# Modelling opportunistic macroalgal productivity and biomass in a shallow eutrophic estuary (Mondego estuary, Portugal). The role of algal spores.

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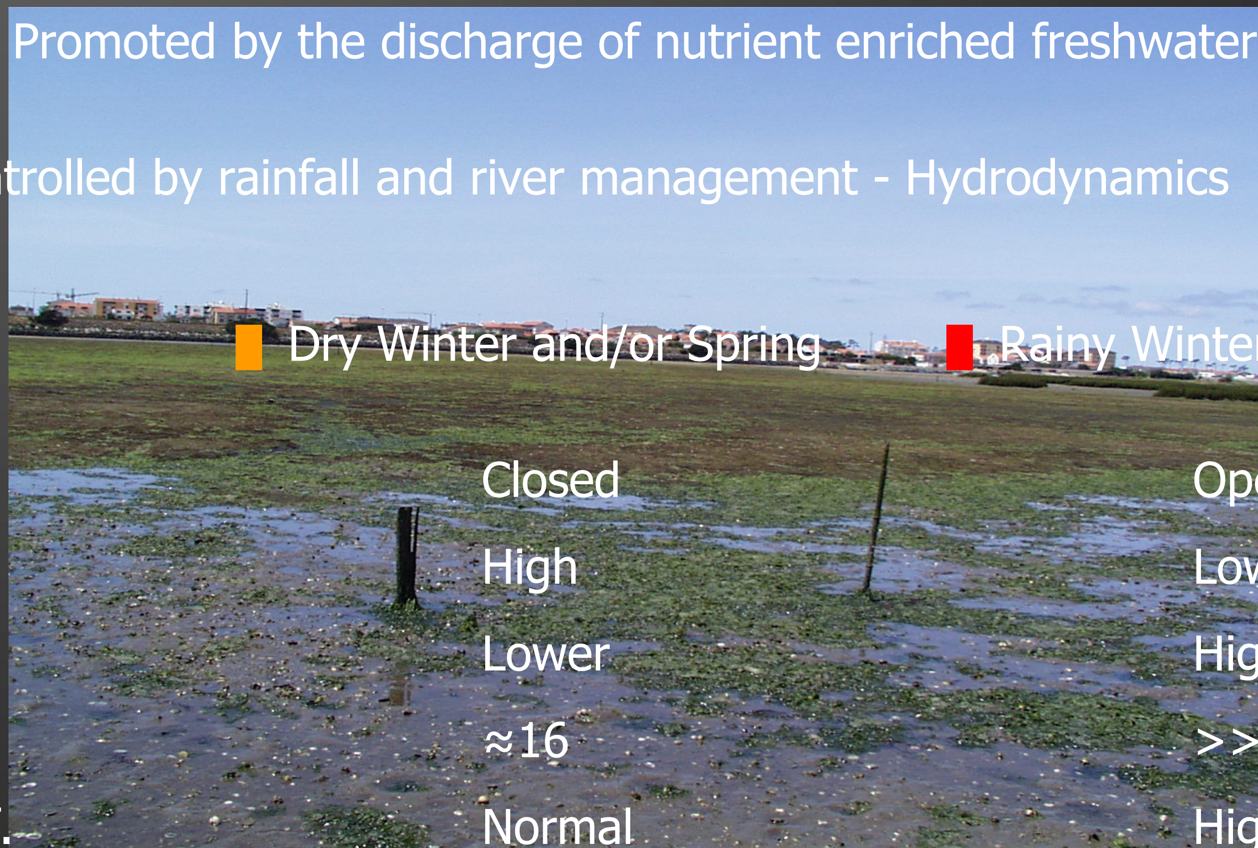
# The Mondego Estuary: Western Atlantic Coast of Portugal

# The south arm of the Mondego Estuary:

# a shallow eutrophic estuary

- From the 80's until the 90's: an increasing eutrophication process
- Increase in the biomass of green macroalgae (*Enteromorpha* spp.)
- Decrease in the biomass of rooted-macrophytes (*Zostera noltii*)
- Several negative impacts in the trophic structure of the system

# The causes of eutrophication and its controlling factors



- Promoted by the discharge of nutrient enriched freshwater
- Controlled by rainfall and river management - Hydrodynamics

| | Dry Winter and/or Spring | Rainy Winter and Spring |
| --- | --- | --- |
| Sluice Gates | Closed | Opened |
| Salinity | High | Low |
| TIN | Lower | High |
| N:P | ≈16 | >>16 |
| Light Ext. Coeff. | Normal | High |
| Water-Flow | Low | High |
| Green Macroalgal growth | High | Low |

# Aims of the present work

- To develop a model able to describe the productivity of green macroalgae in the south arm of the Mondego Estuary

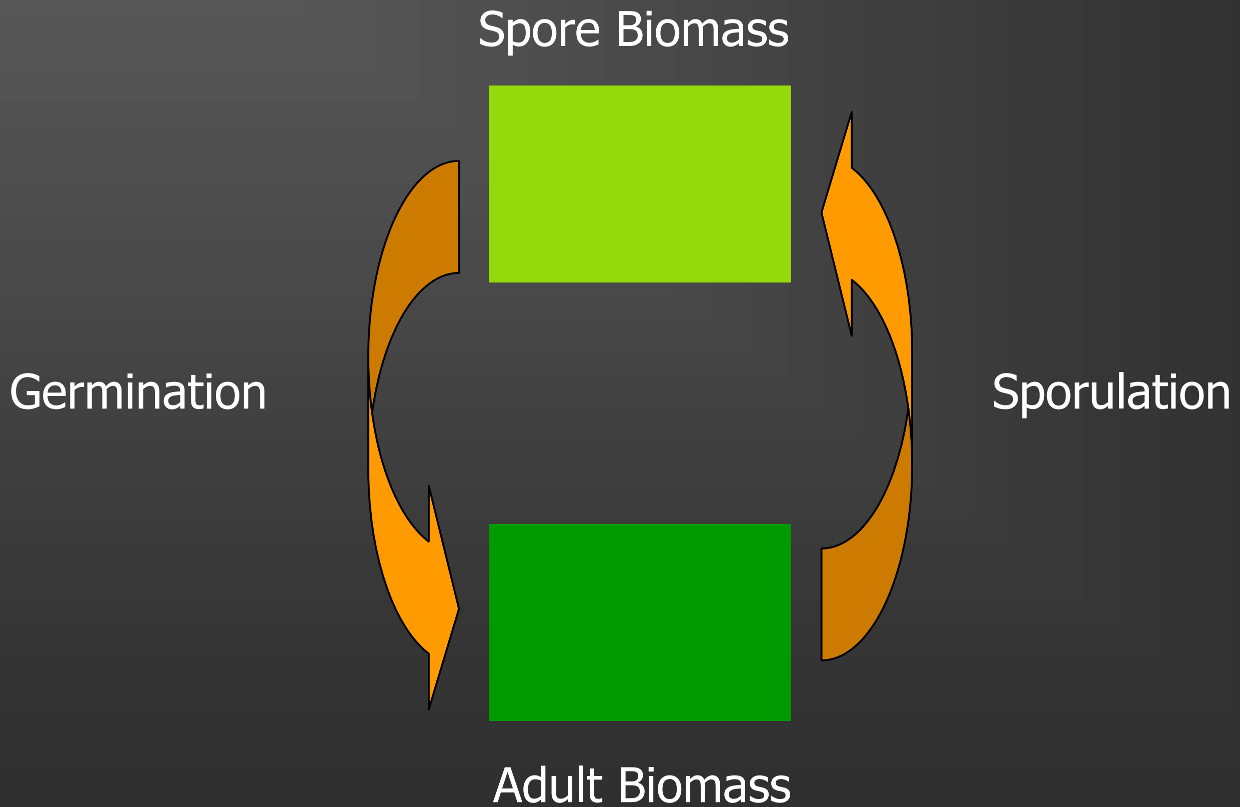
- To predict the occurrence of macroalgal blooms in the system

- To quantify the impacts of macroalgal biomass in the nutrient (N and P) cycles of the south arm of the Mondego Estuary

# Achievement

- Modelling coupled to GIS

# Model Description

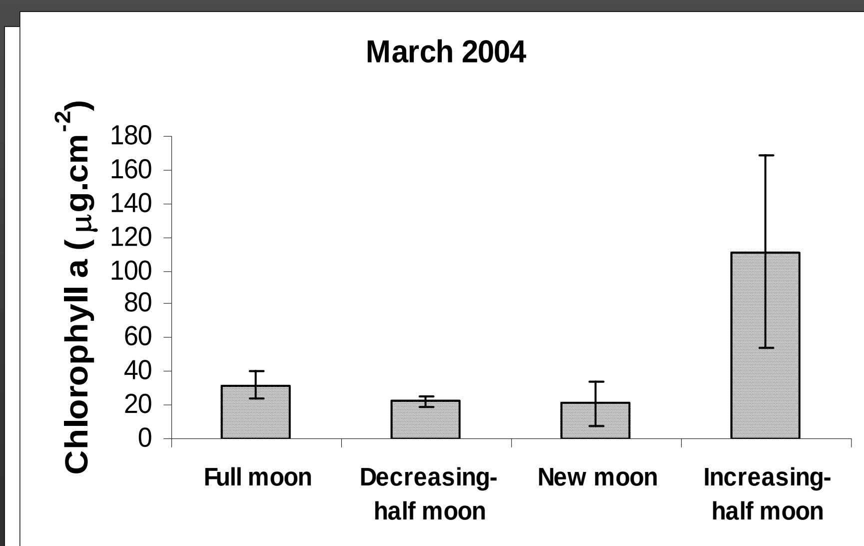


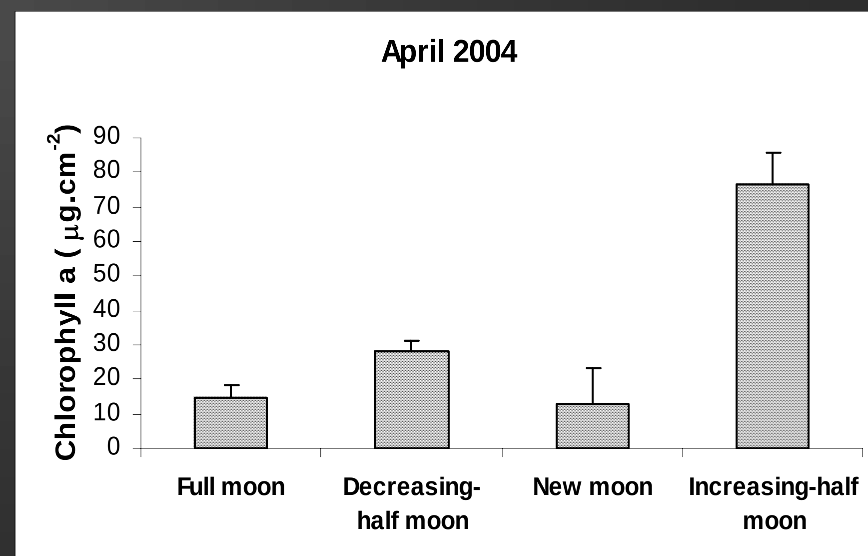
# The microscopic life-phase of macroalgae

- Macroalgal spores represent *propagule banks* for the species
- An important mechanism to escape to adverse conditions (overwintering, intense herbivory, nutrient limitation)
- Factors affecting early life stages determine development and dominance patterns of macroalgal blooms (Lotze et al. 2000)
- Accurate models of macroalgal productivity must account for the description of microscopic life-phases

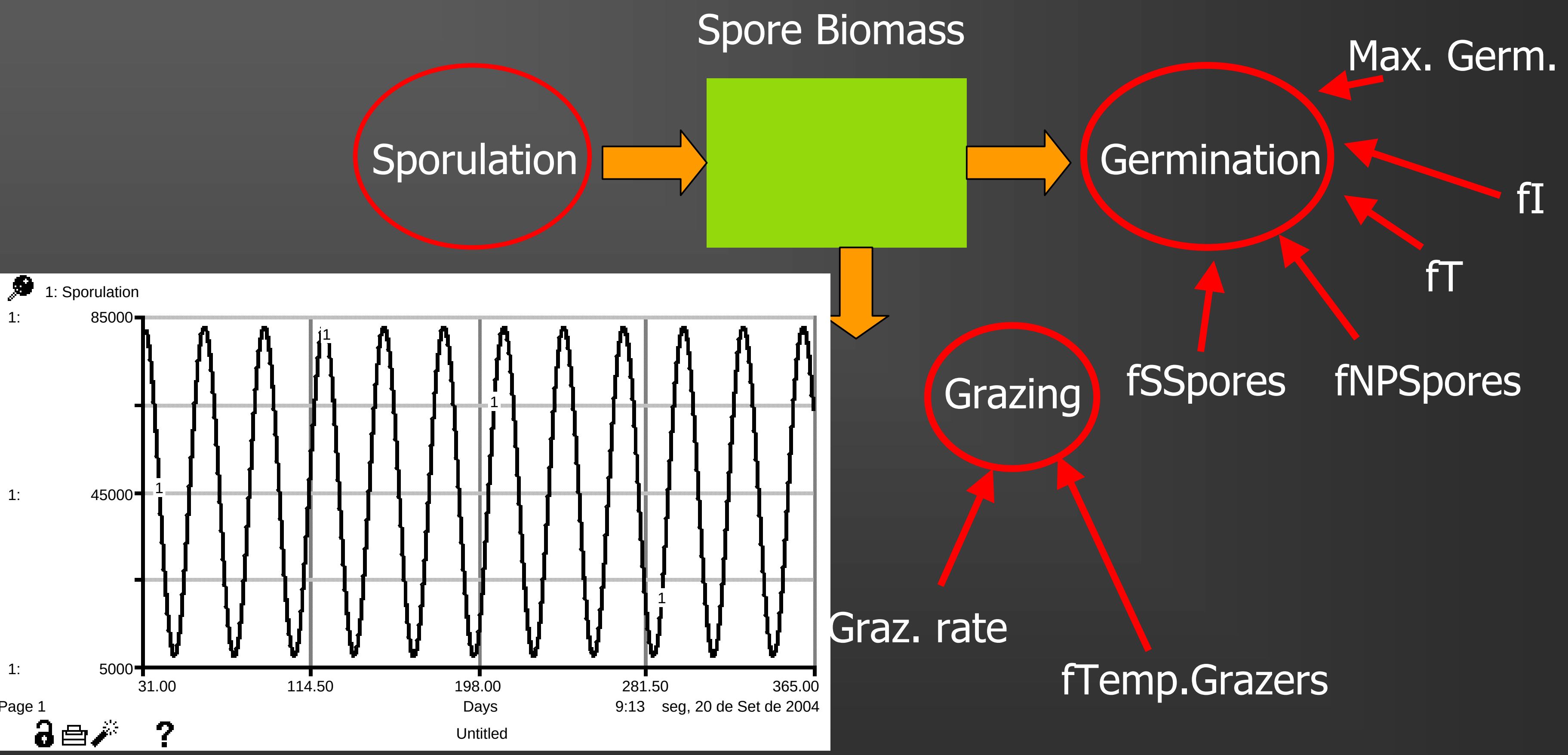
# Experiments with macroalgal spores

- Does sporulation follow some kind of pattern? Very important to model!
  - Lunar cycle and Tidal amplitude (Christie and Evans 1962)

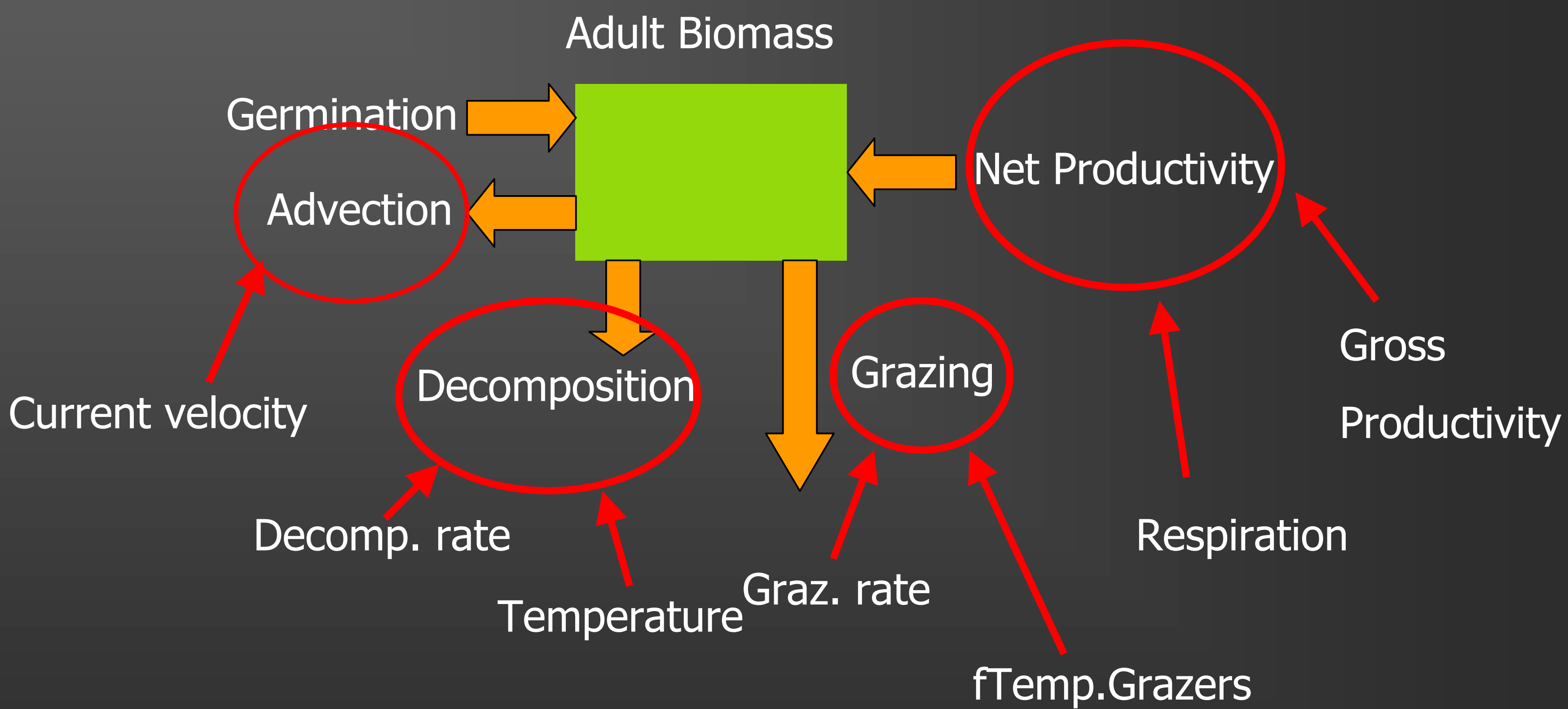


# Modelling Spore Biomass



# Modelling Adult Macroalgae Biomass



# Gross Productivity

- Gross Productivity= Max. Prod. rate*fI*fT*fS*fNP
  - $fI=(PFD_{depth}/PFD_{saturation})*EXP(1-(PFD_{depth}/PFD_{saturation}))$
- $PFD_{depth}= PFD_{surface}*EXP(-(Coeff.\ Ext*Depth))$

Brock model

(annual ligh energy variation, photoperiod and PAR)

- Depth=Tidal height-level (topographic quota)

# Limiting factor of N and P

- According to the "Liebig's law of the minimum"
  - If $N:P \geq 12$ and $N:P \leq 16$, $f(NP)=1$

    If $N:P<12$, $f(NP)=f(N)$

    IF $N:P>16$, $f(NP)=f(P)$

- $f(N)=(N_{int}-N_{imin})/(kq+N_{int}-N_{imin})$

- If $P_{int}<P_{imax}$, $f(P)=P_{int}/P_{imax}$

  If $P_{int} \geq P_{imax}$, $f(P)=1$

- $Uptake=(X_{imax}-X_{int})/(X_{imax}-X_{imin}) * (V_{max}*X_{ext})/(K_x+X_{ext})$

# Limiting factor of salinity and temperature

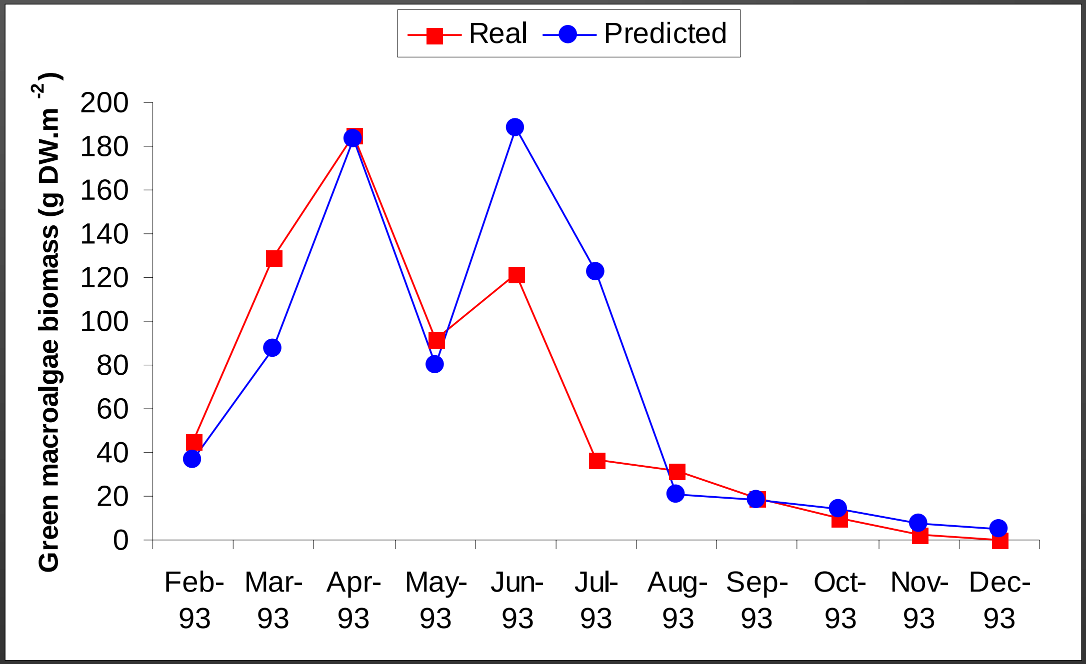
- fS according to experimental data
  - For salinity $\geq 5$, $f(S)=1-((S-S_{opt})/(S_x-S_{opt}))^m$
    For salinity $<5$, $f(S)=(S-S_{min})/(S_{opt}-S_{min})$
- fT follows an optimum curve
  - $f(T)= \exp(-2.3*((T-T_{opt})/(T_x-T_{opt}))^2)$

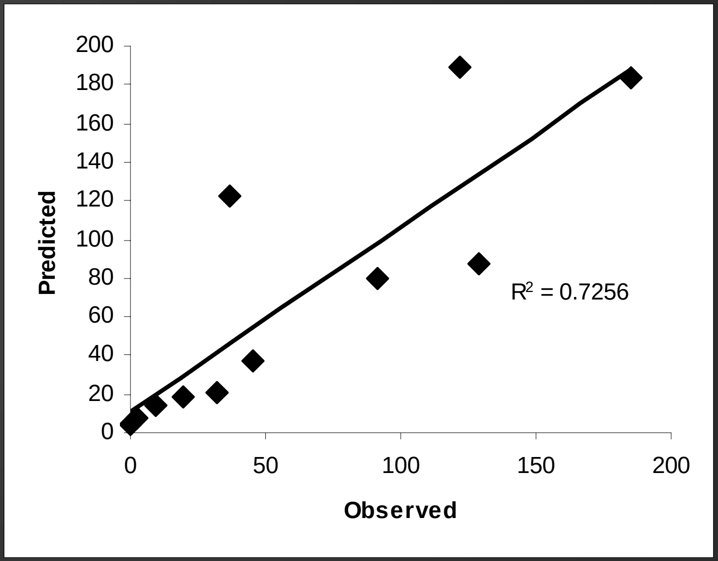
# Model characteristics

- Model results are obtained at a scale of $1m^2$
- A time step of 1.2 h for 365 days
- Developped with STELLA 7.0.3 software
- The spatial differentiation accounted by the model only considers the different topographic quotas in which macroalgae can be placed in the intertidal area (-0.9 m up to 2.3 m); different quotas have different light climates.

# Model results:

## for algae placed at the sea level (0 meters)



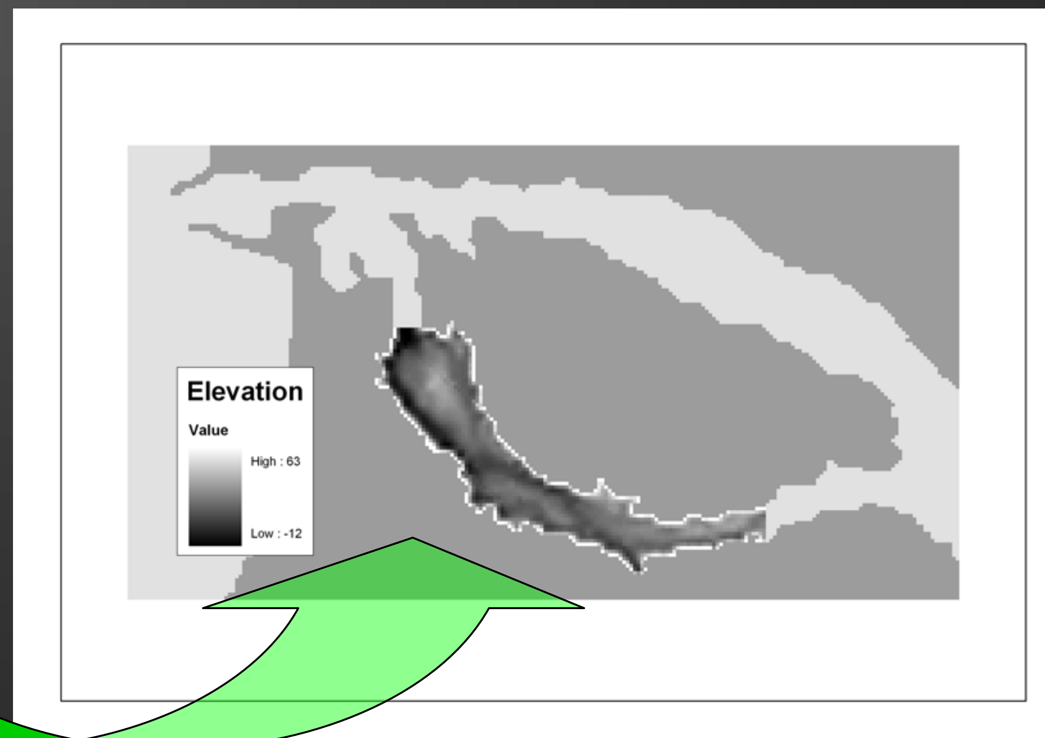
# From modelling to GIS:

## Upscalling from 1m$^2$ to the south arm of the estuary

- Model results

| quota | Feb-93 | Mar-93 | Apr-93 | May-93 | Jun-93 |
|---|---|---|---|---|---|
| … | … | … | … | … | … |
| -0.4 | 20.8 | 51.5 | 153 | 25.87 | 168.91 |
| -0.3 | 20.7 | 51.4 | 153 | 25.87 | 169.22 |
| -0.2 | 20.7 | 51.2 | 152 | 25.87 | 169.46 |
| -0.1 | 20.6 | 51 | 151 | 25.86 | 169.61 |
| 0 | 20.6 | 50.8 | 151 | 25.85 | 169.64 |
| 0.1 | 20.5 | 50.7 | 150 | 25.84 | 169.50 |
| 0.2 | 20.5 | 50.6 | 149 | [illegible] | 169.10 |
| 0.3 | 20.4 | 50.5 | 147 | [illegible] | [illegible]8.29 |
| 0.4 | 20.4 | 50.4 | 145 | 25.7[illegible] | [illegible] |
| … | … | … | … | … | … |

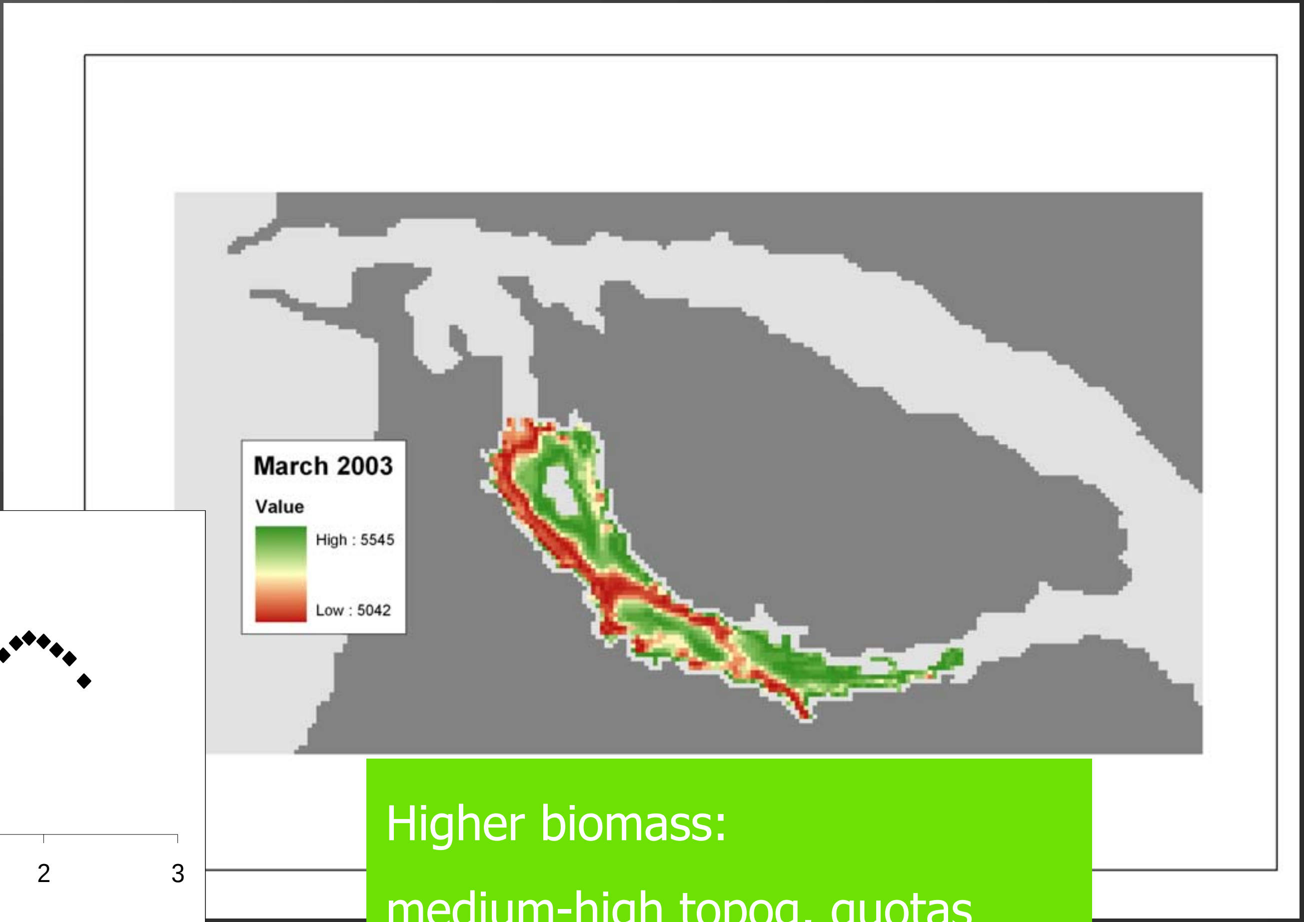
- Map of bathymetry: ArcView



# Model results:

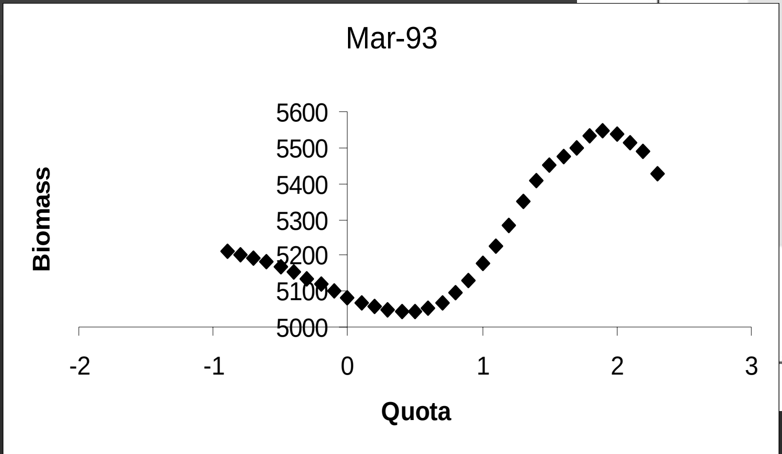
## Green macroalgae biomass in the south arm of the Mondego estuary

- March 1993 (dry winter and spring)




- Average:

5.24 kg DW.m$^{-2}$



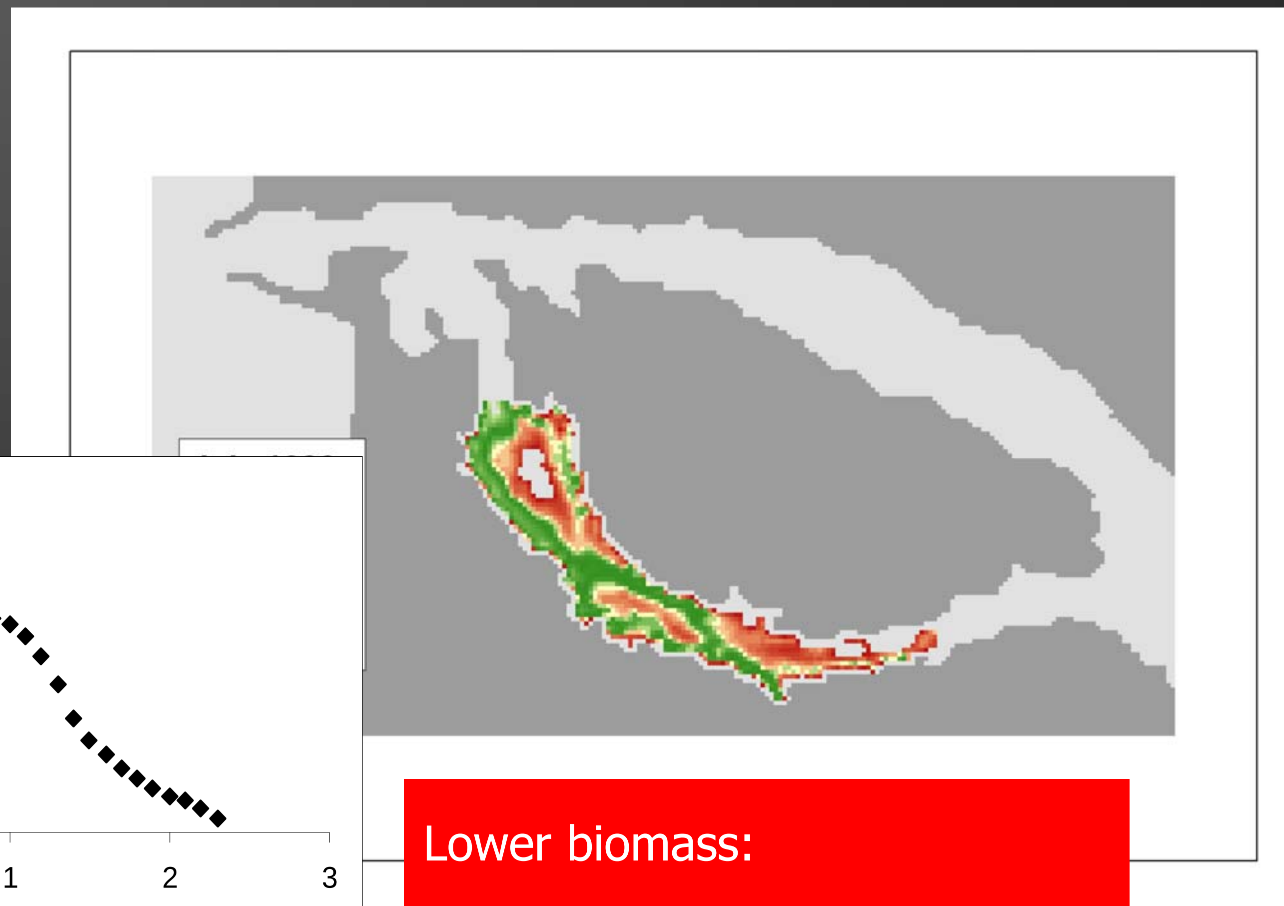

Higher biomass:

medium-high topog. quotas

# Model results:

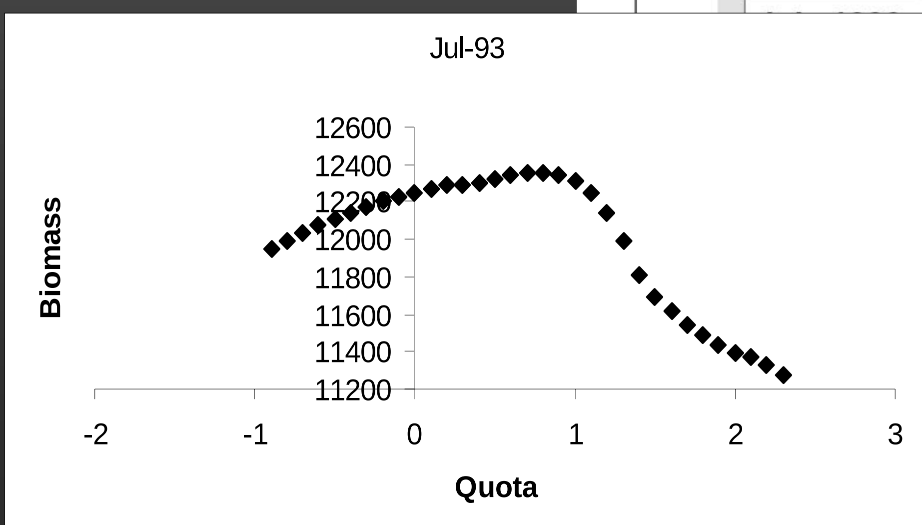
## Green macroalgae biomass in the south arm of the Mondego estuary

- July 1993



- Average:

11.98 kg DW.m$^{-2}$



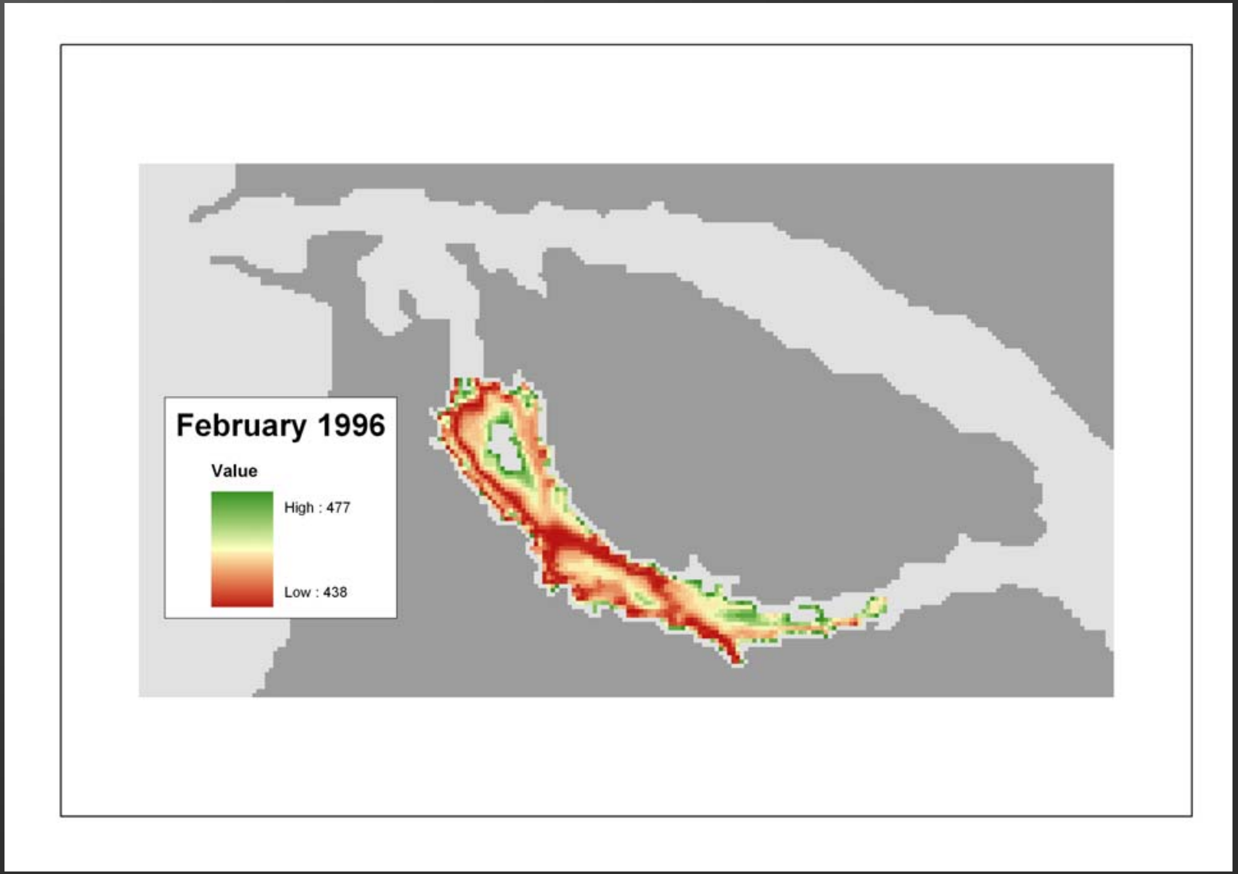

Lower biomass:

medium-high topog. quotas

# Model results:

## Green macroalgae biomass in the south arm of the Mondego estuary

- February 1996 (rainy winter)




- Average:

  0.454 kg DW.m$^{-2}$

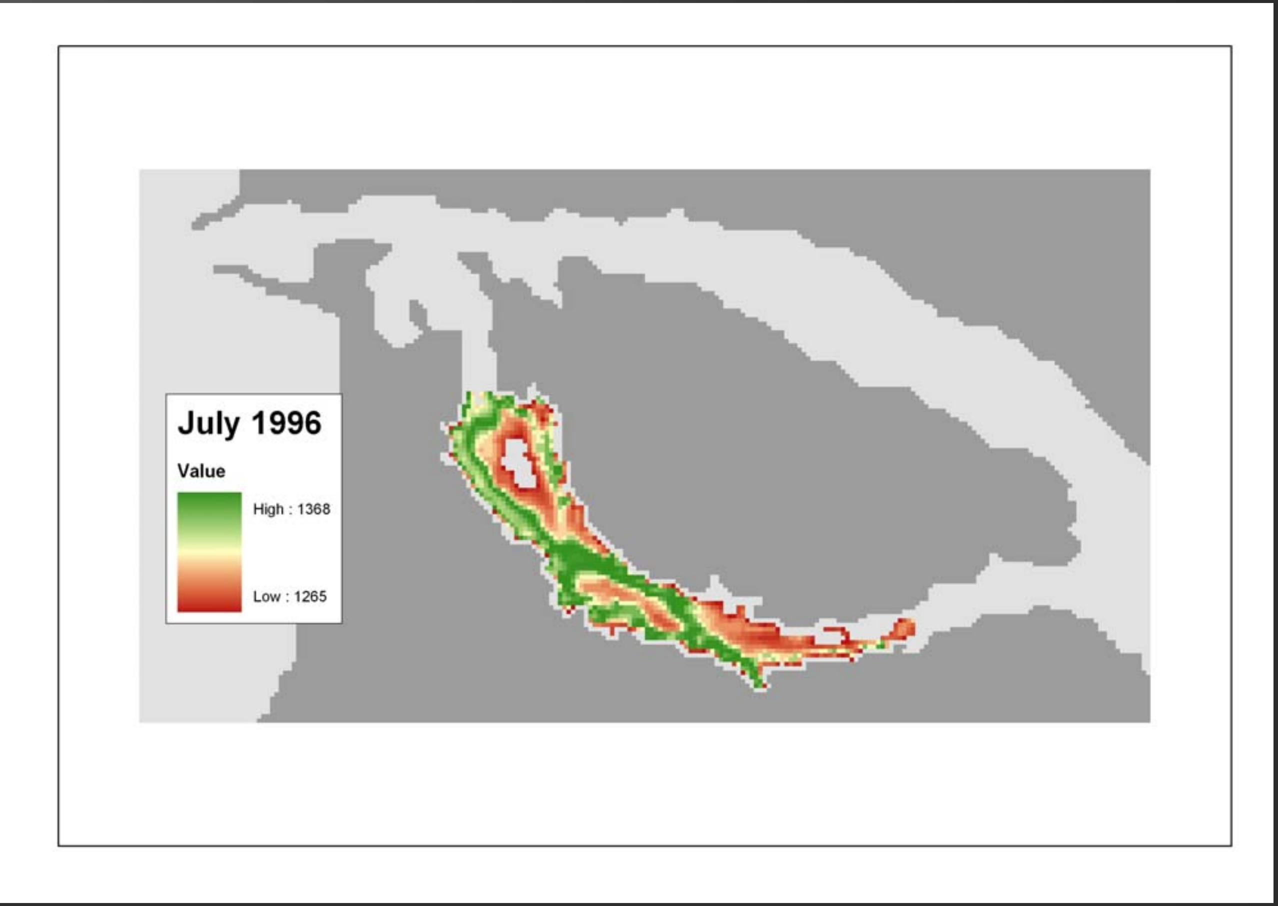
- Some macroalgae

  but no bloom

## Model results:

Green macroalgae biomass in the south arm of the Mondego estuary

- July 1996




- Average:

  1.326 kg DW.$m^{-2}$

- Summer increase of biomass: not expected

- Desiccation stress needs to be described!

# Model results:

## Impacts in the nutrient cycles of the south arm of the Mondego estuary

| | Dry year<br>Macroalgal bloom | Rainy year<br>No macroalgal bloom |
|---|---|---|
| kt DW green macroalgae | 1321 | 136 |
| kt Carbon | 528 | 54 |
| kt Nitrogen | 95 | 10 |
| kt Phosphorus | 13 | 1,4 |

# Discussion

- Including the description of algal microscopic life-phases is benefitial for an accurate description of macroalgal productivity

- The model simulates fairly well the observed variation of macroalgal productivity in dry years and in rainy years

- Due to their high assimilation rates, in years that favour their growth, macroalgae take up large quantities of nutrients from the system. Part of these nutrients is exported to nearby coastal areas (advection), while other part is decomposed in the system

# Discussion

- Because the excessive growth of macroalgae has, at least, negative impacts on other local primary producers and animals, management techniques must be implemented and improved to allow the recovery of rooted-plants (*Zostera noltii*) and to limit the growth of ephemeral macroalgae

# Next improvements in our work

- Better estimation/description of the factors, parameters and processes that affect spore survival and germination

- Better description of the light extinction coefficient variation (e.g. regression with SPM)

- Besides the topographic quota (light), to include other factors that affect the spatial distribution of macroalgae, such as the type of substrate (type of substrate-amount of spores), and the organic matter content of the sediment

- To account for other processes that affect adults, such as desiccation stress or the self-shadding effect

# Acknowledgement

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