Modeling microalgae growth: translating Monod and logistic ODE to BioChemical Reaction Network

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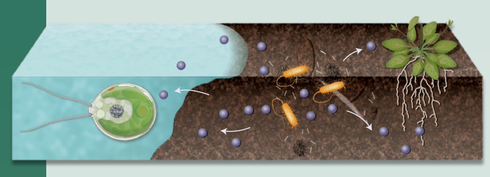
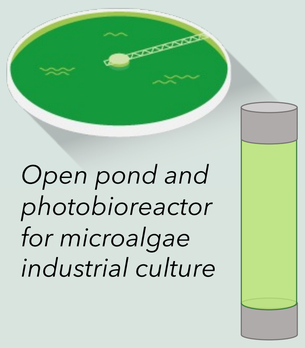
CONTEXT

Microalgae to produce valuable compounds

Microalgae offer significant potential to produce valuable compounds in industry (lipids, pigments, biopolyesters ...).

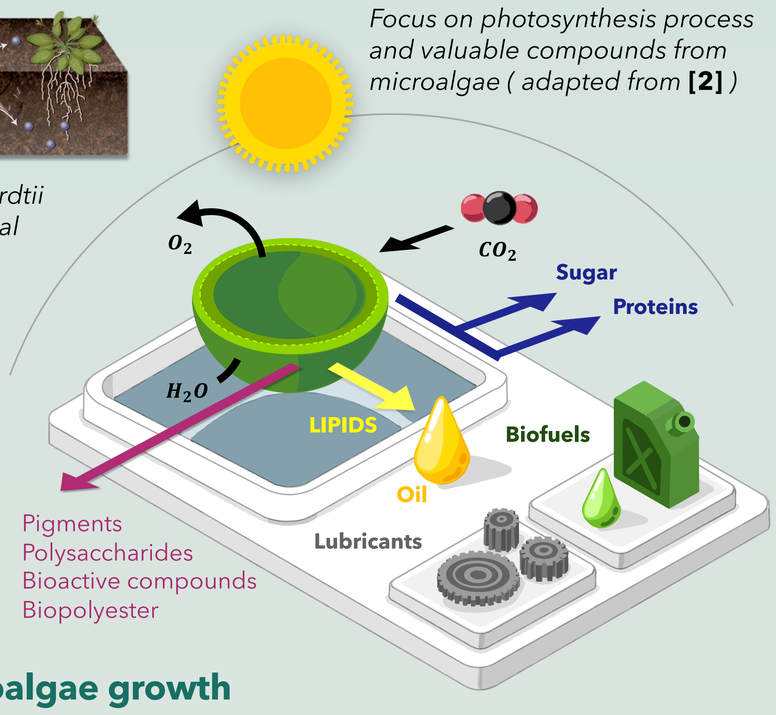


Chlamydomonas reinhardtii interacting with its natural environment **[1]**



Open pond and photobioreactor for microalgae industrial culture

Focus on photosynthesis process and valuable compounds from microalgae (adapted from **[2]** *)*



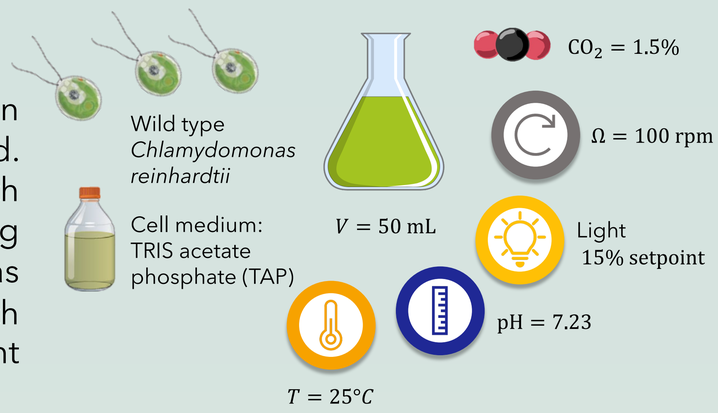
Modeling microalgae growth

Various growth models, including mechanistic ones using ODEs, have been studied, but complexities emerge with multiple resource considerations. We propose a multi-resource Bio-Chemical Reaction Network (BioCRN) **model for microalgae growth**, quantifying the impact of **light** and **nutrient** concentration on biochemical kinetics through microalgal cell-resource reactions.

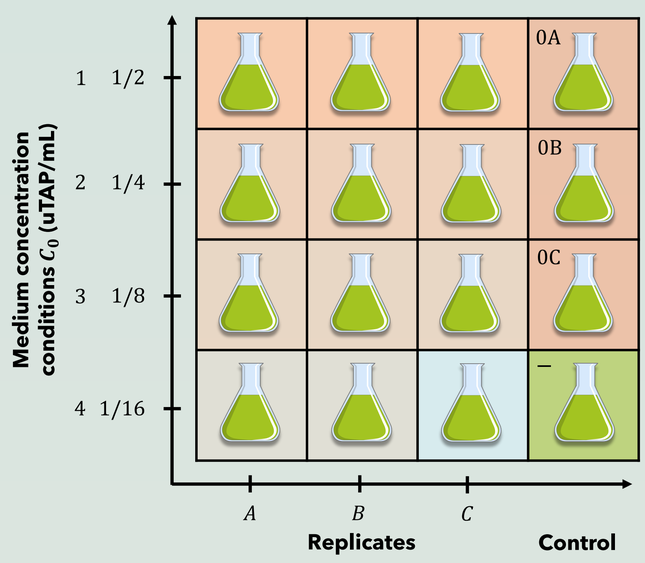
EXPERIMENTS

Growth conditions

16 flasks with different dilution conditions were incubated. Microalgae were rinced twice with distilled water before seeding them in flasks. TAP medium was diluted by 2^i for $i \in [\![0,4]\!]$ with distilled water. The experiment were inspired from **[3]**.



Distribution of flasks in incubator



Distribution of light in the incubator at 400 mm from the LEDs source

13 µW	15 µW	15 µW	13 µW
17 µW	19 µW	19 µW	17 µW
17 µW	18 µW	18 µW	15 µW
11 µW	12 µW	15 µW	11 µW

Optical density

Optical density (OD) at 750 nm were measured in 1 mL cuvettes at a starting $\mathrm{OD}_0 = 0.015$ for each culture. The culture was monitored during 18 days.

MODELING

Two scale interpretations

$$A + B \rightharpoonup C$$

DETERMINISTIC

Ordinary differential equations

$$\frac{\mathrm{d}A(t)}{\mathrm{d}t} = \frac{\mathrm{d}B(t)}{\mathrm{d}t} = -\kappa \cdot A(t) \cdot B(t)$$
$$\frac{\mathrm{d}C(t)}{\mathrm{d}t} = \kappa \cdot A(t) \cdot B(t)$$

STOCHASTIC

Continuous time Markov chains

State space : $\{A, B, C\}$

Transition :
$(A, B, C) \to (A-1, B-1, C+1)$

Microalga

Ressources

Nutrient

Light

Space

Reactions

1 + →

2 + →

3 + → +

BioCRN $N + C \underset{k^-_{\overline{NC}}}{\overset{k^+_{\overline{NC}}}{\rightleftarrows}} \overline{NC}$ $\quad \overline{NC} + L \underset{k^-_{\overline{NC}^\star}}{\overset{k^+_{\overline{NC}^\star}}{\rightleftarrows}} \overline{NC}^\star$ $\quad \overline{NC}^\star + S \xrightarrow{k_N} N + N$

After quasi steady-state and quasi-equilibrium approximations, the ODE formulation of the BioCRN is given by the same model as in **[3]**.

Logistic-Monod equation

$$\frac{\mathrm{d}N}{\mathrm{d}t}(t) = r \cdot \left(1 - \frac{N(t)}{\Gamma}\right) N(t)$$

$$r(L, C) = \mu \cdot r_{light}(L) \cdot r_{medium}(C)$$

$$\begin{cases} r_{light}(L) = \dfrac{L(N(t), E_{in})}{\lambda_L + L(N(t), E_{in})} \\ L(N(t), E_{in}) = \dfrac{E_{in} - E_{out}}{N(t)} = \dfrac{1 - 10^{-\frac{KN(t)}{V.D}}}{N(t)} \cdot E_{in} \end{cases}$$

$$\begin{cases} r_{medium}(C) = \dfrac{C(t)}{\xi_c + C(t)} \\ \dfrac{\mathrm{d}C}{\mathrm{d}t}(t) = -\alpha \cdot \dfrac{\mathrm{d}N}{\mathrm{d}t}(t) \end{cases}$$

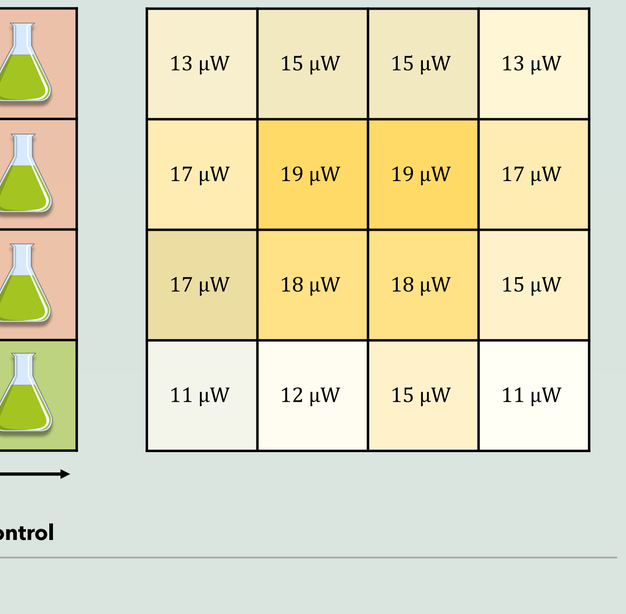
DATA PROCESSING

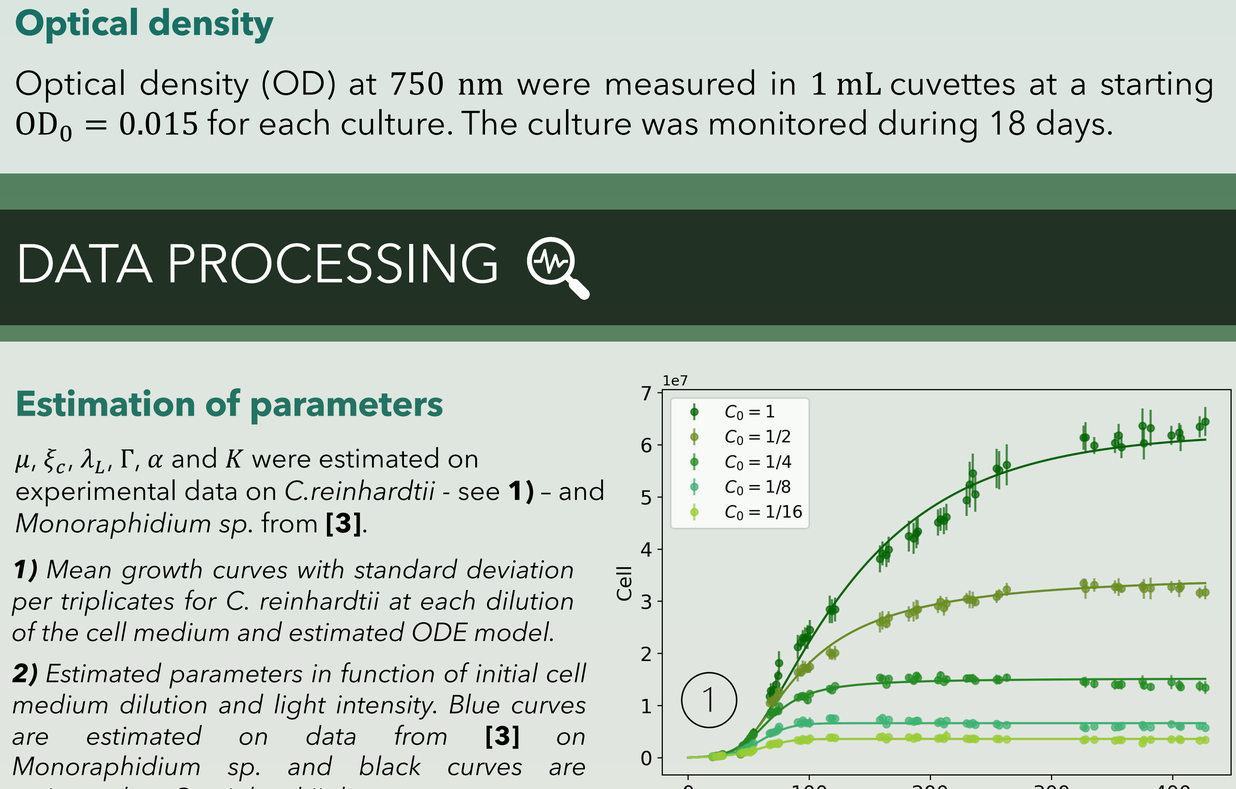
Estimation of parameters

μ, ξ_c, λ_L, Γ, α and K were estimated on experimental data on *C.reinhardtii* - see **1)** – and *Monoraphidium sp.* from **[3]**.

1) *Mean growth curves with standard deviation per triplicates for C. reinhardtii at each dilution of the cell medium and estimated ODE model.*

2) *Estimated parameters in function of initial cell medium dilution and light intensity. Blue curves are estimated on data from* **[3]** *on Monoraphidium sp. and black curves are estimated on C. reinhardtii data.*





Future work

- Simplify the ODE model
- Upscale and downscale the model
- Add experimental data
- Study seawater microalga specie

References

[1] Systematic characterization of gene function in the photosynthetic alga *Chlamydomonas reinhardtii* – F. Fauser et al. (2022)
[2] Dossier de presse – Microalgues, de la recherche à l'industrie - CEA Cadarache (2020)
[3] A parametric logistic equation with light flux and medium concentration for cultivation planning of microalgae – K. Kambe et al. (2022)

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