Universida de Vigo

Control of the structure of marine picoplankton communities by turbulence and nutrient supply dynamics

Grupo de Oceanografía Biolóxica

DO MAR
PHD PROGRAM IN MARINE SCIENCE, TECHNOLOGY AND MANAGEMENT

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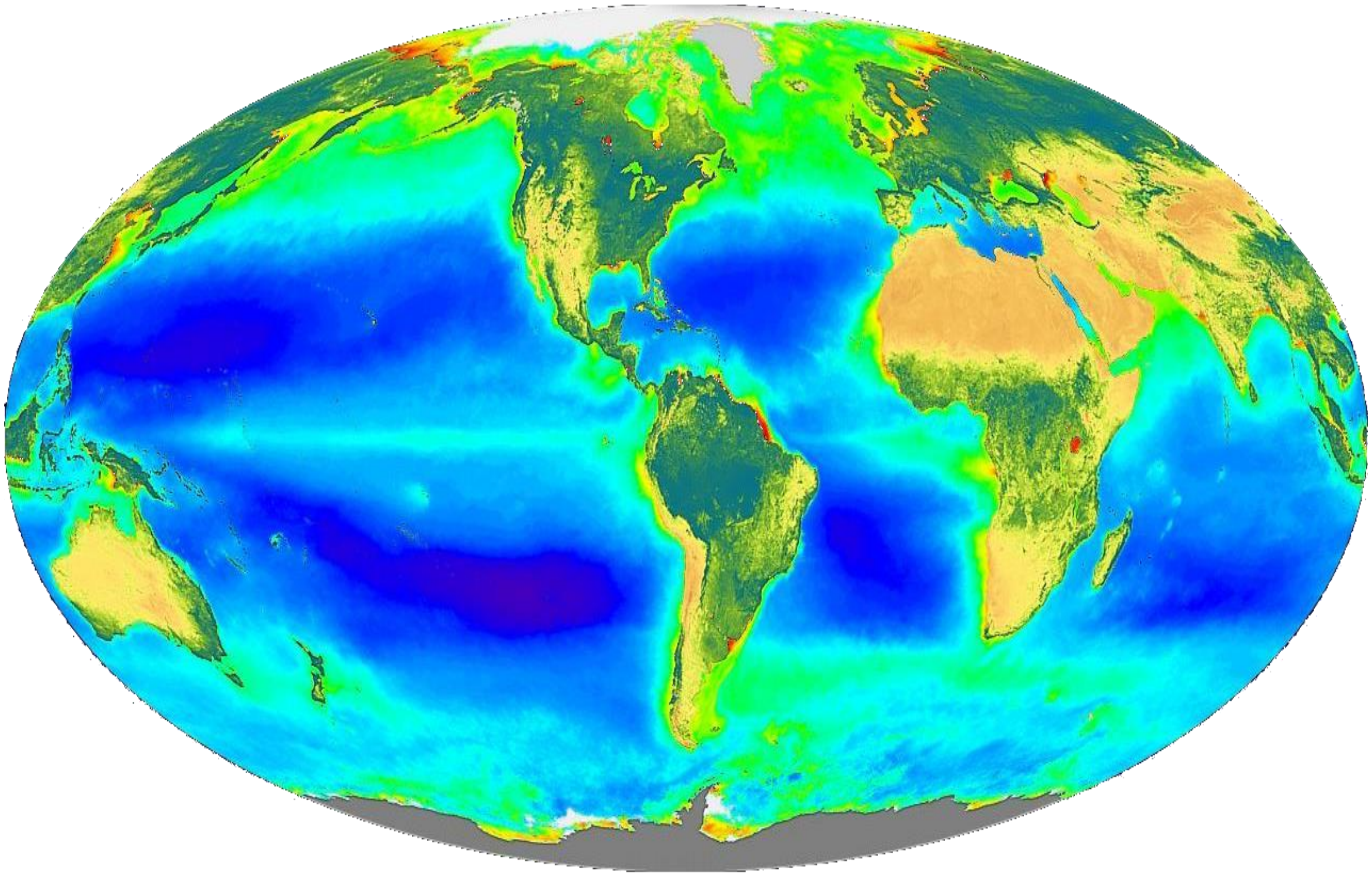
Beatriz Mouriño
Pedro Cermeño

Introduction

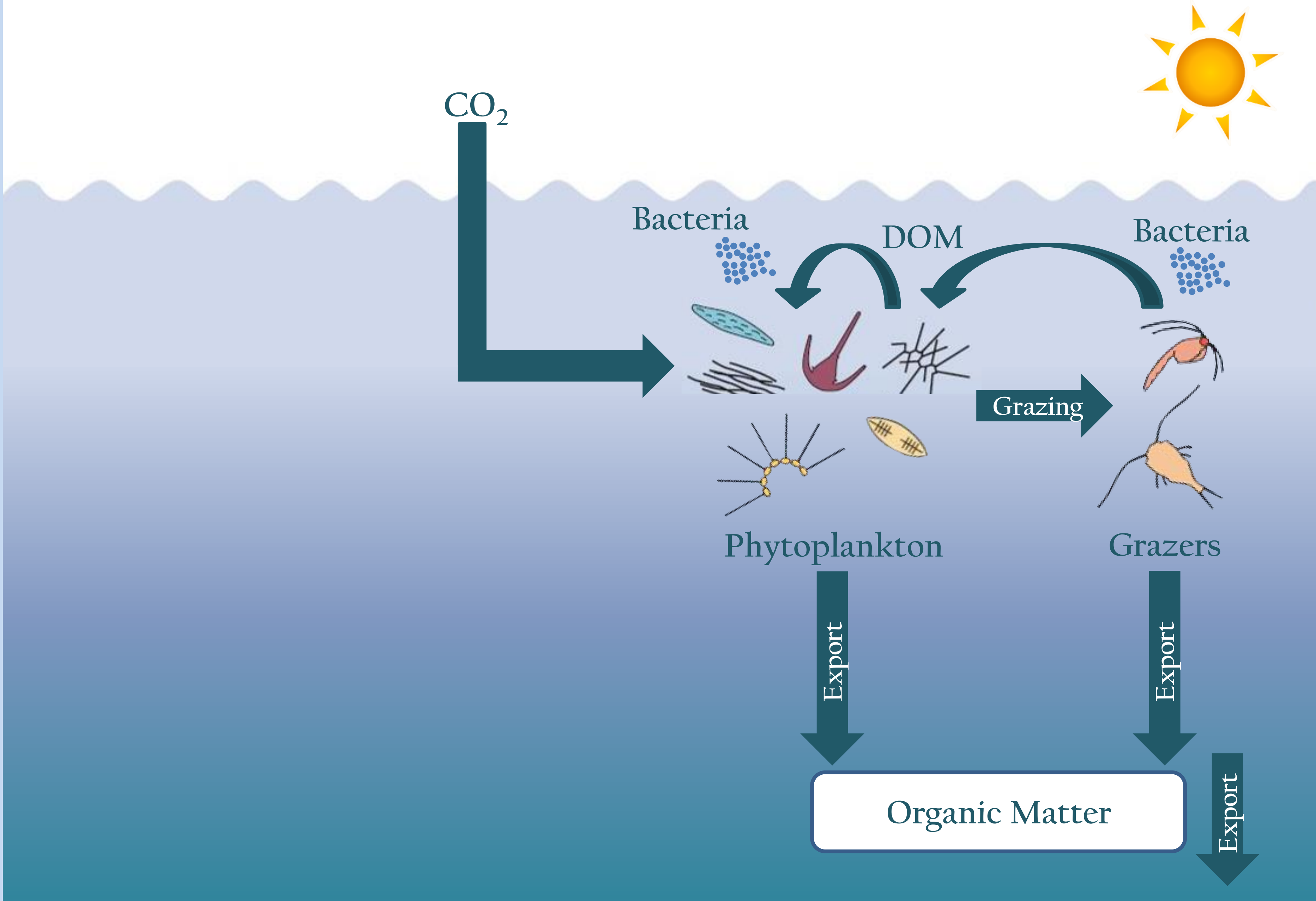
The importance of phytoplankton



MODIS Science Team

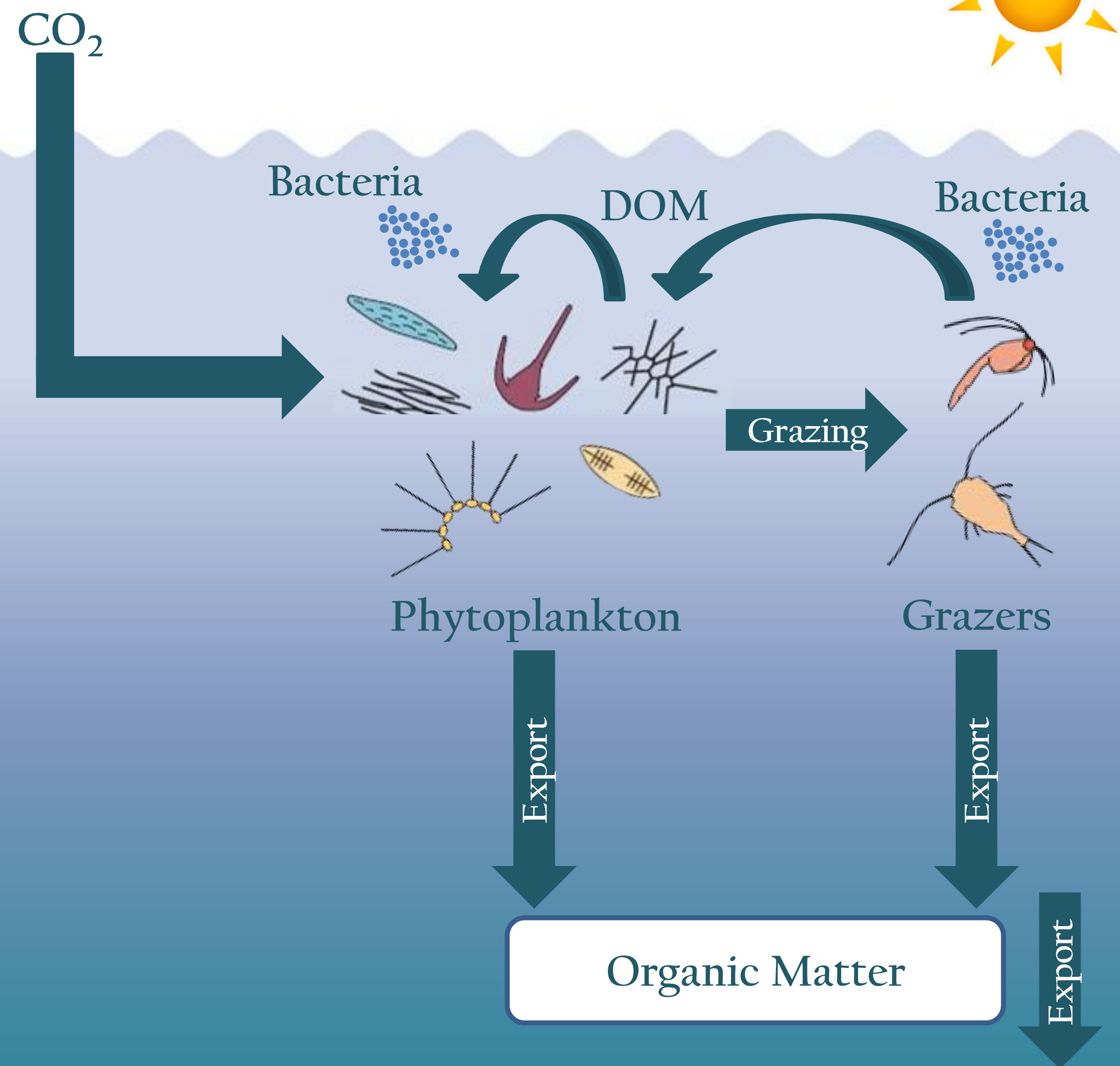
INTRODUCTION

Phytoplankton and the biological carbon pump



Phytoplankton and the biological carbon pump

$$H_2PO_4 + 16NO^-_3 + 106CO_2 + 122H_2O \leftrightarrow (C_{106}H_{263}O_{110}N_{16}P_1) + 138O_2$$



Redfield Ratios

C:N = 6.6

N:P = 16

Phytoplankton and the biological carbon pump

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INTRODUCTION

Redfield Ratios
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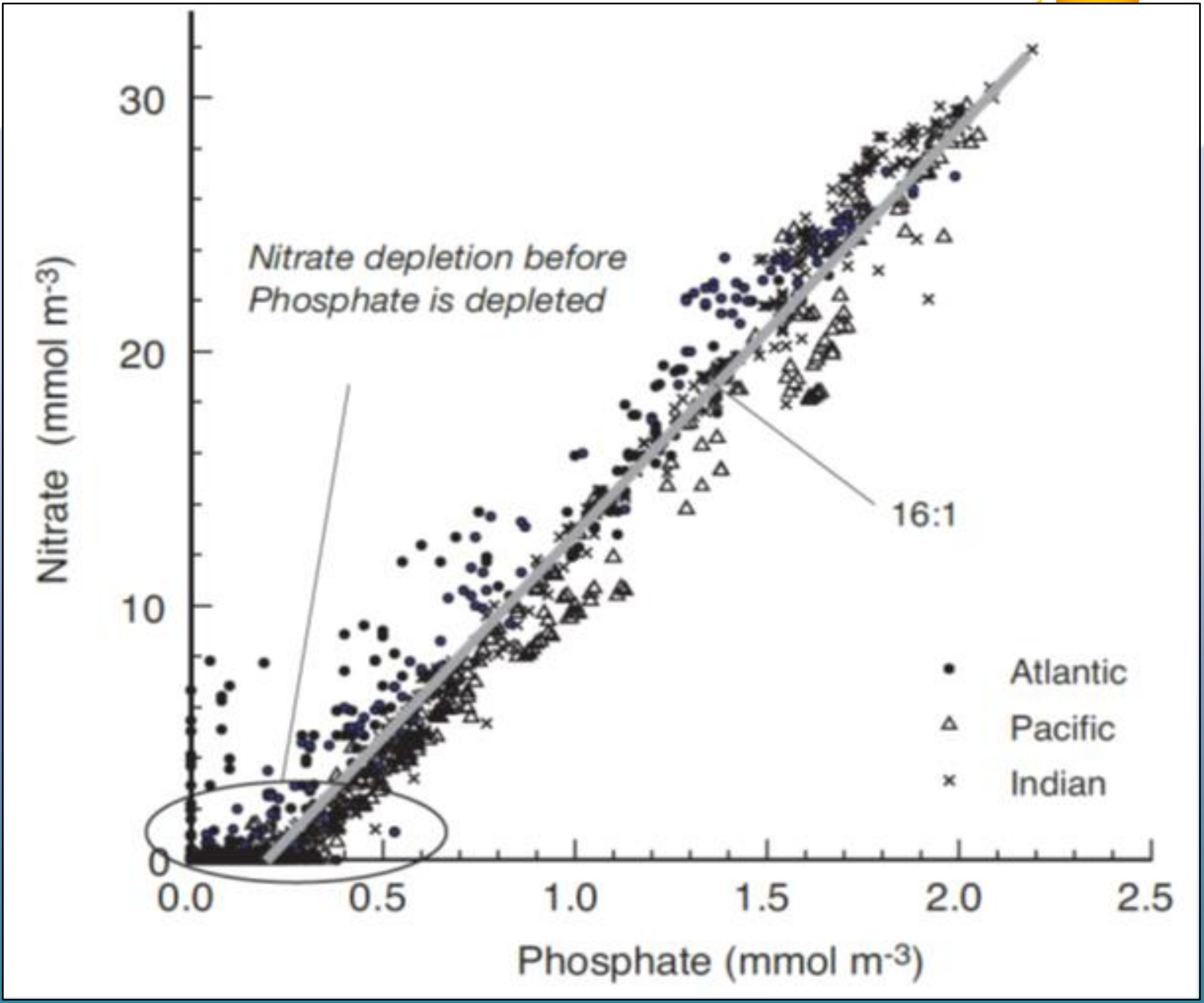
N:P = 16



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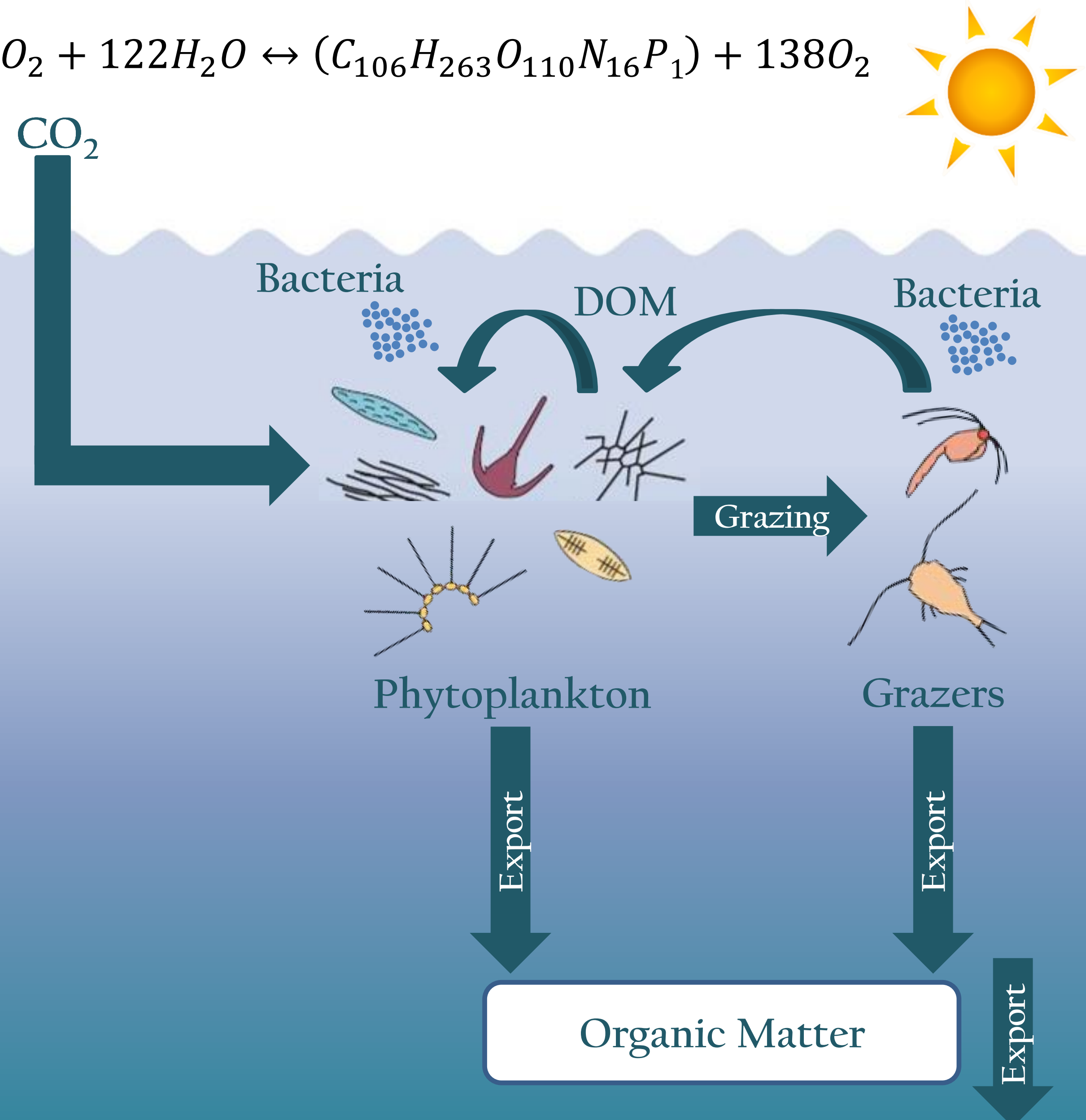

Redfield Ratios

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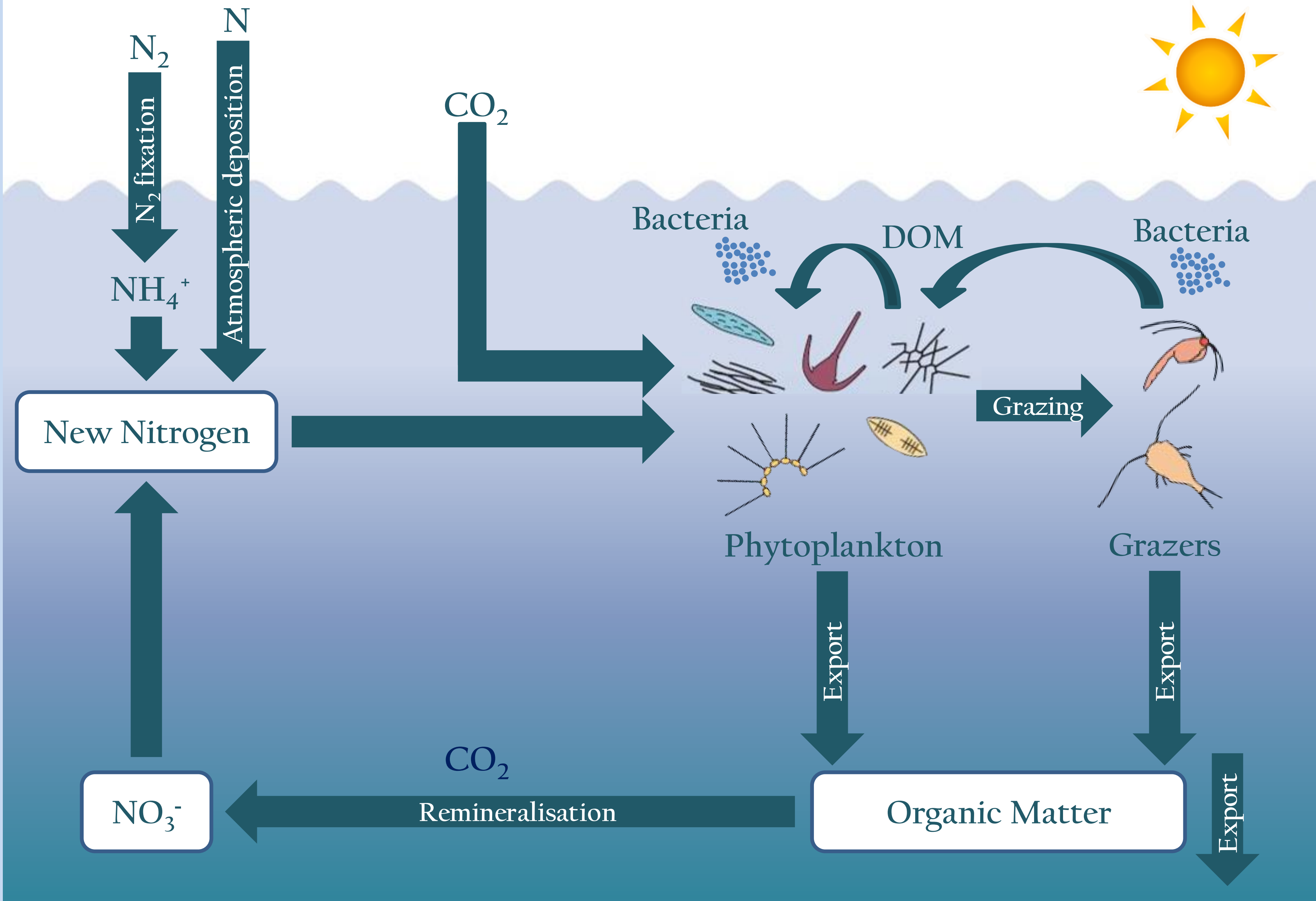
Relevance of nitrogen and supply mechanisms



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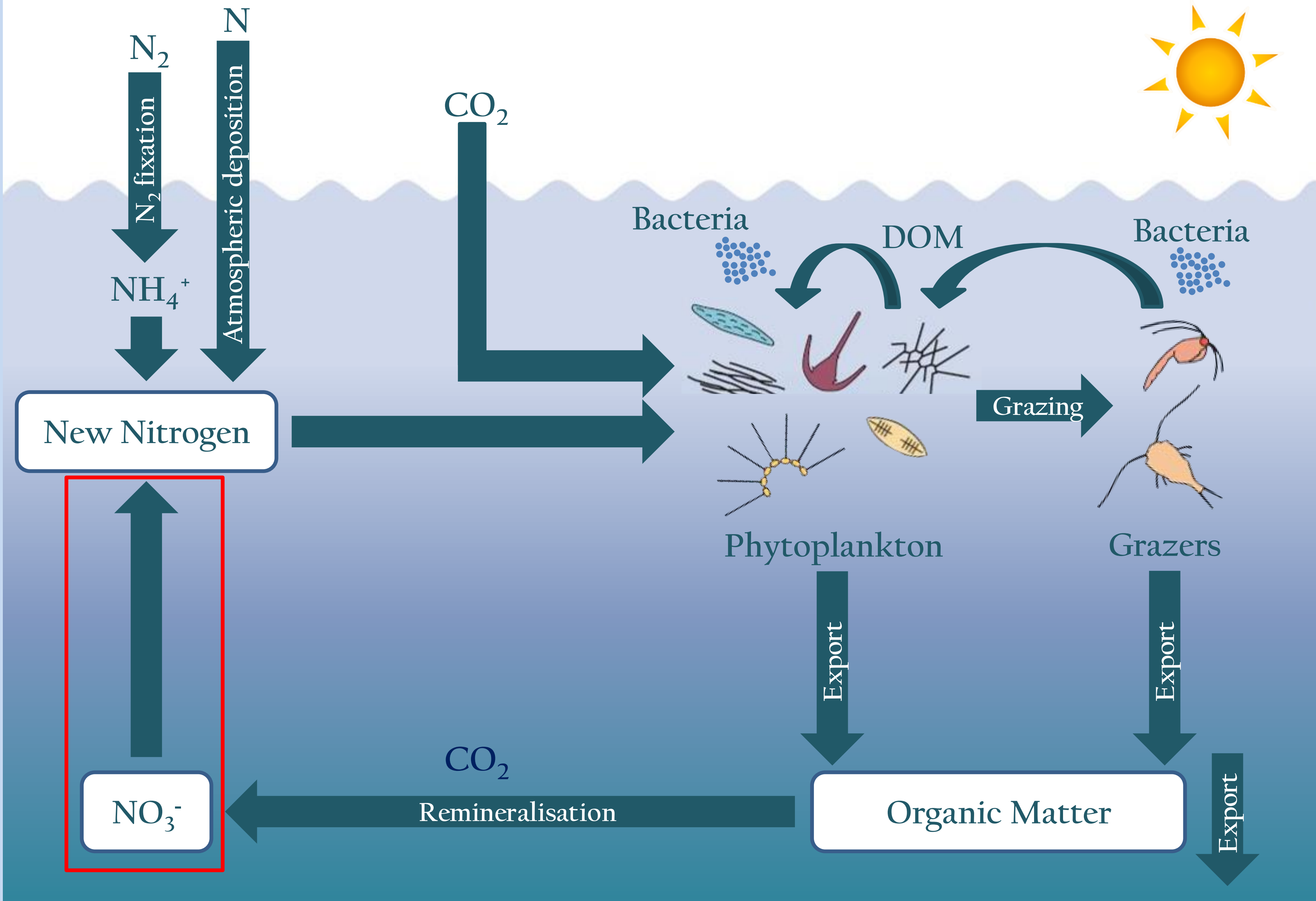
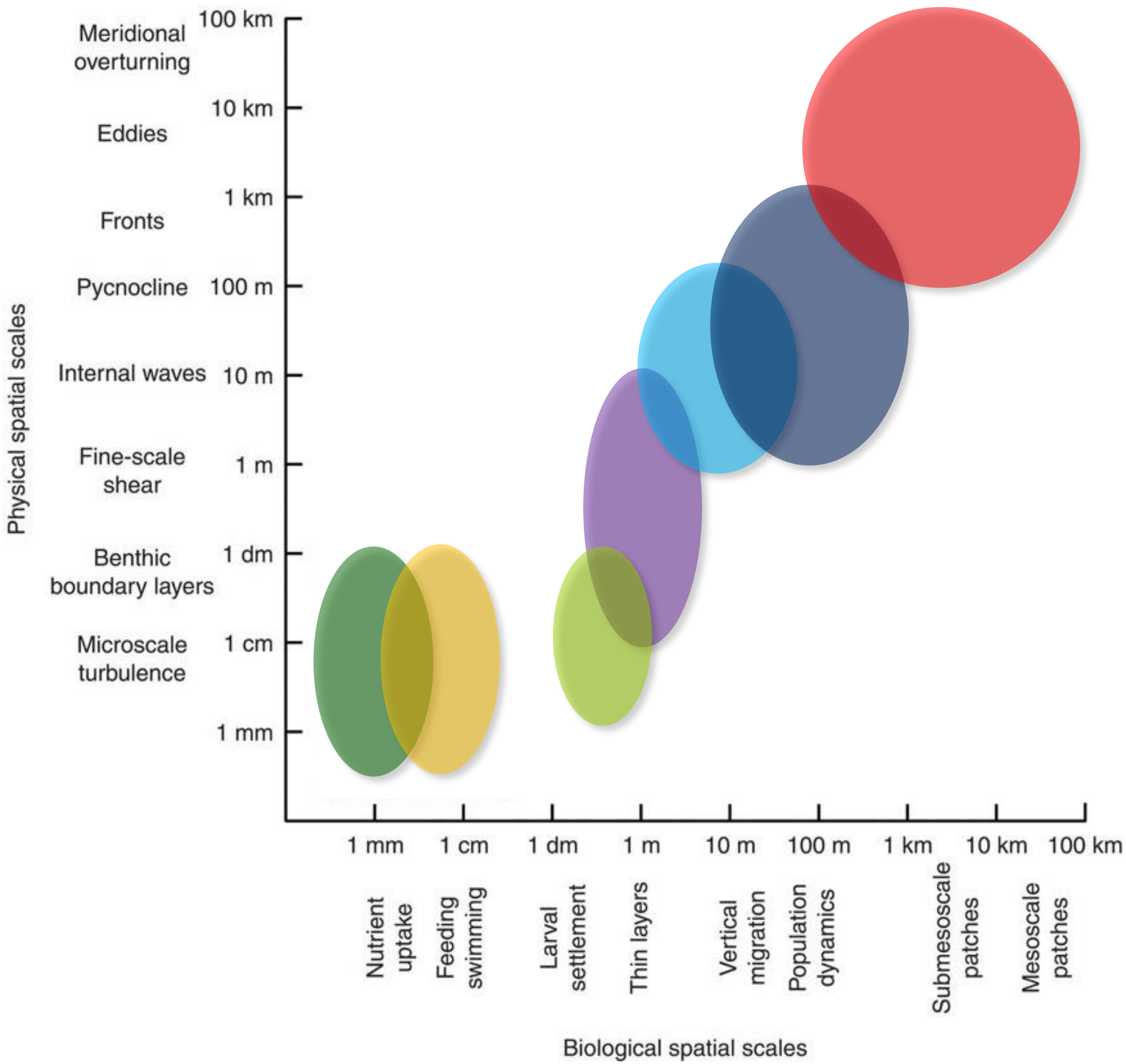


Turbulence effects over biological data



Modified from Prairie et al. (2012)

How is turbulence measured?

- Microstructure shear sensor
- CTD

Microstructure turbulence profiler (MSS)

- ❑ Microstructure shear sensor ➡ Disipation rate of turbulent kinetic energy (ε).
- ❑ CTD ➡ Brunt–Väisälä frequency (N).

Microstructure turbulence profiler (MSS)

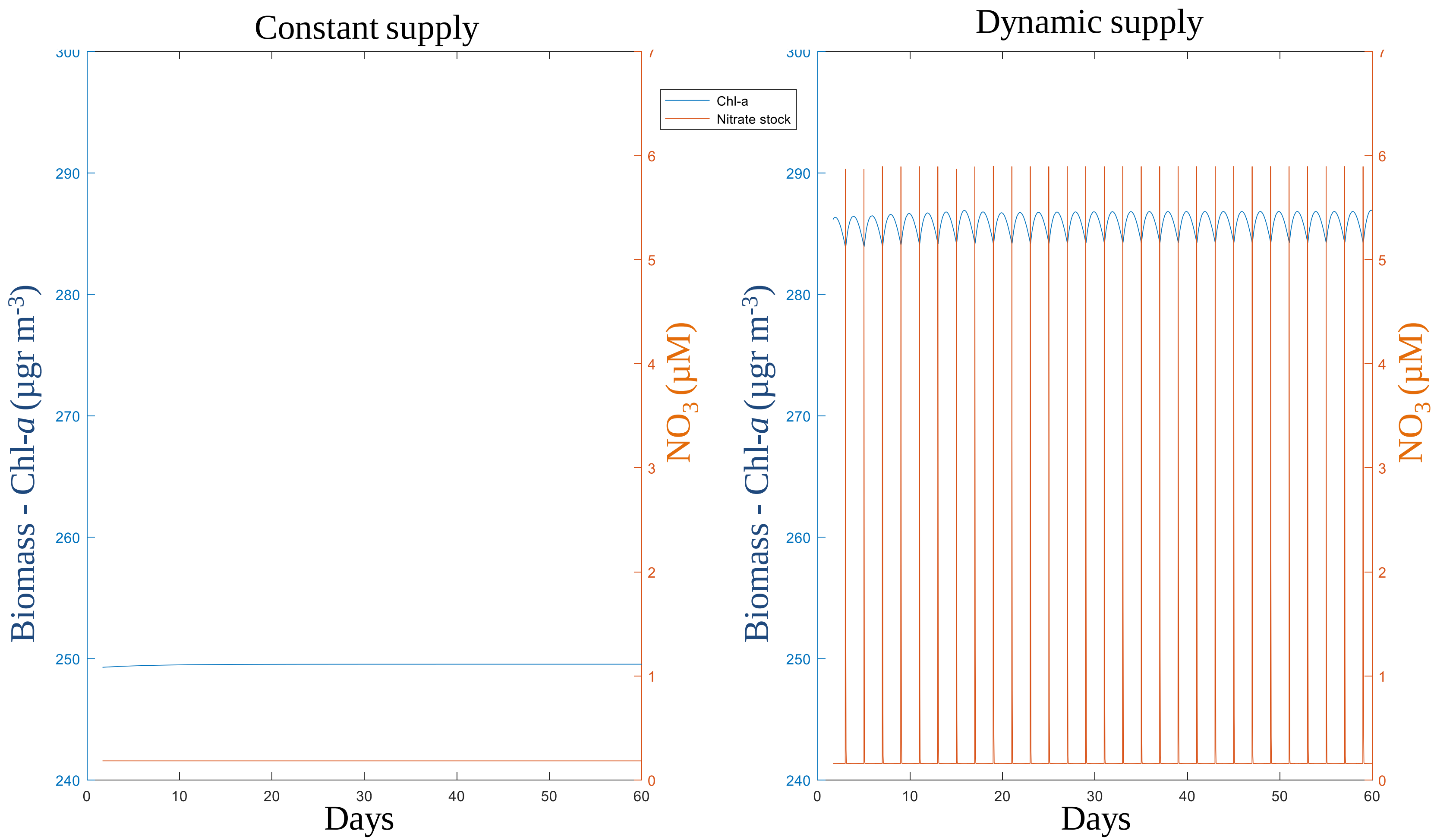
- ❑ Microstructure shear sensor → Disipation rate of turbulent kinetic energy (ε).
- ❑ CTD → Brunt–Väisälä frequency (N).

Vertical diffusivity (K_z):

$$Kz = 0.2\frac{\varepsilon}{N^2}$$

Osborn (1980)

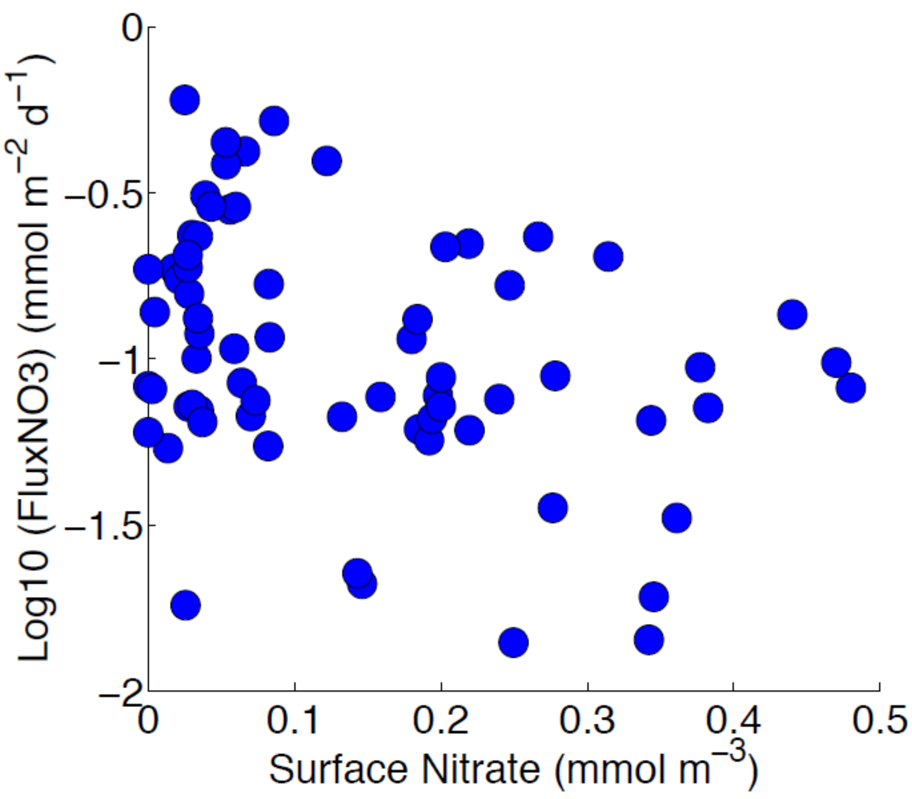
Nutrient stock and nutrient flux



$$\frac{dNO_3}{dt} = Supply - Uptake = 0$$

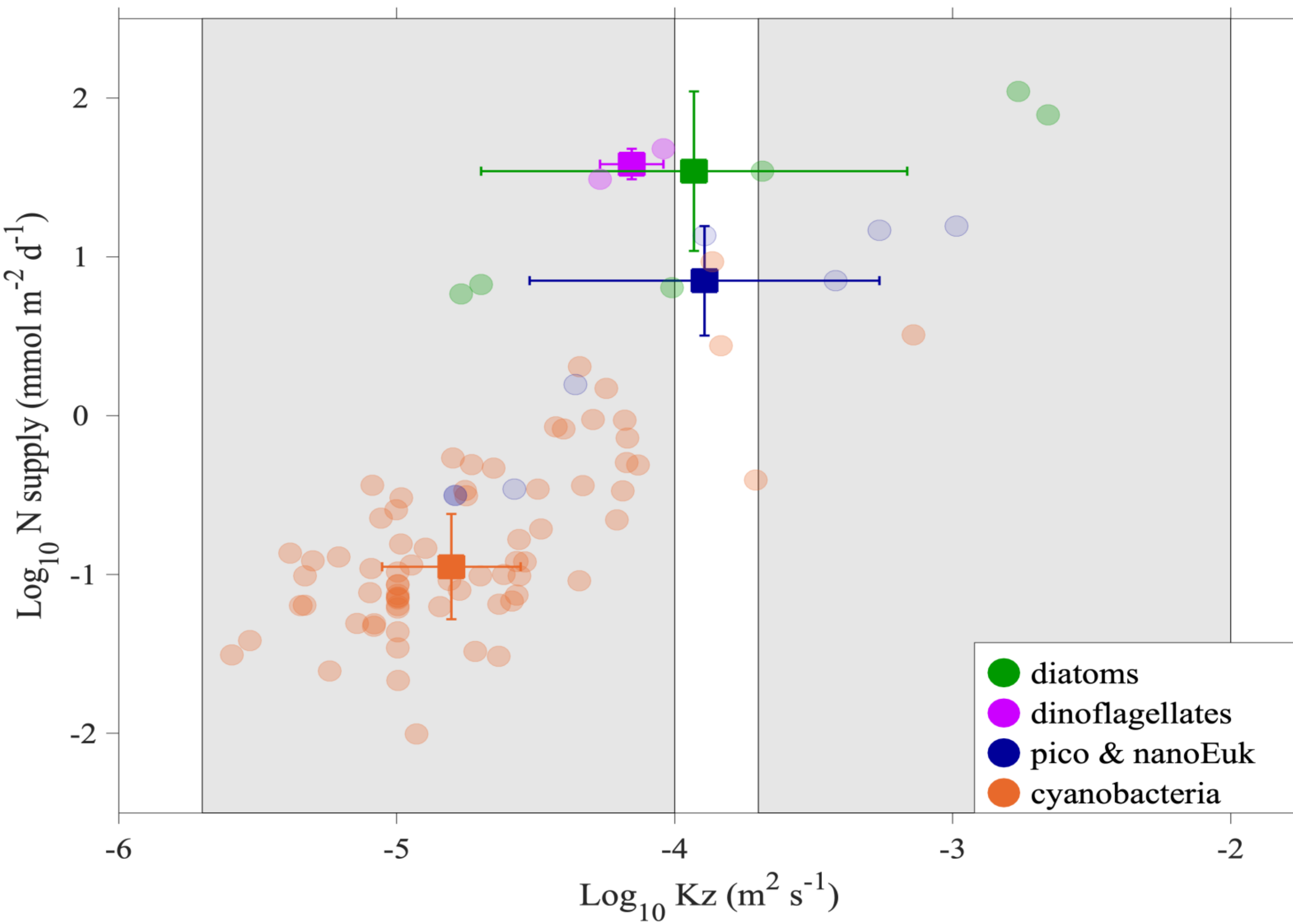
$$\frac{dNO_3}{dt} = Supply - Uptake \neq 0$$

Nutrient stock and nutrient flux in Atlantic Ocean



The variability in nutrient stock **can be disconnected** from changes in nutrient supply (Mouriño-Carballido *et al*. 2011)

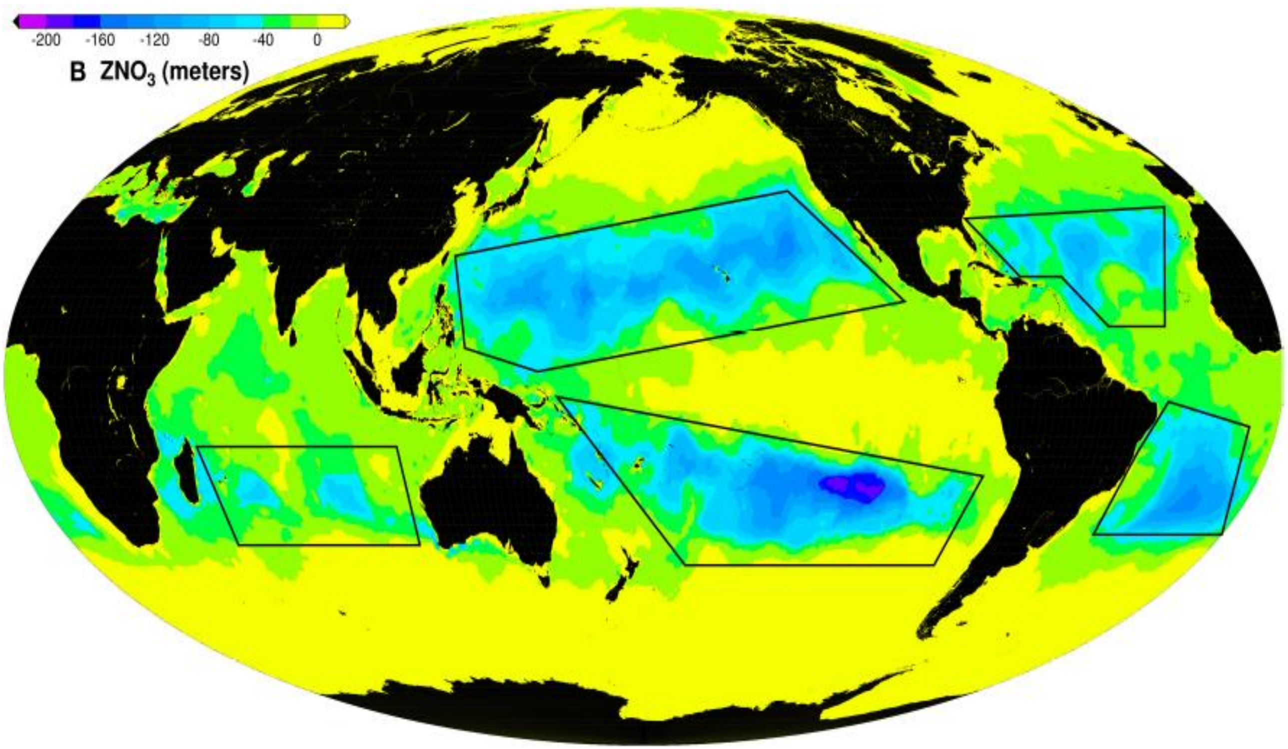
Competition dynamics



Villamaña et al., 2019

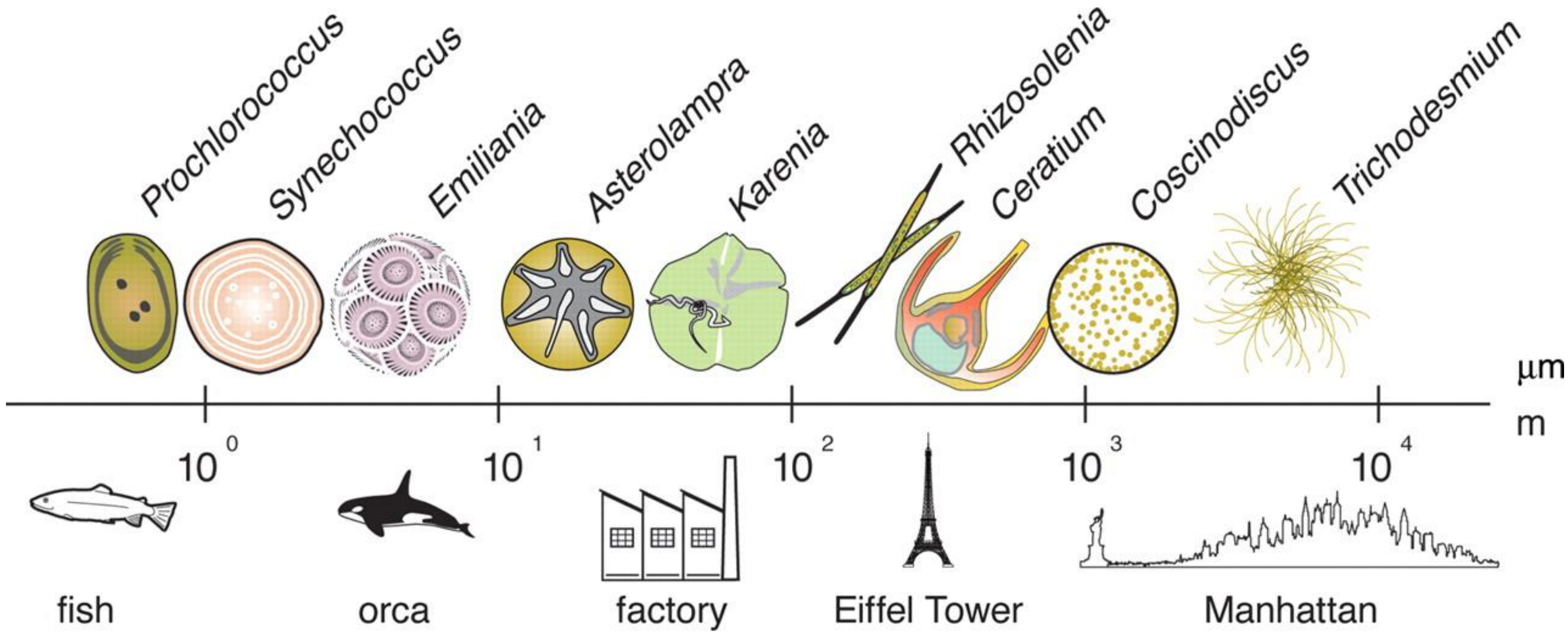
Why picoplankton?

- The most abundant organisms in the ocean
- Picophytoplankton often dominate primary production in gyres
- Expected future expansion of gyres area in a future ocean scenario



INTRODUCTION

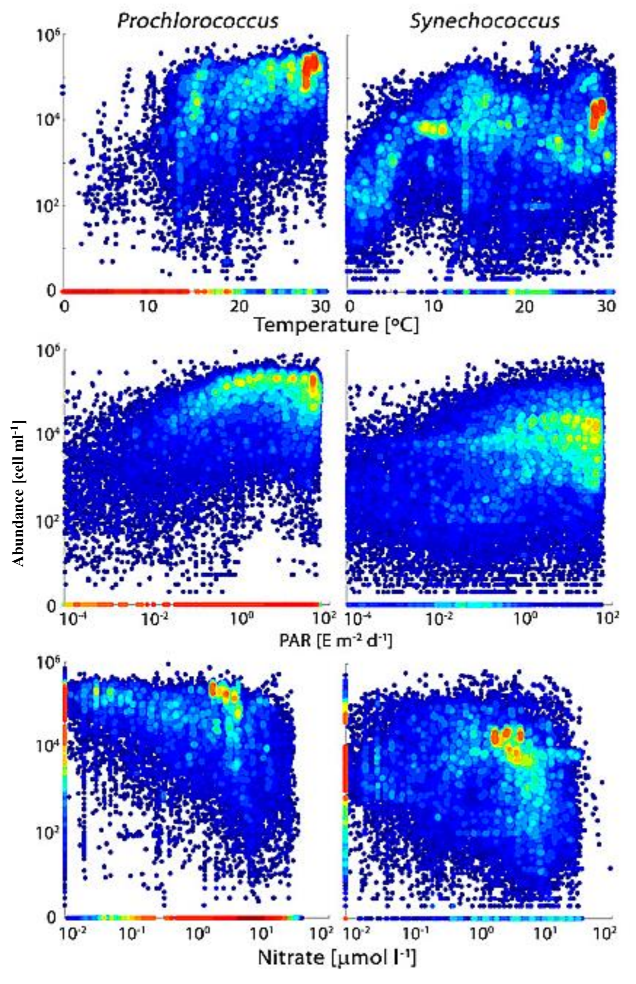
Which groups do picoplankton include ?



Finkel, 2010

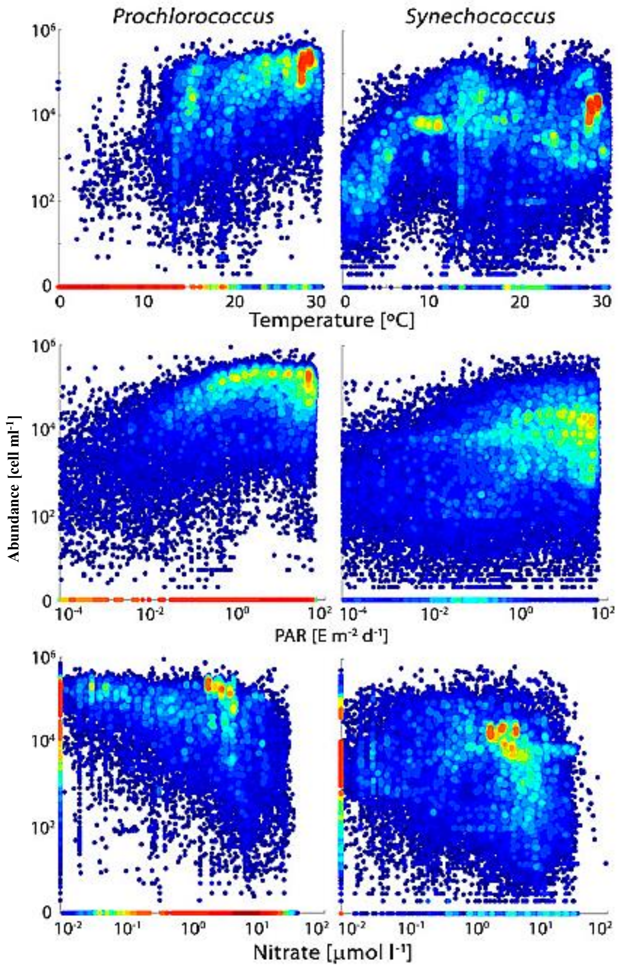
Bacterioplankton	Cyanobacteria	Picoeukaryotes
LNA	*Prochorococcus*	
HNA	*Synechococcus*	

Environmental control factors in the distribution of picophytoplankton



Environmental control factors in the distribution of picophytoplankton

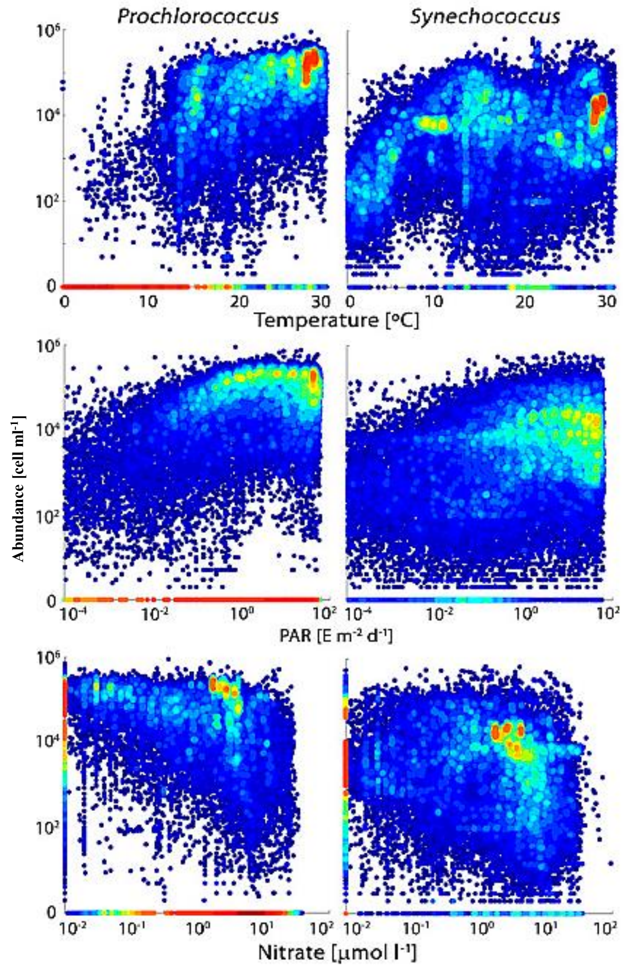
Temperature



Light

Environmental control factors in the distribution of picophytoplankton

Temperature



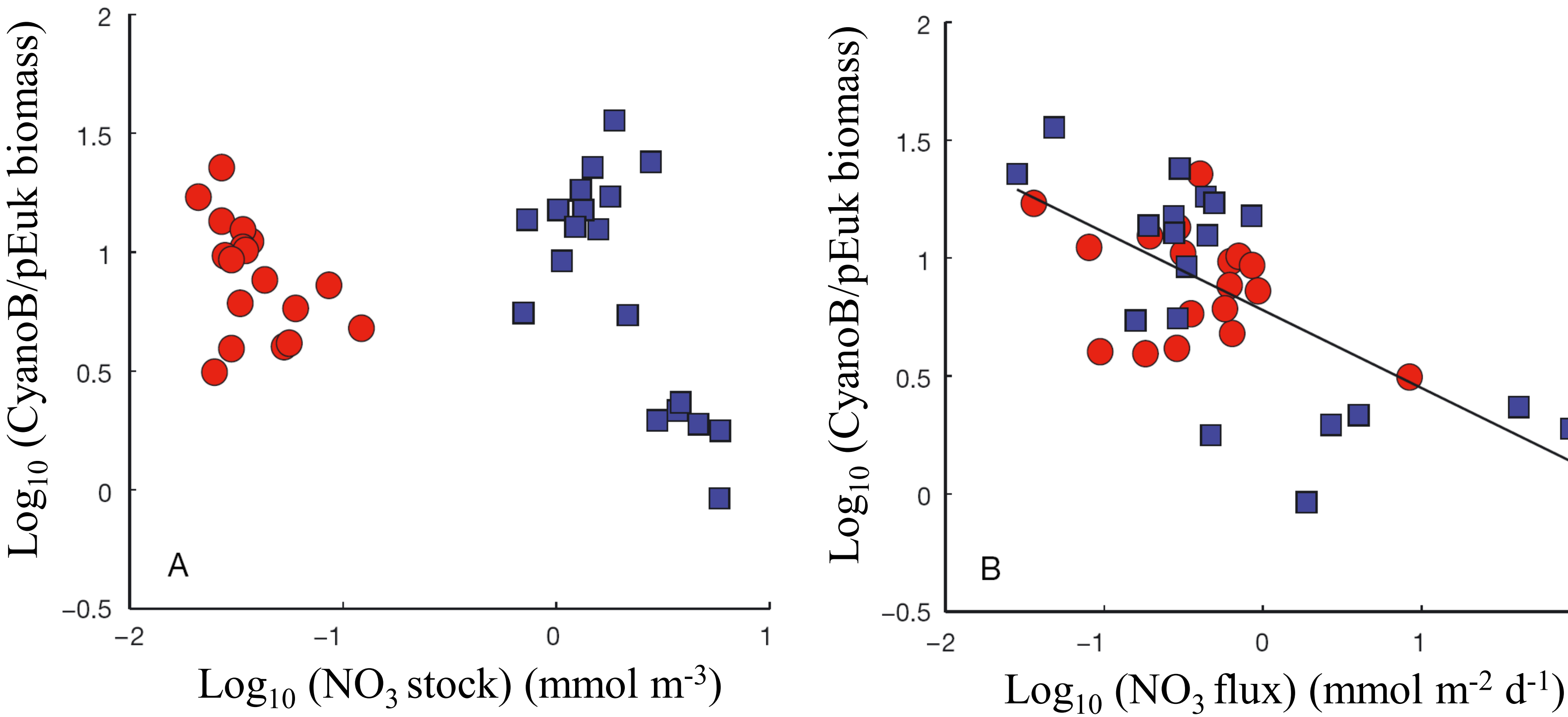
Light

~~Nutrients~~

Temperature & **Light** are the main control factors of the regional distributions of both *Prochlorococcus* and *Synechococcus* (Flombaum *et al.*, 2013).

Environmental control factors in the distribution and activity of picoplankton

BACKGROUND



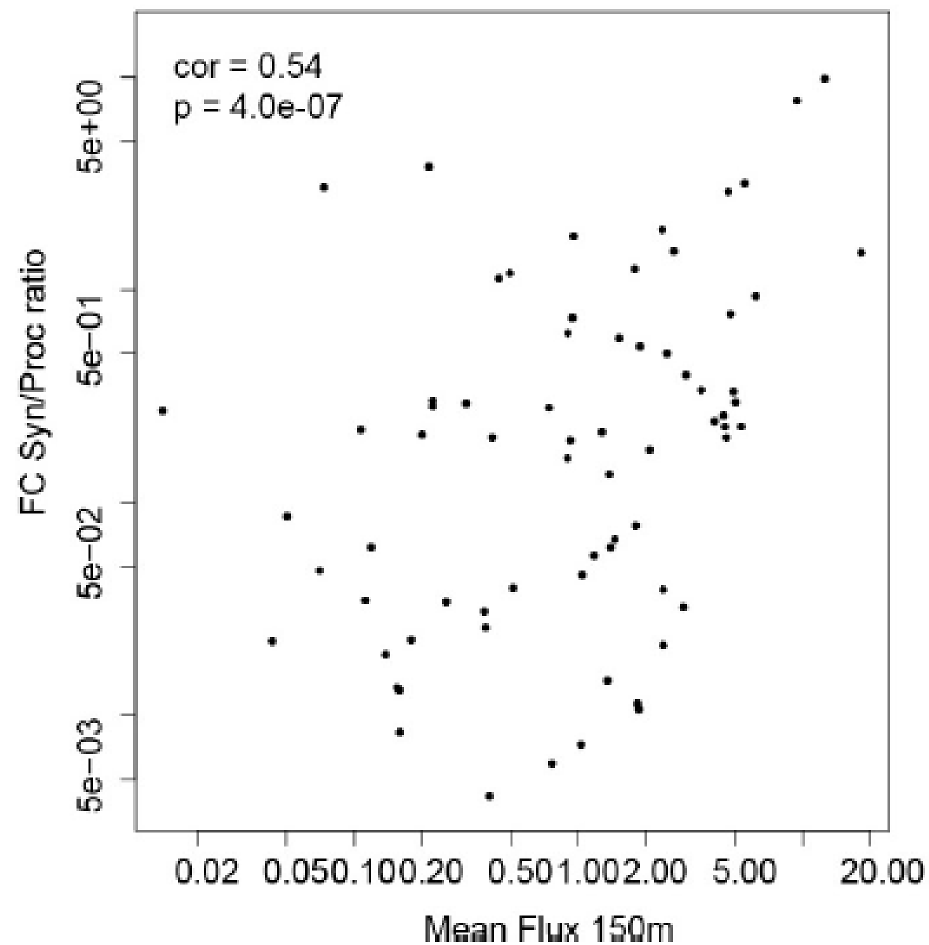
Reproduced from Mouriño-Carballido et al. (2016)

BACKGROUND

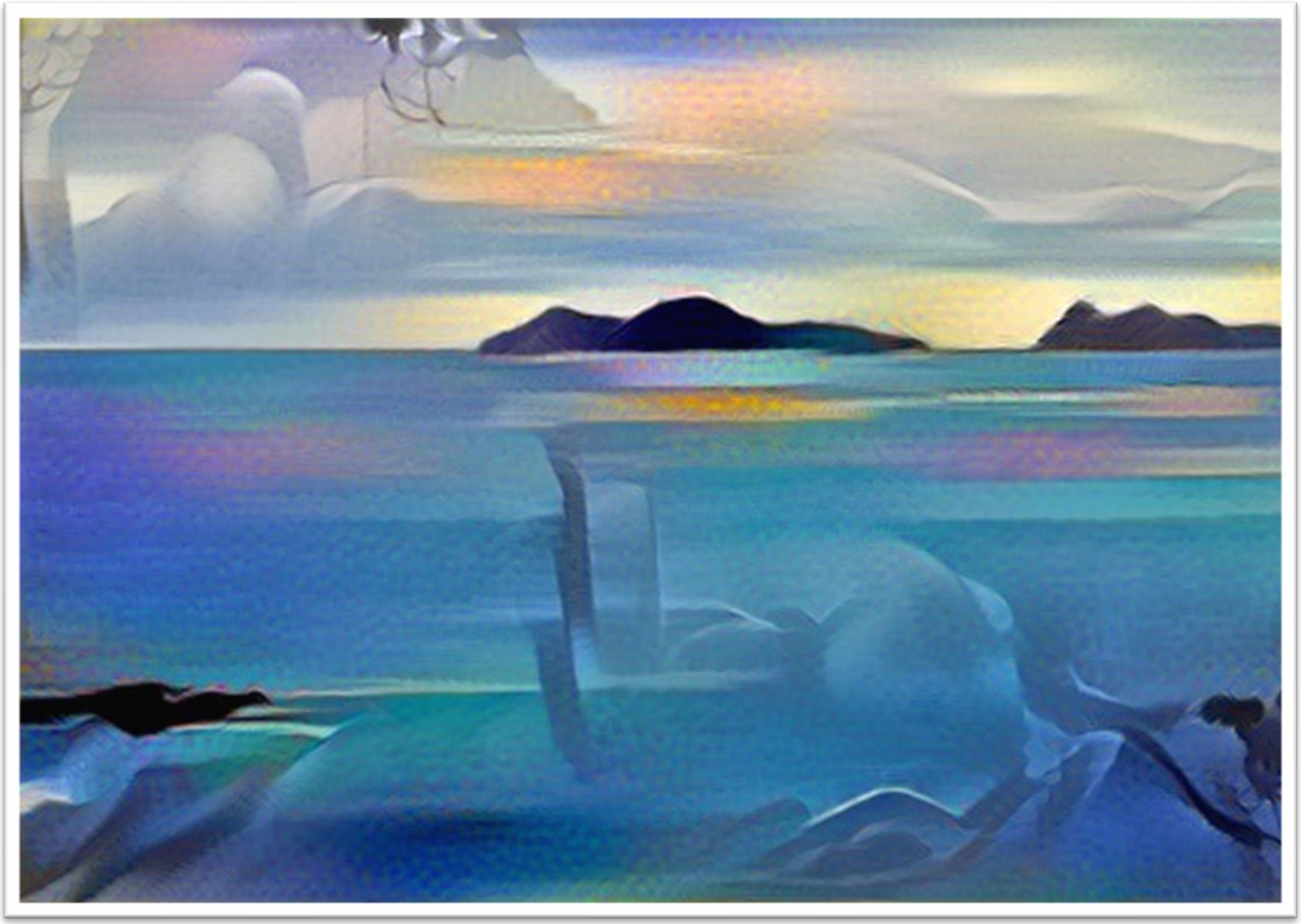
Biogeochemical implications of picoplankton

- Aggregation (Richardson & Jackson, 2007):
  - Avaliable for copepods (fast-sinking fecal pellets).
  - Increase sinking velocity

- Southern ocean (Lomas & Moran, 2011):
  - Pico and nanoplankton export 33±27% of the total carbon



Guidi et al, 2016



Hypothesis and objectives

Hypothesis

Nutrient supply **dynamics** (constant versus variable supply) **controls** the structure of marine **picoplankton** communities.

Objectives

1. To **quantify** the role of **temperature**, **light**, and **nitrate fluxes** as factors controlling the distribution of autotrophic and heterotrophic picoplankton subgroups.

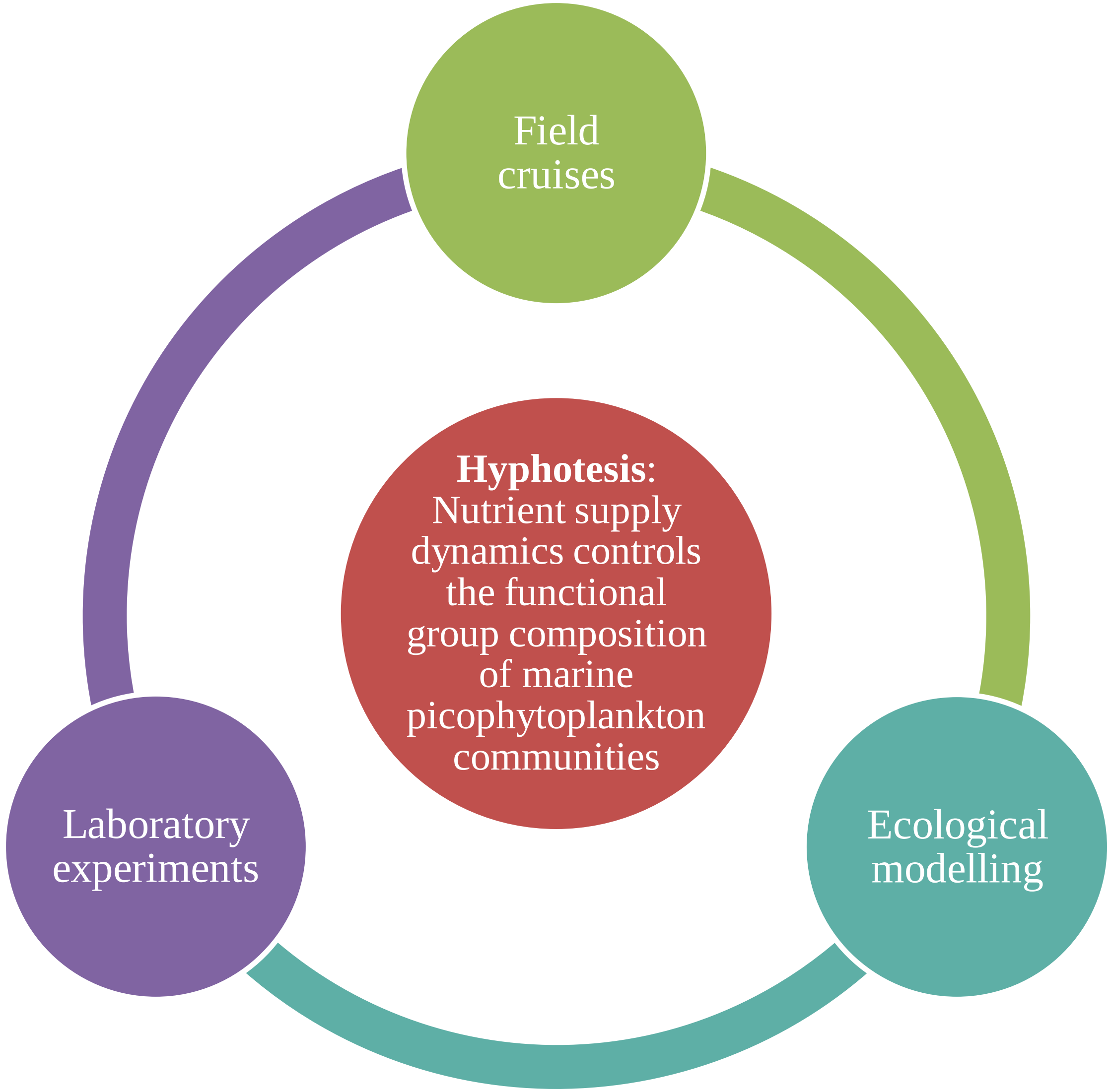
2. To **describe** the **ecological niches** of the various components of the **picoplankton community**.

3. To explore the **effect** of **nitrate supply dynamics** on the competitive dynamics of two model marine picophytoplankton species, namely, the cyanobacterium ***Synechococcus*** sp. and the picoeukaryote ***Micromonas pusilla***.

4. To build a prediction model and obtain the first **climatology** of **nitrate diffusion** into the **euphotic zone**.

5. To **predict** the change in the structure of **picophytoplankton communities** (the cyanobacteria to picoeukaryotes ratio) in a **future ocean scenario**.

Research approach



Chapter II: Factors controlling picoplankton community structure

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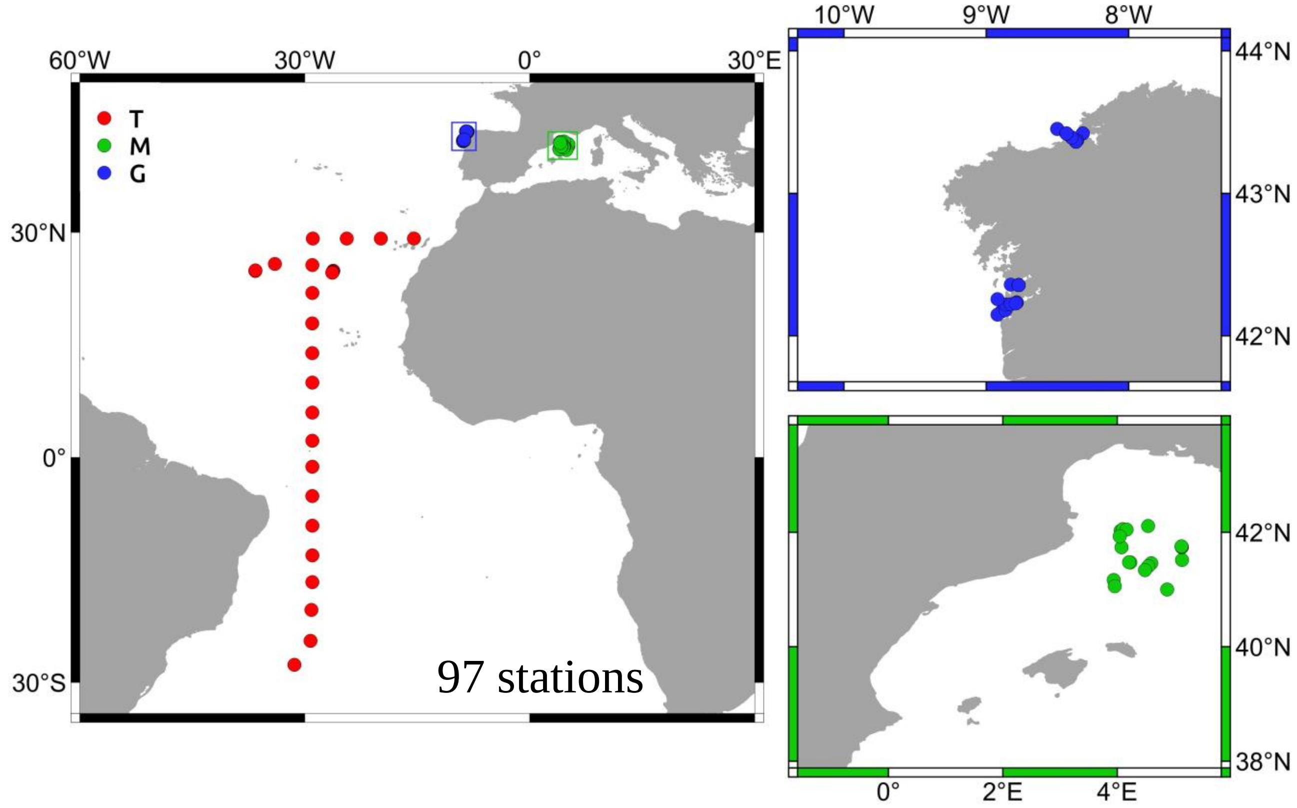
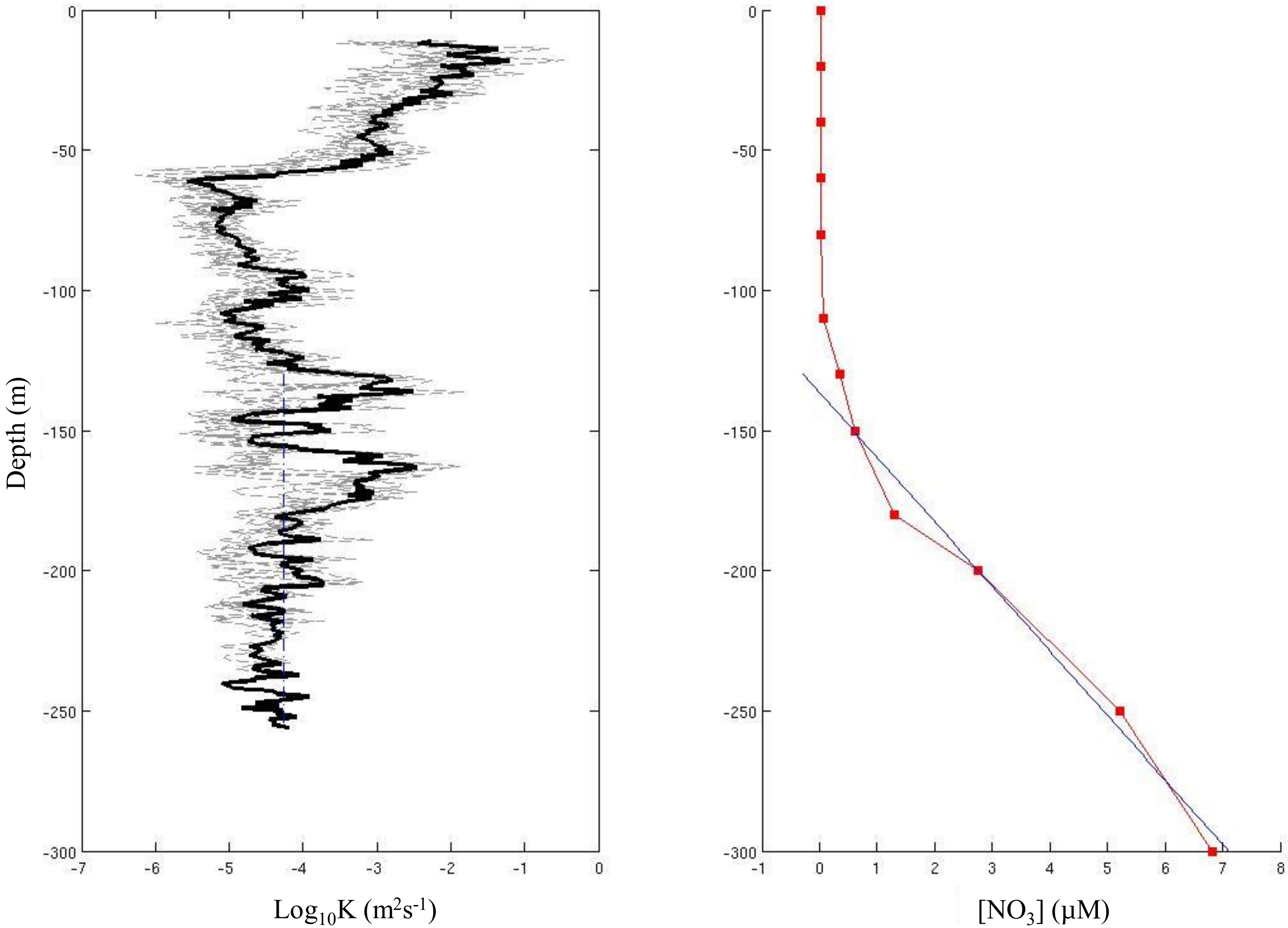
Dataset of biological & physical data (2006-2015)

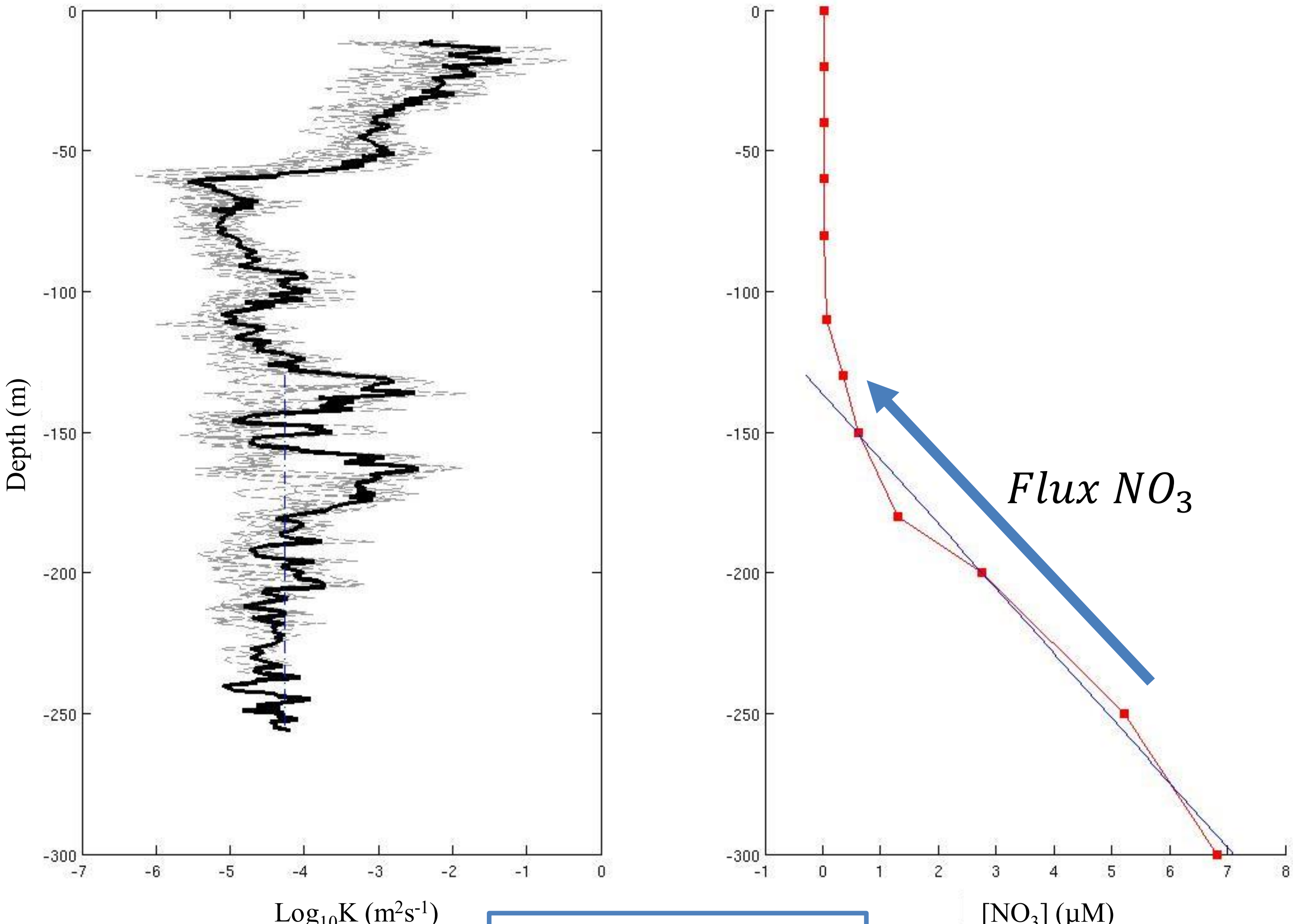


- ❑ Vertical dissipation rate (Kz)
- ❑ Nutrients
- ❑ PAR (Satellite)
- ❑ Picoplankton biomass (Cytometry)

Nitrate diffusive flux

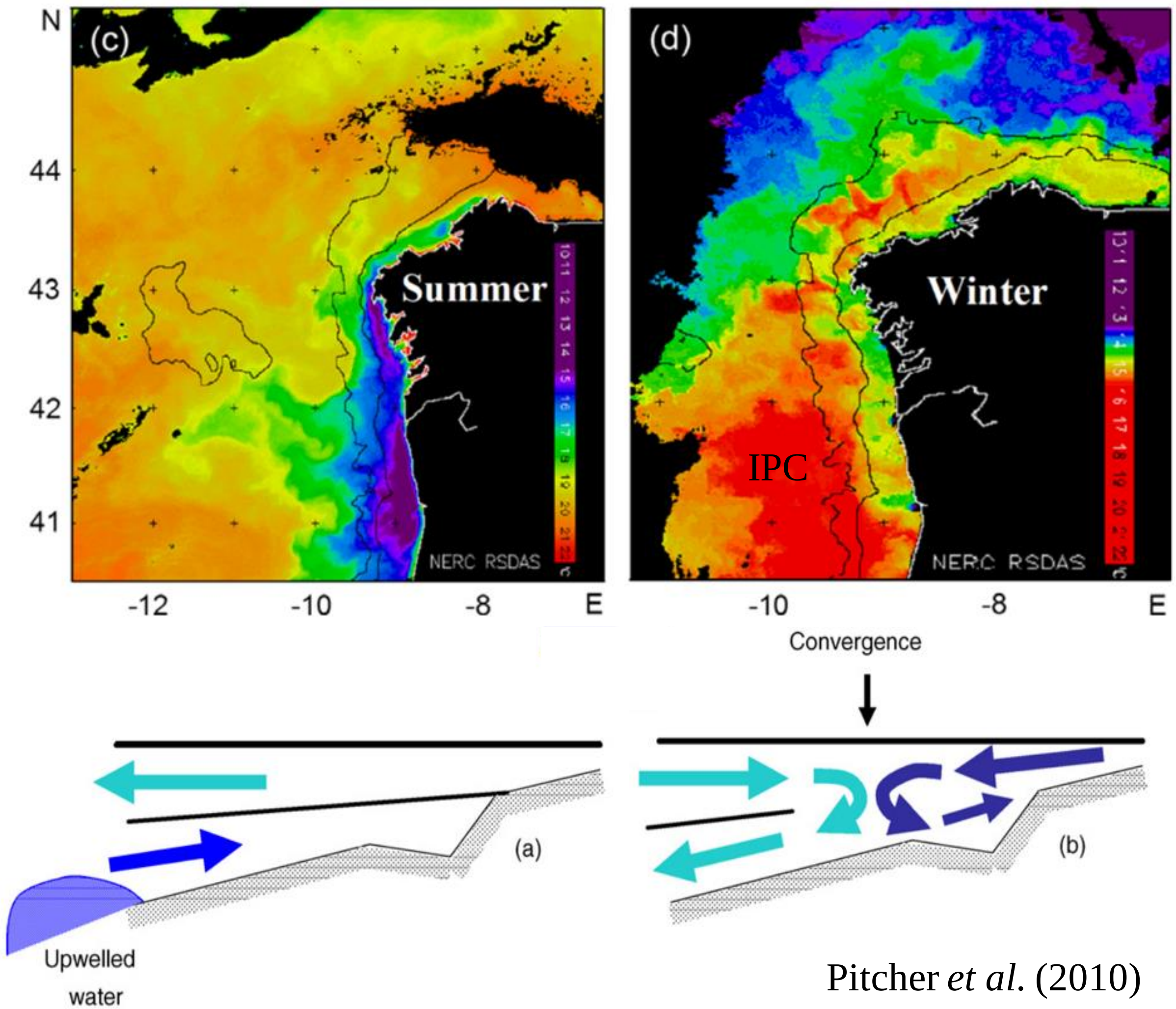


Nitrate diffusive flux



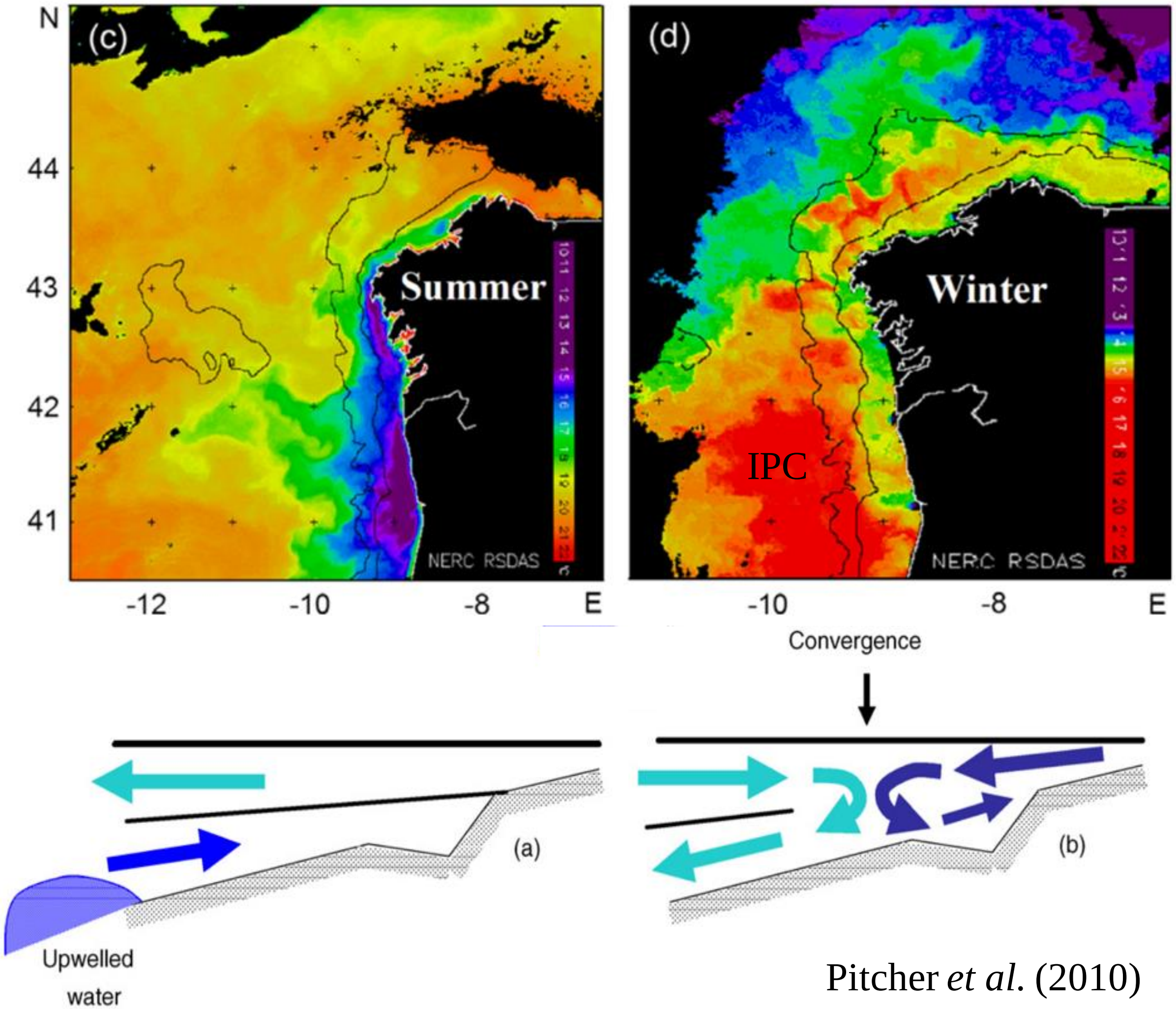
$$F = -K_z \frac{dNO_3^-}{dz}$$

Nitrate advective flux



Pitcher *et al*. (2010)
Crespo *et al*. (2006)

Nitrate advective flux



- ❑ Area (m²)
- ❑ Coast (km)
- ❑ Averaged depth
- ❑ Upwelling index
- ❑ Depth Nitrate concentration

Pitcher *et al.* (2010)
Crespo *et al.* (2006)

Analysis

Analysis

Generalized Additive Models (GAM)

$$yj = I + s(SST) + s(PAR) + s(log(NO_3Flux)) + Error$$

Analysis

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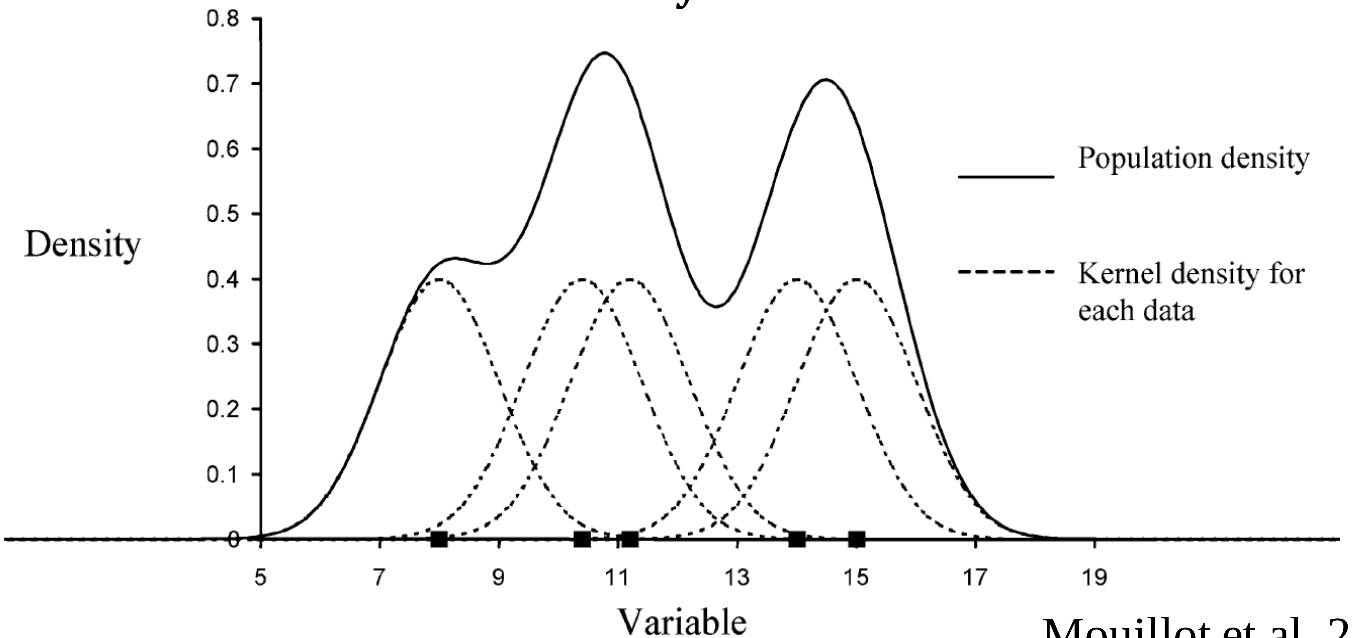
$$yj = I + s(SST) + s(PAR) + s(log(NO_3Flux)) + Error$$

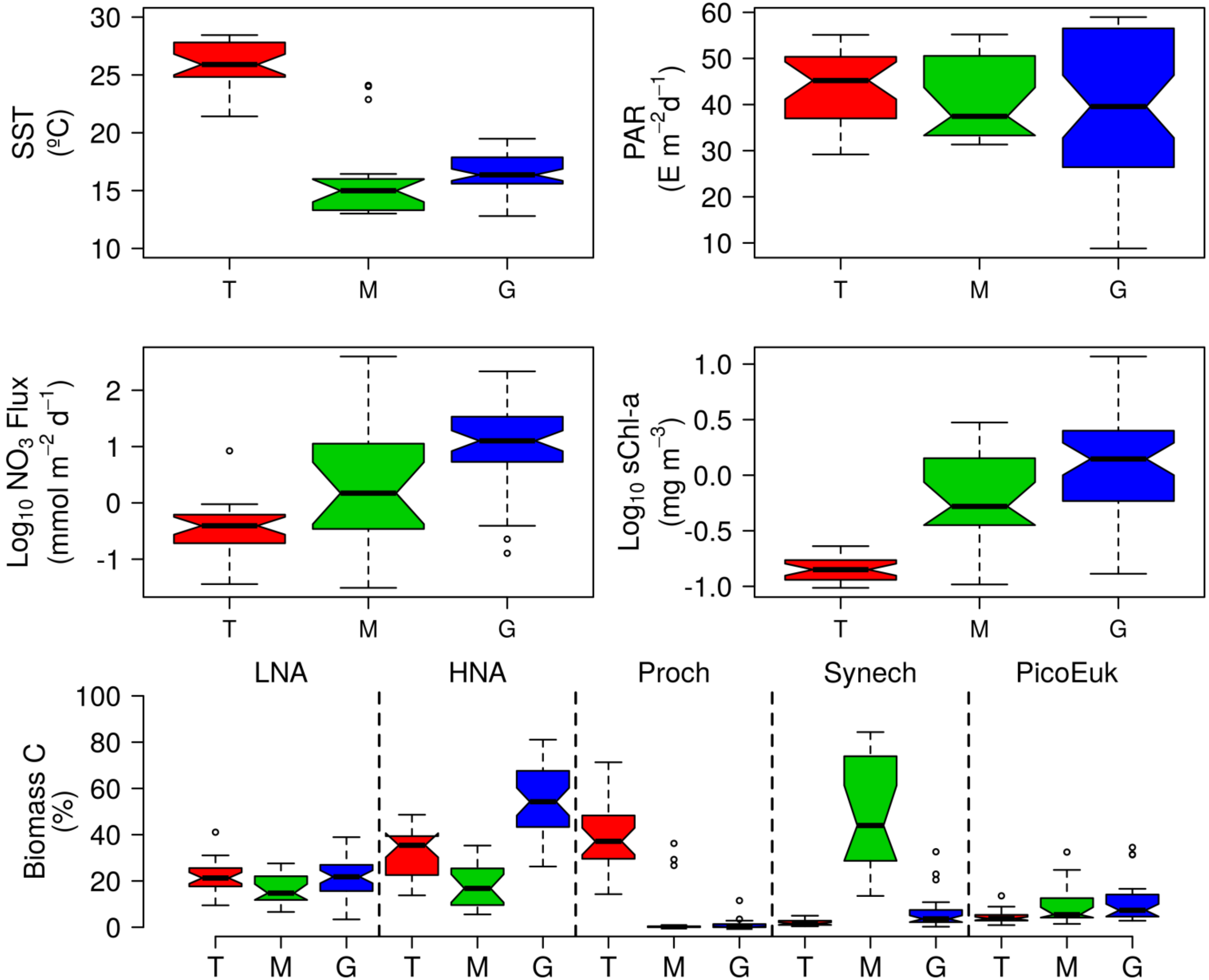
Kernel density & Niche overlap

$$NO_{K_{i,j,t}} = 1 - 1/2 \int |\, f_{it}\,(x) - f_{jt}(x)|dx$$

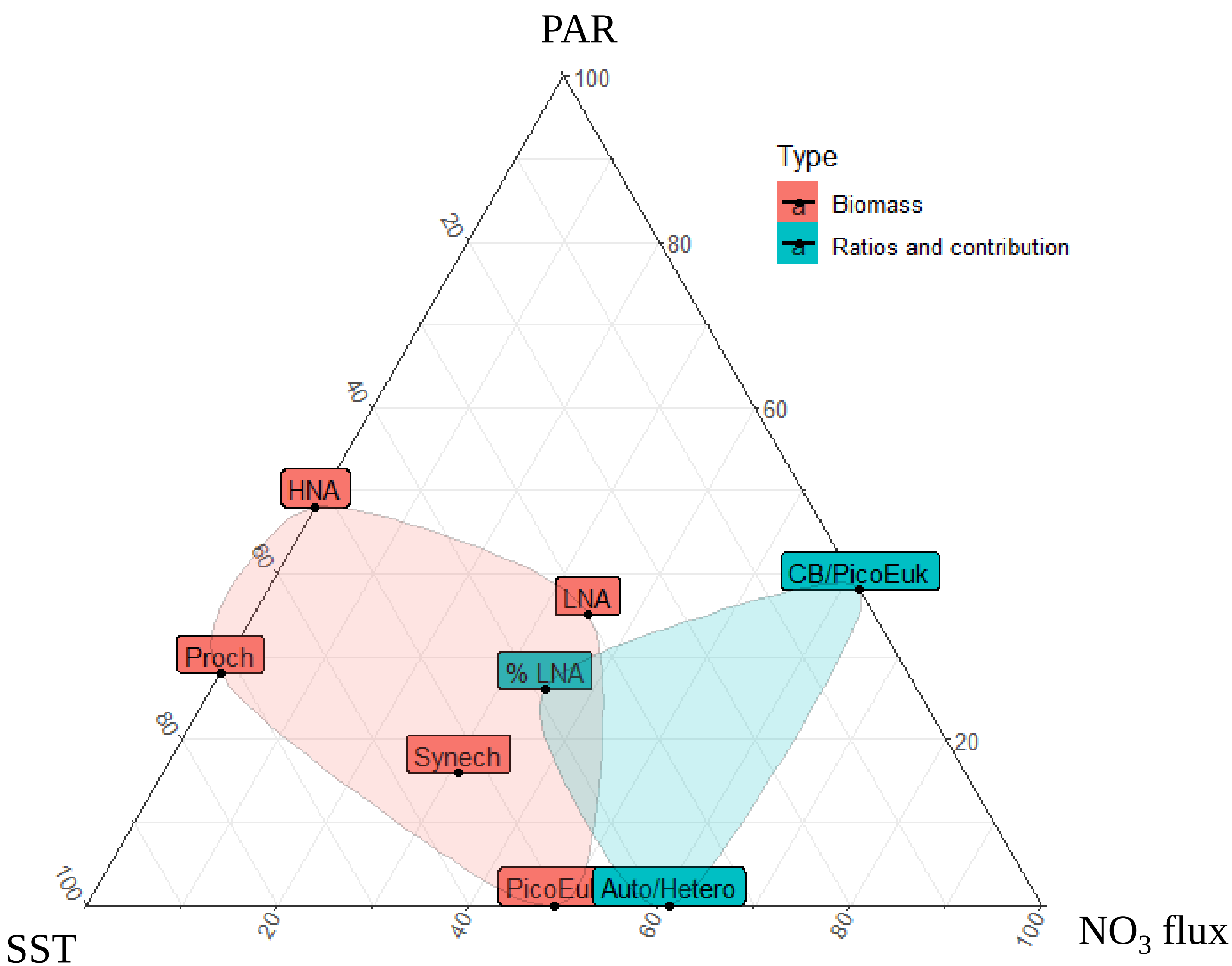


Mouillot et al. 2005

Variability in NO_3 flux, control factors and biomass



Relevance of control factors in biomass groups (GAM)



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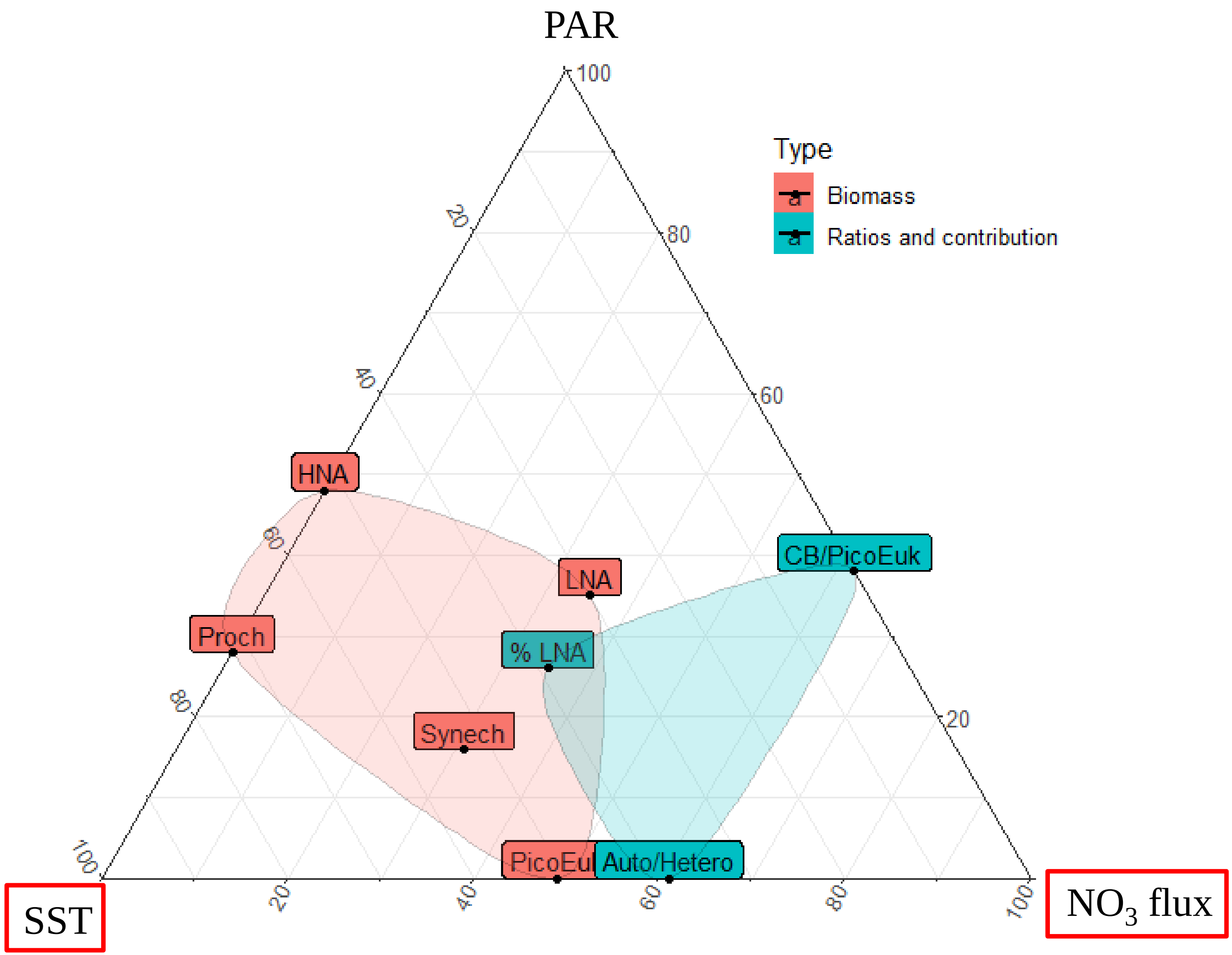
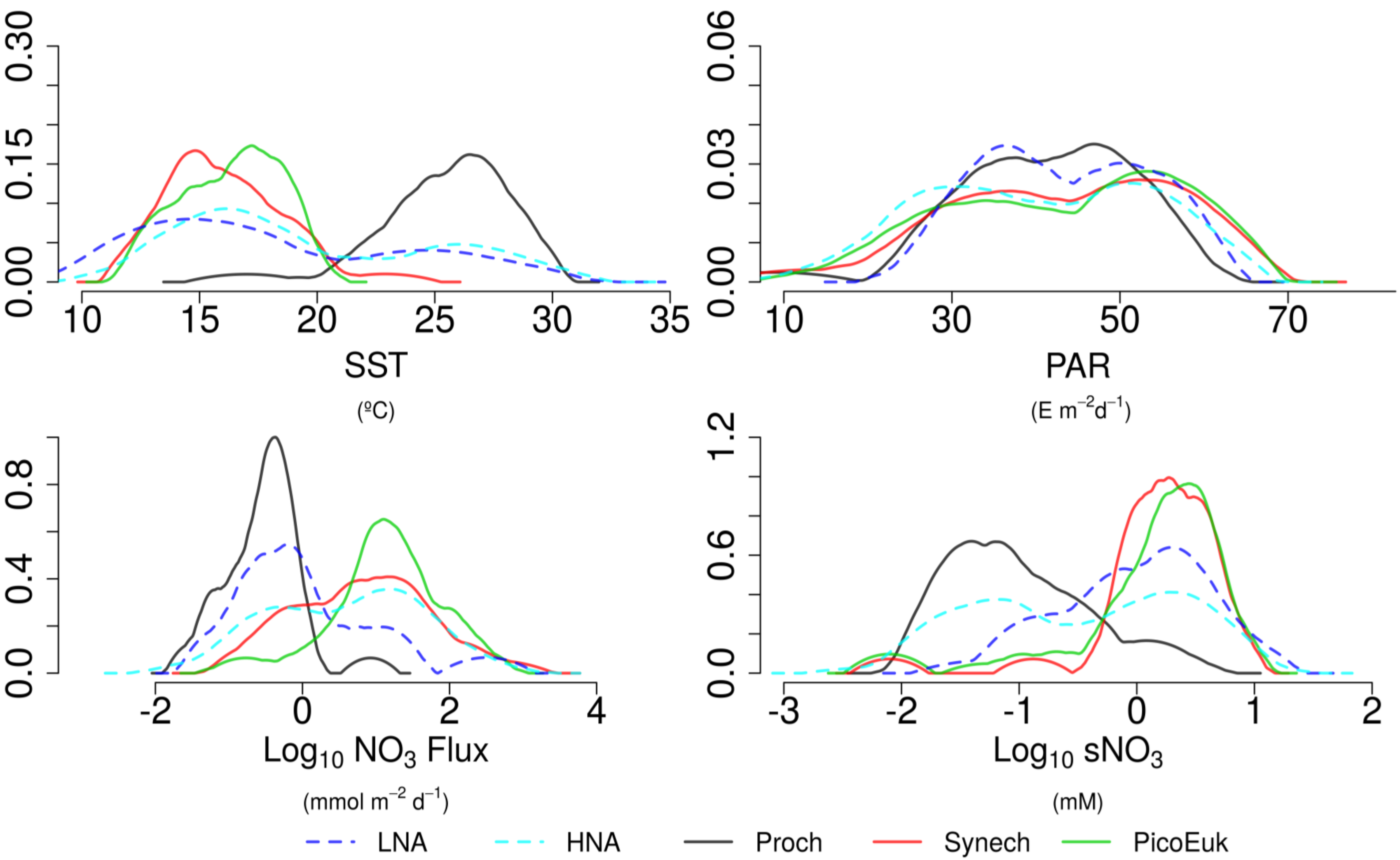


Niche partitioning



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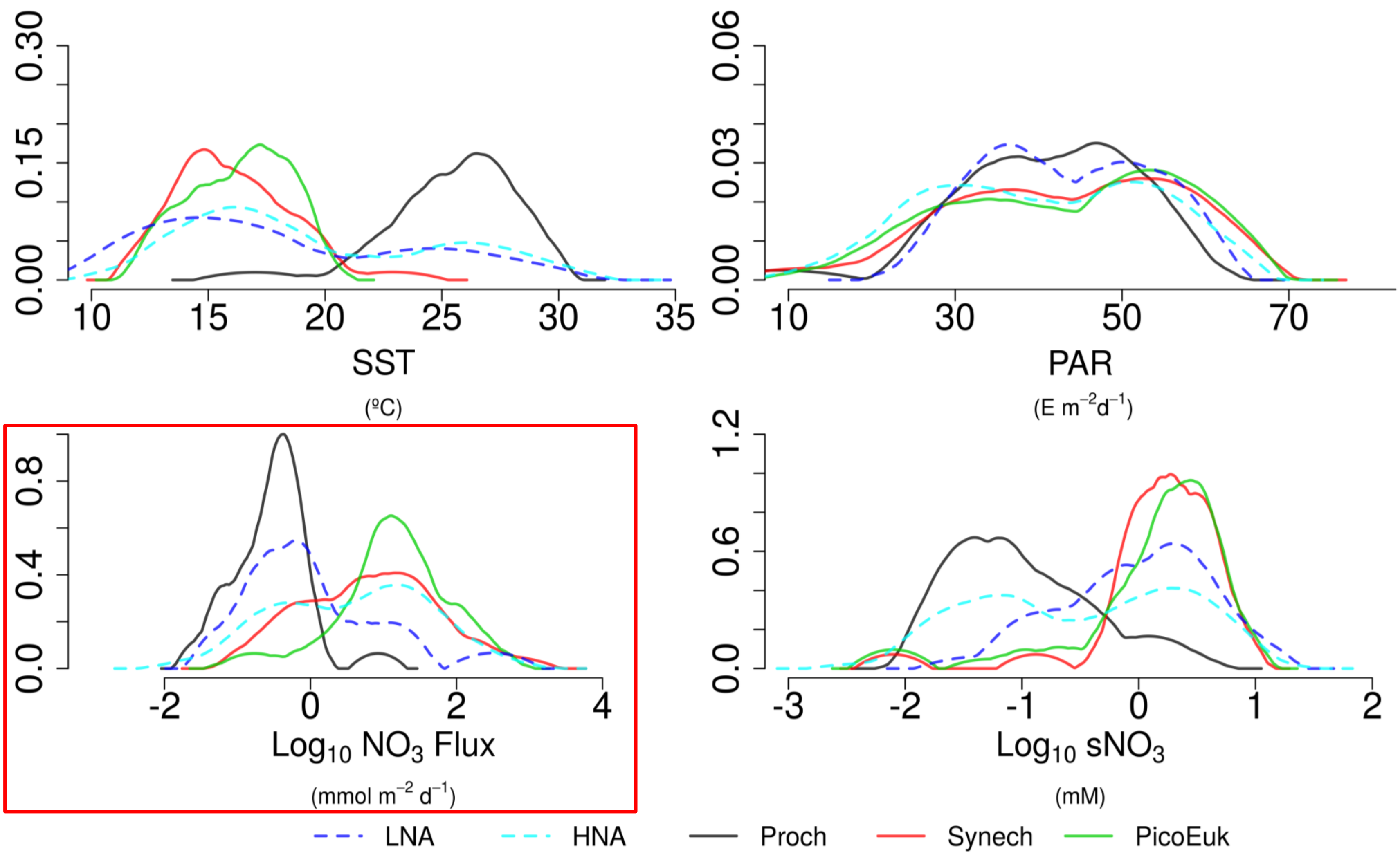
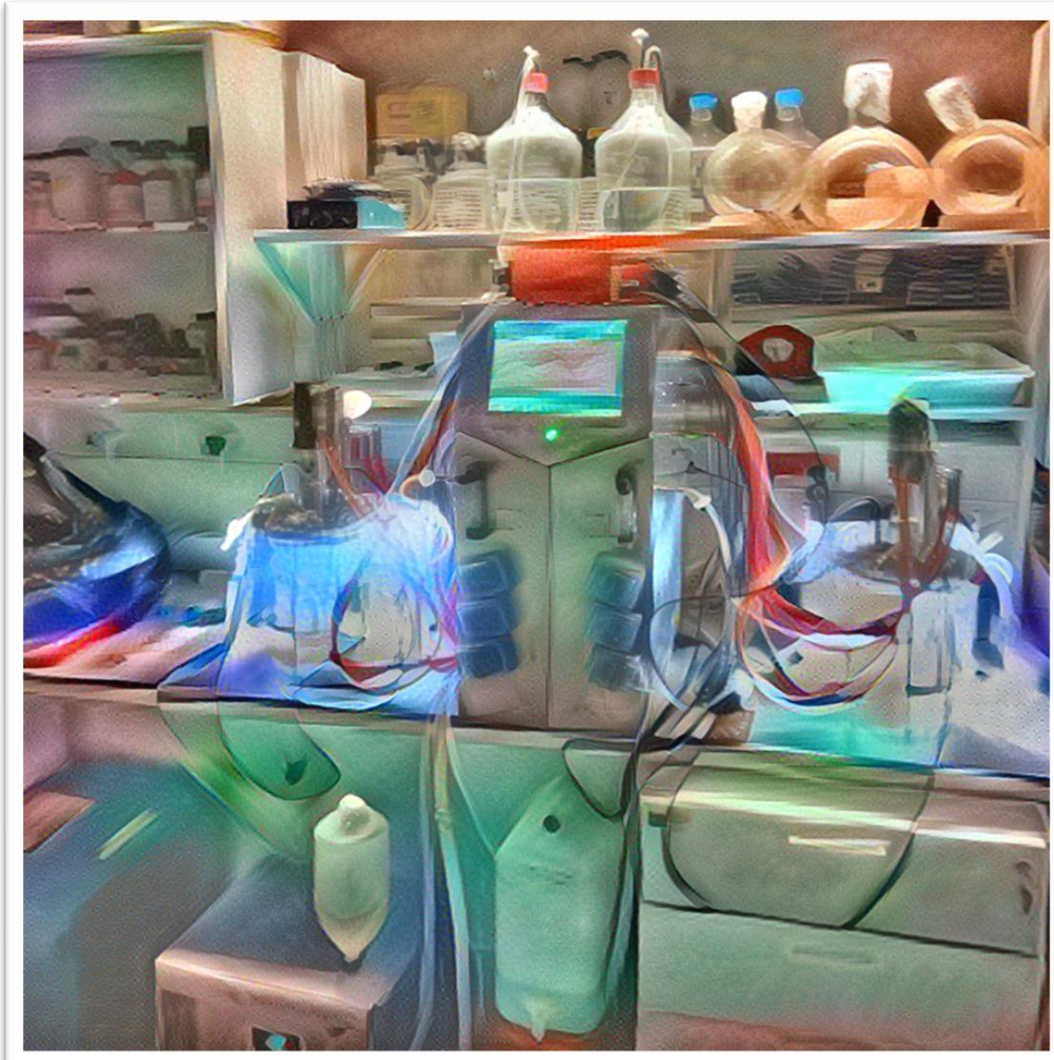
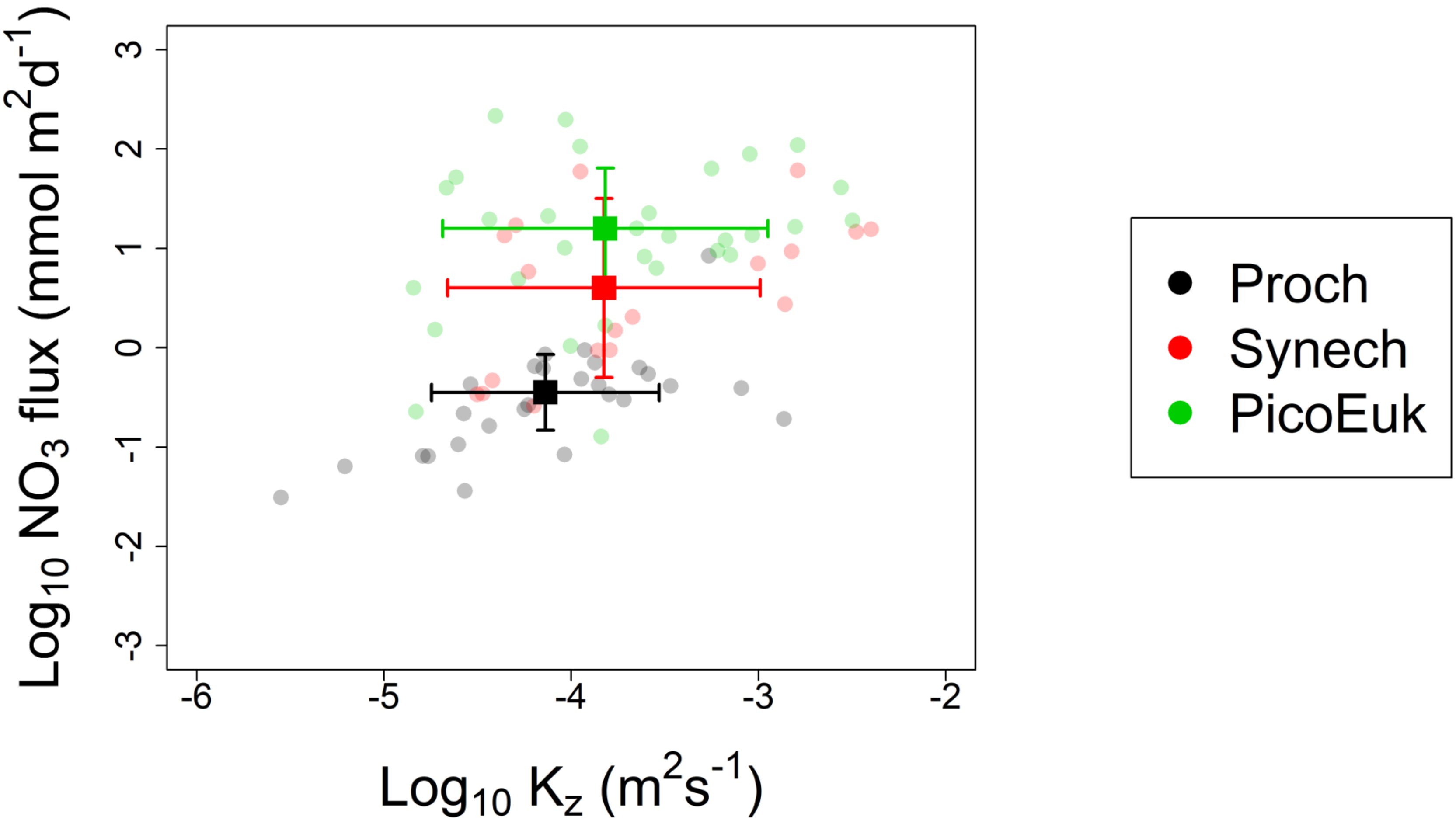




Chapter III: *Micromonas pusilla* and *Synechococcus* competition under constant and dynamic conditions

Dominance of picoplankton groups vs mixing and NO_3



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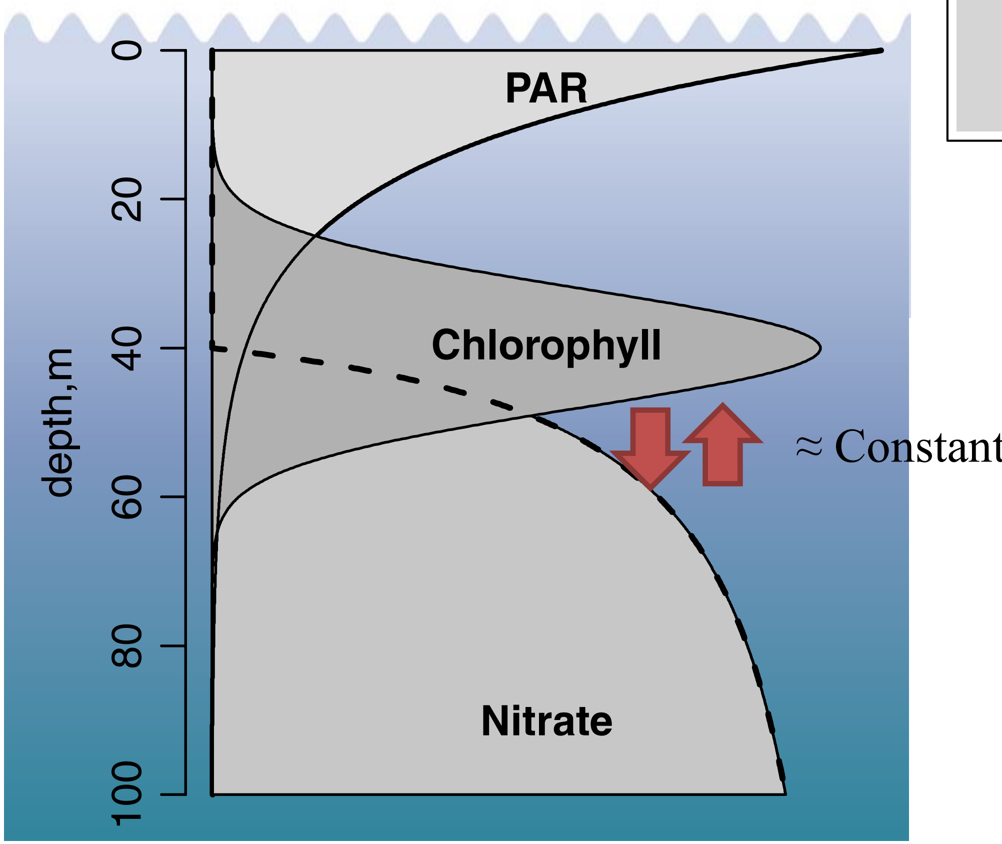
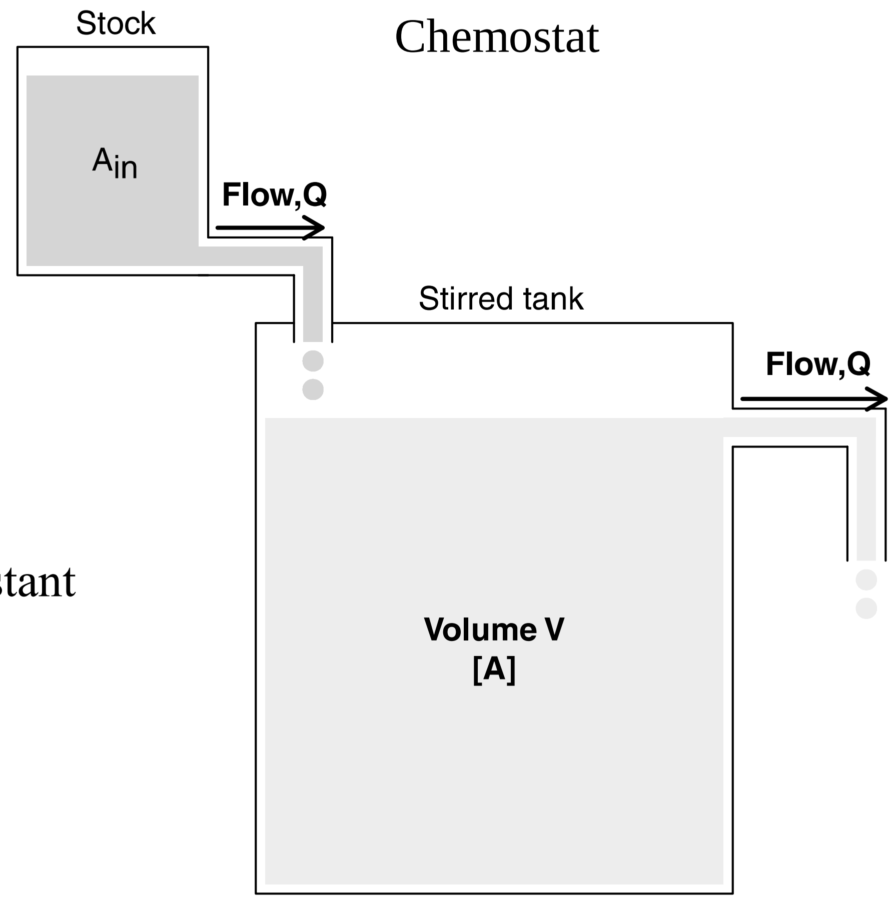
Steady state and chemostats

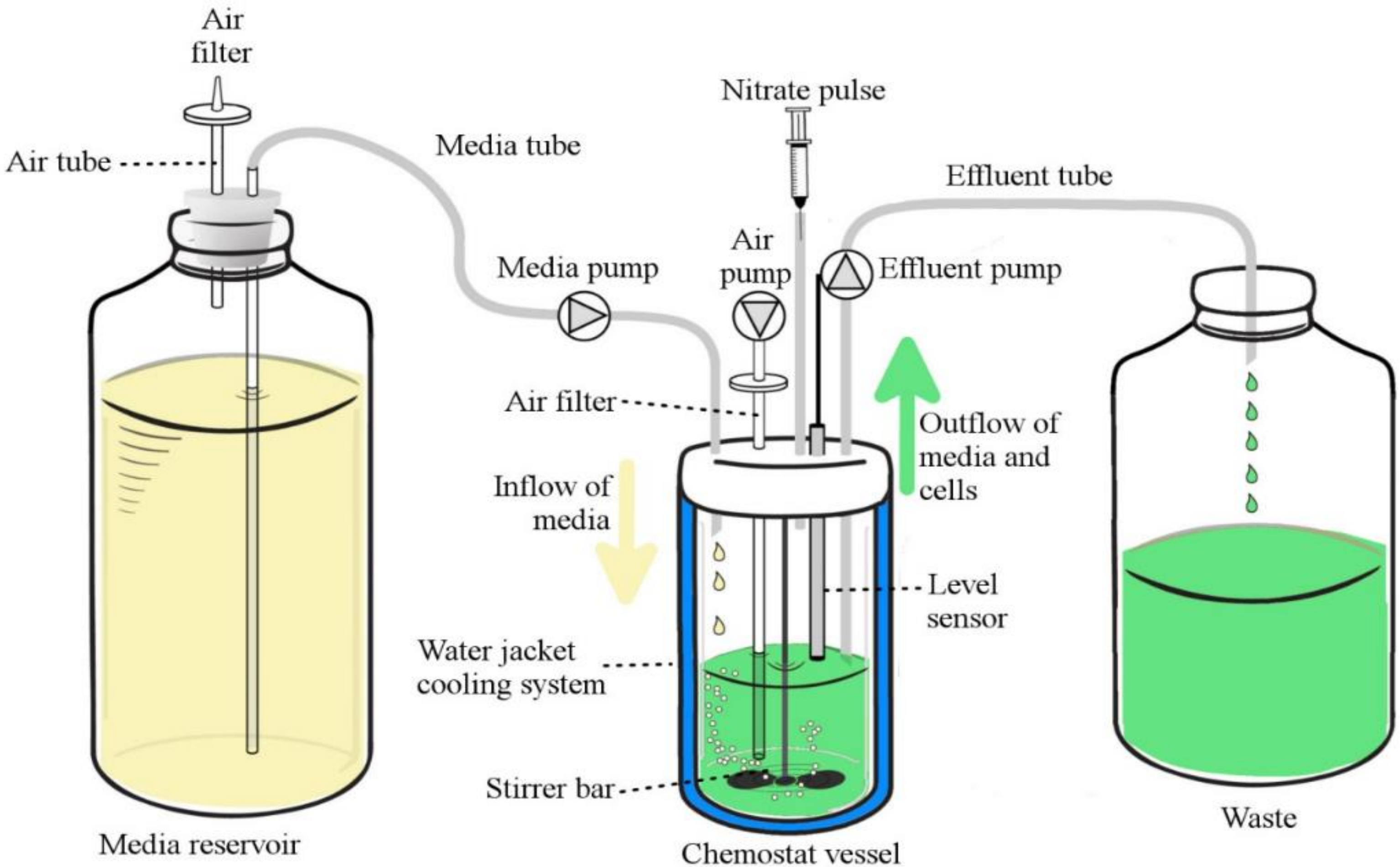
Open waters



Chemostat



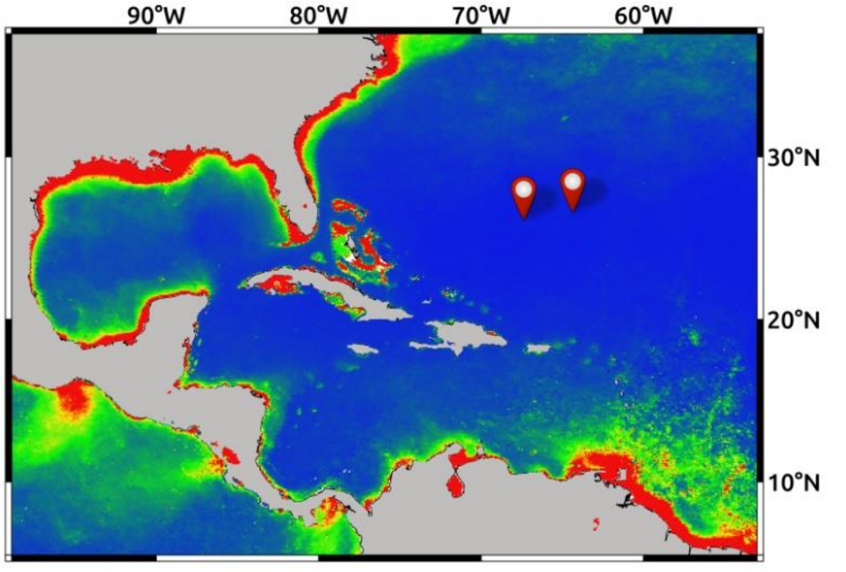
Competition experiments



Population monitoring was carried using Flow Cytometry

Experimental design

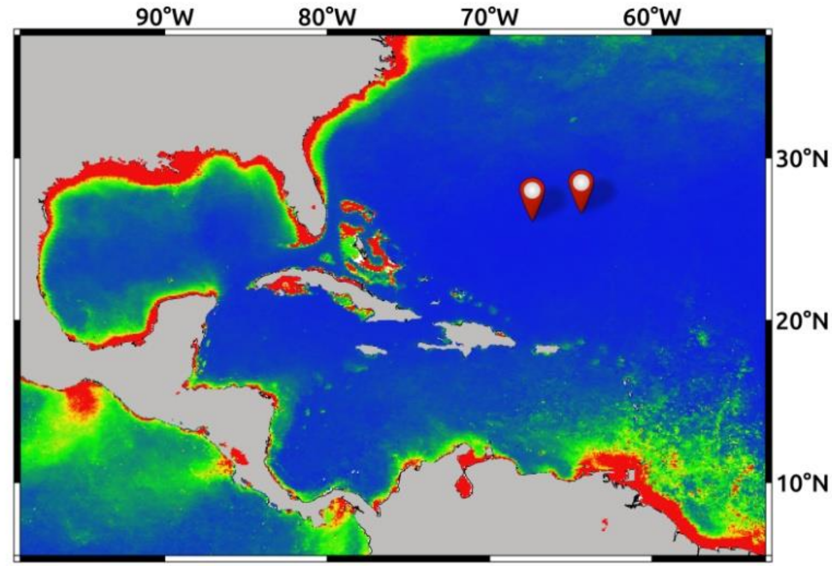
- ❑ Groups
  - ❑ *Synechococcus* (RCC-2366)
  - ❑ *Micromonas pusilla* (RCC-450)



Yearly average surface chlorophyll-*a*

Experimental design

- Groups
  - *Synechococcus* (RCC-2366)
  - *Micromonas pusilla* (RCC-450)
- Fully-aclimated populations
  - Modified PCRS-11 medium (N:P, 5-1)
  - Light: 100 µE
  - Temperature: 21ºC
  - Steady-state (Dilution rate: 0.2 d^{-1})
- Perturbation(5 µM NO_3)
  - 0.5 pulses d^{-1}
  - 1 pulses d^{-1} *
  - 2 pulses d^{-1}
  - 3 pulses d^{-1}



Yearly average surface chlorophyll-*a*

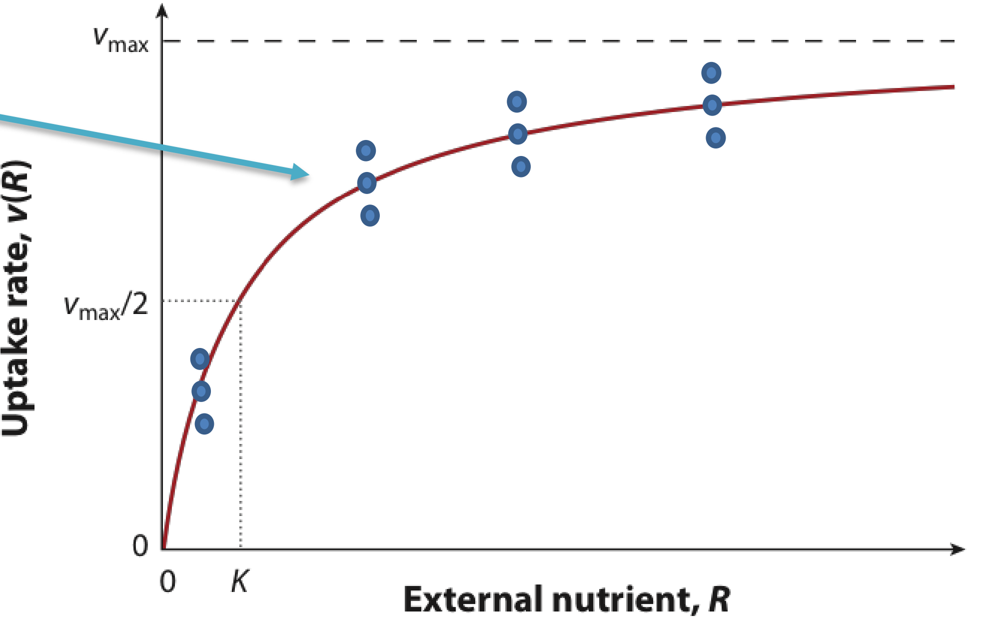

Sartorius Biostat Plus

Uptake experiments

- ❑ Similar light and temperature conditions
- ❑ Short NO_3 incubations (Bulk concentration)
- ❑ $[NO_3]$: 0.5, 1, 1.5, 2.5, 5, 10, 25 µM.
- ❑ Gentle filtration (Ø 0.45 µm)

$NO_{3\,(i)} \longrightarrow NO_{3\,(f)}$

dNO_3/ dt



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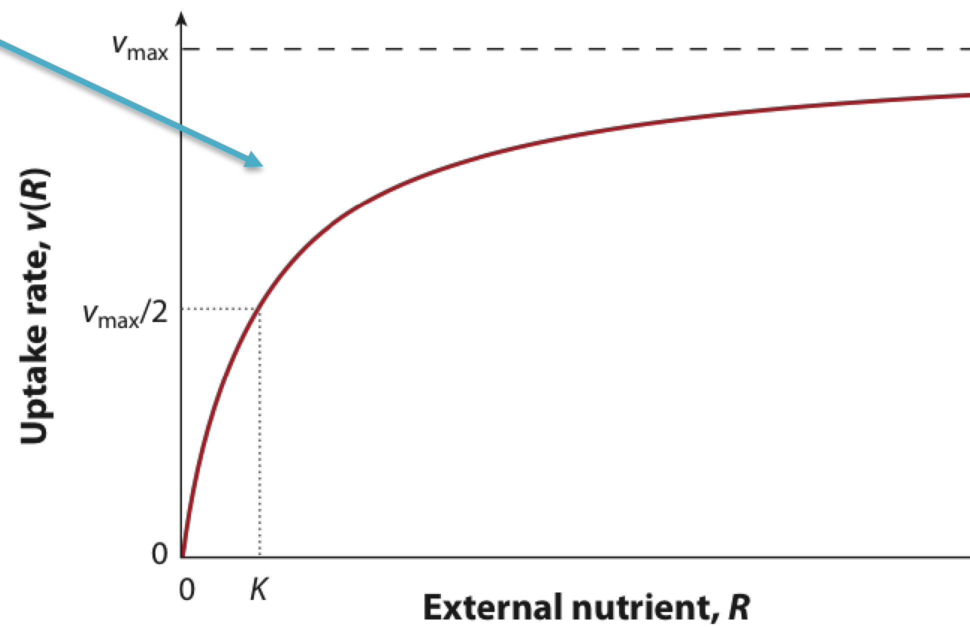
$NO_{3\,(i)} \longrightarrow NO_{3\,(f)}$

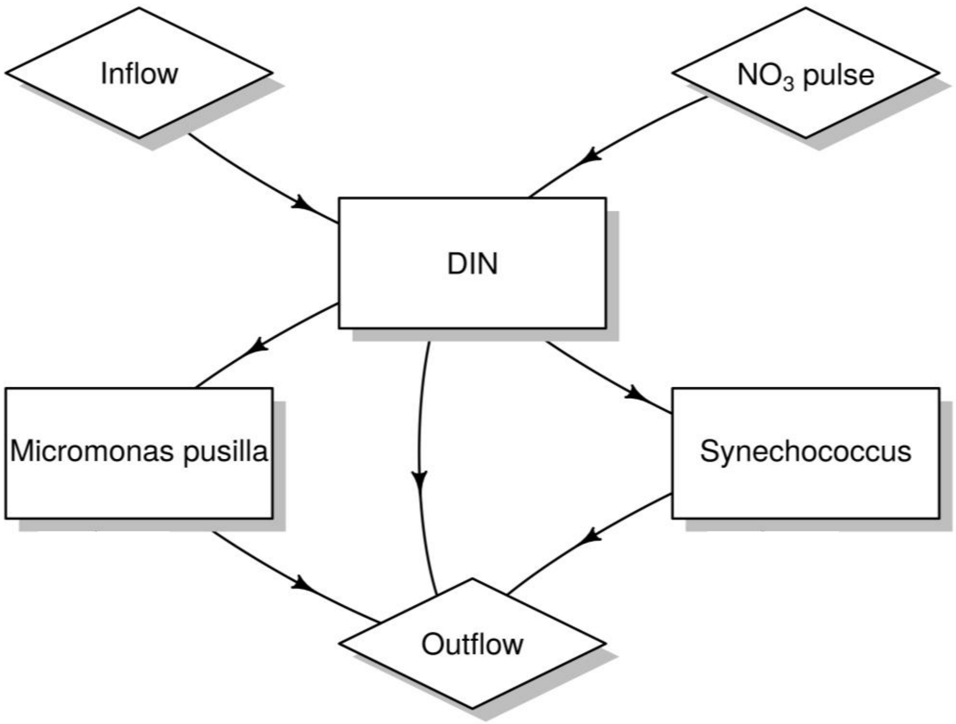
$dNO_3/\,dt$

Under steady state conditions

$$R^* = \frac{D}{(\mu_{max} - D)} * K$$

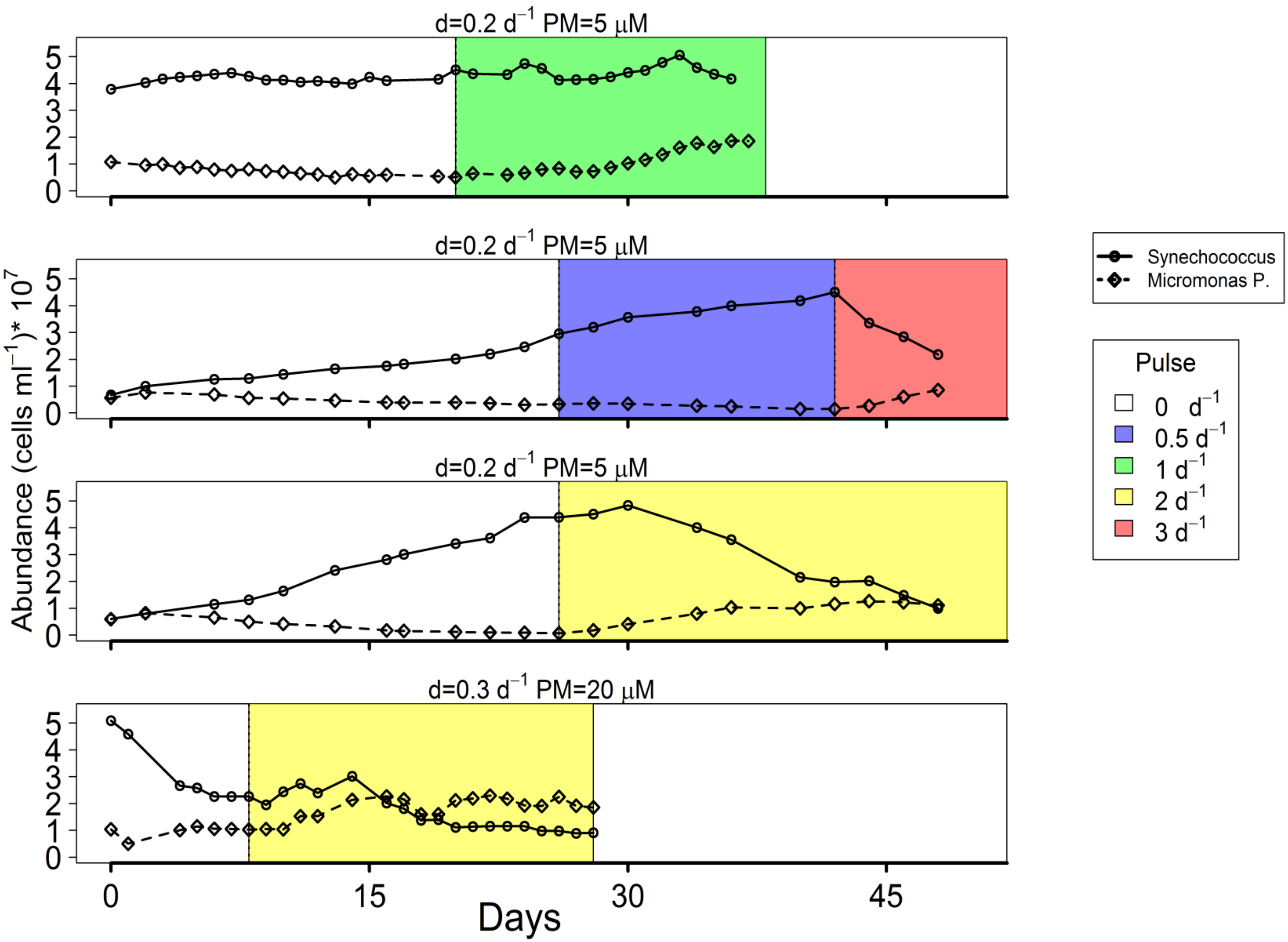


Ecological modelling and calibration

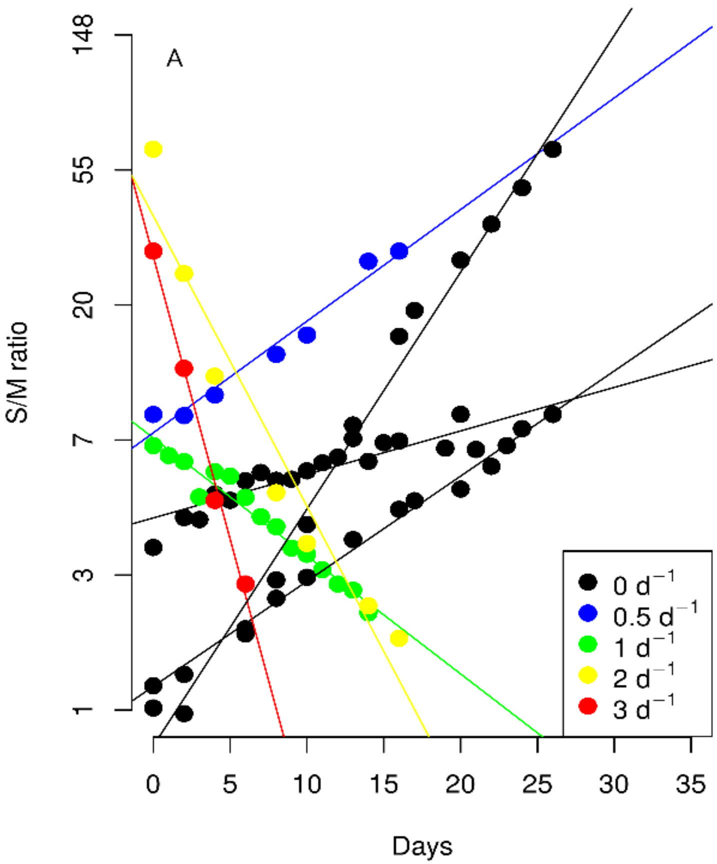


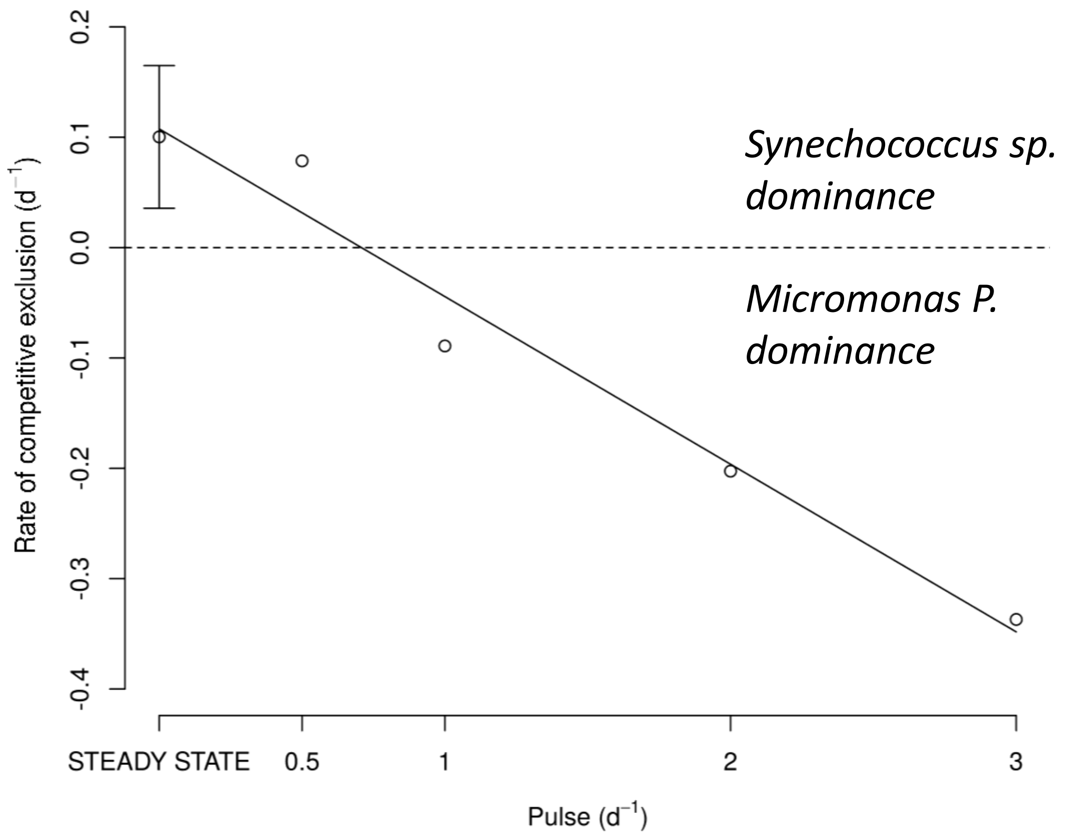
- Droop model
- Delayed Rejection Adaptative Metropolis Algorithm (DRAM):
  - Uptake and batch experiments parameters used as initial parameters.
  - Use one experiment to calibrate and use the other 3 to test.

Competition experiments – Time series

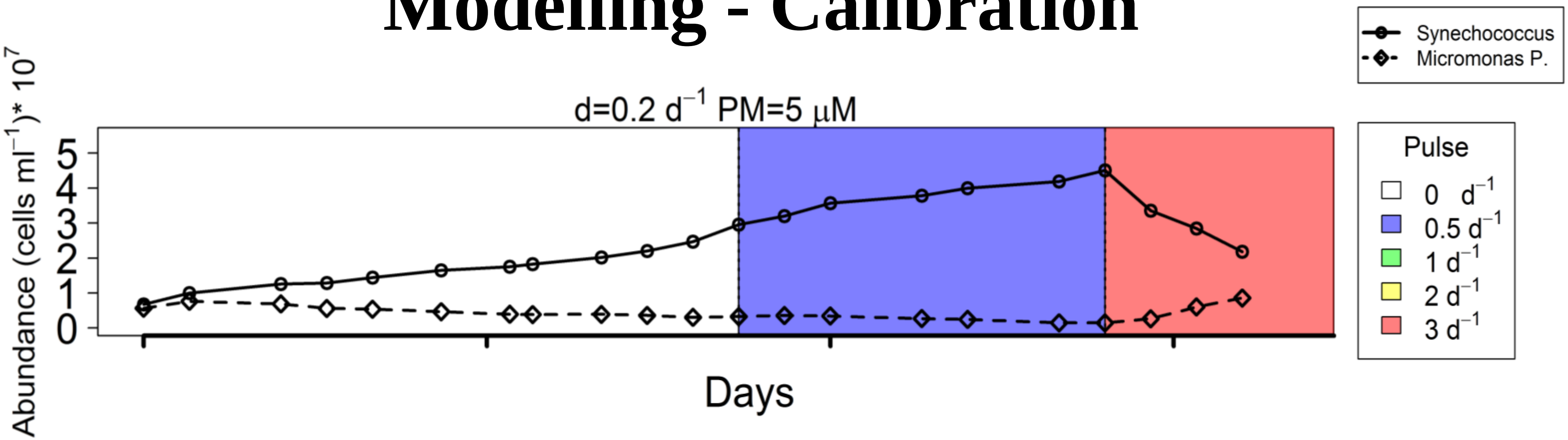


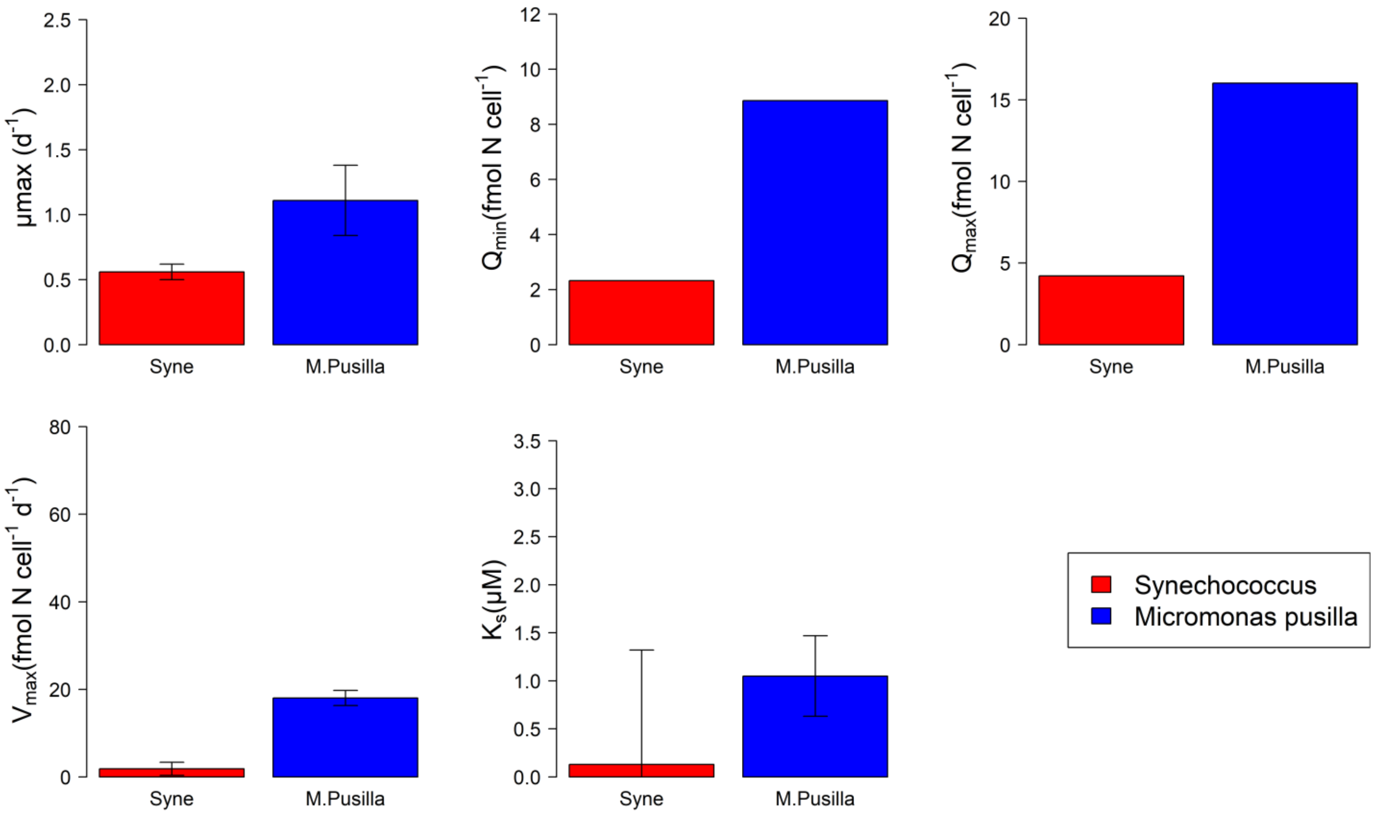
Competitive exclusion rate





Modelling - Calibration





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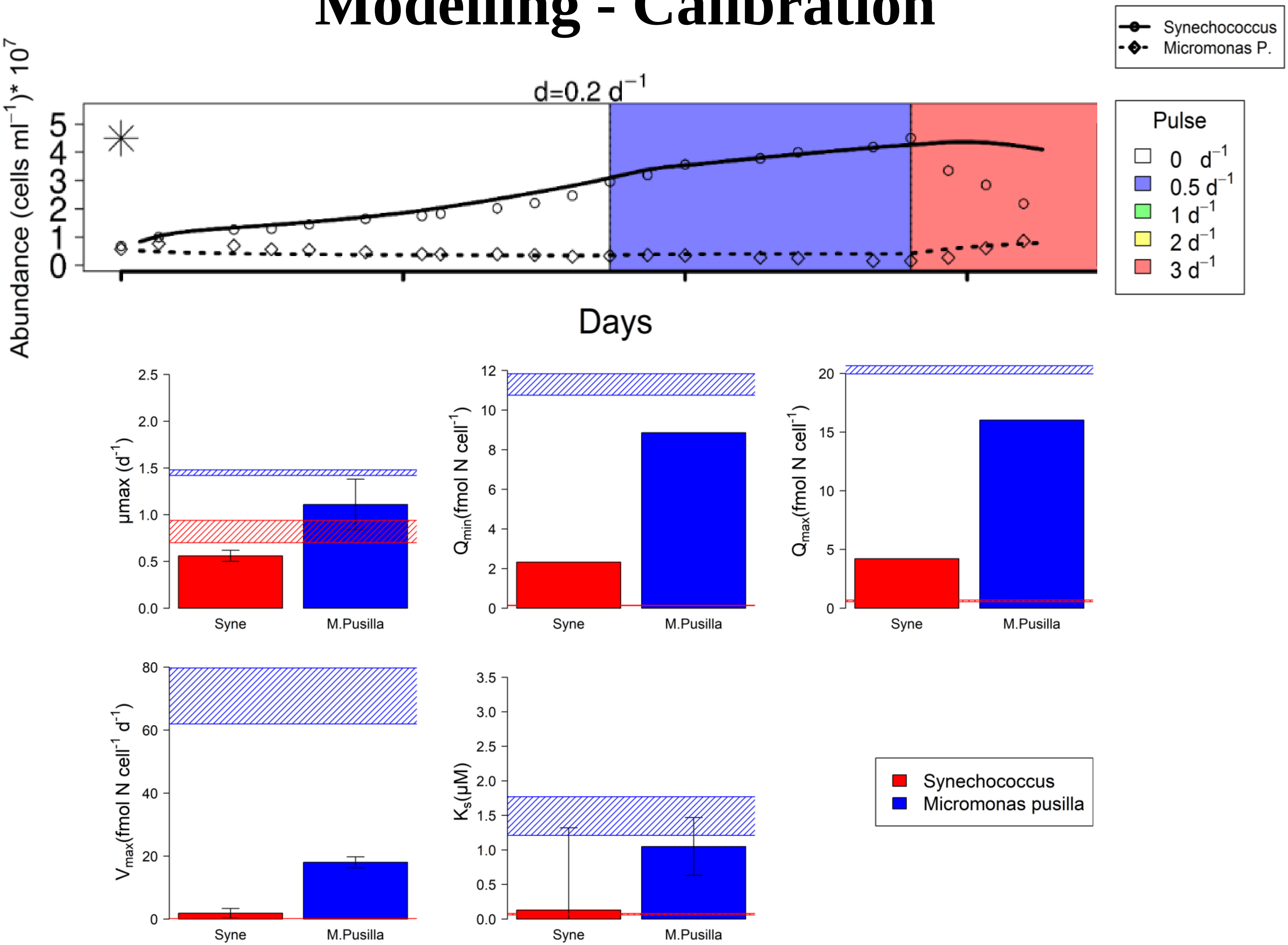

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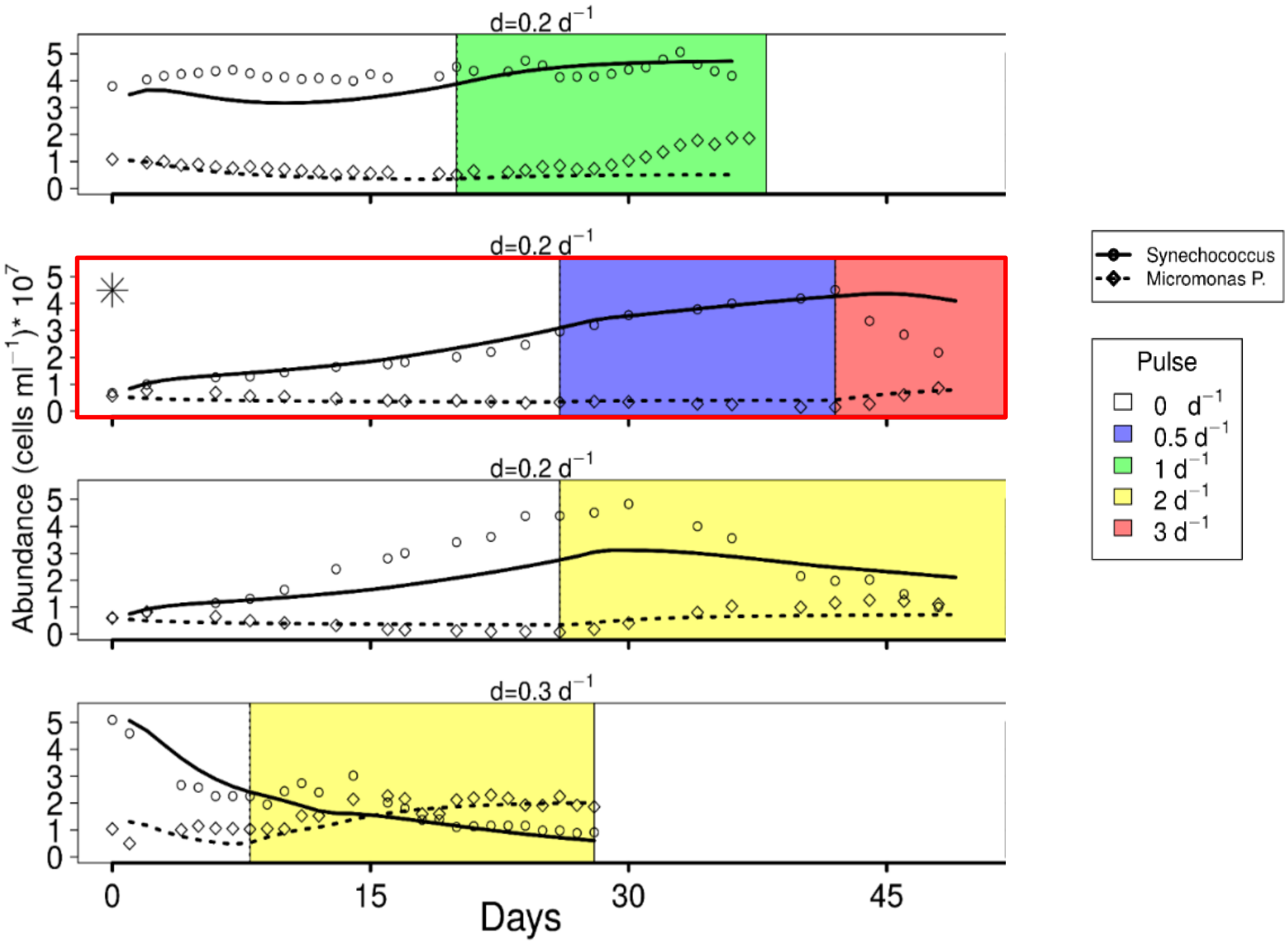

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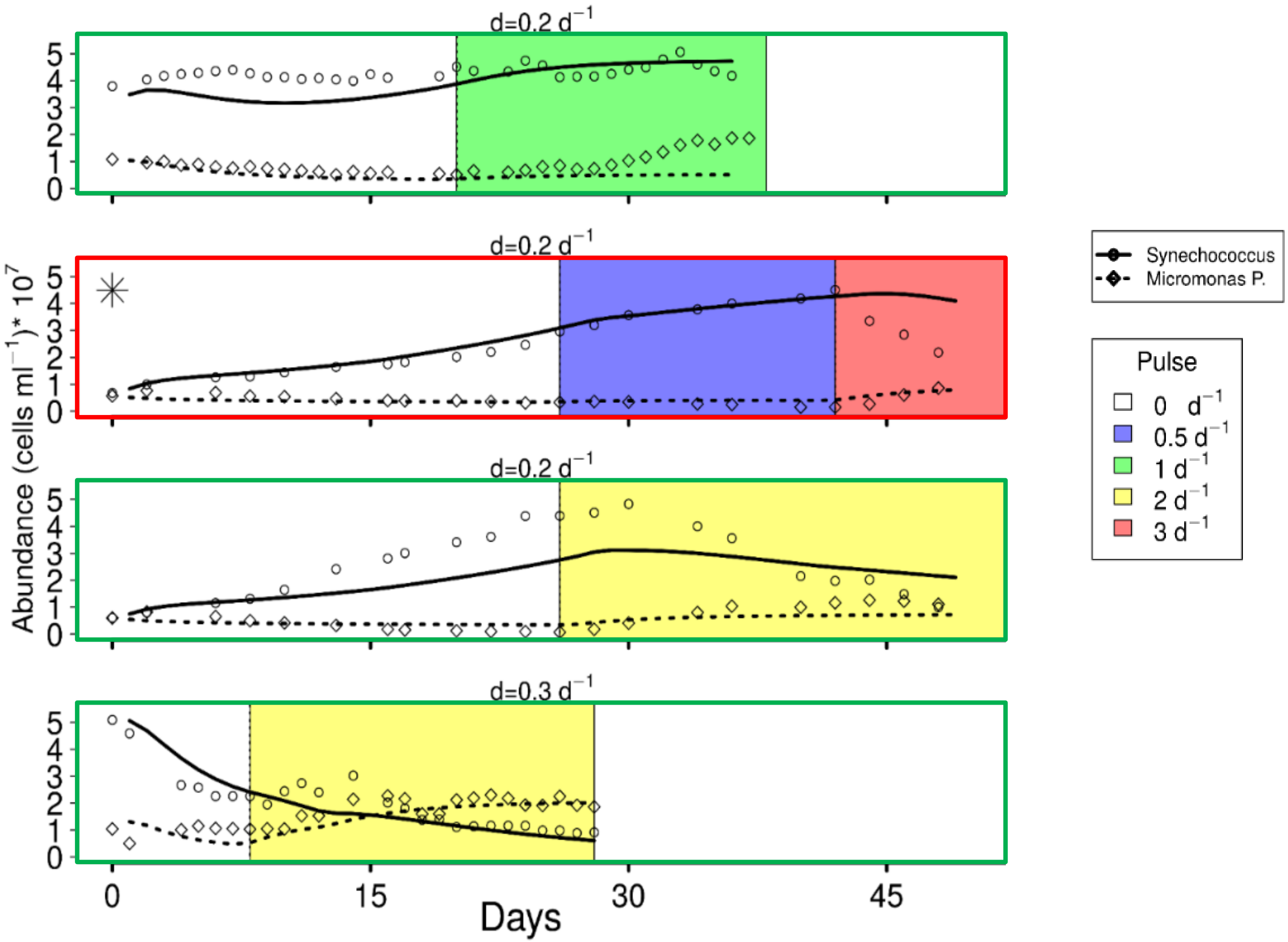
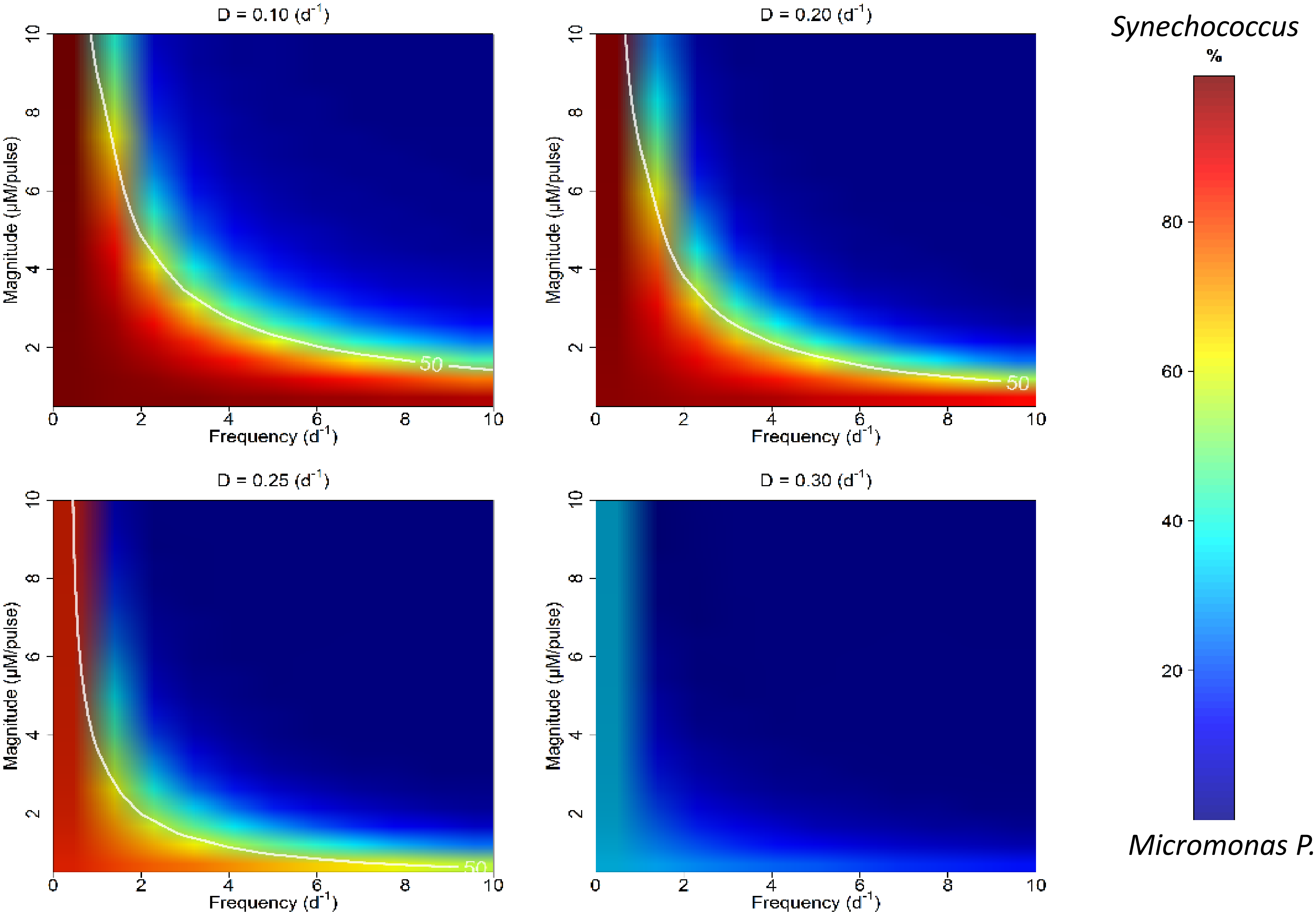
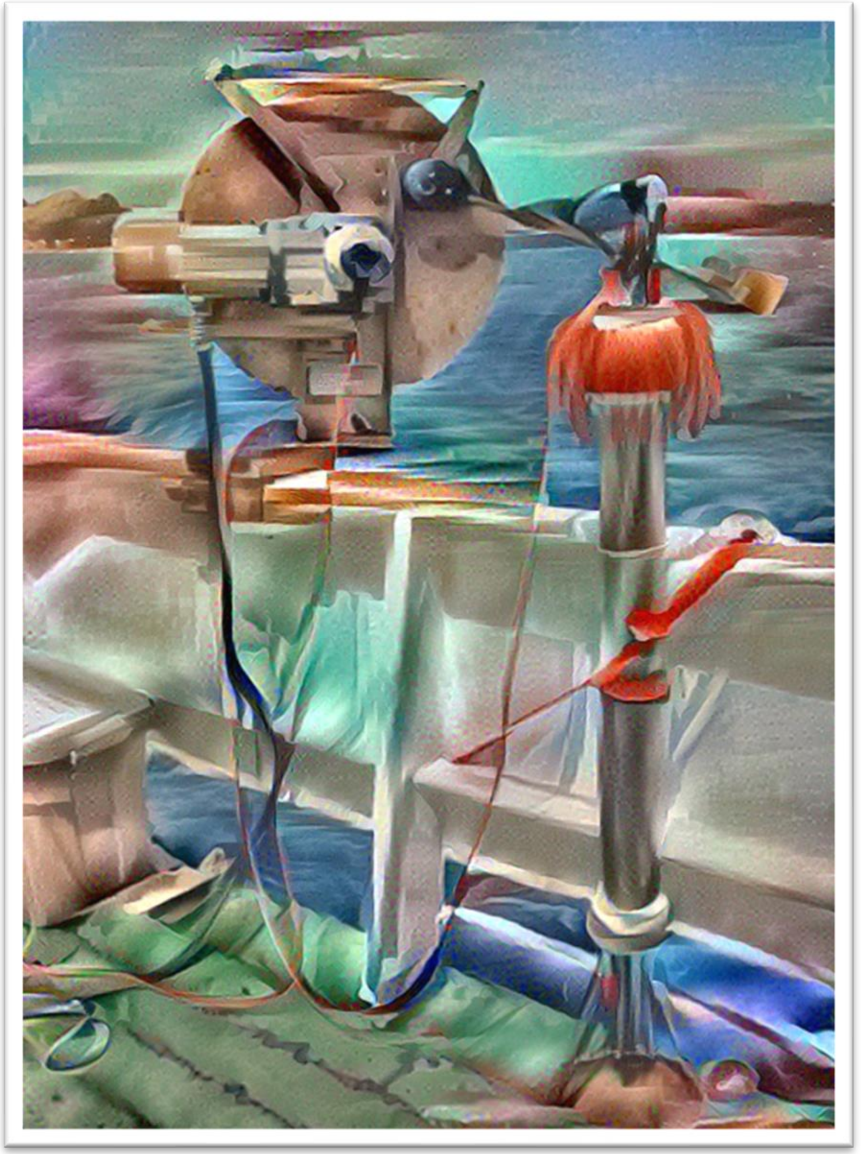


Competition experiments - Modelling





Chapter IV: Climatology of the vertical nutrient supply and future cyanobacteria to picoeukaryotes ratio

Objectives

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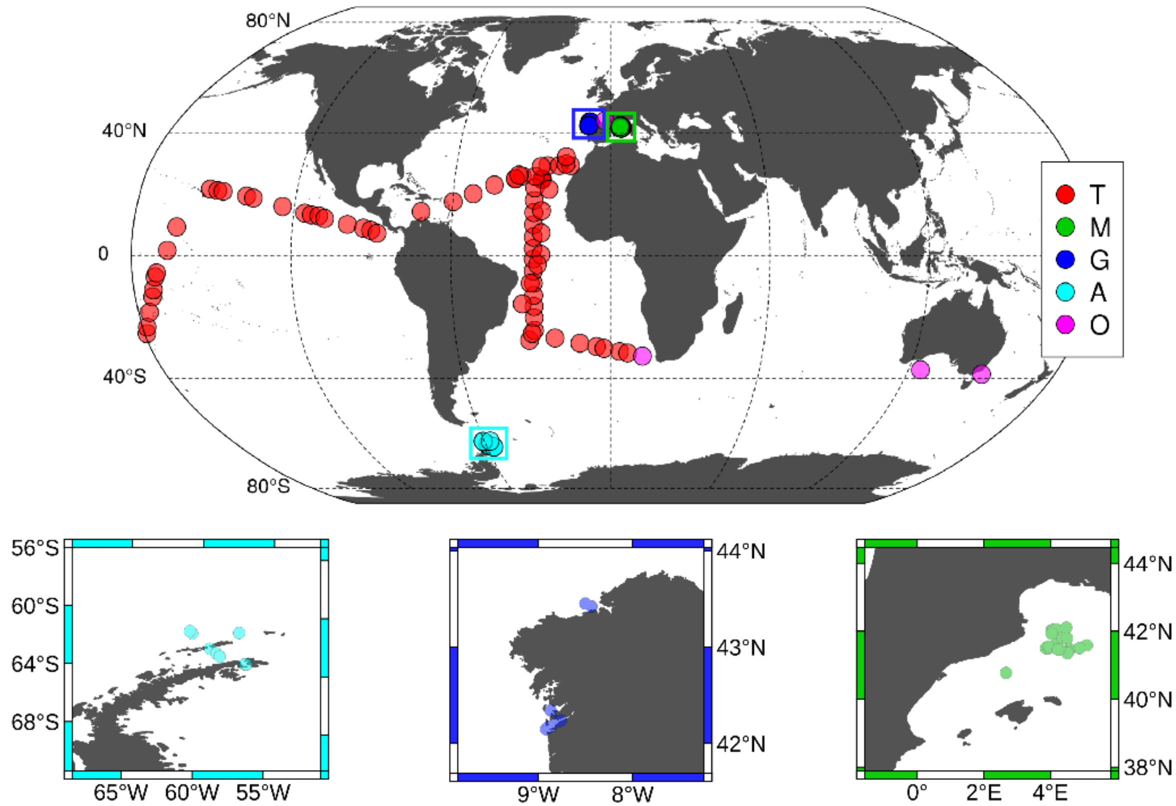
2. To **describe** the **ecological niches** of the various components of the **picoplankton community**.

3. To explore the **effect** of **nitrate supply dynamics** on the competitive dynamics of two model marine picophytoplankton species, namely, the cyanobacterium ***Synechococcus*** sp. and the picoeukaryote ***Micromonas pusilla***.

4. To build a prediction model and obtain the first **climatology** of **nitrate diffusion** into the **euphotic zone**.

5. To **predict** the change in the structure of **picophytoplankton communities** (the cyanobacteria to picoeukaryotes ratio) in a **future ocean scenario**.

Dataset of microstructure turbulence (2006-2015)



16 cruises; 181 stations

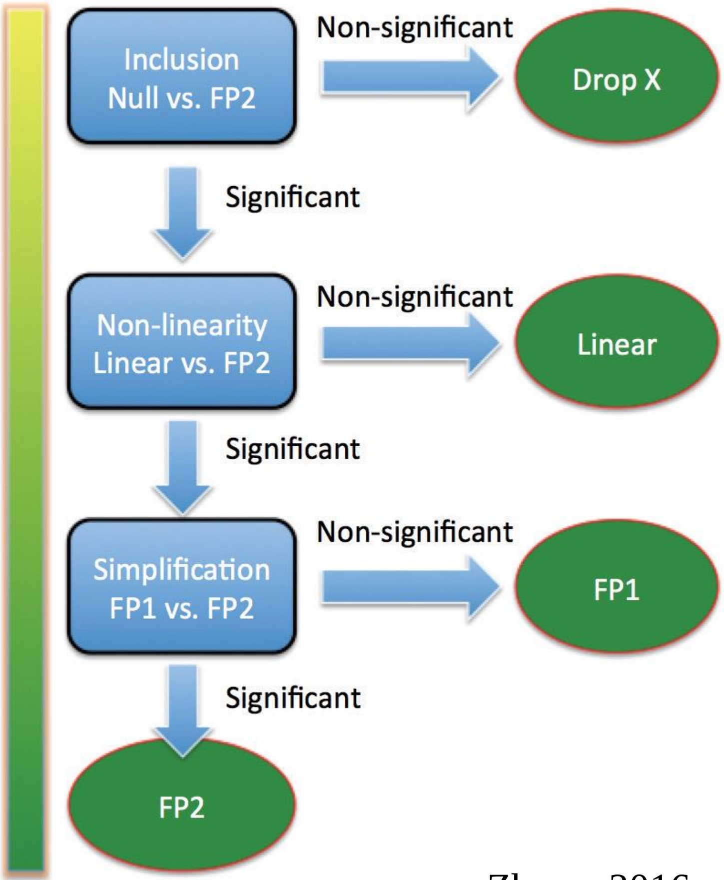
- ❑ 181 Microturbulence (MST, 0-300 m)
- ❑ Nitrate concentration (0-200 m):
  - ❑ 172 Observations
  - ❑ 6 WOA09 database
  - ❑ 3 Nitrate-density relationship

Multivariable fractional polynomial method (MFP)

Independent variables

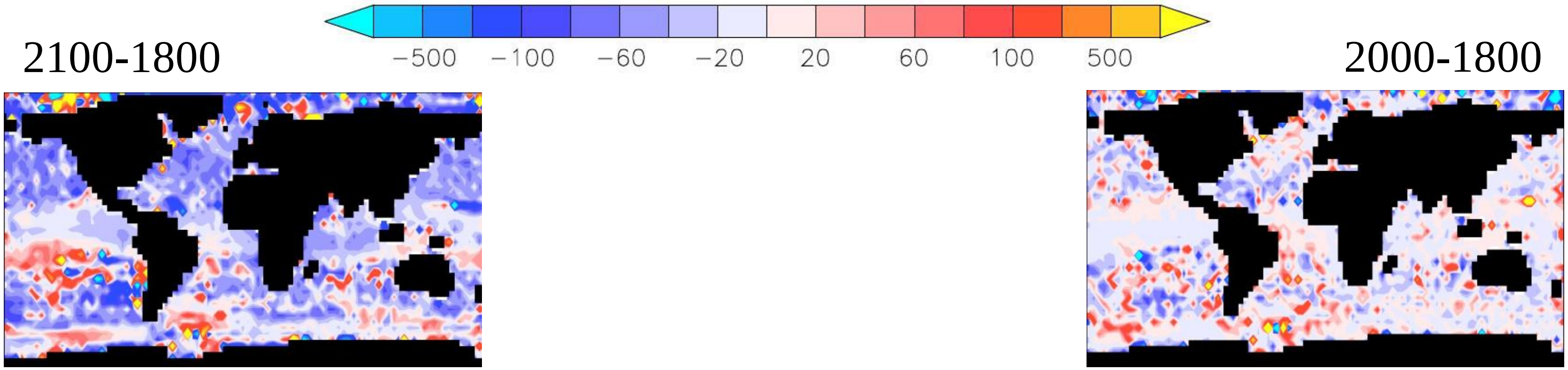
Stratification	Nitrate	Chlorophyll-*a*
SST	sNO_3	DCM
SSS	nitraD	maxChl-*a*
MLD	$grNO_3$	sChl-*a*
$maxN^2$		
$dmaxN^2$		
$avrN^2$		

MFP algorithm



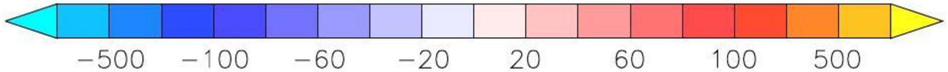
Zhang, 2016

Future scenario (2100)

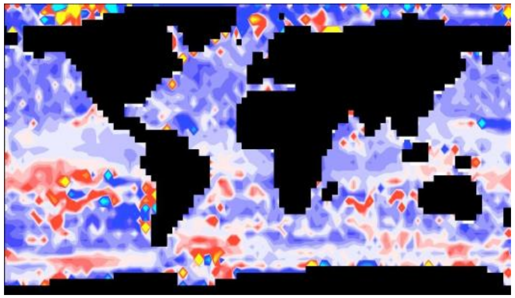


Lewandowska *et al.*, 2014

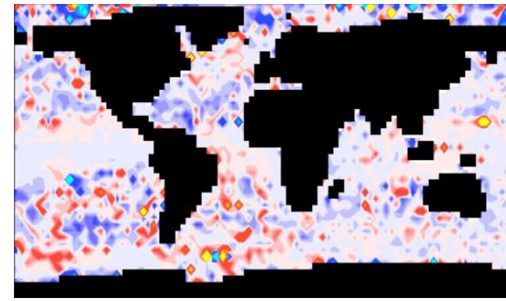
Future scenario (2100)



2100-1800

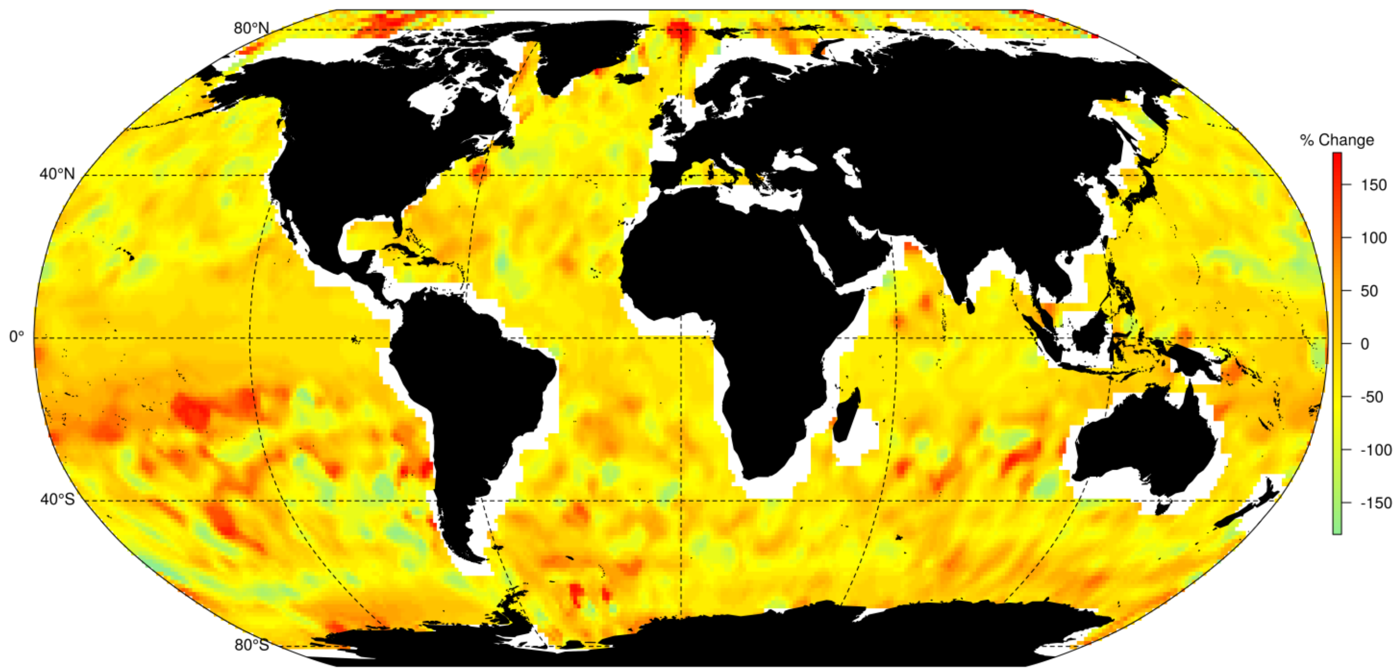


2000-1800

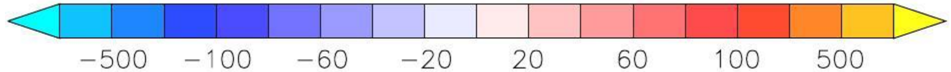


Lewandowska *et al.*, 2014

2100-2000



Future scenario (2100)



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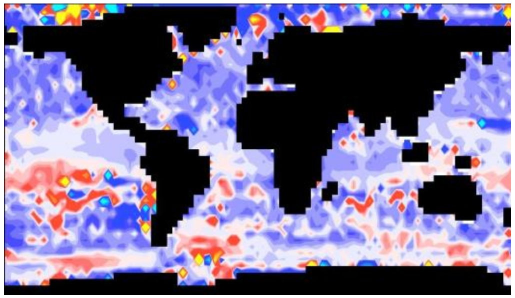

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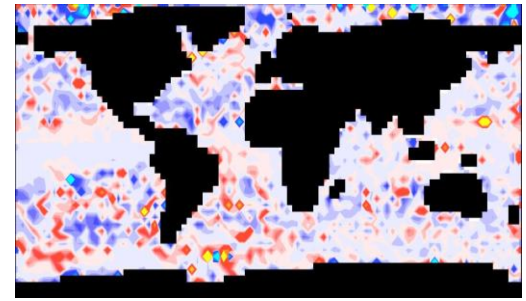
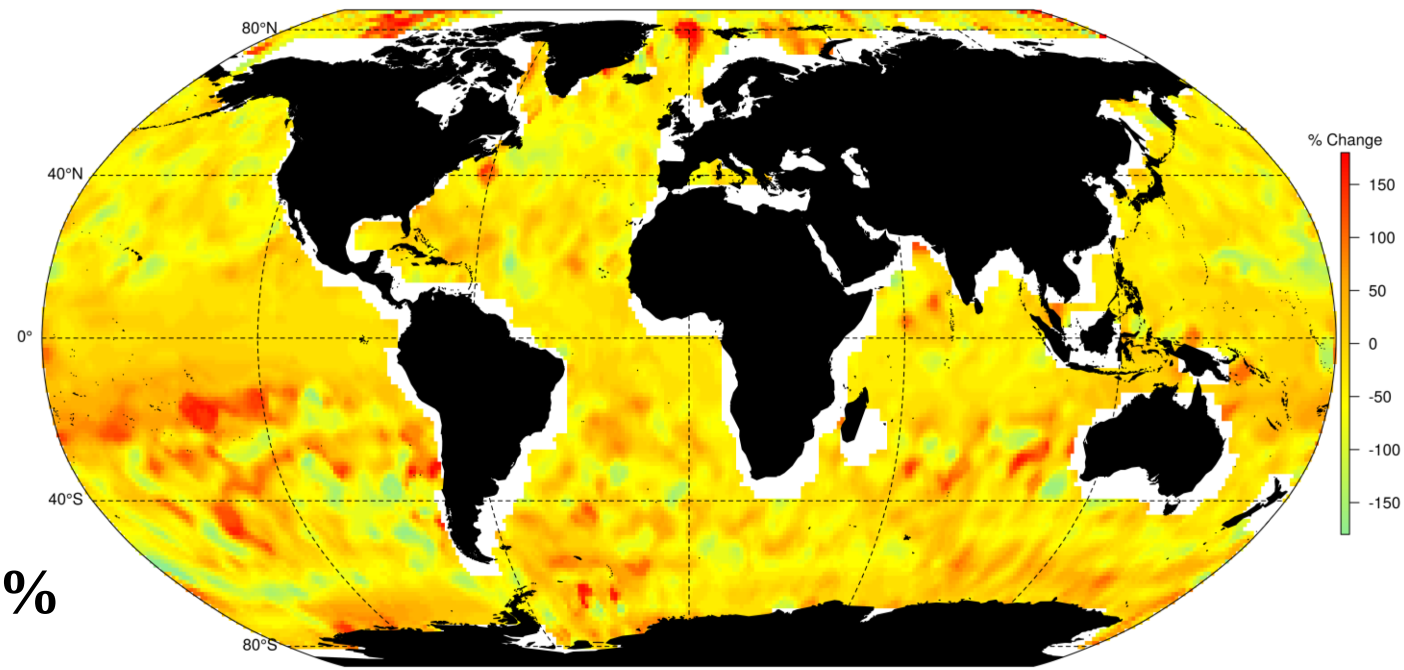


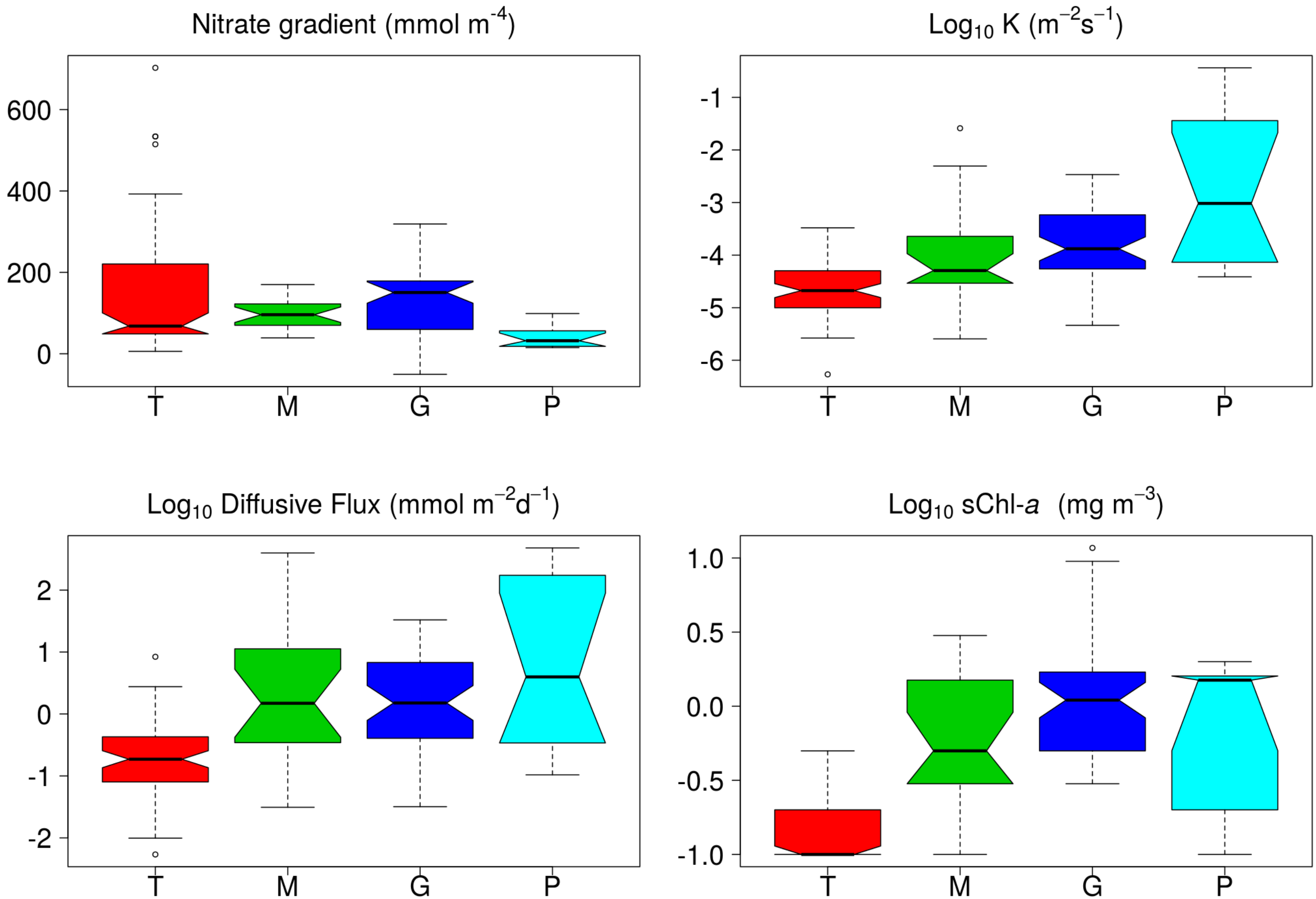
Lewandowska *et al.*, 2014

2100-2000



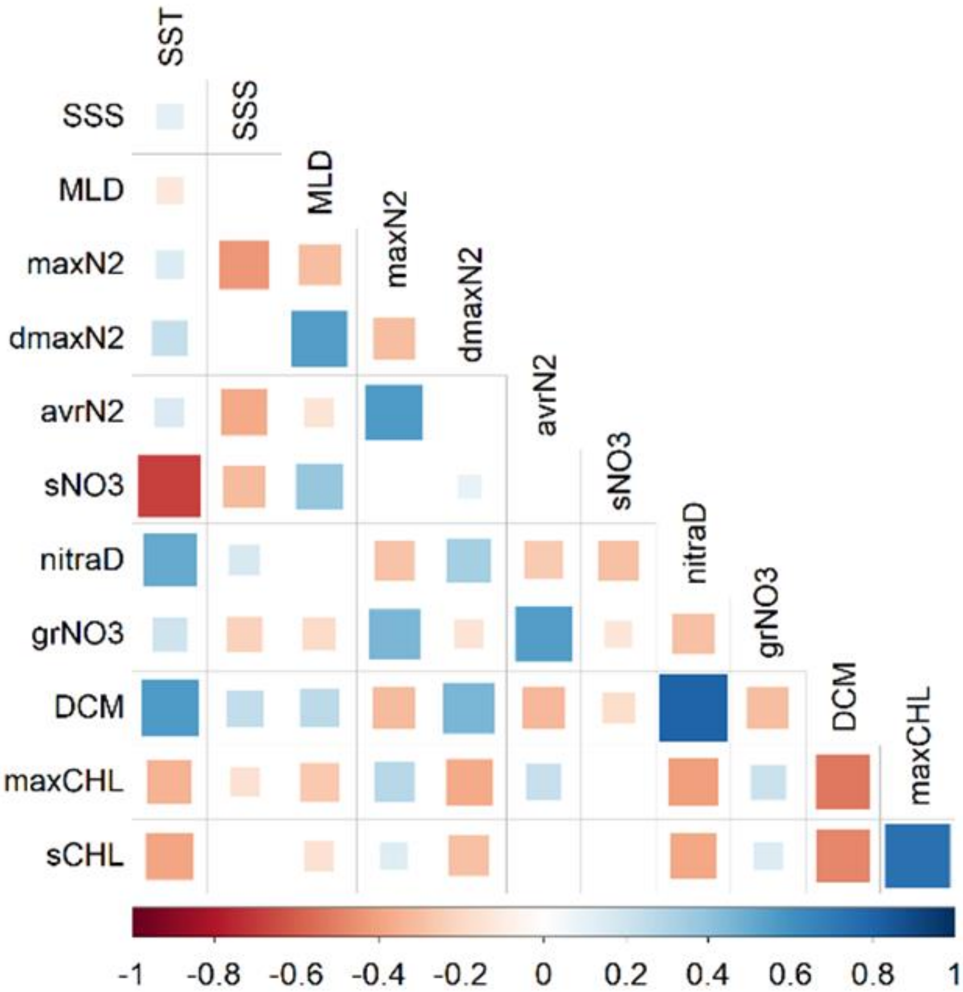
20%

Variability in NO_3 gradient, K, NO_3 flux and sChl-*a*



Collinearity in the dataset

Correlation matrix



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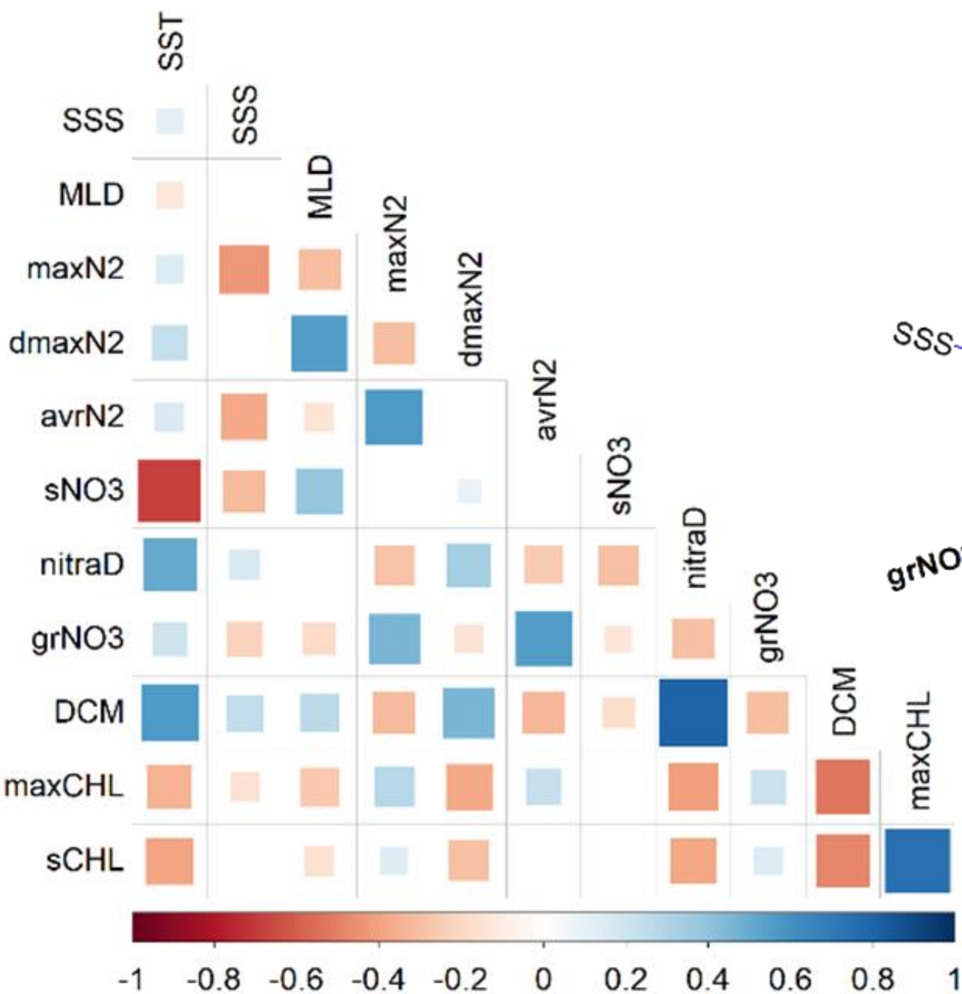
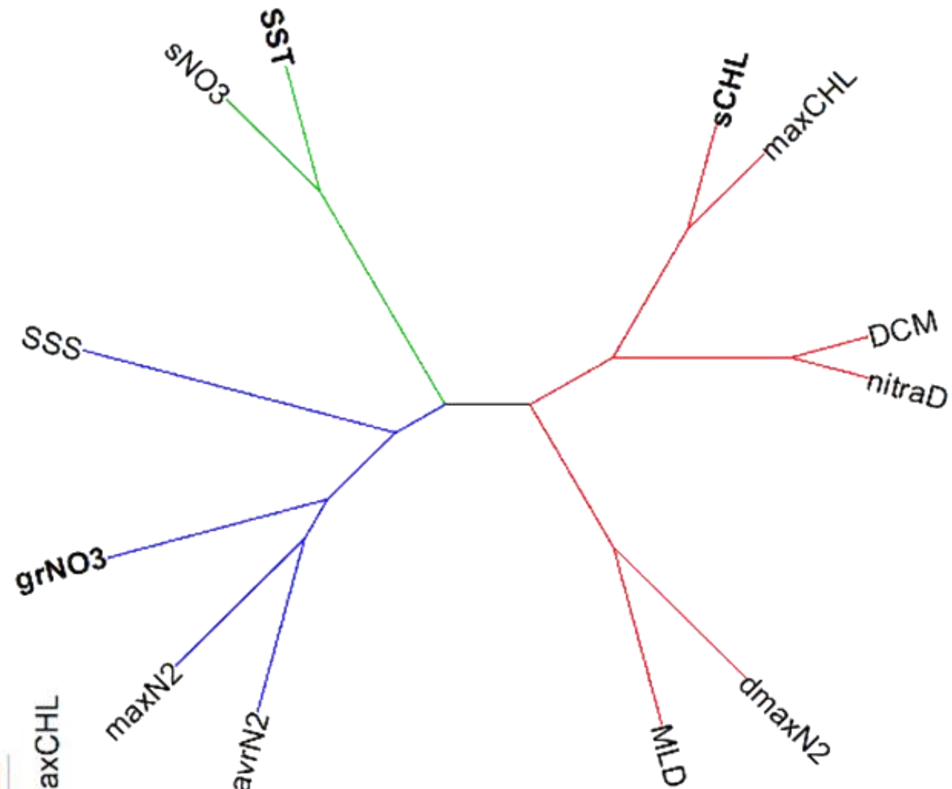


Cluster



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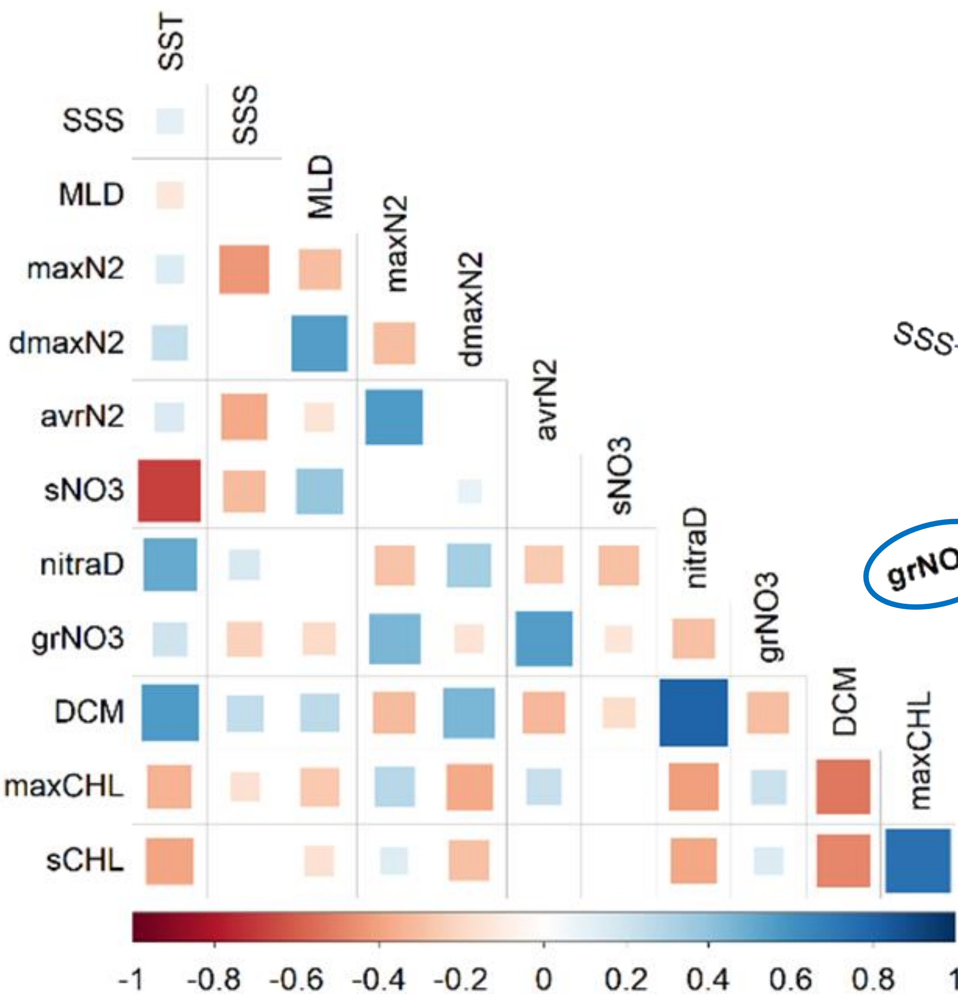

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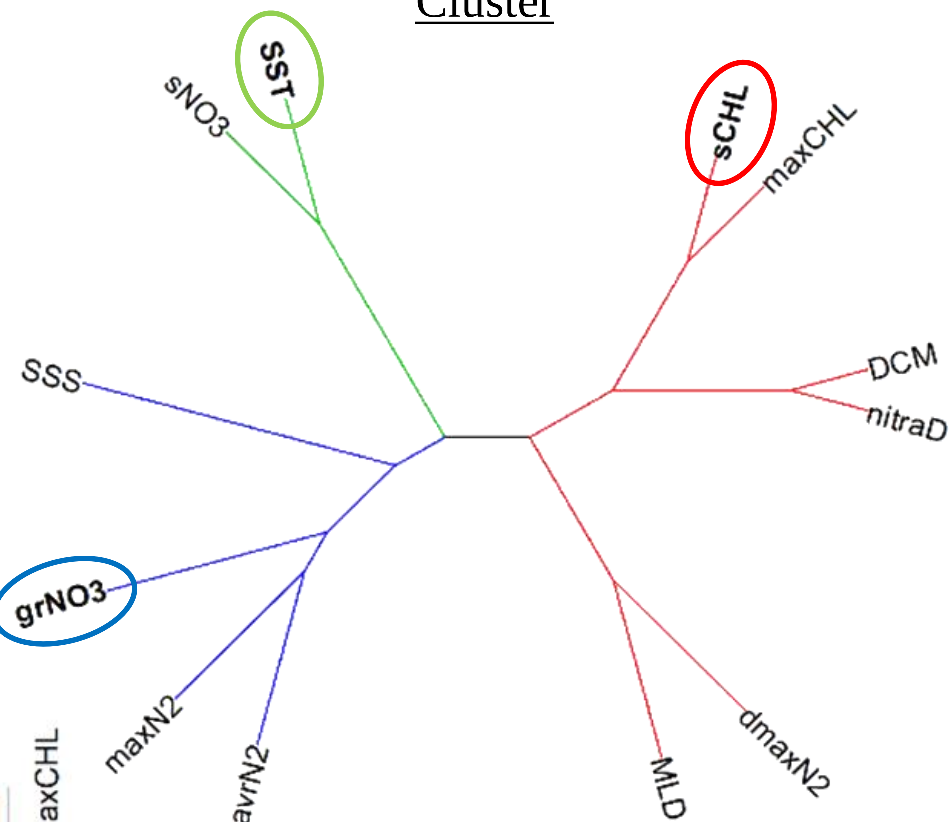

Multivariable fractional polynomial method (MFP)

	R^2-adj	AIC
Tropical and subtropical		
$FNO_3 = f($**$grNO_3$**, *SSS*, sNO_3, $avrN_2)$	0.75	143
$FNO_3 = f($**$grNO_3$, SST**$)$	0.41	189
NW Mediterranean		
$FNO_3 = f(avrN_2)$	0.68	72
$FNO_3 = f($**SST, sChla**$)$	0.64	77
NW Galician upwelling		
$FNO_3 = f($**$grNO_3$**, *maxChla*$)$	0.64	77
$FNO_3 = f($**$grNO_3$**$)$	0.51	110
Antartic		
$FNO_3 = f($**SST**$)$	0.75	38
Global		
$FNO_3 = f($**SST, grNO3, sChla**, *DCM*$)$	0.55	545
$FNO_3 = f($**SST, grNO3, sChla**$)$	0.52	553

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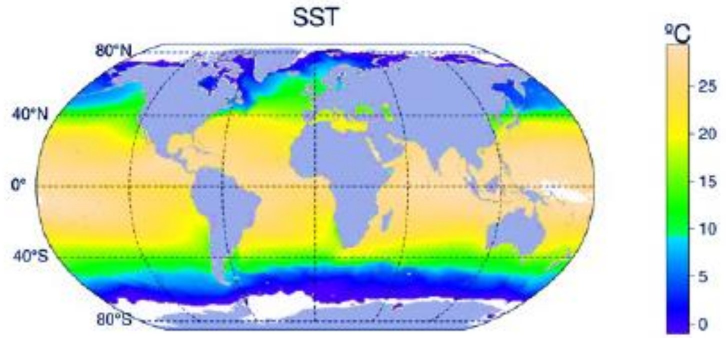
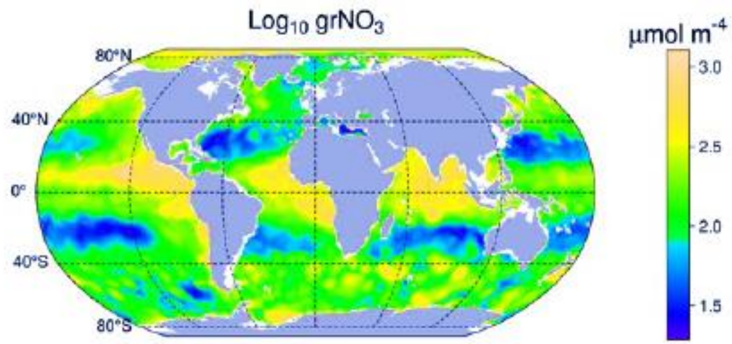
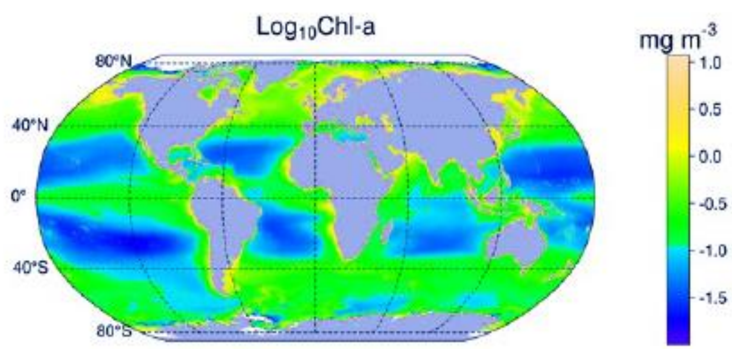
Prediction of NO_3 turbulent diffusion



SST from WOA13

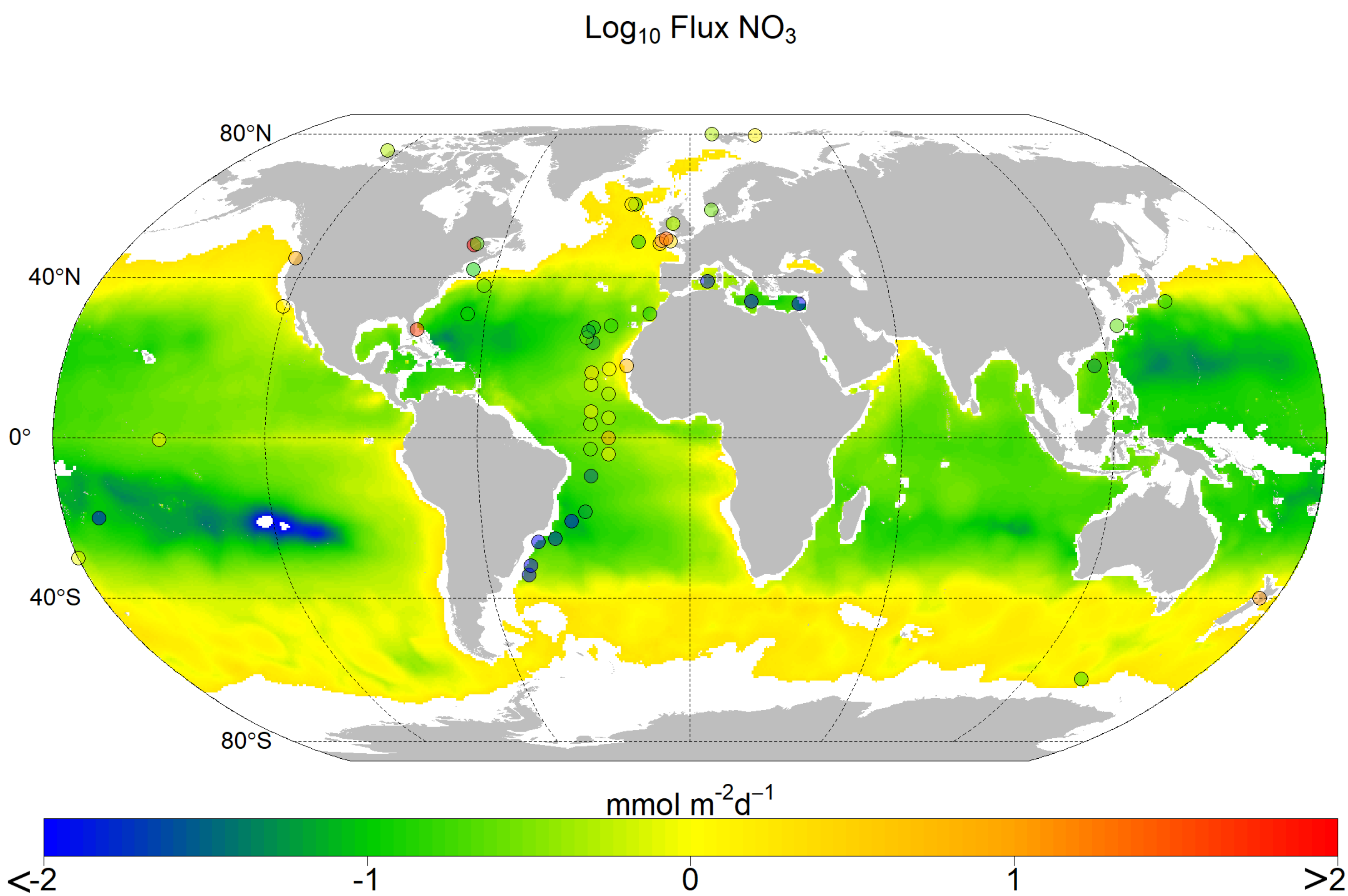


$grNO_3$ from WOA13

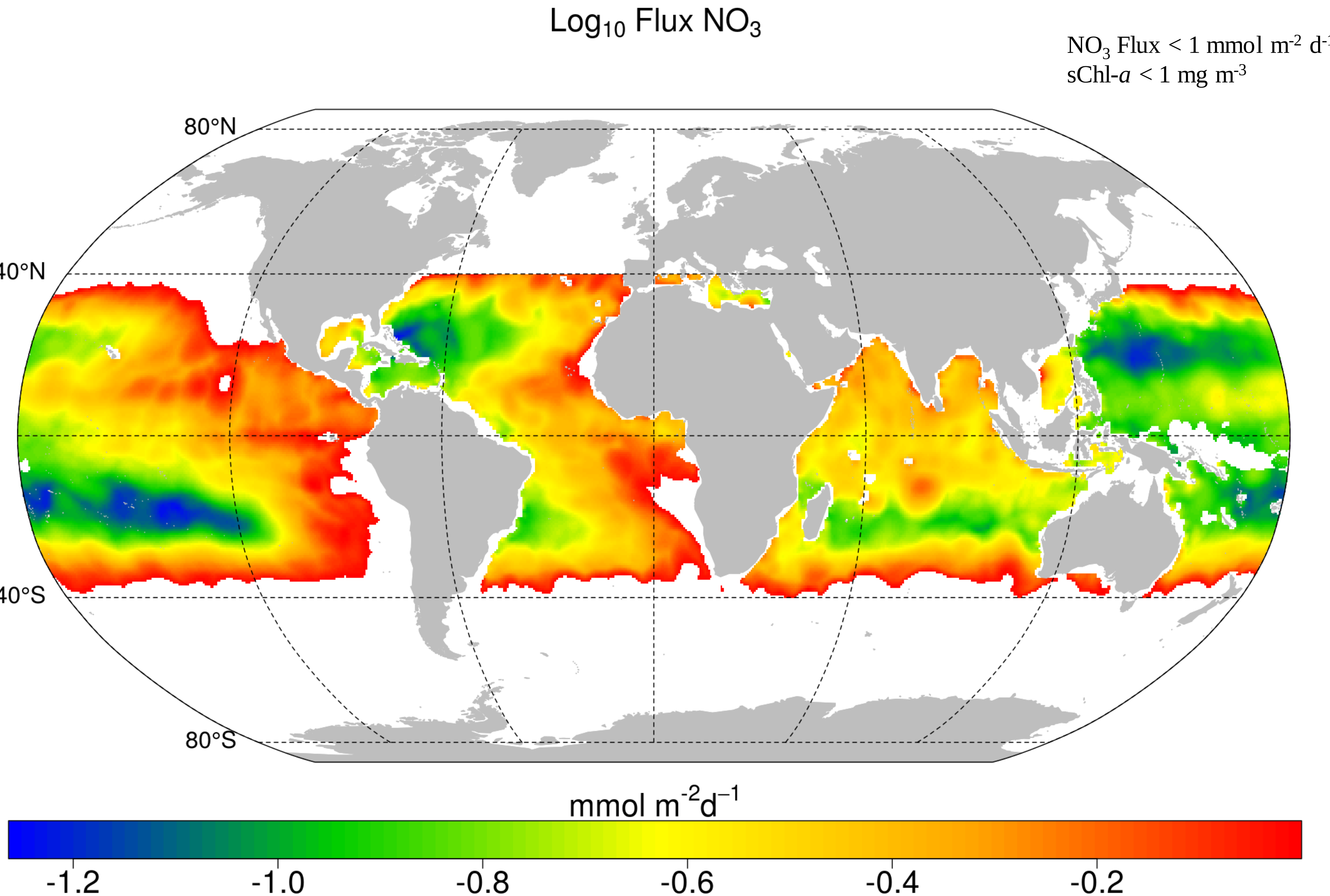


sChla from Globecolour (1998-2017)

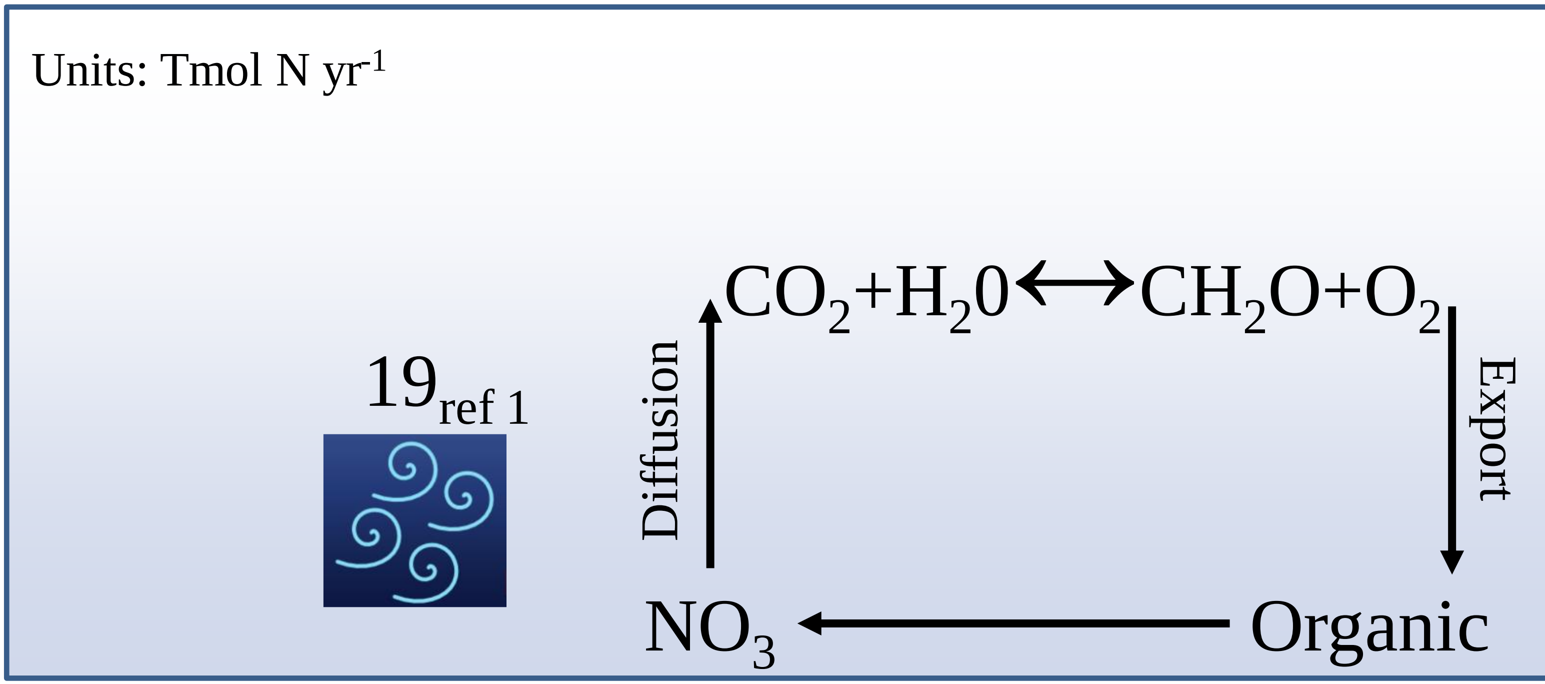
Prediction of NO_3 turbulent diffusion + observations



Prediction of NO_3 diffusion for 40ºN – 40ºS

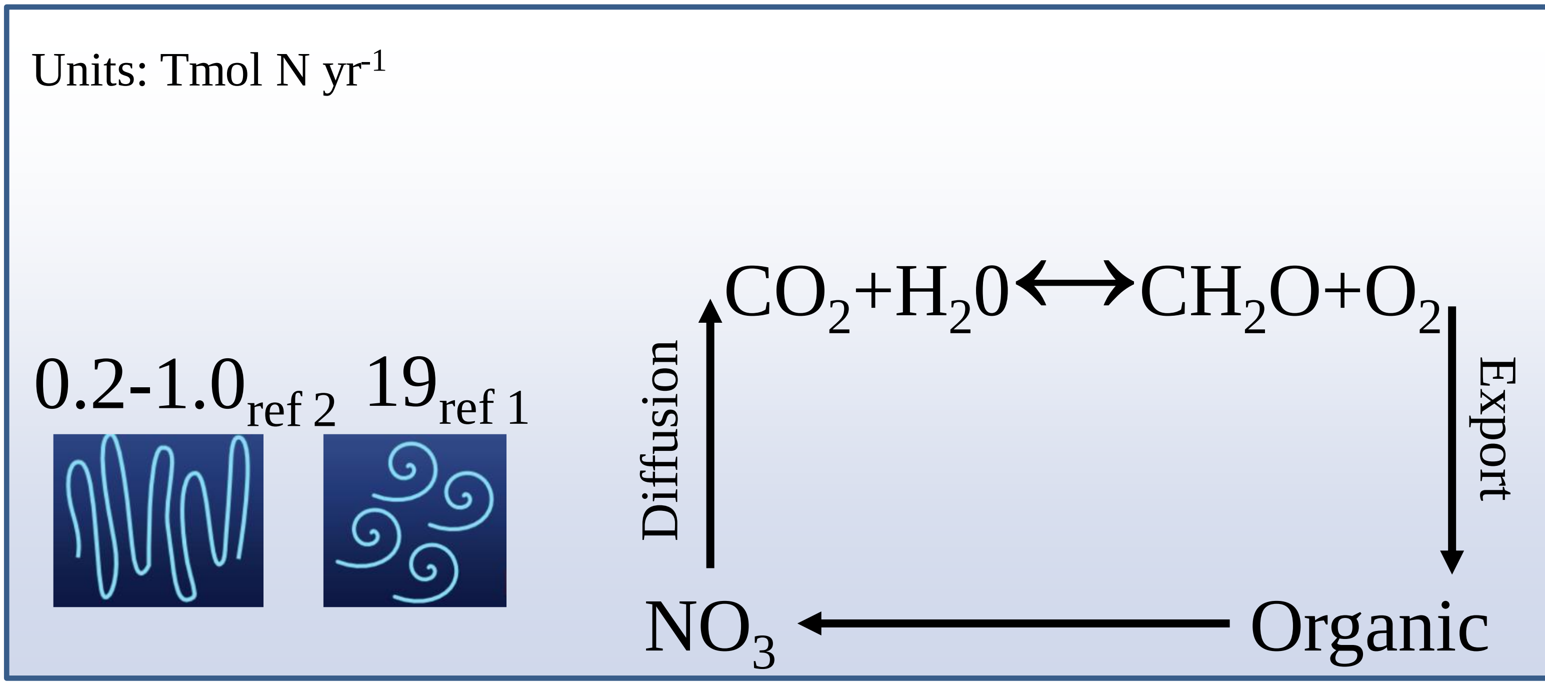


Relevance of diffusive nitrogen fluxes in tropical and subtropical areas



[1]This study

Relevance of diffusive nitrogen fluxes in tropical and subtropical areas



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[2]Fernández-Castro et al. (2015)

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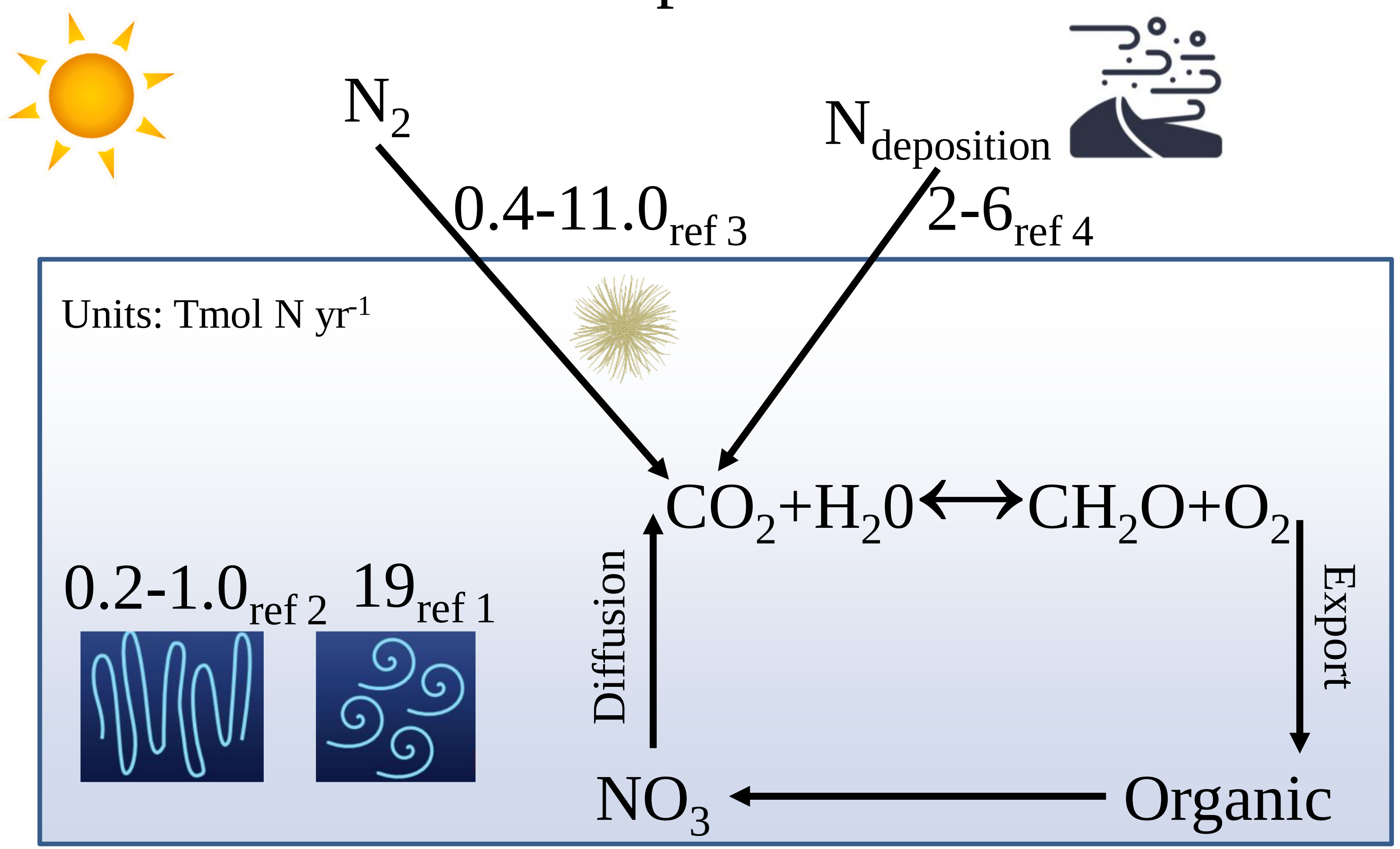

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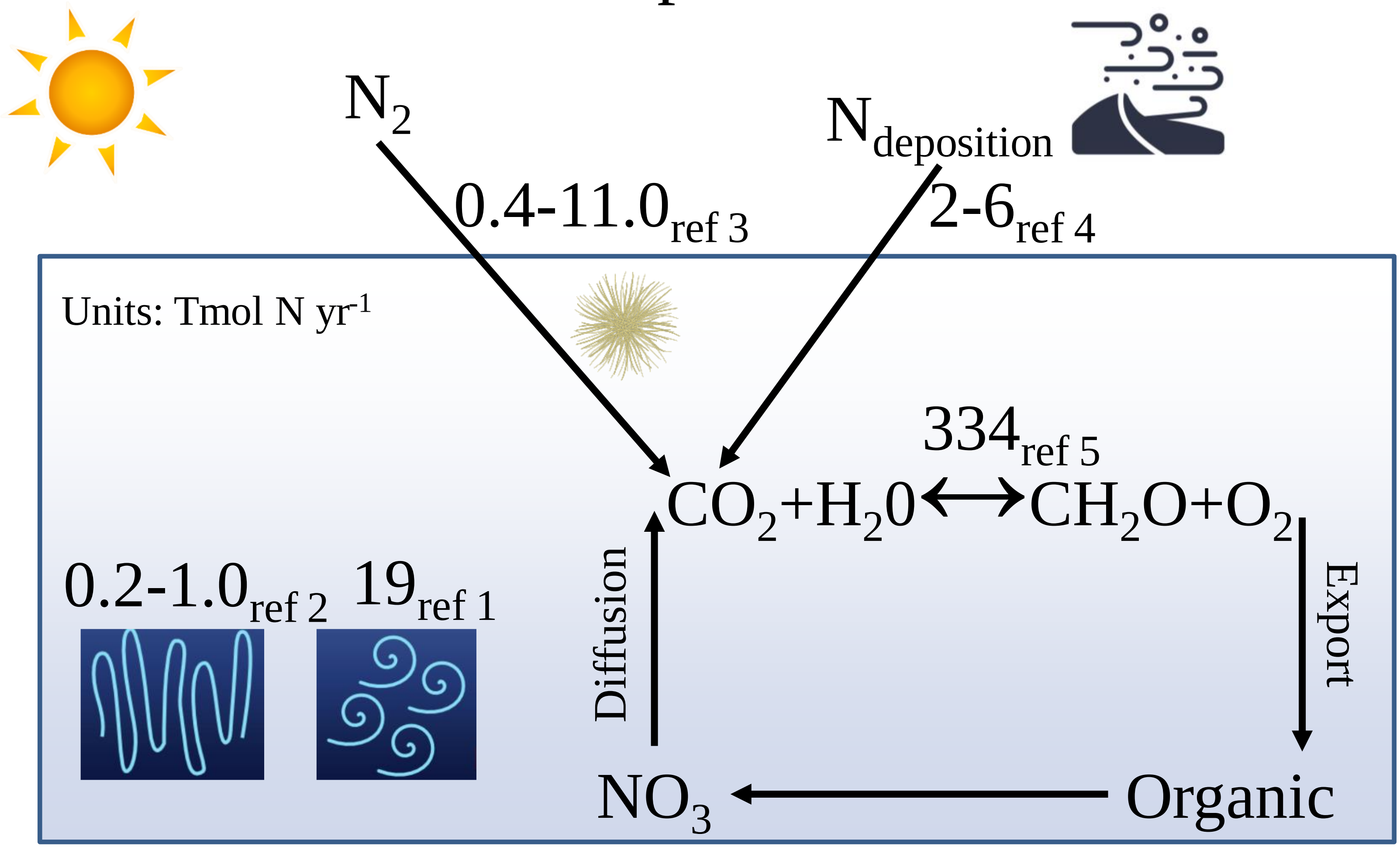

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[5]NPP(Uitz et al, 2008)
20% ratio phyto respiration to GP (Geider, 1992)
23% DOC production (Teira et al, 2001)
Variable stoichiometry (Galbraith & Martiny, 2015)

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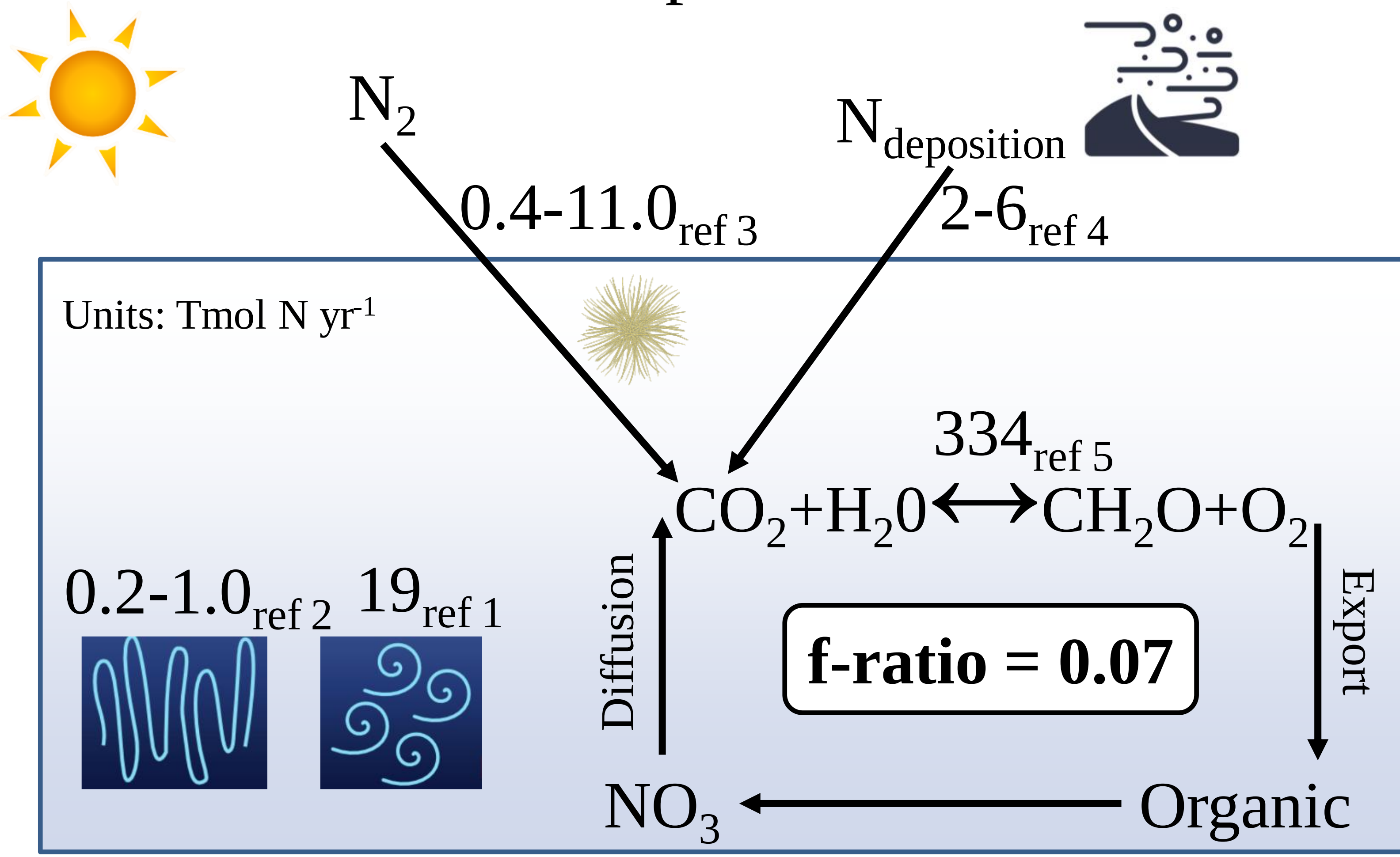

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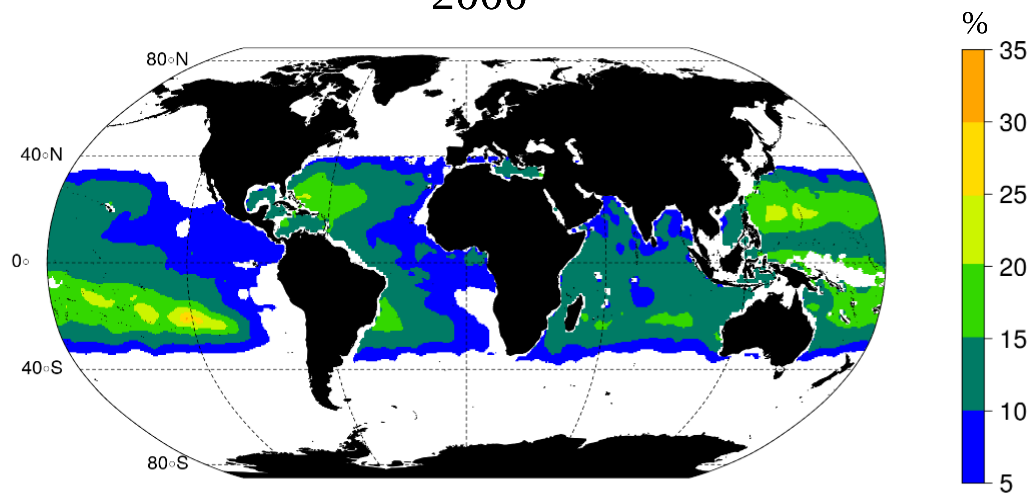
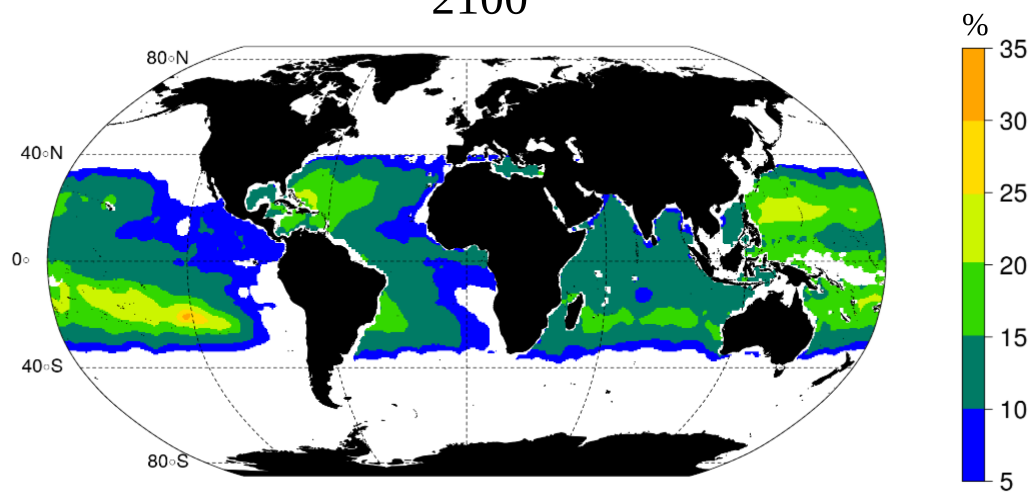
Present and future of cyanoB/pEuk ratio

2000



2100



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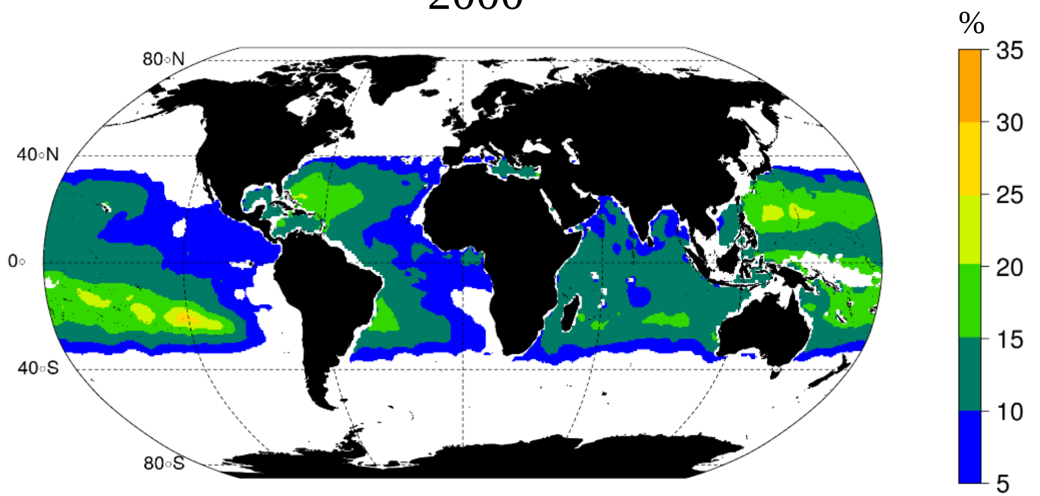
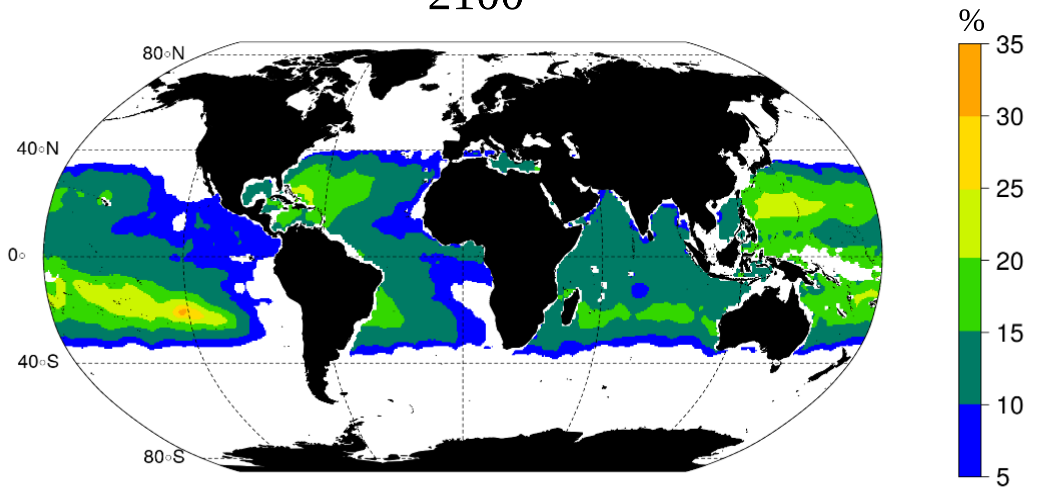


2100



8%

Conclusions

OBJECTIVE I

To **quantify** the role of **temperature**, **light**, and **nitrate fluxes** as factors controlling the distribution of autotrophic and heterotrophic picoplankton subgroups.

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CONCLUSION I

Temperature and **nitrate supply** were **more relevant than light** in predicting the biomass of most picoplankton subgroups, except for *Prochlorococcus* and low-nucleic-acid (LNA) prokaryotes, for which irradiance also played a significant role.

OBJECTIVE II

To **describe** the **ecological niches** of the various components of the **picoplankton community**.

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CONCLUSION II y III

Prochlorococcus and **LNA prokaryotes** were more abundant in warmer waters where the **nitrate fluxes** were **low**, ***Synechococcus*** and high-nucleic-acid (**HNA**) **bacteria** prevailed in cooler environments characterized by **intermediate or high** levels of **nitrate supply**, and finally the niche of **picoeukaryotes** was defined by **low temperatures** and **high nitrate supply**.

Nitrate supply was the **only factor** that allowed the **distinction among the ecological niches** of all autotrophic and heterotrophic picoplankton subgroups.

OBJECTIVE III

To explore the **effect** of **nitrate supply dynamics** on the competitive dynamics of two model marine picophytoplankton species, namely, the cyanobacterium ***Synechococcus*** sp. and the picoeukaryote ***Micromonas pusilla***.

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CONCLUSION IV, V y VI

Nitrate supply dynamics controlled the outcome of competition between the cyanobacterium *Synechococcus* and the picoeukaryote *M. pusilla*.

Under continuous nitrate limitation conditions (**steady-state**), ***M. pusilla* was outcompeted by *Synechococcus sp.***, the **result** of the competition was **reversed** in nutrient supply dynamics scenarios.

The **rate of competitive exclusion of *Synechococcus*** was a **linear function of the frequency of nitrate pulses**, demonstrating that there is a window of opportunity for the coexistence of both species.

OBJECTIVE IV

To build a prediction model and obtain the first **climatology** of **nitrate diffusion** into the **euphotic zone**.

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CONCLUSION VII y VIII

A model including **three predictors** (surface temperature, nitrate vertical gradient, and surface chlorophyll-*a*) **explained 57%** of the **variance** in the nitrate diffusive flux.

Average nitrate diffusion for oligotrophic regions between 40ºN-40ºS (~20 Tmol N y^{-1}) was **comparable** to the **sum** of global estimates of **nitrogen fixation**, **fluvial fluxes** and **atmospheric deposition**.

OBJECTIVE V

To **predict** the change in the structure of **picophytoplankton communities** (the cyanobacteria to picoeukaryotes ratio) in a **future** global change **scenario**.

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CONCLUSION IX

The predicted **decrease of nitrate supply** in tropical and subtropical areas as the result of global change **(~20%)**, would produce an **increase** in the **cyanobacteria to picoeukaryotes biomass ratio** of **8%**.

Universidade Vigo

THANK YOU

FOR YOUR ATTENTION

Grupo de Oceanografía Bioloxica

DO MAR
PHD PROGRAM IN MARINE SCIENCE, TECHNOLOGY AND MANAGEMENT

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN