Characterizing woodlands productivity and phenology to measure ecosystem services in Mediterranean evergreen woodlands

Pedro Pinho
ppinho@fc.ul.pt

Alzira Ramos | Alice Nunes | Melanie Batista | Paula Matos | Cristina Branquinho
drylands in the Mediterranean basin
distribution of evergreen Mediterranean woodlands
Ongoing climate change affects ecosystems structure and functioning, which we assess with productivity and phenology metrics.

To what degree those effects depend on historical versus concurrent climate is poorly known, especially for Mediterranean woodlands.
Ongoing climate change affects ecosystems structure and functioning, which we assess with productivity and phenology metrics.

To what degree those effects depend on historical versus concurrent climate is poorly known, especially for Mediterranean woodlands.
Holm-oak woodlands: spatial gradient from dry sub-humid to semi-arid

- with Holm-oak

- more 750 mm
- less 450 mm

**Aridity Index (1950-2000)**
- hyper-arid (<0.05)
- arid (0.05 - 0.20)
- semi-arid (0.20 - 0.50)
- dry sub-humid (0.50 - 0.65)
- other (>0.65)
sites with holm-oak: homogenization required

- altitude (150-300m)
- inclination (less 5°)
- soil characteristics (acidic, sedimentary and metamorphic)
- no fires
sites for regional assessment (n=~6000)

- with standard conditions
- with Holm-oak

- more 750 mm
- less 450 mm

Aridity Index (1950-2000)
- hyper-arid (<0.05)
- arid (0.05 - 0.20)
- semi-arid (0.20 - 0.50)
- dry sub-humid (0.50 - 0.65)
- other (>0.65)
NDVI over time
NDVI from 2000 to 2011

? How to quantify phenology and productivity from NDVI cycles?
ecological interpretation of seasonal metrics

1. season start
2. season end
3. season length
4. growth rate
5. all ecosystem productivity
6. seasonal productivity
7. senescence rate
8. base level
ecological interpretation of seasonal metrics

1. season start
2. season end
3. season length
4. growth rate
5. all ecosystem productivity
6. seasonal productivity
7. senescence rate
8. base level
average phenology and productivity metrics

1. season start
2. season end
3. season length
4. growth rate
5. all ecosystem productivity
6. seasonal productivity
7. senescence rate
8. base level

- **Season Start**
  - September to November

- **Season End**
  - June to July

- **Season Length**
  - 240 to 320 days

- **Growth Rate**
  - Perennial

- **Seasonal Productivity**

- **Senescence Rate**

- **Base Level NDVI**

- **All Productivity**
are seasonal metrics related to climate?
- average of metrics for the last 10 years
model 1 (53.1%) exponential range 3560 m isotropic
model 2 (46.9%) spherical max. range 38 km min. range 30 km direction 120°

model 1 (50.8%) exponential range 3380 m isotropic
model 2 (49.2%) spherical max. range 49 km min. range 42 km direction 152°

model 1 (48.4%) exponential range 2600 m isotropic
model 2 (51.6%) spherical max. range 41 km min. range 28 km direction 127°
mapping seasonal metrics

**Season Start**

<table>
<thead>
<tr>
<th>Day of the Year</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>195.2 - 251</td>
<td>Exponential (53.6%)</td>
<td>Spherical (46.4%)</td>
</tr>
<tr>
<td>251.1 - 258</td>
<td>Exponential (53.6%)</td>
<td>Spherical (46.4%)</td>
</tr>
<tr>
<td>256.1 - 261</td>
<td>Exponential (53.6%)</td>
<td>Spherical (46.4%)</td>
</tr>
<tr>
<td>261.1 - 268</td>
<td>Exponential (53.6%)</td>
<td>Spherical (46.4%)</td>
</tr>
<tr>
<td>266.1 - 271</td>
<td>Exponential (53.6%)</td>
<td>Spherical (46.4%)</td>
</tr>
<tr>
<td>271.1 - 278</td>
<td>Exponential (53.6%)</td>
<td>Spherical (46.4%)</td>
</tr>
<tr>
<td>276.1 - 281</td>
<td>Exponential (53.6%)</td>
<td>Spherical (46.4%)</td>
</tr>
<tr>
<td>281.1 - 311</td>
<td>Exponential (53.6%)</td>
<td>Spherical (46.4%)</td>
</tr>
</tbody>
</table>

**Season End**

<table>
<thead>
<tr>
<th>Day of the Year</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>142 - 165</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>165.1 - 170</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>170.1 - 175</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>175.1 - 180</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>180.1 - 185</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>185.1 - 190</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>190.1 - 195</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>195.1 - 226.4</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
</tbody>
</table>

**Season Length**

<table>
<thead>
<tr>
<th>Number of Days</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>220.46 - 249</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>249.01 - 257</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>257.01 - 265</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>265.01 - 273</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>273.01 - 281</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>281.01 - 289</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>289.01 - 297</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
<tr>
<td>297.01 - 318.7</td>
<td>Exponential (51.6%)</td>
<td>Spherical (48.4%)</td>
</tr>
</tbody>
</table>

**Model Details**

- **Model 1**
  - Exponential
  - Range: 2390 m
  - Isotropic
  - Direction: 100°

- **Model 2**
  - Spherical
  - Max. Range: 45 km
  - Min. Range: 35 km

- **Model 1**
  - Exponential
  - Range: 3020 m
  - Isotropic
  - Direction: 156°

- **Model 2**
  - Spherical
  - Max. Range: 48 km
  - Min. Range: 42 km

- **Model 1**
  - Exponential
  - Range: 2500 m
  - Isotropic
  - Direction: 156°

- **Model 2**
  - Spherical
  - Max. Range: 38 km
  - Min. Range: 30 km

Direction: 127°
mapping seasonal metrics

Season Start

- **Model 1** (53.6%)
  - Exponential
  - Range: 2390 m
  - Isotropic
- **Model 2** (46.4%)
  - Spherical
  - Max. range: 45 km
  - Min. range: 35 km
  - Direction: 100°

Season End

- **Model 1** (45.2%)
  - Exponential
  - Range: 3020 m
  - Isotropic
- **Model 2** (54.8%)
  - Spherical
  - Max. range: 48 km
  - Min. range: 42 km
  - Direction: 156°

Season End

- **Model 1** (52.5%)
  - Exponential
  - Range: 2500 m
  - Isotropic
- **Model 2** (47.5%)
  - Spherical
  - Max. range: 38 km
  - Min. range: 30 km
  - Direction: 156°
? Are productivity and phenology metrics better related to concurrent (10 years average) or long-term (normal, 30 years) precipitation?

? is there a critical threshold, i.e., a value above or below which the rate of change on ecosystem is different?
more significant relations with long-term precipitation

<table>
<thead>
<tr>
<th>Seasonal metrics</th>
<th>long term precipitation</th>
<th>concurrent precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenology metrics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season-start</td>
<td>-0.32***</td>
<td>-0.19***</td>
</tr>
<tr>
<td>Season-end</td>
<td>0.65***</td>
<td>0.40***</td>
</tr>
<tr>
<td>Season-length</td>
<td>0.60***</td>
<td>0.49***</td>
</tr>
<tr>
<td>Mid-season time</td>
<td>0.03 ns</td>
<td>0.01 ns</td>
</tr>
<tr>
<td>Phenology metrics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Productivity metrics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate-growth</td>
<td>-0.30***</td>
<td>-0.13***</td>
</tr>
<tr>
<td>Rate-senescence</td>
<td>-0.21***</td>
<td>-0.08***</td>
</tr>
<tr>
<td>Amount of evergreen vegetation</td>
<td>0.59***</td>
<td>0.30***</td>
</tr>
<tr>
<td>Annual-Amplitude</td>
<td>-0.37***</td>
<td>-0.23***</td>
</tr>
<tr>
<td>Amount of evergreen vegetation</td>
<td>0.20***</td>
<td>0.05***</td>
</tr>
<tr>
<td>Overall-productivity</td>
<td>0.63***</td>
<td>0.30***</td>
</tr>
<tr>
<td>Annual-productivity</td>
<td>-0.15***</td>
<td>-0.07*</td>
</tr>
<tr>
<td>Seasonal metrics</td>
<td>long term precipitation</td>
<td>concurrent precipitation</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td><strong>Phenology metrics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season start</td>
<td>0.22***</td>
<td>0.10***</td>
</tr>
<tr>
<td>Season-end</td>
<td>0.65***</td>
<td>0.40***</td>
</tr>
<tr>
<td>Season-length</td>
<td>0.60***</td>
<td>0.49***</td>
</tr>
<tr>
<td>Mid-season time</td>
<td>0.03ns</td>
<td>0.01ns</td>
</tr>
<tr>
<td><strong>Productivity metrics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate-growth</td>
<td>-0.30***</td>
<td>-0.13***</td>
</tr>
<tr>
<td>Rate-senescence</td>
<td>-0.21***</td>
<td>-0.08***</td>
</tr>
<tr>
<td>Amount of evergreen vegetation</td>
<td>0.59***</td>
<td>0.30***</td>
</tr>
<tr>
<td>Annual-Amplitude</td>
<td>-0.57***</td>
<td>-0.23***</td>
</tr>
<tr>
<td>Amount of evergreen vegetation</td>
<td>0.20***</td>
<td>0.05***</td>
</tr>
<tr>
<td>Overall-productivity</td>
<td>0.63***</td>
<td>0.30***</td>
</tr>
<tr>
<td>Annual-productivity</td>
<td>-0.15***</td>
<td>-0.07*</td>
</tr>
</tbody>
</table>
relation between phenology and precipitation

- Season end
  \[ \rho = 0.65 \]

- Season length
  \[ \rho = 0.59 \]
relation between productivity and precipitation

all ecosystem productivity
\( \rho = 0.64 \)

perennial vegetation
\( \rho = 0.58 \)
holm-oak woodlands response to climate

production of biomass by annual plants

\( \text{g m}^{-2} \)

- 35 - 66
- 67 - 85
- 86 - 100
- 110 - 120
- 130 - 140
- 150 - 160
- 170 - 180
- 190 - 200
- 210 - 230
- 240 - 310

![Map of Portugal and Spain showing the production of biomass by annual plants](image)

\[ p = 0.0019 \]
\[ R^2 = 0.5382 \]

Graph showing the relationship between annual NDVI increment (amplitude) and (log) production of biomass by annual plants (g m\(^{-2}\)) [2014]

- Annual NDVI increment (amplitude) [average 2002-2012]
- (log) production of biomass by annual plants (g m\(^{-2}\)) [2014]

Histogram showing the number of observations of annual biomass production (classes) (g m\(^{-2}\))

- Annual biomass production (classes) (g m\(^{-2}\))
- More
The influence on ecosystem productivity and phenology of long-term climate prevailed over concurrent one.

This can be due to a legacy effect, caused e.g. by seed bank and soil quality.

There will be a strong influence of historical legacies in the response of these ecosystems to the ongoing climate change. This, together with the observed non-linear response, must be taken into account in forecasting scenarios.
publications, acknowledgments & participants


Alice Nunes, Cristina Branquinho, Paula Matos, Pedro Pinho

Amílcar Soares, Alzira Ramos, Maria João Pereira, Pedro Pinho