

# Methods

January 21, 2020

## Model

We use the model developed by Shoemaker & Melbourne (2016); Wisnoski *et al.* (2019), and previous findings in Picoche & Barraquand (2019a,b).

We consider two steps in the discrete-time model: species first grow following a Beverton-Holt model for the coastal and oceanic cells, while seeds are only subject to a small mortality. Then, we take into account exchanges between the coast and the open-ocean, and between the water column and the benthos.

$$\begin{cases} N_{t+h,i,c/o} &= \frac{e^{r_i(T)} N_{t,i,c/o}}{1 + \sum_j \alpha_{i,j,c/o} N_{t,j,c/o}} \\ N_{t+h,i,b} &= N_{t,i,b}(1 - m_i) \end{cases} \quad (1)$$

$$\begin{cases} N_{t+1,i,c} &= N_{t+h,i,c}(1 - s_i - e) + \gamma_i N_{t+h,i,b} + e N_{t+h,i,o} \\ N_{t+1,i,o} &= N_{t+h,i,o}(1 - s'_i - e) + e N_{t+h,i,c} \\ N_{t+1,i,b} &= N_{t+h,i,b}(1 - \gamma_i) + s_i N_{t+h,i,c} \end{cases} \quad (2)$$

with growth rate defined according to Scranton & Vasseur (2016) (eq. 3).

$$\begin{aligned} r_i(T) &= a_r(\tau_0) e^{E_r \frac{(T - \tau_0)}{kT\tau_0}} f_i(T) \\ \text{where } f_i(T) &= \begin{cases} e^{-|T - T_i^{opt}|^3 / b_i}, & T \leq T_i^{opt} \\ e^{-5|T - T_i^{opt}|^3 / b_i}, & T > T_i^{opt} \end{cases} \\ \text{and } b_i &\text{ is defined by numerically solving } \int r_i(\tau) d\tau = A \end{aligned} \quad (3)$$

Parameters and state variables definitions are given in Table 1.

Param	Name	Value (unit)
$N_{i,c/o/b}$	Abundances of species $i$ at time $t$ in the coast (c) or ocean (o) water column, or in the benthos (b)	NA (Number of cells)
$T$	temperature	NA (K)
$r_i(T)$	growth rate of species $i$	NA
$b_i$	Normalization constant for the thermal decay rate	$(K^3)$
$\tau_0$	Reference temperature	293 (K) / 20 (°C)
$a_r(\tau_0)$	Growth rate at reference temperature	$386(\frac{\text{kg}}{\text{kg} \times \text{year}})^{-1}$
$E_r$	Activation energy	0.467 (eV)
$k$	Boltzmann's constant	$8.6173324 \cdot 10^{-5} (\text{eV} \cdot \text{K}^{-1})$
$f_i(T)$	Fraction of the maximum rate achieved for the $i^{th}$ species	(NA)
$T_{\min}$	Minimum thermal optimum	288 (K)
$T_{\max}$	Maximum thermal optimum	298 (K)
$T_i^{opt}$	Optimal temperature for species $i$	Adapted from Picoche & Barraquand (2019b)
$\alpha_{ij,c/o}$	interaction strength of species $j$ on $i$	$\mathcal{N}(\mu, \sigma), \mu = 0.0, \sigma = 0.01$ ; adapted from Picoche & Barraquand (2019b)
$k_{c2o}$	conversion coefficient from coastal to oceanic interactions	1.5
$m_i$	seed mortality of species $i$	$\approx 10^{-4} / 10^{-5}$ Values from on McQuoid <i>et al.</i> (2002)
$s_i$	sinking rate of species $i$ in a coastal environment	$30\beta(0.55, 1.25)$ from values given in Passow (1991)
$s'_i$	sinking rate of species $i$ in an oceanic environment	$s = s'_i$
$e$	exchange rate between ocean and coast	0.64 d <sup>-1</sup> from Plus <i>et al.</i> (2009)
$\gamma_i$	germination + resuspension rate of species $i$	$[0.1, 0.01, 0.001] * 0.5 * s_i$ (arbitrary)

Table 1: Definition of variable states and parameters

## Parameter definition

**Interactions** Interaction matrices are inspired by previous works on phytoplankton abundance time-series (Barraquand *et al.*, 2018; Picoche & Barraquand, 2019b). The model used in these two papers is a multivariate autoregressive (MAR) model, that is a discrete-time linear model of the dynamics in which  $X_{t+1} = BX_t$  where  $X_t$  is the vector of log-abundances of the phytoplankton species and  $B$  is the interaction matrices. Based on Picoche & Barraquand (2019b),  $b_{ij, i \neq j} \sim \mathcal{N}(\mu, \sigma)$  with  $\mu$  and  $\sigma$  around 0.0 and 0.01. Centric diatoms, pennate diatoms and dinoflagellates can only interact with each other, i.e. the community matrix is modular. Self-regulation is computed as a function of vulnerability, with  $b_{ii} \sim -0.49b_{i,} - 0.37$ . Assuming that nutrients are rarer in the ocean than in the coast [ref],  $\alpha_{ij, c} < \alpha_{ij, o}$ , with a fixed coefficient  $k$  such that  $b_{ij, c} = k_{c2o}b_{ij, o}$ .

Certain *et al.* (2018)<sup>2</sup> showed that MAR and Beverton-Holt interaction coefficients, respectively  $b_{ij}$  and  $\alpha_{ij}$ , could map once abundances at equilibrium  $N_i^*$  are defined.

$$\begin{cases} b_{ii} - 1 = \frac{-\alpha_{ii}N_i^*}{1 + \sum_l \alpha_{il}N_l^*} \\ b_{ij, i \neq j} = \frac{-\alpha_{ij}N_j^*}{1 + \sum_l \alpha_{il}N_l^*} \end{cases}$$

Let's define  $f_A(i) = \sum_l \alpha_{il}N_l^*$ .

$$b_{ij}(1 + f_A(i)) = -\alpha_{ij}N_j^*$$

We then sum on columns (on j).

$$\begin{aligned} \sum_j [b_{ij}(1 + f_A(i))] &= -f_A(i) \\ \Leftrightarrow -f_A(i)(1 + \sum_j b_{ij}) &= \sum_j b_{ij} \\ \Leftrightarrow f_A(i) &= -\frac{\sum_j b_{ij}}{(1 + \sum_j b_{ij})} \\ \Leftrightarrow \alpha_{ij} &= -\frac{1}{N_j^*} b_{ij} \left(1 - \frac{\sum_j b_{ij}}{1 + \sum_j b_{ij}}\right) \\ \Leftrightarrow \alpha_{ij} &= -\frac{1}{N_j^*} \frac{b_{ij}}{1 + \sum_j b_{ij}} \end{aligned}$$

**Optimal temperature** To define each species growth rate according to daily temperature, species are defined according to their optimal temperature. In the toy model of Picoche & Barraquand (2019a), optimal temperatures followed a uniform law between 15 and 25°C. This does not seem realistic, especially if we look at the effect of temperature in Picoche & Barraquand (2019b). We can define two species preferring the cold (around 15°C), as we had *Asterionellopsis* and *Skeletonema* in our datasets, and the other preferring warmer temperatures (uniform law between 20 and 25°C).

Note that these temperature values are 5 degrees above the observed temperature mean in the REPHY dataset, but they are in the domain of application of the model from Scranton & Vasseur (2016).

This leads to growth rates between  $10^{-1}$  and  $10^{-8}$ . However, if we follow Reynolds (2006), such values should be vary between 0.7 and 1.8 (only considering Bacillariophyta), and may be calibrated on the surface/volume ratio instead of temperature.

**Exchange rate** This parameter depends on the estuary. In the Arcachon Bay, the exchange rate for each tide has been estimated around 64% (Plus *et al.*, 2009). If we take a daily time-step and consider only the tide that takes place during the day, there is only one tide and then,  $e=0.64^3$ .

<sup>1</sup>As the final dimension of this variable is year-1, I don't think we have to convert to number of cells but I am still wondering about the usability of this parameter + we have to convert from year to day

<sup>2</sup>Corrected in the Appendices of Picoche & Barraquand (2019b)

<sup>3</sup>We need to have very good arguments to take into account only one tide per day.

**Seed mortality Mortality in the sediment:** McQuoid *et al.* (2002) present maximum and mean depth at which germination of diatoms and dinoflagellates occurred in sediments. They also present sediment datation according to depth. Depth can therefore be related to maximum and mean age of phytoplankton before death.

Assuming  $m$  is the probability of mortality,  $m$  follows a geometric law, i.e.,  $m$  is the probability distribution of the number of days needed for a phytoplankton spore to die. The expectancy for the life duration (the number of days without dying) is  $\frac{1}{m} \Leftrightarrow m = \frac{1}{L_{mean}}$  where  $L_{mean}$  is the average life duration.

Another way to look at the process is that life expectancy  $L$  follows the distribution  $p(L > l) = e^{-ml}$ . With maximum values, we can arbitrarily choose that for these values  $p(L > l_{max}) = 0.05$ . In this,  $m = -\frac{\ln(p(L > l_{max}))}{l_{max}}$ .

In both cases,  $m \propto 10^{-4} \text{d}^{-1}$ .

**Burying by deposition** Even when seeds can be resurrected, they are not accessible when they are below a certain depth. Deposition happens, which reduces the reachable stock of seeds<sup>4</sup>.

**Sinking rate** According to Passow (1991) (who measured sinking rates in real conditions), rates can vary between 1 and 30% for the same species (*Chaetoceros* spp.), with a mean value for two diatom species of 10 (*Chaetoceros* and *Thalassiosira*). Values are much for the others, around 1% for the others.

Sinking rate values around 10% are consistent with the loss rate values in Wiedmann *et al.* (2016).

We can arbitrarily fix a beta distribution with mean value close to the one observed in both papers (between 9 and 10), and maximum around 30%, that is  $s \sim \beta(0.55, 1.25) * 30$ .

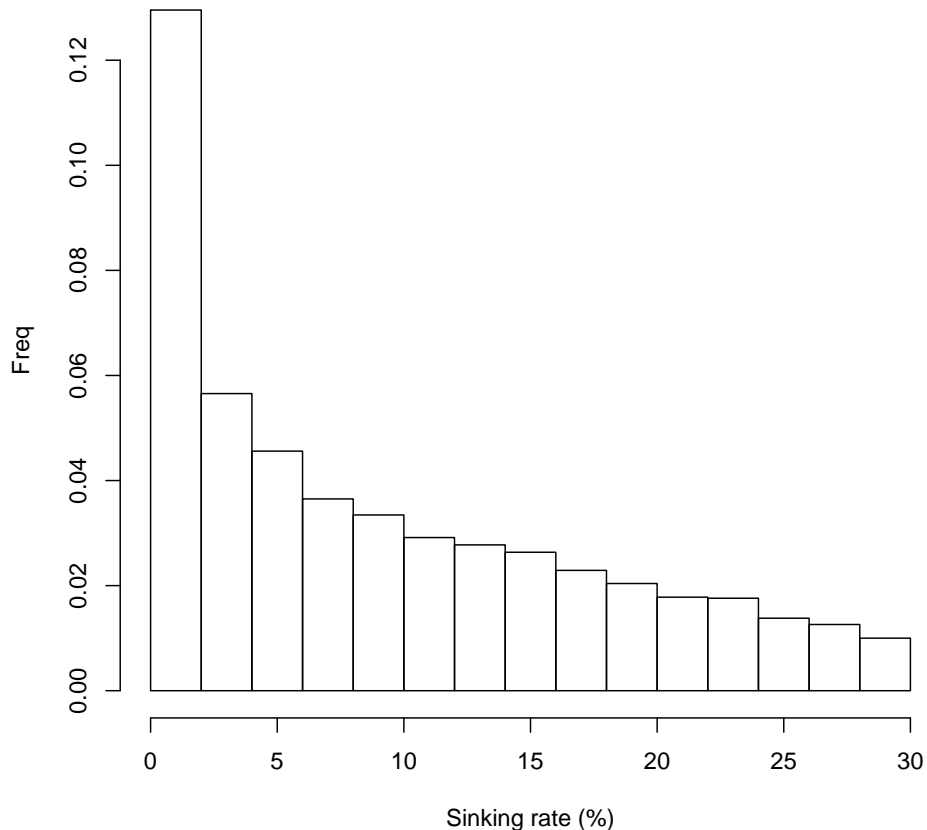


Figure 1: Possible distribution of sinking rates

<sup>4</sup>No idea how to parameterize this. Arcachon tends to silt-up, by what rate? We also need to know the maximum depth of sediments which can resuspended through hydrodynamics. However, this might become a key parameter (much higher than mortality in the sediment).

We may have to force the values for species like *Chaetoceros*, *Thalassiosira*, to have higher sinking rates.

**Germination/resuspension** Germination and resuspension might be difficult to differentiate, they are defined by the same parameters ( $\gamma = \text{resuspension} \times \text{germination}$ ). Even though we have no estimation of germination and resuspension rate, we can try several values. Germination can be 1%, 0.1%, 0.01%. Resuspension is arbitrarily set as a function of sinking rate. Species that have the highest sinking rates have the lowest resuspension values, and conversely. We use only half of the resulting value (arbitrary too). Contrary to what we previously thought, this value has a strong effect on the dynamics even though germination was supposed to be the most important.

Resuspension values vary from one publication to another: in Fransz & Verhagen (1985), resuspension rate of sediments is evaluated around  $5.10^{-5} \text{ day}^{-1}$  in winter and decreases in summer (there is a link between resuspension/sinking and light extinction coefficient). In Kowe *et al.* (1998), resuspension rate of diatoms is evaluated around  $1.9.10^{-5} \text{ day}^{-1}$ , with a maximum sinking rate of  $0.085 \text{ day}^{-1}$ . In Le Pape *et al.* (1999), resuspension rate of sediments and dead diatoms is  $0.002 \text{ day}^{-1}$ .

Additional information regarding germination: from McQuoid *et al.* (2002), we can assume that there is a temperature threshold for germination (but this cannot explain a lot of long-term dormancy) and the existence of such threshold is confirmed by the review by Agrawal (2009). Photoperiodicity does not seem to have a strong effect according to this review (but see Eilertsen *et al.* (1995)). We could use a temperature threshold at  $15^{\circ}\text{C}$ , as we already take this temperature for the growth rate (Scranton & Vasseur, 2016).

## Species definition

The composition of the community is inspired by the most common species along the French coast (see time series in Picoche & Barraquand, 2019b), with a preference for species also present in McQuoid *et al.* (2002)<sup>5</sup>.

- *Chaetoceros* (2 species) are one of the most common diatoms present along the French coast. We can define a small and big species among this genera, with potentially different sinking rates, related to their volume.
- *Thalassiosira*
- *Skeletonema* (also interesting because of a preference towards colder temperatures)
- *Gyrodinium/Rhizosolenia* (the idea behind is to have a very large species, maybe leading to higher sinking rate/lower growth rate?)
- *Pseudo-Nitzschia* and *Nitzschia*
- *Asterionellopsis* (also interesting because of a preference towards colder temperatures)
- *Gymnodinium* and *Protopridinium* as two of the most common dinoflagellates

## Intermediate results

Looking at species in isolation, we aim to obtain realistic abundances, that is of the same order of magnitude than observed abundances. Each compartment (ocean, coast, seed bank) contain  $10^6$  cells at the beginning of the simulation, which is run for 10000 time steps. Up to now, we focused on *Chaetoceros* species.

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<sup>5</sup>But if we finally ignore this paper as mortality in the sediment is too low, we might as well change this a bit

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