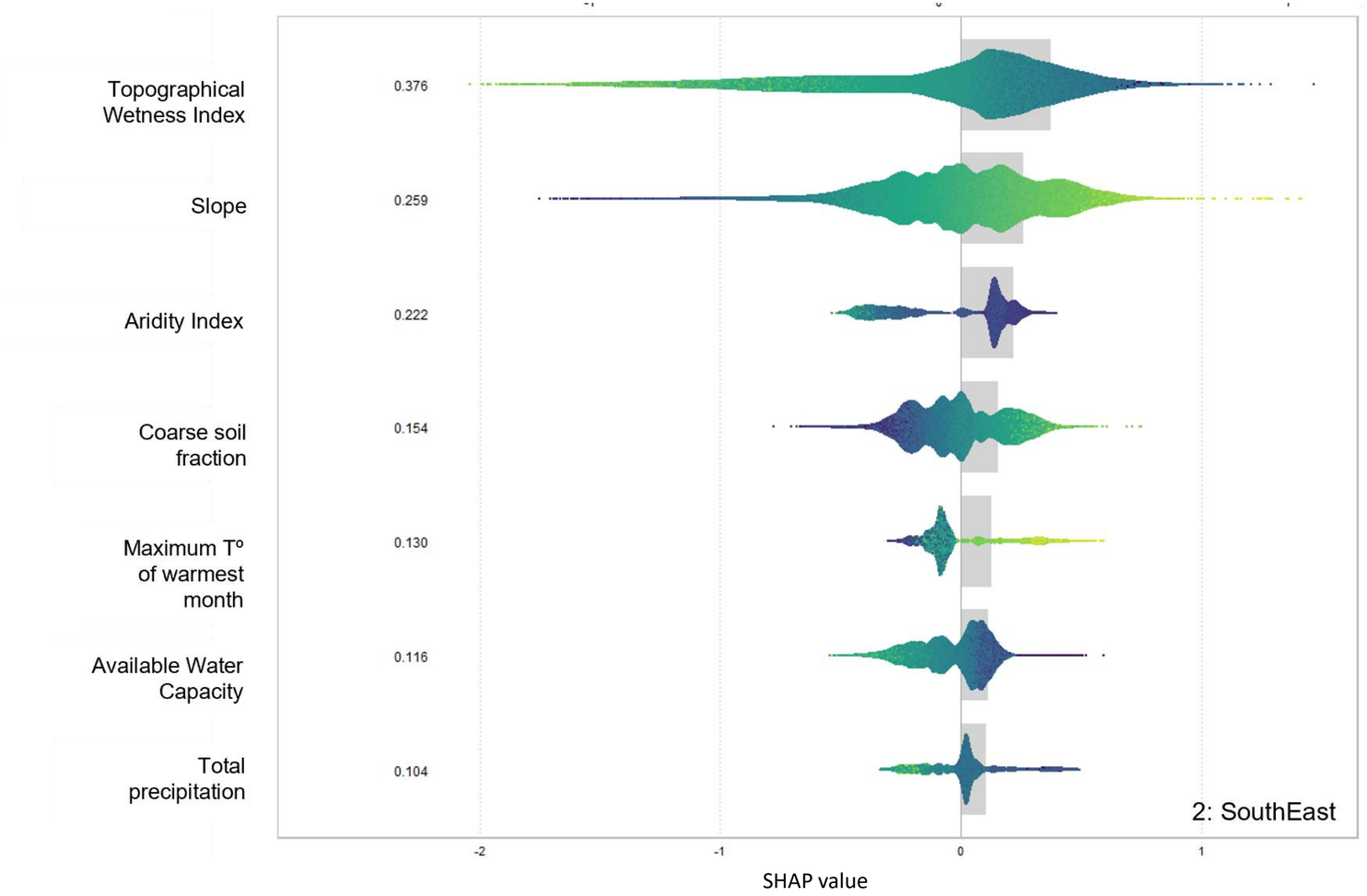
- Computationally efficient
- Handles large dimensionality in data
- Ranks predictor variables according to their importance to the classification of each farm to a pasture type

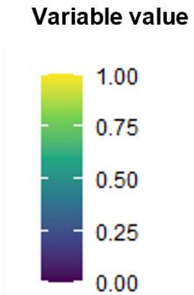


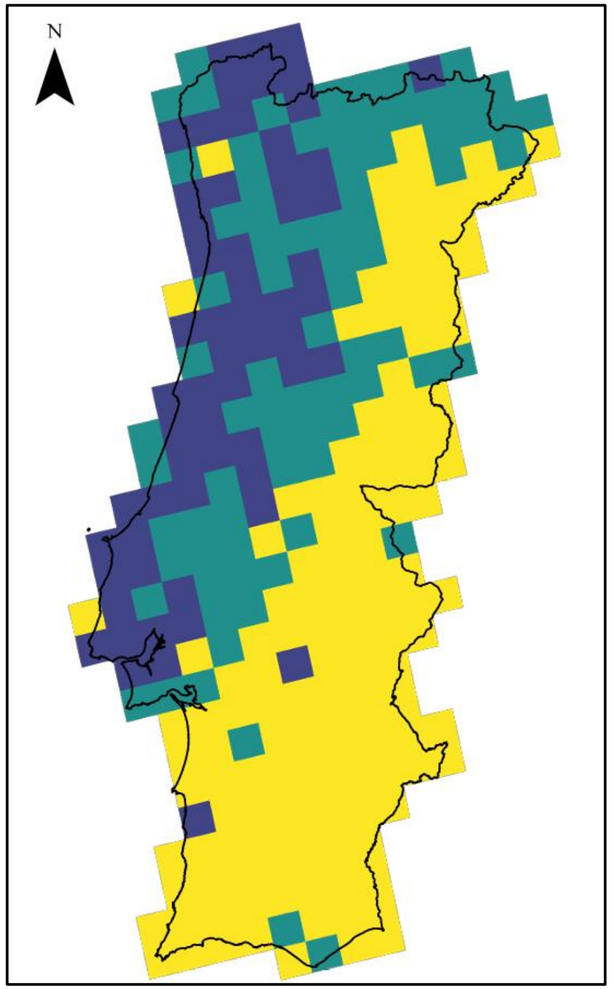


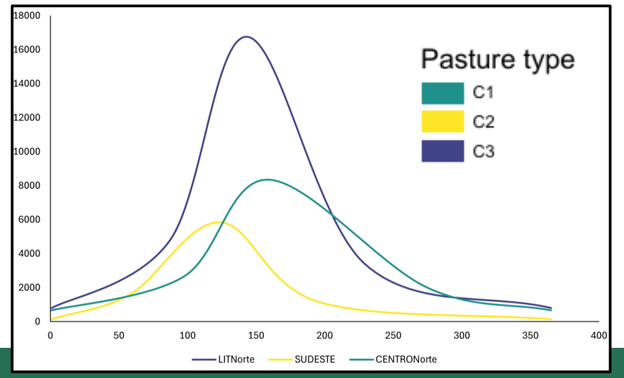
Unraveling phenology patterns

SOUTH-EAST PASTURES









Unraveling phenology patterns

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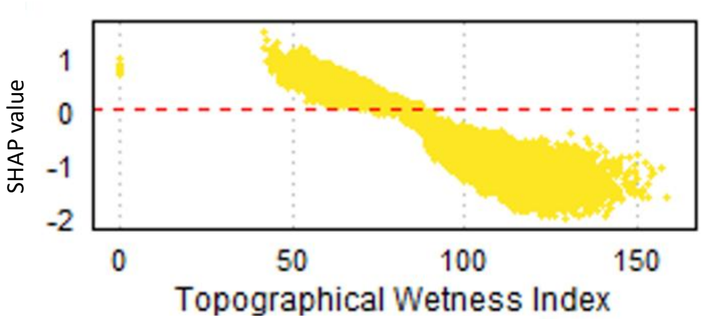
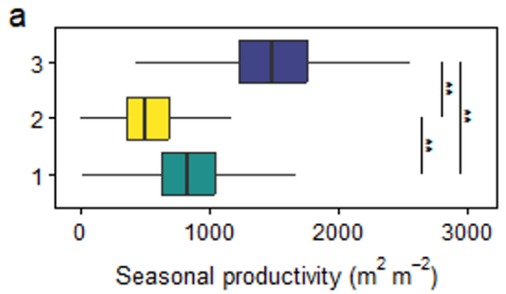
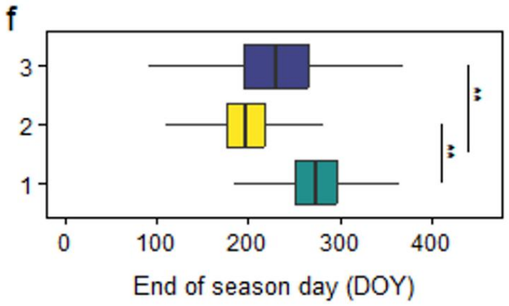
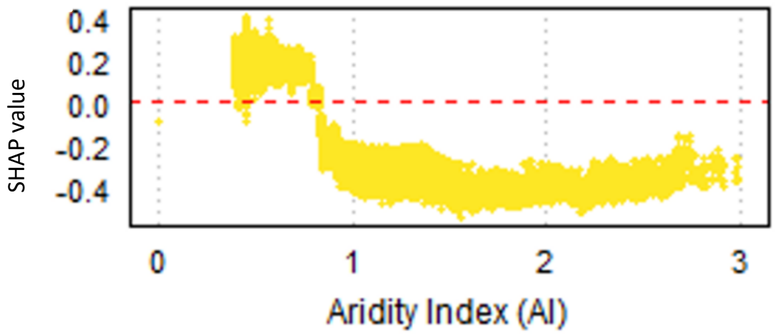
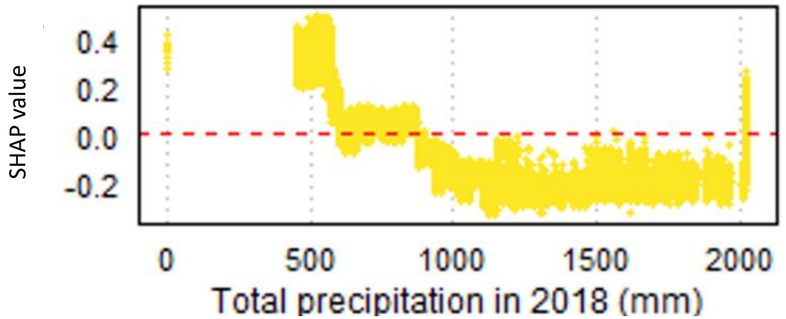
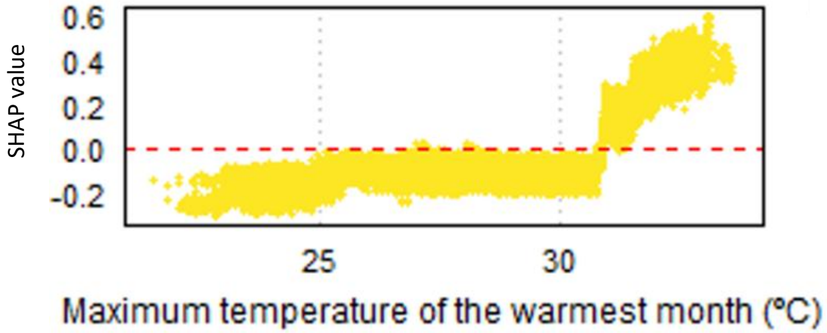


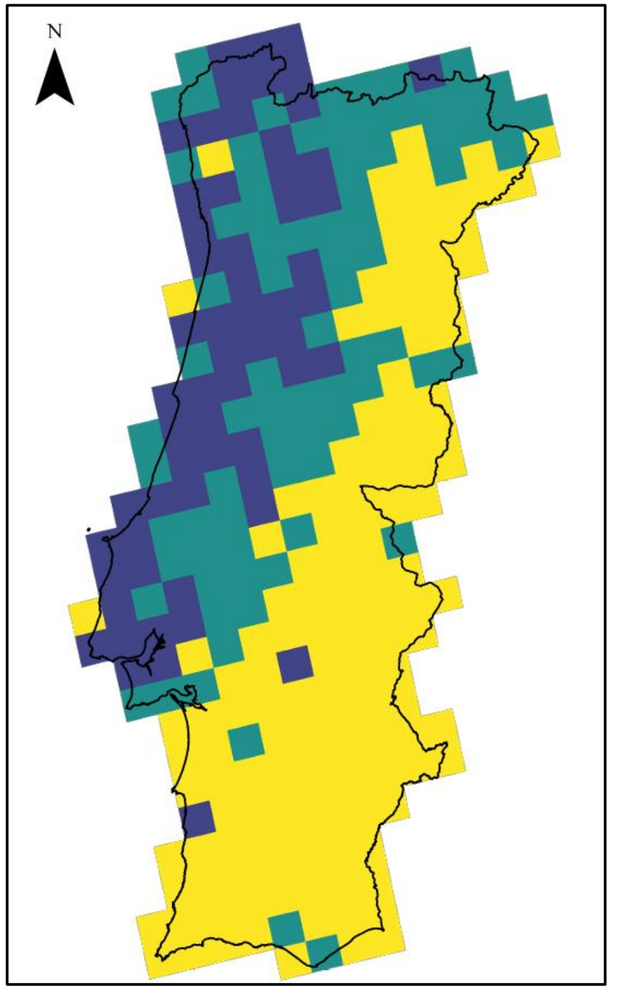


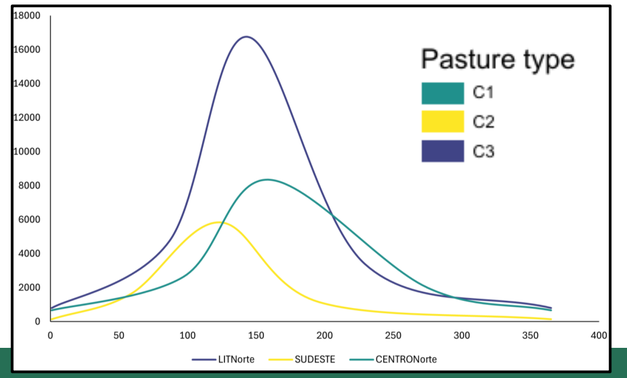










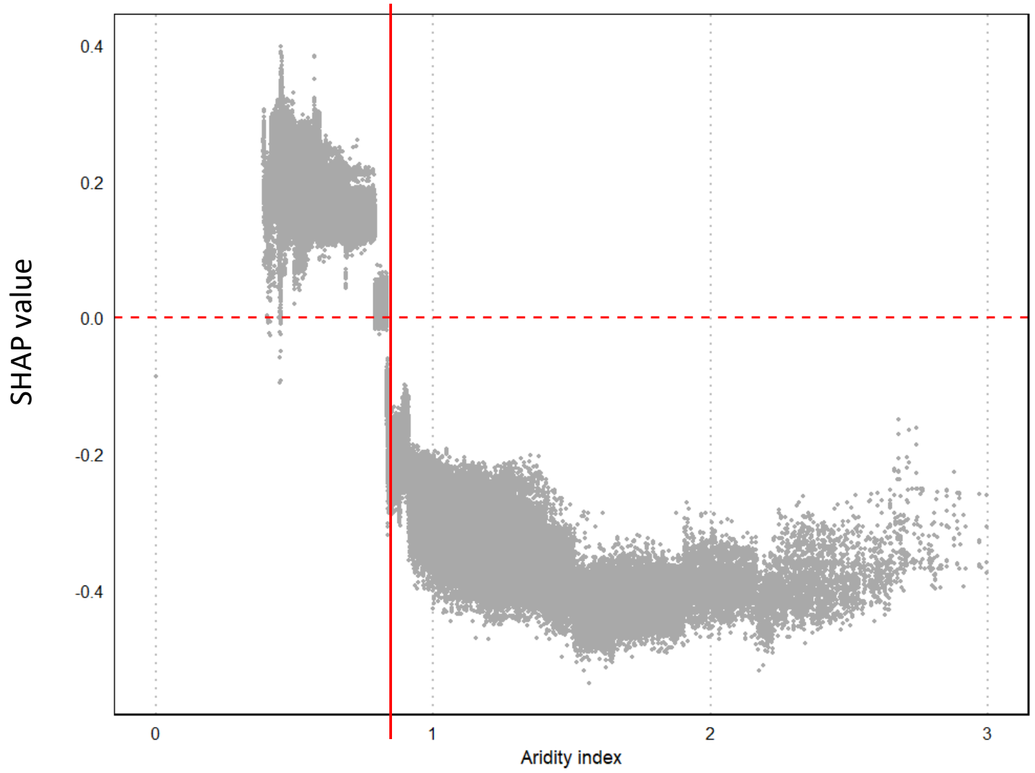


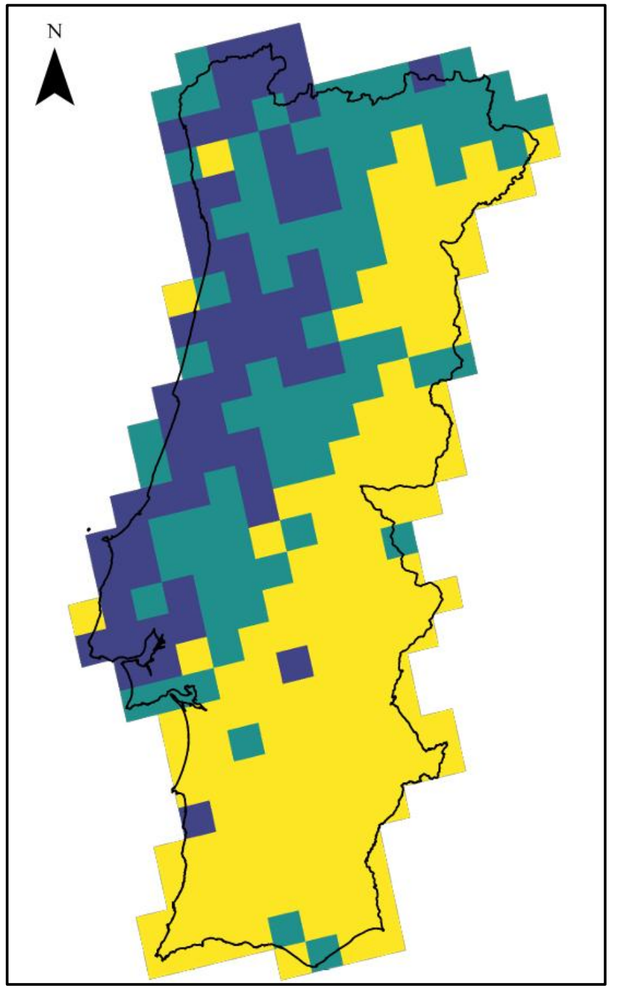
Unraveling phenology patterns

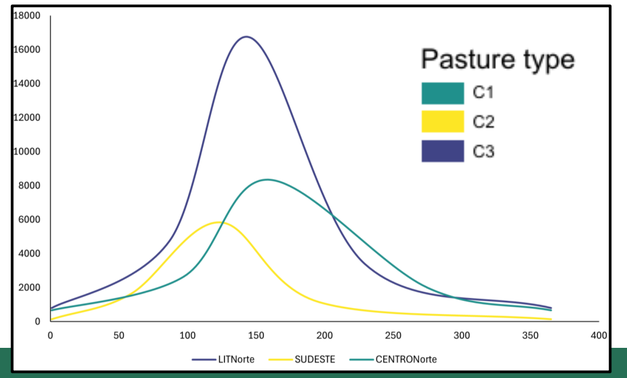
SOUTH-EAST PASTURES

- **Water** is the limiting factor in southern pastures (TWI, aridity index, precipitation), causing the **lower productivity**, **earlier end** to the season and shorter season overall
- Above an **aridity index of 0.8** we are no longer in these pastures, which suggests a **potential tipping point**

Aridity Index = ~0.8 (aridity = 1- AI = ~0.2)

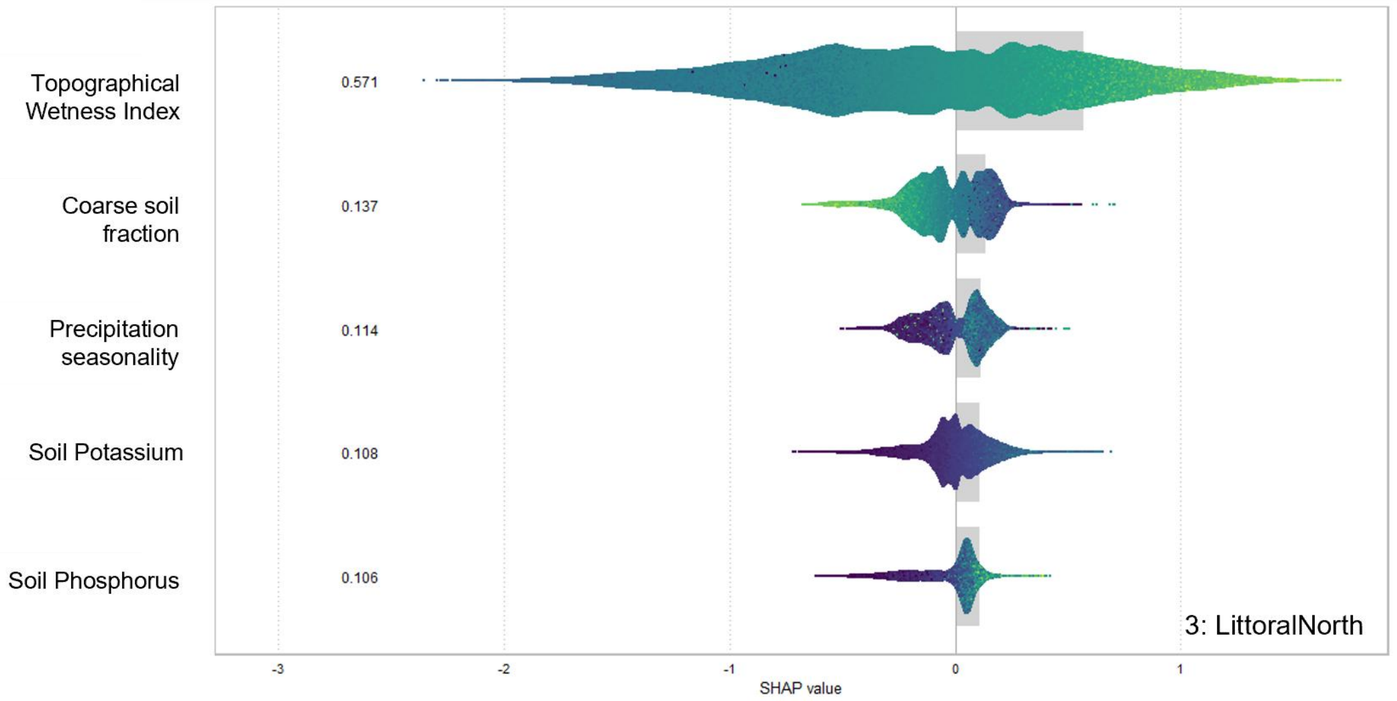


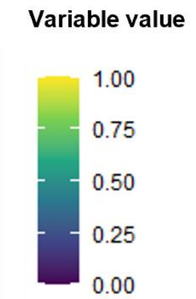


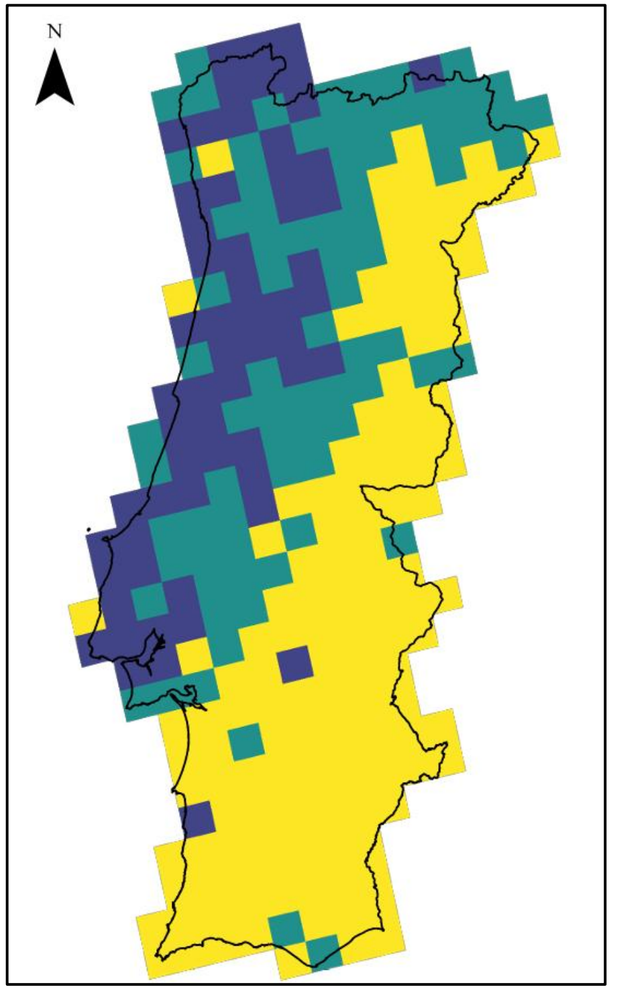


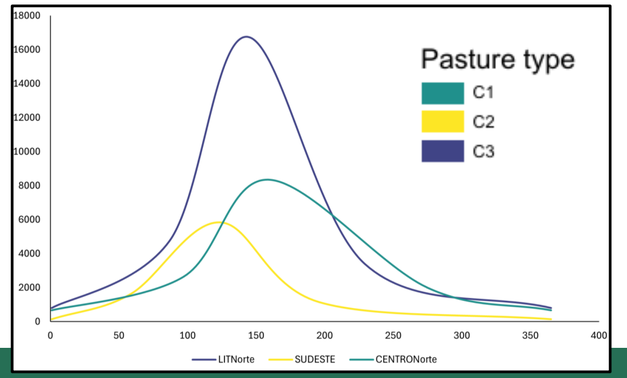
Unraveling phenology patterns

NORTH-LITTORAL PASTURES



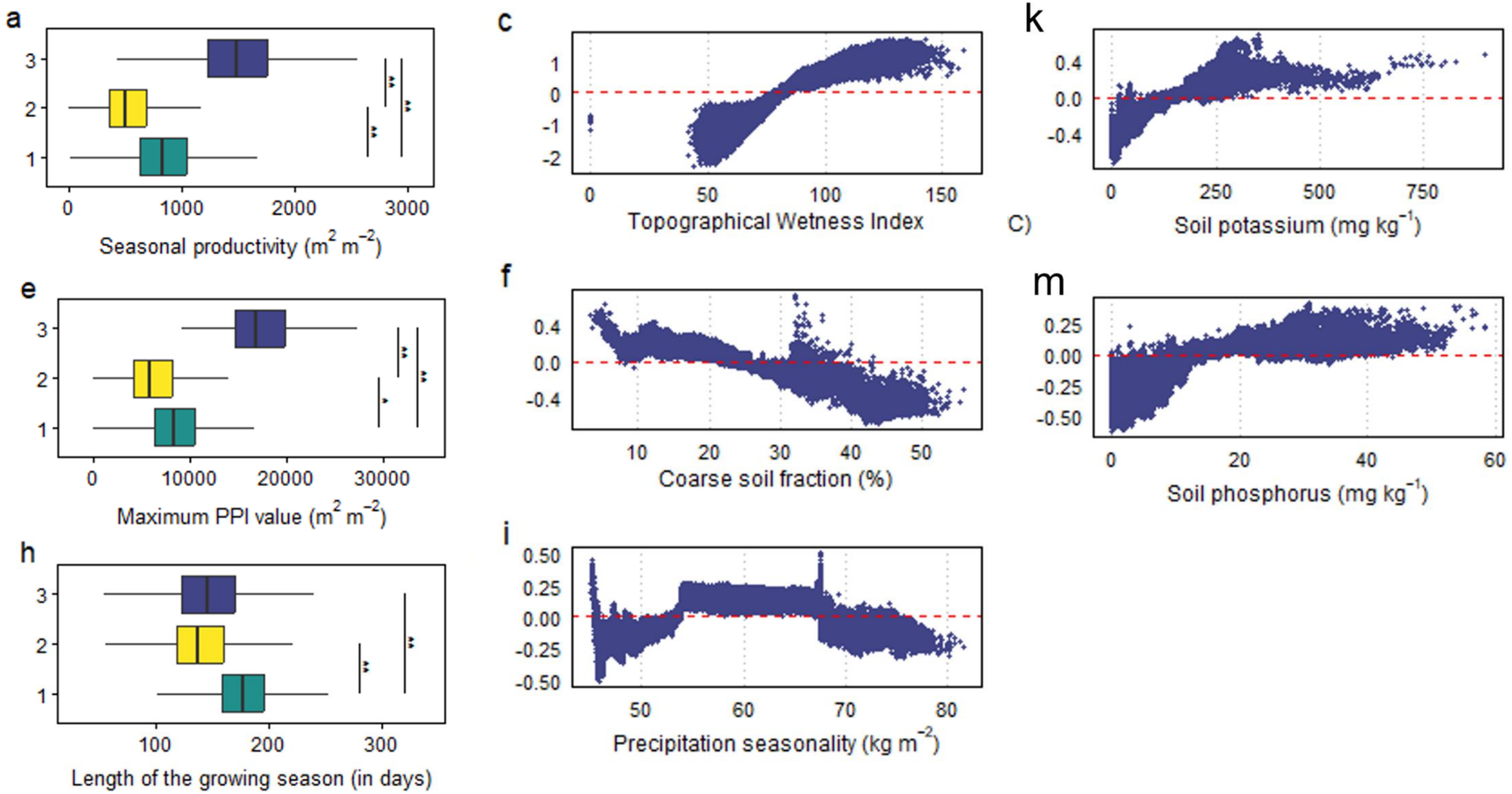


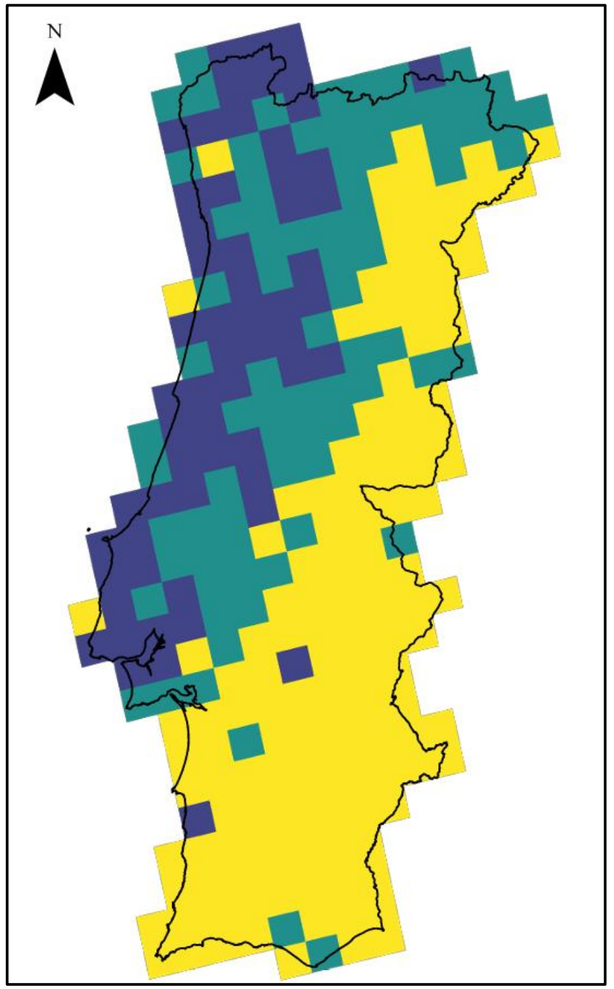


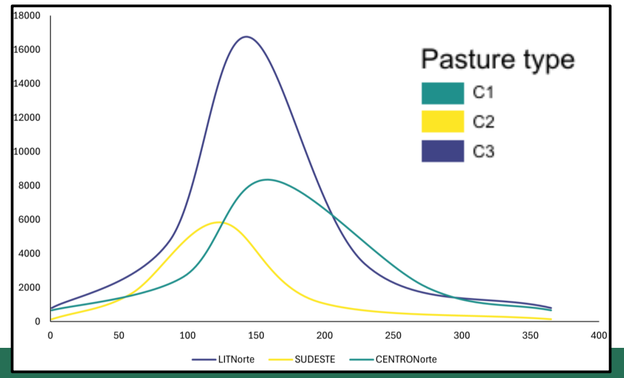


Unraveling phenology patterns

NORTH-LITTORAL PASTURES



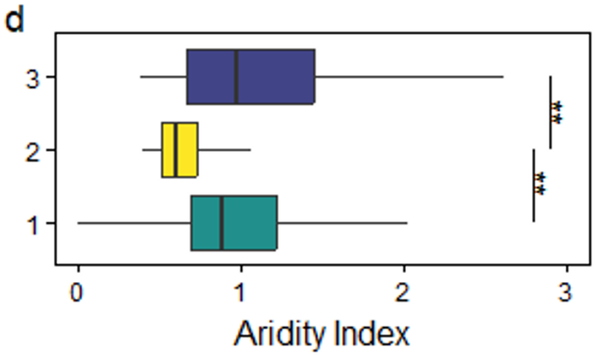


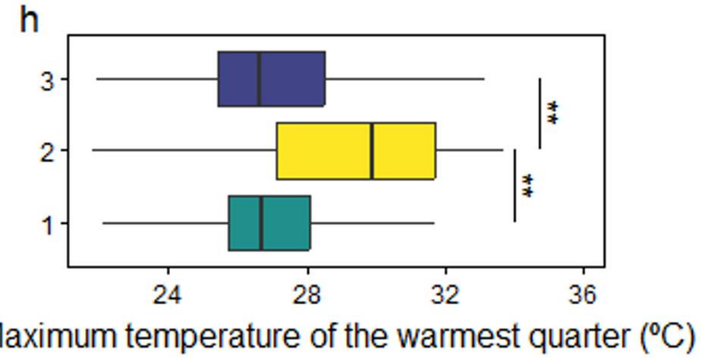


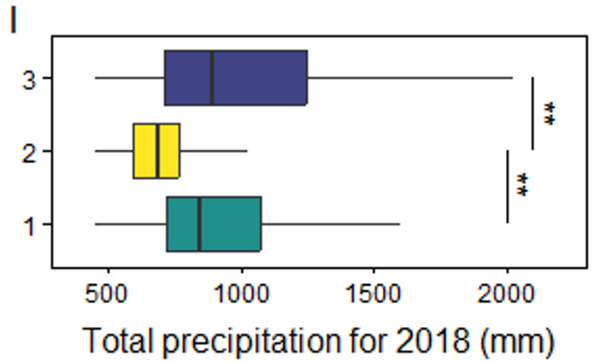
Unraveling phenology patterns

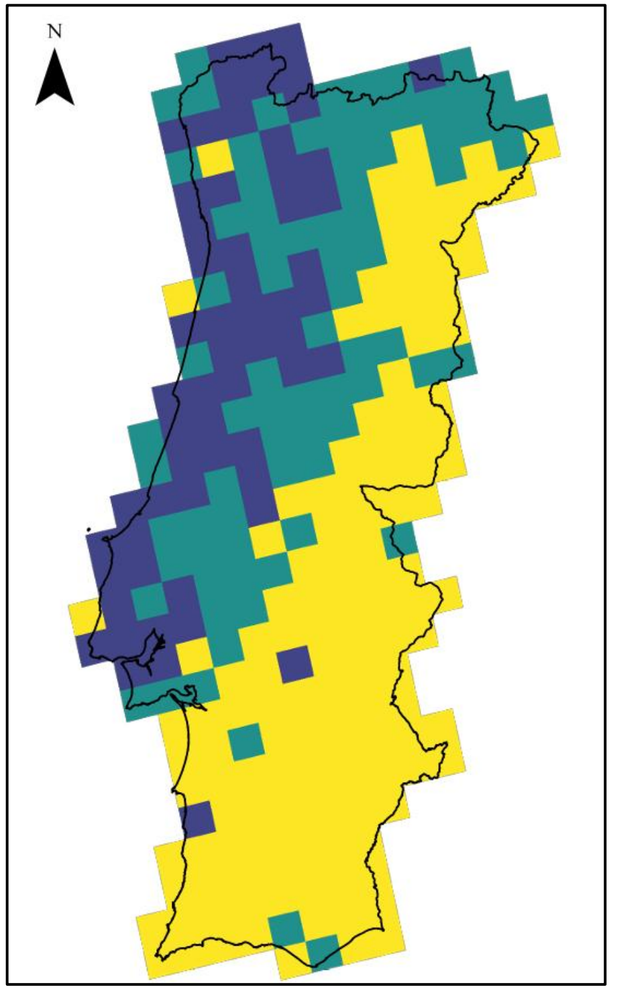
NORTH-LITTORAL PASTURES

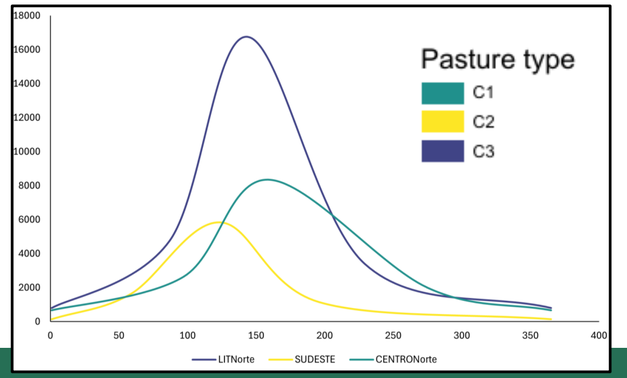
- **Lower water limitation** (higher TWI, lower aridity, lower summer temperatures and higher precipitation) could be driving the higher productivity





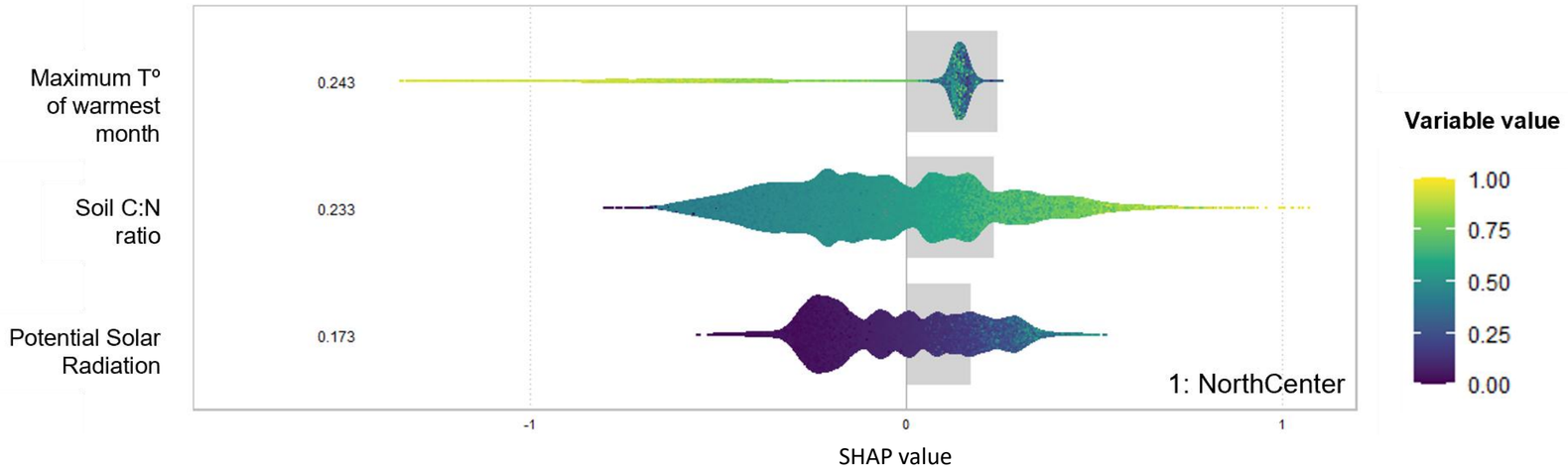


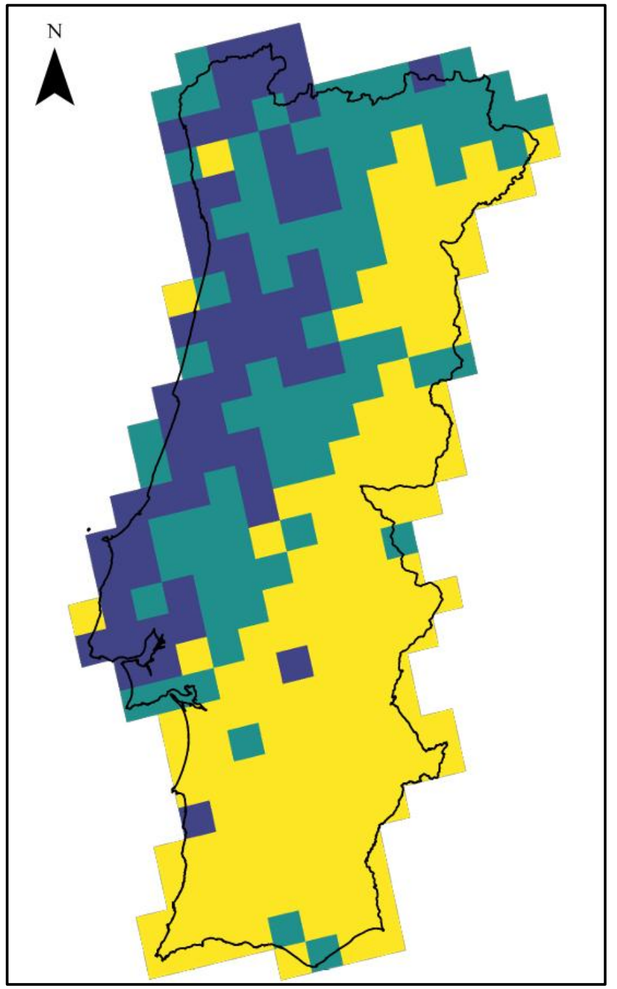


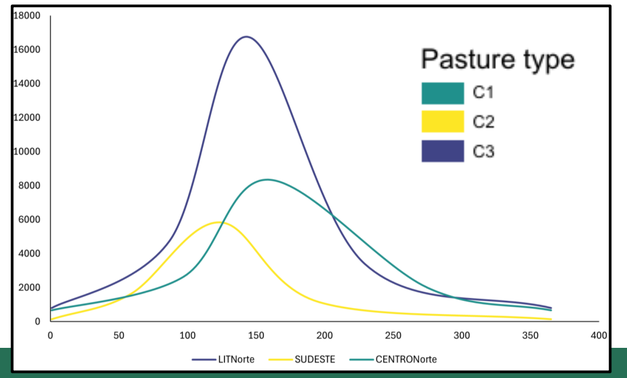


Unraveling phenology patterns

NORTH-CENTER PASTURES



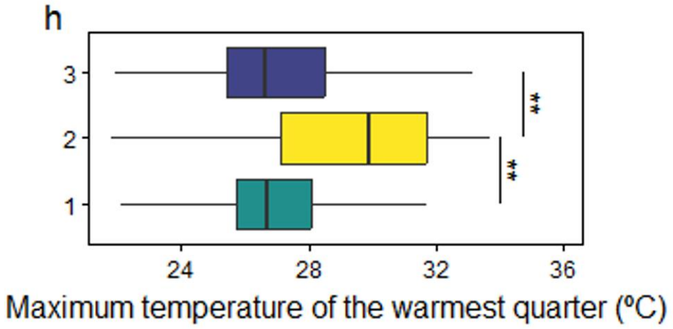


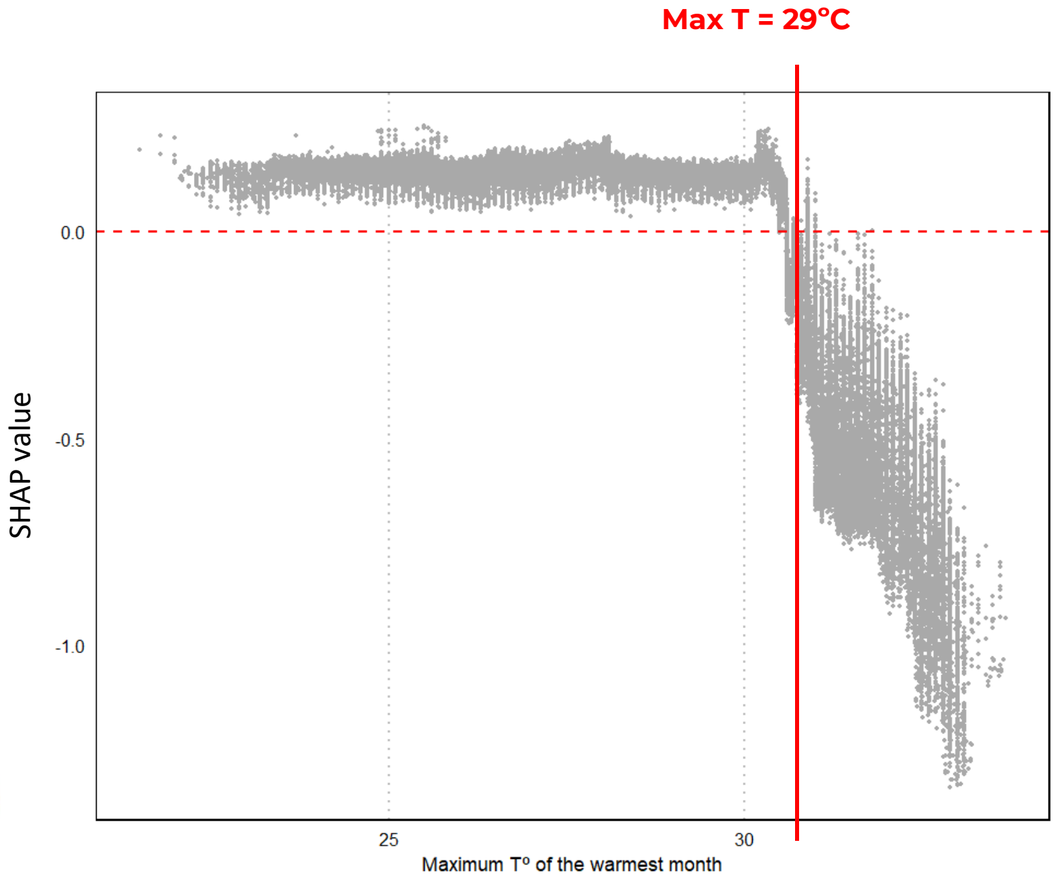


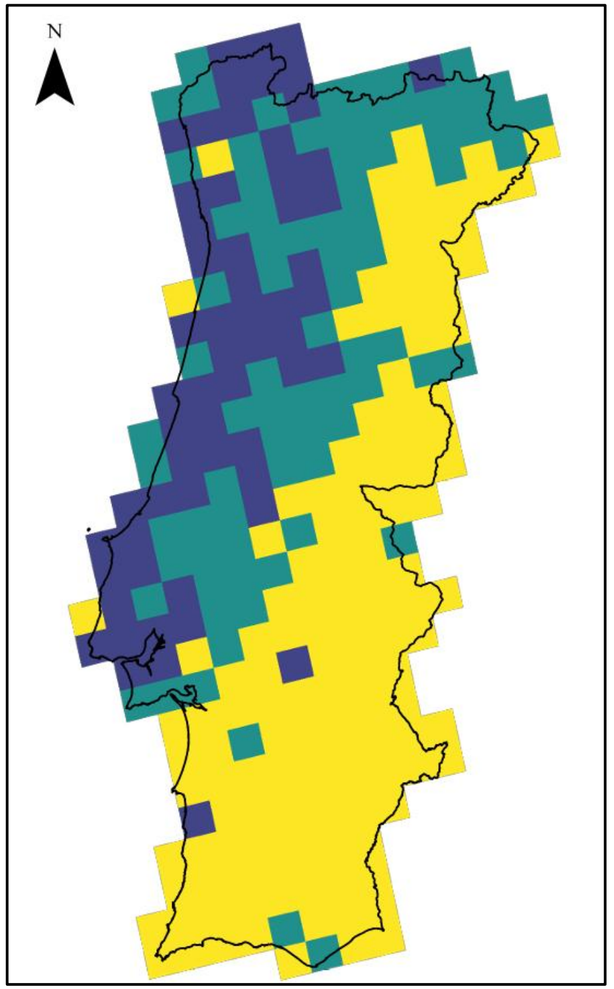
Unraveling phenology patterns

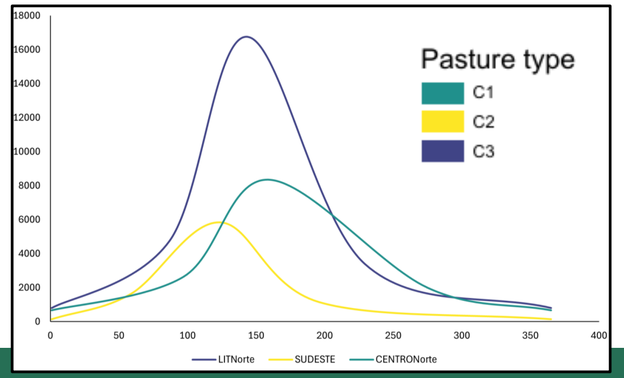
NORTH-CENTER PASTURES

- **Lower summer temperatures** should allow vegetation to maintain growth longer and senesce later
- Above a temperature maximum of 29°C in the summer





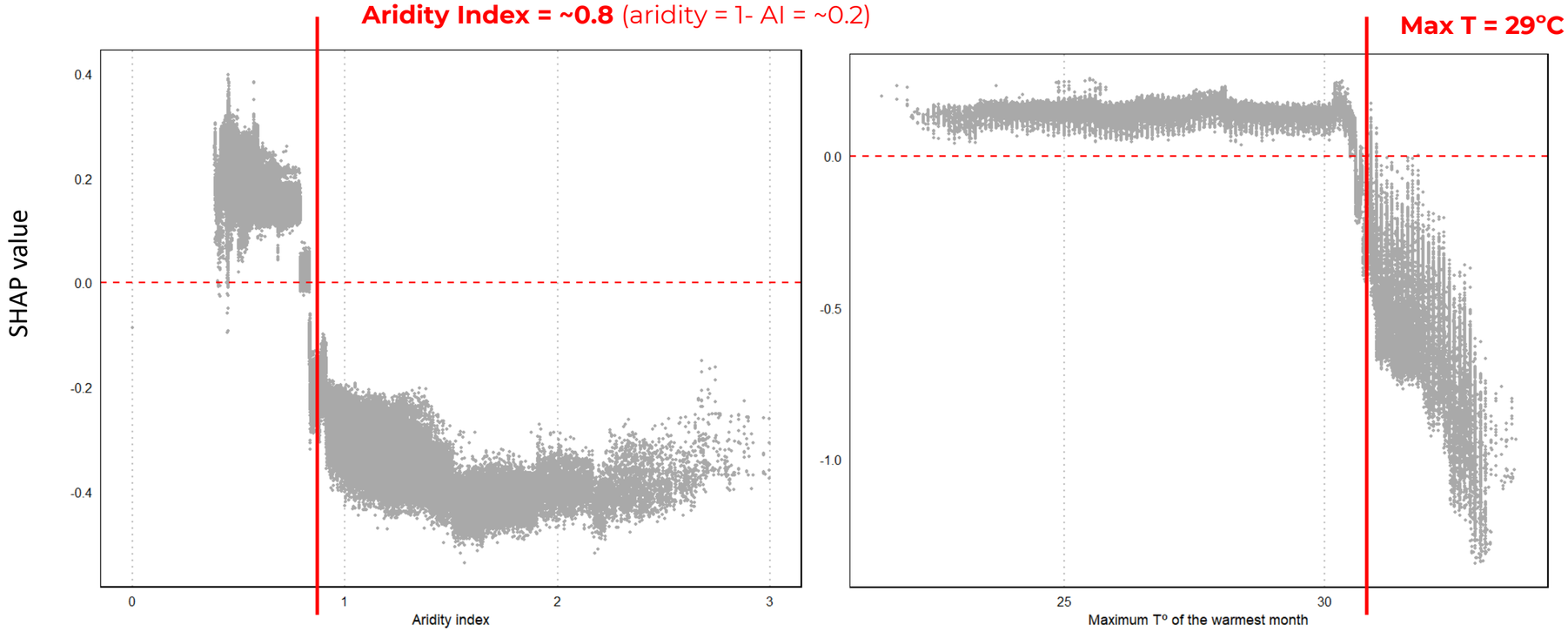




Implications under climate change

Future scenarios of temperature and aridity

Non-linear relationships between phenology groups and drivers suggest critical tipping points of aridity and temperature which could lead to changes in pasture functioning under climate change



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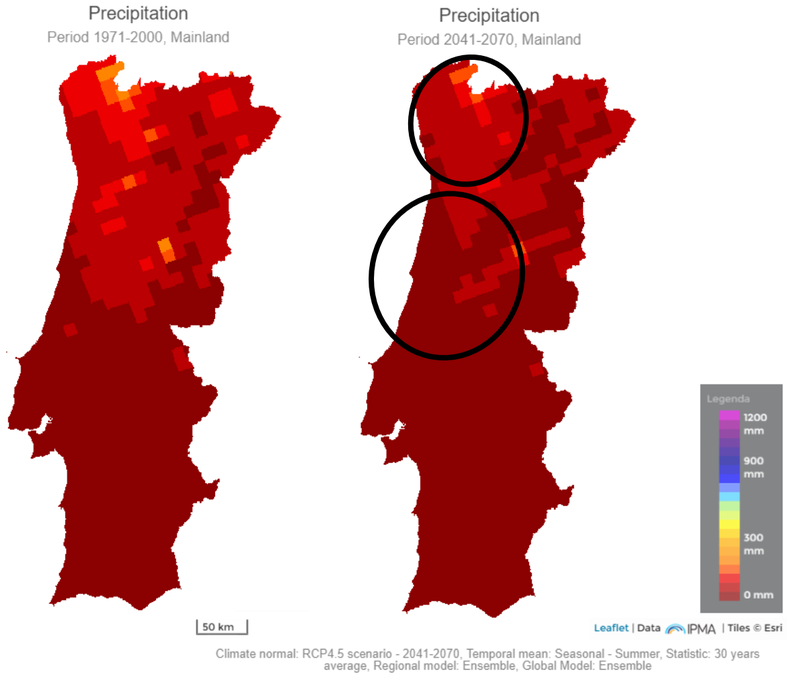
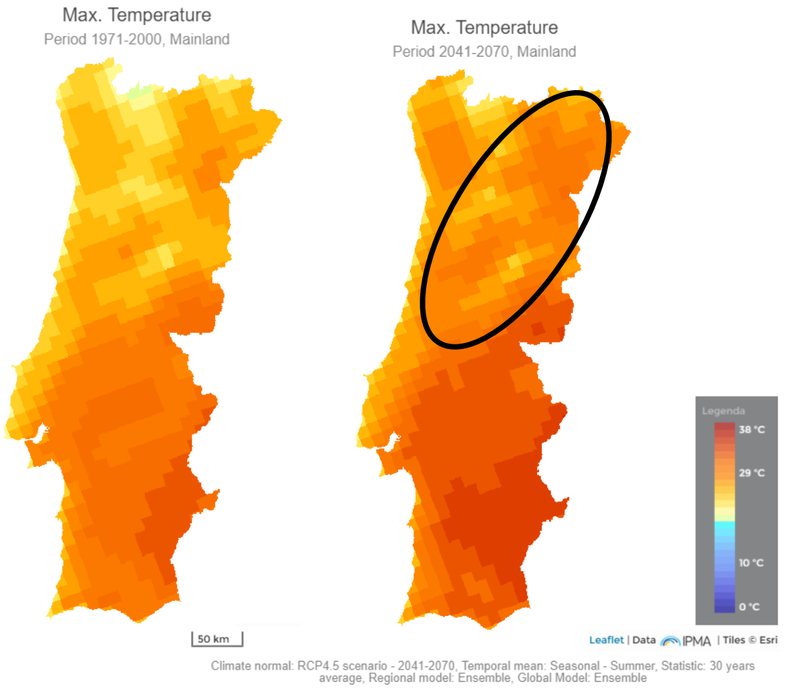


(RCP4.5 – 2041-2070)



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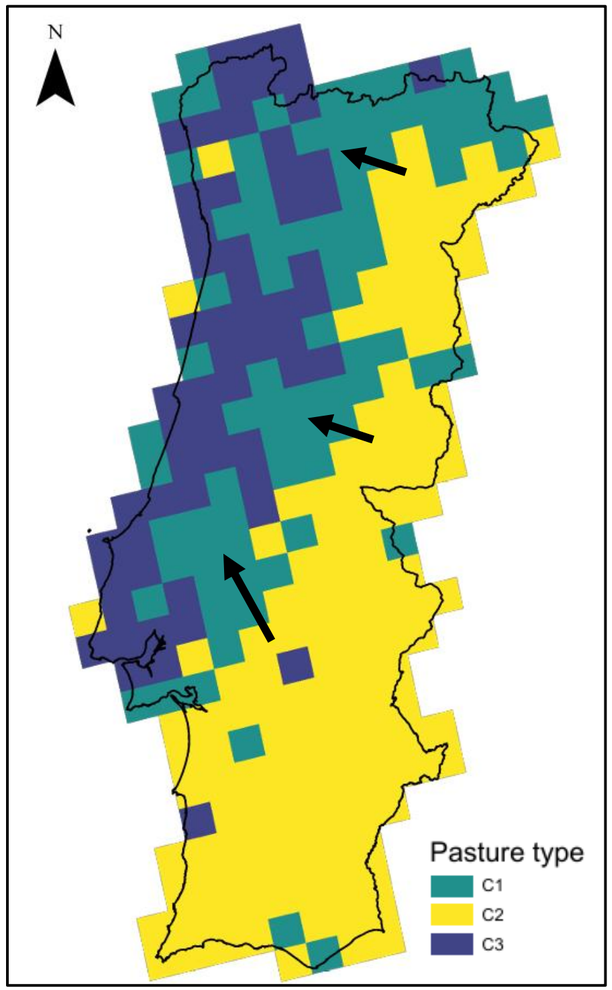
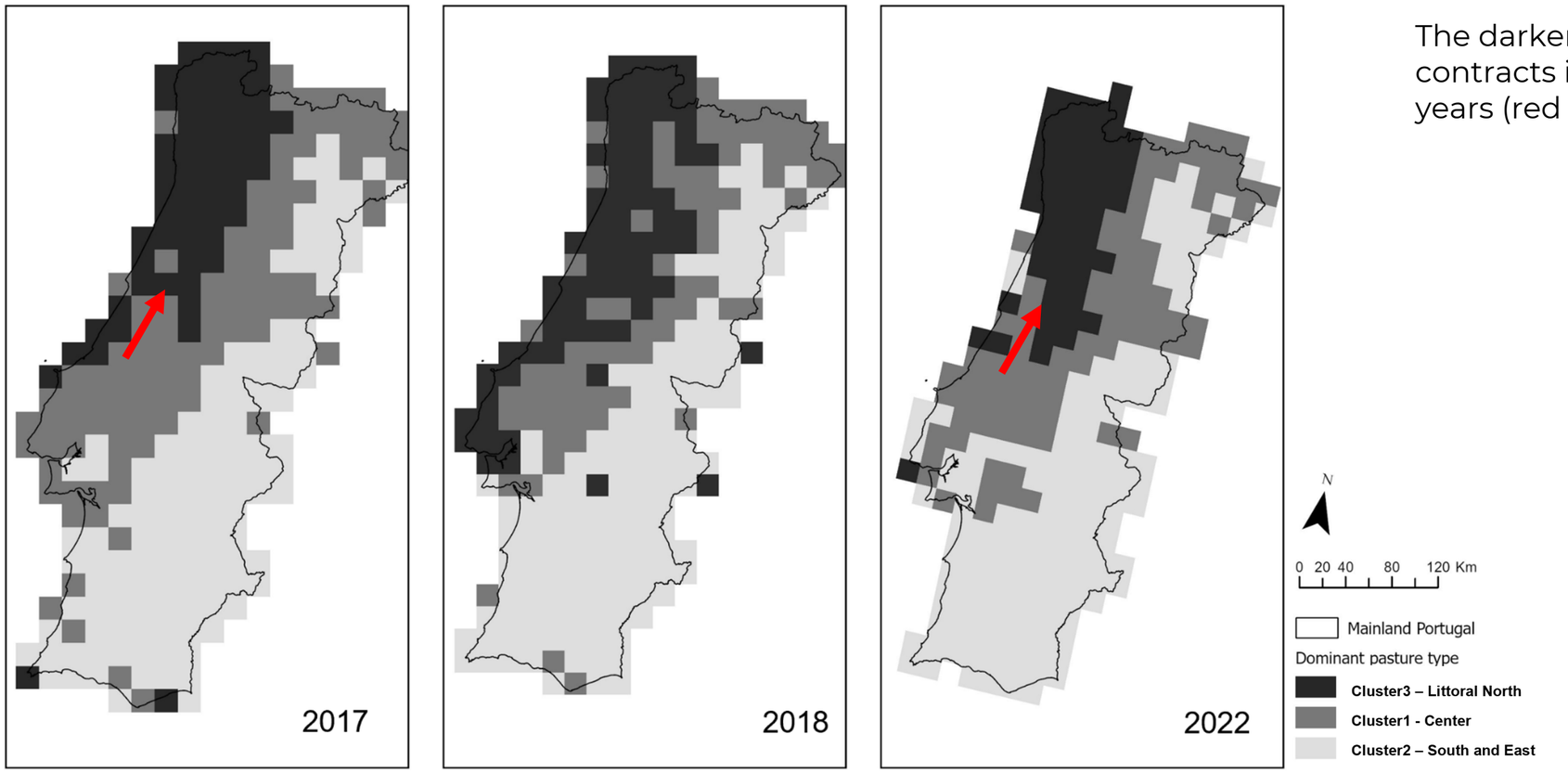


Implications under climate change

Repeating the analyses in **drier (2017)** and **warmer (2022)** years yielded similar reuslts



The darker pasture type contracts in drier and warmer years (red arrow)

Take-home messages

Grazed pastures were organized in three spatially continuous dominant phenological regions along the studied climatic gradient, in response to temperature and water availability filters:

- **Ecological filters** explained close to 70% of pasture types along the gradient, even under a wide range of unknown management conditions
- **One-size-fits-all agricultural policies** are not ideal
- Strategies need to be **tailored according to pasture types** and take into account the different vulnerabilities these are subjected to under climate change

THANK YOU

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