Biogeographical patterns in nitrogen fixers linked to proteome allocation trade-offs

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Motivation

N_2-fixing cyanobacteria have different ecological strategies.

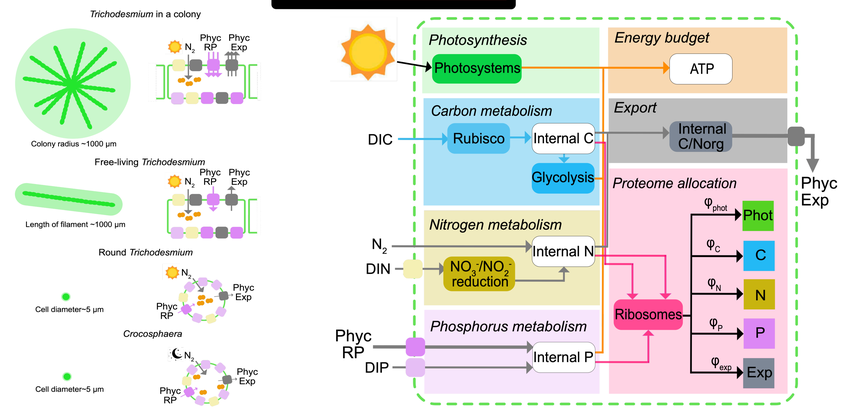
Round (*Crocosphaera* like) | Filamentous (*Trichodesmium* like)



-Why do they coexist in the ocean?

-Is a strategy more advantageous under some environmental conditions?

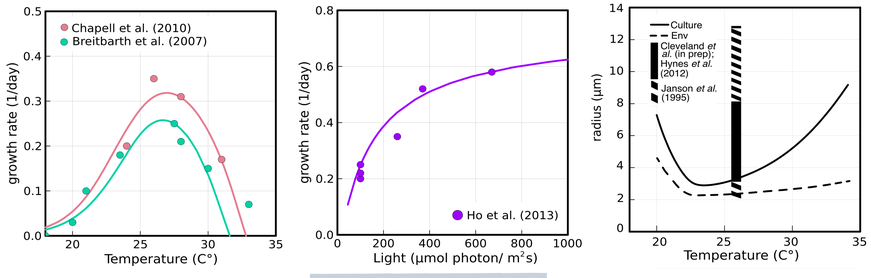
The model



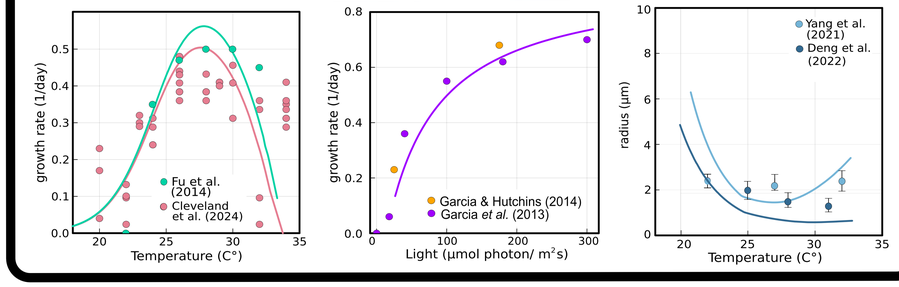
N_2-fixing phytoplankton cells simulated in this study. Left: Size of the phycosphere (light green) relative to cell size (bright green; not to scale). Right: Properties of the different cell types incorporated in our model. Arrows for Phycosphere-Related Phosphorus (Phyc RP) and Phycosphere Export (PE) are proportional to the size of the phycosphere, and represent the relative access to P from the phycosphere and the C and N exported in return, respectively.

Functional representation of the single-cell proteome allocation models developed in this study. Each square inside the cell represents a separate metabolic function, where color boxes represent protein pools and white boxes represent internal molecular pools. Arrows indicate one-way fluxes. Proteome allocations to each function are represented in the pink box and are optimized by the model.

Validations for *Trichodesmium*



Validations for *Crocosphaera*



We developed proteome allocation models for Trichodesmium and Crocosphaera. The models optimize protein pools to maximize growth.

We find that:

The enhanced phosphorus access provided by *Trichodesmium* colonies confers an advantage in oligotrophic environments

Crocosphaera has a growth advantage under elevated temperatures, and when inorganic phosphorus is available

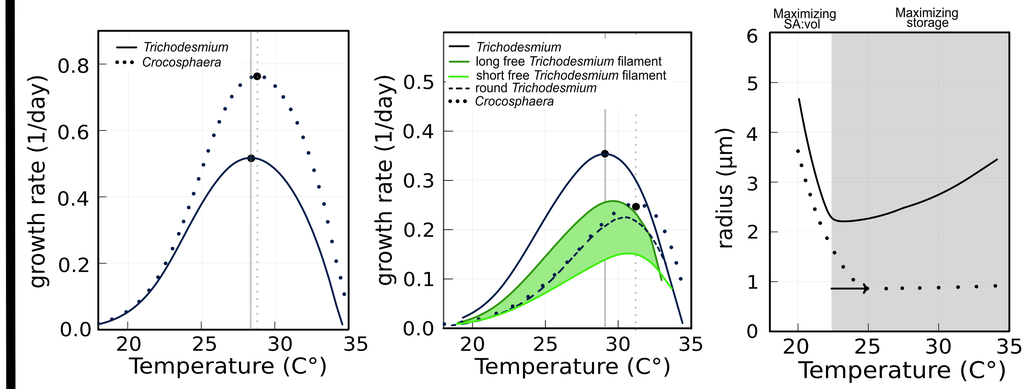
Under certain conditions, non-colonial, filamentous *Trichodesmium* can be successful

Non-filamentous *Trichodesmium* (fixing nitrogen during the day as single cells) is a sub-optimal strategy

Model prediction of Trichodesmium with the optimal size closely matches that of the clade with the wider geographical distribution

Cyanobacteria respond differently to variable T and P

P replete | **P limited**



Model predictions for growth rate and radius of cyanobacteria under variable temperature.

* *Crocosphaera* is more successful under abundant P, and *Trichodesmium* fares better under limited P because it gets proportionally more PRP from the colony.

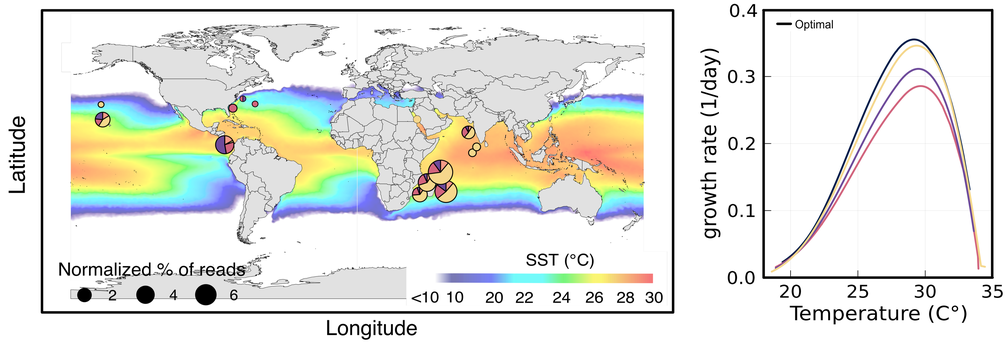
* Round *Trichodesmium* fares poorly under environmental conditions, which explains why this strategy is not observed in nature. Our model predicts that only the longest free *Trichodesmium* filaments can outcompete *Crocosphaera* in nutrient-limited environments.

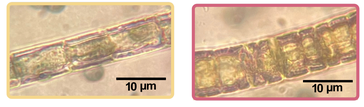
* The optimal growth temperature (Topt) increases under limited nutrients. This is consistent with previous predictions from our lab and experimental observations, and indicates a strategy of maximizing nutrient uptake by increasing storage capacity (and thus larger radius at higher temperatures).

Trichodesmium's optimal dimensions dominate *in situ*

T. thiebautii clades

Ia: average size | Ib: average length and slim | Ic: short and thick | Id: long and average thickness





Biogeographical distribution of *Trichodesmium* clades with different dimensions (left), and model predictions of their fitness (right).

* Some *Trichodesmium* cells are long and slim (left of the left panel), short and thick (right of the left panel), or anywhere in between. The most widely distributed are the slim ones.

*Our model predicts that the optimal cell dimensions for *Trichodesmium* are very close to those of slim cells, which would explain their abundance.

Acknowledgements

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