Multispecies modeling approach to predict foraminifer growth and ecological niches

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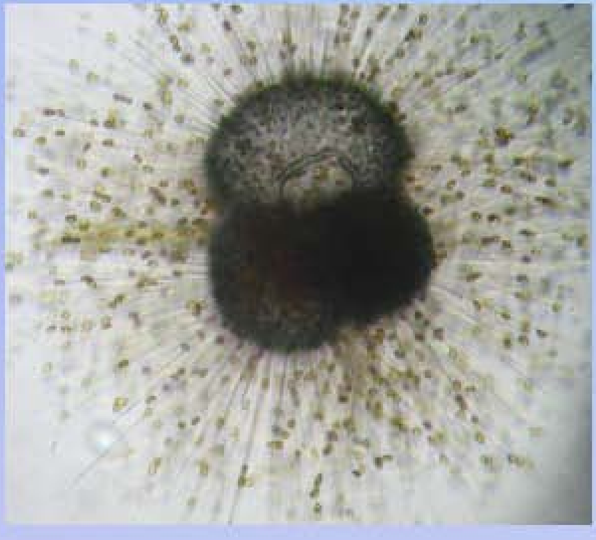

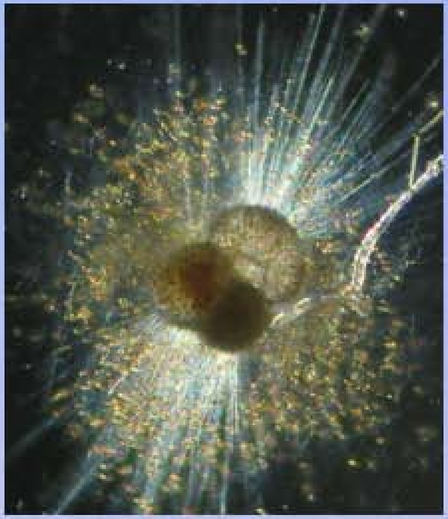

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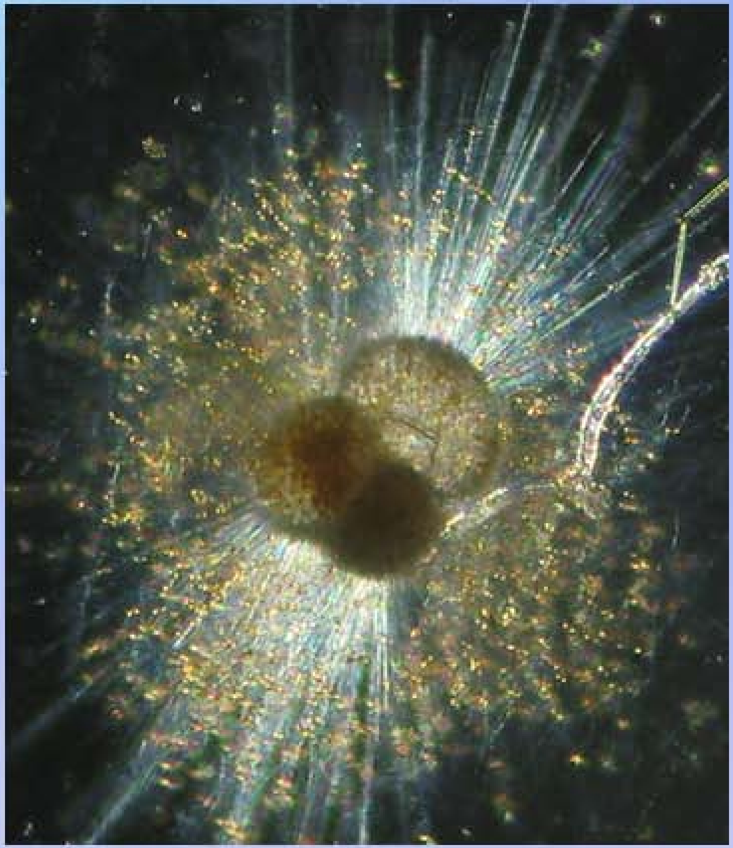
What is a foraminifer?

- Planktonic protozoa
- Construct a calcareous shell
- Herbivorous to carnivorous
- Some tropical species have symbiotic algae
- Low abundance
- High impact on $CaCO_3$ fluxes
  (32-80% of the global $CaCO_3$ flux to the sediments - Schiebel 2002)
- Fossil shells used for paleoclimatic reconstructions
  (species assemblages, shell isotopic composition…)

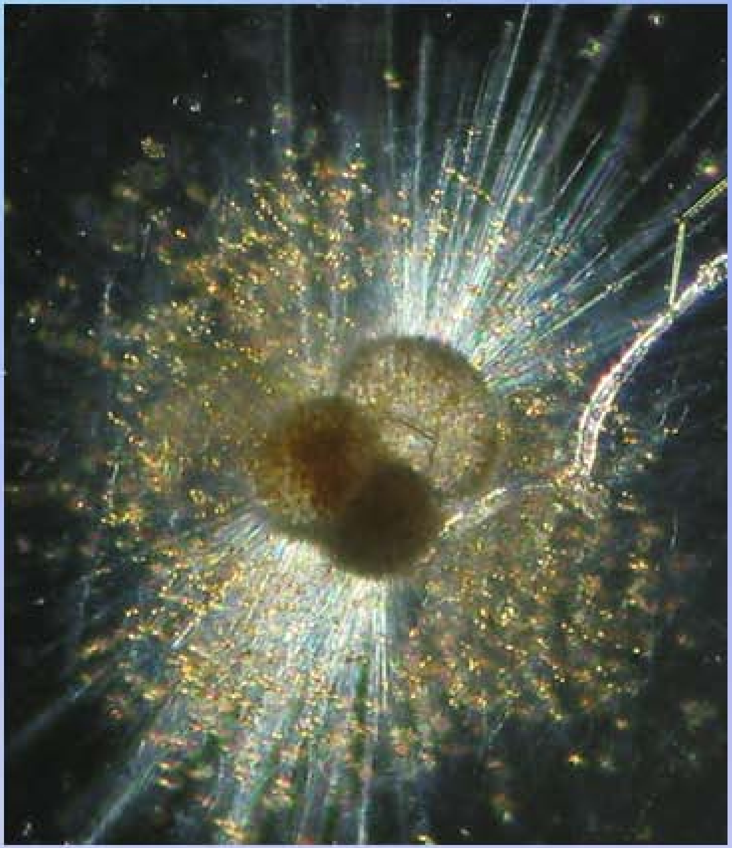


Globigerinoides ruber

Goals

- Modeling foraminifers growth
  - Mechanistic approach based on their physiology
  - Use of data from laboratory to constrain the model

- Questions :
  - Which factors controls foraminifers physiology and growth
  - in what extend foraminifer physiology constrains their species repartition (geographical, seasonal and vertical dimension)



Globigerinoides ruber

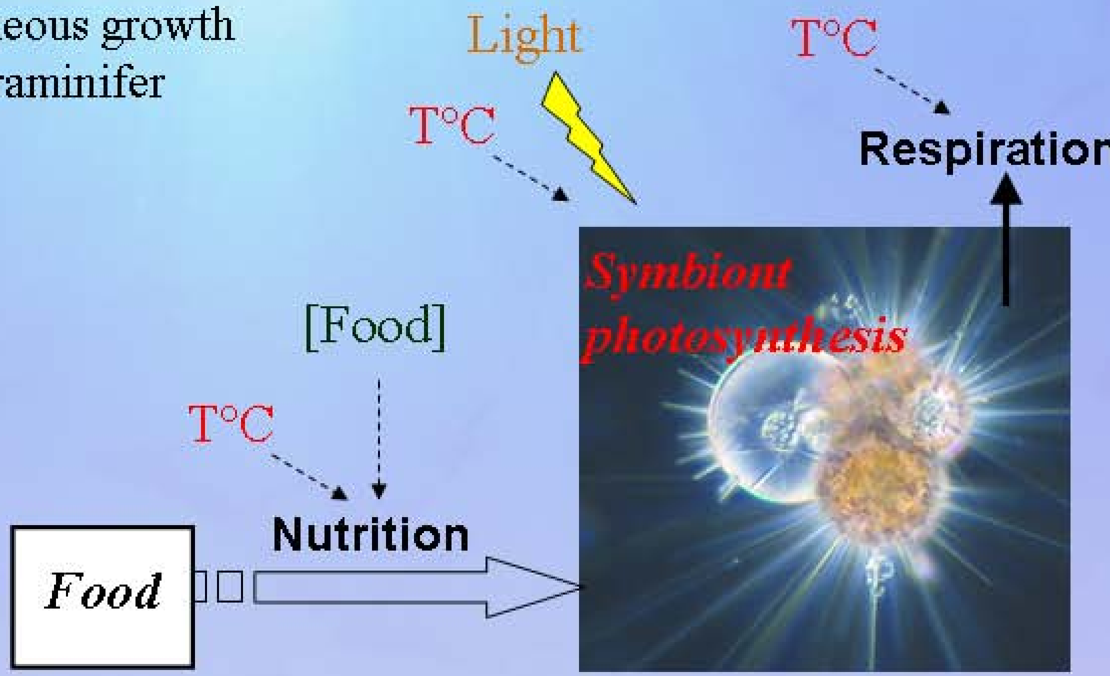
Foraminifer model

<u>Simple model</u>:

-Estimate the instantaneous growth rate for a mean size foraminifer

-no life cycle

-no shell



Forcing variables: T°C [Food] Light, Symbiont number

Species retained

Neogloboquadrina pachyderma Sin
Neogloboquadrina pachyderma Dex
Neogloboquadrina dutertrei
Globigerina bulloides
Globigerinoides ruber
Globigerinoides sacculifer
Globigerinella siphonifera
Orbulina universa

-Biology well known

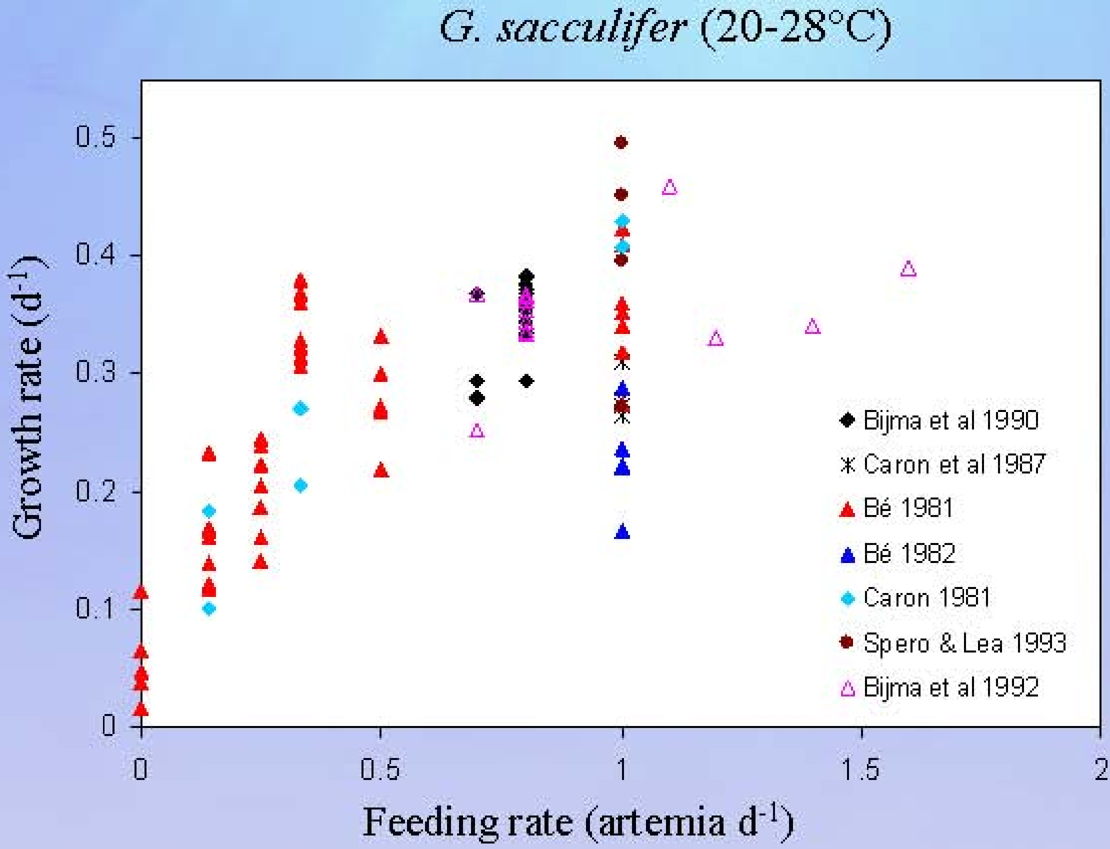
-Studied under laboratory cultures

-Physiology observed under different forcing conditions ([food], light, T° C)

-Represent the most abundant species in zooplankton

-Most studied species in paleoclimatology

Food effect on nutrition

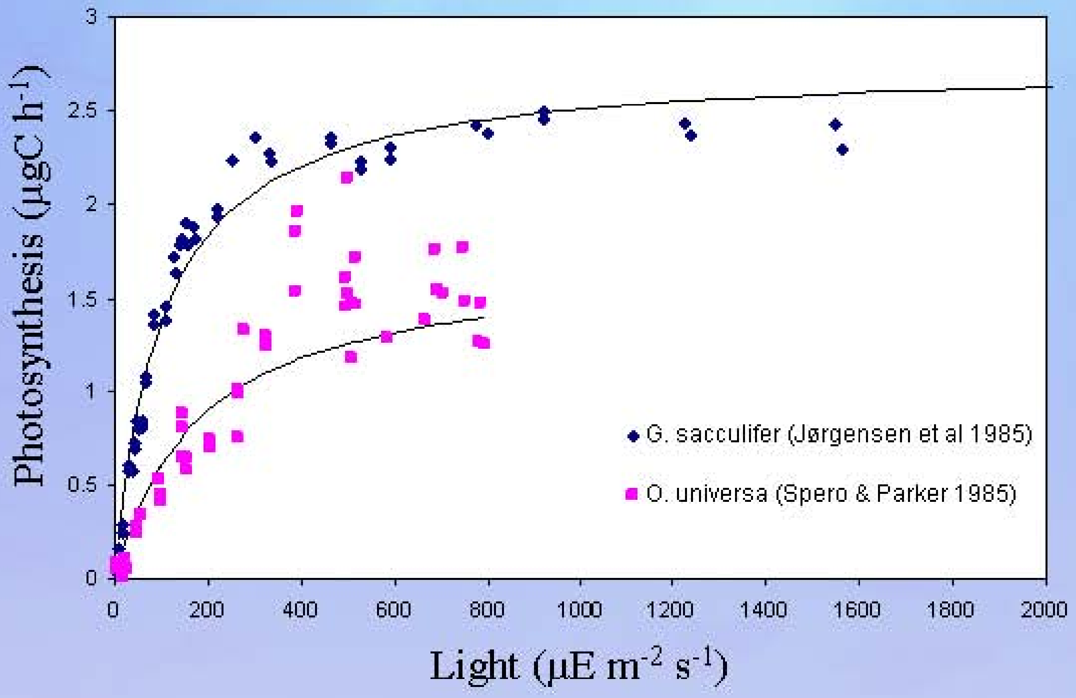


Saturated feeding over a certain concentration

Michaelis-Menten kinetic

$$N = N_{max} \frac{Food}{k_p + Food}$$

Light effect on photosynthesis



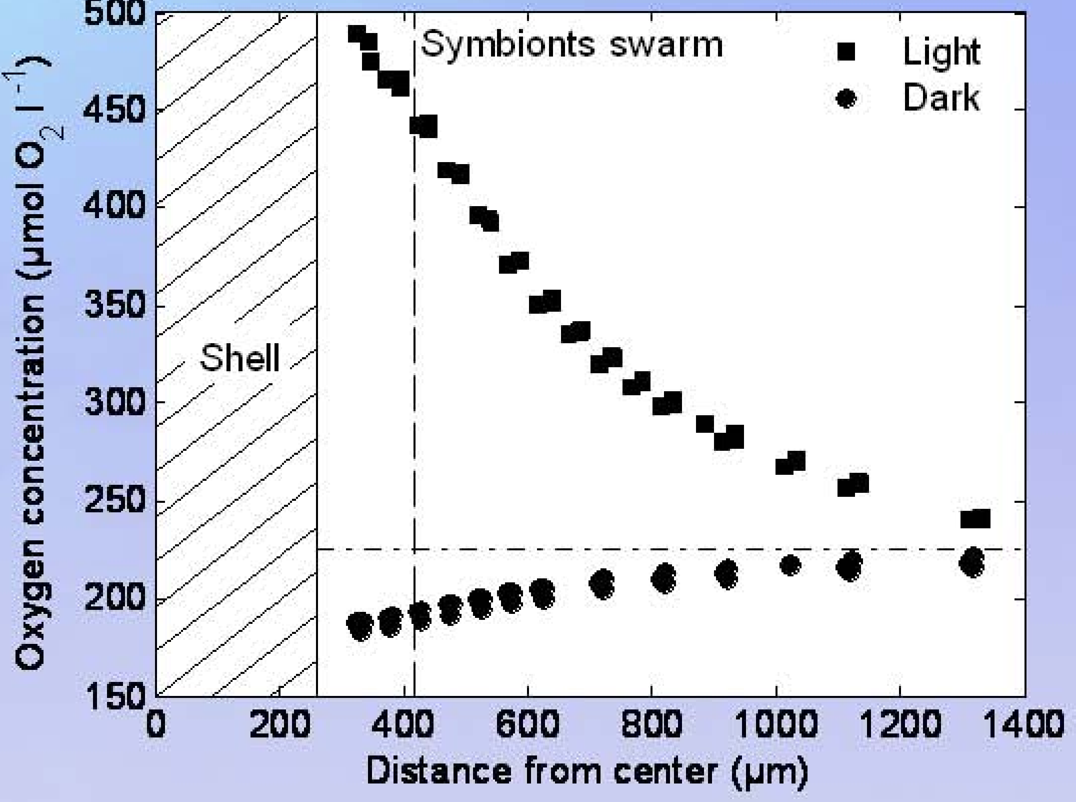
Obtained for the same symbiont type (different temperatures and symbiont numbers)

Michaelis-Menten kinetic

$$P = P_{\max} \frac{Light}{k_p + Light}$$

T°C effect on respiration and photosynthesis

O. universa 29°C



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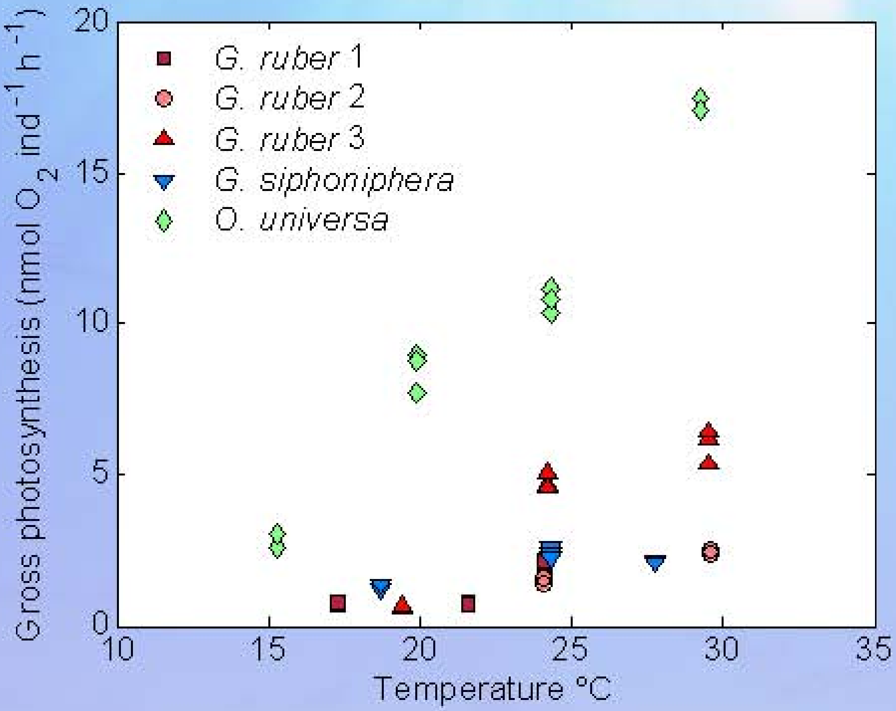
PHOTOSYNTHESIS



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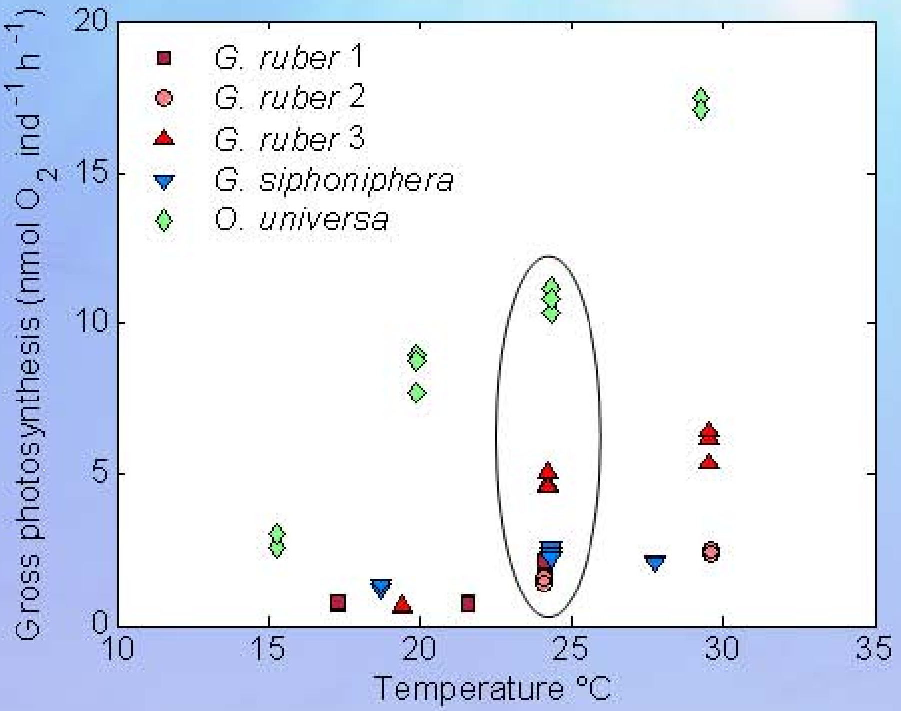

Normalized photosynthesis (ref=24°C)

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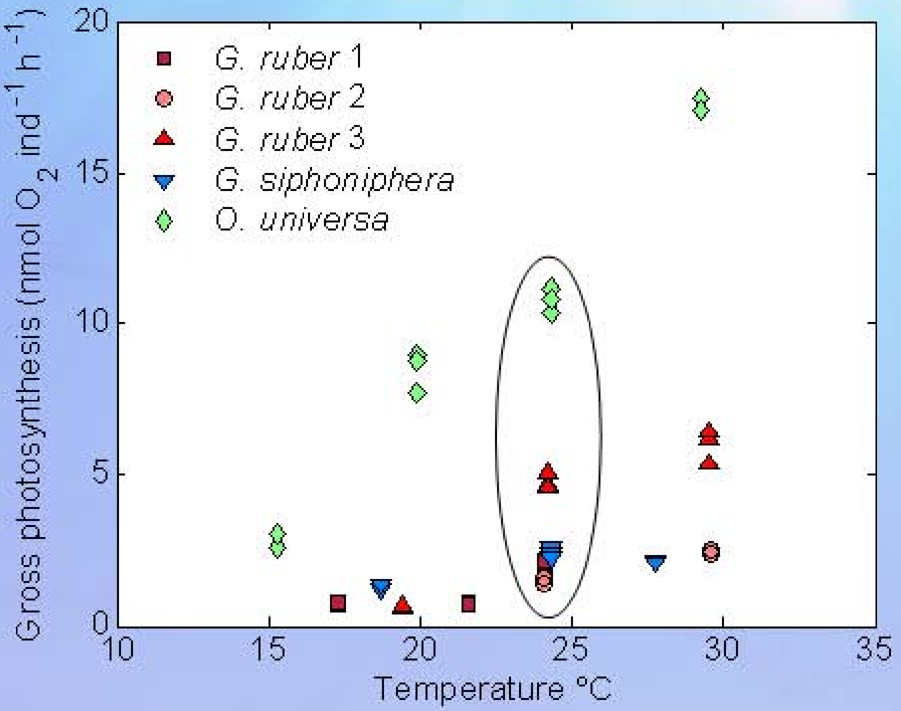

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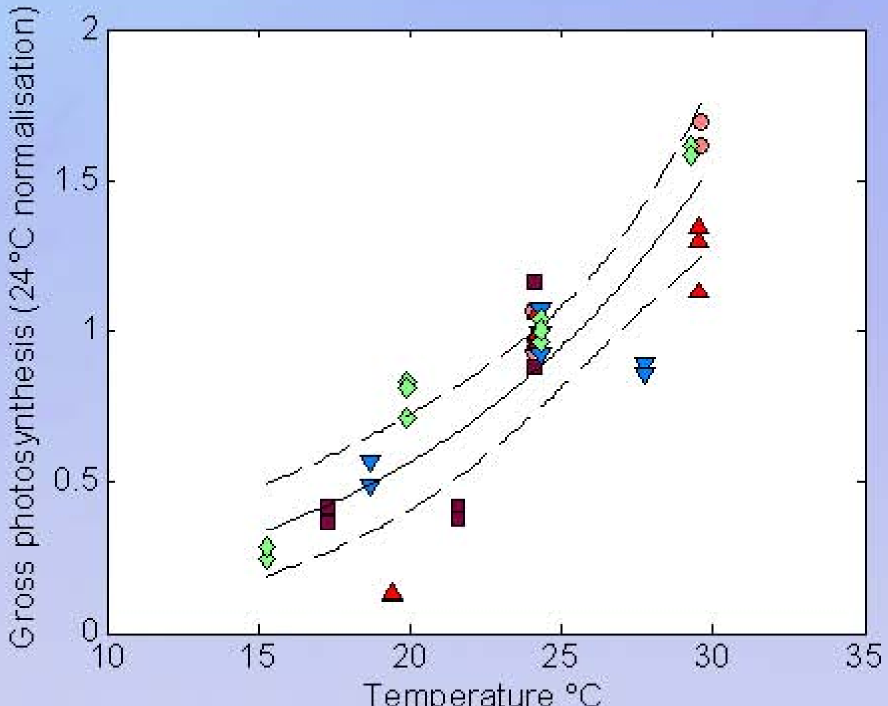

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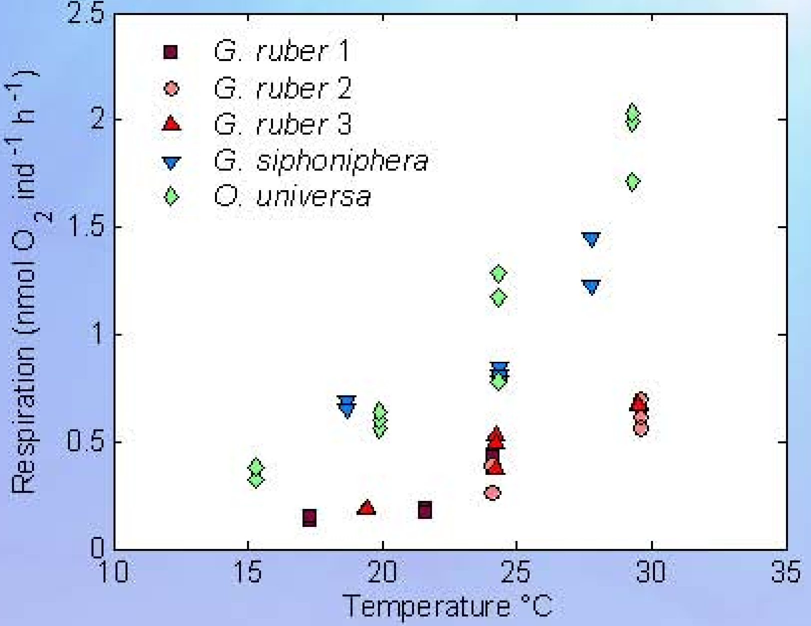
RESPIRATION



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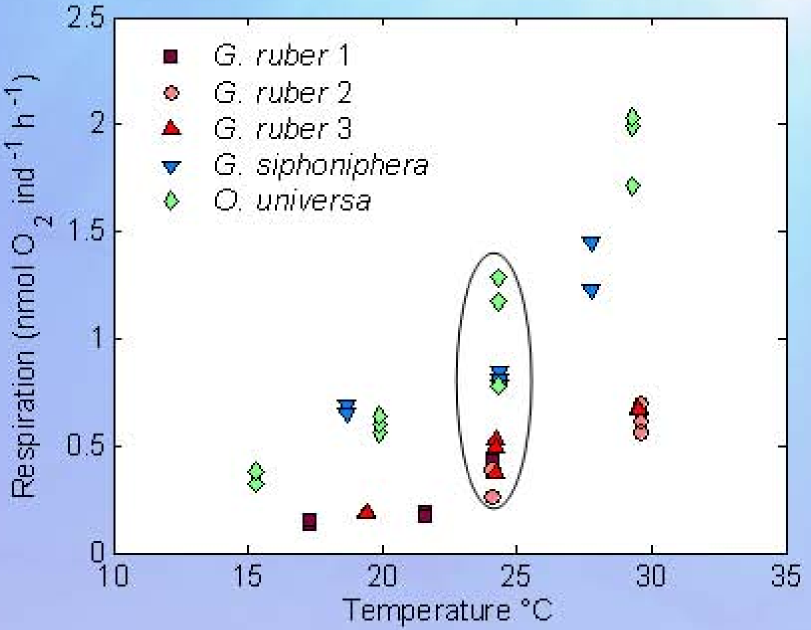

Normalized Respiration (ref=24°C)

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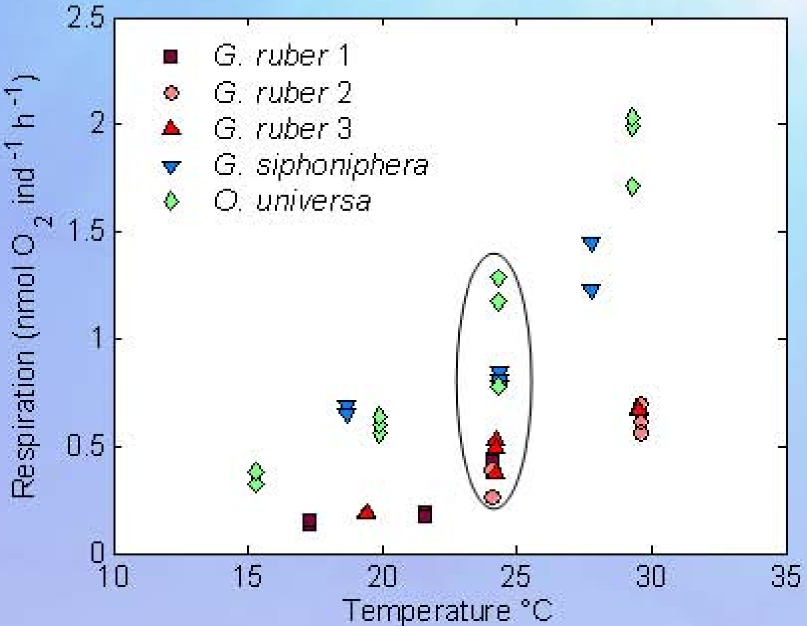
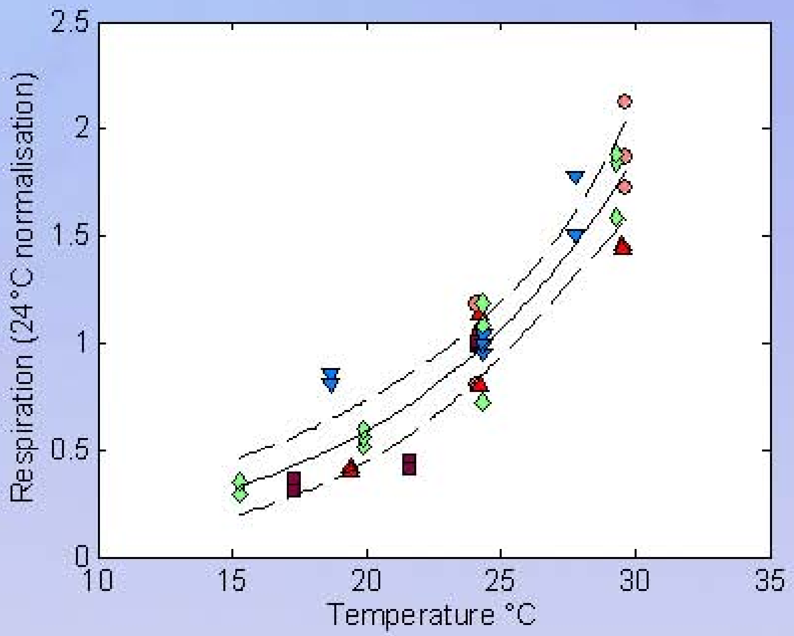
RESPIRATION



Normalized Respiration (ref=24°C)



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T° C and effect on physiology

General calculation

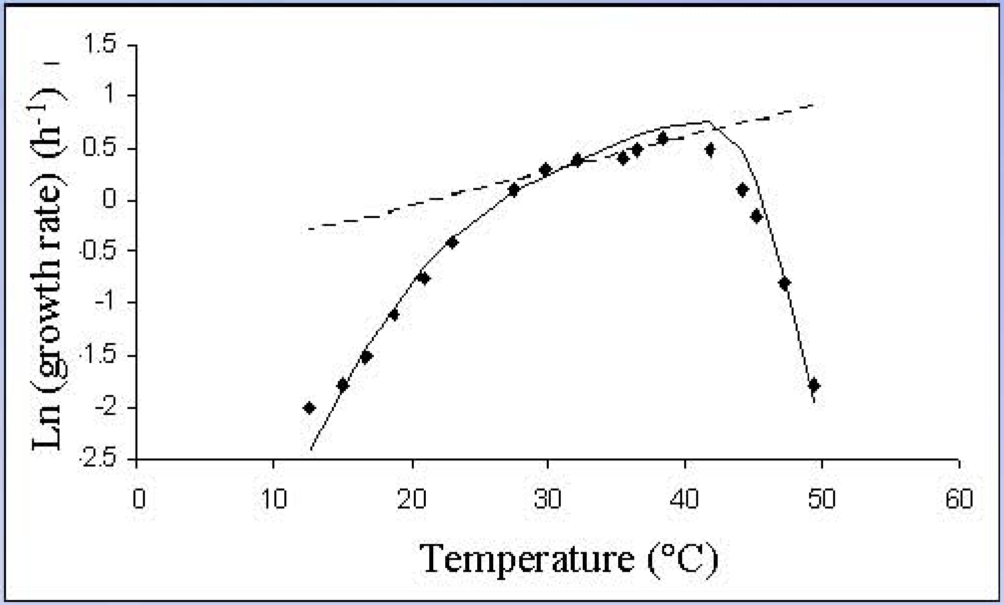
-Respiration and photosynthesis: classic exponential increase

$$\boldsymbol{rate} = \max \boldsymbol{rate} \cdot \exp\left(\frac{T_a}{T_{ref}} - \frac{T_a}{T}\right) \quad \approx \quad \boldsymbol{rate} = \max \boldsymbol{rate} \cdot Q_{10}^{T}$$

-Nutrition (based on growth data): exponential increase + enzymes inactivation

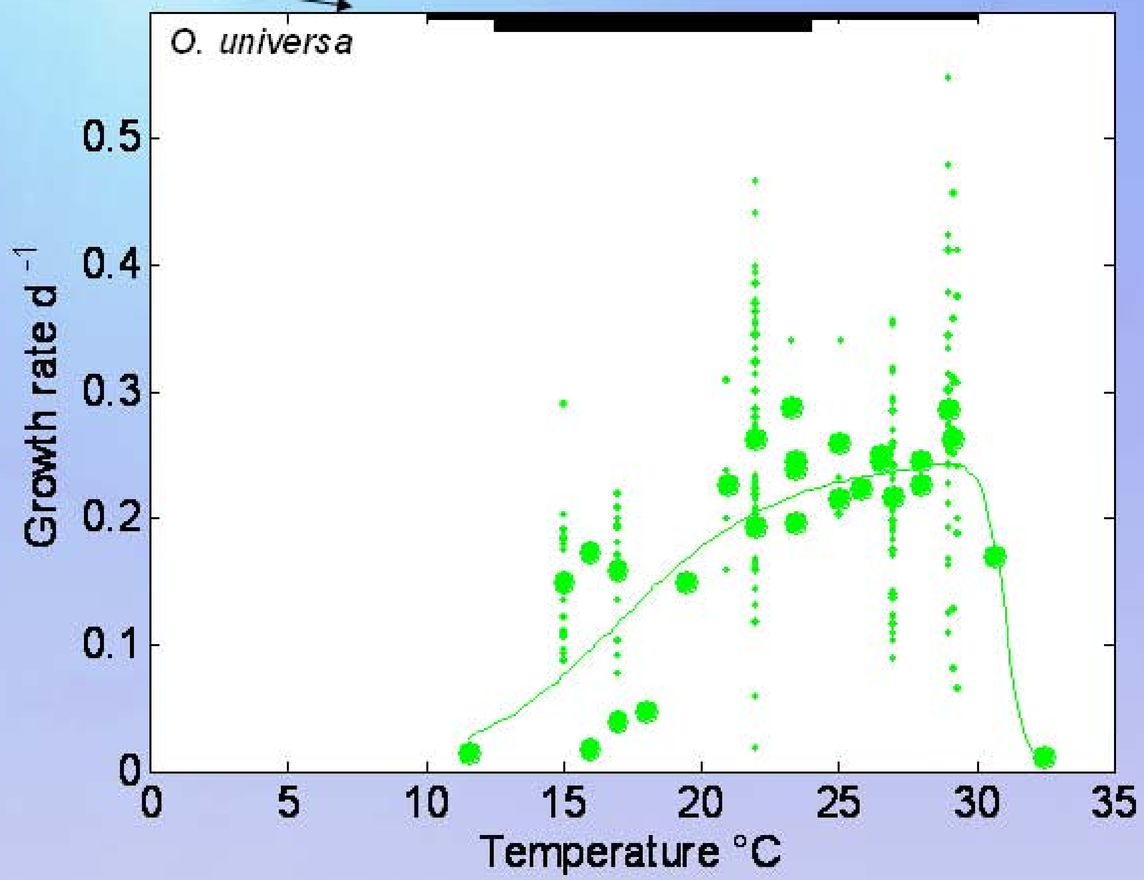
Mechanistic approach

Exemple: *Escherichia coli*
(Herendeen 1979)



Model results

Relative abundance
in plankton tows
(Bé & Tolderlund 1971)



Culture results from:

Bijma et al 1990
Bijma et al 1992
Caron et al 1987
Lea & Spero
(unpublished data)

Lombard et al *on prep*

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Relative abundance
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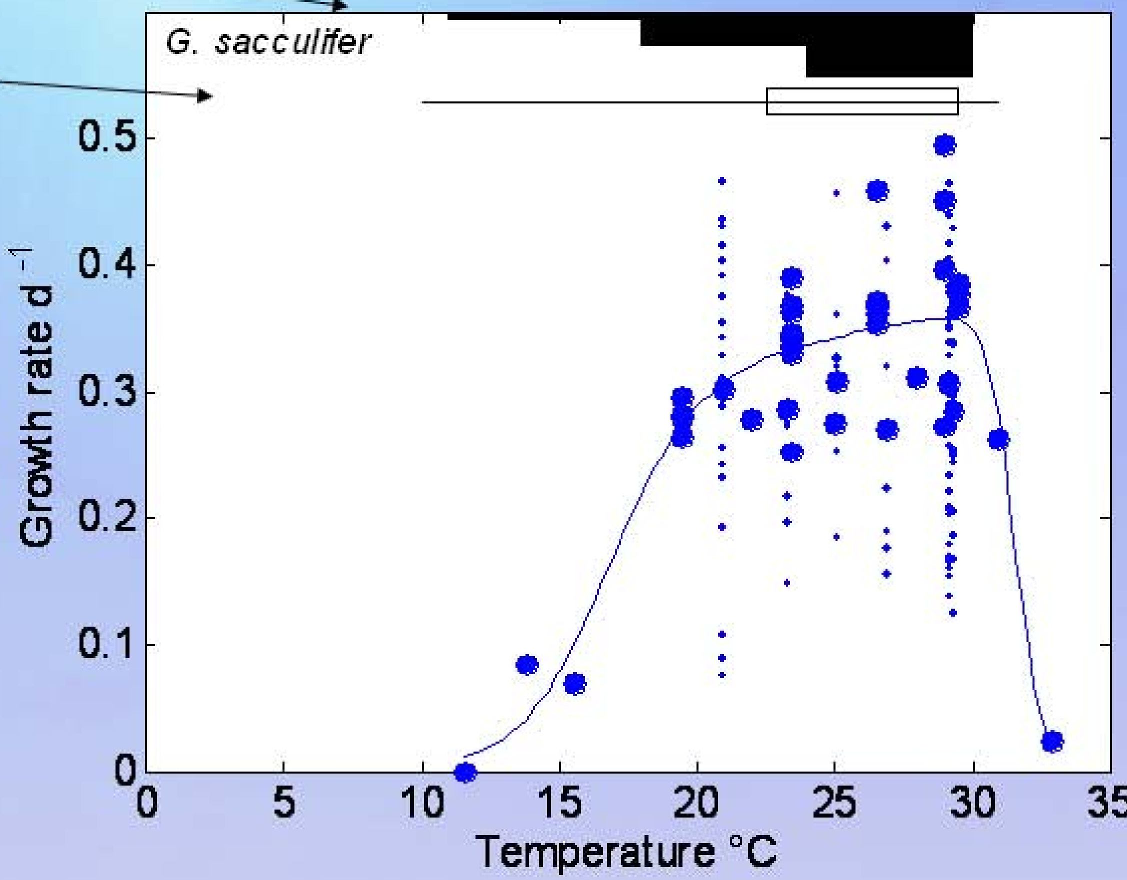

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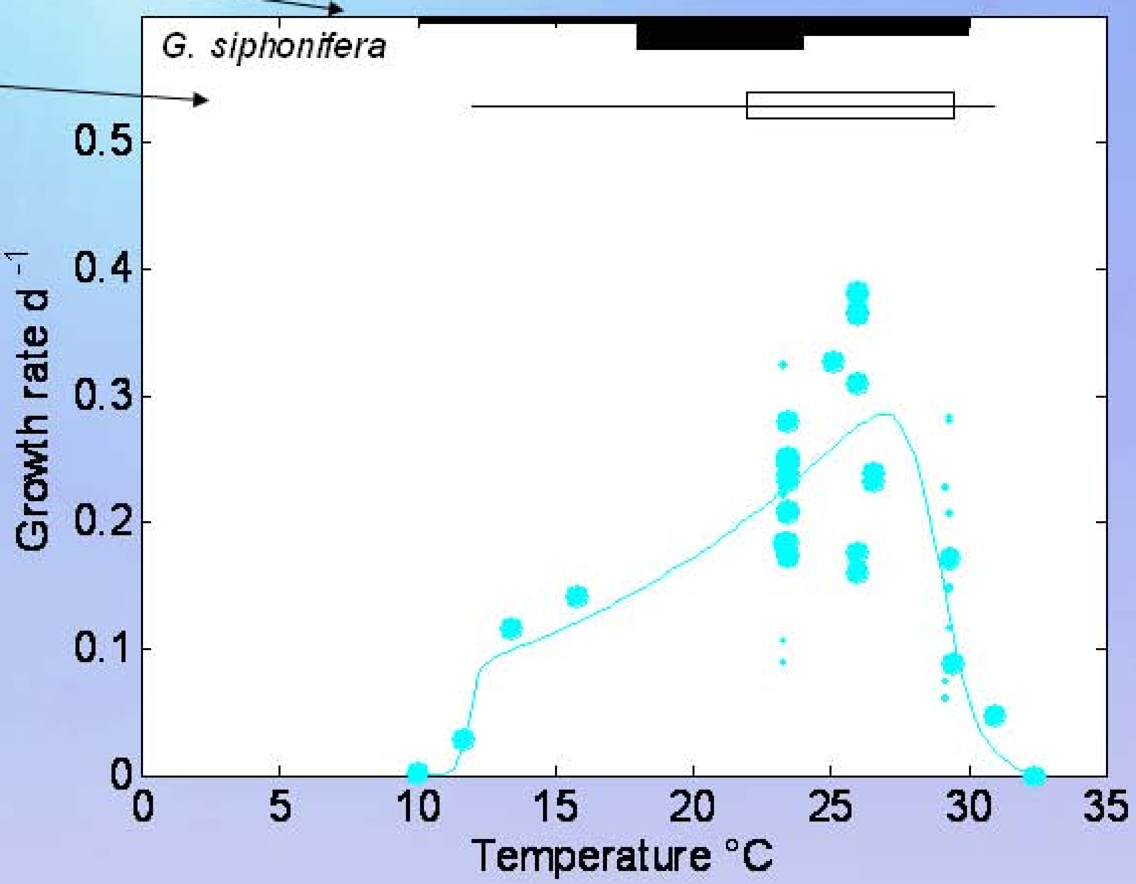

Culture results from:

Bijma et al 1990
Bijma et al 1992
Bijma et al 1998
Faber et al 1989
Lea & Spero
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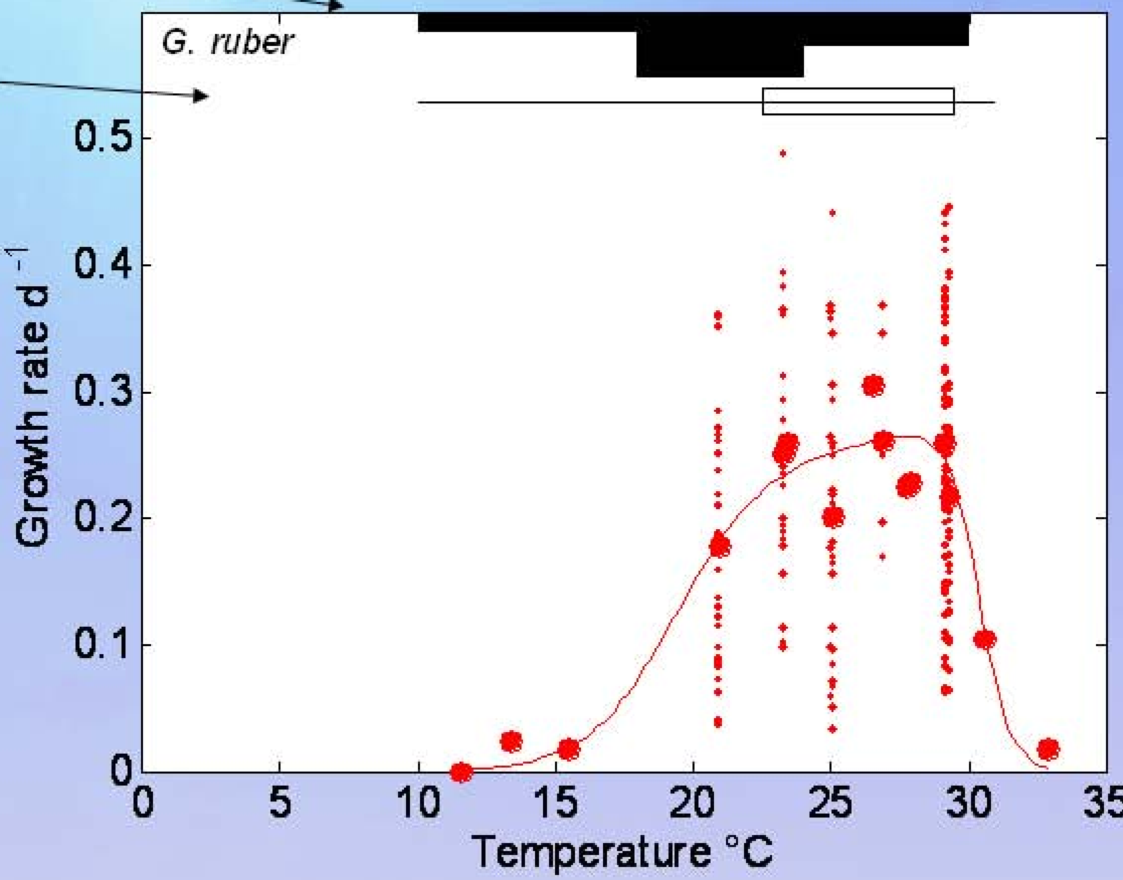

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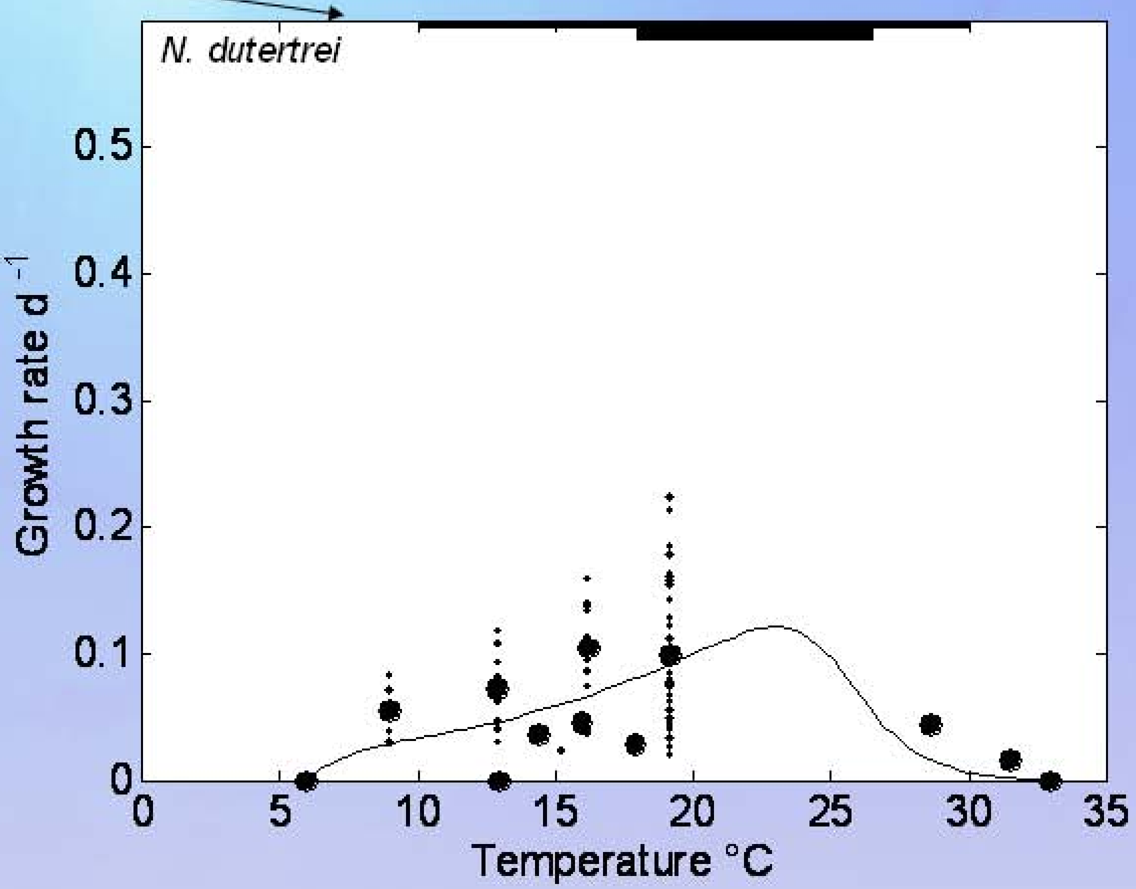

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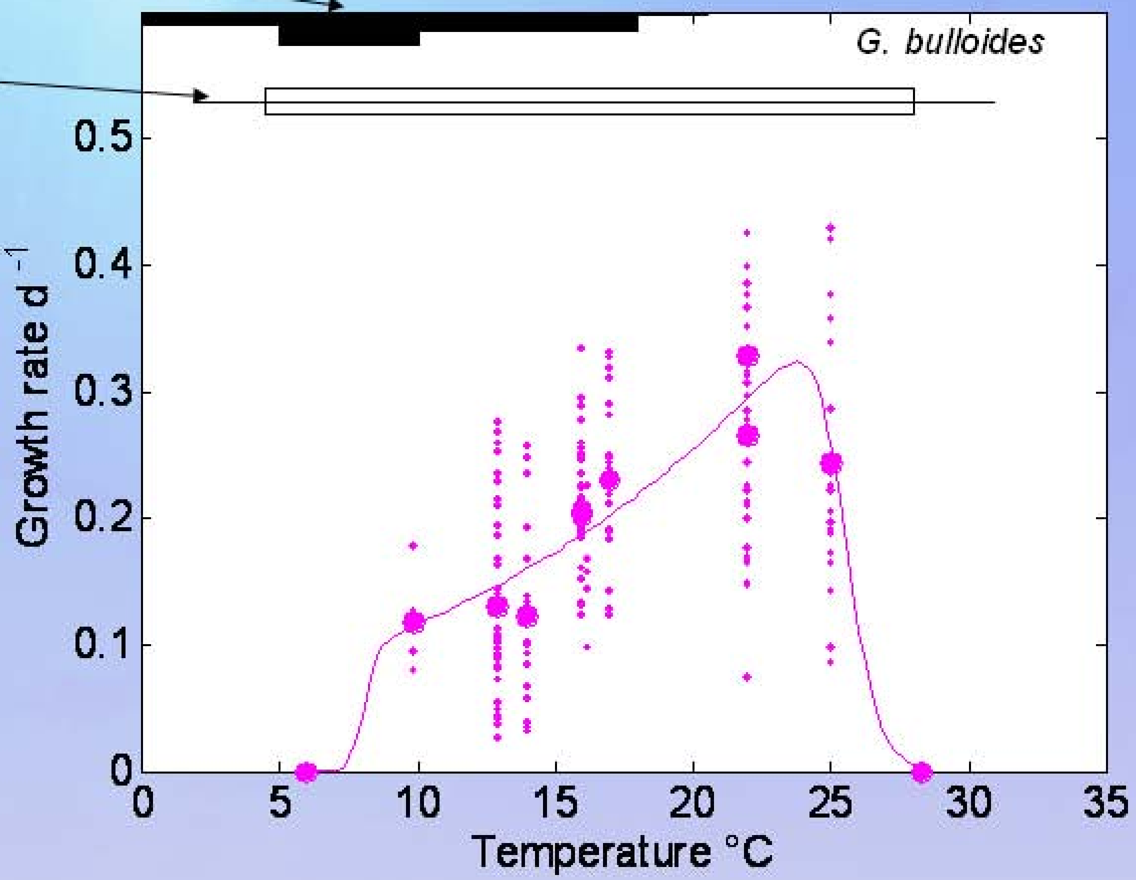

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Relative abundance
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Culture results from:

Lea & Spero
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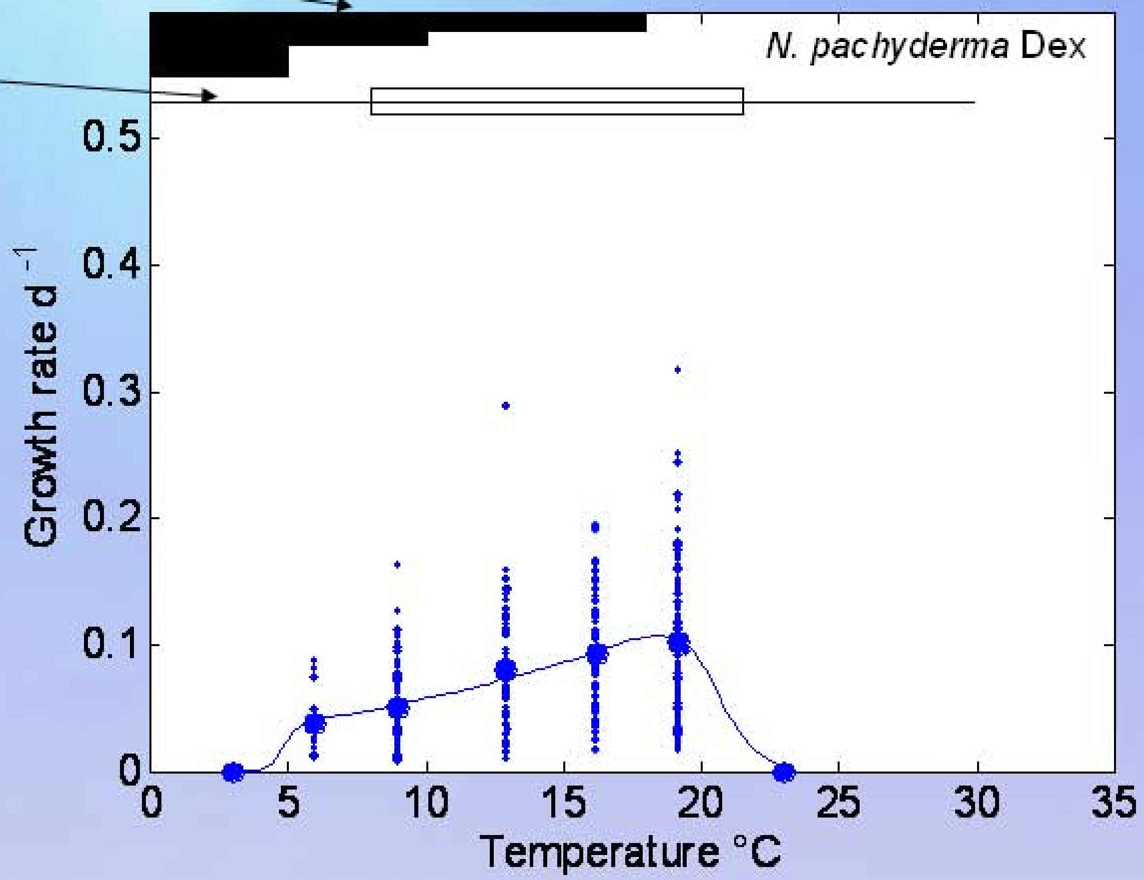
Combined dextral and sinistral forms



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Relative abundance
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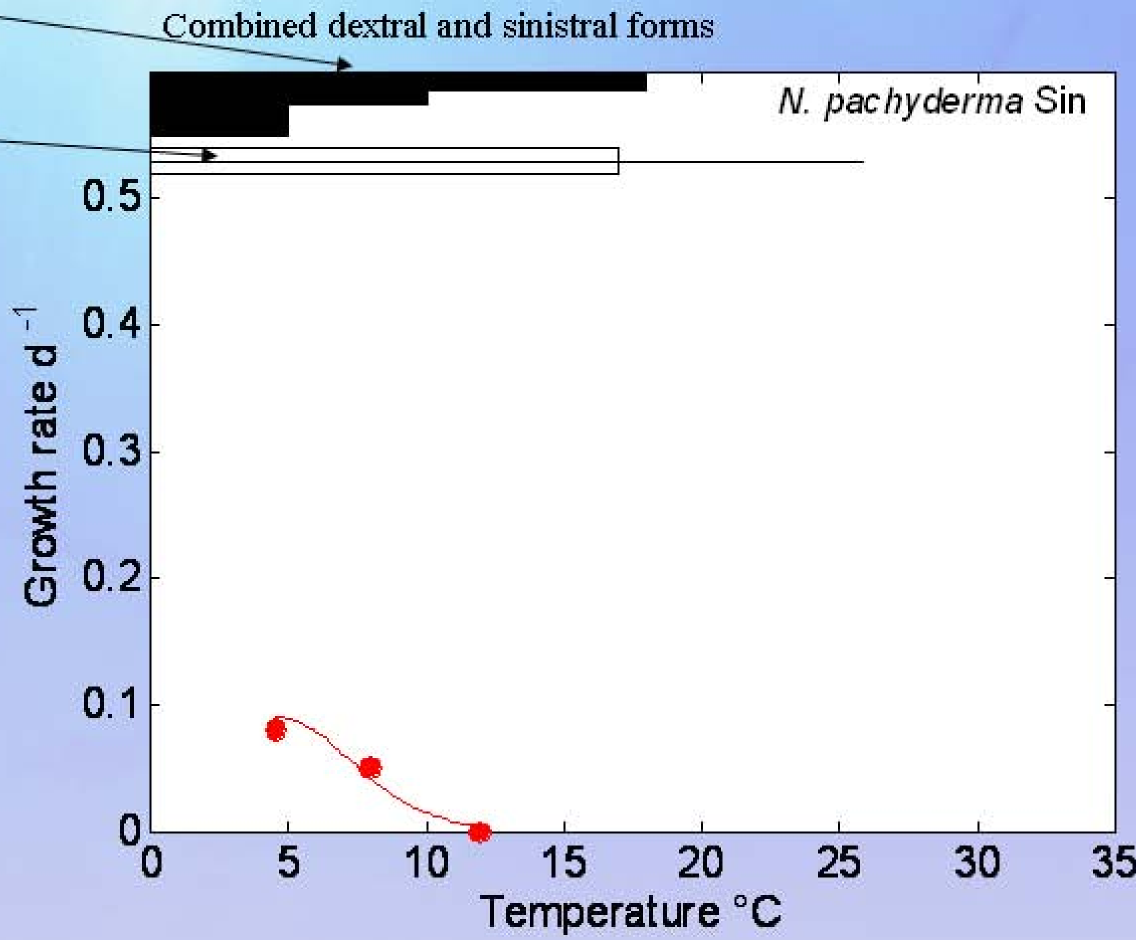
Culture results from

Kimoto
(unpublished data)



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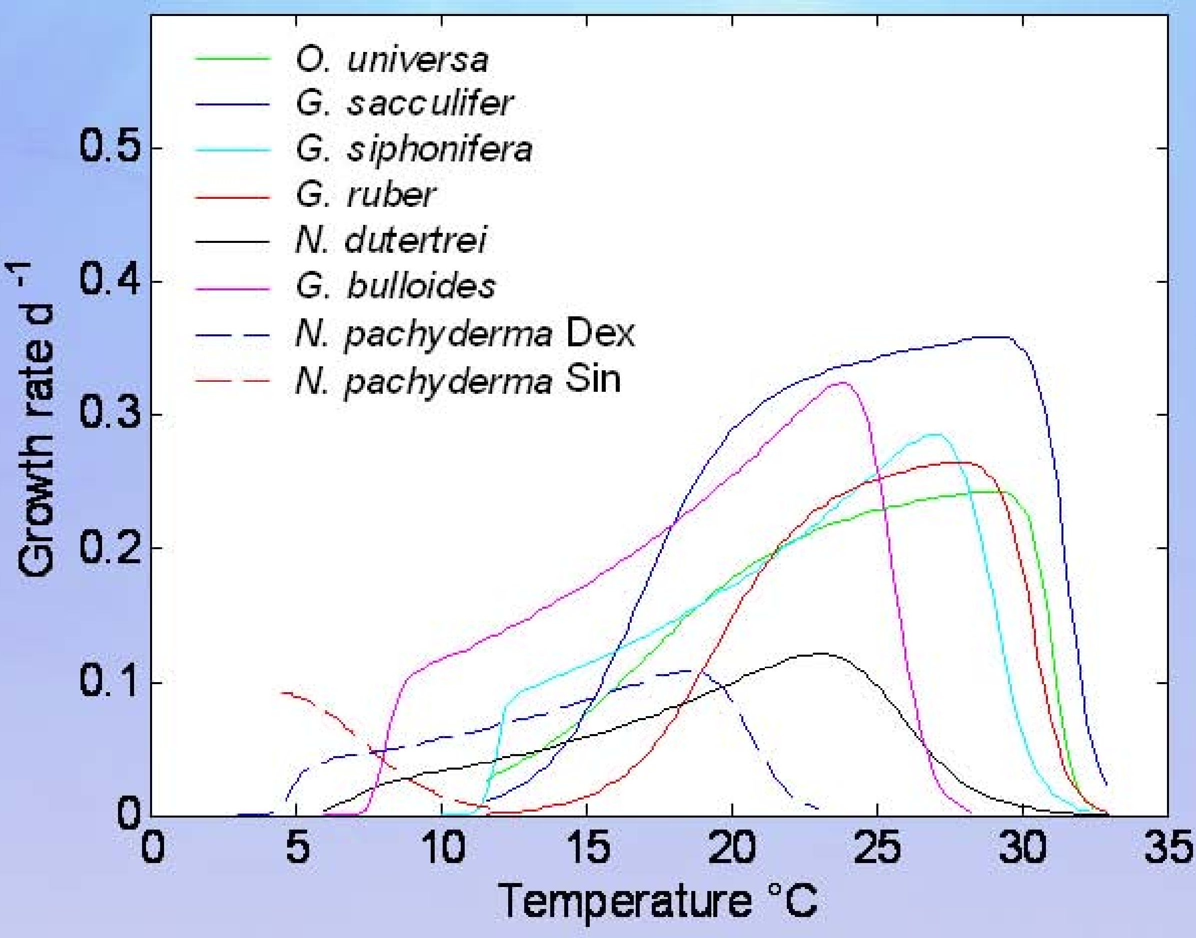

Food saturated conditions
(half saturation coefficient for food missing)

Same respiration and photosynthesis rates for all species
(different symbiont number)

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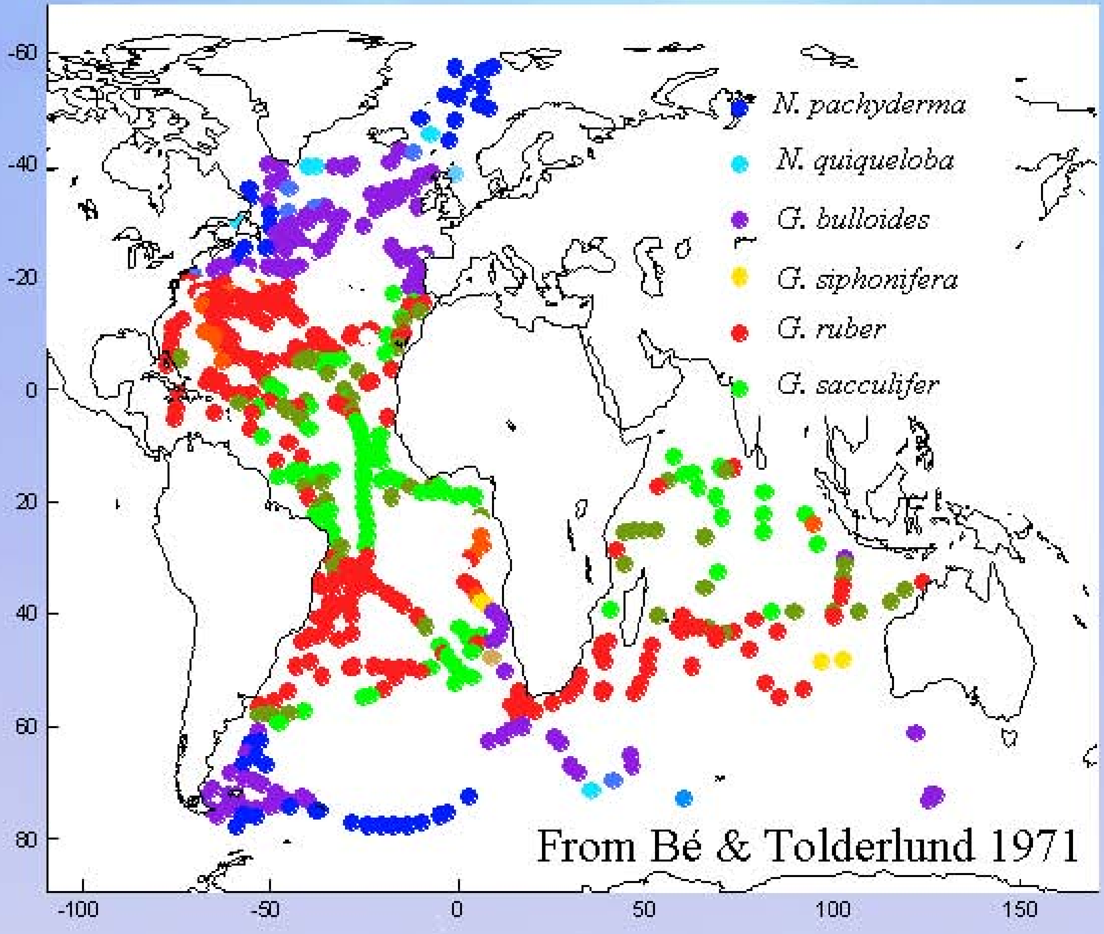
Goals

Succeed to reproduce geographical species localization



Map of dominant species

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Model results from SeaWifs

- Satellite data :
  - SST
  - light (PAR)
  - Estimator of food concentration = Chl *a* (transformed to $\mu gC\ l^{-1}$ Taylor et al 1997)

- Only one parameter was calibrated (Half saturation coefficient for nutrition)

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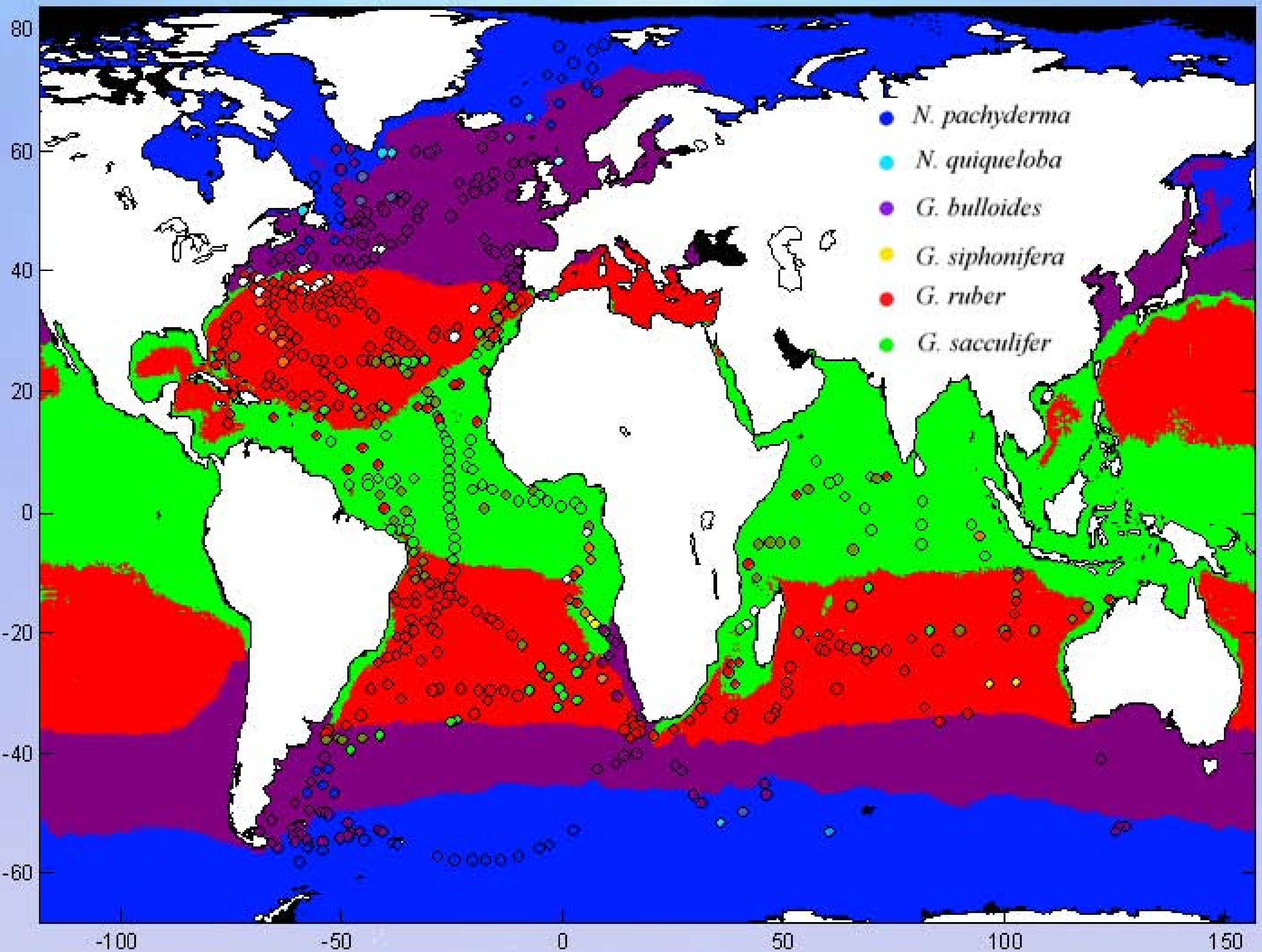
Model results from SeaWifs

Comparison: most abundant species *vs* species with highest growth rate



68% of 703 data points correctly represented

But also work with other inputs data (PISCES model input= 60% efficiency)

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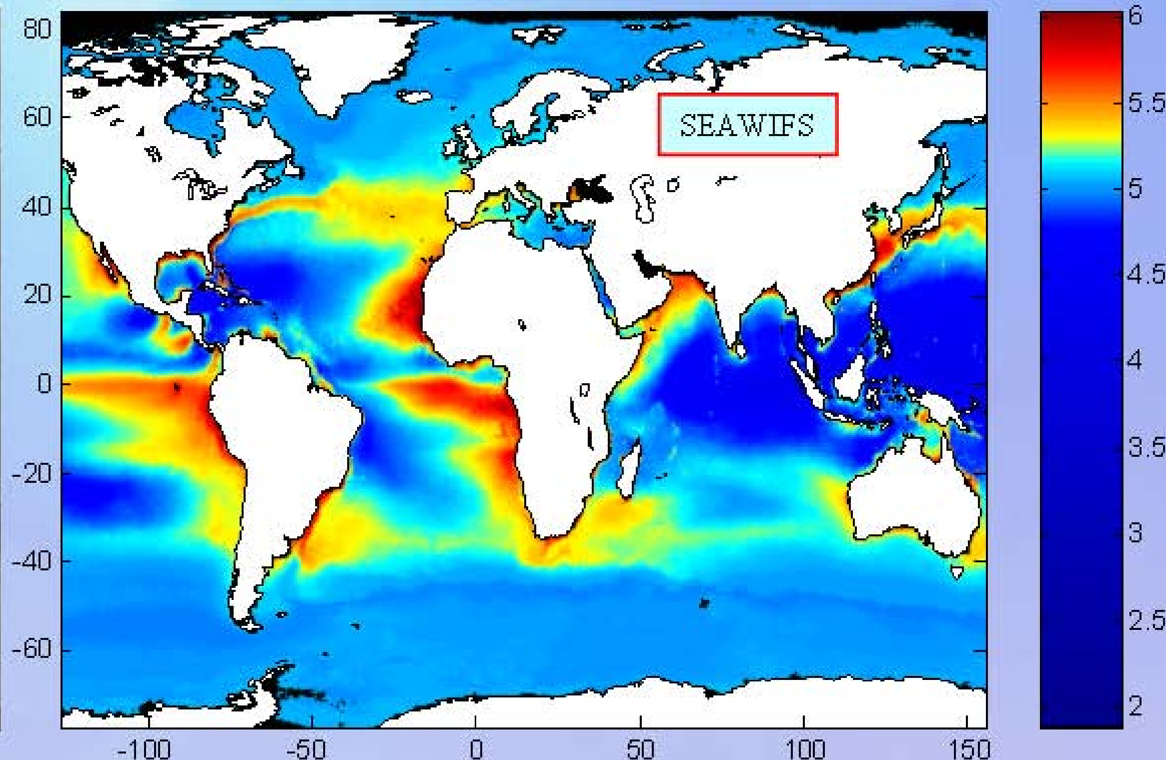
Abundance *vs* Model

Bé & Tolderlund 1971



Growth rates of the model can be in a certain level an abundance indicator

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Conclusions

- Energetic balance of foraminifer is completed (Respiration, nutrition, photosynthesis, growth)
  - First observation on the temperature effect on respiration and photosynthesis
  - Modeling of the growth in function to T° C, food concentration and light availability for different species
  - Temperatures limits for growth corresponds to *in-situ* observations

- The model is able to reproduce species dominance only with few data inputs (T° C, Chl *a*, Light)
  - Physiology can explain species repartition in ecosystems
  - Works as well from satellite images (SeaWifs)
    - Species dominance
    - Growth rate can be an abundance estimator
  - or for model outputs (PISCES)
    - Vertical dimension

Perspectives

- Succeed to reproduce:
  - Species abundances
  - Temporal succession
  - Vertical variability

  data acquisition for model calibration in progress (multinet and sediment trap samples)

- Predict foraminifer shell fluxes to the seafloor
- Adding calcification and stable isotopes to the model??

- Paleoclimatic applications
  - Prediction of the season and depth where the different species have grown (lower paleoclimatic reconstruction uncertainties)

  - Inversing the model: prediction of T° C, Chl a, and light availability on the whole water column from fossil foraminifer assemblages and isotopic composition

Thanks for your attention