The role of carbon allocation efficiency in the temperature dependence of growth rates in autotrophs

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&

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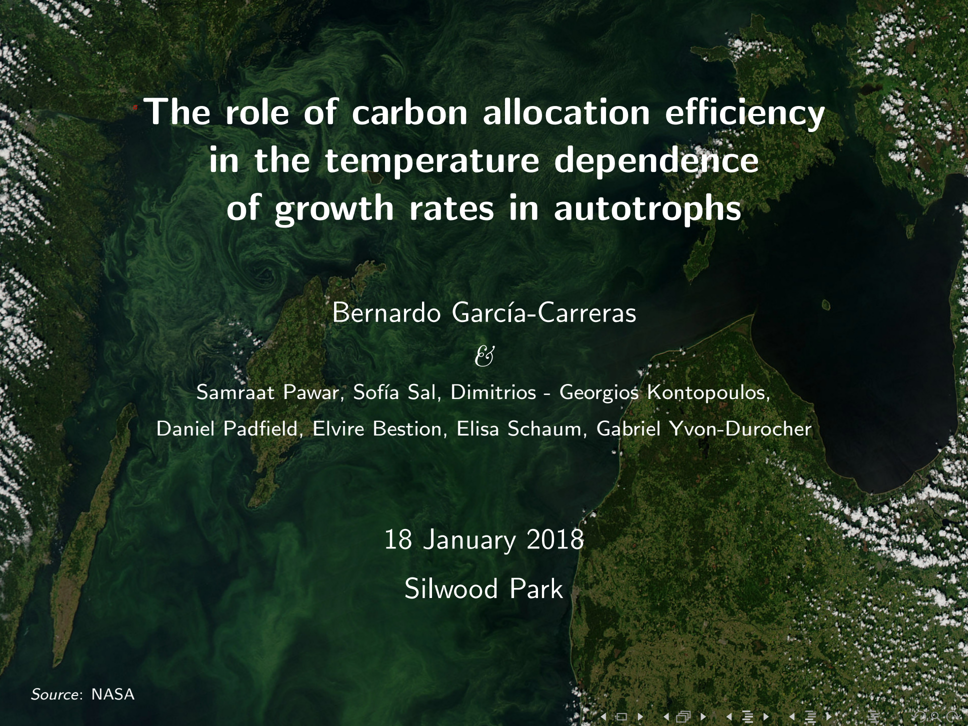
Silwood Park

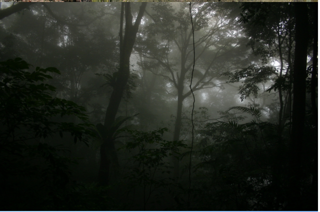


Source: NASA

Introduction

- Autotroph population growth rates are temperature dependent.
- Patterns in weather and climate are changing.
- We need a more mechanistic understanding of growth rate thermal performance curves (TPCs).
- Key metabolic rates include photosynthesis, respiration. . .
- But what about *efficiency?*

Introduction



I will:

- Introduce the population model.
- Fit it to data from a unique laboratory experiment on a phytoplankton species.
- Explore the potential importance of temperature-dependent allocation efficiency across a wider range of species using a meta-analysis.

The model

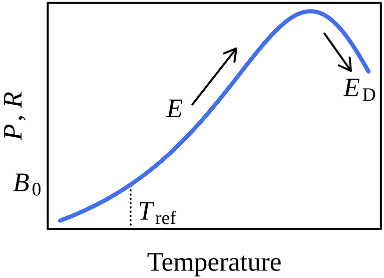
$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}t} = r = \varepsilon\, F$$

where

- N is the autotroph population's biomass density.
- r is the growth rate.
- Net carbon flux $F = P - R$.
- ε is carbon allocation efficiency.

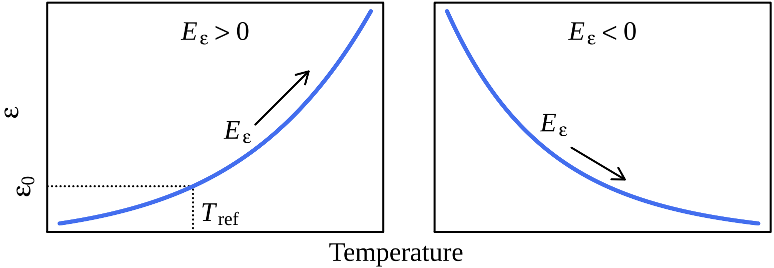
Photosynthesis P & respiration R

$$B = \frac{B_0 \exp\left(-\frac{E}{k}\left(\frac{1}{T} - \frac{1}{T_{\text{ref}}}\right)\right)}{1 + \exp\left(\frac{E_{\text{D}}}{k}\left(\frac{1}{T_{\text{h}}} - \frac{1}{T}\right)\right)}$$



Allocation efficiency ε

$$\varepsilon = \varepsilon_0 \, \exp\left(-\frac{E_\varepsilon}{k}\left(\frac{1}{T} - \frac{1}{T_{\mathrm{ref}}}\right)\right)$$



A laboratory experiment: Chlorella vulgaris

ECOLOGY LETTERS

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LETTER

Rapid evolution of metabolic traits explains thermal adaptation in phytoplankton

Daniel Padfield,[1] Genevieve Yvon-Durocher,[2] Angus Buckling,[1] Simon Jennings[3,4] and Gabriel Yvon-Durocher[1]*

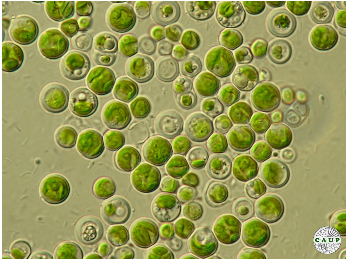
Abstract

Understanding the mechanisms that determine how phytoplankton adapt to warming will substantially improve the realism of models describing ecological and biogeochemical effects of climate change. Here, we quantify the evolution of elevated thermal tolerance in the phytoplankton, *Chlorella vulgaris*. Initially, population growth was limited at higher temperatures because respiration was more sensitive to temperature than photosynthesis meaning less carbon was available for growth.

Isolated from a pond in N. England, maintained at 20°C.

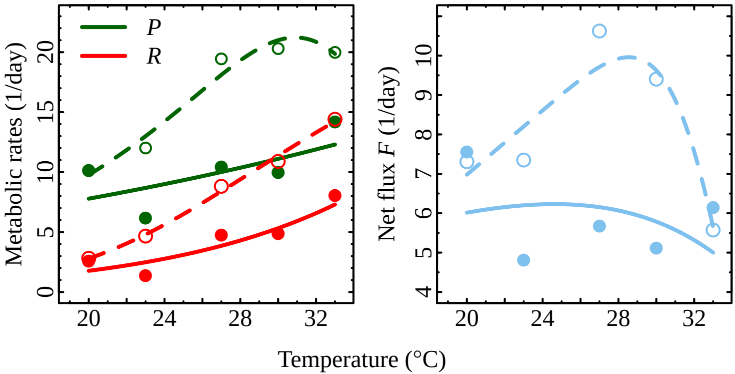
Growth, P and R for two sets of populations:

- *Acclimated*: ≈ 10 generations.
- *Adapted*: ≈ 100 generations.

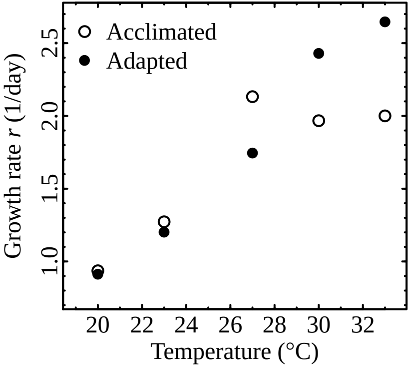


Source: botany.natur.cuni.cz

A laboratory experiment: Chlorella vulgaris



A laboratory experiment: Chlorella vulgaris



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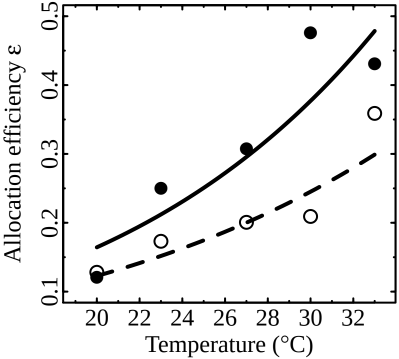
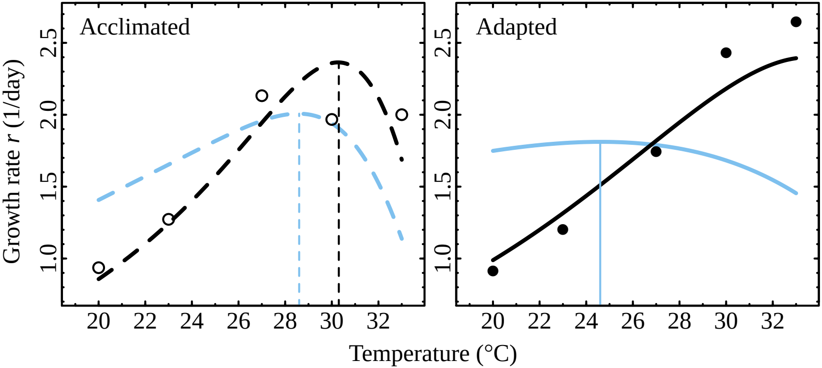
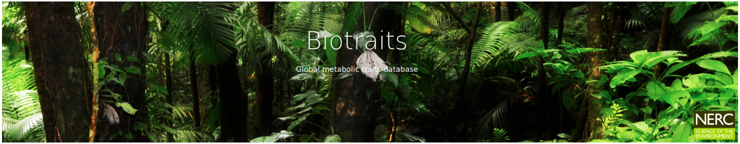


A laboratory experiment: Chlorella vulgaris



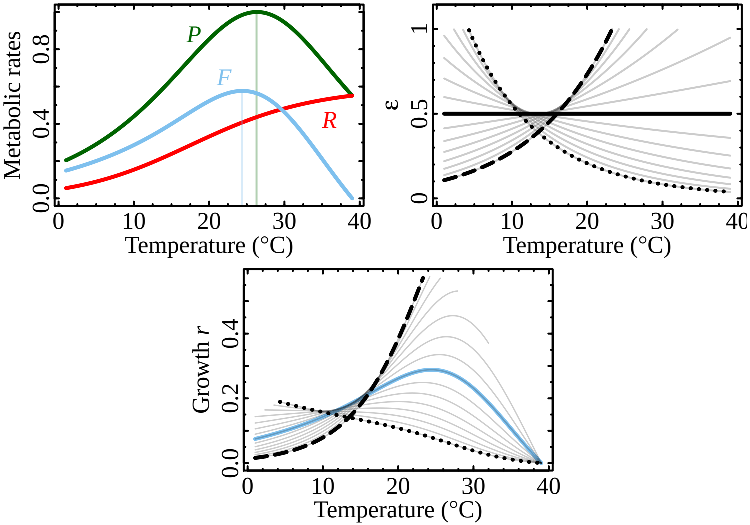
A meta-analysis



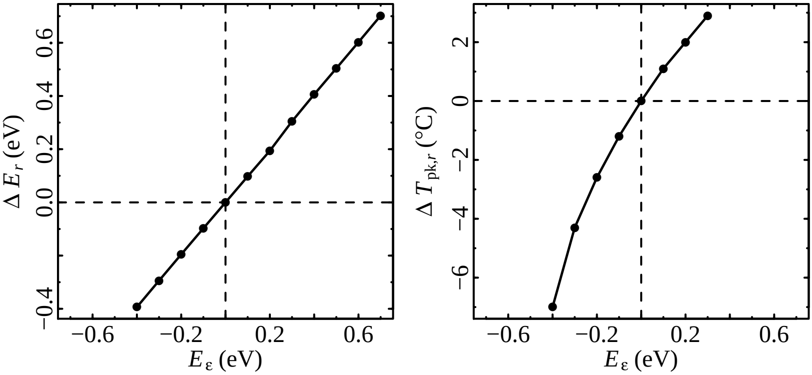
Extracted autotroph TPCs for which both P and R were measured on the same population. Filtering produced:

- 21 pairs of TPCs for aquatic species.
- 22 pairs of TPCs for terrestrial species.
- 38 species in total.

An example

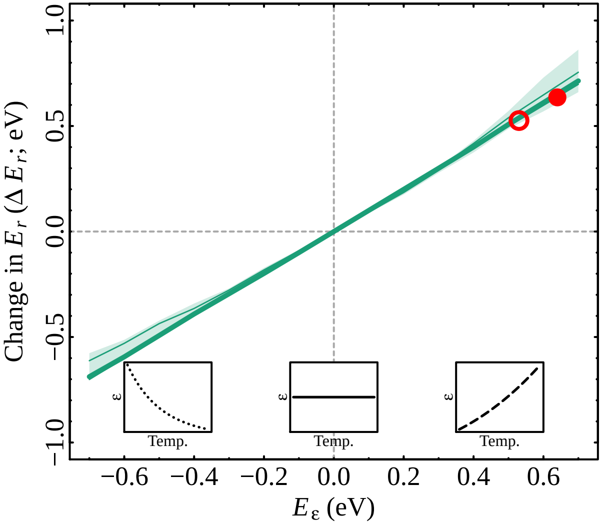

P
F
R
Metabolic rates
0.0
0.4
0.8
0
10
20
30
40
Temperature (°C)
ε
0
0.5
1
0
10
20
30
40
Temperature (°C)
Growth r
0.0
0.2
0.4
0
10
20
30
40
Temperature (°C)

An example



ΔE_r (eV)
E_ε (eV)
−0.4
0.0
0.2
0.4
0.6
−0.6
−0.2
0.2
0.6
$\Delta T_{\mathrm{pk},r}$ (°C)
E_ε (eV)
−6
−4
−2
0
2
−0.6
−0.2
0.2
0.6

A meta-analysis



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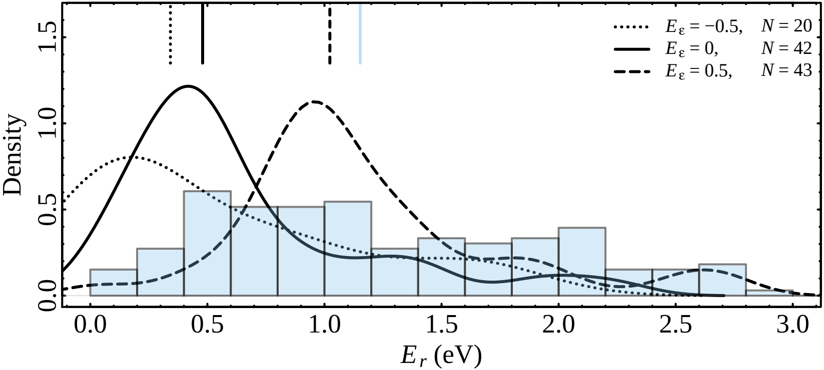

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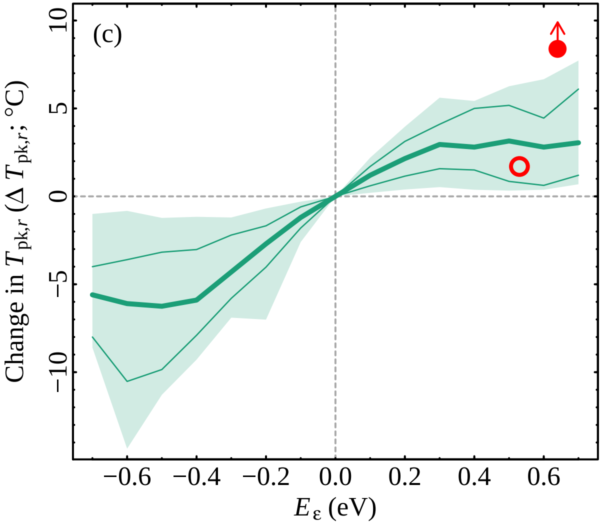
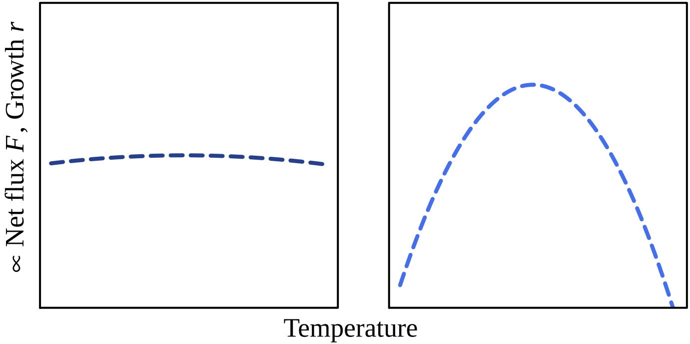
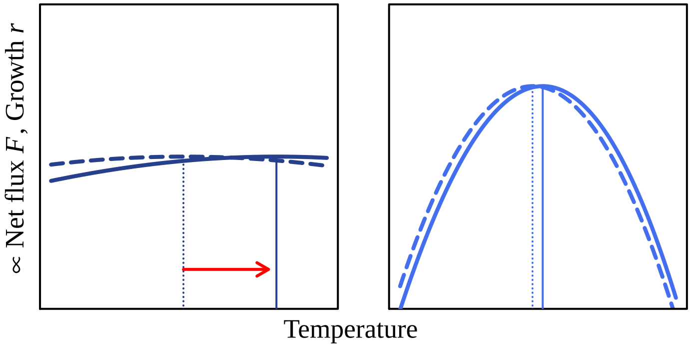


A meta-analysis



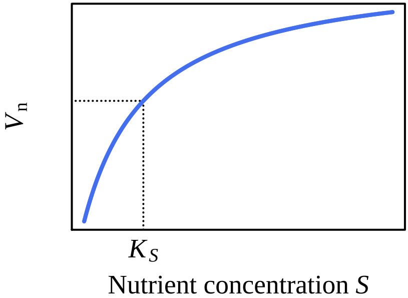
A meta-analysis



Nutrient limitation

$$r = \varepsilon\, F\, V, \quad \text{with}$$

$$V = \frac{S}{K_S + S}$$



If K_S increases with T, V decreases with T, and

- E_r is reduced, and
- $T_{\mathrm{pk},r}$ is reduced,

analogous to when $E_\varepsilon < 0$.

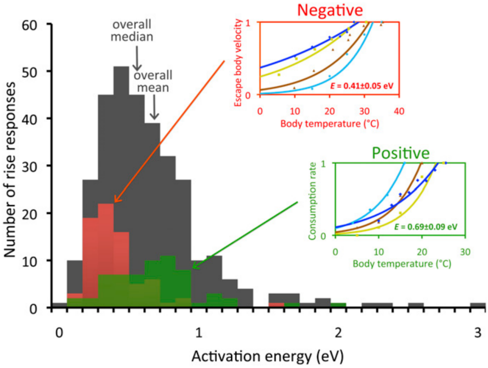
Respiration

$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}t} = r = \varepsilon\left(P - R\right)$$

- Role of respiration greatly simplified.
- R uses carbon, making it unavailable for growth...
- ...but R also supports growth (e.g., ATP production).
- Disentangle what components of respiration are measured in P and R in experiments.

Heterotrophs

- Implications of temperature-dependence in ε extend to heterotrophs, e.g., mass-conversion efficiency.
- Variation in growth rate TPCs might stem from variation in ε.
- Growth and metabolism not necessarily interchangeable.



Source: Dell, Pawar & Savage (2011). *PNAS*.

Experiments

We recommend further experiments!

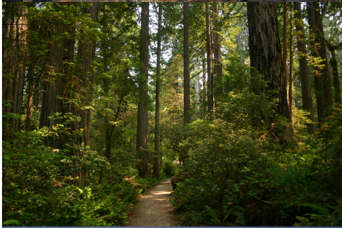
- Growth, P, R, at the same levels of acclimation / adaptation to temperature.
- Preferably measuring metabolic rates on the *same* cells undergoing growth.
- A reasonable number of replicates.
- Across a range of species.

These would allow us to quantify variation in ε.



Conclusion

- A simple framework that only requires measurement of three rates (growth, P, R) to better understand the temperature dependence of growth.
- Necessary step prior to developing more mechanistic models.
- Demonstrated the potential importance of temperature dependence of allocation efficiency.



Thank you!

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Source: ESA