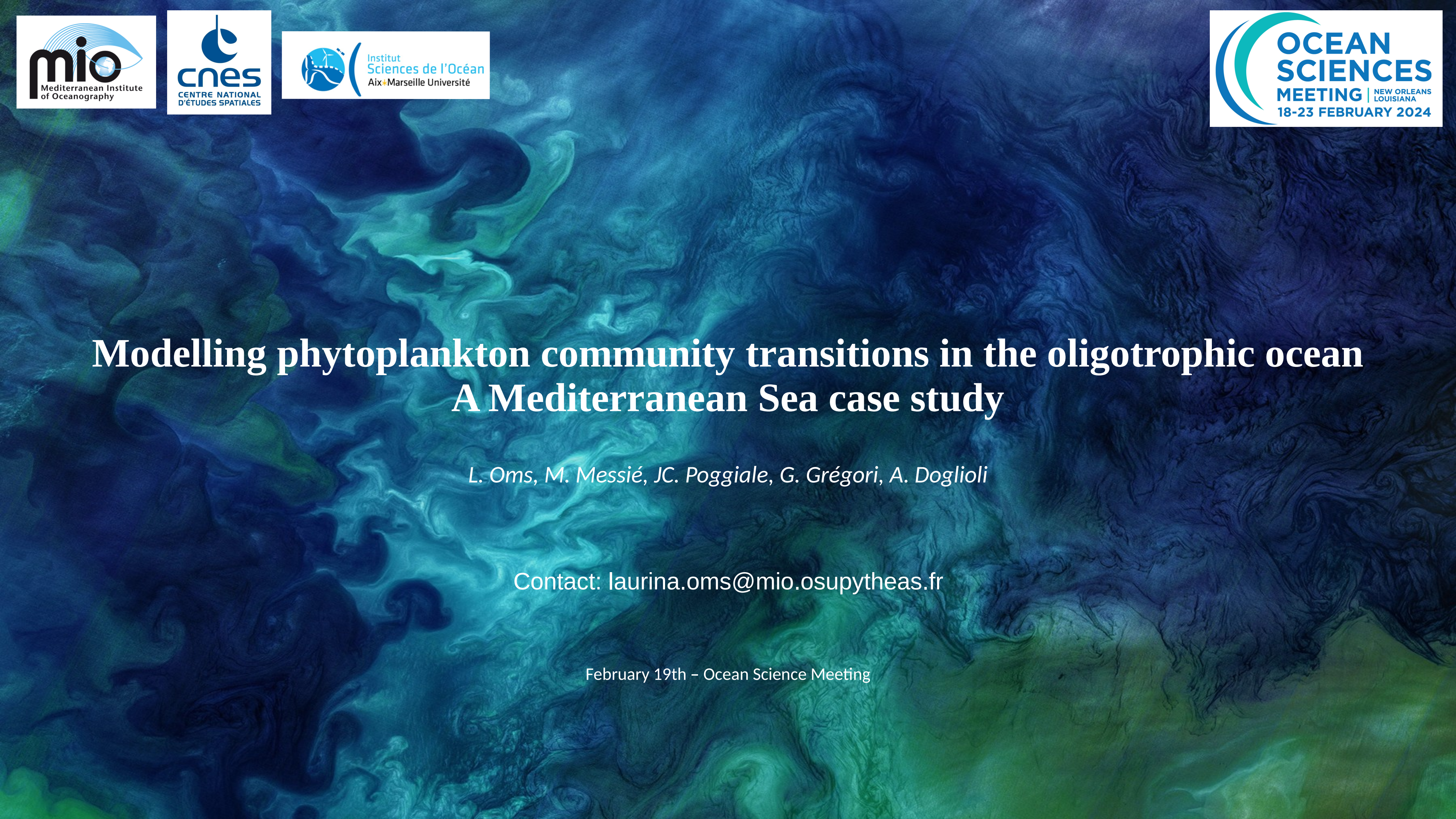


Modelling phytoplankton community transitions in the oligotrophic ocean
A Mediterranean Sea case study

L. Oms, M. Messié, JC. Poggiale, G. Grégori, A. Doglioli

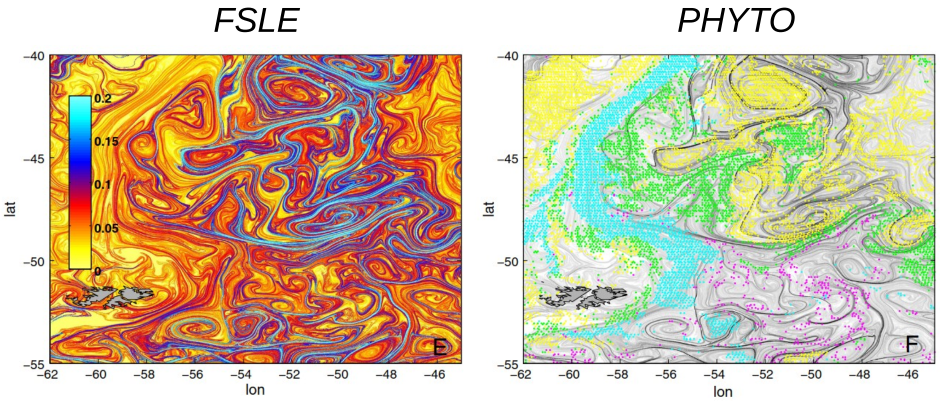
Contact: laurina.oms@mio.osupytheas.fr

February 19th – Ocean Science Meeting

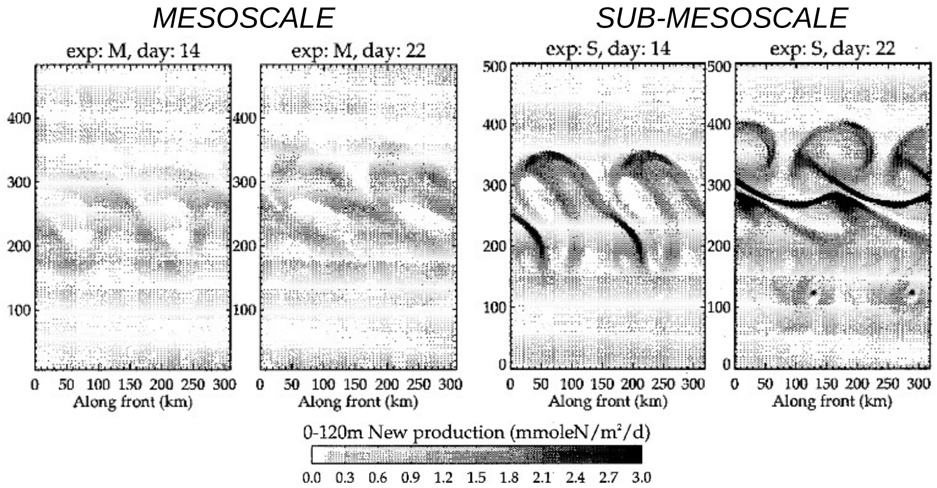
Phytoplankton diversity and ocean dynamics

Pivotal role of **fine-scale dynamics** in shaping the seascape and consequently the phytoplankton communities

d’Ovidio et al (2010)



Lévy et al (2001)

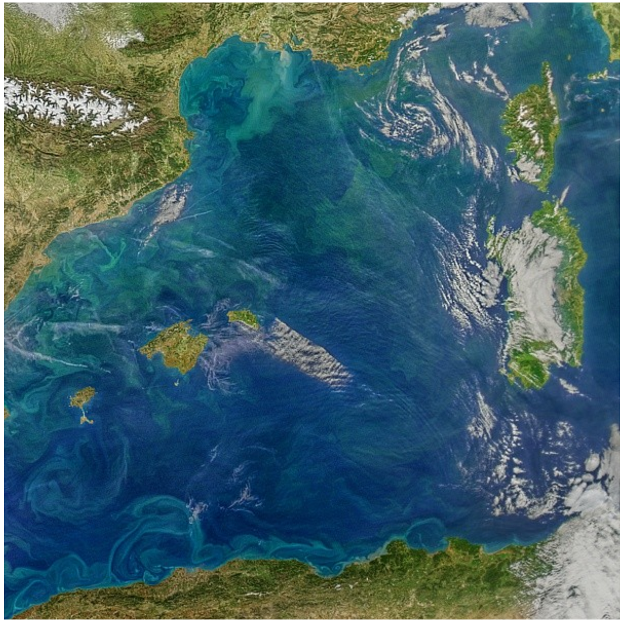


Fine-scales drive diversity

Fine-scales boost primary production in oligotrophic conditions

Oligotrophic regions are set to expand with future warming
(Polovina et al., 2008)

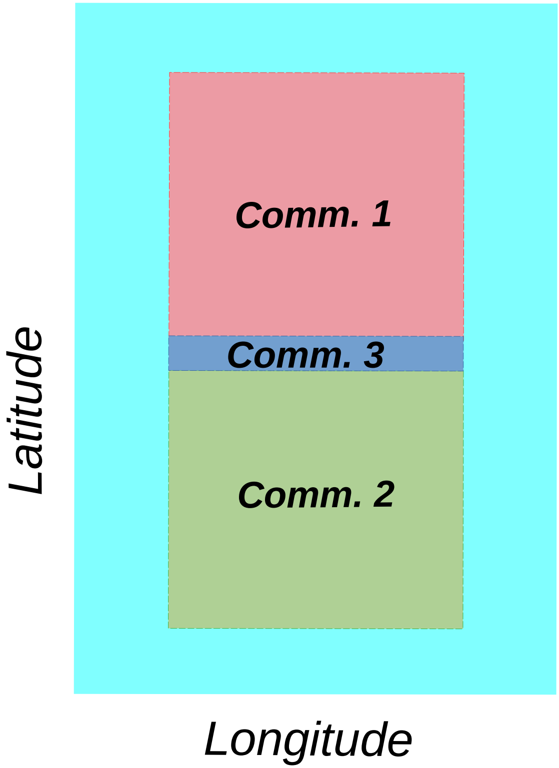
Mediterranean Sea

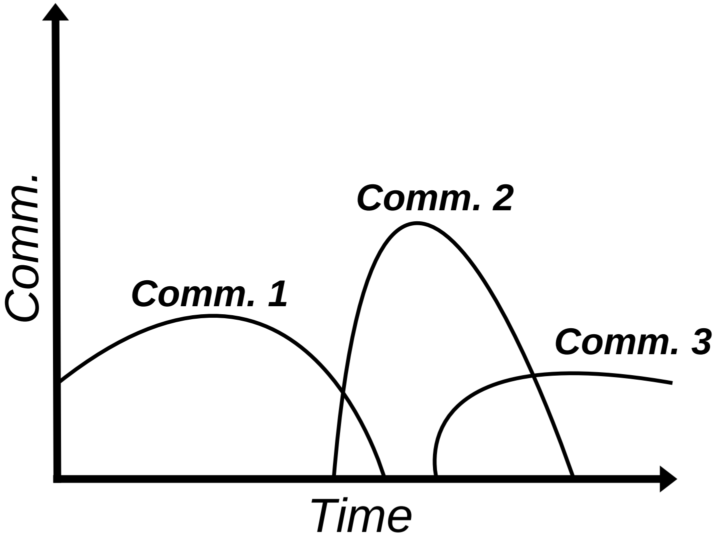


* Oligotrophic sea
* Moderate energy
* A small-scale model of the global ocean

Phytoplankton diversity and ocean dynamics

Phytoplankton Community Transitions (PCTs): **spatial or temporal transitions from one community to another**

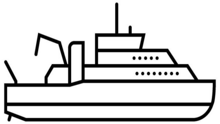


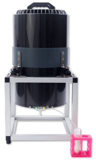


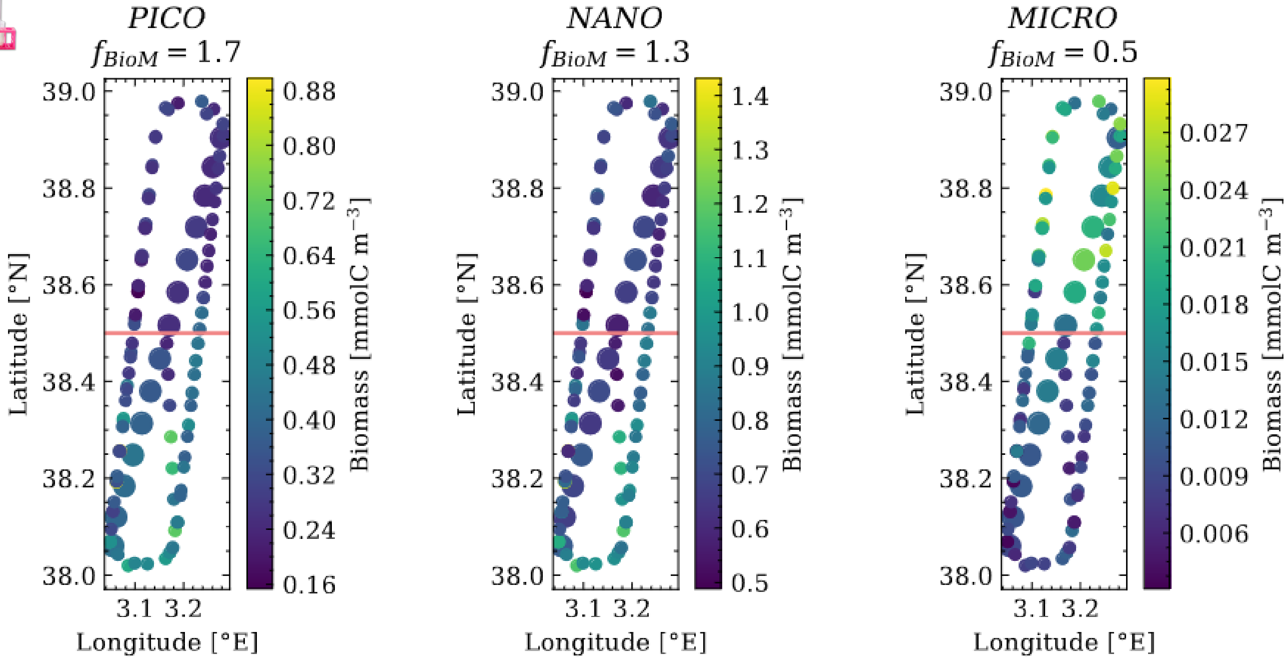
Links between seascape and PCTs?

Phytoplankton Community Transitions (PCTs) – Cytometry data

PROTEVSMED-SWOT CRUISE (DOI: 10.17183/protevsmed_swot_2018_leg1)





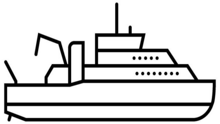


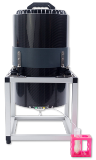
Constrasted abundances and biomasses of phytoplankton *(Tzortzis et al, 2021)*

PCTs: Phytoplankton Community Transitions

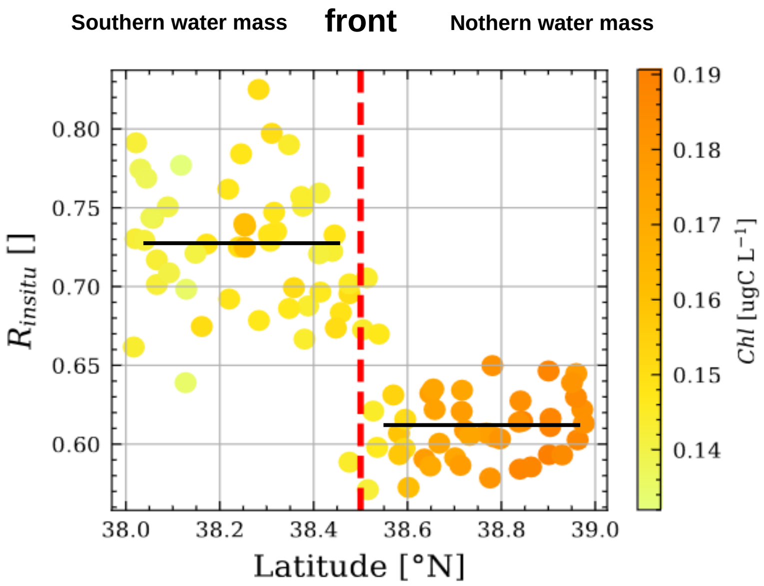
Phytoplankton Community Transitions (PCTs) – Cytometry data

PROTEVSMED-SWOT CRUISE (DOI: 10.17183/protevsmed_swot_2018_leg1)





$$0 \leq R_{insitu} = \frac{Biomass_{small}}{Biomass_{total}} \leq 1$$



The constrasted abundances can be linked to constrasted growth and loss rates and not only advection by currents *(Tzortzis et al, 2021)*

2 hypotheses affecting loss and growth rates:

i) Differential nutrient fluxes through physical processes (bottom-up)

ii) Biotic interactions, including zooplankton grazing (top-down)

(Lévy et al, 2018)

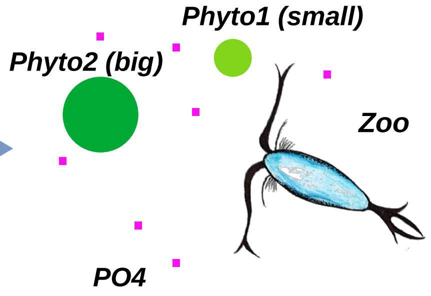
PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Tools

NP2Z model: developed for the oligotrophic Mediterranean Sea. It tests the bottom-up effect with **1 nutrient**, observes transitions with **2 phytoplankton** and the top-down effect with **1 zooplankton**

Complex seascape

Let's start by simplifying the story



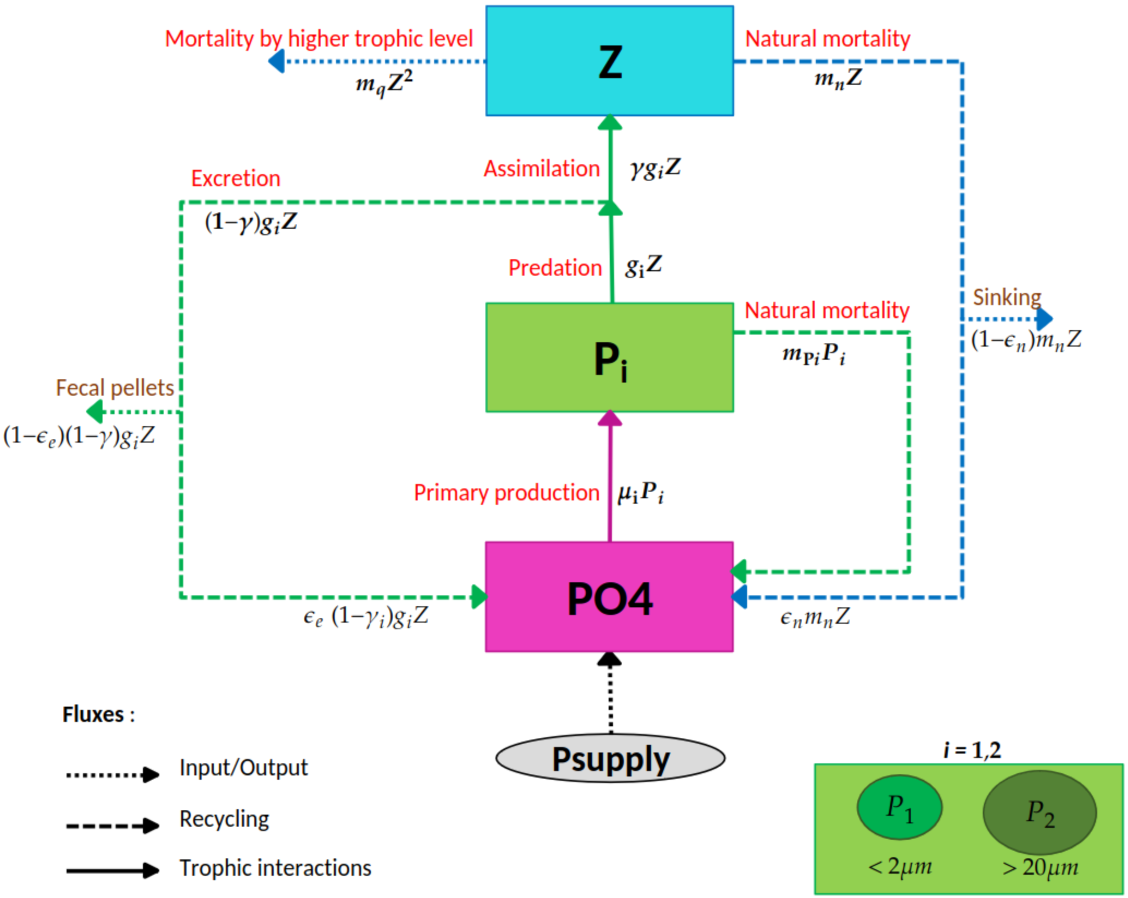
Simple trophic model

Assumptions:

1. Phosphate limits growth *(Moutin & Raimbault, 2002)*
2. Phyto1 excels in low-nutrient uptake, Phyto2 in predator defense *(Thingstad & Rassoulzadegan, 1999; Bohannan & Lenski, 2000)*

PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Tools



***Psupply* = externe flux of phosphate**

PEACETIME CRUISE (DOI:10.17600/17000300)

Estimation of Psupply (Pulido-Villena et al, 2021)

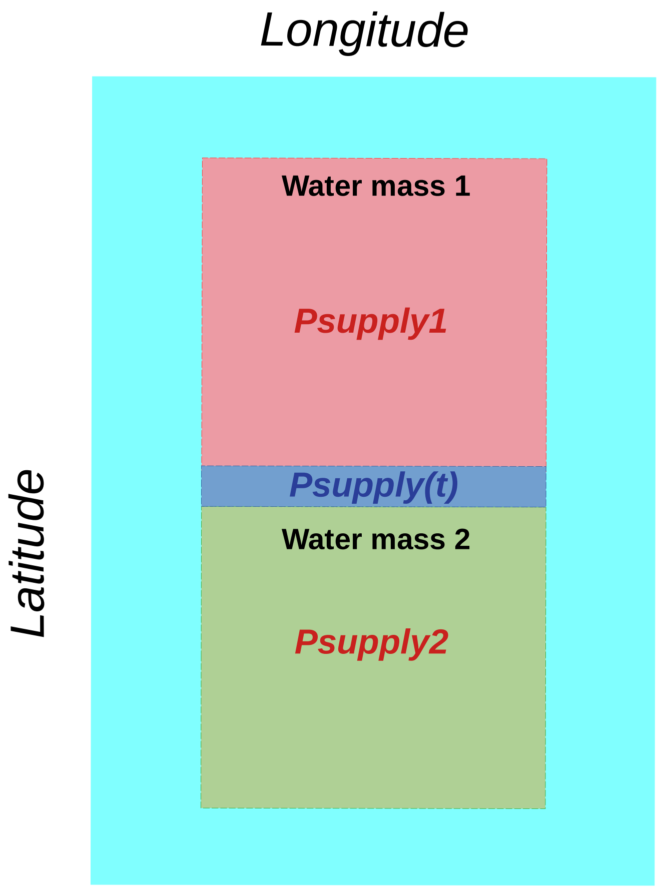
PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Methods

*** 2 study cases:**

1/ Homogeneous environment (constant forcing)

2/ variable environment (pulsed forcing)



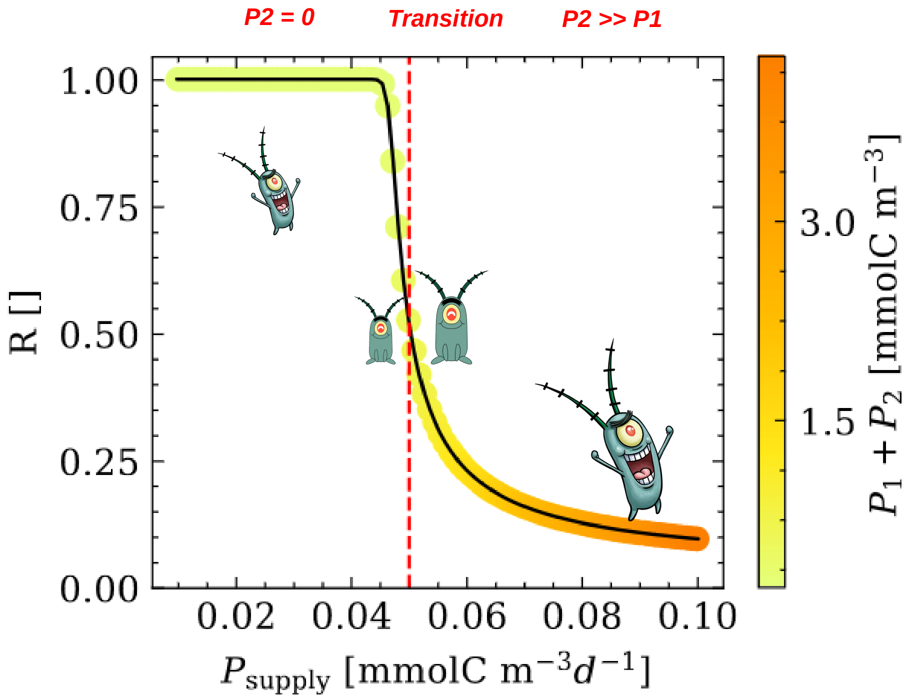
PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Results

1/ Homogeneous environment (constant forcing)

$$0 \leq R = \frac{P_1}{P_1 + P_2} \leq 1$$

PCTs depend on the Psupply value



*** Steady-state solutions of 100 simulations**

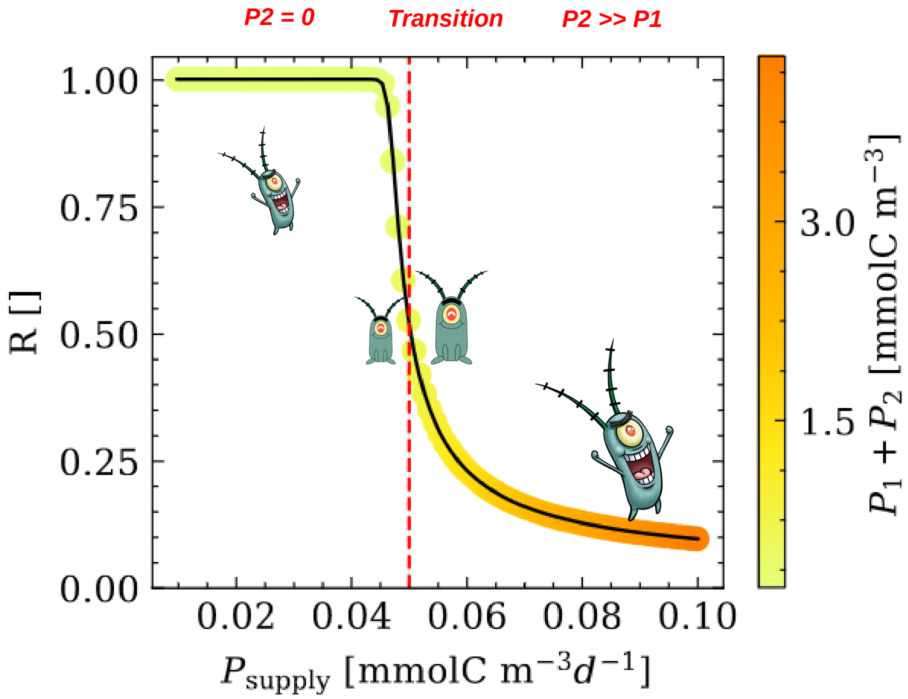
PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Results

1/ Homogeneous environment (constant forcing)

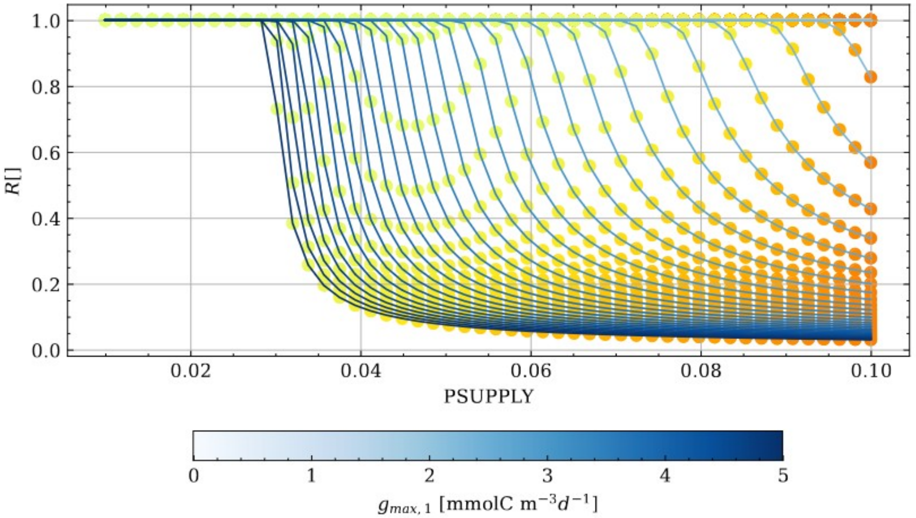
$$0 \le R = \frac{P_1}{P_1 + P_2} \le 1$$

PCTs depend on the Psupply value



*** Steady-state solutions of 100 simulations**

* Role of grazing

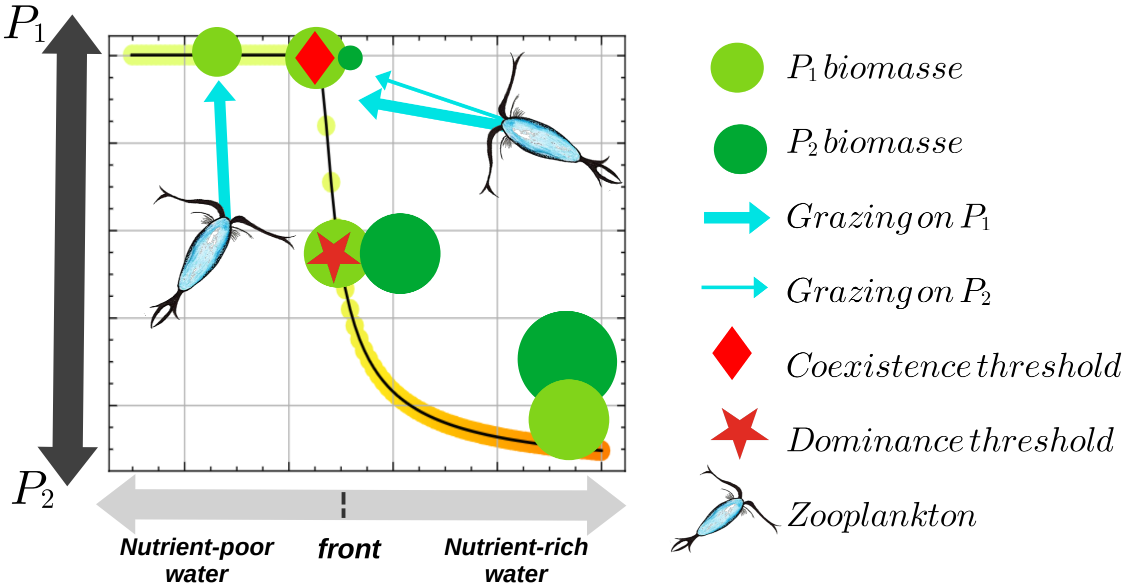


gmax,1 = grazing rate on P1

PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Results

1/ Homogeneous environment (constant forcing)



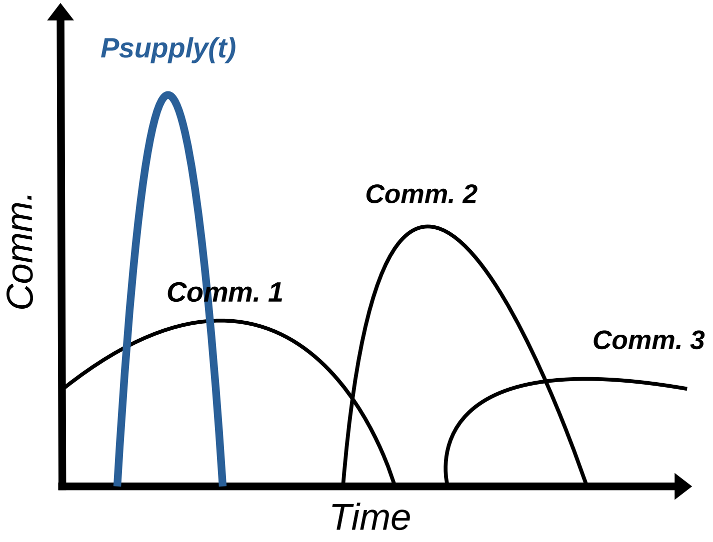
In a homogeneous environment the interplay of bottom-up and top-down controls determines spatial PCTs

PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Methods

2/ Variable environment (pulsed forcing)

Frontal area



Step function

$$P_{\mathrm{supply}}(t) = b \cdot (U(t - t_1) - U(t - t_2)) + P_{\mathrm{supply},0}$$

$$U(x) = \begin{cases} 0 & \text{if } x < 0 \\ 1 & \text{if } x \geq 0 \end{cases}$$

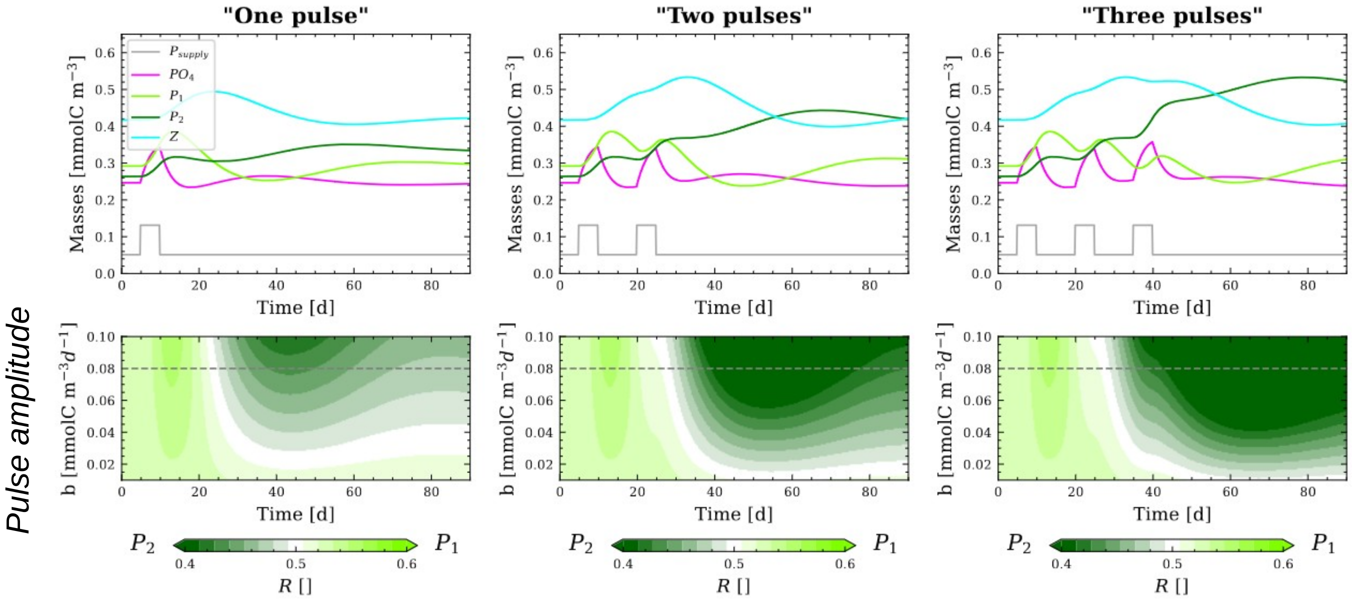
PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Results

2/ Variable environment (pulsed forcing)

*** Dynamical-state solutions of 100 simulations for 1, 2 and 3 pulses**

$$0 \leq R = \frac{P_1}{P_1 + P_2} \leq 1$$



PCTs depend on the number of pulses and their amplitude

How does zooplankton contribute to the dynamics of PCTs?

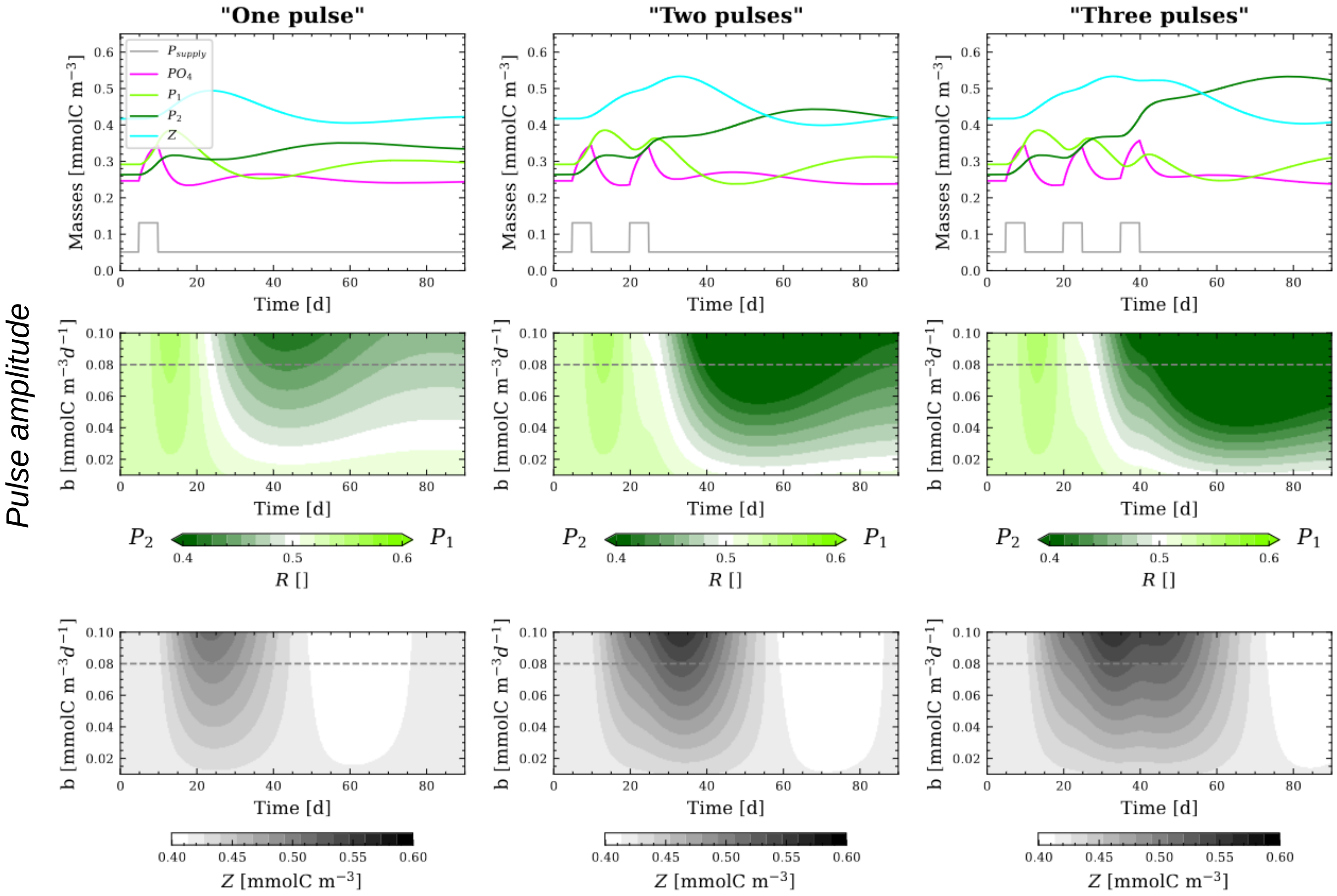
PCTs: Phytoplankton Community Transitions

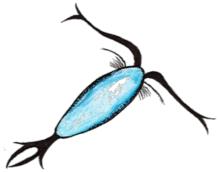
How do fine-scale dynamics explain PCTs? - Results

2/ Variable environment (pulsed forcing)

*** Dynamical-state solutions of 100 simulations for 1, 2 and 3 pulses**

$$0 \leq R = \frac{P_1}{P_1 + P_2} \leq 1$$





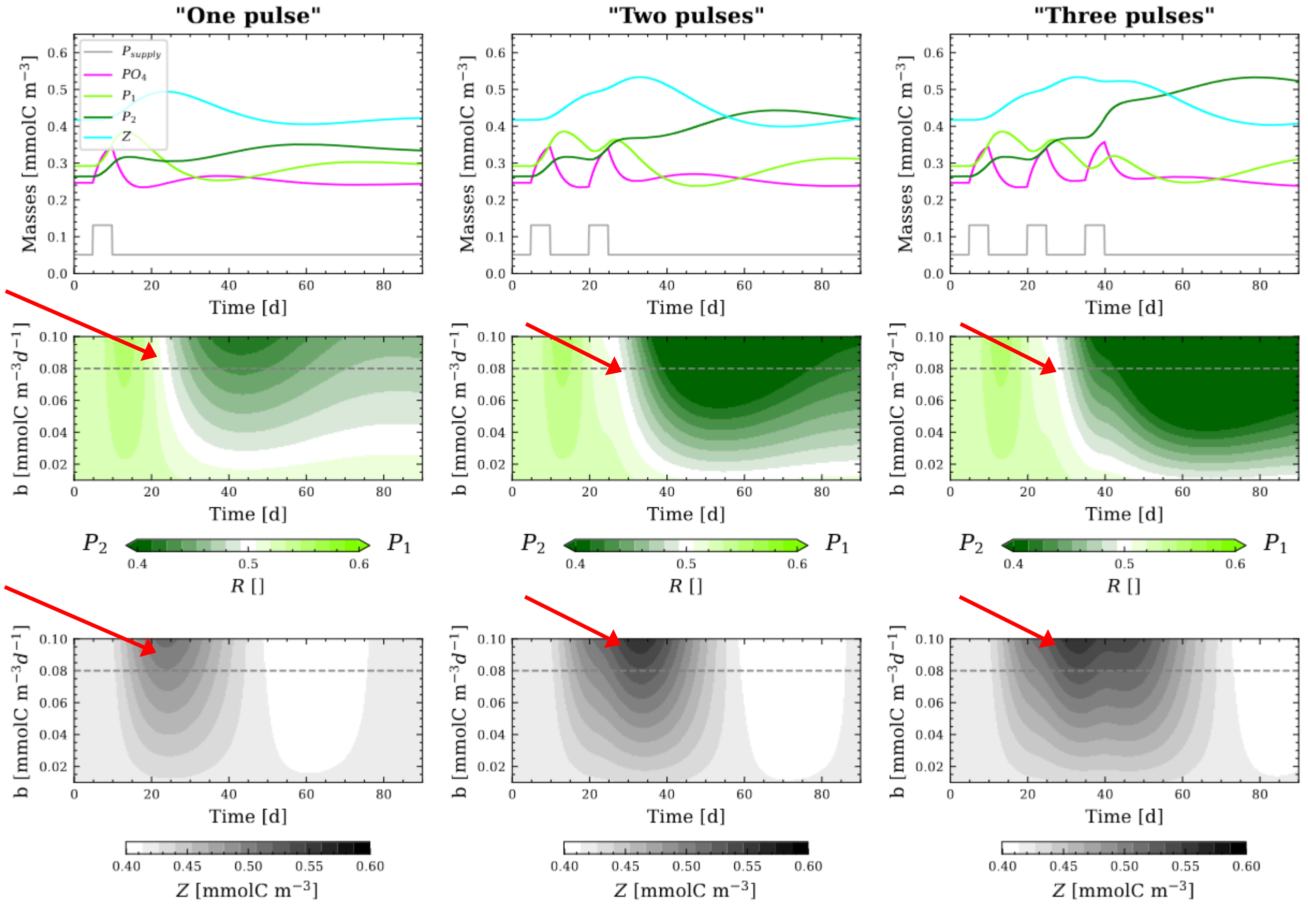
PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Results

2/ Variable environment (pulsed forcing)

*** Dynamical-state solutions of 100 simulations for 1, 2 and 3 pulses**

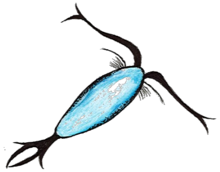
$$0 \leq R = \frac{P_1}{P_1 + P_2} \leq 1$$



Pulse amplitude

transition

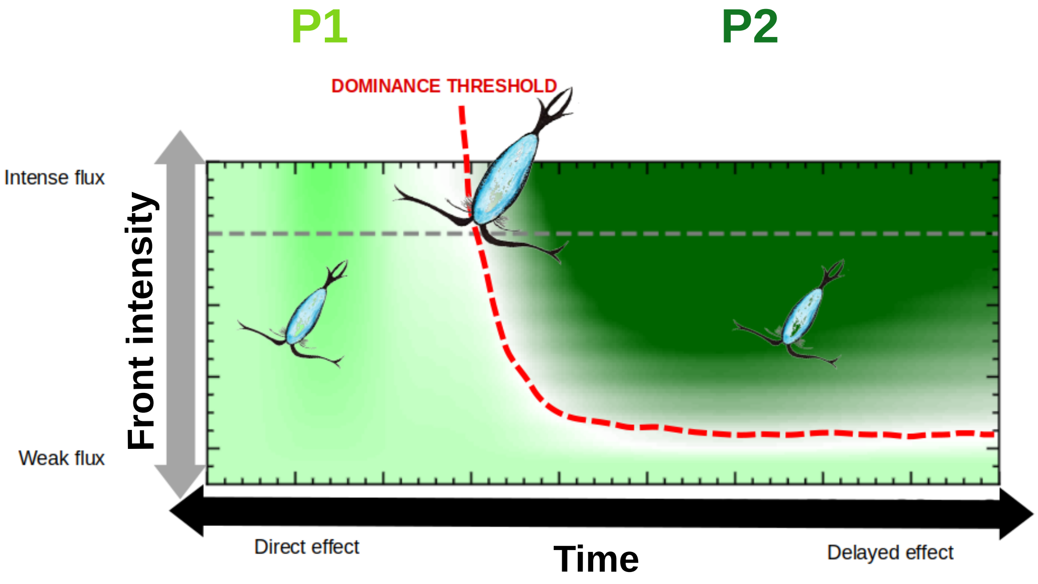
[Z] max



PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Results

2/ Variable environment (pulsed forcing)



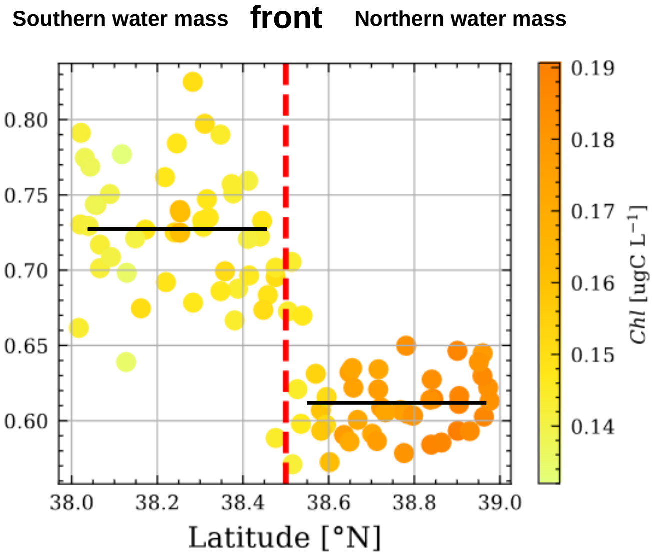
In a variable environment the interplay of bottom-up and top-down controls determines temporal PCTs as a function of pulse characteristics

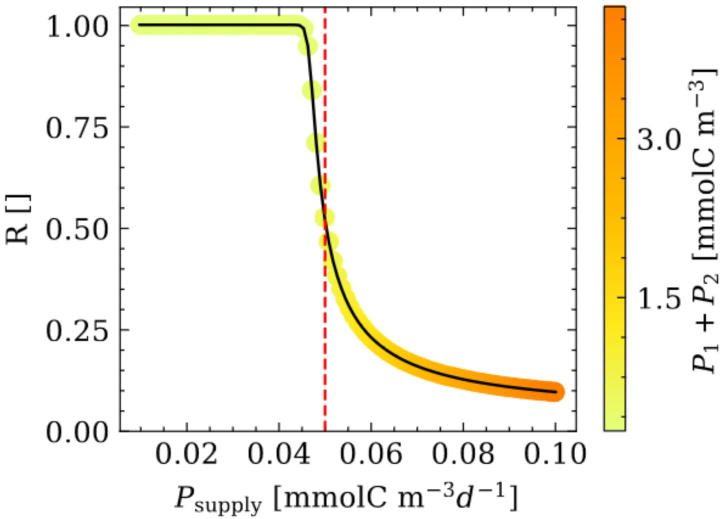
PCTs: Phytoplankton Community Transitions

How do fine-scale dynamics explain PCTs? - Conclusions

Fine-scale dynamics shapes the nutrient seascape and creates PCTs via cascading effects of nutrient transfer through the plankton food chain

* PCTs occur at the scale of **water masses**, where constant Psupply conditions lead to spatial PCTs
* PCTs occur at the scale of **fronts**, where variable Psupply conditions lead to temporal PCTs
* PCTs are controlled by the synergy of bottom-up and top-down controls



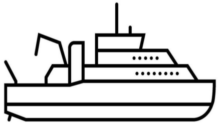


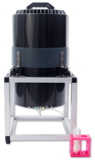
PCTs: Phytoplankton Community Transitions

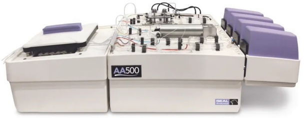
How do fine-scale dynamics explain PCTs? - Perspectives

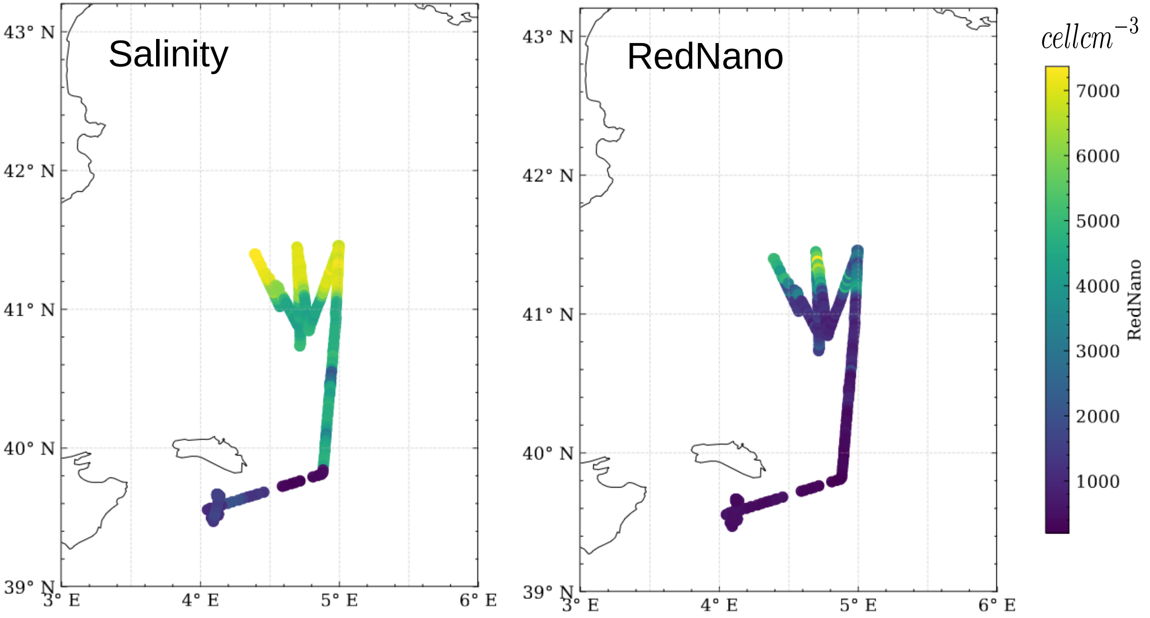
BioSWOT-Med CRUISE (DOI:10.17600/18002392)

BioSWOT Med









High-resolution observations of PCTs accros a frontal area

PCTs: Phytoplankton Community Transitions

mio Mediterranean Institute of Oceanography

cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

Institut Sciences de l'Océan Aix Marseille Université

OCEAN SCIENCES MEETING NEW ORLEANS LOUISIANA 18-23 FEBRUARY 2024

Thank you for listening !!


Andrea Doglioli


Gérald Grégori

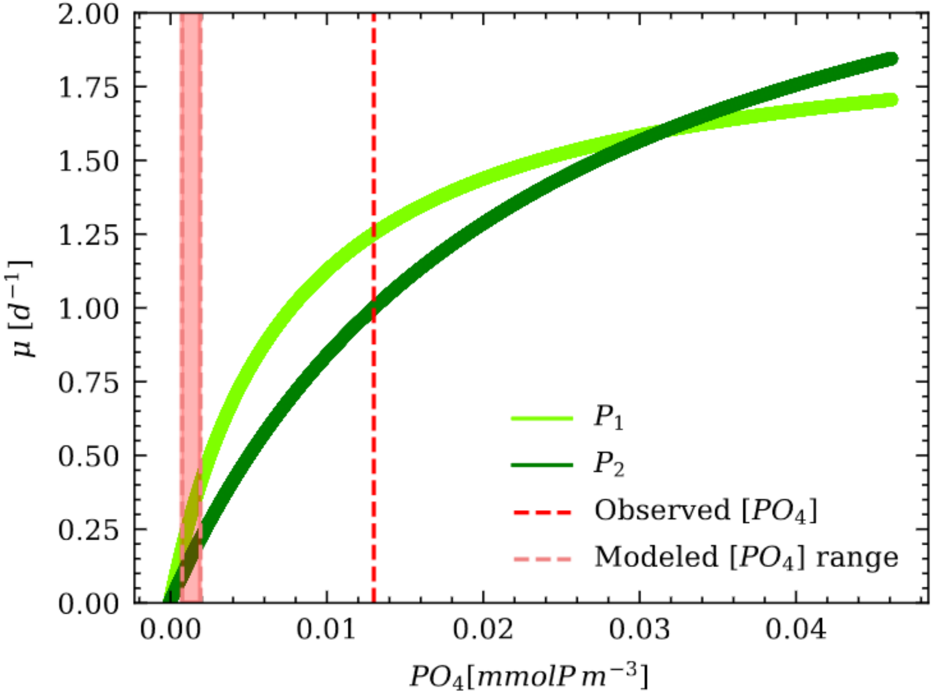

Monique Messié


Jean-Christophe Poggiale

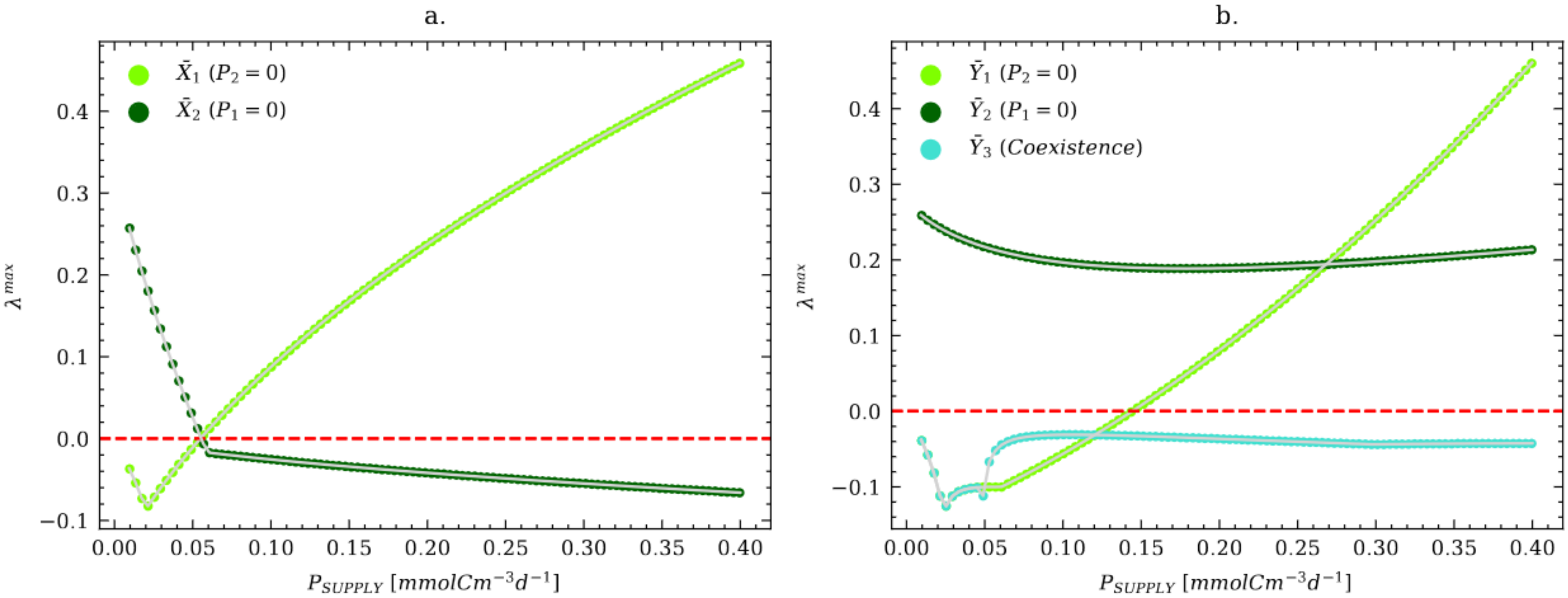
Contact: laurina.oms@mio.osupytheas.fr

February 19th – Ocean Science Meeting

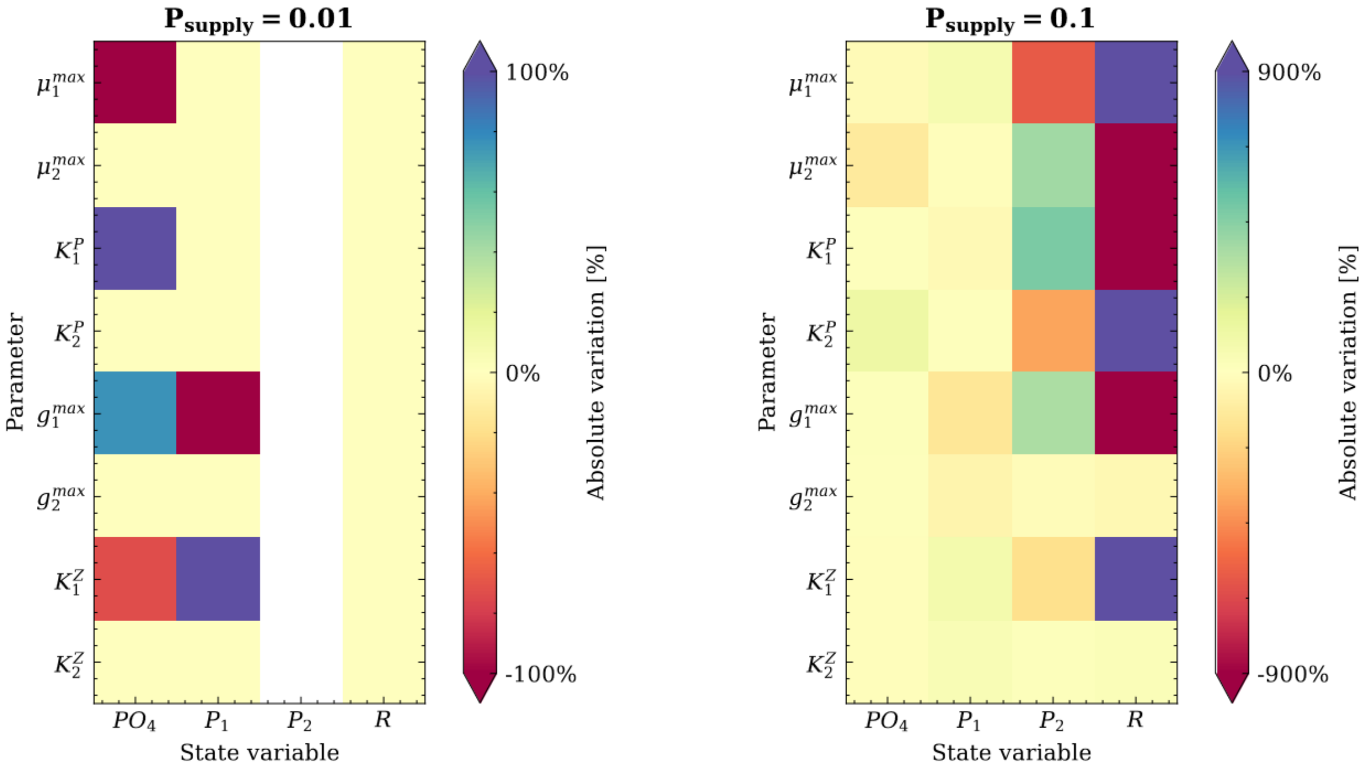
Monod curves



Bifurcation diagrams

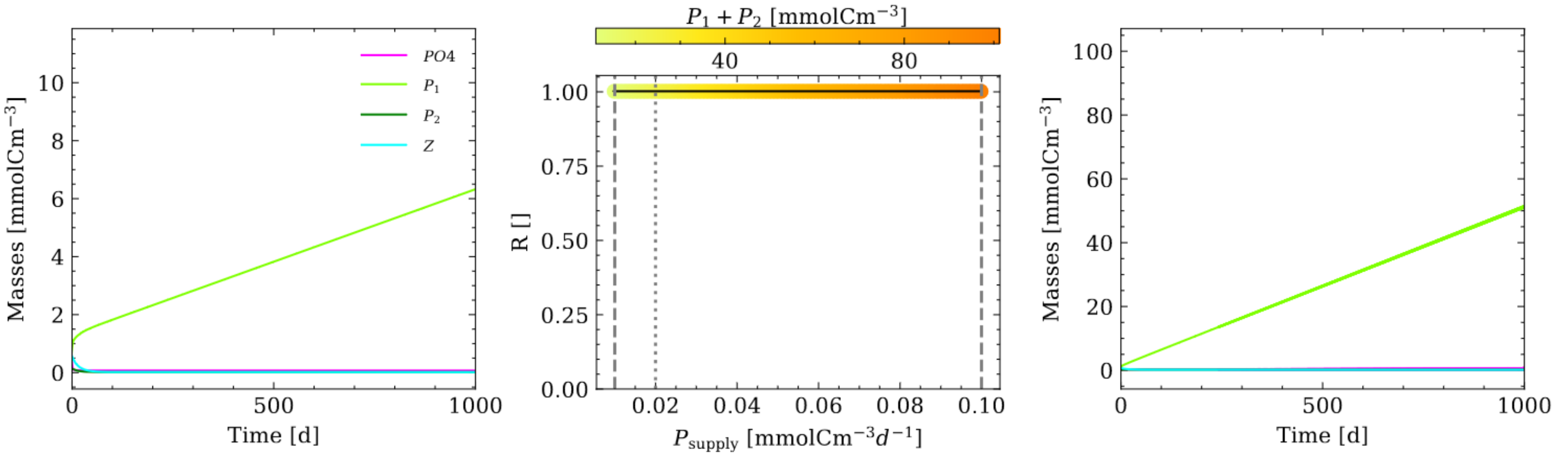


Sensitivity analysis

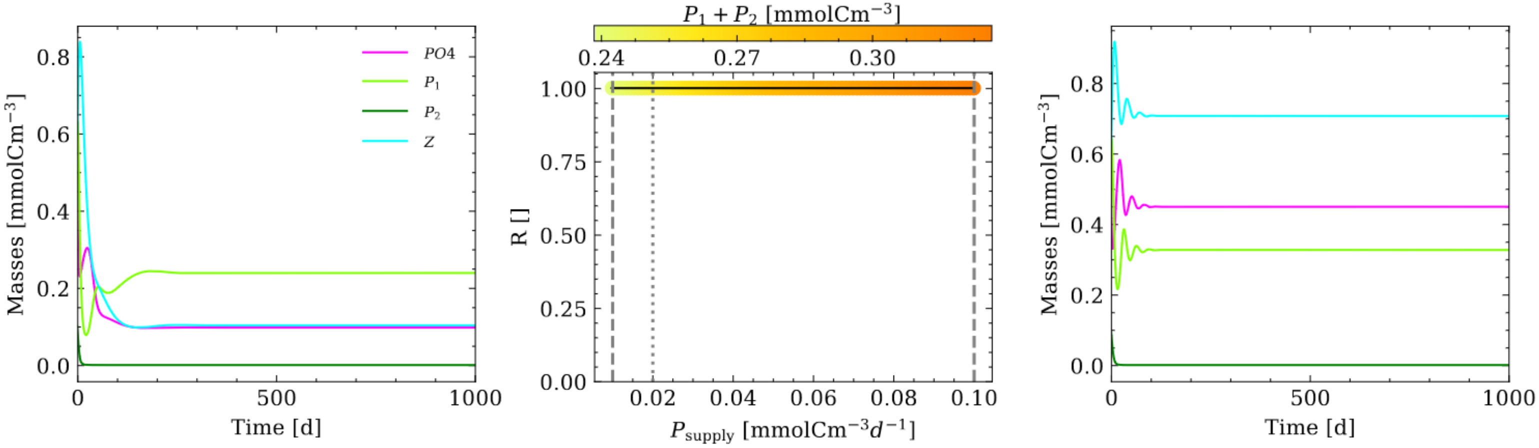


Grazing tests

**** Without grazing (Z=0)***



**** Equal grazing (gmax1 = gmax2)***

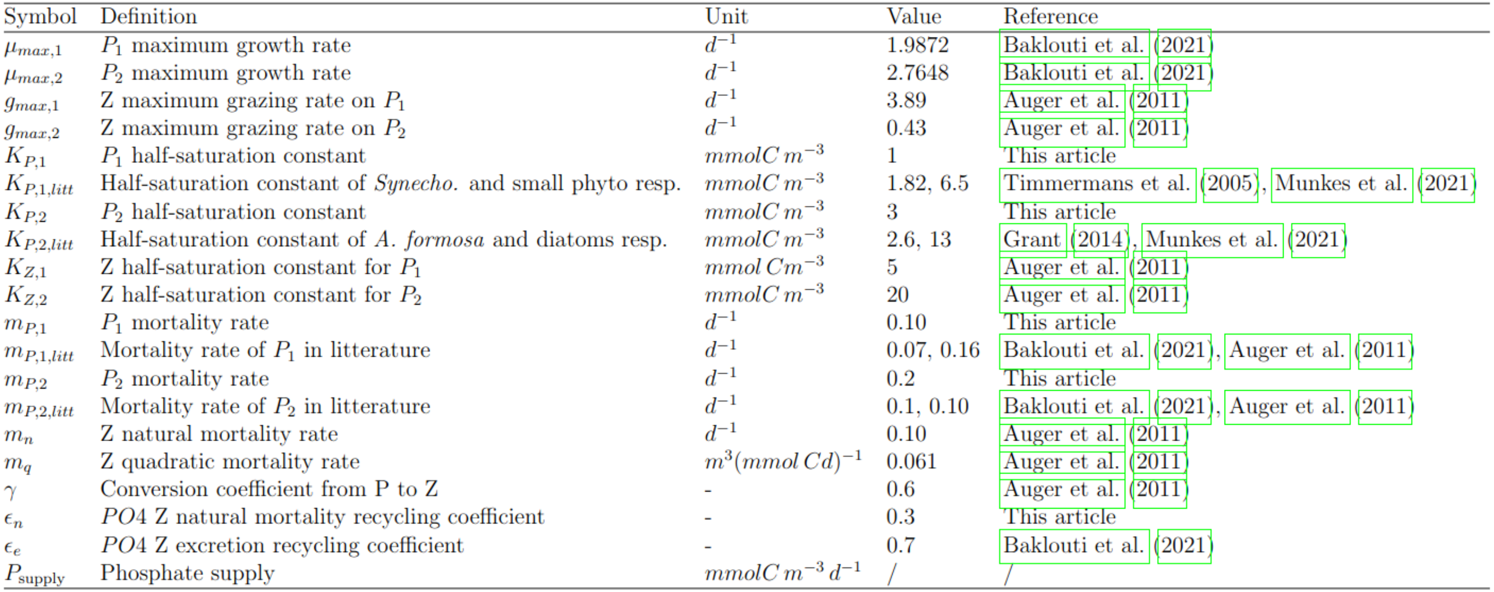


Equations - Parameters

$$\frac{dPO_4}{dt} = P_{supply} + \epsilon_e(1-\gamma)Z\sum g_i + \sum m_{P,i}P_i + \epsilon_n m_n Z - \sum \mu_i P_i$$

$$\frac{dP_i}{dt} = \mu_i P_i - g_i Z - m_{P,i}P_i$$

$$\frac{dZ}{dt} = Z\gamma\sum g_i - m_q Z^2 - m_n Z$$



Symbol	Definition	Unit	Value	Reference
$\mu_{max,1}$	P_1 maximum growth rate	d^{-1}	1.9872	Baklouti et al. (2021)
$\mu_{max,2}$	P_2 maximum growth rate	d^{-1}	2.7648	Baklouti et al. (2021)
$g_{max,1}$	Z maximum grazing rate on P_1	d^{-1}	3.89	Auger et al. (2011)
$g_{max,2}$	Z maximum grazing rate on P_2	d^{-1}	0.43	Auger et al. (2011)
$K_{P,1}$	P_1 half-saturation constant	$mmolC\,m^{-3}$	1	This article
$K_{P,1,litt}$	Half-saturation constant of *Synecho.* and small phyto resp.	$mmolC\,m^{-3}$	1.82, 6.5	Timmermans et al. (2005), Munkes et al. (2021)
$K_{P,2}$	P_2 half-saturation constant	$mmolC\,m^{-3}$	3	This article
$K_{P,2,litt}$	Half-saturation constant of *A. formosa* and diatoms resp.	$mmolC\,m^{-3}$	2.6, 13	Grant (2014), Munkes et al. (2021)
$K_{Z,1}$	Z half-saturation constant for P_1	$mmol\,Cm^{-3}$	5	Auger et al. (2011)
$K_{Z,2}$	Z half-saturation constant for P_2	$mmolC\,m^{-3}$	20	Auger et al. (2011)
$m_{P,1}$	P_1 mortality rate	d^{-1}	0.10	This article
$m_{P,1,litt}$	Mortality rate of P_1 in litterature	d^{-1}	0.07, 0.16	Baklouti et al. (2021), Auger et al. (2011)
$m_{P,2}$	P_2 mortality rate	d^{-1}	0.2	This article
$m_{P,2,litt}$	Mortality rate of P_2 in litterature	d^{-1}	0.1, 0.10	Baklouti et al. (2021), Auger et al. (2011)
m_n	Z natural mortality rate	d^{-1}	0.10	Auger et al. (2011)
m_q	Z quadratic mortality rate	$m^3(mmol\,Cd)^{-1}$	0.061	Auger et al. (2011)
γ	Conversion coefficient from P to Z	-	0.6	Auger et al. (2011)
ϵ_n	*PO4* Z natural mortality recycling coefficient	-	0.3	This article
ϵ_e	*PO4* Z excretion recycling coefficient	-	0.7	Baklouti et al. (2021)
P_{supply}	Phosphate supply	$mmolC\,m^{-3}\,d^{-1}$	/	/

Biomass calculations

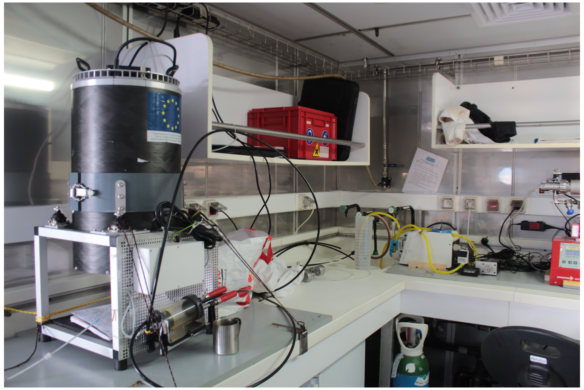
$$\mathrm{BioV} = \mathrm{FWS}^{\beta_1} \cdot e^{-\beta_0}$$

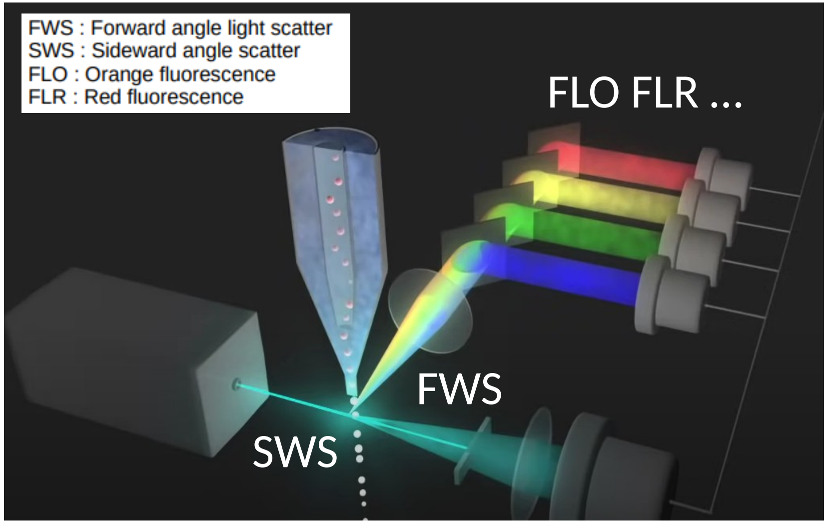
$$Q_c = \alpha_0 \cdot \mathrm{BioV}^{\alpha_1}$$

$$\mathrm{BioM} = \mathrm{abundance} \cdot \bar{Q}_c$$

	Menden-Deuer and Lessard (2000)	α_0	α_1
PICO	Protist plankton* (line 1)	0.210	0.939
NANO	Protist plankton (line 2)	0.260	0.860
MICRO	Diatoms (line 3)	0.287	0.811

Automated Flow Cytometry





FWS : Forward angle light scatter
SWS : Sideward angle scatter
FLO : Orange fluorescence
FLR : Red fluorescence