Size-scaling of phytoplankton abundance and metabolism: a review of recent field and laboratory studies

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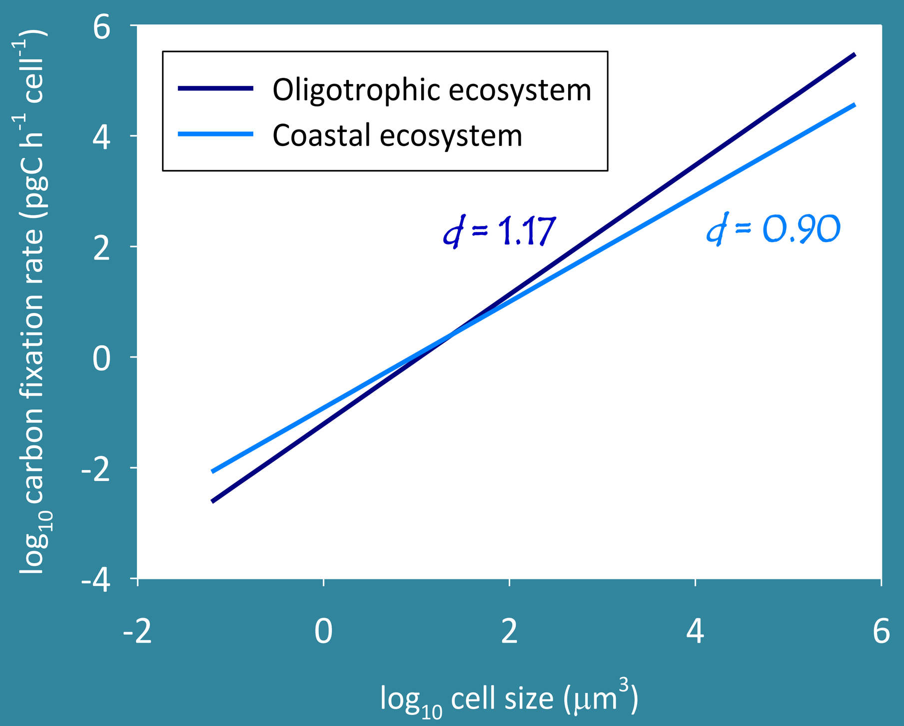
Introduction: The size structure of phytoplankton plays a key role in pelagic ecosystems, affecting the trophic organization of plankton communities and, hence, their functioning in the biogeochemical cycling of many elements, including nitrogen and carbon. Phytoplankton cell size spans over more than nine orders of magnitude in cell volume, and its taxonomic affiliation varies along the size spectrum from the smallest cyanobacteria to the largest diatoms. Cell size influences many aspects of the metabolism and ecology of phytoplankton, such as growth, metabolic rate, access to and use of resources, sedimentation rates and grazing pressure. Here we present a review of recent studies on the size-scaling of phytoplankton cell abundance and metabolism that is used to explain marine phytoplankton community structure in contrasting ecosystems.

Conclusion: Phytoplankton individual metabolic rates scale isometrically with cell size both in natural communities and cultures, consistently negating the applicability of the ¾ -power rule in autotrophic unicellular protists. Large cells are able to counterbalance the biophysical constraints imposed by their cell size thanks to, among other factors, their ability to increase nitrogen uptake rate faster than their requirements does, when nitrogen is not limiting. This trait makes large cells well-adapted to oceanographic settings where nutrient supply is intermittent, thus contributing to explain the size structure of phytoplankton communities in different ecosystems.

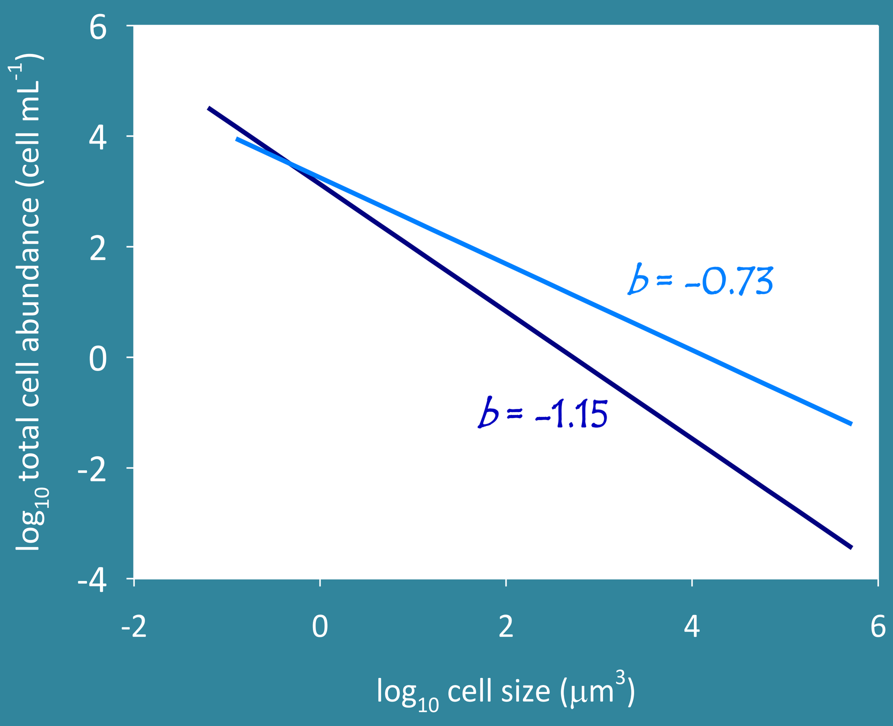
Patterns in the size-scaling of abundance and metabolism in natural phytoplankton communities

Natural phytoplankton communities of the subtropical and tropical Atlantic Ocean (oligotrophic , near steady-state ecosystem) and the NW Iberian Peninsula (coastal, enriched, dynamic ecosystem) were analysed by an ataxonomic approach (Huete-Ortega *et al.* 2012; Huete-Ortega *et al.* in prep.)

1. Size-scaling of carbon fixation rate



2. Size-scaling of total cell abundance

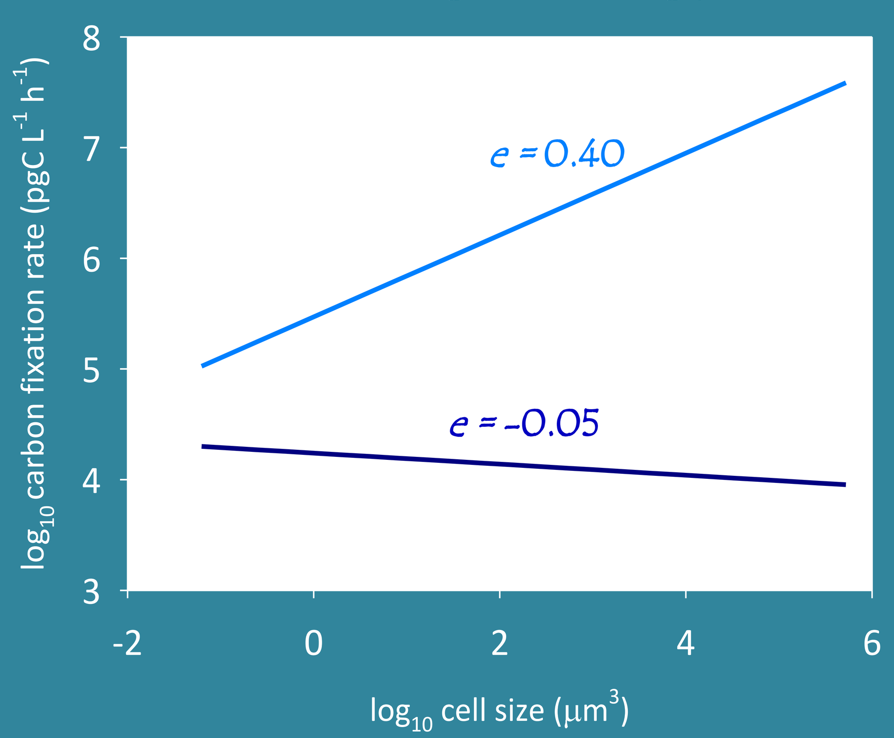


3. Size abundance distribution (N) can be predicted from the supply rate (R) of limiting resources and the individual rate of resource use (i.e. metabolic rate), (Q), so that $N = R/Q$ (Enquist et al. 1998). Being S body size, if $R \propto S^0$ and $Q \propto S^b$, then $N_{max} \propto S^{-b}$. Considering cell-specific carbon fixation rate as a proxy for Q we will have:

Reciprocal size-scaling of abundance (-1.15) and metabolic rate (1.17) for the Oligotrophic ecosystem.

Non-reciprocal size-scaling of abundance (-0.73) and metabolic rate (0.90) for the Coastal ecosystem.

4. Size-scaling of energy use

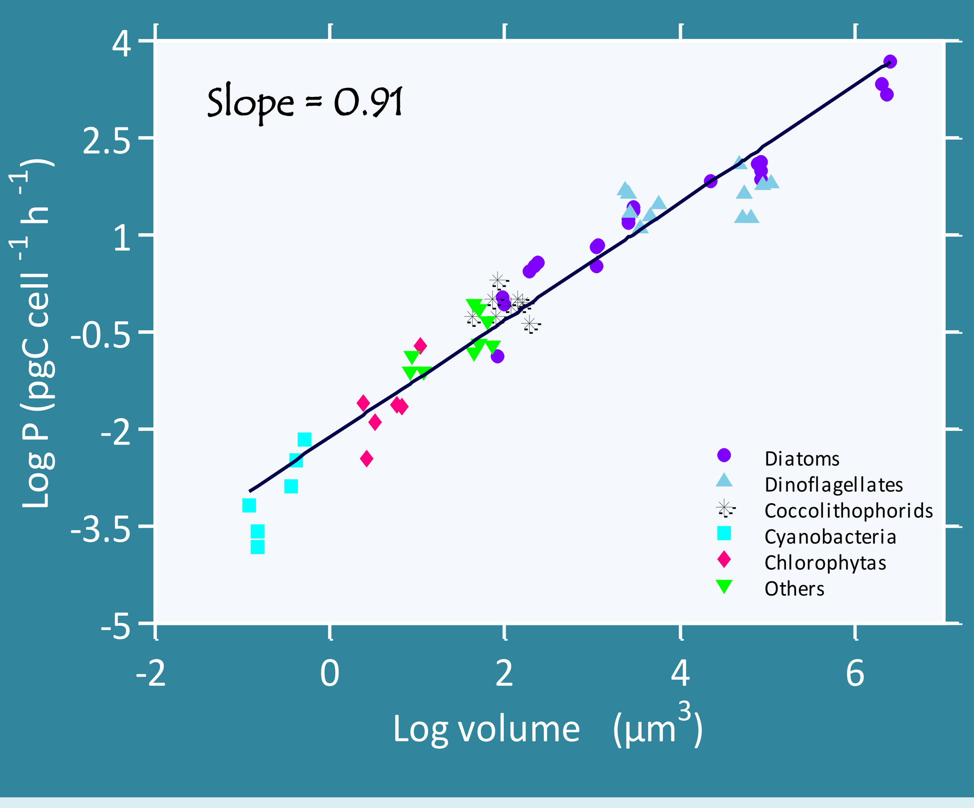


1. **Isometric size-scaling of individual carbon fixation rate in both oligotrophic and coastal ecosystems: biomass-specific photosynthesis rates of marine phytoplankton are largely independent on cell size over a broad oceanic scale.**
2. **Less steep slope values for the size-scaling of phytoplankton abundance in the coastal, dynamic ecosystem: shift towards larger cells with increasing PP.**
3. **Conversely to coastal, dynamic ecosystems, in near steady-state ecosystems, the size-scaling of abundance reflects the size-scaling of metabolic rate: role of the rate of resource supply.**
4. **The total use of energy significantly increases with cell size along the size spectrum in coastal, dynamic ecosystems, whereas it is cell-independent in the oligotrophic ones.**

Size-scaling of phytoplankton metabolism and the rate of nitrogen uptake in marine phytoplankton cultures

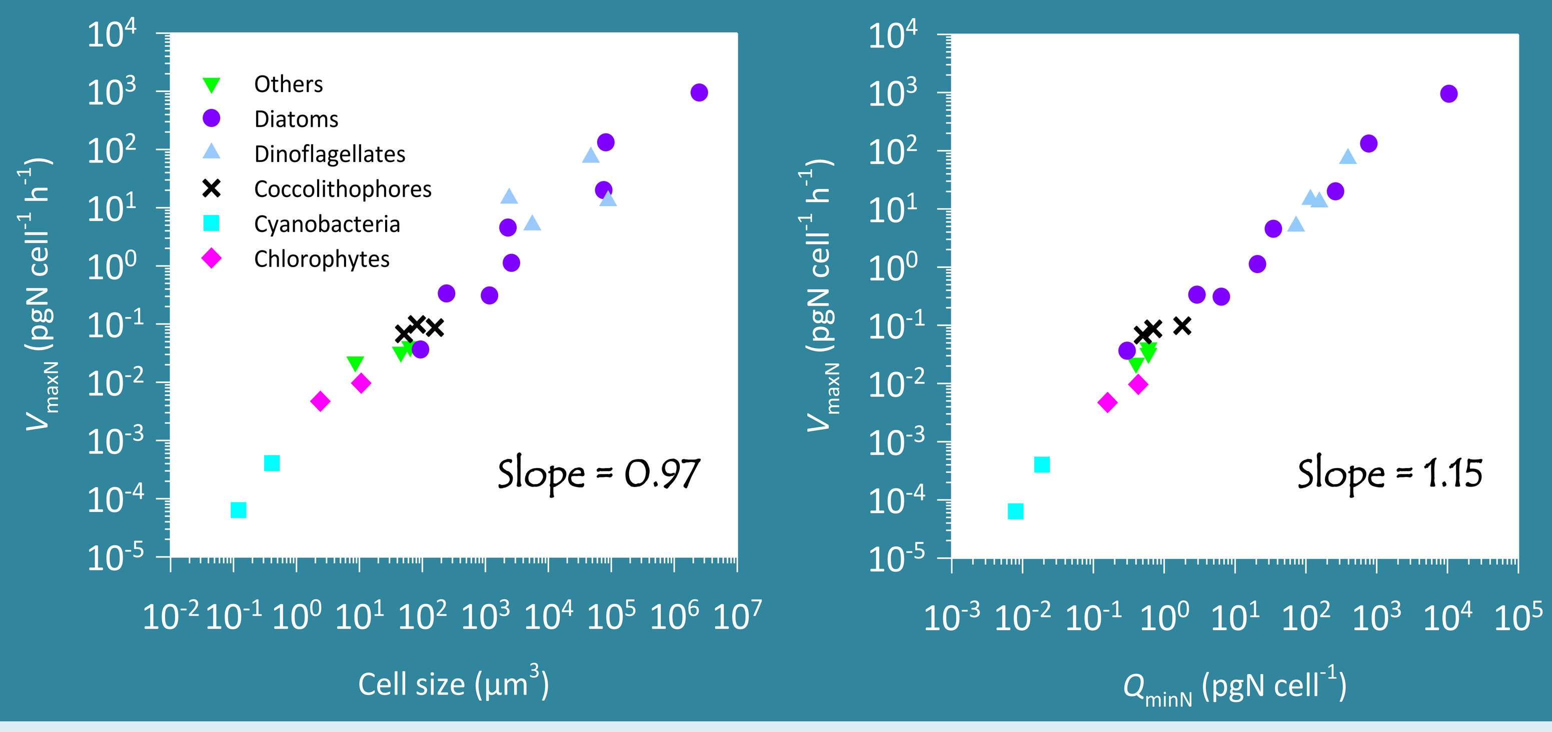
Rates of carbon fixation, respiration, exudation and maximum nutrient uptake rates and nutrient minimum quota were determined in batch cultures of 22 phytoplankton species from five phyla and covering a range of 7 orders of magnitude in cell volume at exponential growth and stationary phases, always following the same protocol and growing conditions (López-Sandoval *et al.* 2013; Marañón *et al.* 2013; López-Sandoval *et al.* Submitted).

5. Size-scaling of carbon fixation rate



5. **Isometric size-scaling of individual metabolic rates (carbon fixation, respiration and exudation) in all growth phases.**

6. Size-scaling of nitrogen uptake rate



6.1. **Maximum nitrogen uptake rate (V_{maxN}) scales isometrically with cell volume, implying that the rate of nutrient uptake per unit of cell surface area increases with cell size.**

6.2. **Minimum nitrogen quota (Q_{minN}) scales allometrically with V_{maxN} : as cell size increases, the ability of phytoplankton to uptake nitrogen increases faster than their minimum nitrogen requirements does.**

References:

1. Enquist B. J. et al. 1998. Nature 395: 163-165.
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4. Marañón E. et al. 2013. Ecol. Let. 16: 371-379.

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