Font Rovira, Elisabet; Soler Membrives, Anna tut. Temperature and irradiance effects on Cymodocea nodosa (Ucria) Aschers. growth, biomass, production and reproduction across its distribution range. 2024. 1 pag. (Grau en Biologia Ambiental)

Bachelor's Degree Final Project - ApS I BSc in Environmental Biology (2023-2024)

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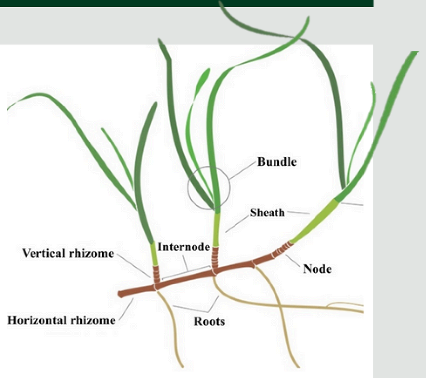
Temperature and irradiance effects on *Cymodocea nodosa* (Ucria) Aschers. growth, biomass, production and reproduction across its distribution range.

Introduction and Objectives

Cymodocea nodosa is a species of seagrass distributed in the Mediterranean Sea and the eastern coast of the Atlantic Ocean. The largest extensions are found in the Canary Islands, reflecting the species' **tropical affinity.**



It is a fast growing seagrass that predominantly relies on **vegetative reproduction,** but it can also **reproduce sexually.**

C.nodosa meadows, like other seagrasses, are a key structural habitat considered among the **world's most valuable ecosystem**. However, high human pressure along marine coasts has led to observed **stress and functional decline** in meadows.

1 **Law protection** OSPAR and Bern convention + 2 **Restoration programs** → Understand the functioning of these meadows throughout their entire distribution range

OBJECTIVES: Determine changes in growth, production, biomass and reproduction of *C.nodosa* across its distributional range. The primary focus is on studying the role of temperature and irradiance, considering latitude and depth as proxies.

These results will be used by *The Mediterranean Institute for Advanced Studies*, to **improve the existing restoration techniques** within the framework of the EU project:

Marine forest coastal restoration underwater gardening socio-ecological plan

HORIZON-MISS-2021-OCEAN-02-01

Methodology

Database: 50 previous published articles + unpublished data and observations provided by N.Marbà on *Cymodocea nodosa* meadow structure, growth, production and reproduction across the species distribution range.

206 sites sampled, 77 different meadows

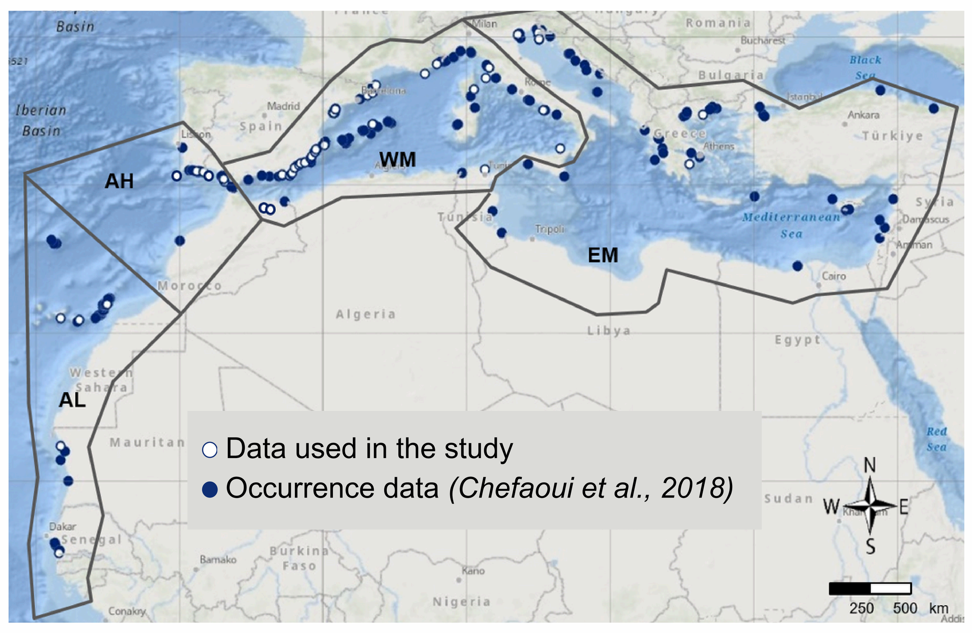


Figure 1. Occurrence data of *C.nodosa* at scale 1:25,000,000 and genetic regions identified by *Alberto et al. (2008)*: low-latitude Atlantic (AL), high-latitude Atlantic (AH), Western Mediterranean (WM) and Eastern Mediterranean (EM).

Data analysis:

- Software: R Studio, GraphPad Prism, ArcGIS Pro
- Statistical tests: Significance $p < 0.05$
  - Kolmogorov-Smirnov Test ⟶ Data distribution
  - ANOVA, Pairwise Wilcox Tests ⟶ Comparative analysis
  - Pearson Correlation Tests ⟶ Linear regression analyses
  - Principal Component Analysis (PCA)

*Extinction coefficient of water (exponential) ⟶ logarithmic conversion applied to water depth.

Explanatory variables

- Water depth: 0.4 - 15m
- Latitude (ºNorth): 13.69 - 45.50ºN
- Sea Surface Temperature (SST, ºC) → Copernicus facility Global Ocean OSTIA SST (*Good et al., 2020*) 1982-2023
  - Mean annual
  - Summer mean (June to September)
  - Summer maximum
  - Winter minimum
  - Coefficient of variation (CV: sd/mean)

Response variables ⟶

1. Minimum winter value
2. Maximum summer value
3. Temporal change (%)

Biomass & Structure

- **d:** Density (shoots m^{-2})
- **sb:** Shoot biomass (gDW $shoot^{-1}$)
- **tb:** Total biomass (gDW m^{-2})
- **ab:** Aboveground biomass (gDW m^{-2})
- **bb:** Belowground biomass (gDW m^{-2})
- **rhb:** Rhizome biomass (gDW m^{-2})
- **rob:** Root biomass (gDW m^{-2})
- **AB:** Above-to-belowground biomass ratio
- **lel:** Mean leaf length (mm)

Production

- **ap:** Aboveground productivity (gDW m^{-2} $year^{-1}$)
- **rhp:** Rhizome productivity (gDW m^{-2} $year^{-1}$)
- **hre:** Horizontal rhizome elongation rate (cm $apex^{-1}$ $year^{-1}$)
- **rhtr:** Rhizome turnover rate (P/B $year^{-1}$)
- **ltr:** Leaf turnover rate (P/B $year^{-1}$)
- **lp:** Annual leaf production (leaves $shoot^{-1}$ $year^{-1}$)

Reproduction

- **fld:** Flower density (nº of flowers m^{-2})
- **%fl:** Percentage of flowering shoots
- **frd:** Fruit density (nº of fruits m^{-2})
- **% fr:** Percentage of fruiting shoots
- **s:** Seed density (seeds m^{-2})
- **%g:** Germination rate (seed density/seeds started)

Results

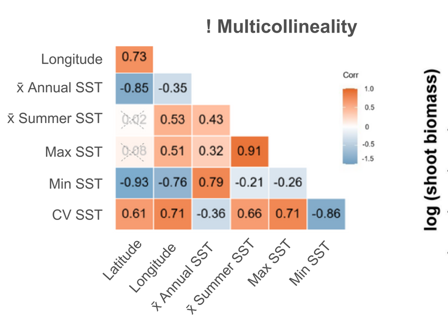


Figure 2. Correlation matrix using Pearson correlation coefficient (r) between the different explanatory variables. Non-significant coefficient (p value > 0.05) are crossed out.

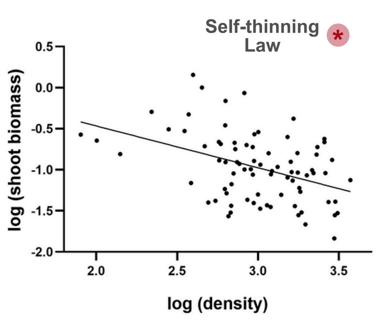


Figure 3. Shoot biomass as a function of shoot density. Solid lines indicate significant linear regressions. Equation was fitted to log-transformed data. $y = 3.55\,x^{-0.51}$ ($R^2 = 0.17$)

Table 1. Structure, biomass, production and reproduction metrics of *C.nodosa* at the winter minimum and summer maximum. Values are given as mean, standard deviation (sd) and number of observations (n). Temporal change between winter and summer values is included.

	Winter			Summer			Temporal change (%)
	Mean	SD	n	Mean	SD	n	
d	668.9	342.9	1.4	1237.2	773.8	131	140.2 ↓
sb	0.064	0.07	4.03	0.2	0.2	101	403.5 ↑
tb	185.2	125.1	2.6	420.6	289.0	91	257.0
ab	35.5	35.06	5.9	138.8 ↑	125.4	107	590.6 ↑
bb	153.6	106.5	2.1	291.5 ↓	195.8	86	211.6 ↓
rob	66.4	42.6	1.9	138.3	128.9	33	195.2
rhb	111.6	77.4	1.6	208.2	148.5	31	156.7
AB	–	–	–	0.7	0.5	87	–
lel	–	–	–	303.8	153.7	48	
ap	–	–	–	664.1	557.7	25	
rhp	–	–	–	201.3	264.6	17	–
hre	–	–	–	44.7	49.5	51	–
lp	–	–	–	11.8	3.6	31	–
ltr	–	–	–	3.2 ↑	1.2	41	–
rhtr	–	–	–	1.07 ↓	1.2	16	–
fld	–	–	–	120.13	175.2	31	–
%fl	–	–	–	13.5 ↓	15.6	34	–
frd	–	–	–	76.4	62.8	7	–
%fr	–	–	–	6.3 ↓↓	5.2	7	–
s	–	–	–	143.4	398.9	28	–
%g	–	–	–	54.3	39.7	7	–

high seasonal patterns: phenotypic plasticity

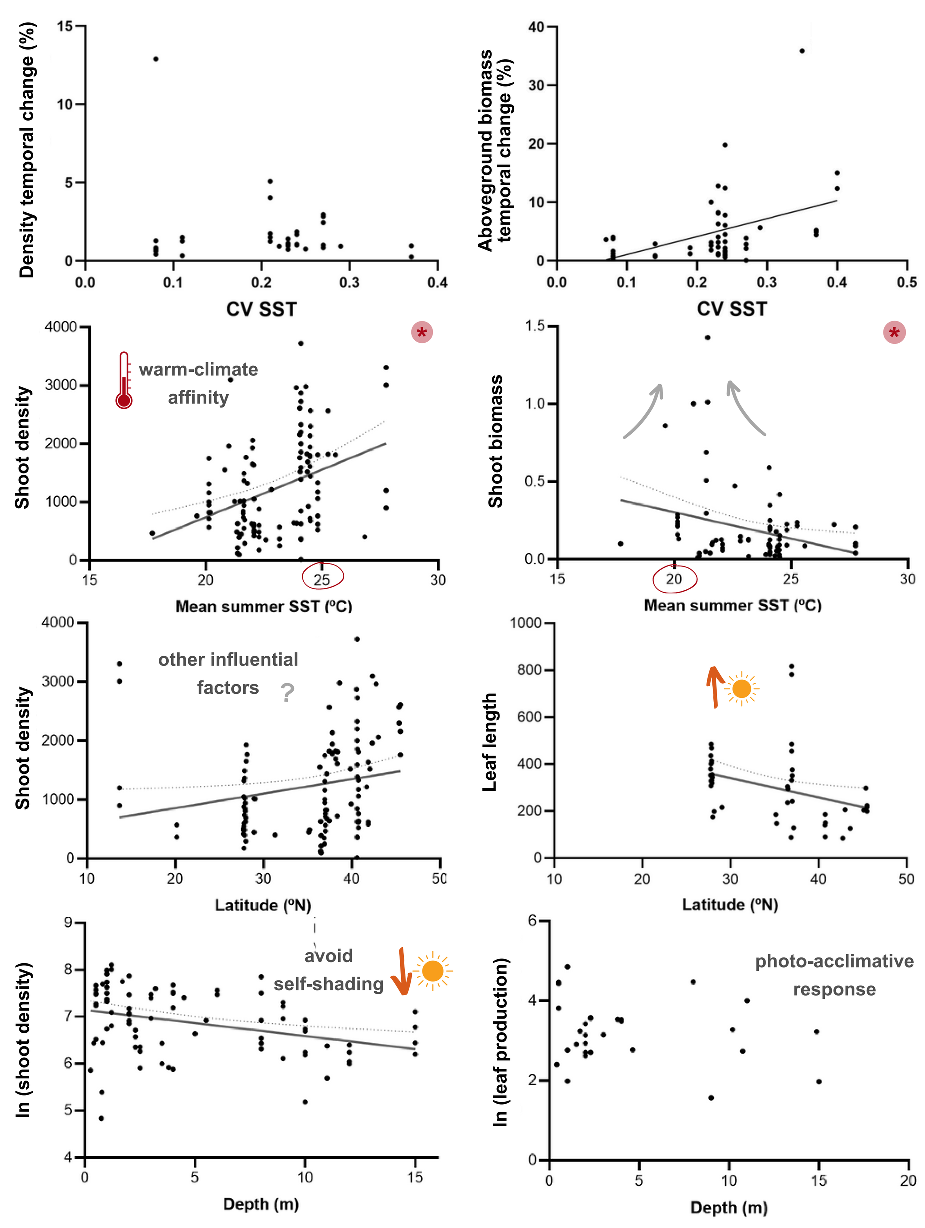


Figure 4. Different *C.nodosa* summer variables as functions of latitude (ºN), variation in SST (via CV), mean summer SST (ºC), minimum SST (ºC) and water depth (m). Solid lines indicate significant linear regressions; dashed lines are upper 95% CI.

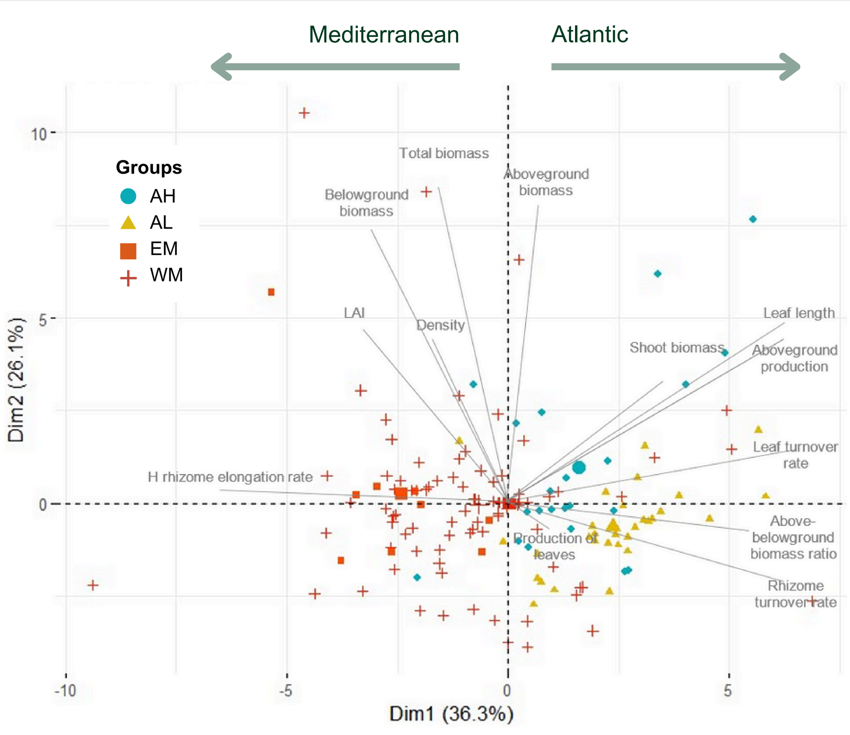


Figure 5. Principal Component Analysis (PCA) based on summer biomass and production among the studied *C.nodosa* meadows. Relevant variables driving Dim1 and Dim2 scores are overlaid.

Figure 6. Correlation matrix using Pearson correlation coefficient (r) between the different growth and biomass peak variables (summer). Non-significant coefficient (p value > 0.05) are crossed out.

Discussions

1) Seasonality patterns

- Phenotypic plasticity modulates response to environment heterogeneity
- Belowground compartment remains stable, stores nutrients to cope with winter vs Aboveground compartment turns-over quickly, limiting accumulation
- Density is more independent of annual variation compared to shoot biomass

2) Light influence

- Density and biomass correlated with depth ⟶ mechanisms to prevent self-shading
- Leaf length and production did not correlate with depth ⟶ photo-acclimative responses

Limitation: Deep medows were not included (15 - 35m)

- Leaf length and leaf production higher at lower latitudes ⟶ higher SI
- Other influential factors: conservation status, nutrient availability and hydrodynamic conditions (Atlantic vs. Mediterranean)

Limitation: Turbidity coefficient was not taken into account

3) Temperature influence

- Suitable areas: Winter 5.6-18.4ºC, Summer 22.9-30.6ºC
- Density and h rhizome elongation correlated with summer T(ºC) ⟶ warm-climate affinity of *Cymodocea* genera
- Shoot biomass negatively correlated with T(ºC) ⟶ form of allometric scalling with density (self-thinning rule)
- Change in aboveground compartment correlated with SST CV ⟶ T(ºC) is the factor regulating high seasonal fluctuations
- Optimal range: Summer 20-21ºC and 24-25ºC, Winter 12-15ºC
  **should be tested with non-linear regression analysis*
- Optimal T(ºC) varies depending on geographical location reflecting the ability to adapt its thermal niche to local temperature regimes. ⟶ *Chefaoui et al. (2015), Peduzzi & Vukovič (1990), Savva et al. (2018), Bennett et al. (2022) & Olsen et al. (2012)*

4) Sexual reproduction

- Flowering shoots and germinating rate enhanced by short-term stressful conditions ⟶ thermal variation and low temperatures

CONCLUDING REMARKS:

- Low R2 coefficients suggest **other influential factors**:
  - Wave exposure
  - Nutrient availability
  - Dune movement
  - Human pressure
  - Genetics: Mediterranean vs Atlantic genotypes *Alberto et al. (2008)*
- **Mediterranean Sea vs Atlantic Coasts:**
  - M: Opportunistic seagrass (pioneer), competing with *Posidonia oceanica* (climax).
  - A: Larger extensions, no competition.
- **Climate change**
  - Meadows with higher CV T(ºC) ⟶ more resistant.
  - Possible change in range limits (TºC) ⟶ potential expansion polewards along the Atlantic coast.
- **Manegement:**
  - Thorugh understand of local conditions *(not only light and TºC)*
  - Incorporate genetic considerations ⟶ ecotypes might have unique adaptations.
- **Continued research** especially in Mauritania and Eastern Mediterranean coasts.

References