Extracting plankton physiological parameters from batch culture data

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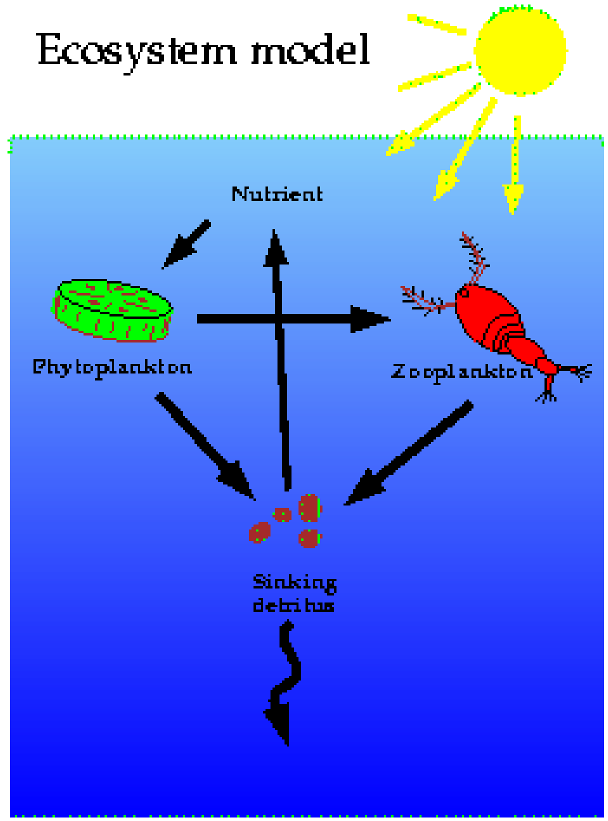
Ocean ecosystem models: the olden days

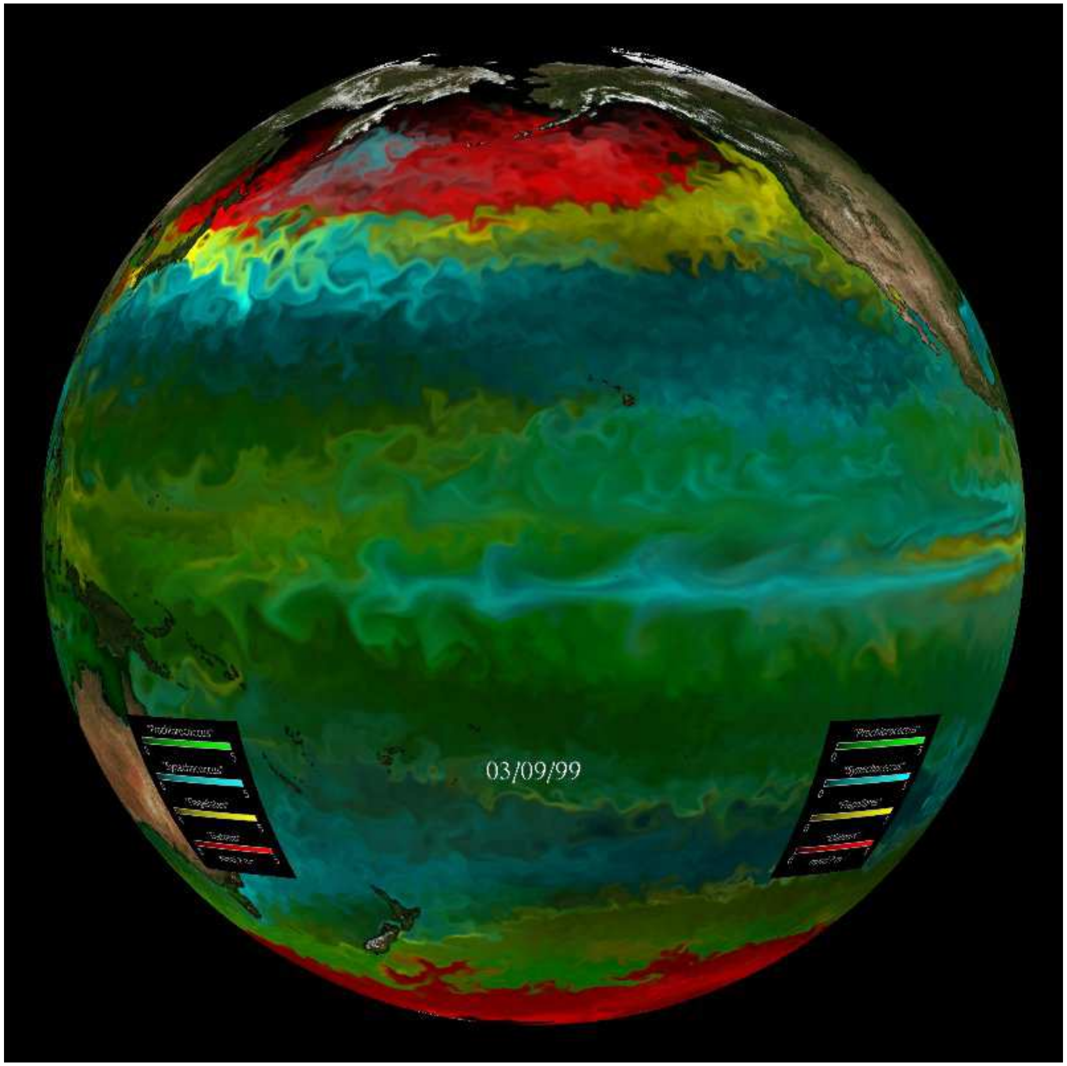


http://www.geos.ed.ac.uk/homes/hkettle

Only 2 plankton types (Phytoplankton & Zooplankton)

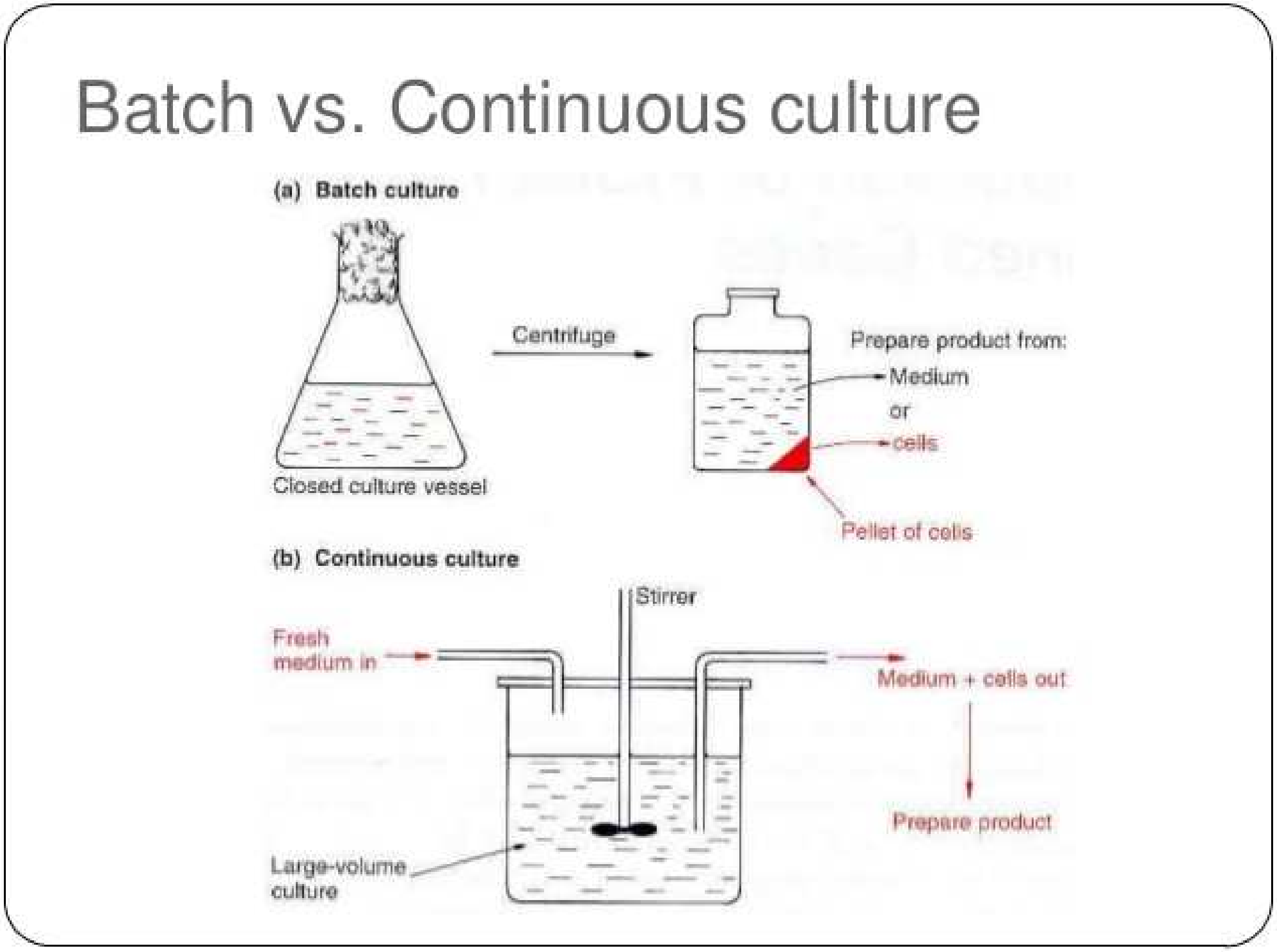
Parameter values not that critical:
Ecosystem will consume nutrients that are supplied

Ocean ecosystem models: nowadays



Competition between many plankton types: $\Longrightarrow$
Need to know parameter values for different plankton species

Data to constrain plankton parameters



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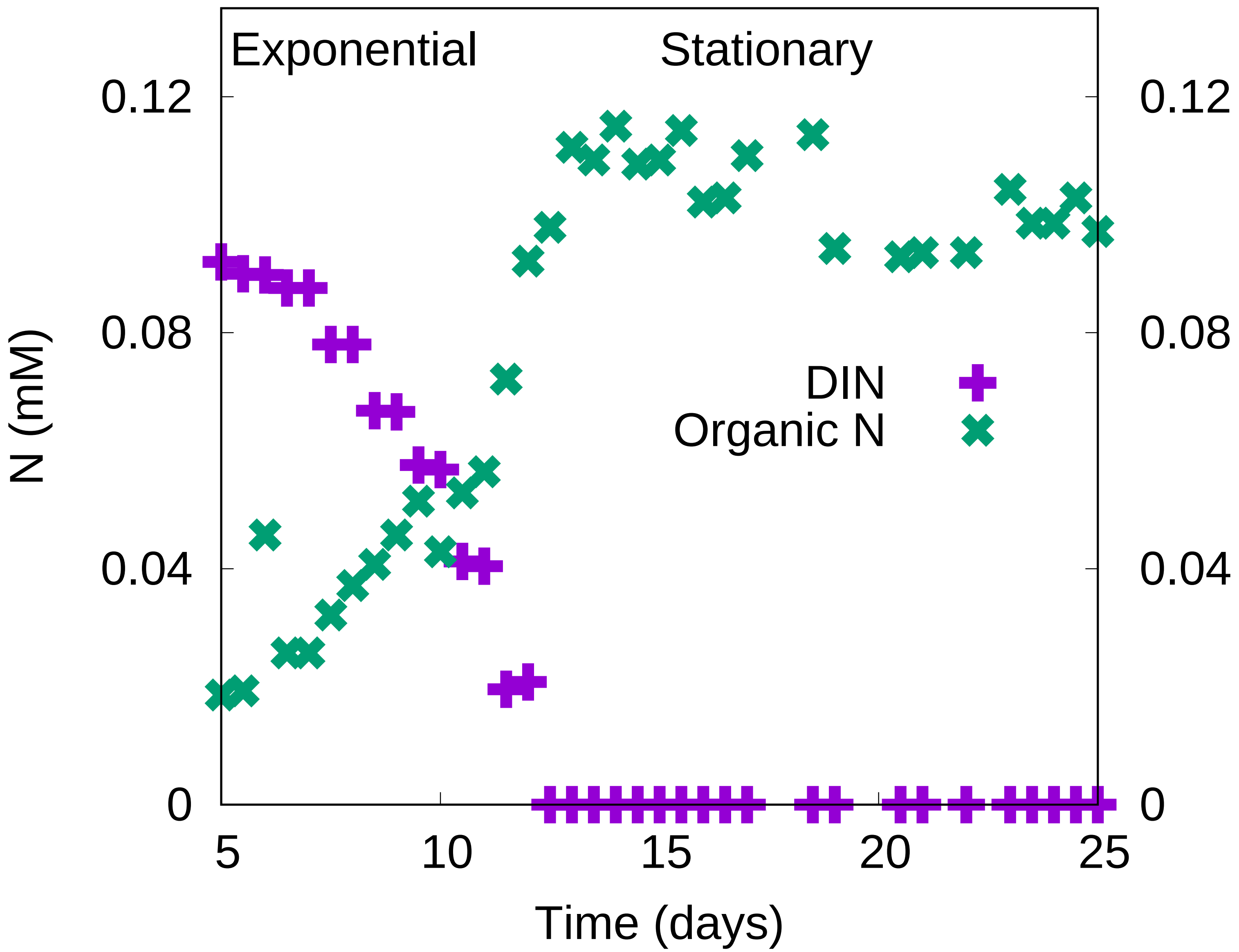
We consider batch culture data on the prymnesiophyte *Isochrysis galbana* (Flynn et al., 1994)

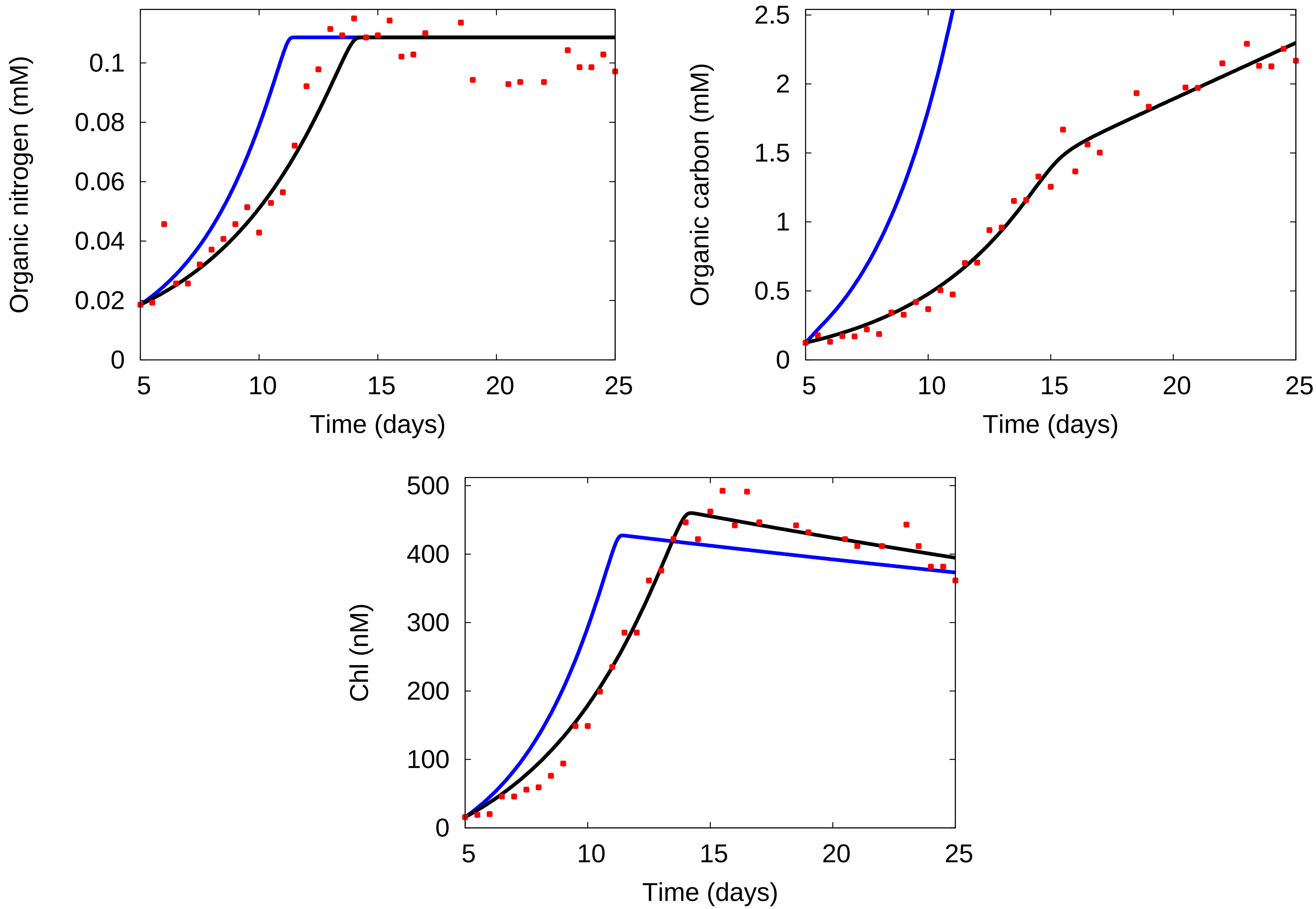
Flynn et al. (1994) batch culture data



Omta et al. (2017) model formulation

$$
\begin{aligned}
\frac{dC}{dt} &= \left(C_{syn} - E\right) P, E = \frac{m_{ex}\left(1 + \tanh\left(\frac{C}{P} - r_{ex}\right)\right)}{2} \\
\frac{dP}{dt} &= P_{syn} P, P_{syn} = \mu\left(\frac{N}{N+K}\right) \\
\frac{dN}{dt} &= -\frac{dP}{dt} \\
\frac{dr}{dt} &= \frac{r_0 - r}{\tau}, r_0 = b\frac{P}{C}
\end{aligned}
$$

Model fits

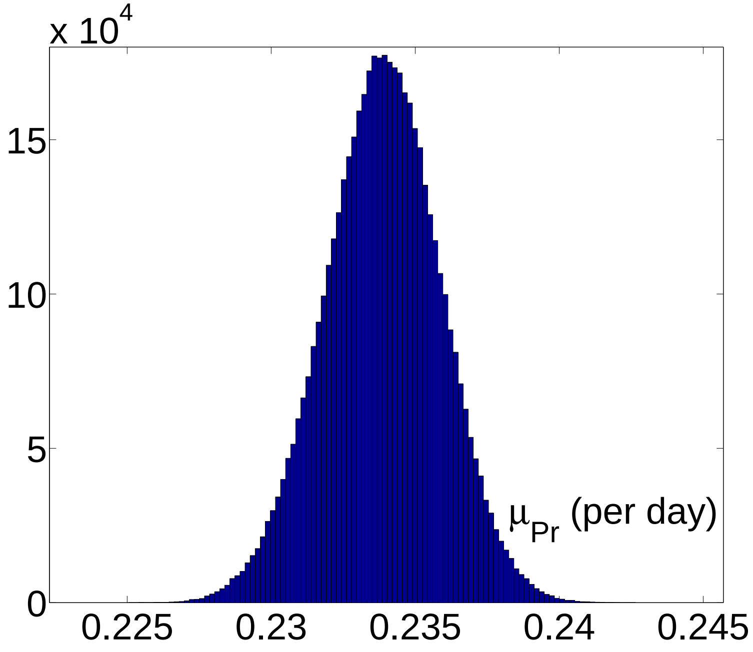


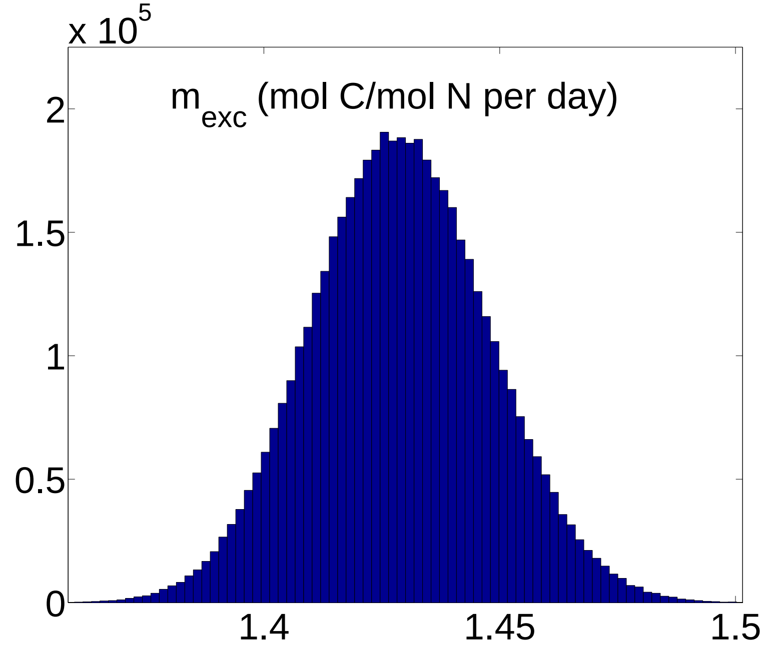
Organic nitrogen (mM)
0
0.02
0.04
0.06
0.08
0.1
5
10
15
20
25
Time (days)
Organic carbon (mM)
0
0.5
1
1.5
2
2.5
5
10
15
20
25
Time (days)
Chl (nM)
0
100
200
300
400
500
5
10
15
20
25
Time (days)

Estimated parameter values

Parameter	Description	Estimated value	Units
μ	Maximum protein synthesis rate	0.234±0.002	d^{-1}
C_{syn}	Maximum photosynthesis rate	2.19±0.02	mol C/(mol N) d^{-1}
m_{ex}	Maximum C exudation rate	1.43±0.02	mol C/(mol N) d^{-1}
r_{ex}	Carb:protein ratio above which exudation occurs	13.49±0.11	mol C/(mol N)
τ	Photoacclimation time	9.59±0.13	d
b	Photoacclimation parameter	57.1±0.2	μmol Chl mol C (mol N)$^{-2}$

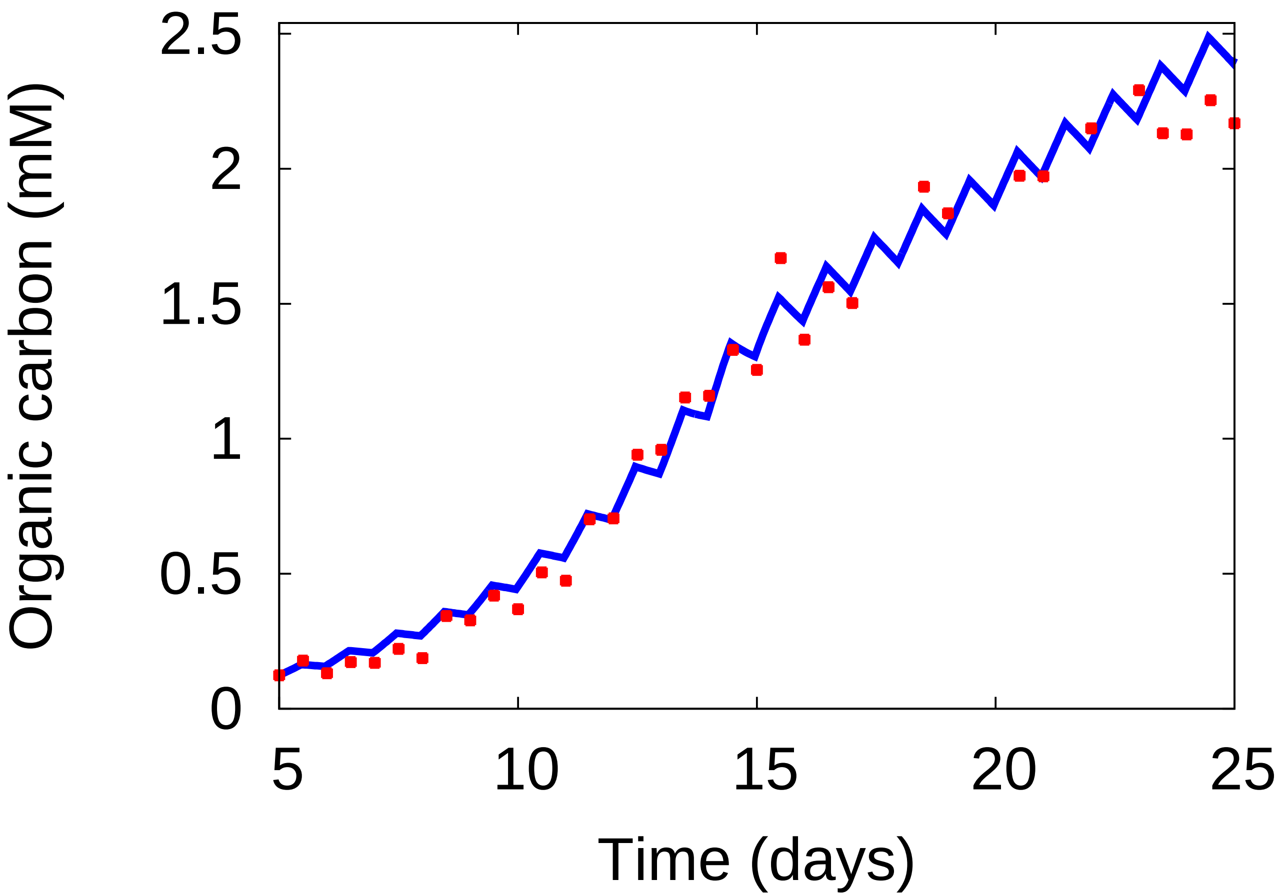
Posterior parameter distributions





Model extension: diurnal cycle

$$I = \begin{cases} 100 & 12 \text{ hrs/d} \\ 0 & 12 \text{ hrs/d} \end{cases}$$



Possible model extension: Multiple limiting nutrients

Minimum formulation most straightforward:

$$P_{syn} = \mu * \min\left(\frac{N}{N + K_N}, \frac{I}{I + K_I}\right)$$

But tricky in Stan...

Synthesizing Unit provides an alternative:

$$P_{syn} = \mu \frac{1}{1 + \frac{K_N}{N} + \frac{K_I}{I} - \frac{1}{\frac{N}{K_N} + \frac{I}{K_I}}}$$

Possible model extension: Pahlow/Smith optimal uptake kinetics

Optimal allocation between surface uptake sites and internal enzymes leads to slightly modified uptake kinetics. Instead of:

$$P_{syn} = \mu \frac{N}{N + K_N}$$

we obtain:

$$P_{syn} = \mu \frac{N}{N + 2\sqrt{K_N N} + K_N}$$

Possible model extension: Different exudation formulation

Perhaps make C exudation linearly proportional to Carb:protein ratio?

Instead of:

$$E = \frac{m_{ex}\left(1 + \tanh\left(\frac{C}{P} - r_{ex}\right)\right)}{2}$$

We could simply have:

$$E = m_{ex}\frac{C}{P}$$