Understanding and predicting the regulation of ocean C:N:P and export production

Adam C. Martiny

University of California, Irvine

Acknowledgement

UCI: Greg Britten, Catherine Garcia, Nathan Garcia, Alyse Larkin, Jenna Lee, Keith Moore, Allison Moreno, Francois Primeau, Weilei Wang

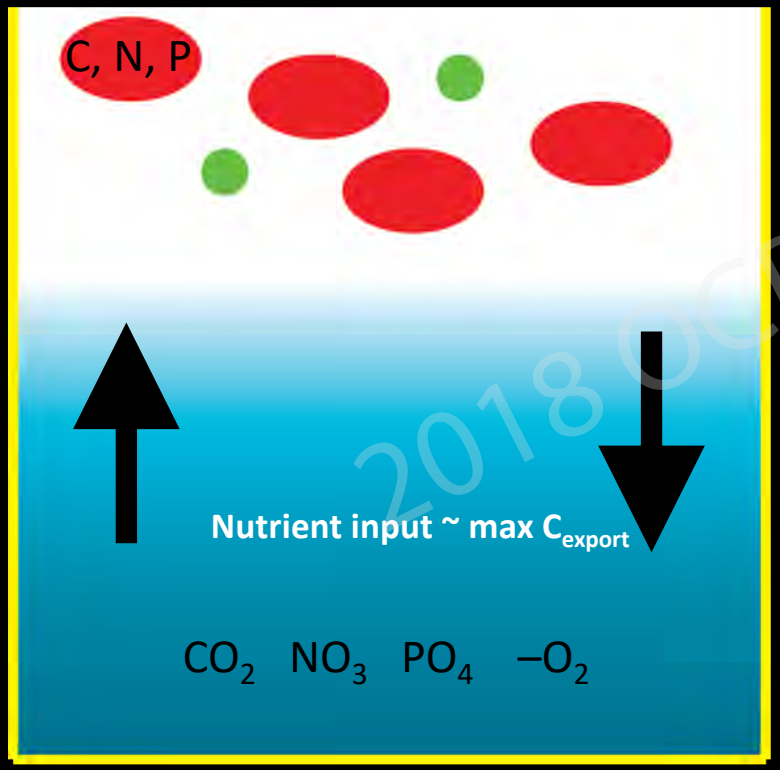
Princeton: George Hagstrom, Simon Levin

Bigelow: Mike Lomas

GO-SHIP: Lynne Talley, Greg Johnson, Rik Wanninkhof etc.

Dimensions of Biodiversity
Biological Oceanography

The Redfield ratio



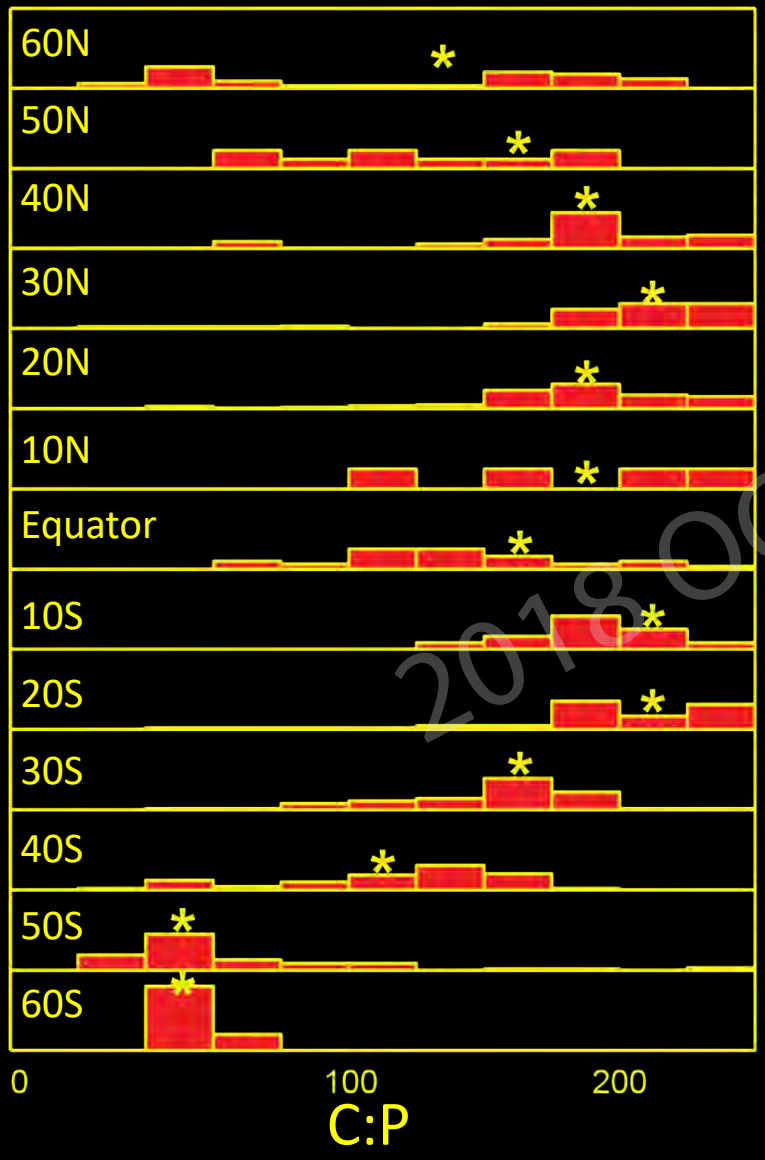
C:N:P = 106:16:1

Tight link between vertical elemental inputs and outputs

Static elemental composition of all marine communities!!

This concept has immense influence on ocean biogeochemistry

C:P stoichiometry of surface ocean particles

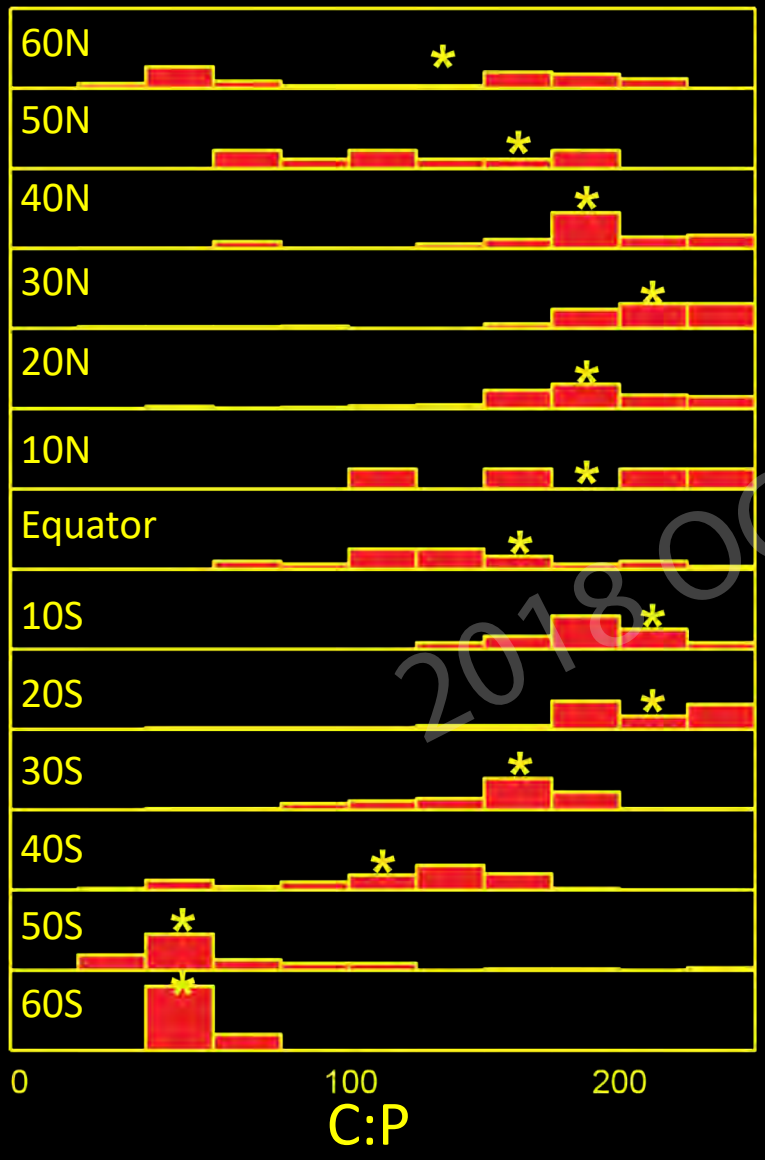


Low at high latitudes

Low at high latitudes

Martiny et al., Strong latitudinal patterns in the elemental ratios of marine plankton and organic matter. 2013

C:P stoichiometry of surface ocean particles



Low at high latitudes

High at low latitudes

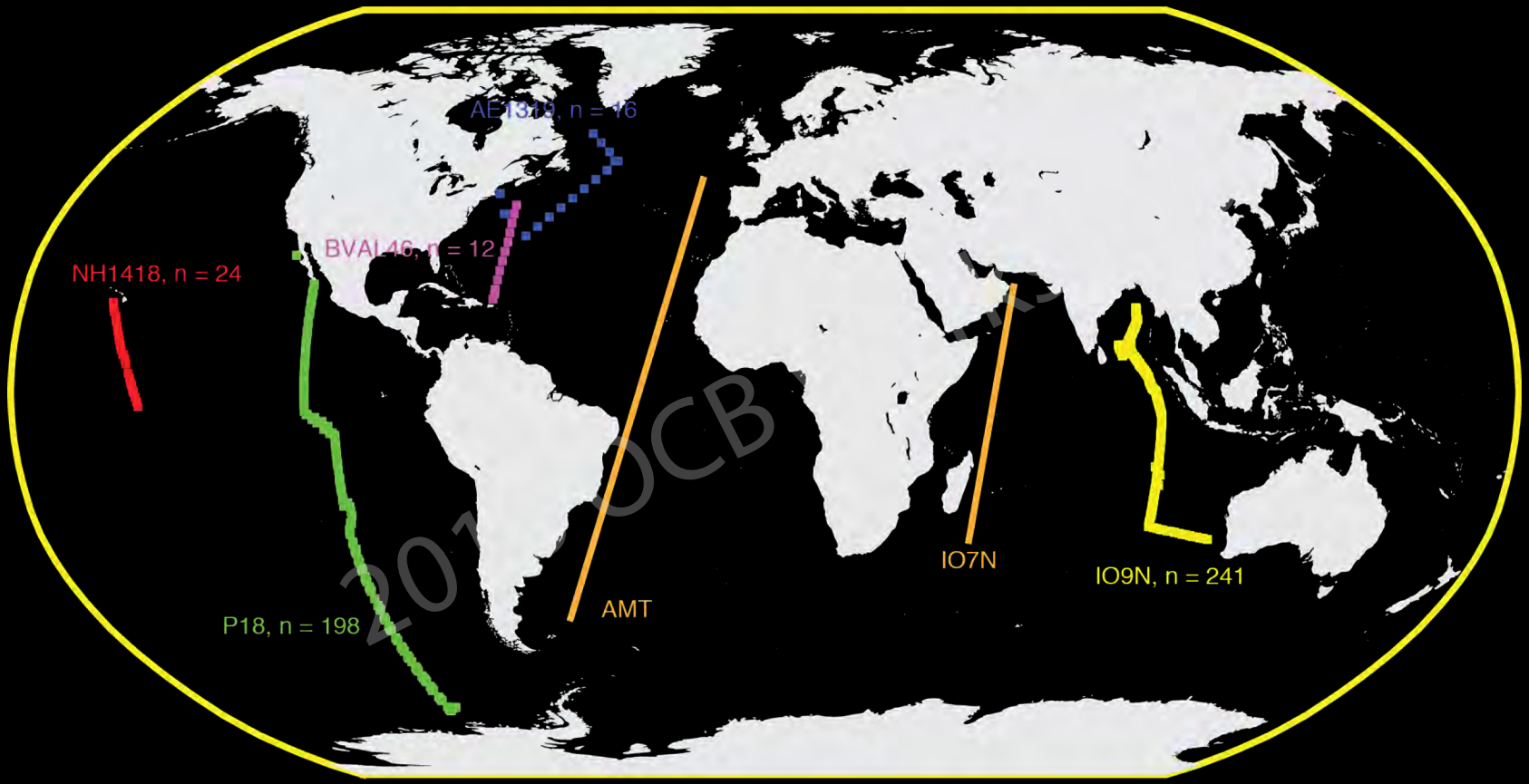
Lower in equatorial zones

High at low latitudes

Low at high latitudes

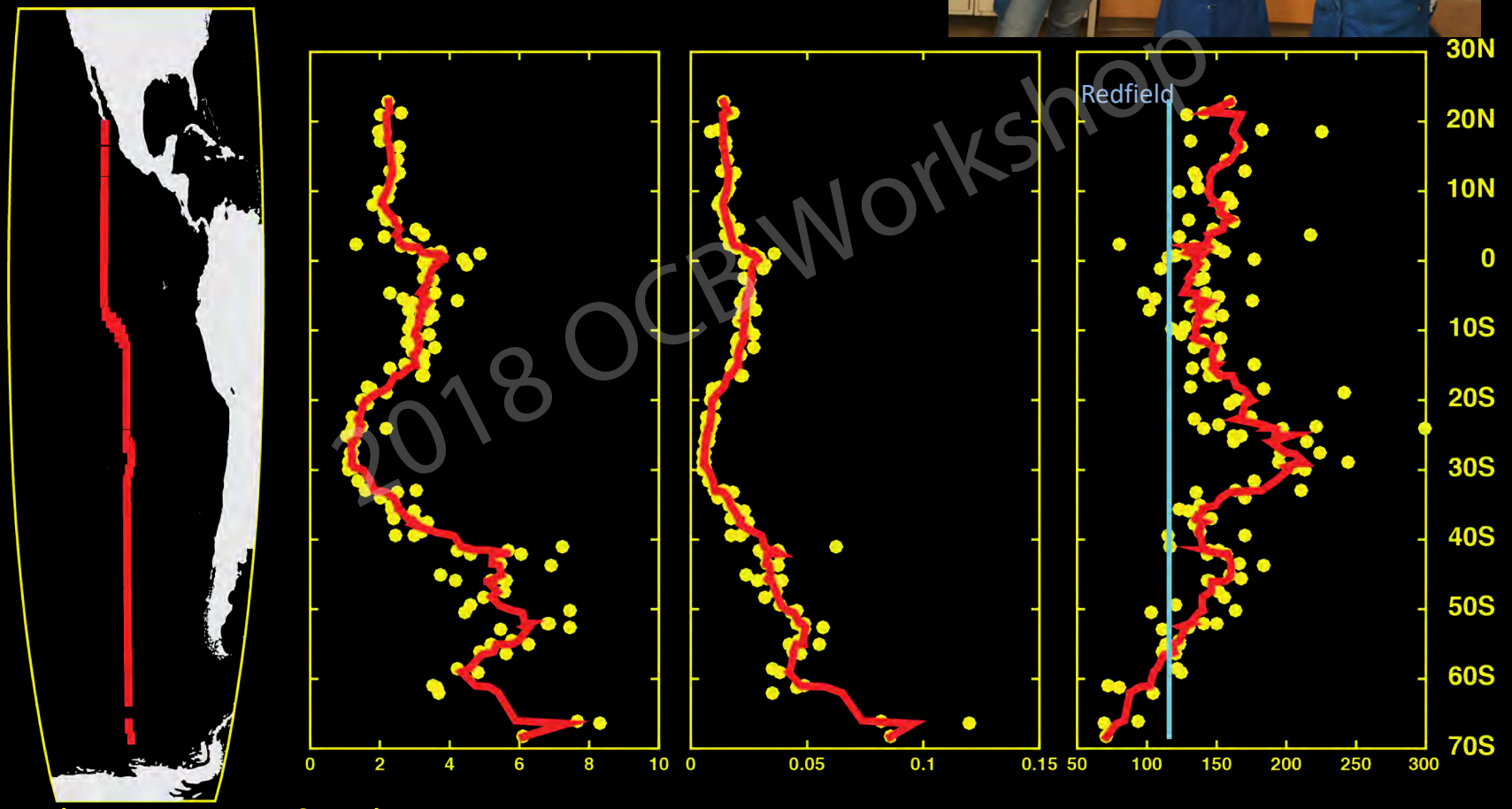
Martiny et al., Strong latitudinal patterns in the elemental ratios of marine plankton and organic matter. 2013

Field sampling design



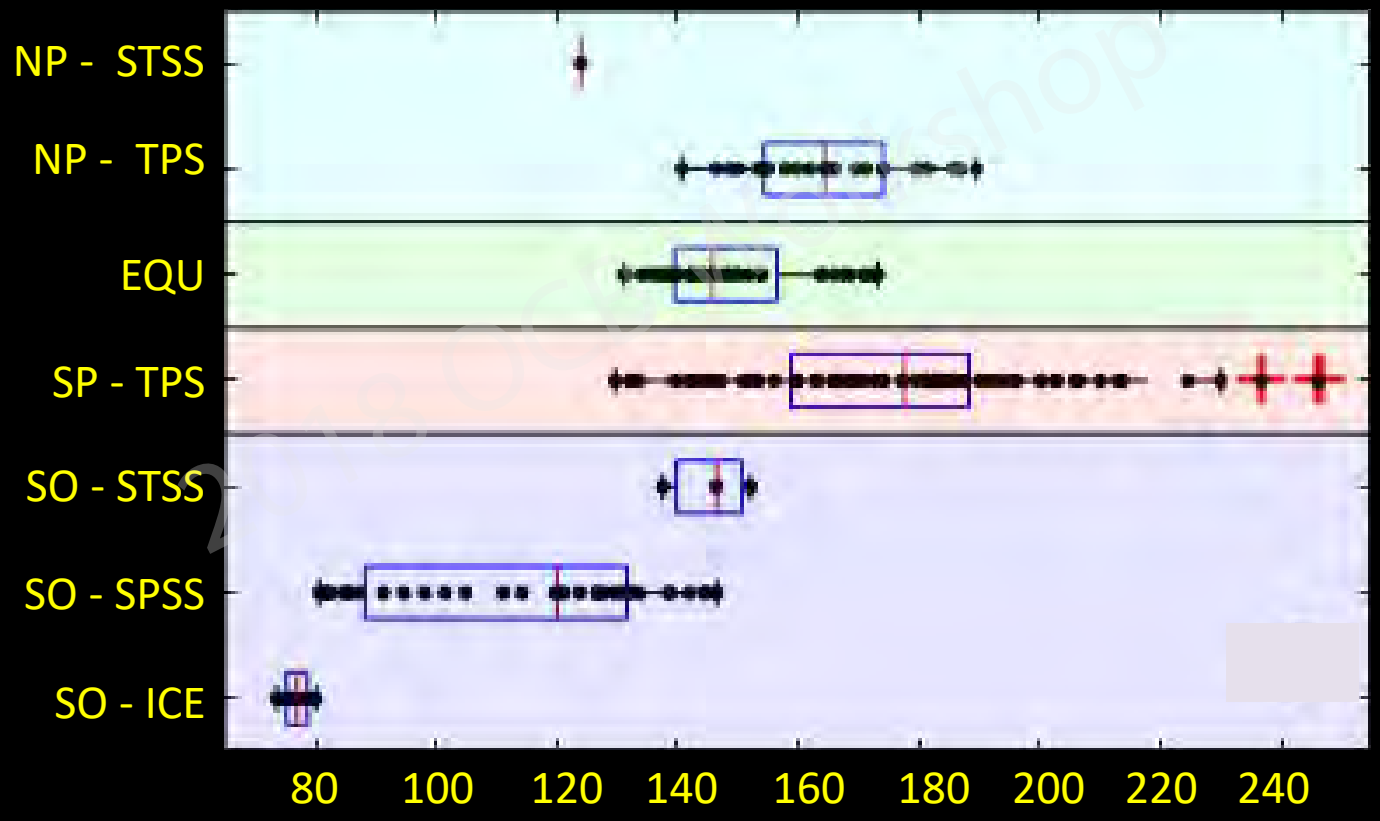
A big thanks to GO-SHIP for allowing us to participate

Latitudinal transect



P18 (n = 198, surface) POC (µM) POP (µM) C:P (mol:mol)

Regional difference



Fay and McKinley: Global open-ocean biomes: mean and temporal variability. 2014.

Clear patterns but why?

- Latitudinal pattern in C:N:P
  - Low in high latitude waters (but variation in SO)
  - High in gyres
  - Intermediate in equatorial upwelling regions
- Here, we tested for growth rate and nutrient limitation using *Synechococcus* as model
  - Hyp1: High C:P and N:P at low growth
  - Hyp2: High C:P and N:P under P limitation

Chemostat setup

Strain: *Synechococcus* WH8102

Inflow

Medium
NO_3^- : PO_4^{3-}

N-limited (6:1)
P-limited (70:1)

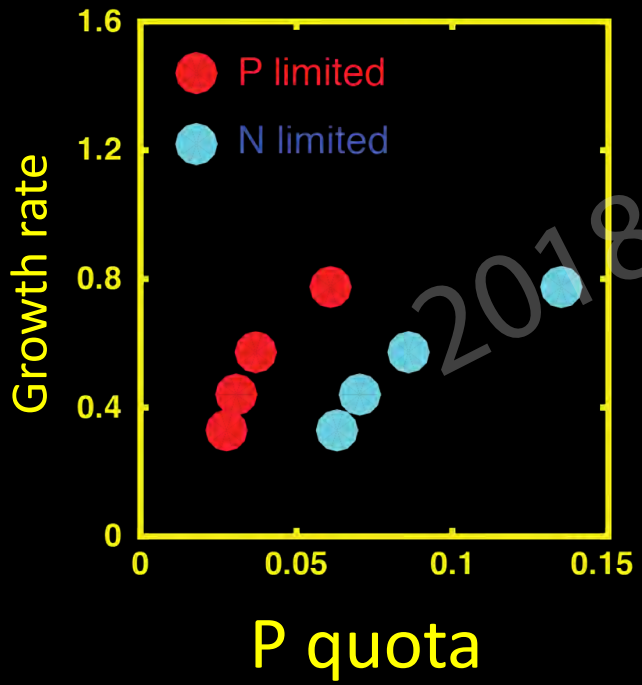
Outflow

Growth rates
0.77 d^{-1}
0.60 d^{-1}
0.45 d^{-1}
0.34 d^{-1}

Temp. = 24°C, 195 μE m^{-2} s^{-1}

Cell quota

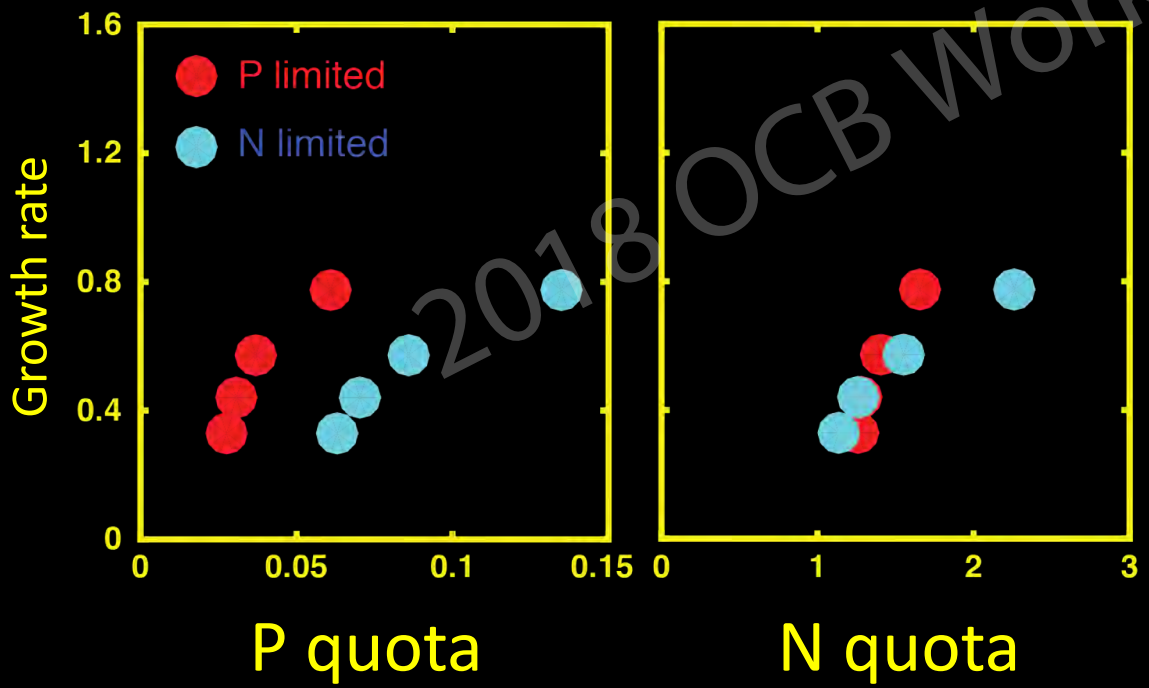
Work by N. Garcia



Increase w. growth rate (Droop-like)

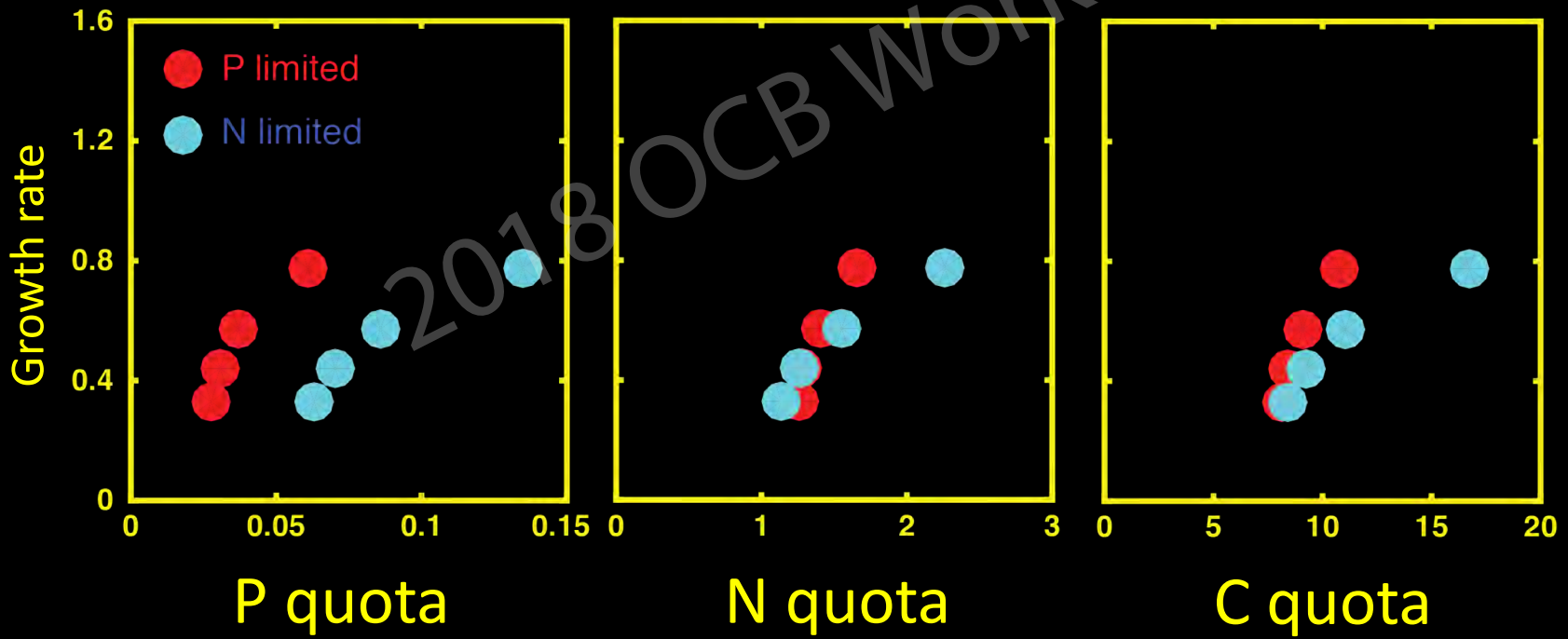
P quota smaller under P limitation

Cell quota

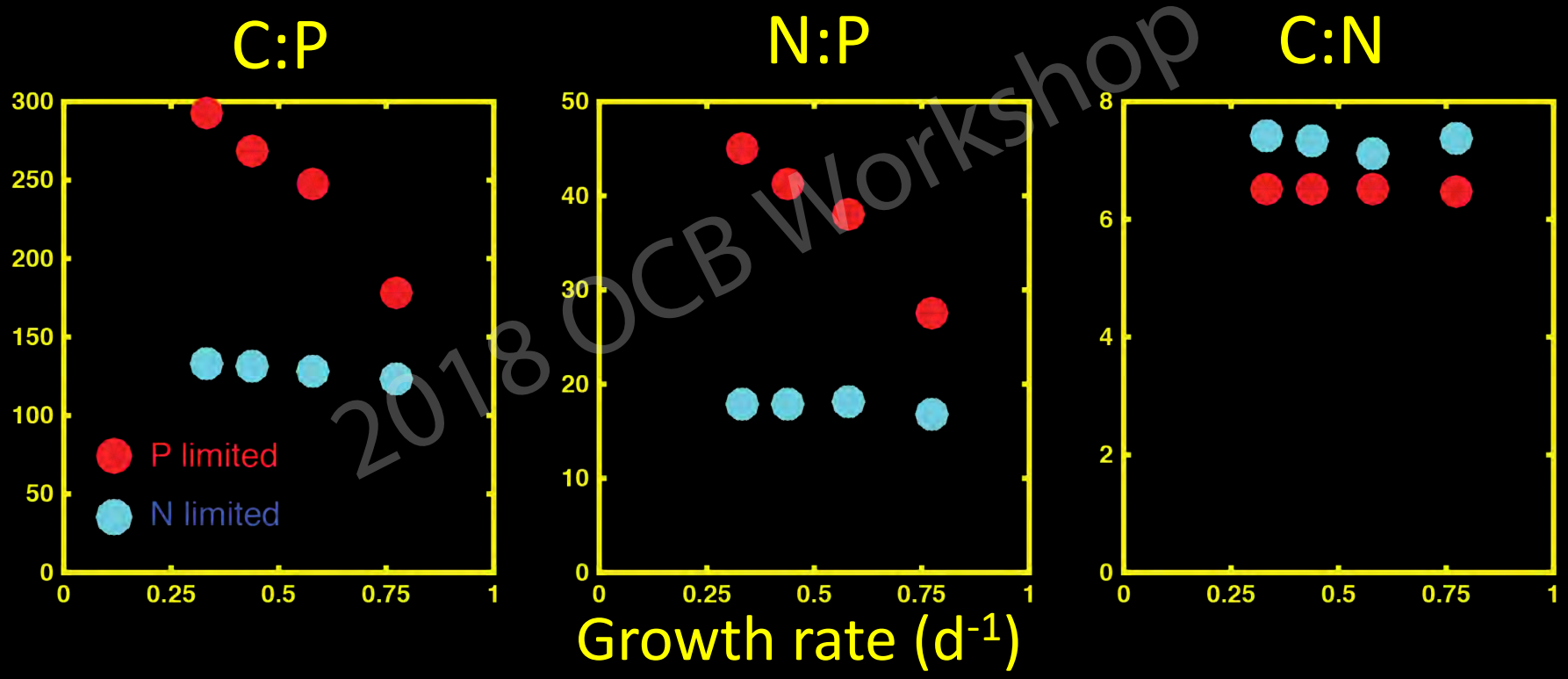


Cell quota

Large increase in C quota (and cell size) w. growth!



Interactive effect of growth rate and nutrient limitation on stoichiometry



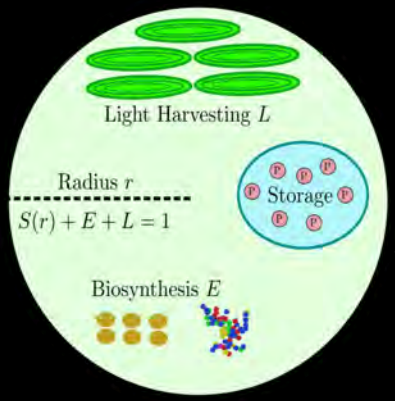
Degree of P stress important

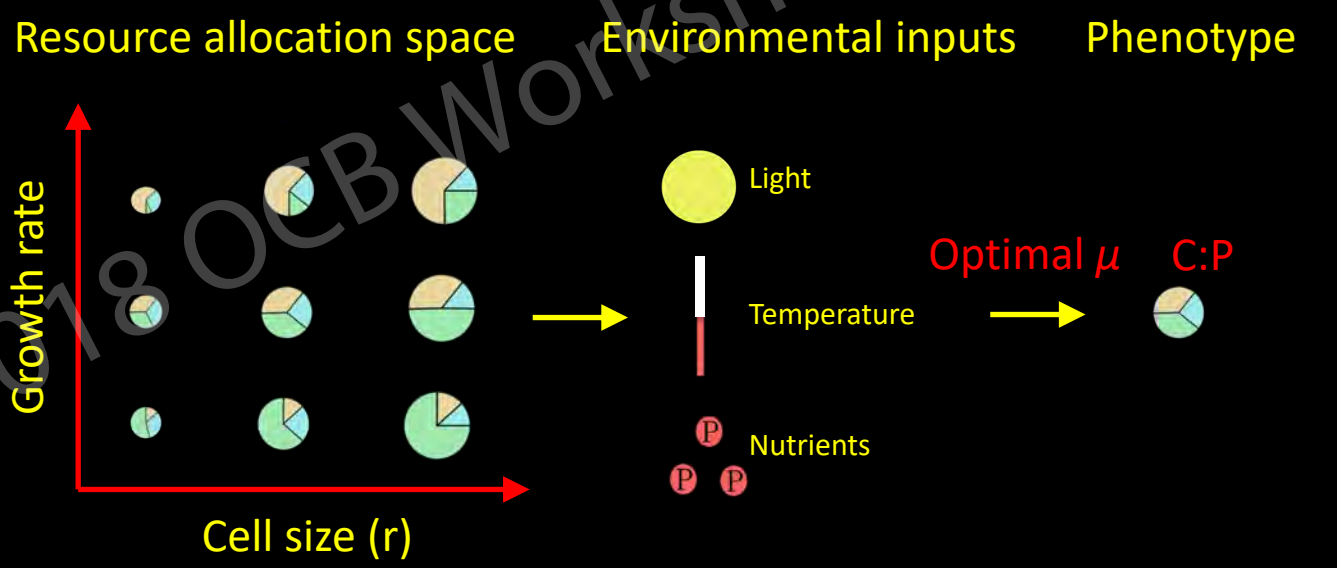
Data to model

1. Design a trait-based model to describe regulation of C:P (acclimation + adaptation)
2. Embed trait-based model in an ocean GCM model w. an optimized P cycle (optimized match to global DIP from WOA)
3. Predict patterns and magnitude $C:P_{export}$ and C_{export}

Trait-based model

Structure (~ cell size)
Light harvesting + CO_2 fix
Biosynthesis (ribosomes)
Storage (polyP)



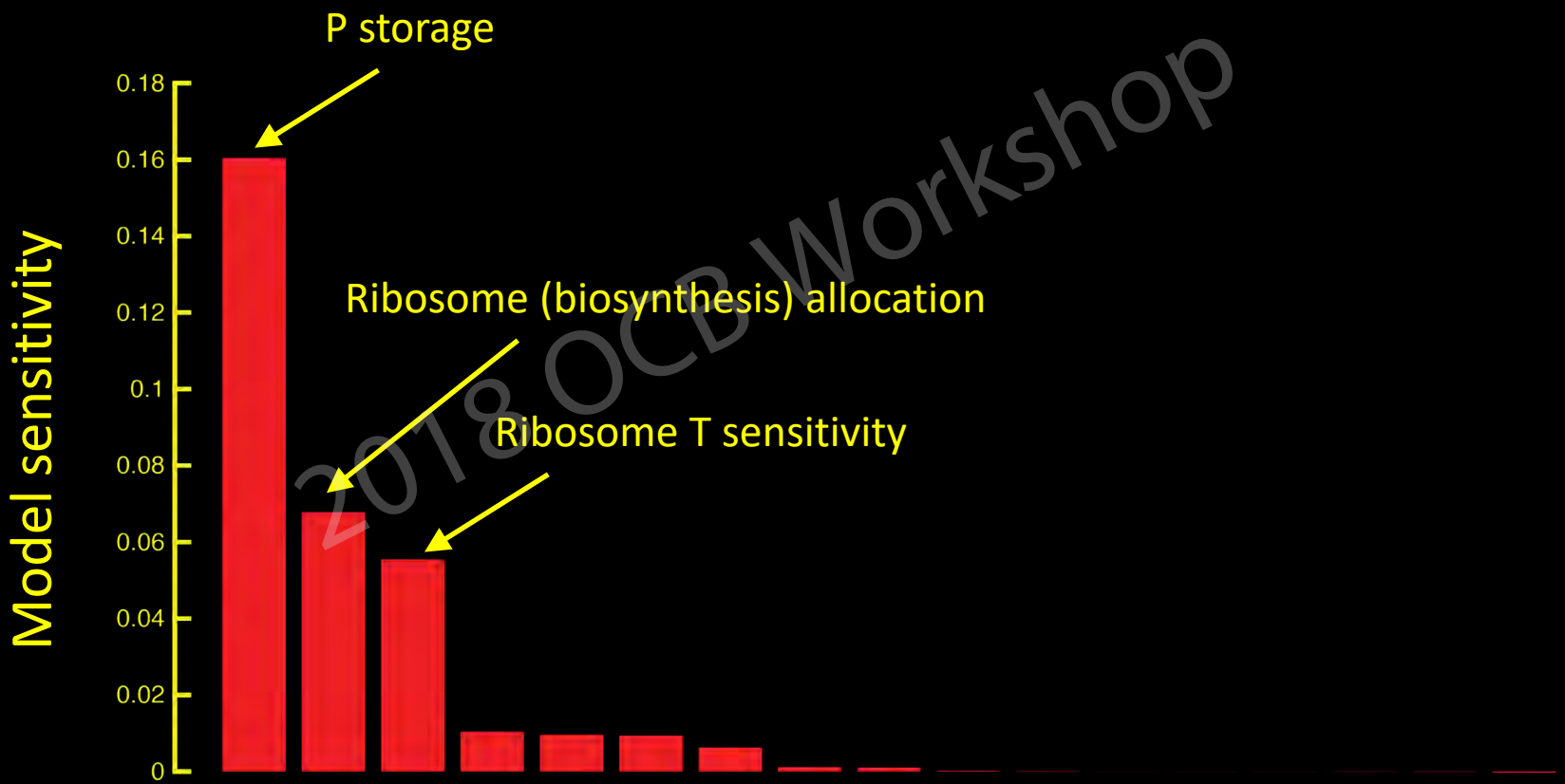


Designed by George Hagstrom
Inspired by Daines et al., 2014

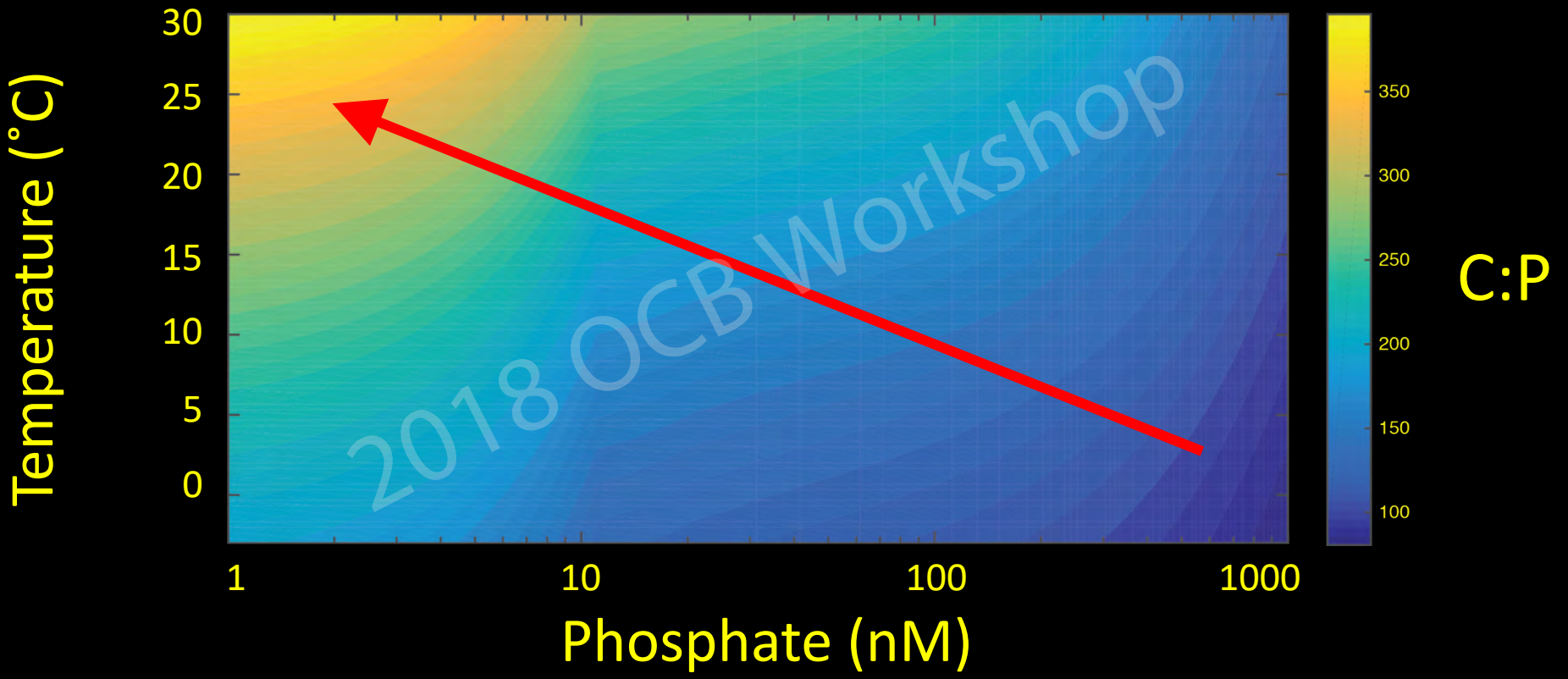
Moreno, Hagstrom et al., *Biogeosci.*. 2018

Model optimization and sensitivity

(optimized against POM data)



Prediction

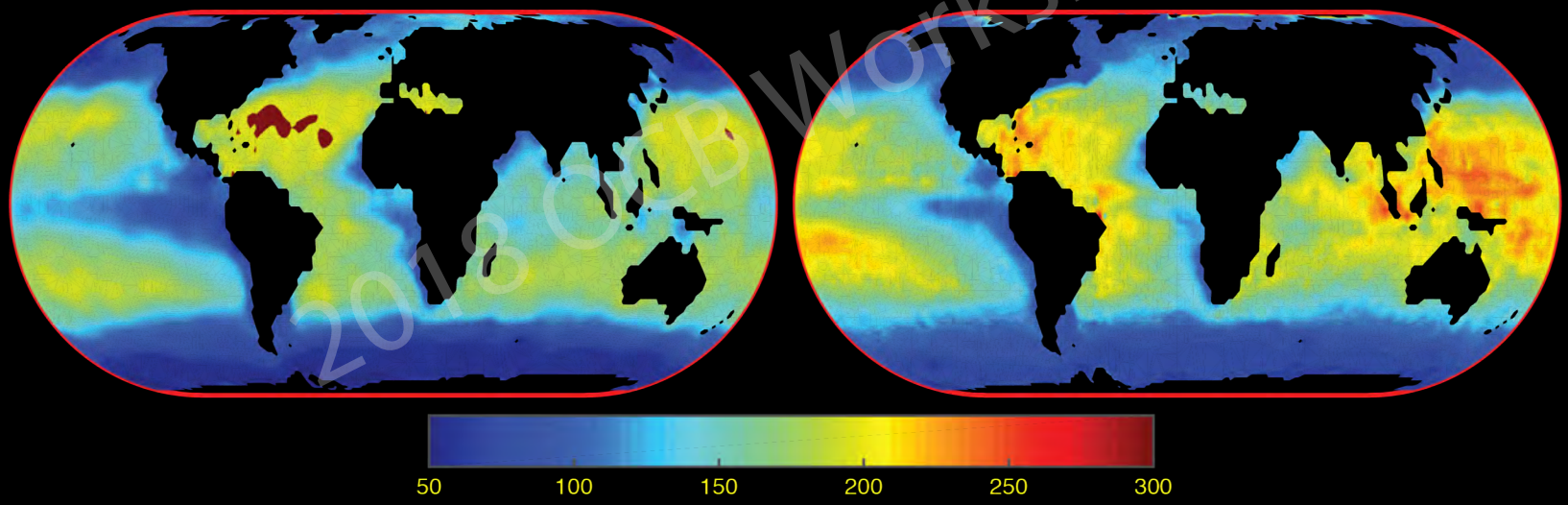


Surface P concentration important parameter in controlling C:P -
but highly uncertain in many low latitude regions

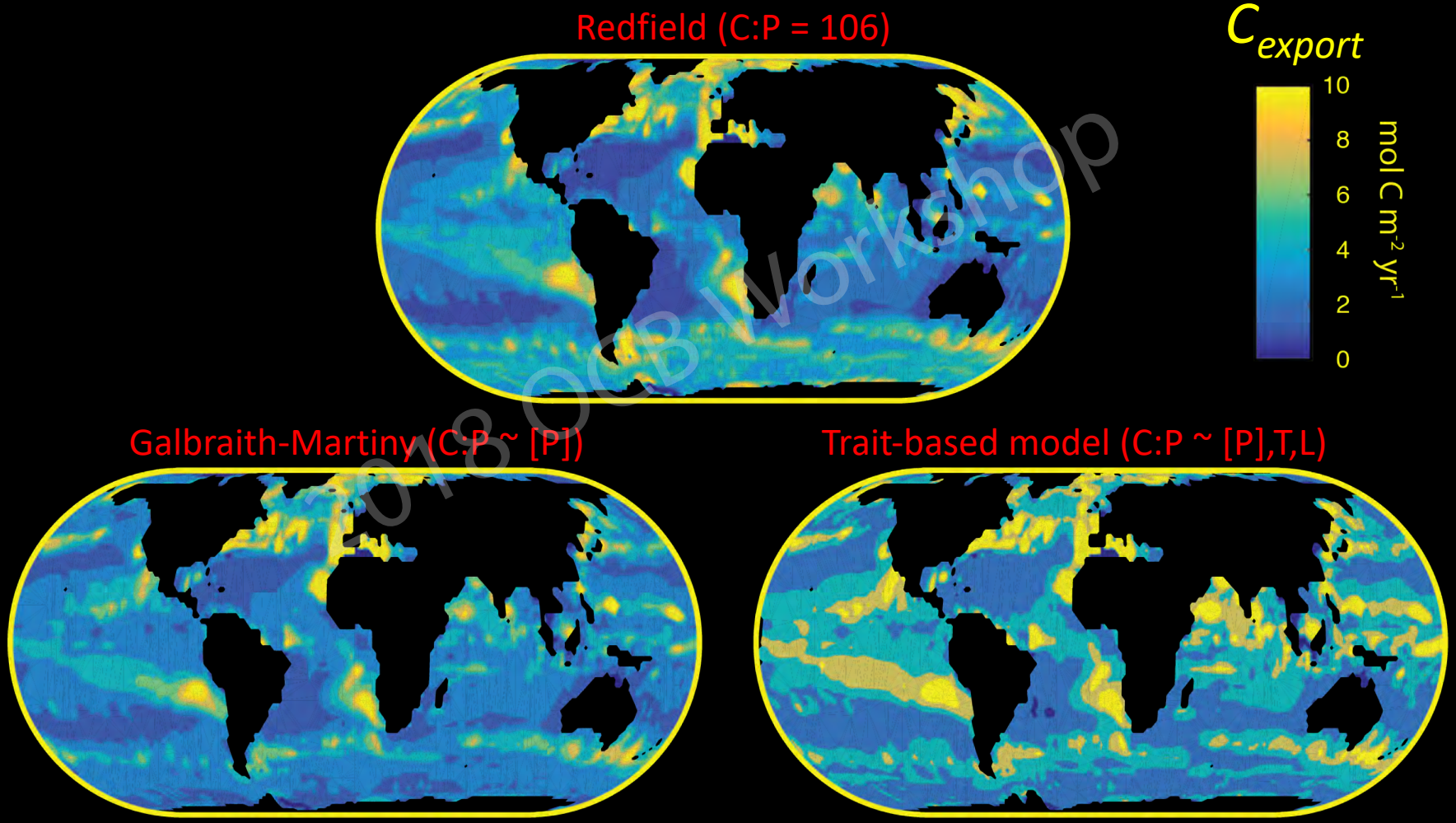
C:P of exported material

Galbraith-Martiny empirical model (C:P ~ [P])

Trait-based model (C:P ~ [P],T,L)

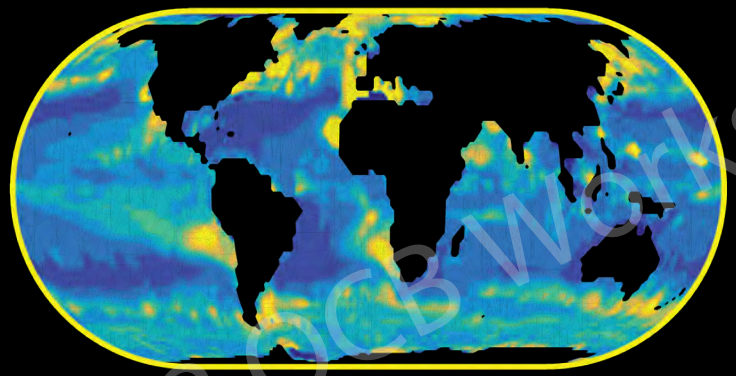


Carbon export flux

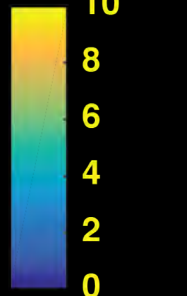


Carbon export flux

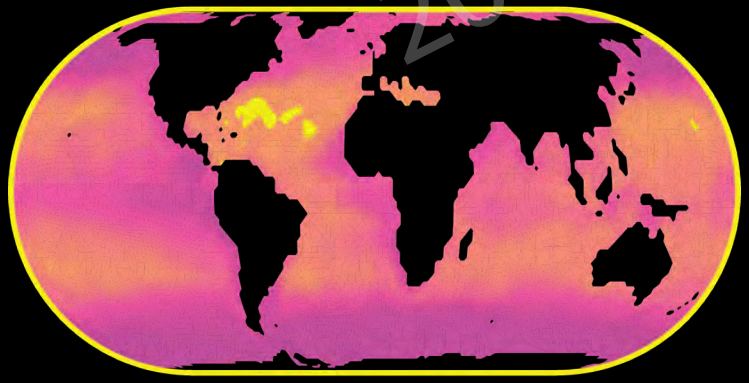
Total C_{export} Redfield (C:P = 106)



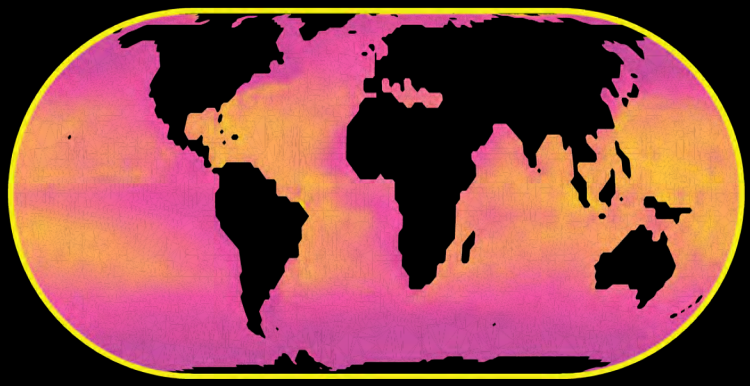
mol C m^{-2} yr^{-1}



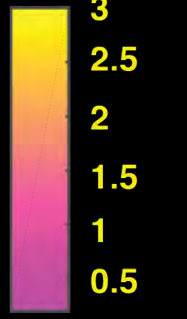
Galbraith-Martiny : Redfield



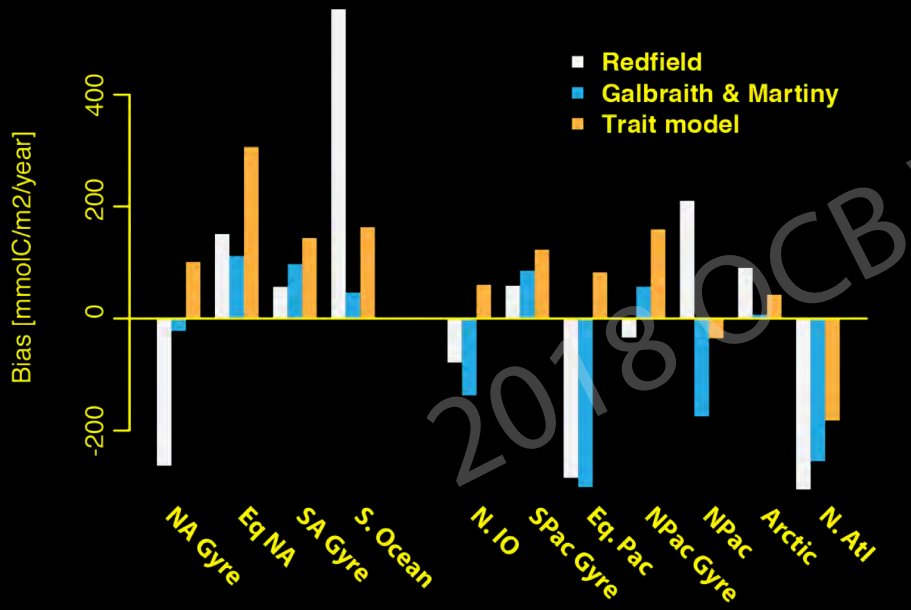
Trait-model : Redfield

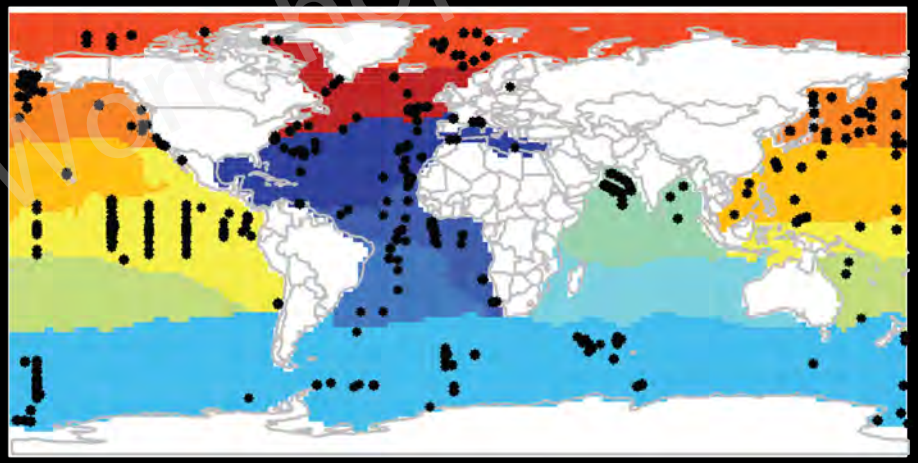


Ratio



Better match to trap data

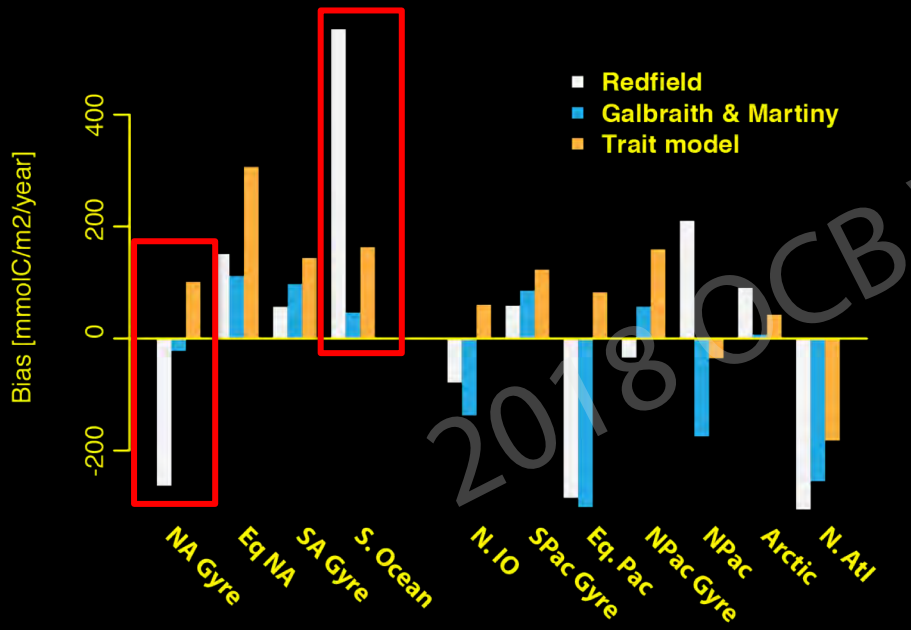


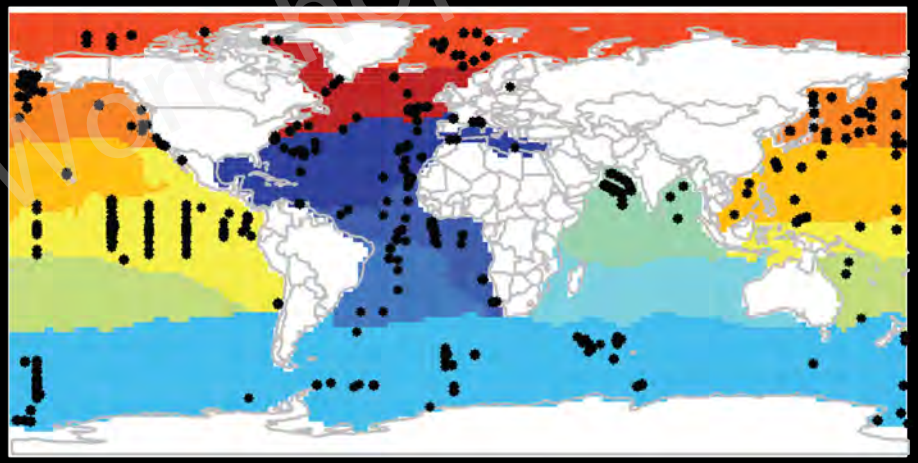


Mouw et al., Global ocean particulate organic carbon flux merged with satellite parameters. 2016.

Better match to trap data

Redfield model underestimate C_{export} in NA gyre and underestimate in S. Ocean





Conclusions

- Clear latitudinal pattern in C:N:P
- Culture experiments can help describe biological mechanisms regulating C:N:P
- Trait model suggests C:P of exported predicted by higher in low nutrient, warm low latitude waters
- Higher C_{export} in oligotrophic regions than currently predicted by ESMs

Conclusions

- Clear latitudinal pattern in C:N:P
- Culture experiments can help describe biological mechanisms regulating C:N:P
- Trait model suggests C:P of exported predicted by higher in low nutrient, warm low latitude waters
- Higher C_{export} in oligotrophic regions than currently predicted by ESMs

Thank You!