Constructing a size-structured plankton model for CESM

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NCAR Climate and Global Dynamics

OMWG / BGC Working Group Meeting, Jan 12, 2018

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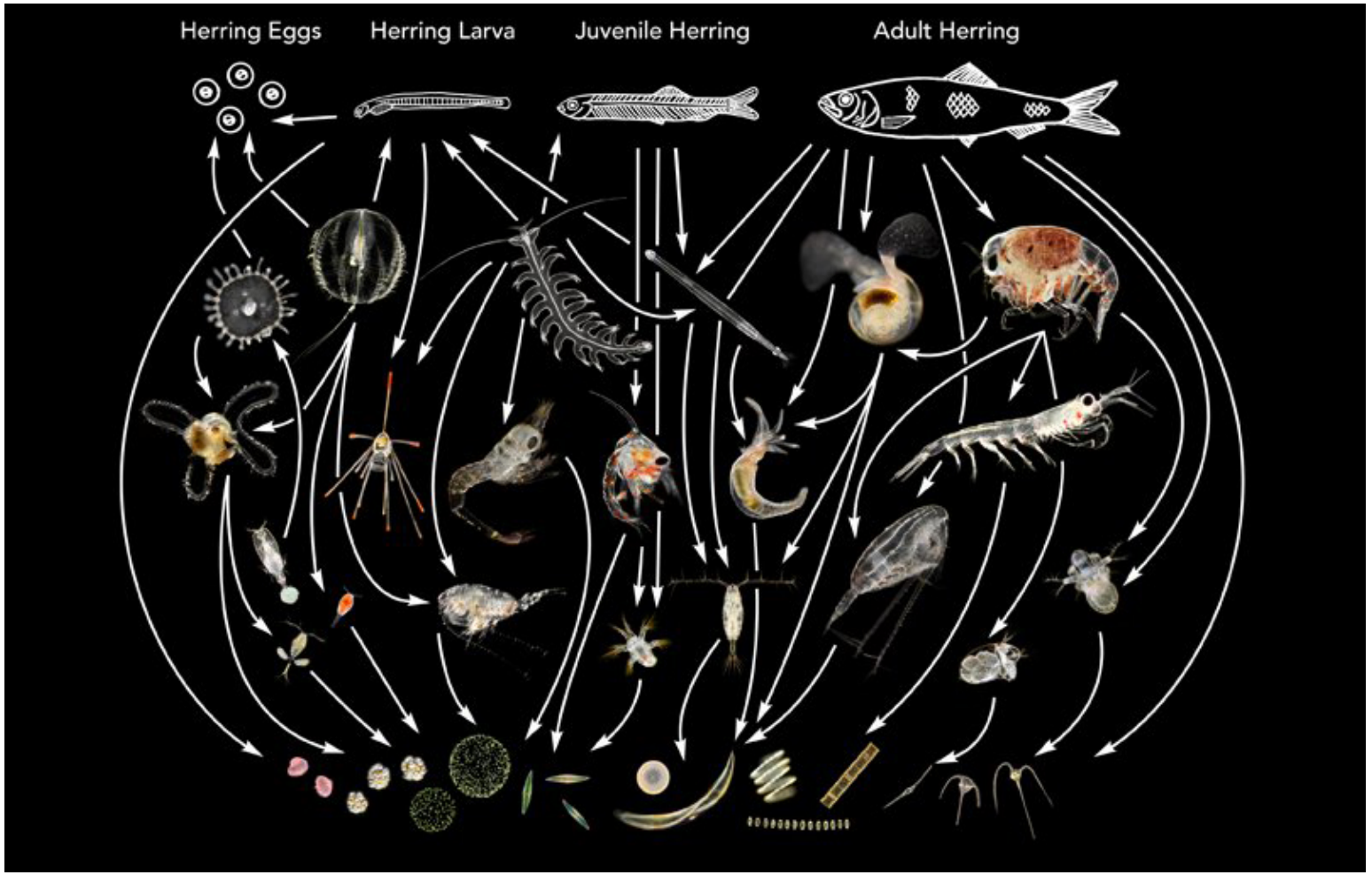
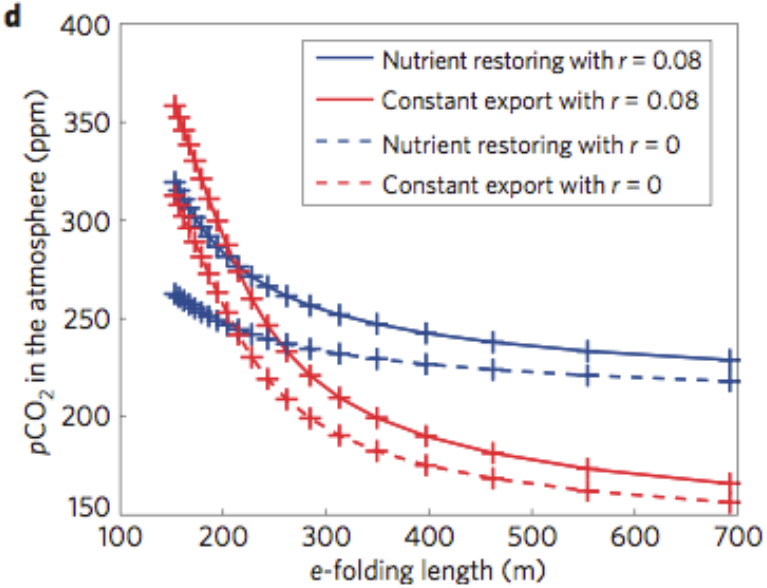
Challenge: predicting climate change impacts on marine foodwebs & biological climate-carbon feedbacks



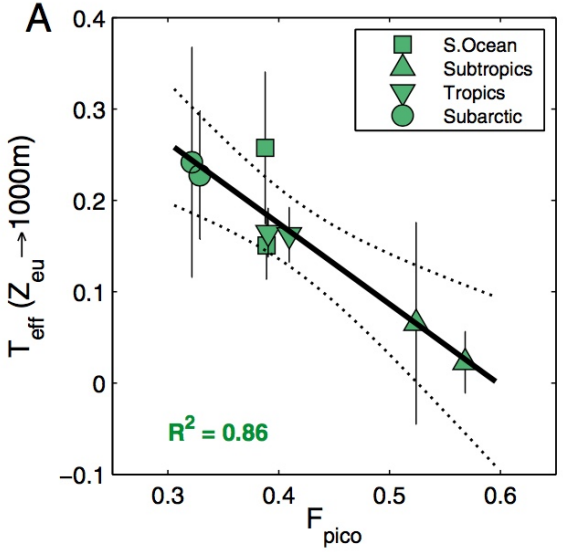
POC export and transfer efficiency

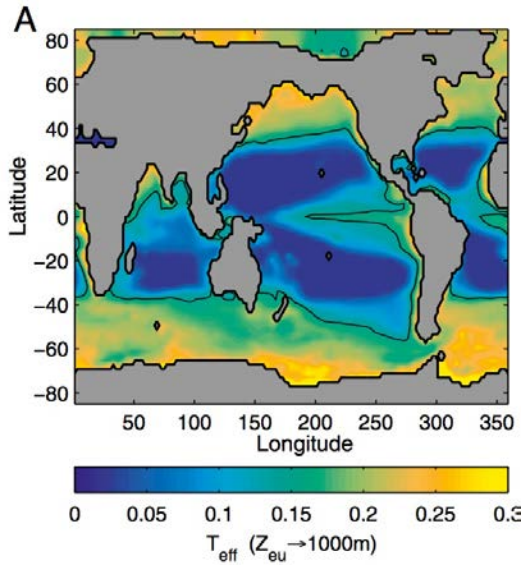


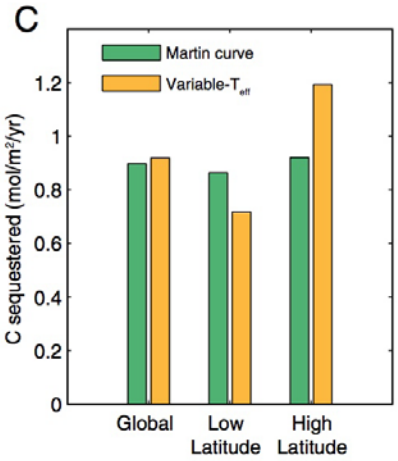
Kwon et al. 2009

e-folding depth: depth by which 63% of organic matter exported from the euphotic layer has become remineralized

e.g.: changes in the *e*-folding depth from 204 to 228 m decreases $pCO_{2(atm)}$ by 10-27 ppm



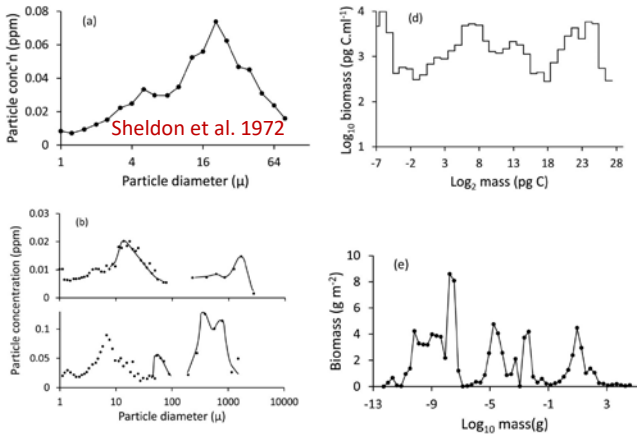




Weber et al. 2016

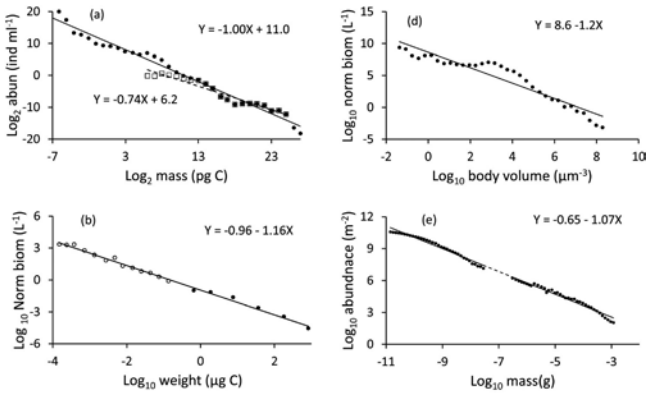
Size as a ‘master trait’ for marine organisms

Biomass spectra

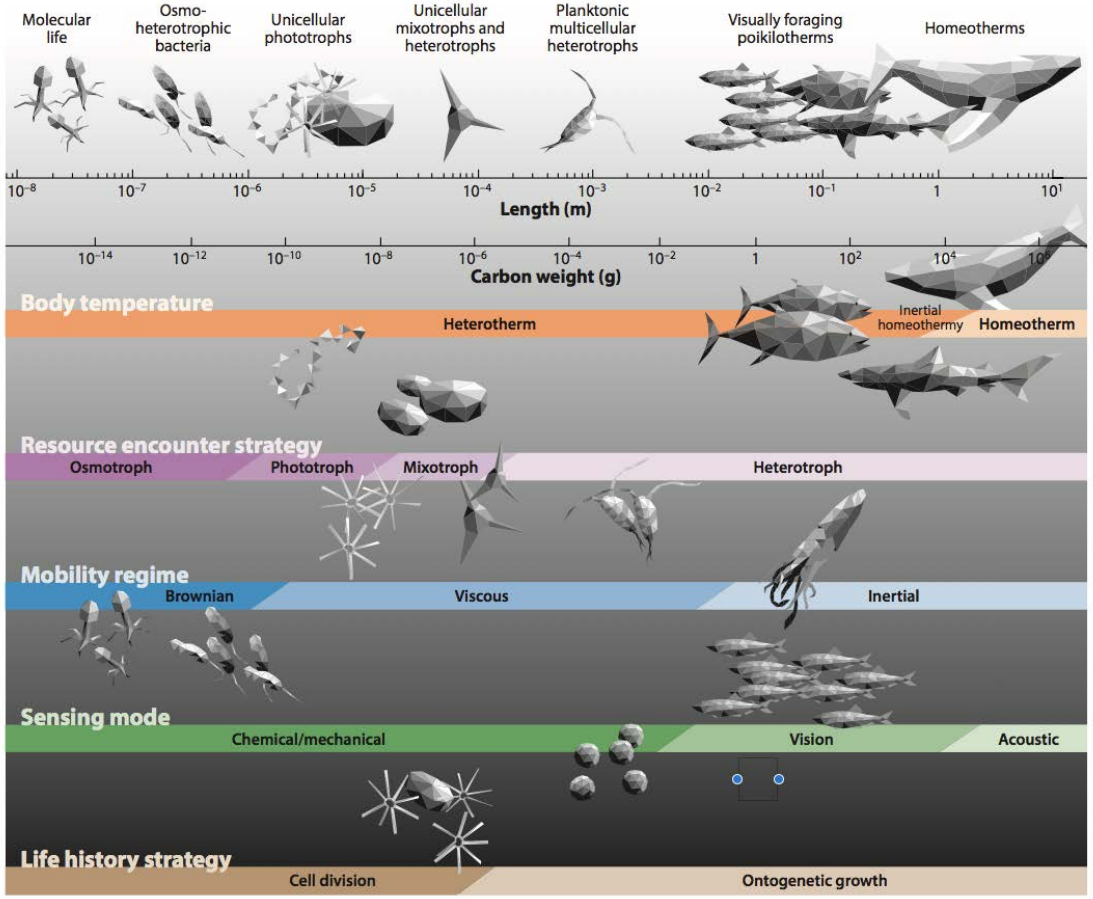


Sheldon et al. 1972

Normalized biomass spectra



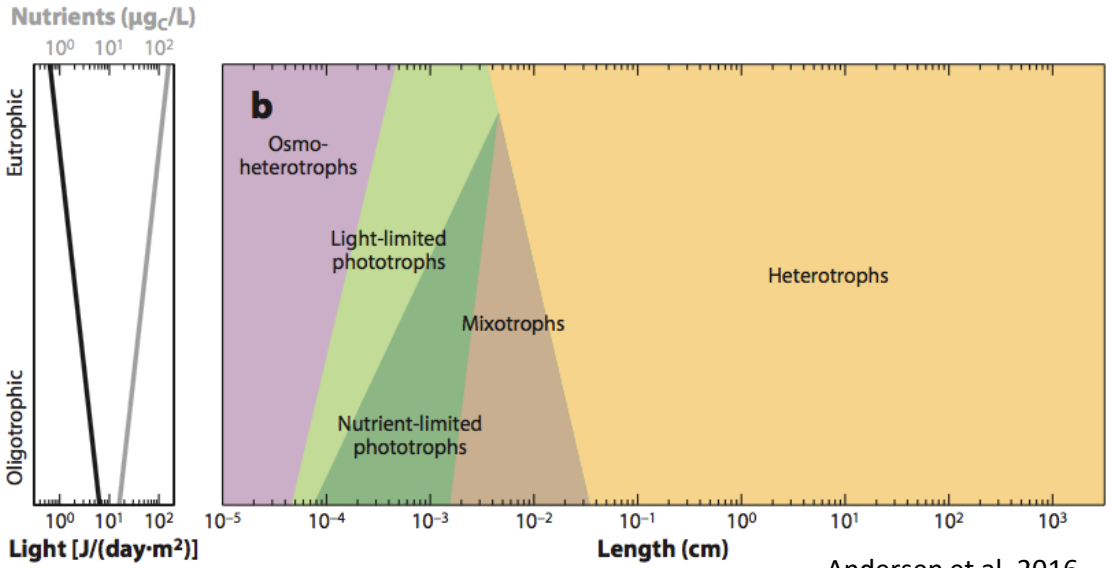
Sprules and Barth 2016



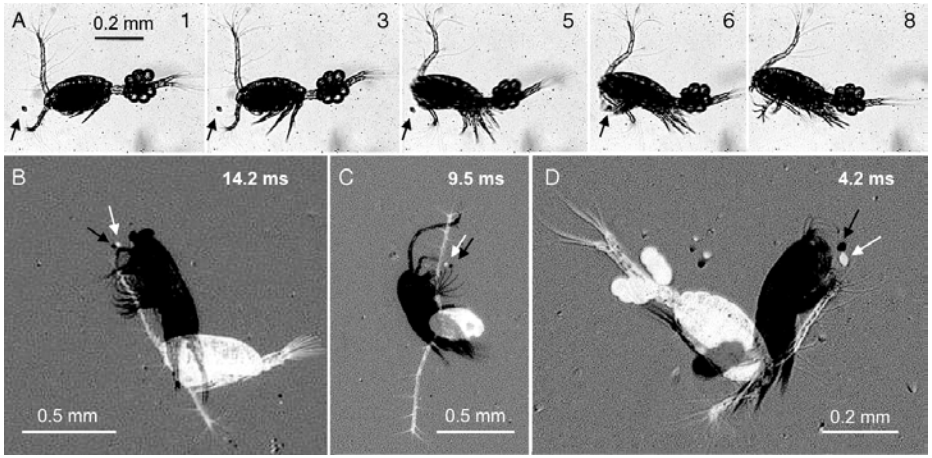
Andersen et al. 2016

Using power-law functions, organism size can describe: metabolism, population growth rates, light affinity, diffusive uptake affinities & rates, predator-prey size ratios, predator-prey functional responses, swimming speed, mortality rates

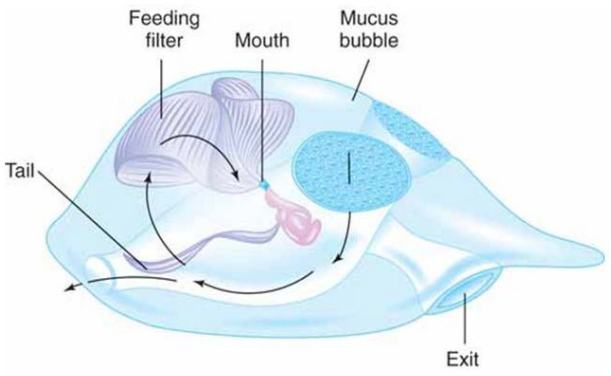
Beyond the size trait: predation strategy



Andersen et al. 2016

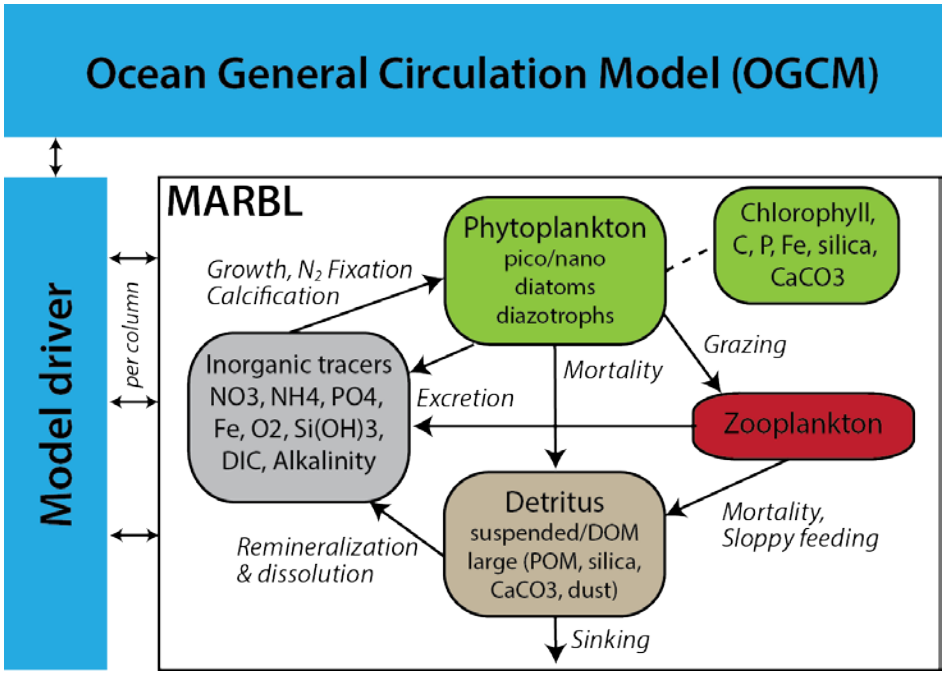


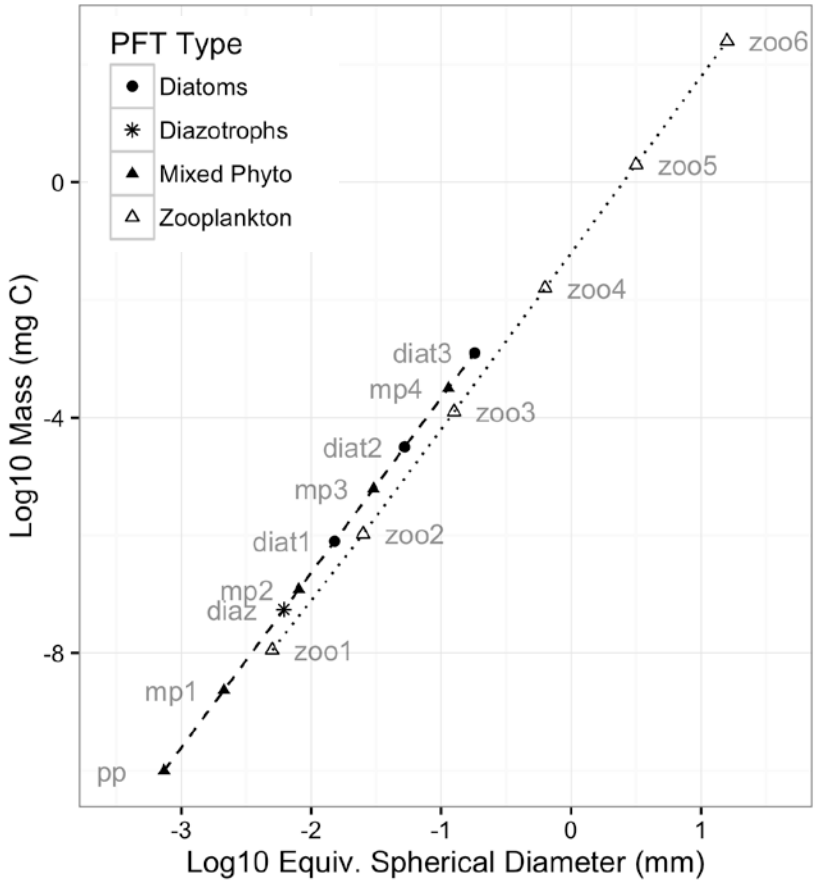
Kiorboe et al. 2009



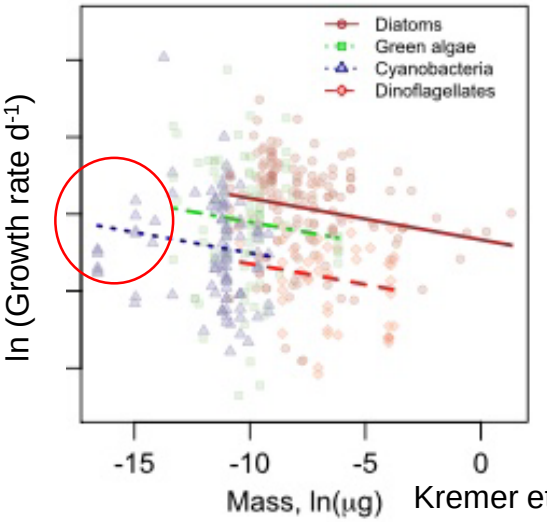
Selective filter feeding pelagic tunicate

Model construction (1) - MARBL

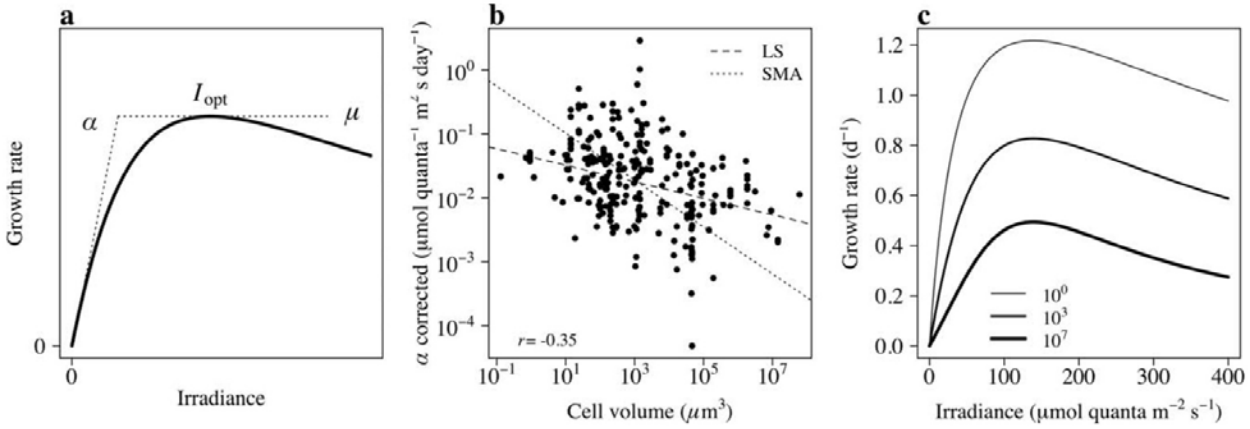




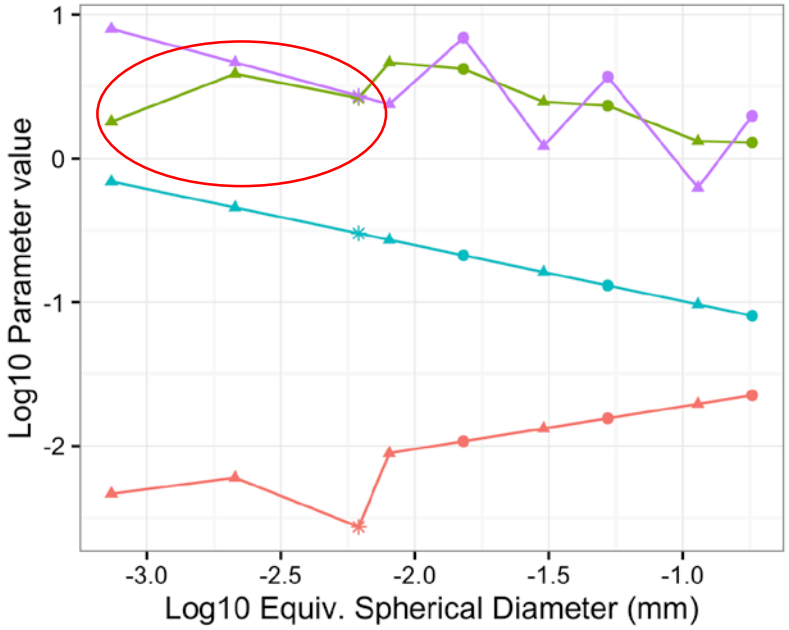
Model construction (2) – Growth



Kremer et al. 2017



Edwards et al. 2015



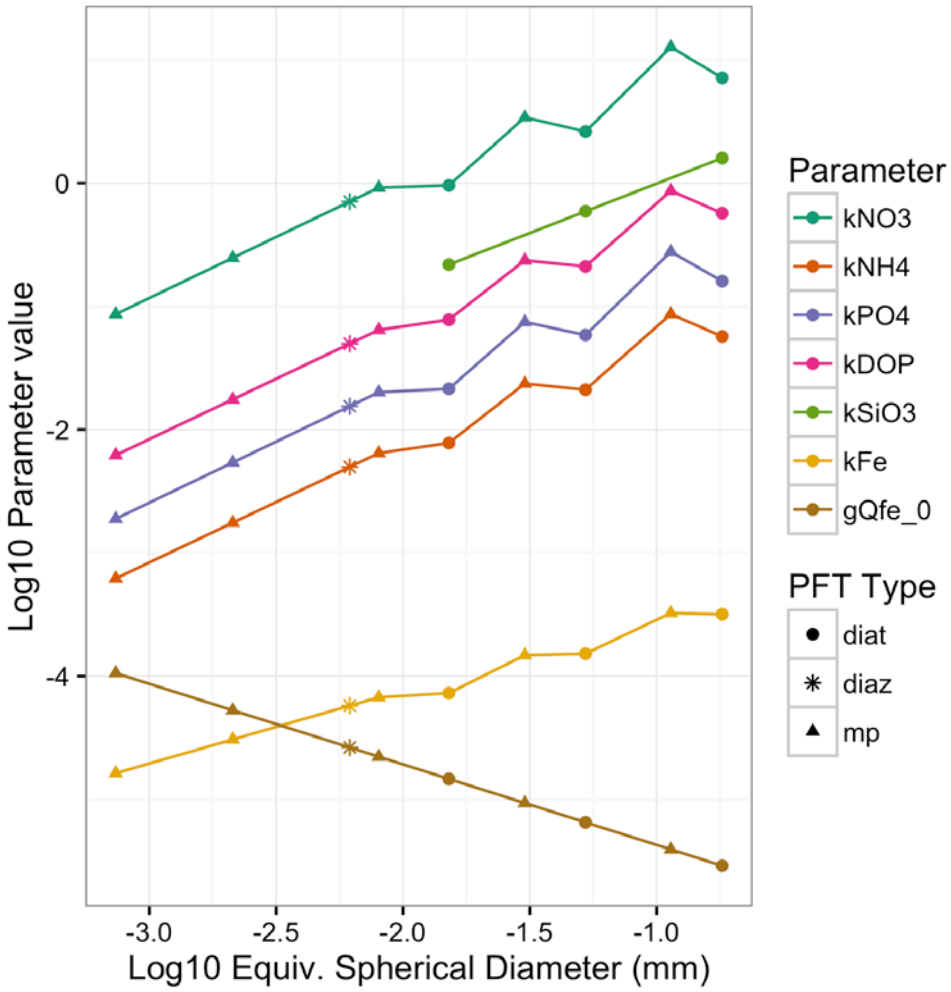
PCref: Maximum photosynthesis rate

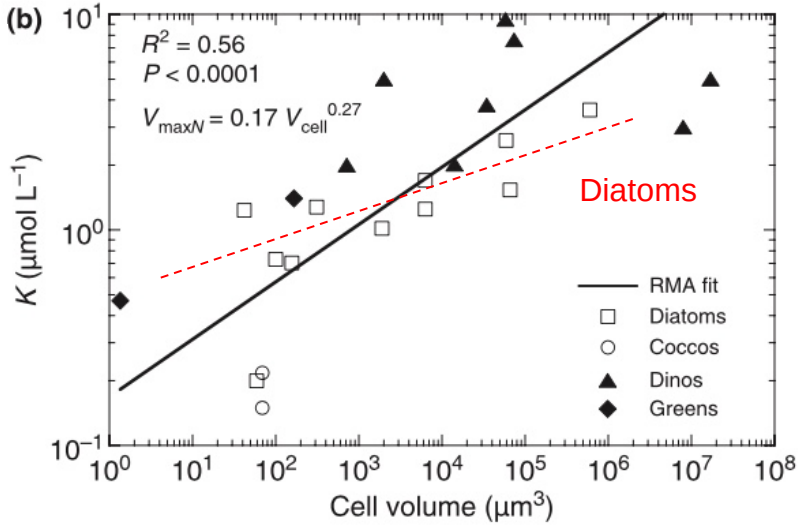
alphaPI: initial slope of photosynthesis-irradiance curve (performance under low-light)

thetaN: Chlorophyll to cellular nitrogen ratio

Qp_fixed: Phosphorus to carbon ratio

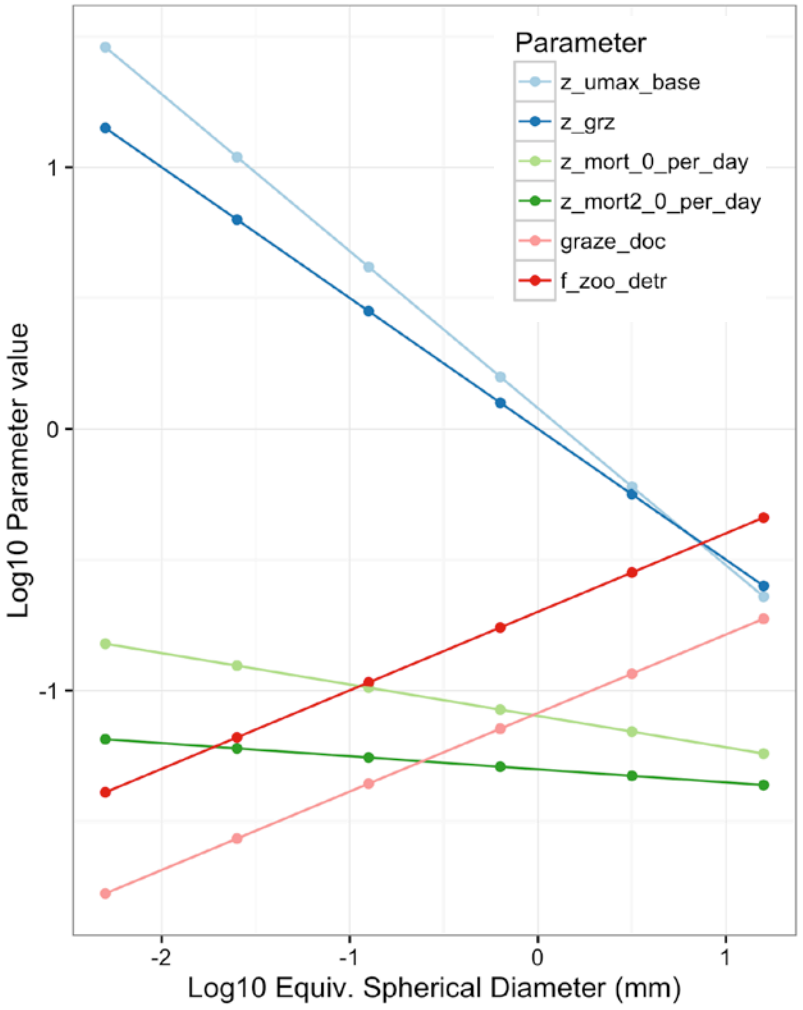
Model construction (3) – Nutrient uptake

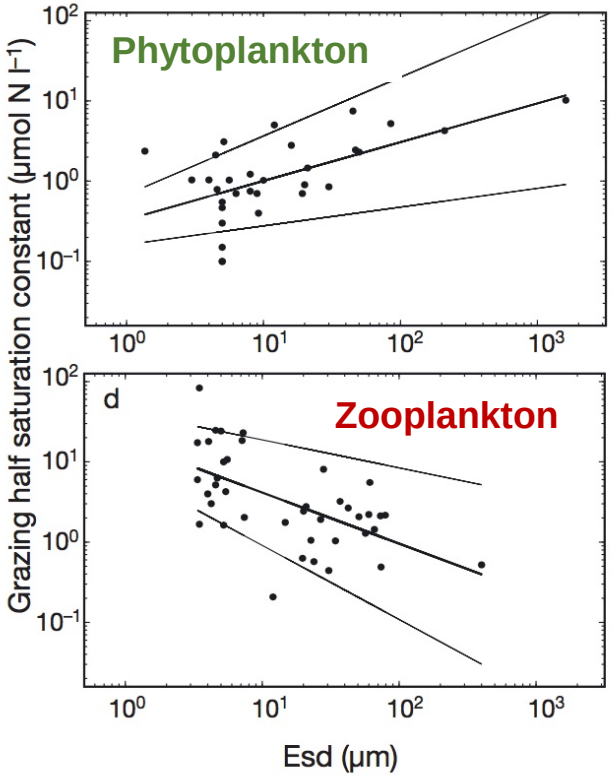




Litchman et al. 2007

Model construction (4) - Zooplankton

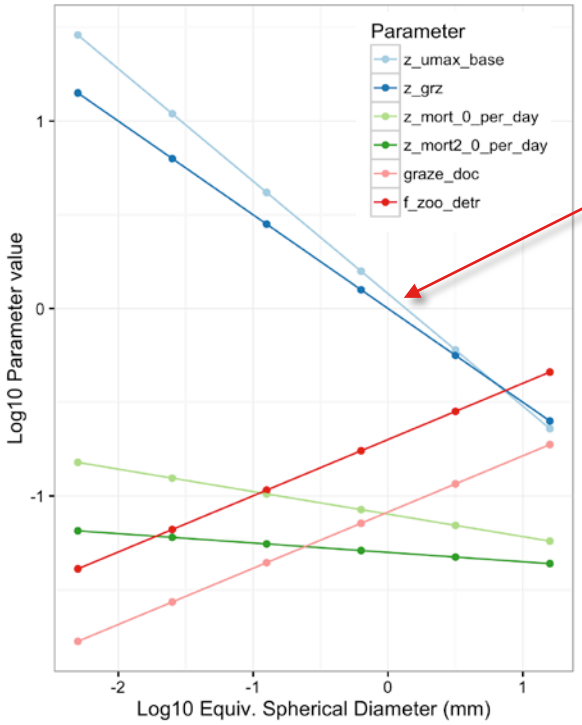




Taniguchi et al. 2014

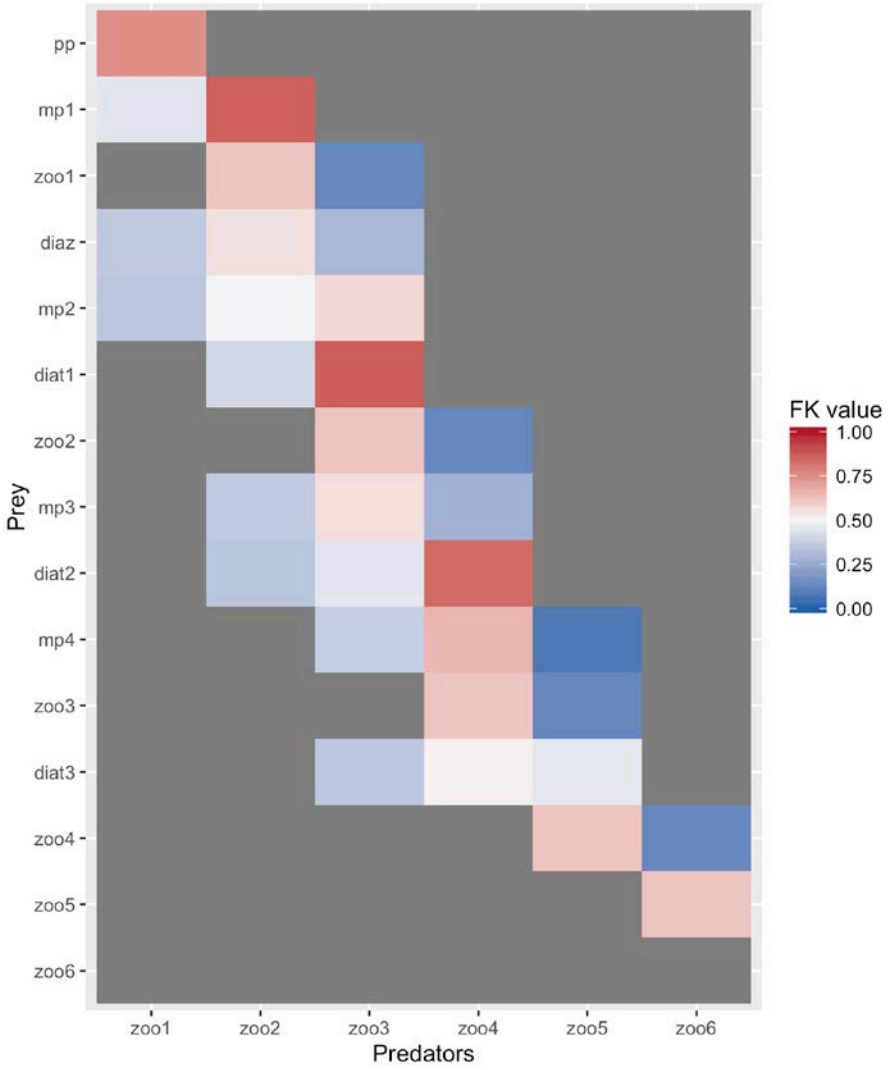
Z_umax_base: Maximum grazing rate (base)
Z_grz: Grazing half-saturation constant
Z_mort: Linear mortality
Z_mort2: Quadratic mortality
graze_doc: Amount of grazing C to DOC (equiv. to zooplankton respiration rate)
f_zoo_detr: fraction of zoo losses to detritus

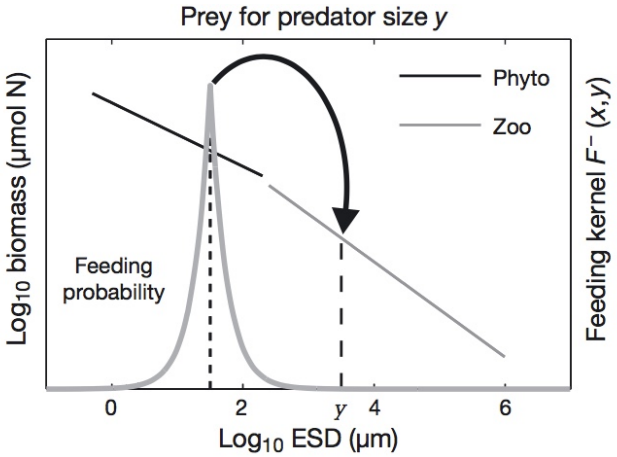
Model construction (5) – Feeding Kernel



FK value modifies Z_umax_base value

Predator-Prey "Feeding Kernel" value

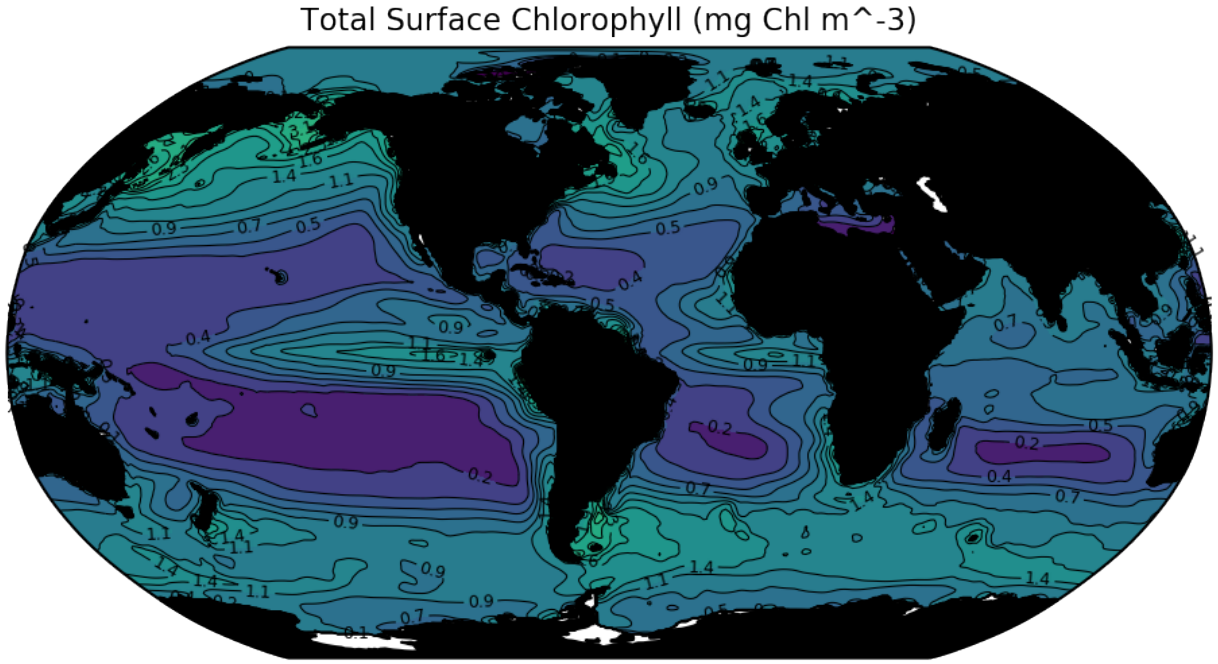


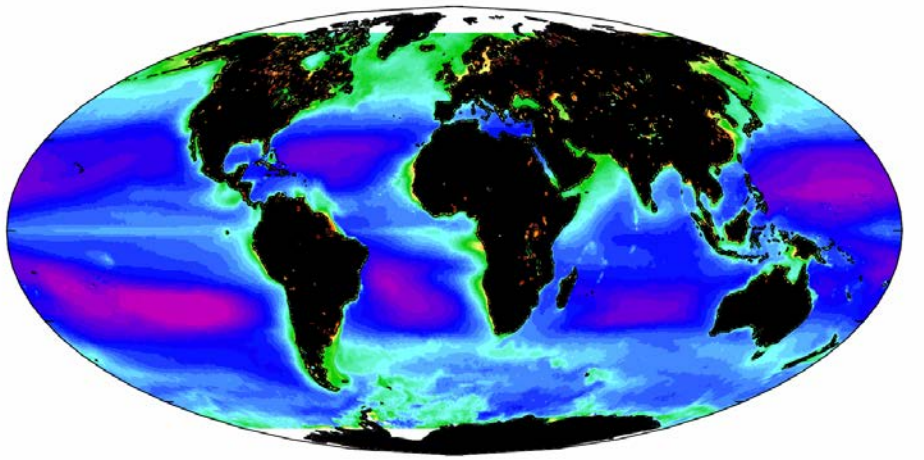


Fuchs and Franks 2010

Model results - total chlorophyll

NPP:
60.8 Pg C y^{-1}



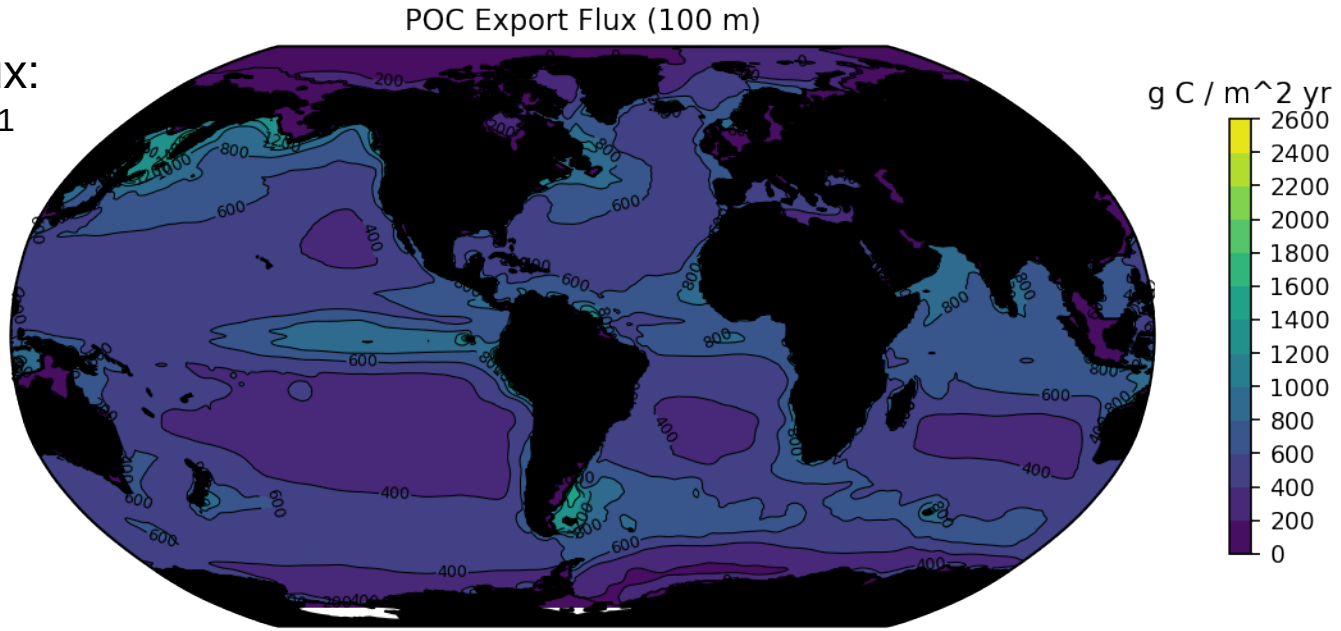


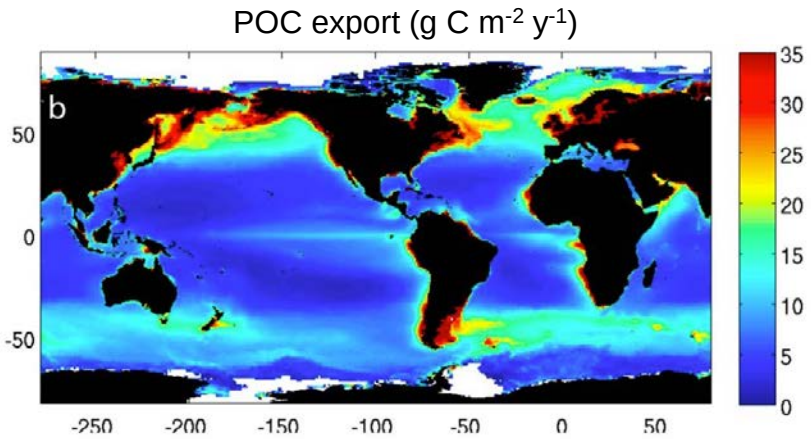
SeaWiFS Average sea-surface chlorophyll, 1998 to 2006 [mg chl m^{-3}]

0.03 0.1 0.3 1 3 10 30

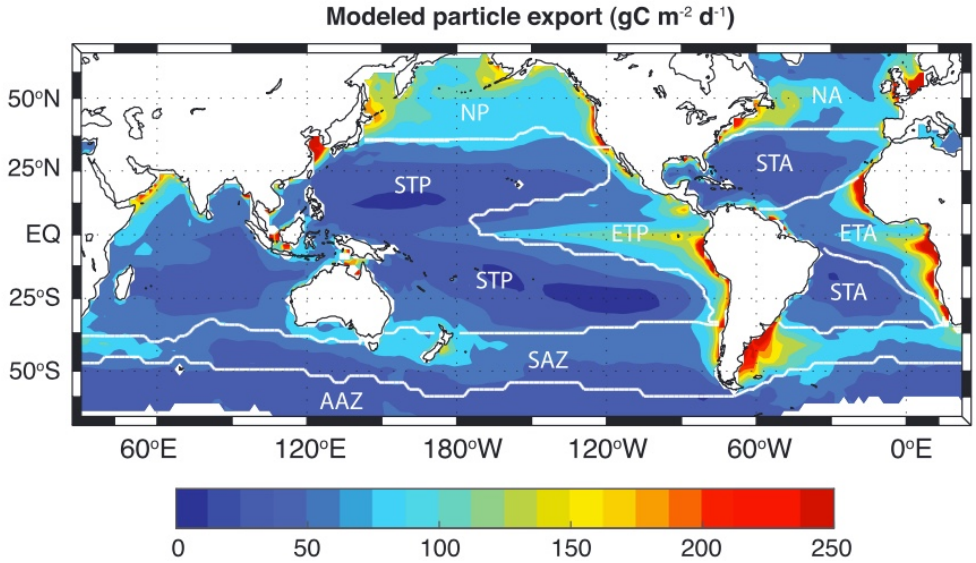
Model results – Export flux

Export Flux:
4.69 Pg y^{-1}



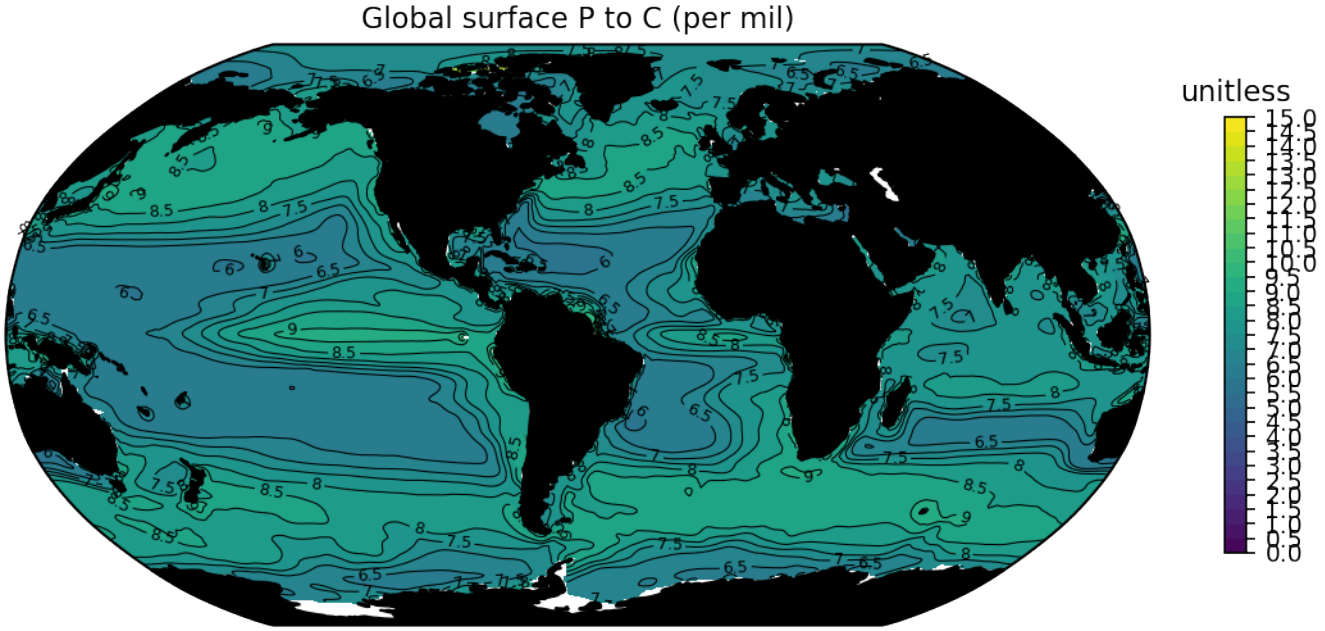


Henson et al. 2011

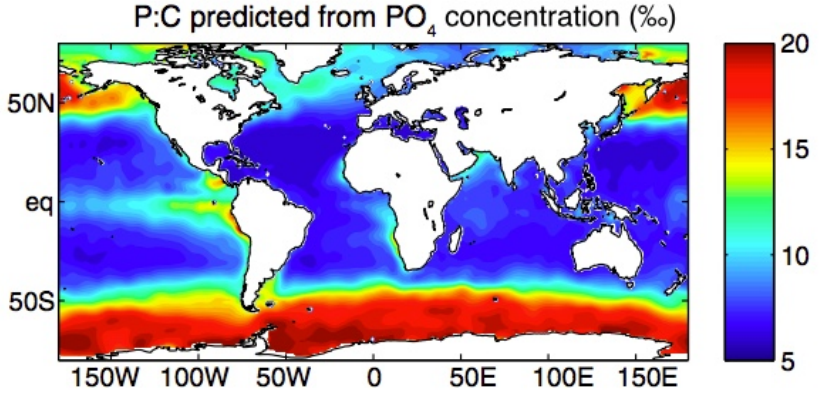


DeVries and Weber 2017 GBC

Model results – Stoichiometry

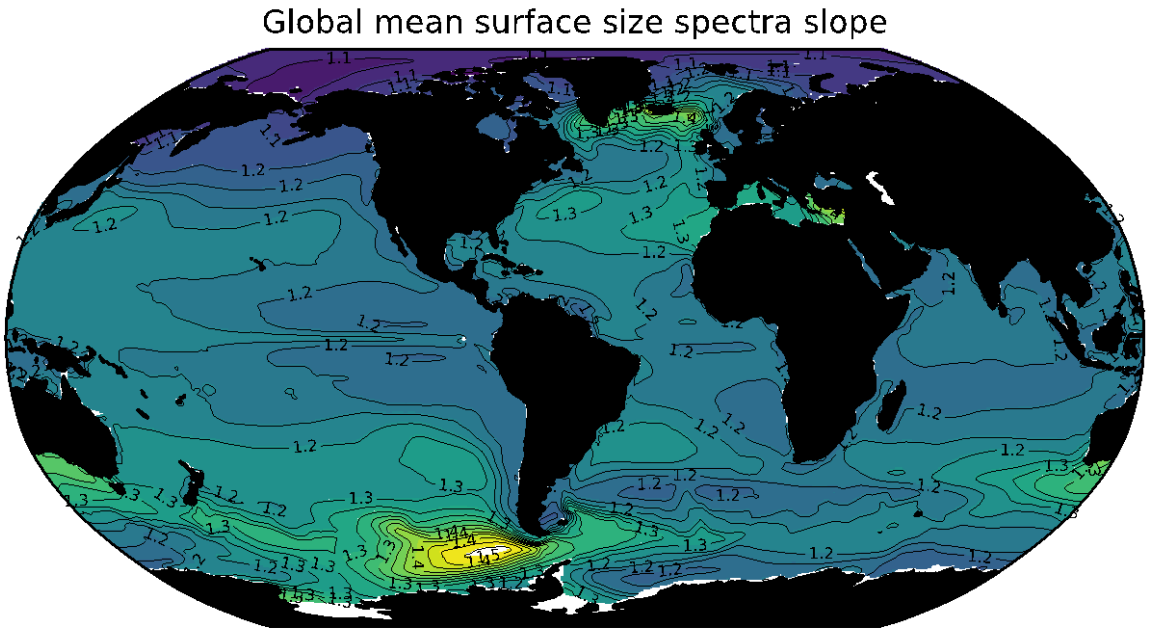


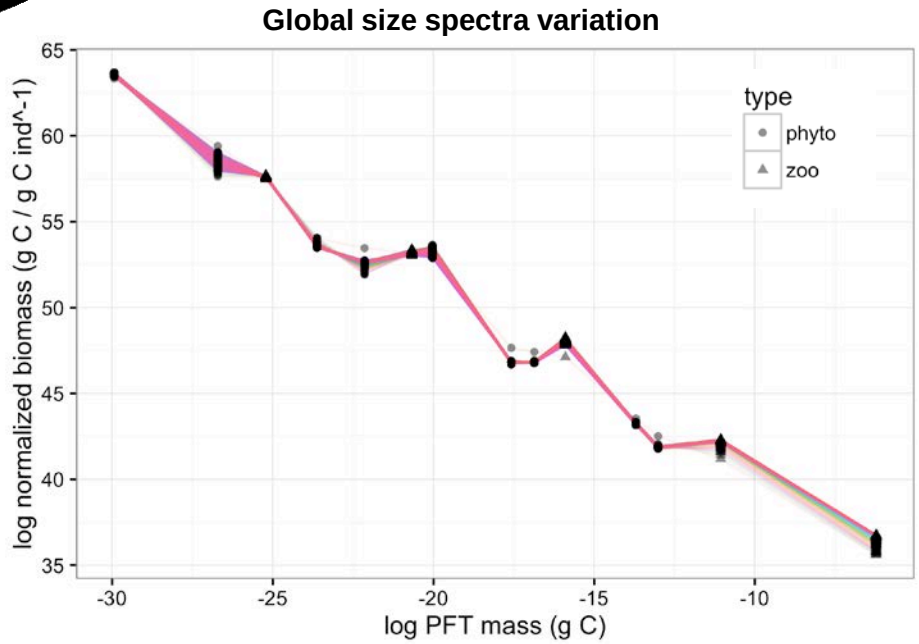
Mean P:C (per mil) = 7.5



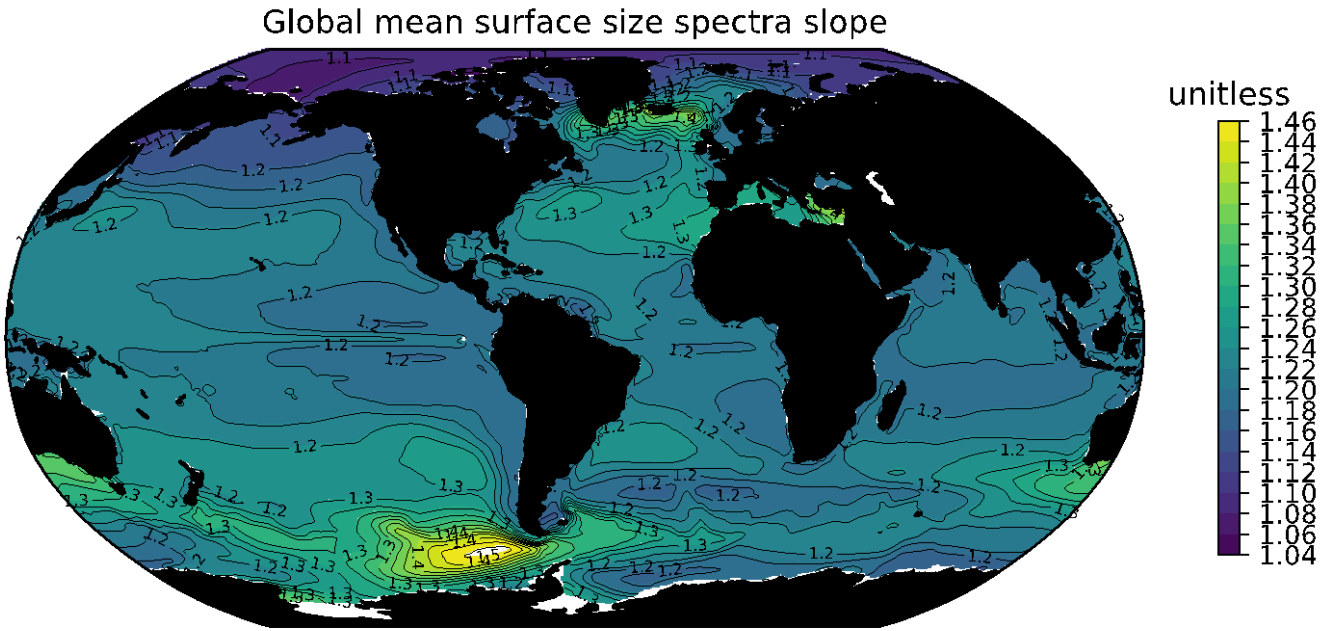
Galbraith and Martiny 2015

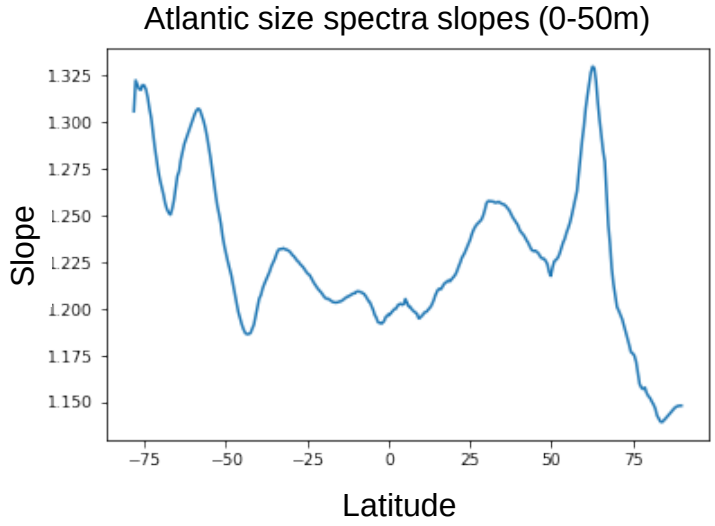
Plankton size spectra

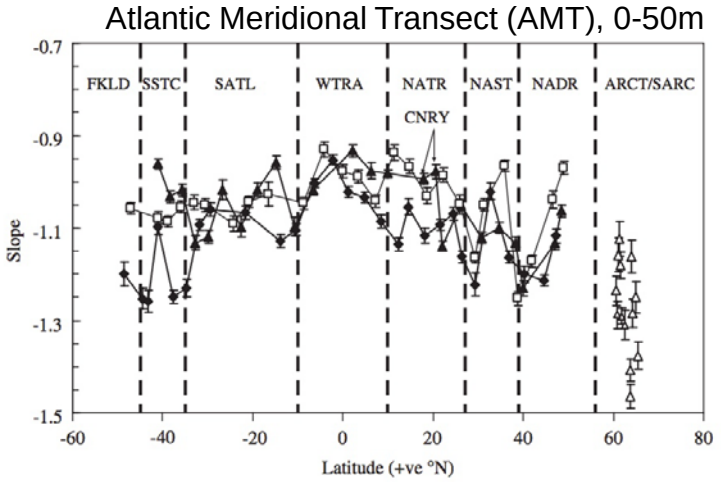




Plankton size spectra



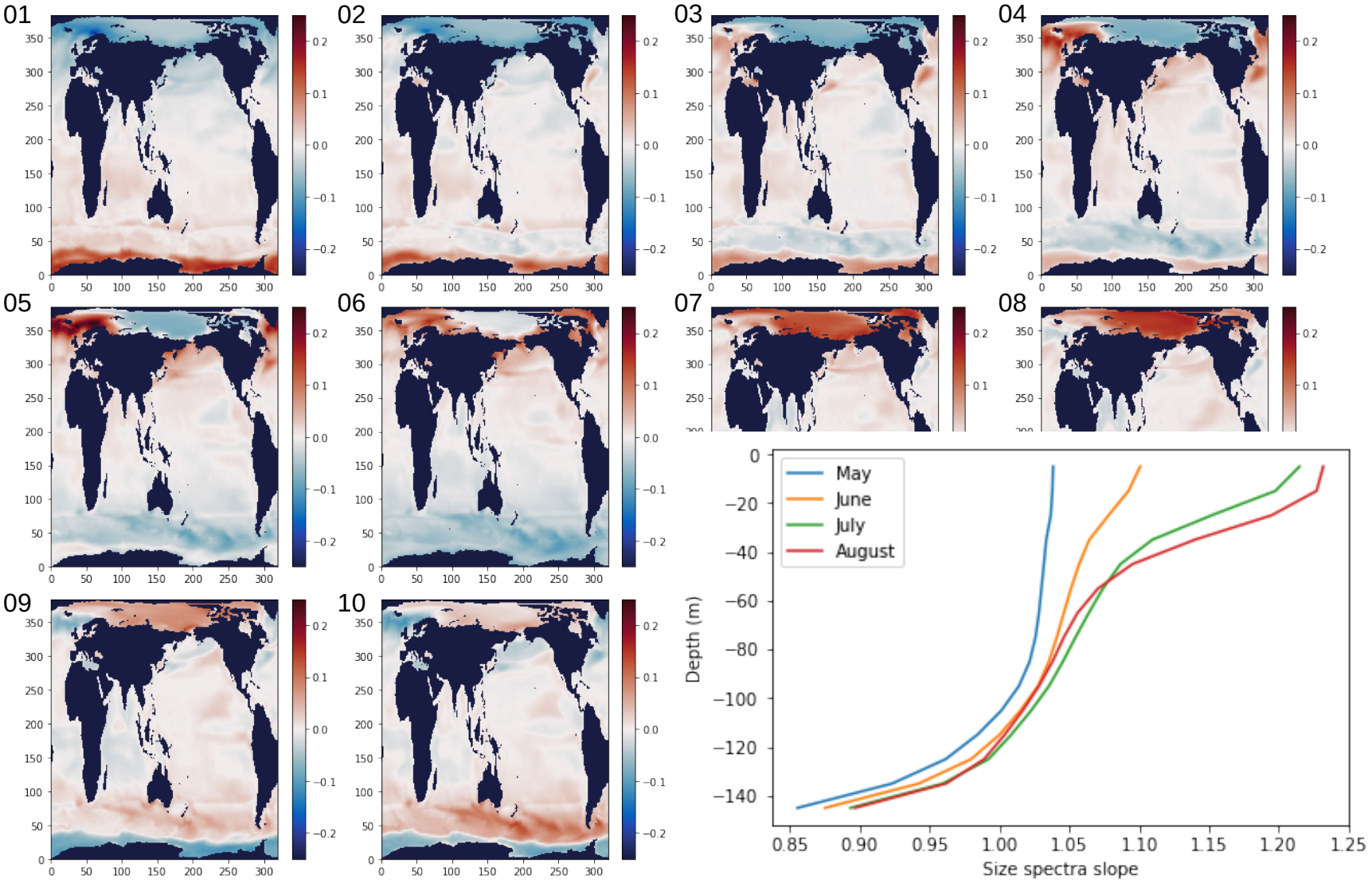




NB: opposite sign convention

San Martin et al. 2006

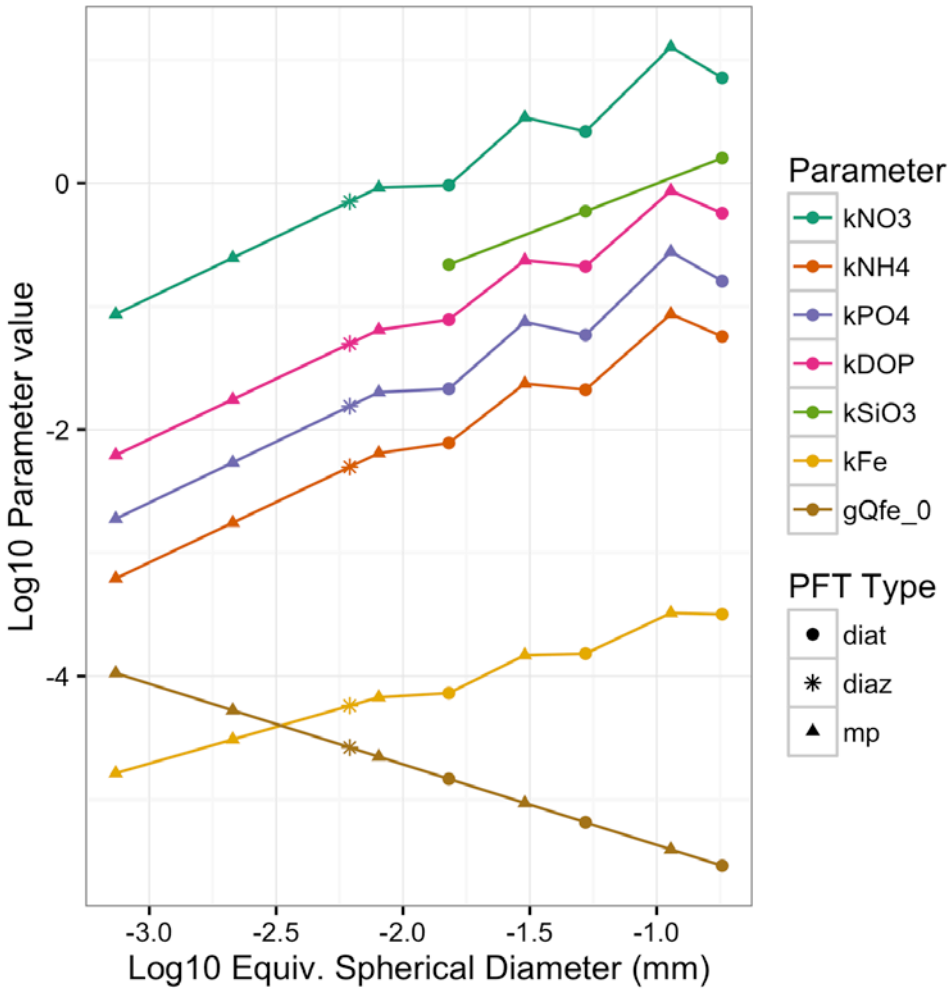
Size spectra seasonal cycle (anomaly plot)

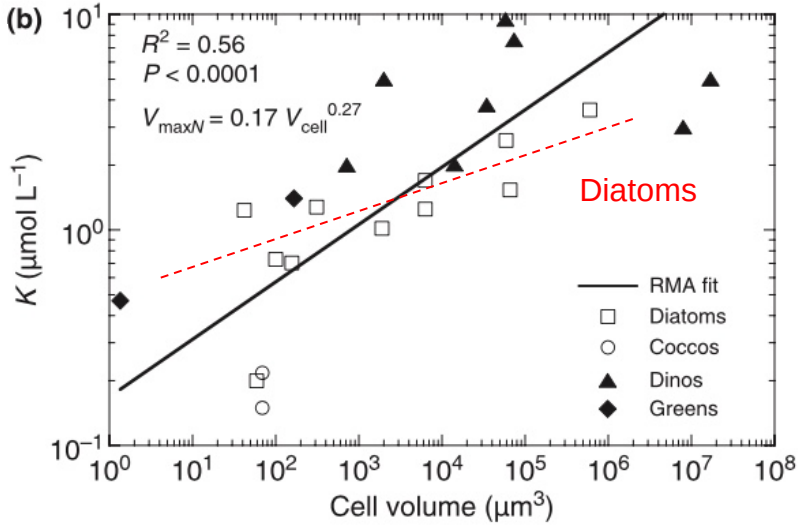


Summary

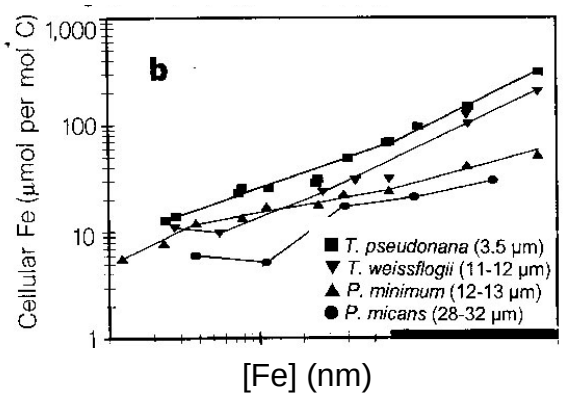
- **A size-structured plankton model is a parsimonious method of adding ecosystem complexity**
  - Allometric relationships are key
  - Useful for studying plankton food-web dynamics
  - Enables future integration with size-resolved detritus groups
- **The plankton size-axis is separate from plankton biogeochemical function**
  - E.g. Diatoms have different nutrient acquisition needs
  - Key exceptions also apply: Low picoplankton growth rates are essential for reducing small-celled dominance at high latitudes
- **Zooplankton feeding kernels can be used to generalize grazing relationships**
  - With discrete size-classes, grazer sizes must be carefully chosen
- **Plankton size-spectra dynamics are an emergent feature of the system**
- **Many outstanding issues still:**
  - Low global POC production
  - Nutrient drift
  - Large zooplankton biomass declines over time
  - No zooplankton size growth

Model construction (3) – Nutrient uptake





Litchman et al. 2007



Sunda and Huntsman 1997