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Size-scaling of phytoplankton metabolism and growth

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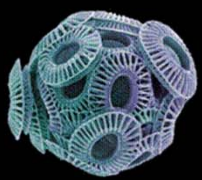

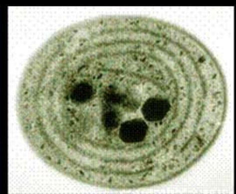

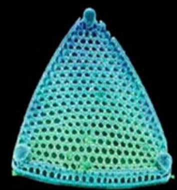

Research funded by:

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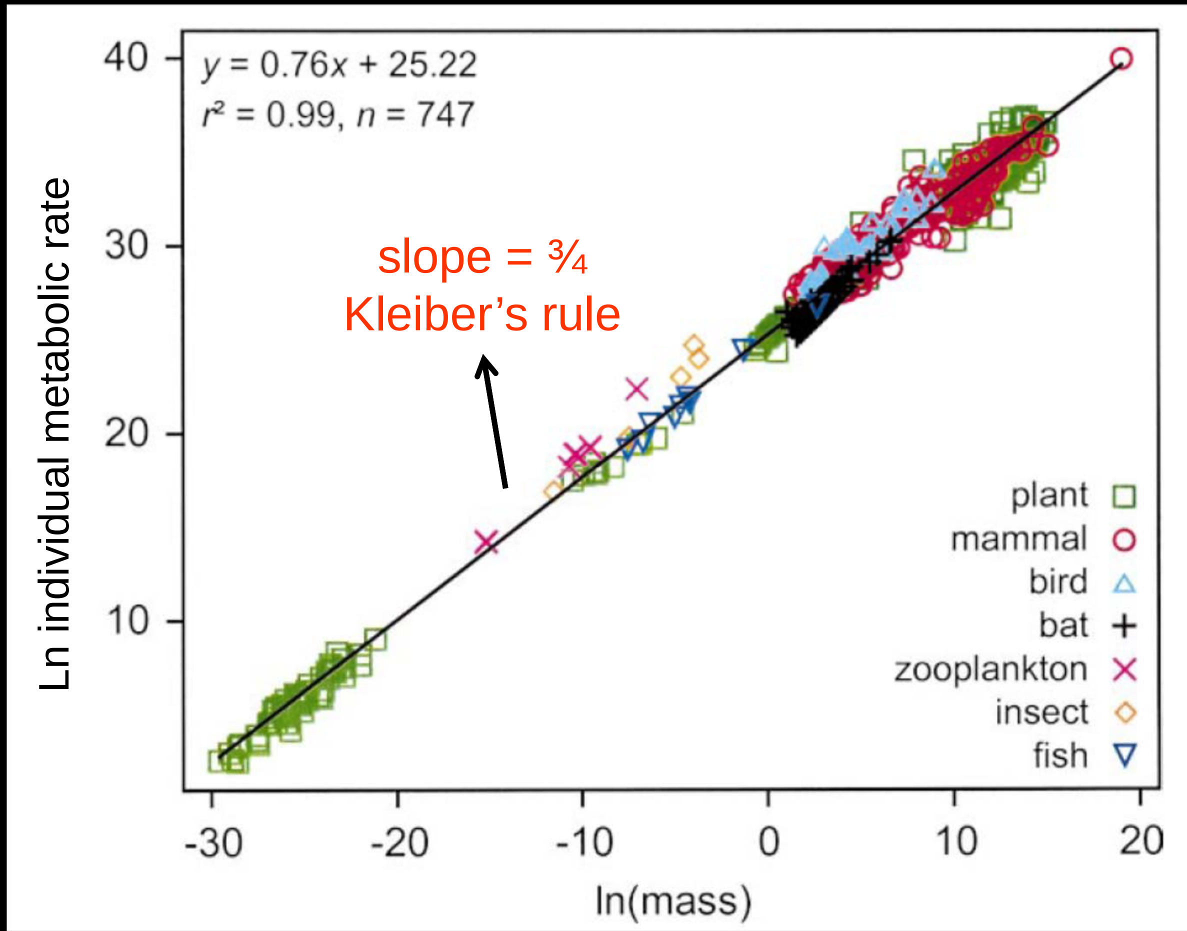
Things are different, so we need science;
things are similar, so science is possible

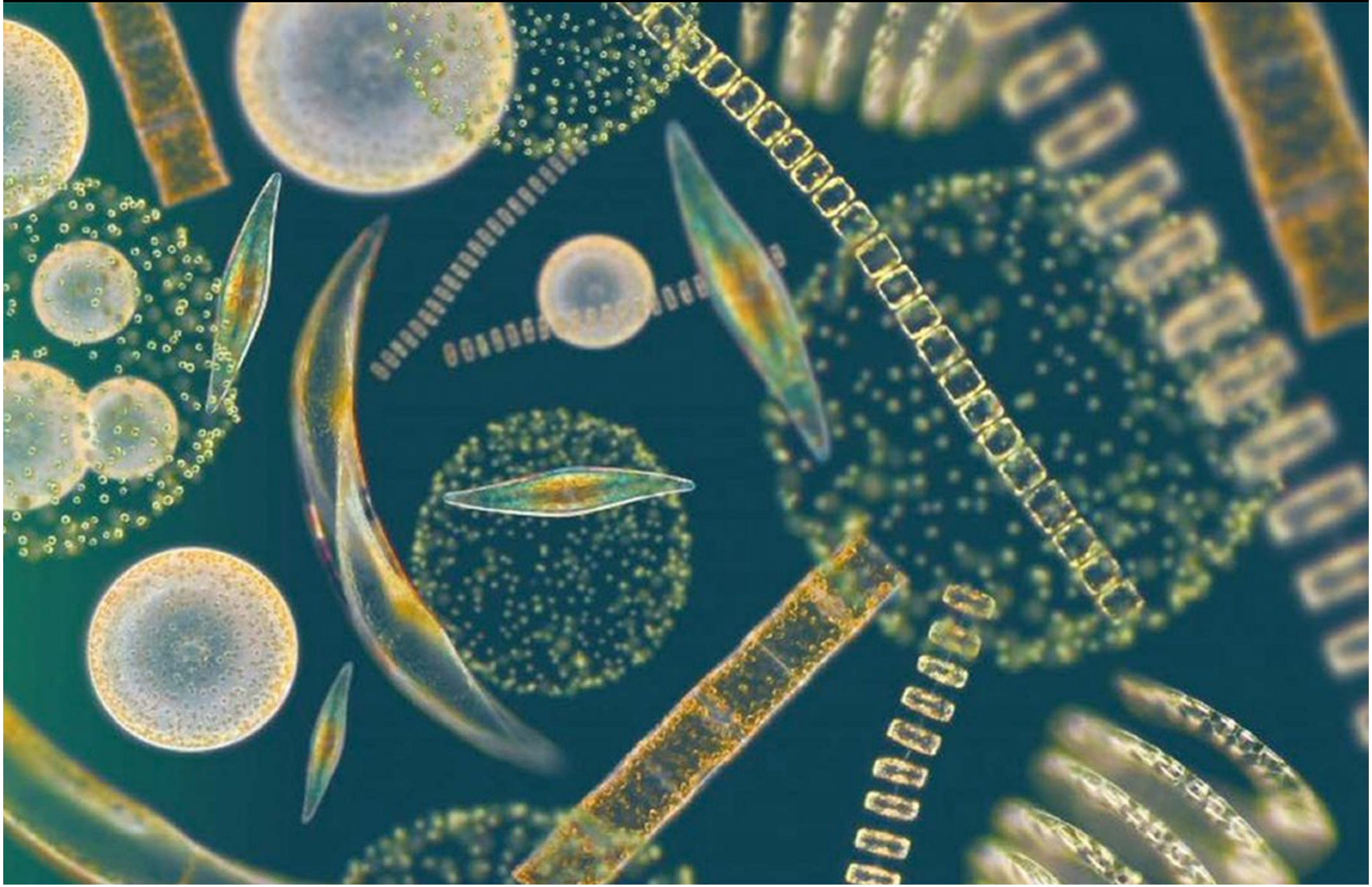
Levins & Lewontin, 1980

Macroecological pattern: body size and metabolic rate



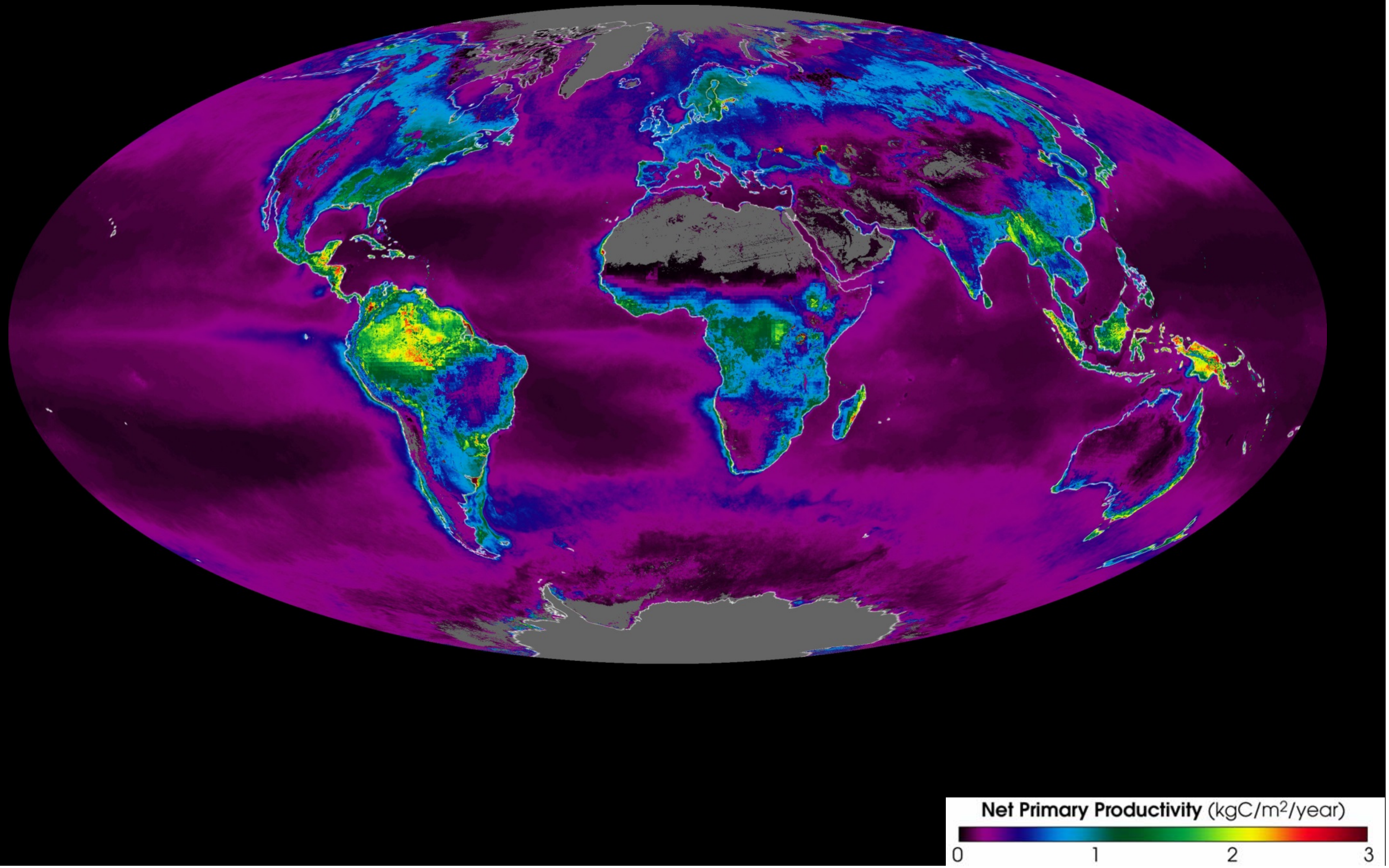
Brown et al. 2004 Ecology

Phytoplankton: basis of most aquatic ecosystems



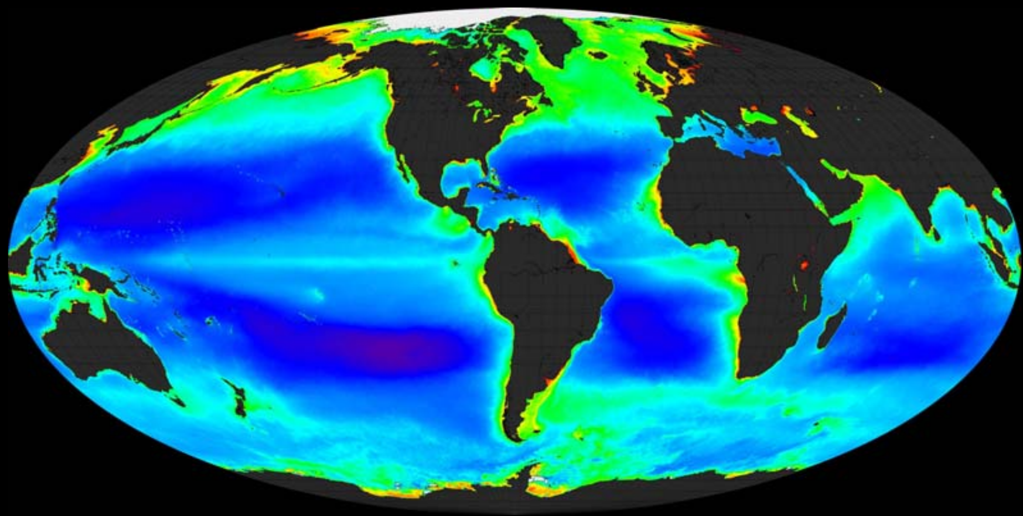
Phytoplankton: basis of most aquatic ecosystems

Global primary productivity



Outline

- Do phytoplankton follow Kleiber’s rule?
- Mechanisms underlying the size-scaling of growth
- Links with phytoplankton size structure



The importance of phytoplankton cell size

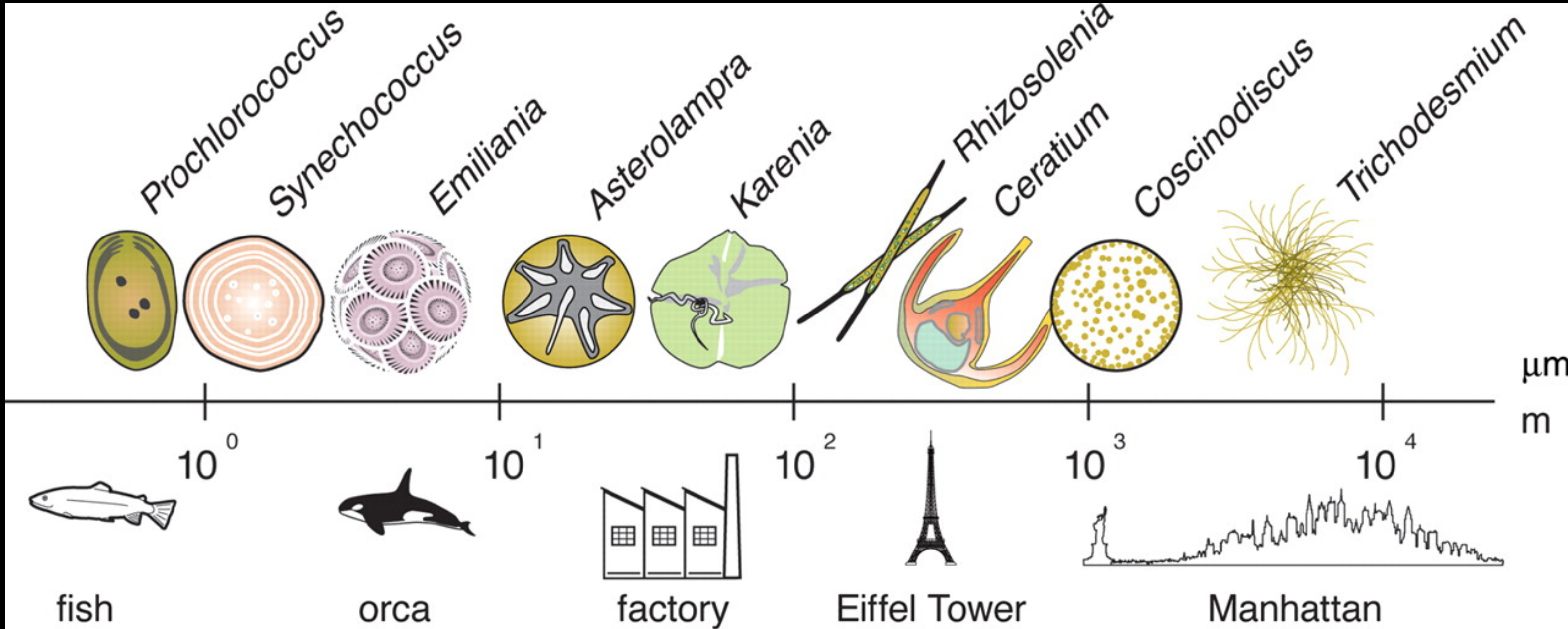


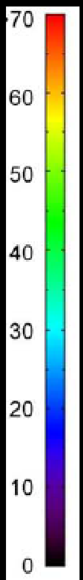
Figure from Finkel et al. 2010 J Plankton Res

Many key phytoplankton processes are affected by cell size:

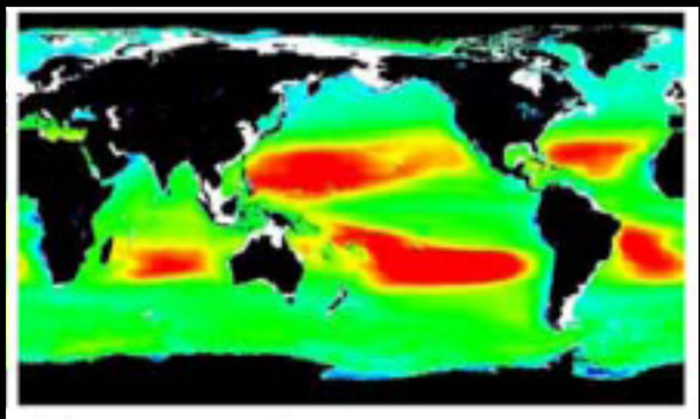
- Growth and metabolic rates
- Resource acquisition and use
- Susceptibility to predation and sinking

The importance of phytoplankton cell size

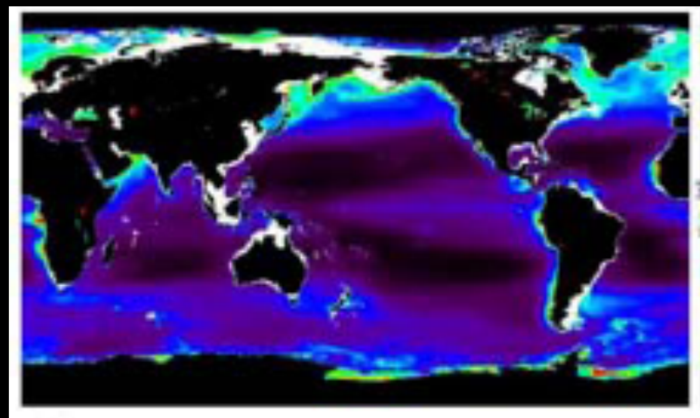
	Phytoplankton dominated by:	
Property	**Small cells**	**Large cells**
Dominant trophic pathway	Microbial food web	Herbivorous food chain
Main fate of primary production	Recycling in the upper layer	Export toward deep waters



% picophytoplankton chl a (small cells)



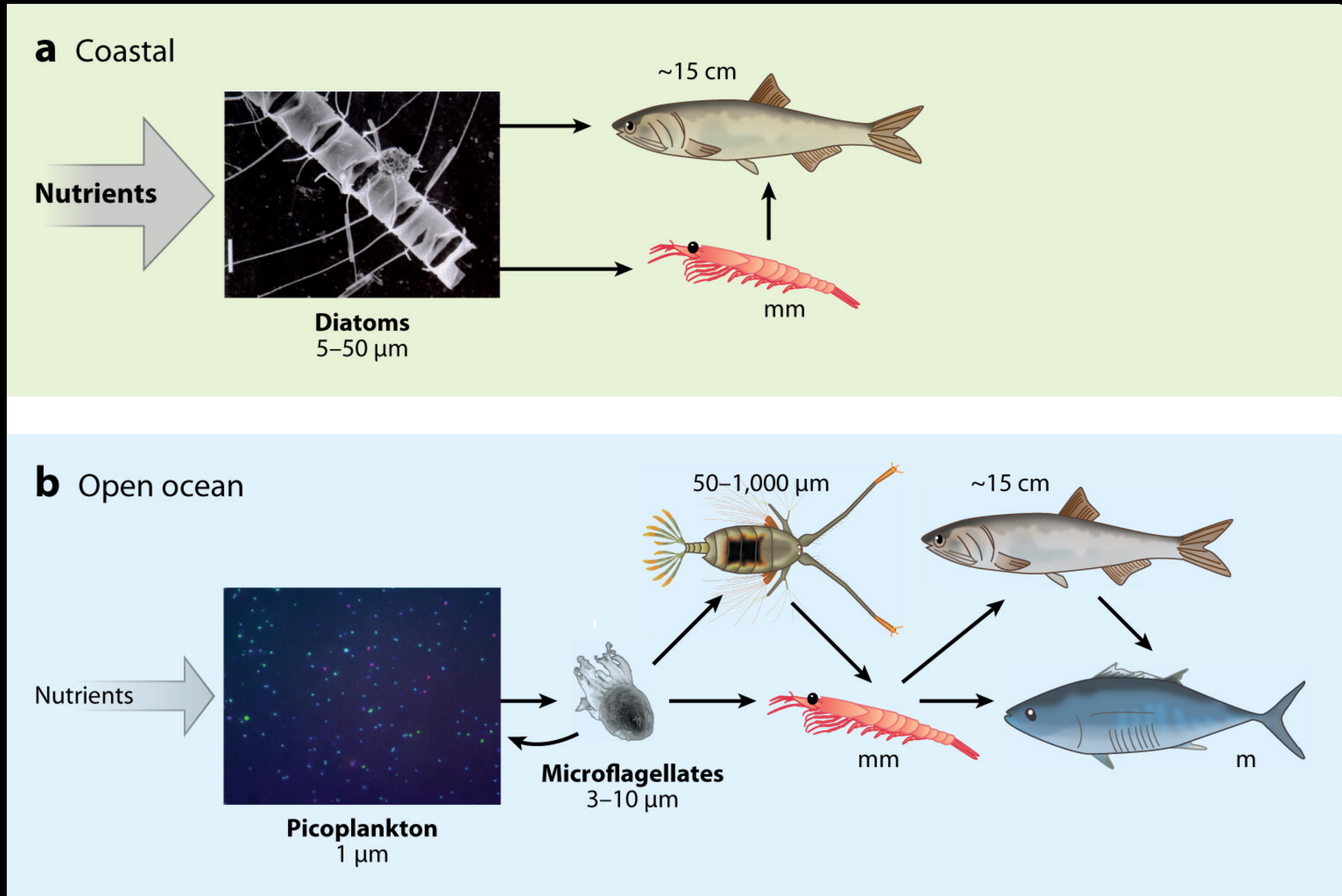
% microphytoplankton chl a (large cells)



Hirata et al 2011 Biogeosci.

The importance of phytoplankton cell size

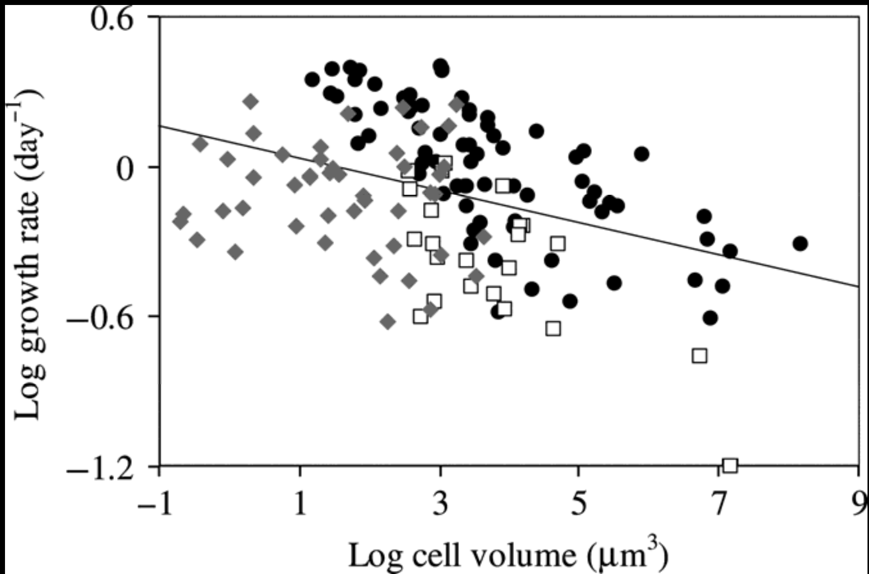
Phytoplankton size largely determines food-web structure and the fate of primary producion



Chavez FP, et al. 2011.
Annu. Rev. Mar. Sci. 3:227–60

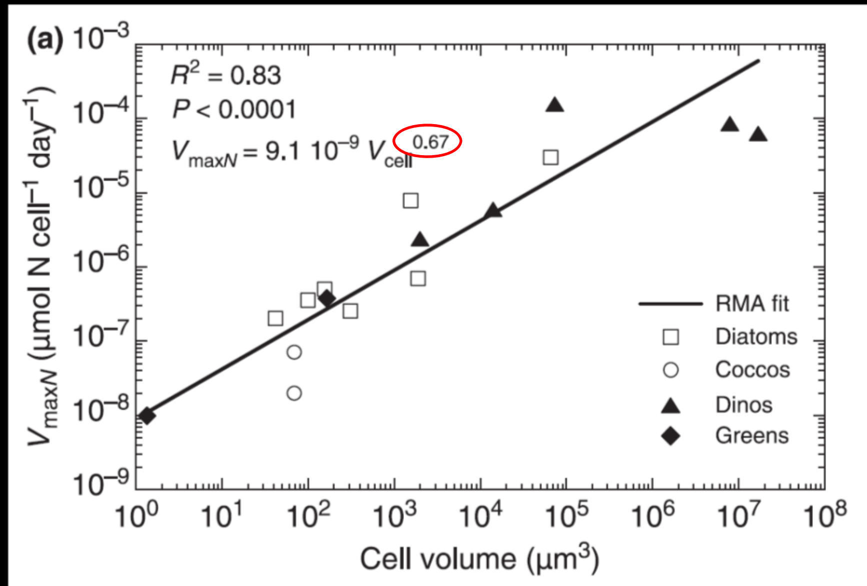
Size-scaling of phytoplankton properties (meta-analysis of literature data)

Maximum growth rate (μ)



Finkel et al. 2010 J Plankton Res

Maximum nutrient uptake rate

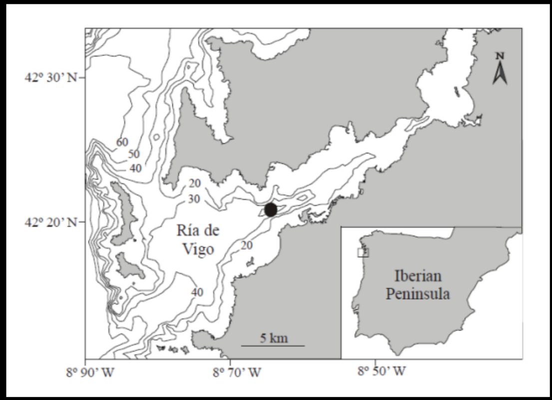


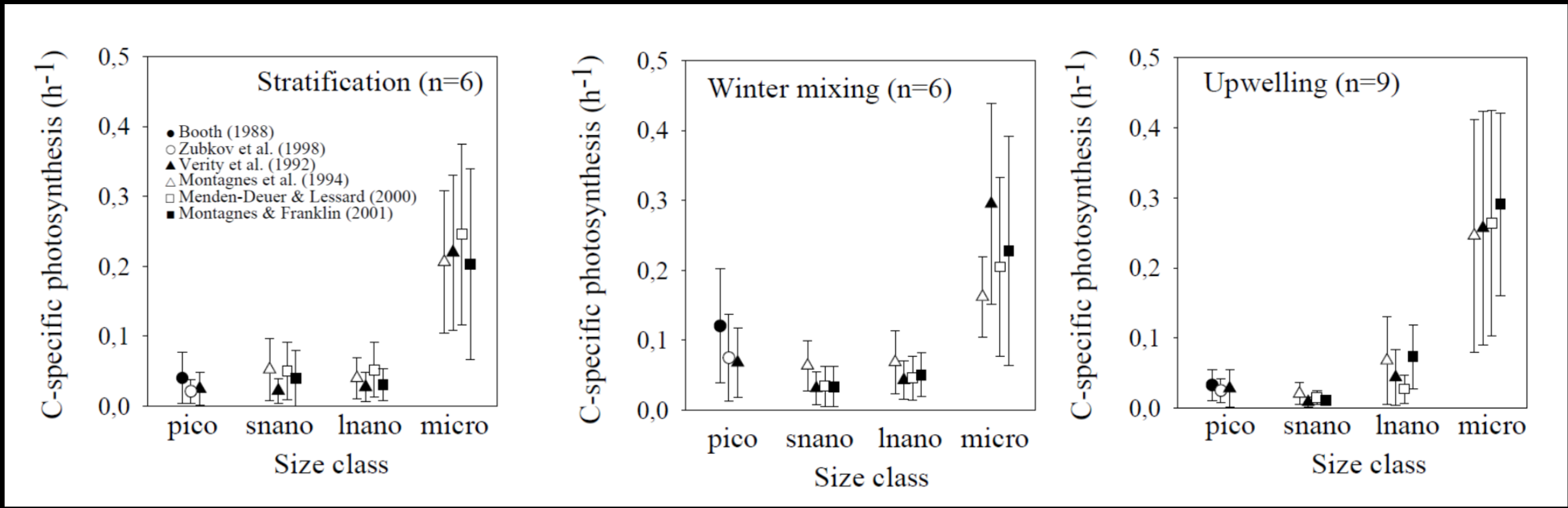
Litchman et al. 2006 Ecol Lett

Negative slope implies that small cells are controled by top-down processes

Exponent of 2/3 implies that larger cells are limited by nutrient supply

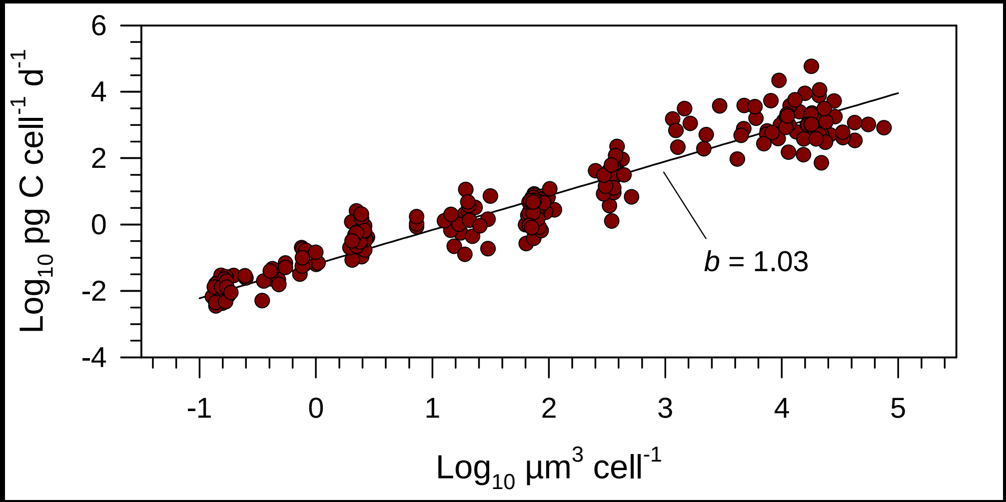
Large phytoplankton sustain high C-specific production in nutrient-rich waters





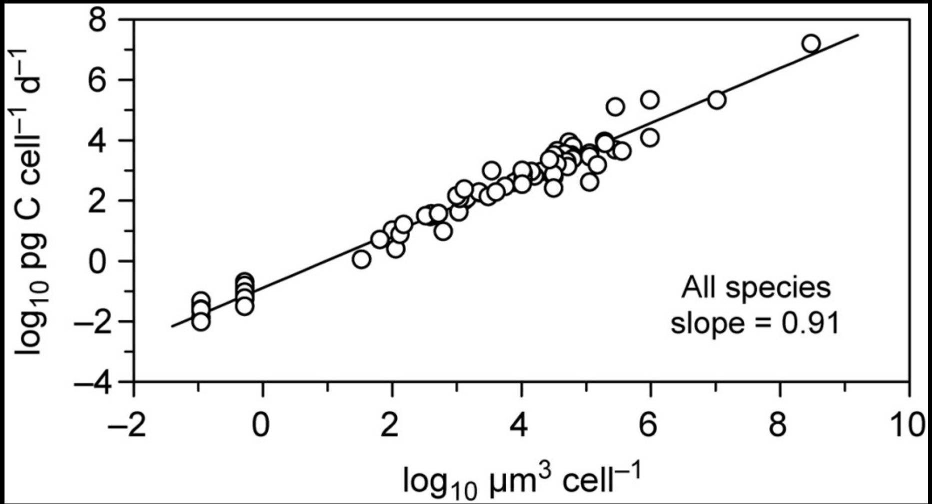
Cermeño et al. 2005 MEPS

Early estimates suggested a slope value higher than ¾…



Marañón et al. 2006 L&O

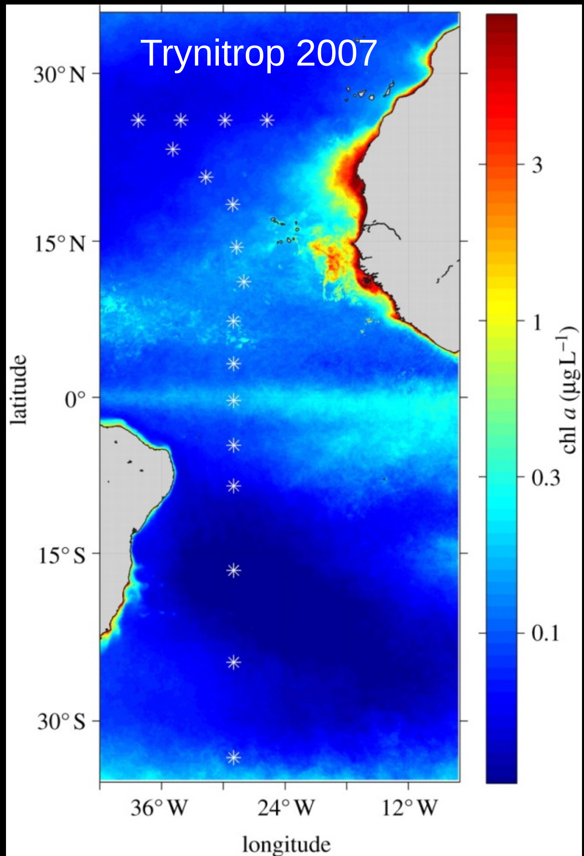
Size-fractionated production and biomass data from many locations



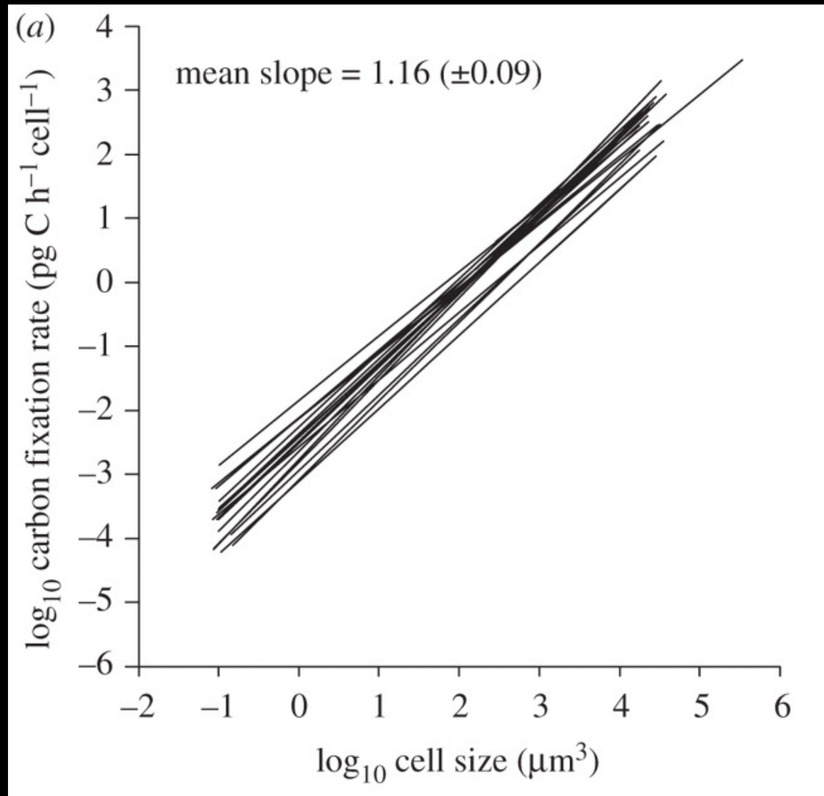
Marañón 2008 J Plankton Res

Data from the literature

…and more accurate measurements confirm that the slope is approximately 1 (isometric size-scaling)



Chl a map from MODIS Aqua (NASA)

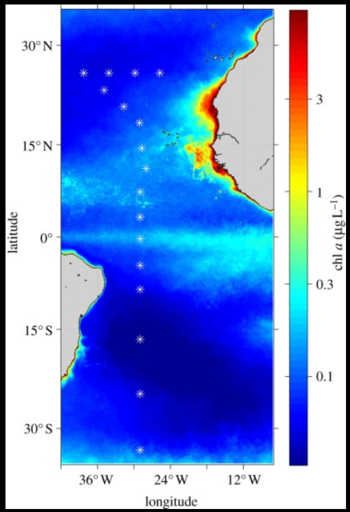


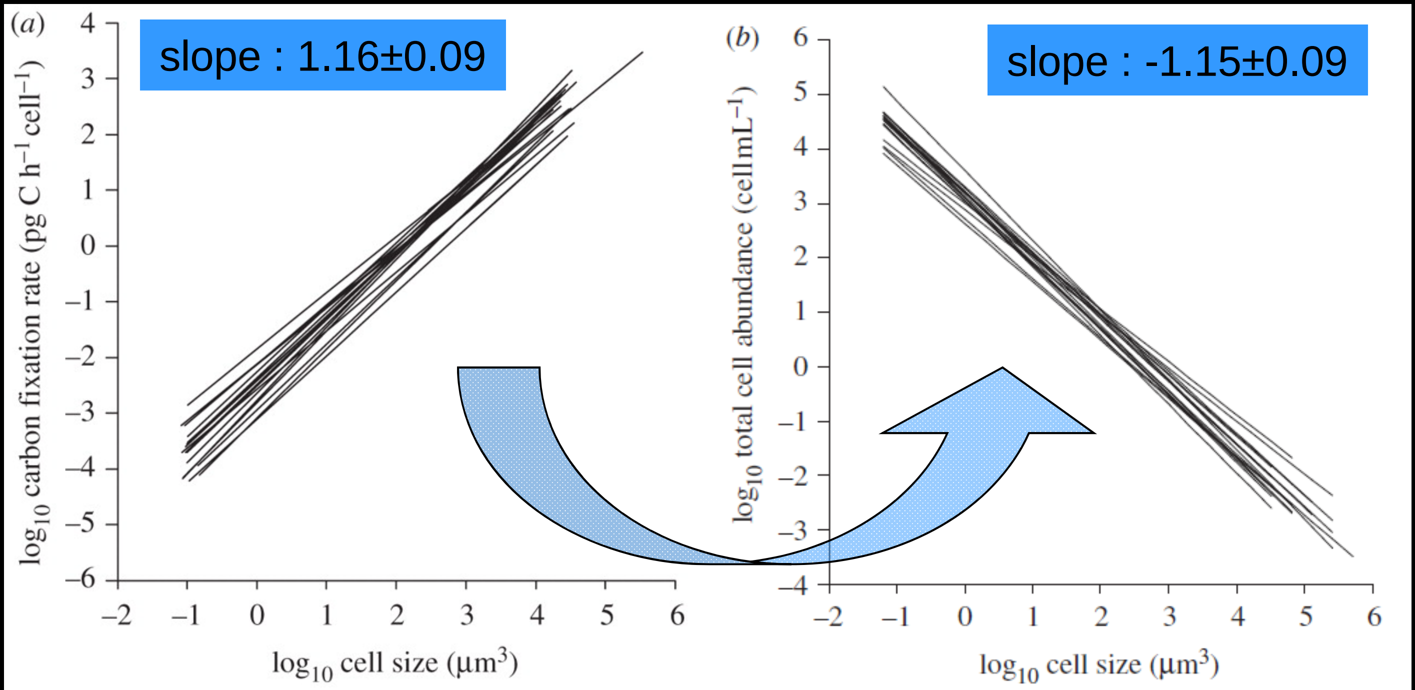
Huete-Ortega et al. 2012 Proc Roy Soc B

Linking the size-scaling of abundance and metabolic rate

Assuming populations grow until resources are limiting, in steady-state we will have (Enquist et al 1998) that $N_{max} = R/Q$, where N is abundance, R is resource supply rate and Q is the individual rate of resource use (e.g. metabolic rate).

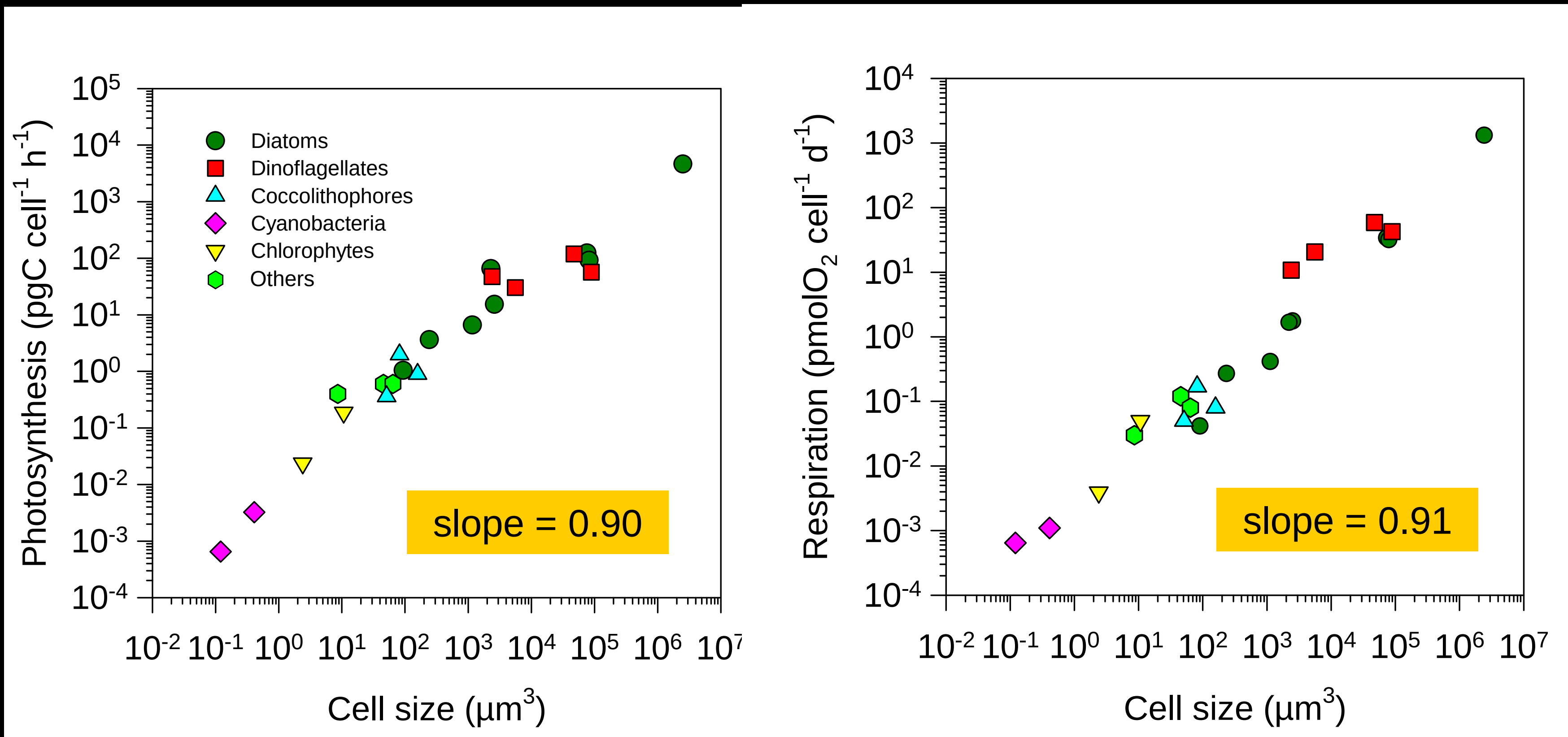
Let S be body size. If $R \propto S^0$ and $Q \propto S^b$ then $N_{max} \propto S^{-b}$ → reciprocal size-scaling of abundance and metabolic rate.





Huete-Ortega et al. 2012 Proc Roy Soc B

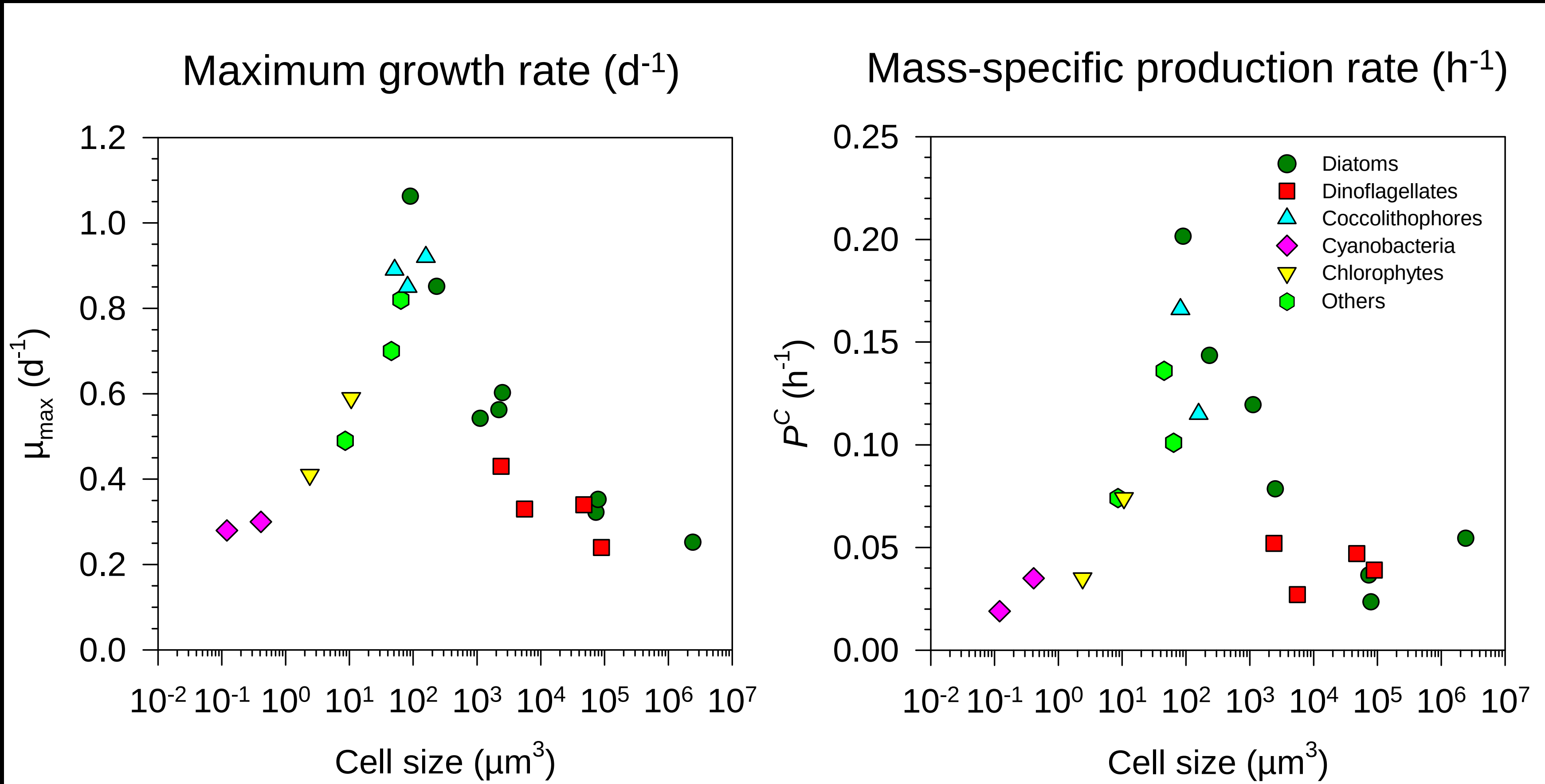
Phytoplankton cultures grown under identical conditions show near-isometric size-scaling of metabolic rates



López-Sandoval et al. 2014

→ phytoplankton metabolism does not follow the ¾-power rule

A closer look reveals that in fact the size-scaling of phytoplankton growth and production is *unimodal*

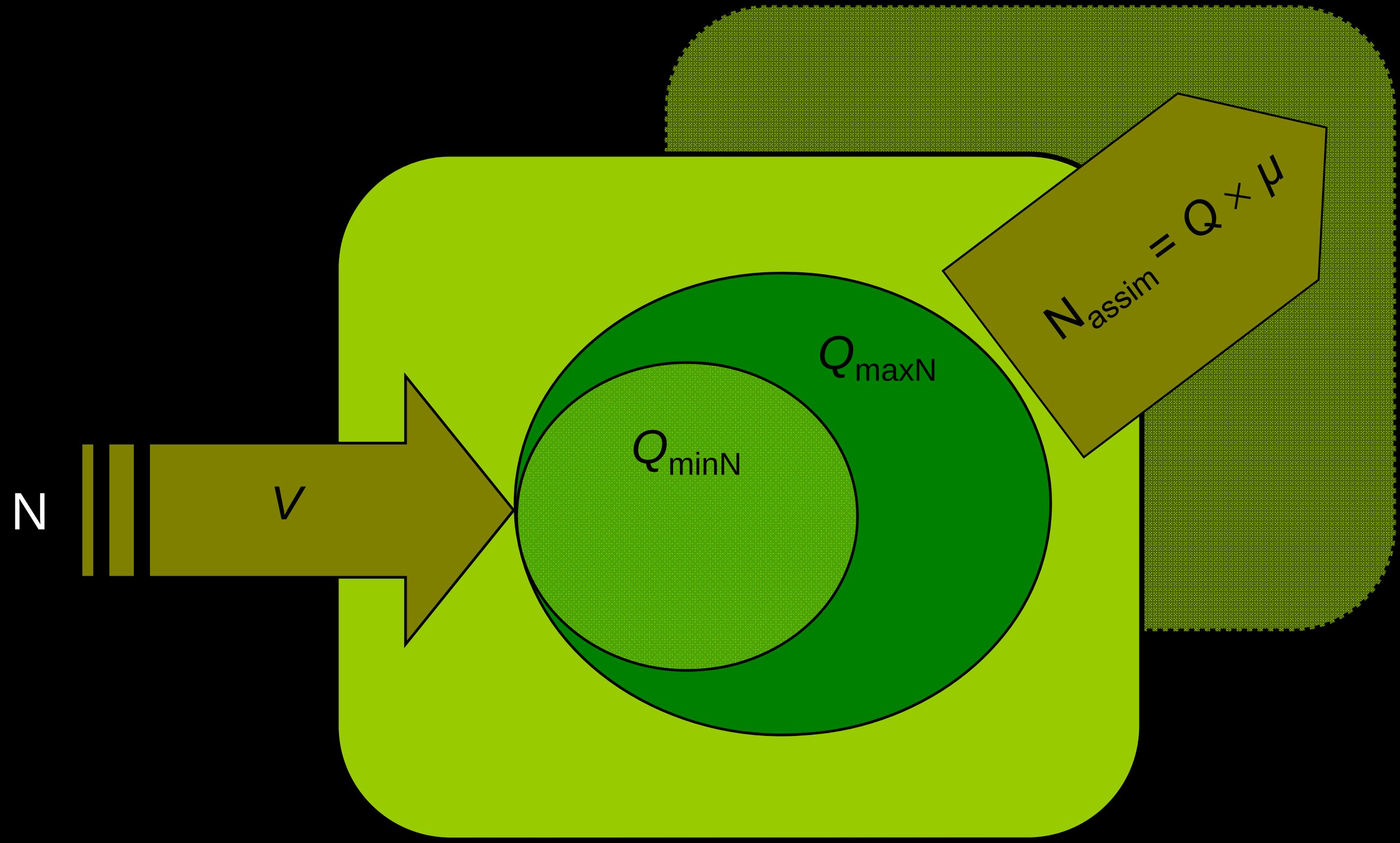


Marañón et al. 2013 Ecol Lett

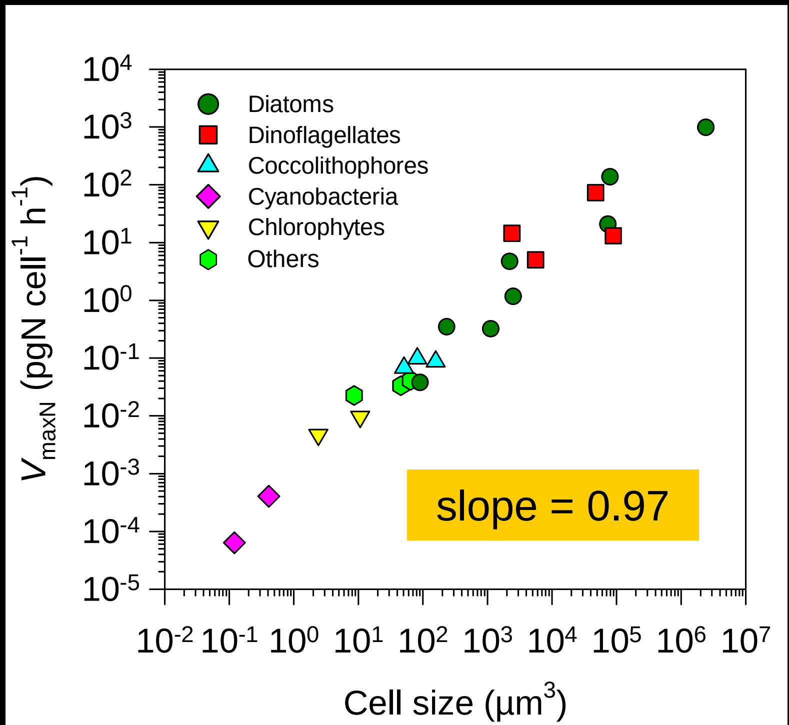
Droop’s model of phytoplankton growth

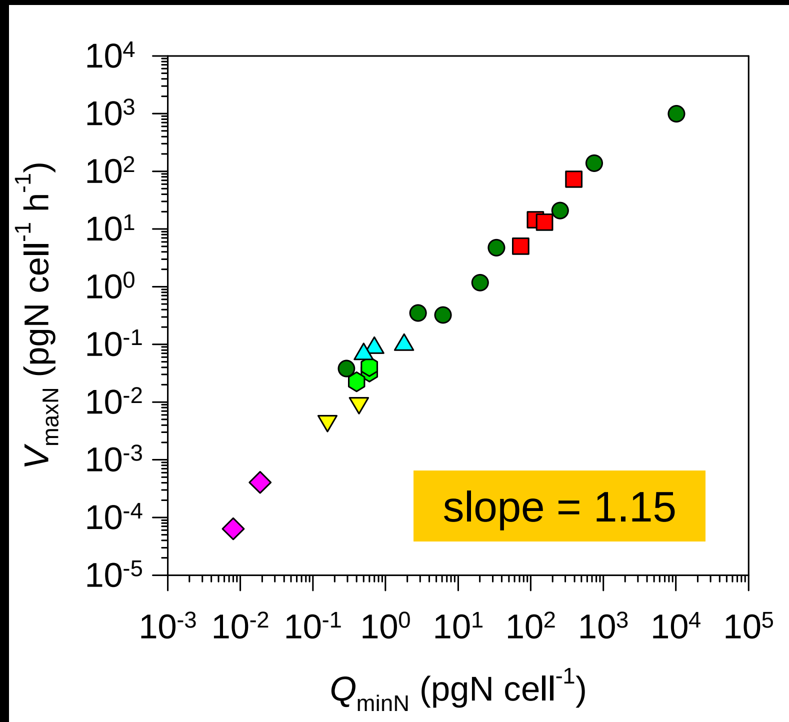
$$\mu = \mu_\infty \left(1 - \frac{Q_{min}}{Q} \right)$$

$$\frac{dQ}{dt} = V - N_{assim}$$



Unexpected size-scaling of nutrient maximum uptake rate (V_{maxN})





Theoretically, Vmax $\propto$ (cell size)$^{2/3}$, and volume-specific Vmax $\propto$ (cell size)$^{-1/3}$. In contrast, our data suggest that volume-specific Vmax is size-independent

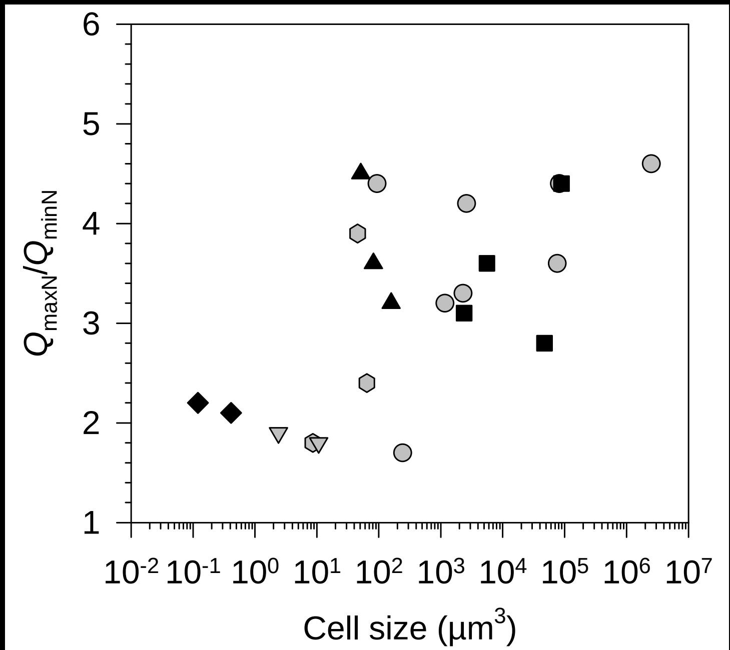
As cell size increases, the ability to take up nutrients increases ***faster*** *than requirements*

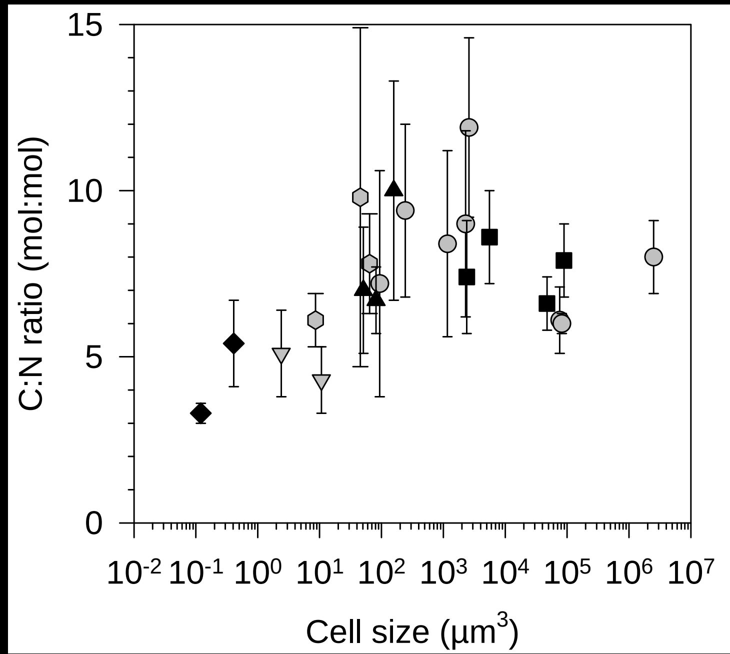
Marañón et al. 2013 Ecol Lett

An illustration of the importance of using different size-scaling exponents for nutrient uptake

Cell volume (μm^3)	Uptake rate ($fgN\ cell^{-1}\ h^{-1}$) $V_{max} \propto V^1$	Uptake rate ($fgN\ cell^{-1}\ h^{-1}$) $V_{max} \propto V^{0.66}$	Difference	
1	0.1	1	10-fold	Overestimation
10	1	5	5-fold	Overestimation
100	10	22	2-fold	Overestimation
1000	100	100	-	
10000	1000	457	2-fold	Underestimation
100000	10000	2089	5-fold	Underestimation
1000000	100000	9549	10-fold	Underestimation

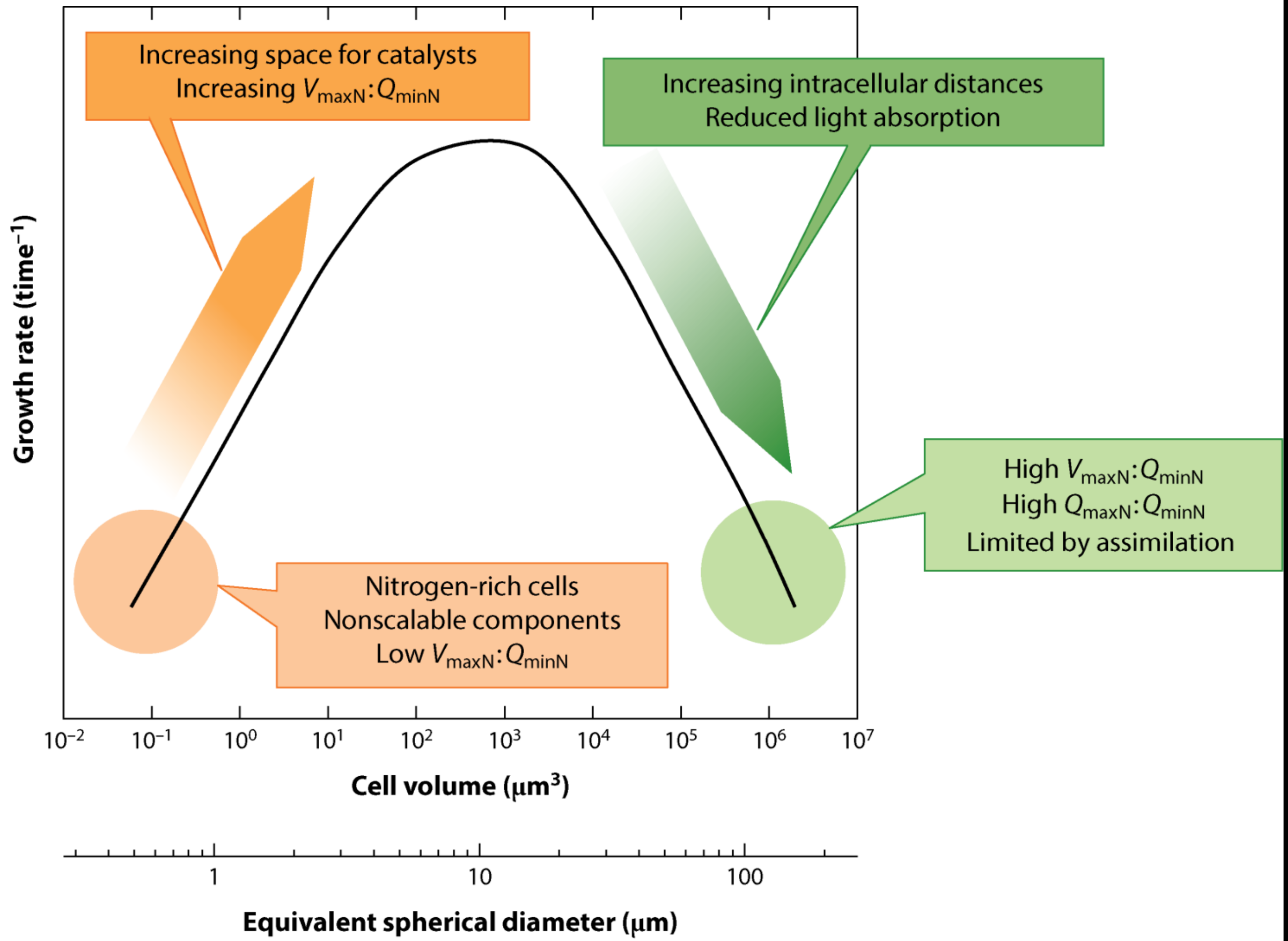
Size-scaling of Q_{max}:Q_{min} and C:N ratios





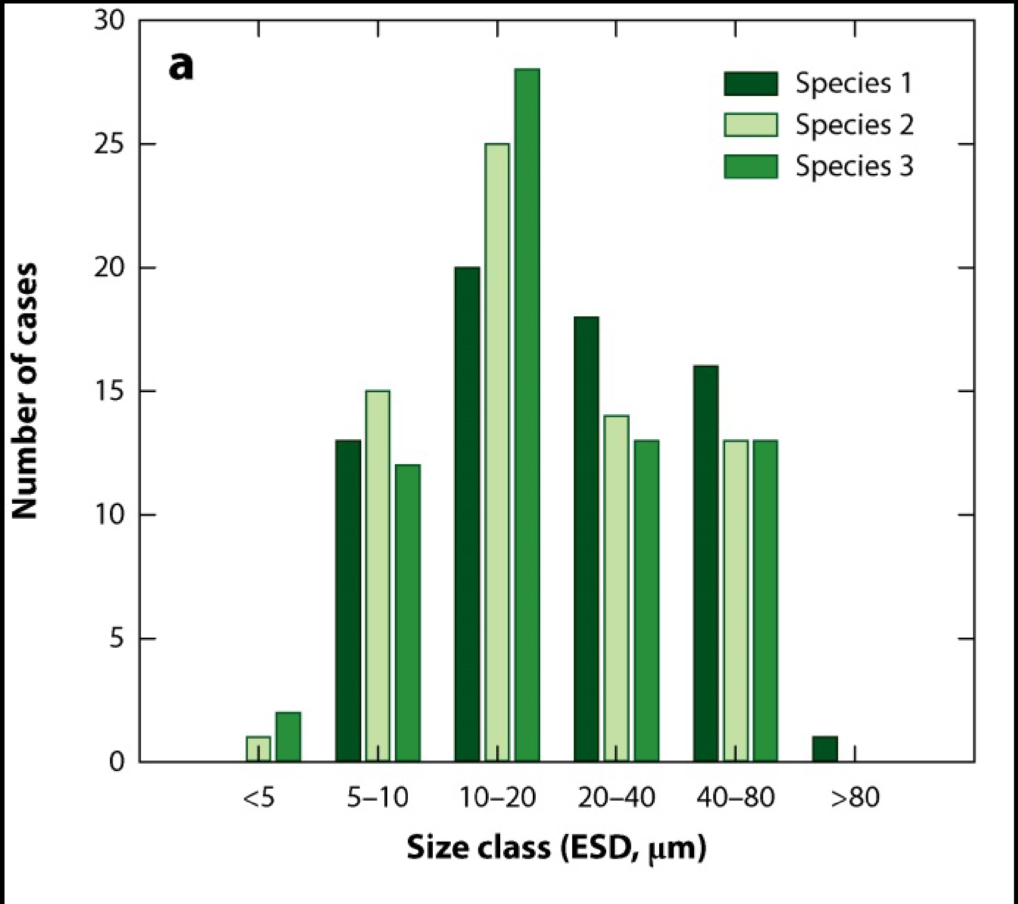
Marañón et al. 2013 Ecol Lett

Potential mechanisms underlying the size-scaling of phytoplankton metabolism and growth



Marañón E. 2015.
Annu. Rev. Mar. Sci. 7:241–64

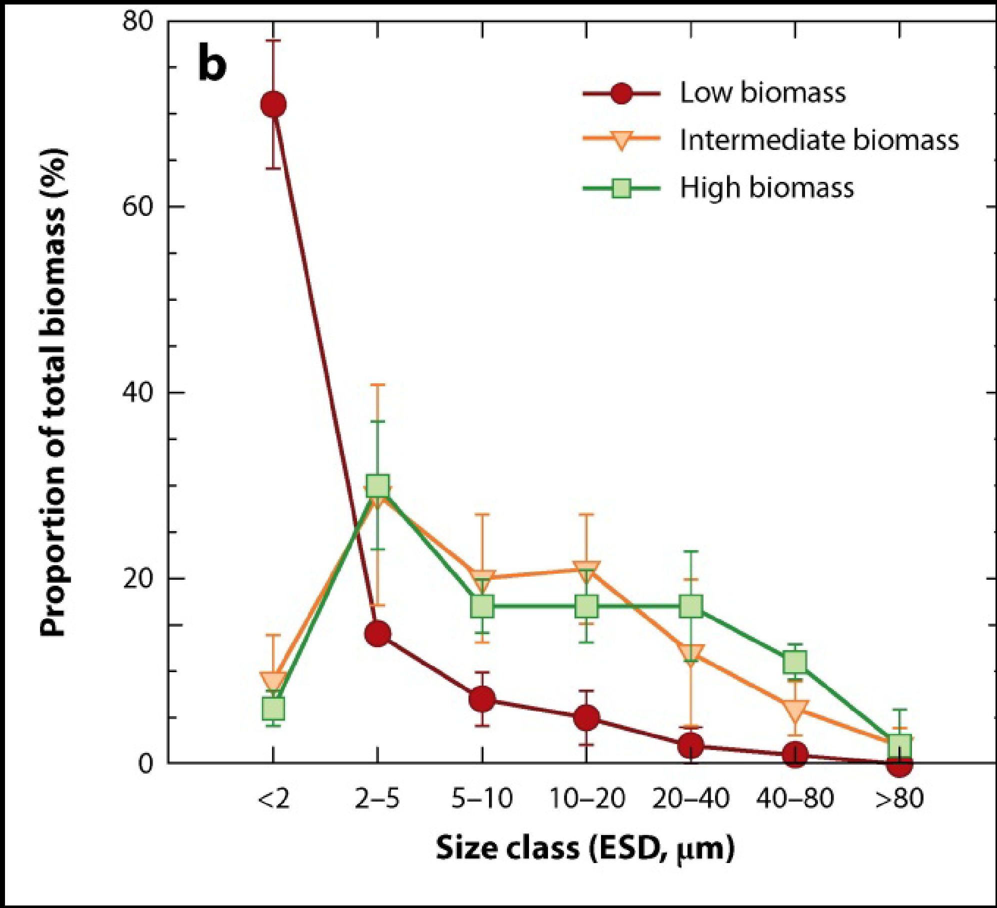
Links with natural patterns of size structure



70 bloom samples, species ranked according to their contribution to total biomass

Marañón 2015 Ann. Rev. Mar. Sci

Links with natural patterns of size structure



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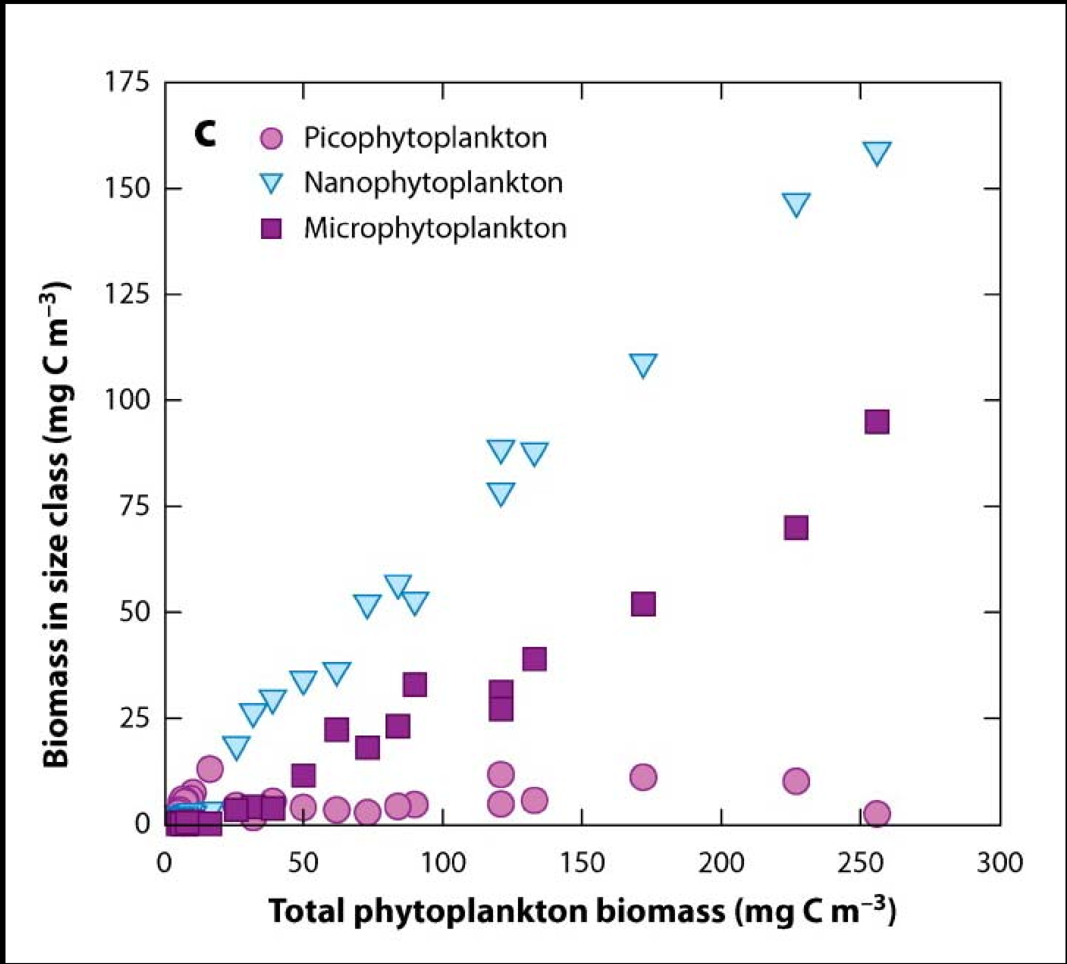

Marañón 2015 Ann. Rev. Mar. Sci

Main points

• Size-scaling of phytoplankton metabolism and growth is unimodal

• Unimodality results from trade-off processes between nutrient requirement, uptake and assimilation

• Intermediate-size species dominate natural blooms and biogeochemical cycling in the ocean

References

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