OPEM – **O**ptimality-based non-Redfield **P**lankton **E**cosystem **M**odel

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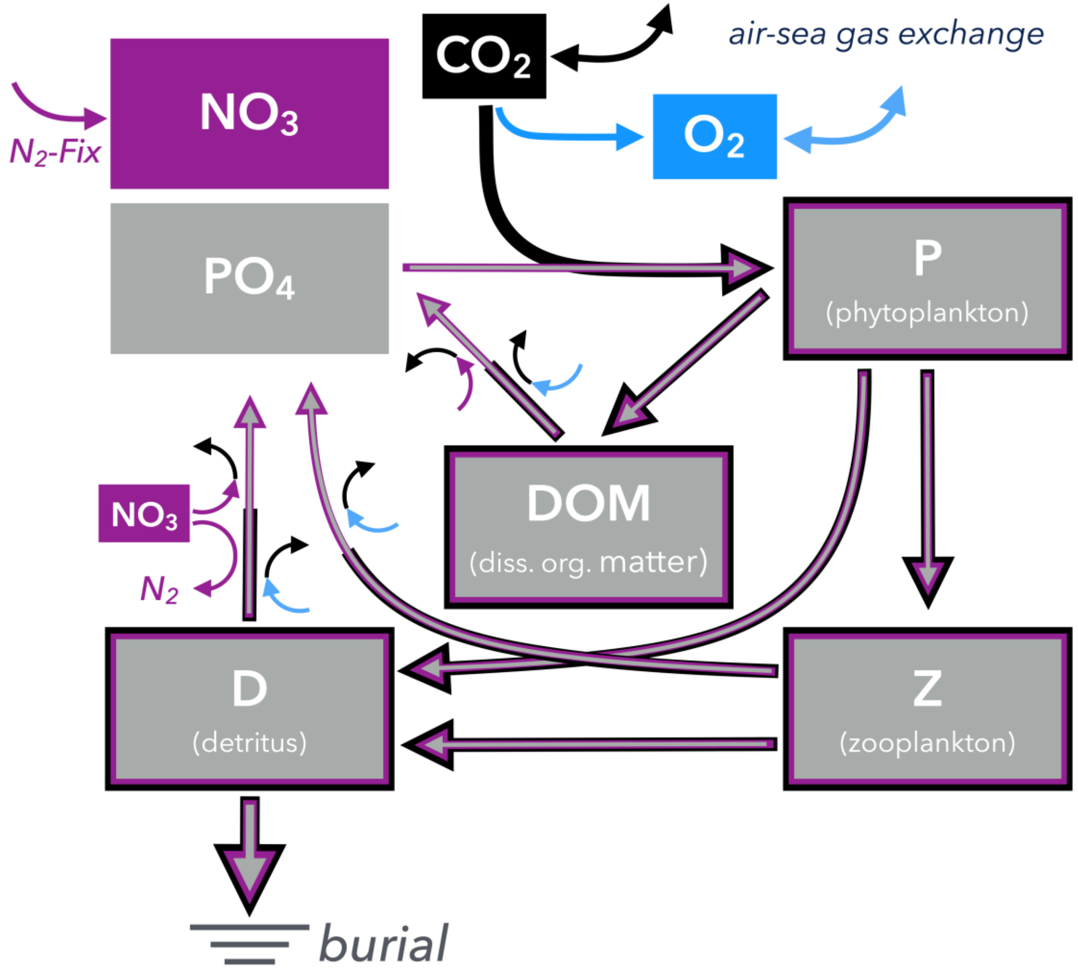
Traditional route:
MOPS: Model of Oceanic Pelagic Stoichiometry

→ IronMOPS (?)

Assume diaz. biomass = const. & immediate N_2fix → NO_3

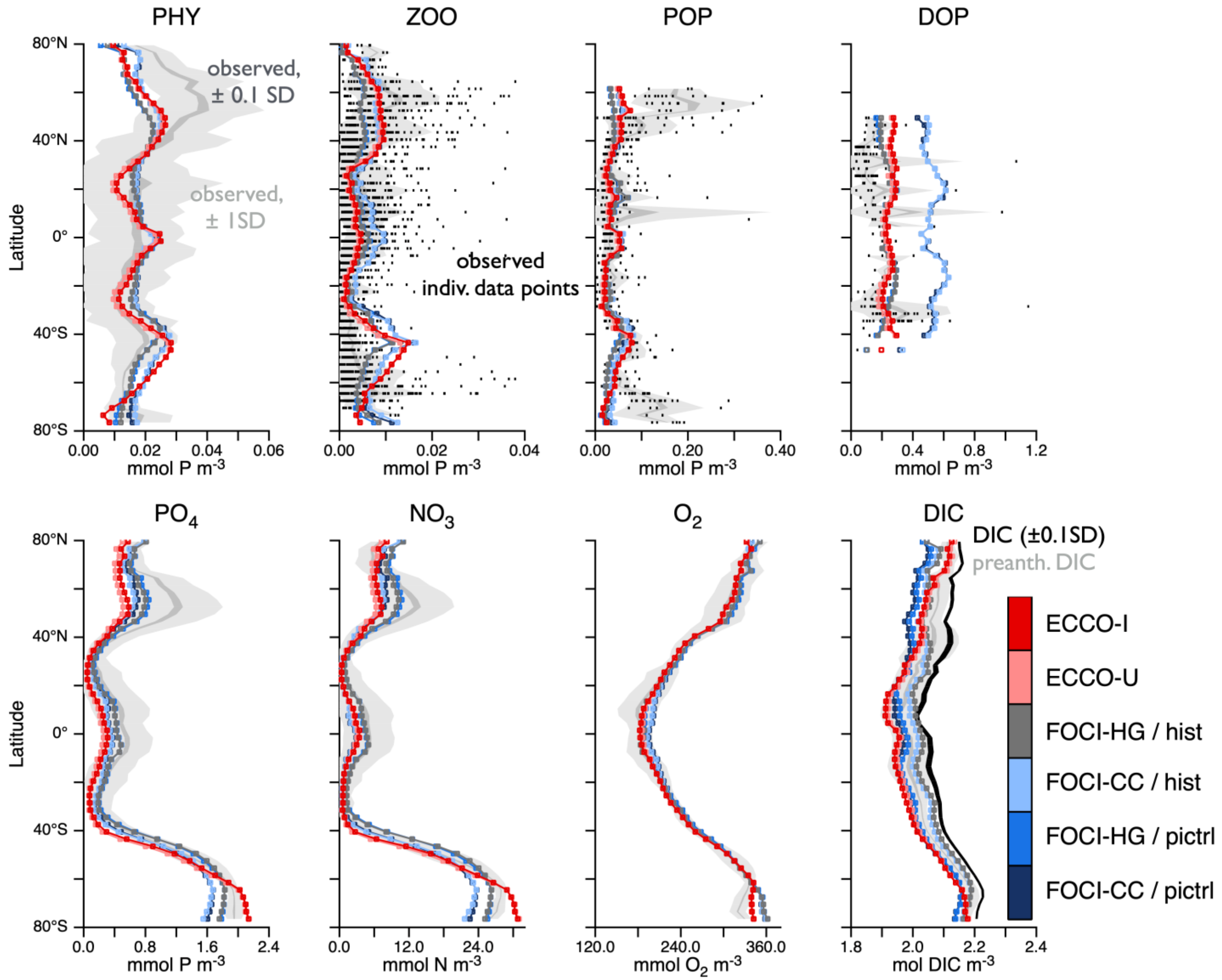
oxidant-dependent remineralization



- **4 elements:**
  P, N, O_2, C
- **9 tracers:**
  PHY, ZOO, DOM, DET, PO_4, NO_3, O_2, DIC, alkalinity
- **cross-boundary mass exchanges:**
  air-sea gas exchange, burial, river runoff, N-fixation, denitrification
- **calibration:**
  objective parameter optimisation against observed tracers in climatological circulations (TMM) after millennial spinup
- **coupled to:**
  TMM (Transport Matrix Method, 5 TMs available)
  FABM (Framework for Aquatic Biogeochemical Models)
  NEMO3.x (NEMO5 underway)
  FOCI (NEMO3.x)

Kriest & Oschlies (GMD 2015)

MOPS in FOCI (NEMO3.x with ORCA05)



All model and observations evaluated between 0-100m, except phytoplankton (0-10m).

Evaluation of new FOCI-MOPS and TMM-MOPS setup after 665 years

(FOCI-MOPS: 500 years piCtrl, 165 years hist)
(TMM-MOPS: 665 years climatology with 280ppm)

- Pre-calibration in TMM against observed nutrients and oxygen:
  Kriest et al. (2020) [not shown here]

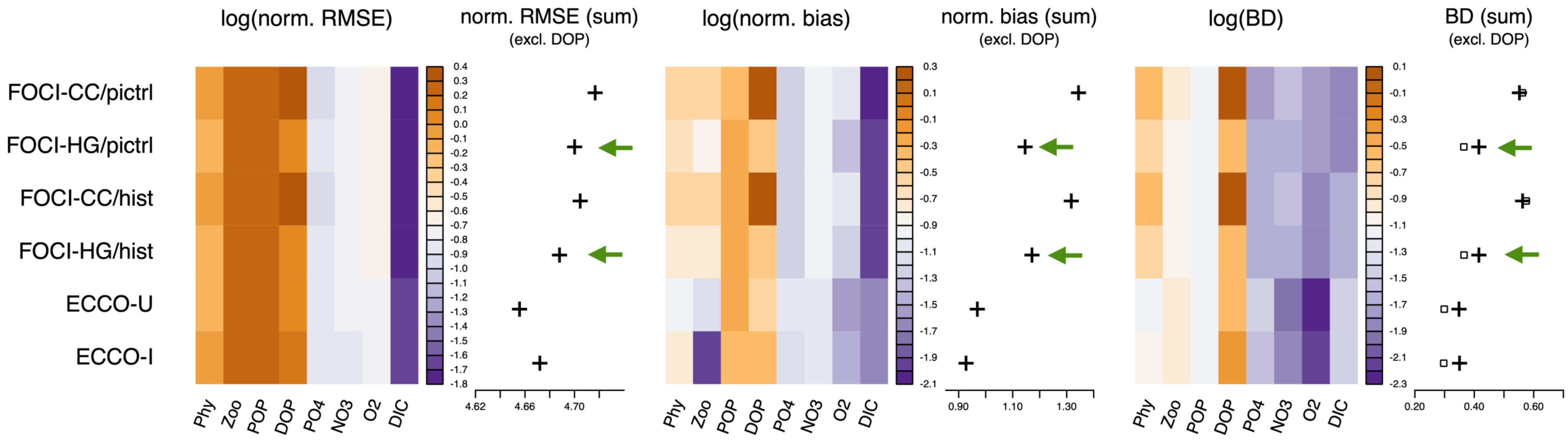
➡Transfer to FOCI:
Chien et al. (2022) [FOCI-CC/hist]

- Pre-calibration in TMM against observed nutrients and oxygen and observations for all organic components:
  Kriest et al. (2023) [ECCO-U]

➡Transfer to FOCI:
Kriest et al. (in prep.) [FOCI-HG/hist]

MOPS in FOCI (NEMO3.x with ORCA05)

Various parametric metrics (here: RMSE, normalised by observed mean), the bias (here: normalised by observed mean) and non-parametric statistics (here: Bhattacharyya distance from kernel densities, BD) point towards **better performance of new version of MOPS-FOCI.**



Metrics for zooplankton and DOP evaluated between 0-100m, for phytoplankton between 0-10m, for inorganic tracers between 0-2000m and for POP for whole model domain.

MOPS in FOCI (and in TMM)

+ ‘affordable’, N, P, O_2, C; 9 variables, calibrated via TMM,
  newly available: Andersen acceleration (Khatiwala et al., 2024)

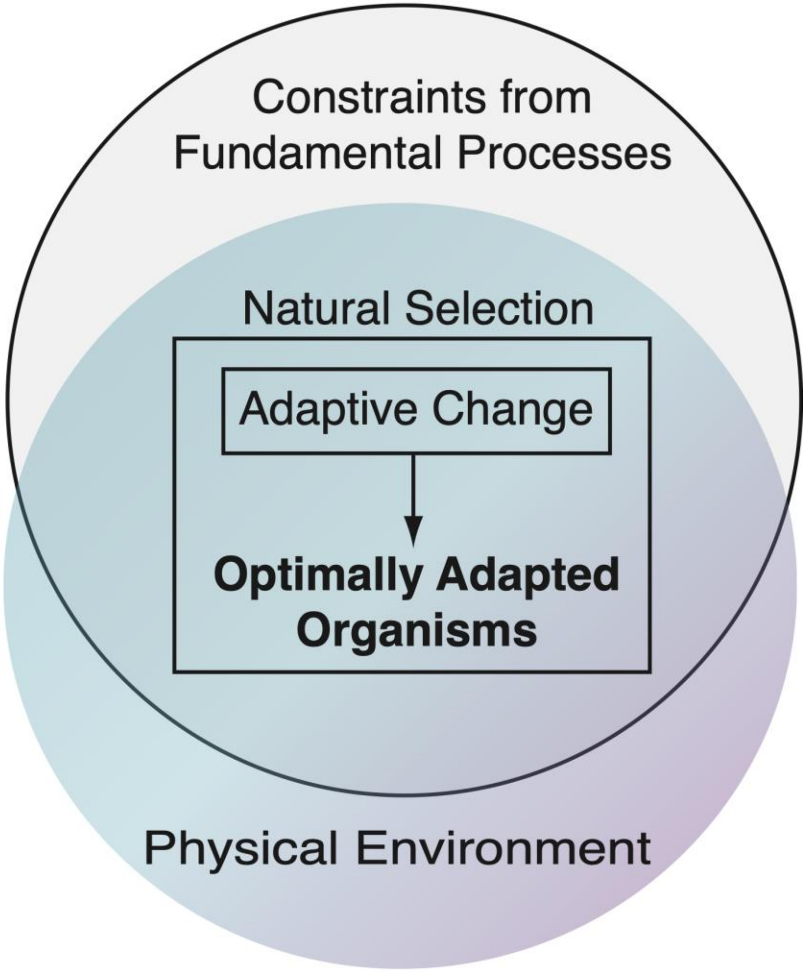
- ‘empirical’, ‘average species’

OPEM (in UVic)

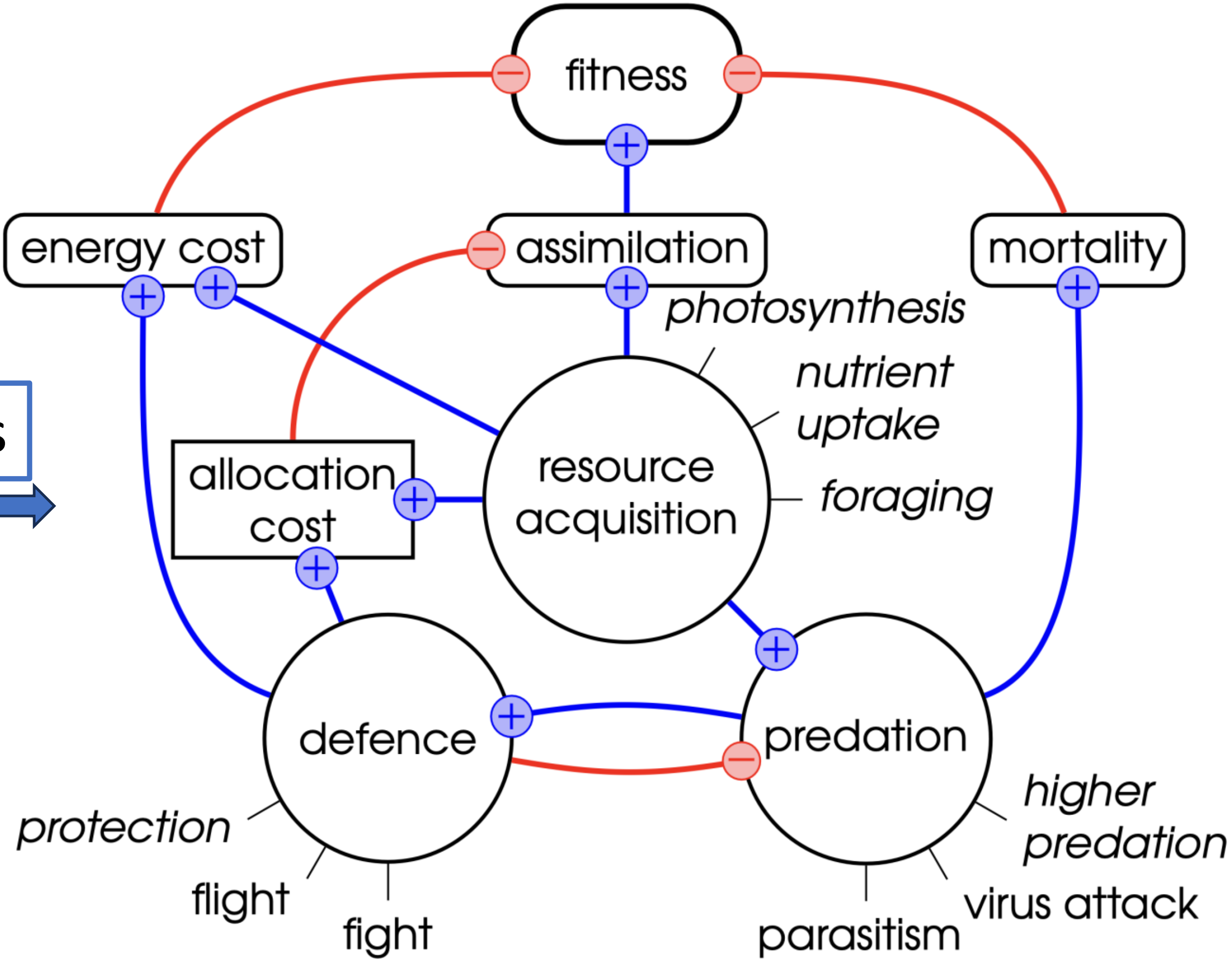
OPEM = Optimality-based non-Redfield Plankton Ecosystem Model,
13 variables; N, P, O_2, C; calibrated

+ ‘adaptive capacity’, ‘optimality’ as consequence of natural selection
+ calibrated against lab & mesocosm experiments & WOA, satellite data
+ already used for paleo studies

Optimality = here: maximum specific growth rate

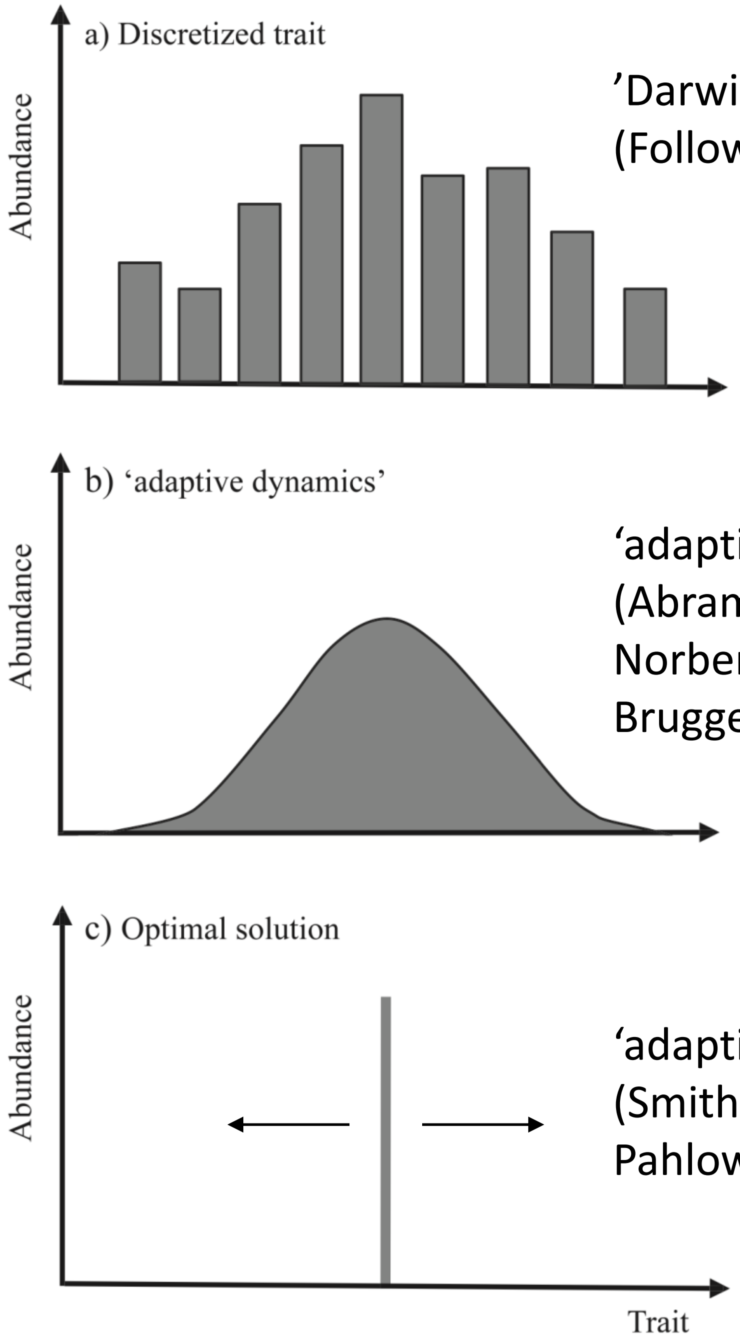


trade-offs



Smith et al. (2011)

Practical solutions for solving optimality-based models



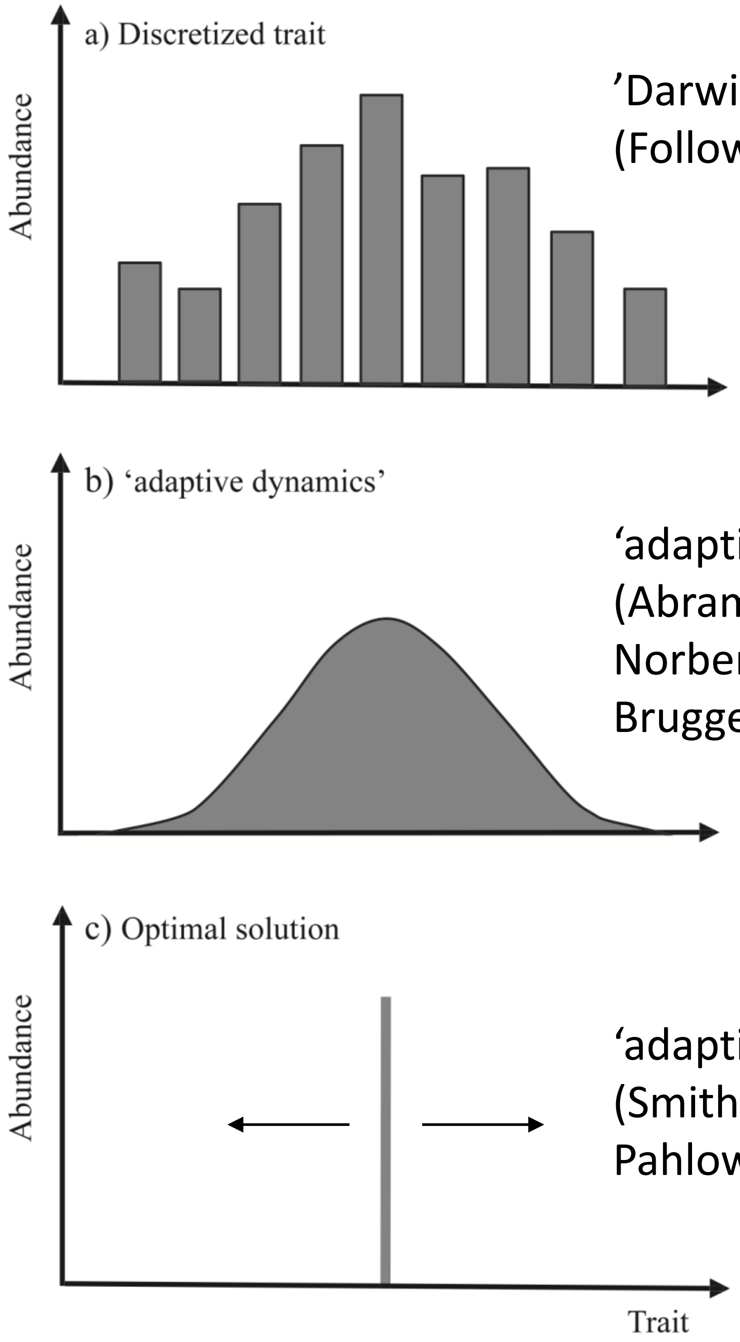
'Darwin model'
(Follows et al., 2007)

'adaptive dynamics'
(Abrams, 2005;
Norberg et al., 2001;
Bruggeman & Kooijman, 2007)

'adaptive dynamics'
(Smith & Yamanaka, 2007;
Pahlow & Oschlies, 2009)

Smith et al. (2011)

Practical solutions for solving optimality-based models



Smith et al. (2011)

’Darwin model’
(Follows et al., 2007)

→ only few species survive

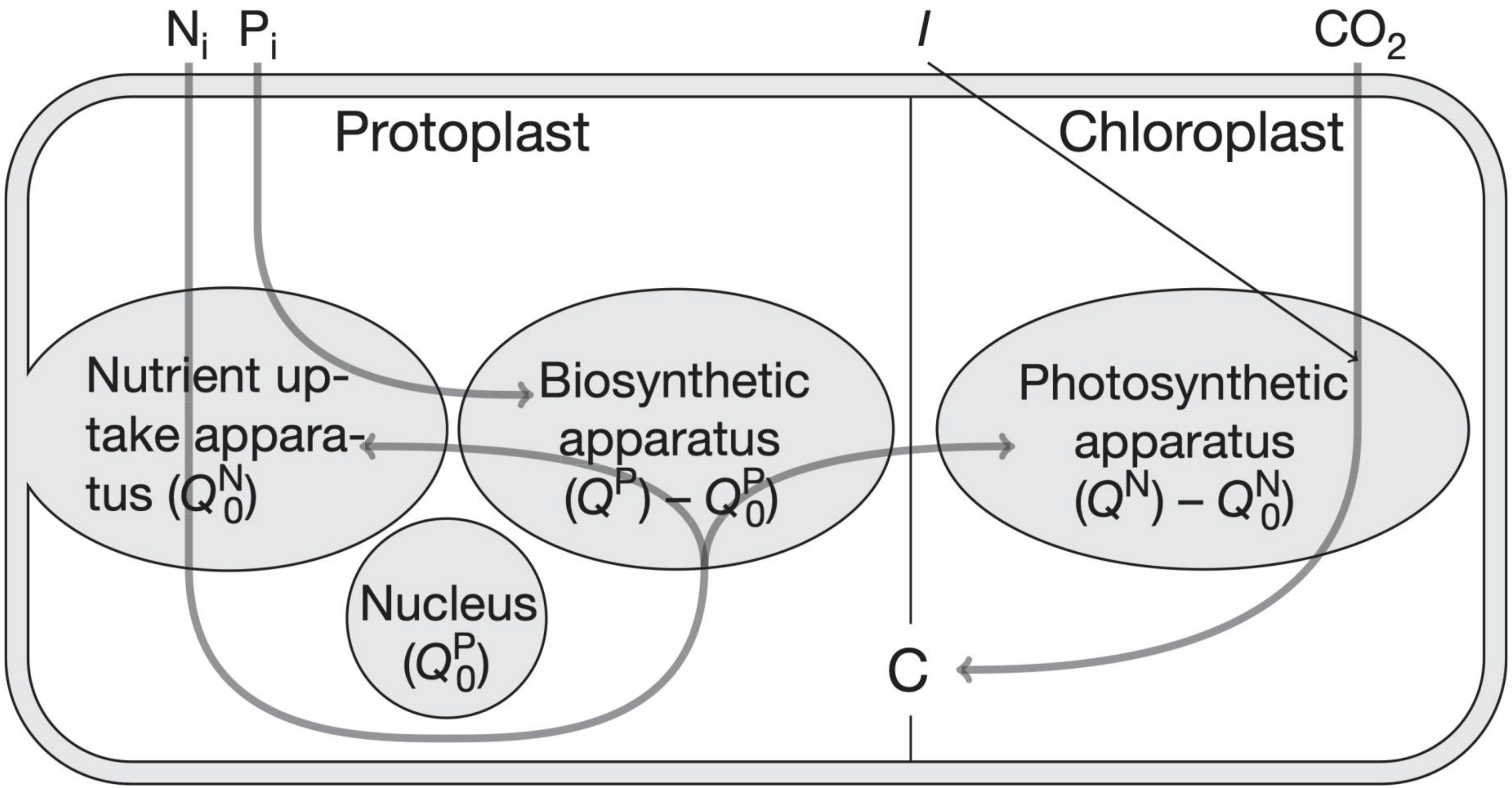
‘adaptive dynamics’
(Abrams, 2005;
Norberg et al., 2001;
Bruggeman & Kooijman, 2007)

→ collapse of variance

‘adaptive dynamics’
(Smith & Yamanaka, 2007;
Pahlow & Oschlies, 2009)

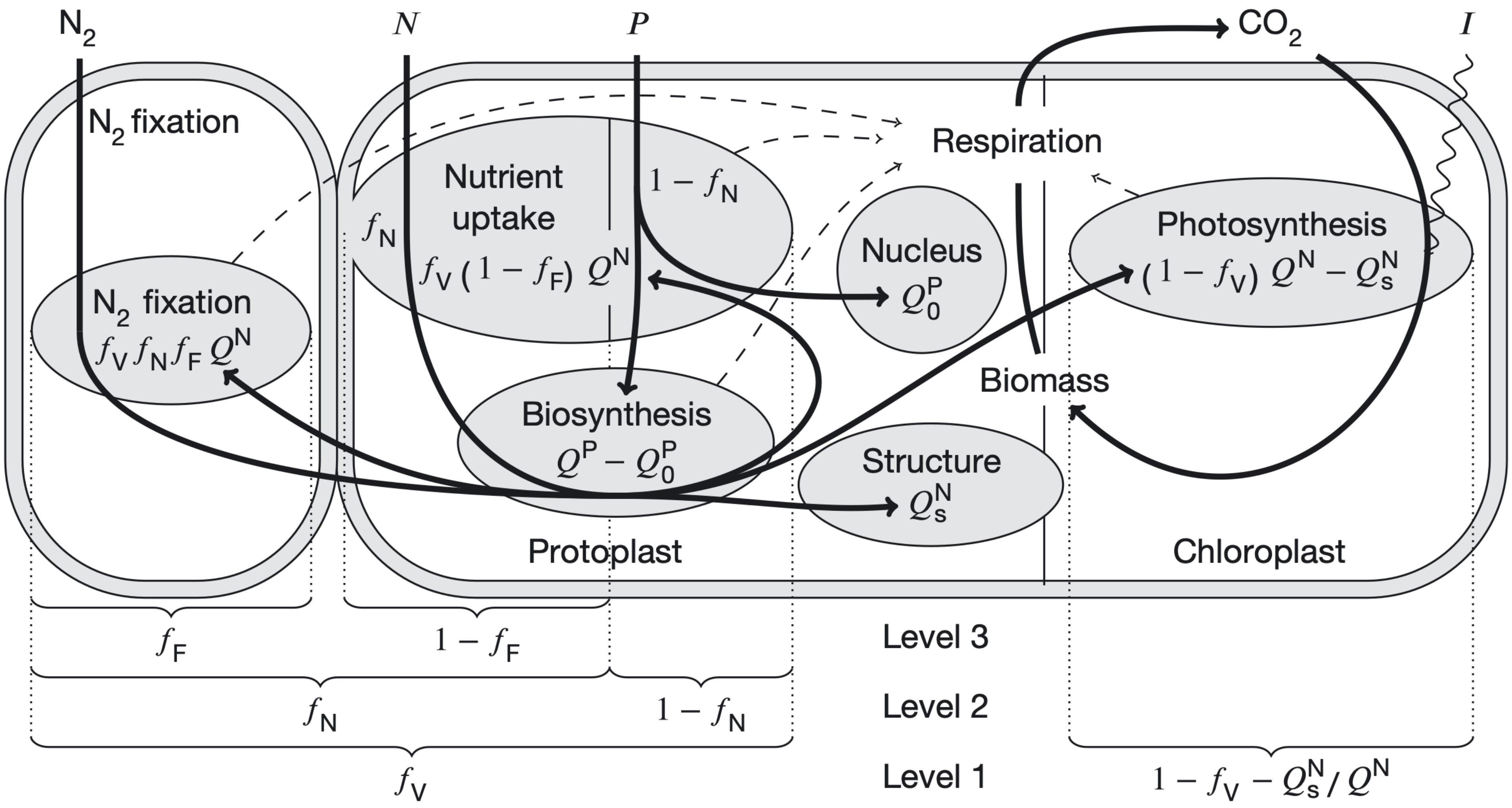
→ zero diversity, ’infinite’ pool of options

OPEM – Phytoplankton
Chain Model, Phytoplankton P, N, light limitation



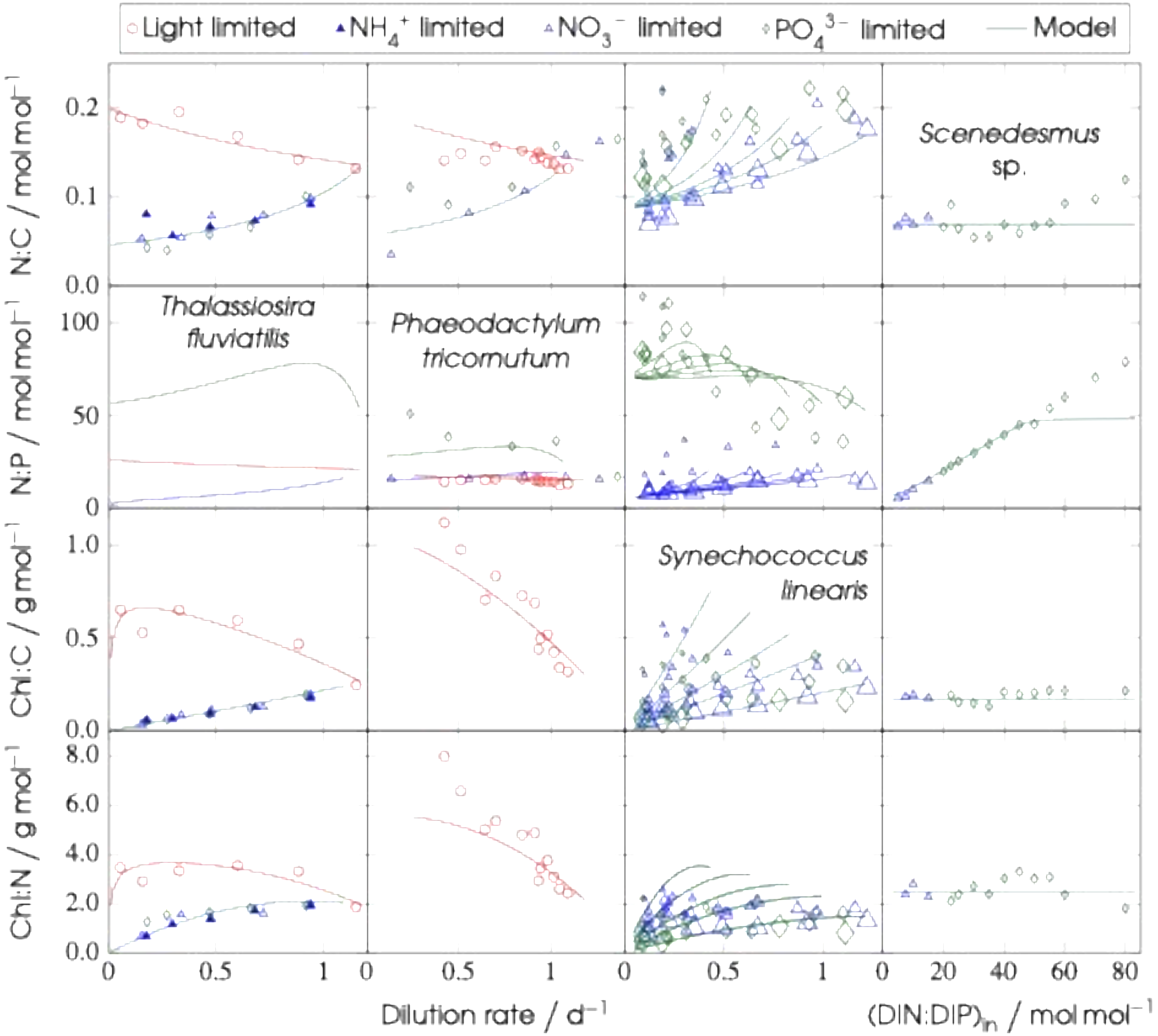
Pahlow & Oschlies (MEPS 2009)

OPEM – Diazotrophs:



Pahlow et al. (MEPS 2013)

OPEM – Phytoplankton: Calibration against data from lab experiments

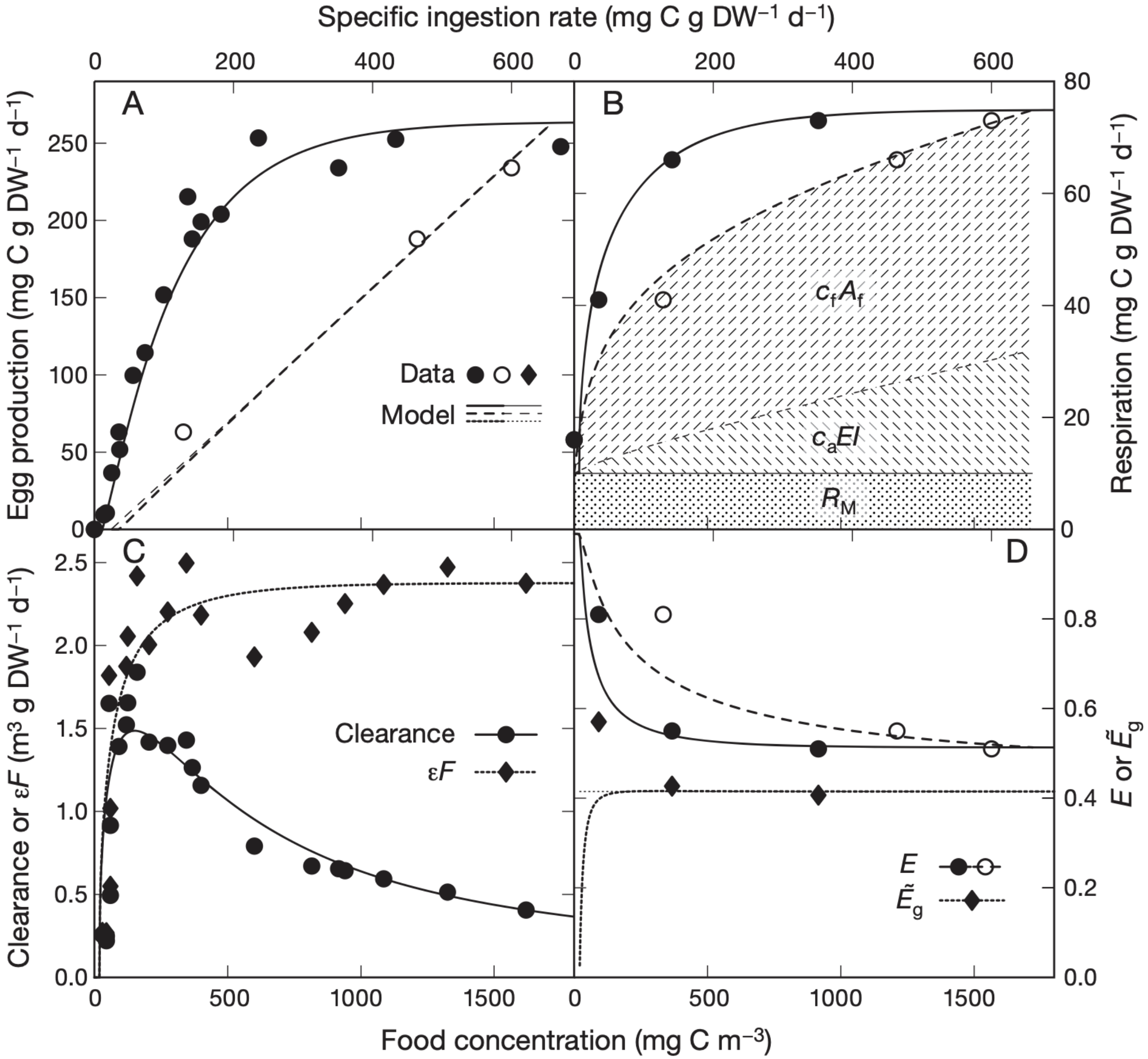


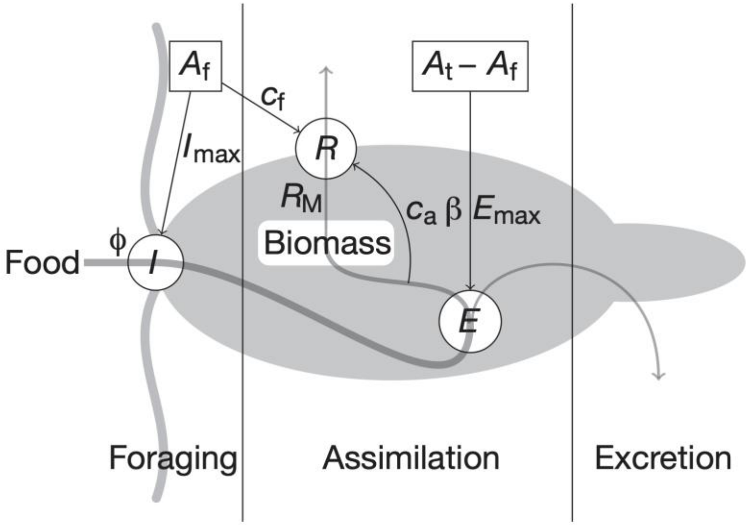
Comprehensive data sets are rare!

- Rhee (1974)
- Laws & Bannister (1980, 2004)
- Healey (1985)

Pahlow & Oschlies (MEPS 2009)
Pahlow et al. (MEPS 2013)

OPEM – Zooplankton: Optimal current feeding model





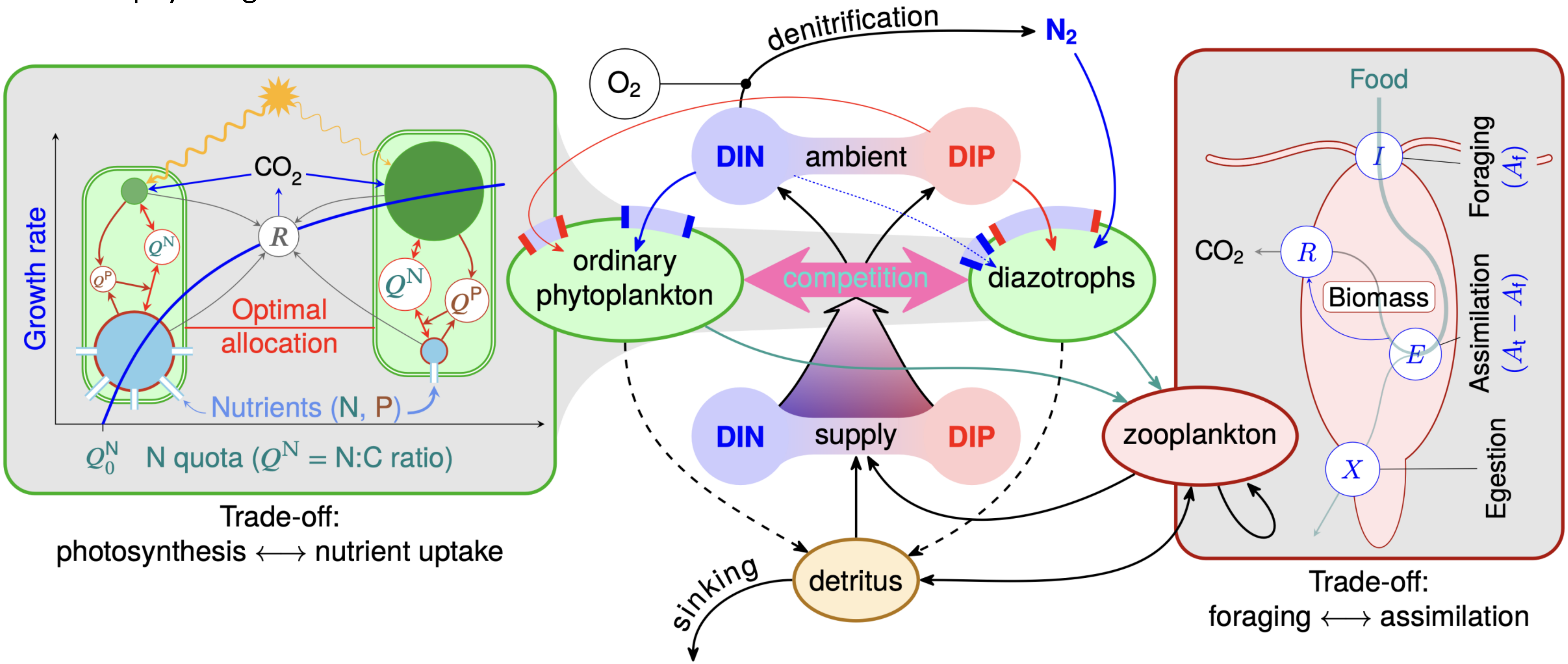
Calibration against lab data,
here marine copepod
Acartia Tonsa feeding on *Rohodomonas baltica*.
(Kiorboe et al., 1985)

Pahlow & Prowe (MEPS 2010)

OPEM structure ~ NPZD model

physiological trade-offs

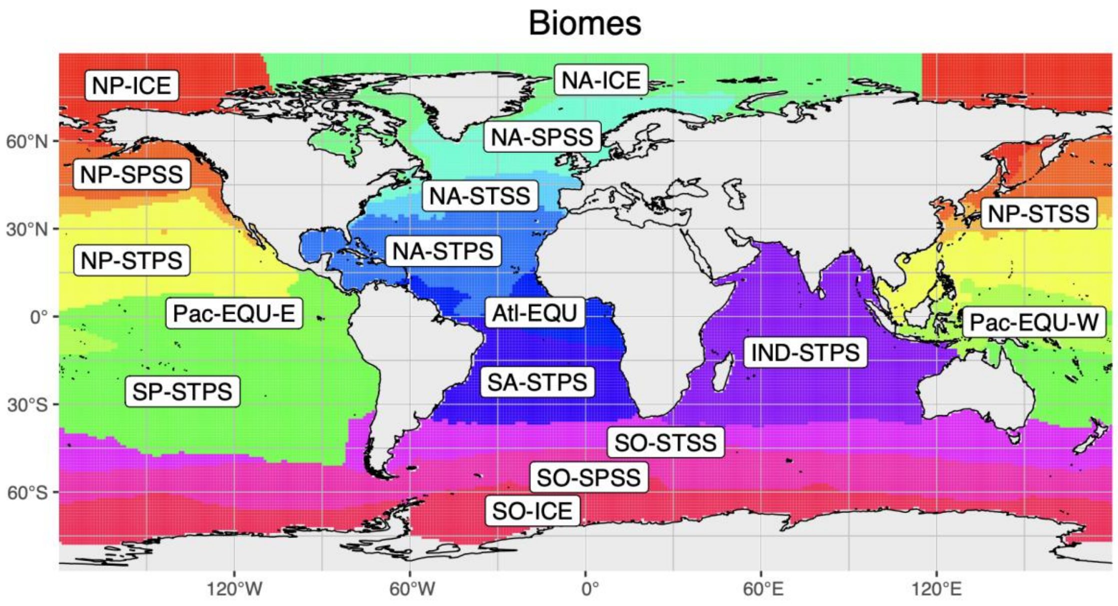
behavioral trade-offs

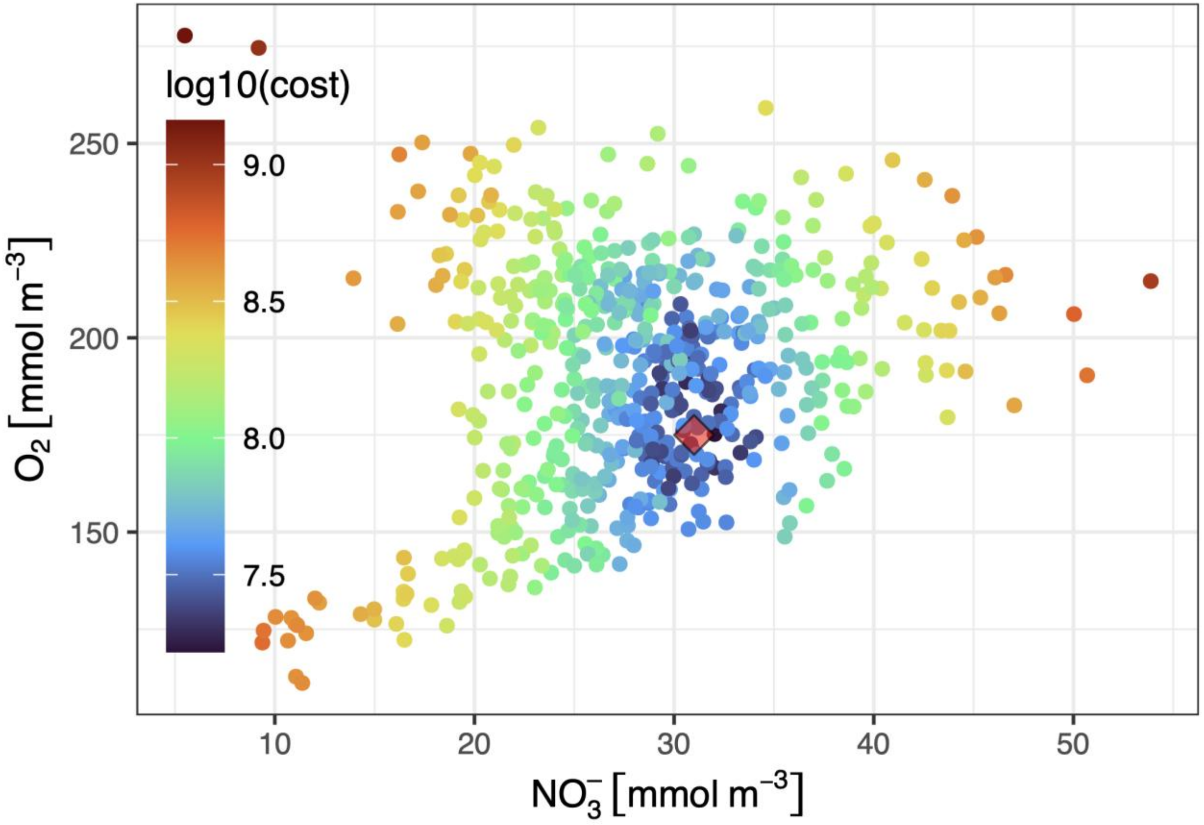


Pahlow et al. (GMD 2020)

UVic - OPEM calibration

- likelihood-based cost function considers correlations among tracers
- means, variances, correlations of Chl *a*, PO_4^{3-}, N*, AOU* in 17 biomes



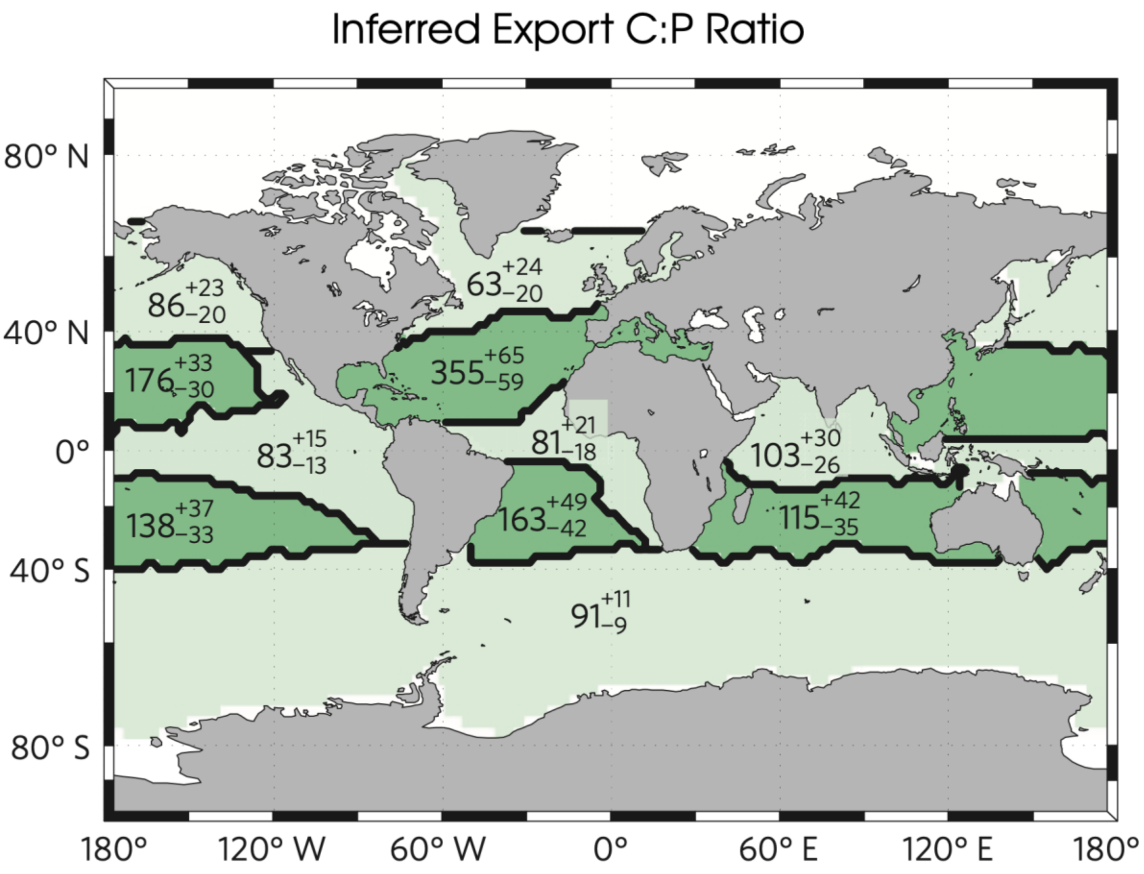


♦ = World Ocean Atlas 2018

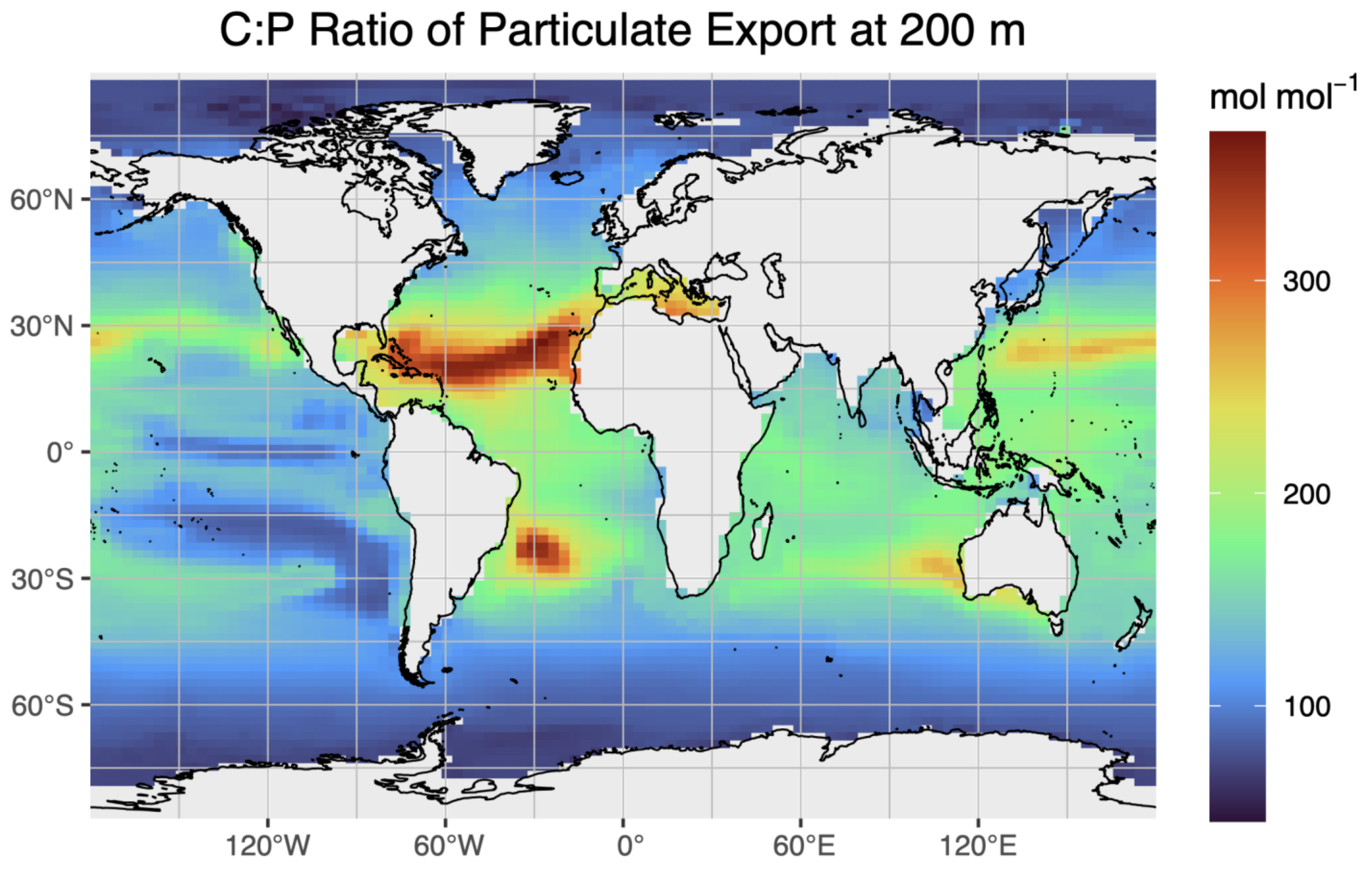
Chien et al. (GMD 2020)

UVic – OPEM: Export C:P

Teng et al., (2014)



UVic-OPEM



UVic – OPEM: Performance

	HD	IQD $\cdot 10^3$	Total
	NO_3^- / PO_4^{3-} / O_2	NO_3^- / PO_4^{3-} / O_2	HD / IQD $\cdot 10^3$
Kriest et al. (2020)			
MITgcm2.8, MOPS	0.030 / 0.028 / 0.030	1.103 / 0.751 / 1.147	0.089 / 3.001
ECCO, MOPS	0.030 / 0.028 / 0.027	1.038 / 0.743 / 0.852	0.086 / 2.632
UVic17.5, MOPS	0.035 / 0.031 / 0.032	1.549 / 1.036 / 1.361	0.098 / 3.946
UVic20, MOPS	0.033 / 0.028 / 0.030	1.217 / 0.773 / 1.057	0.090 / 3.047
UVicHigh, MOPS	0.032 / 0.029 / 0.031	1.094 / 2.420(?) / 1.076	0.093 / 4.590(?)
Heinemann et al. (2019)			
HAMOCC – standard	0.040 / 0.037 / 0.030	3.751 / 2.349 / 1.183	0.107 / 7.283
HAMOCC – ballast	0.043 / 0.038 / 0.029	4.707 / 2.380 / 1.314	0.110 / 8.402
Pahlow et al. (2020), Chien et al. (2020)			
UVic, OPEMv1.0	0.027 / 0.027 / 0.027	0.606 / 0.505 / 0.739	**0.080 / 1.850**

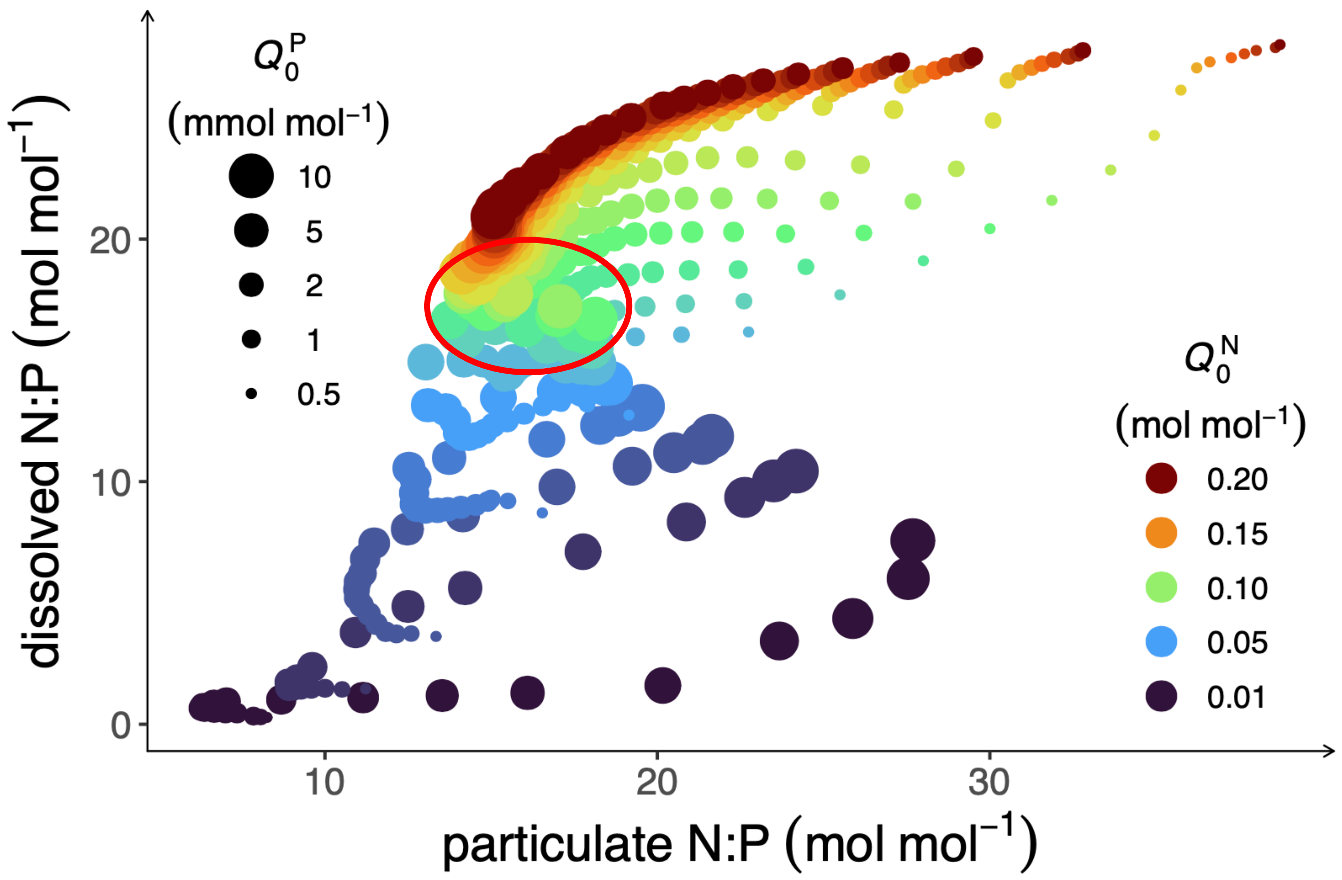
Metrics

HD Hellinger distance

IQD Integrated Quadratic Distance

From Kriest & Schartau (2020), Final Report, WG4.1, PalMod

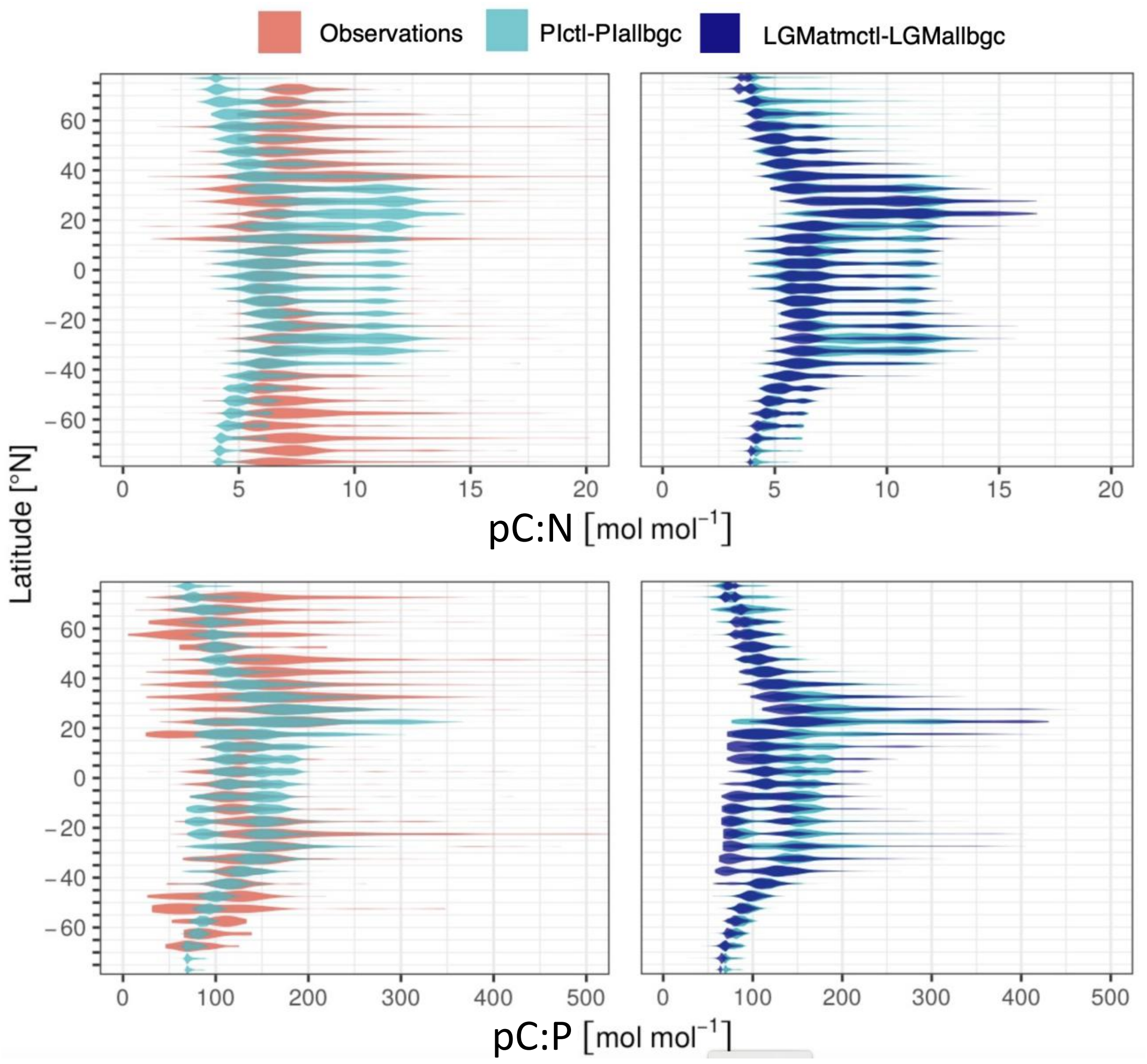
UVic – OPEM: Impacts of phytoplankton physiology on global ocean biogeochemistry



- Experiment: Varying subsistence N:P by a factor 400
  - ➢ yields 100-fold variation in dissolved N:P and only 6-fold in particulate N:P! **Redfield Ratio is "center of attraction"**
- Redox-mediated feedbacks between cell-scale physiology and Earth system stabilize oceanic nutrient N:P stoichiometry

Chien et al. (Sci.Adv. 2023)

UVic – OPEM: Last glacial maximum



UVic-OPEM applied to LGM

(atm.CO_2, winds, atm.moisture diffusivity, PO_4 inventory, atm. Fe supply, reduced benthic Fe supply, reduced benthic denitrification)

pC:N and pC:P in mid/low latitudes are **lower** during LGM.

Reduced sedimentary Fe supply outweighs increased atm. Fe supply

→ stronger Fe limitation

→ higher sPO_4, sNO_3

→ Lower pC:N, pC:P

Chien et al., in prep.

Conclusions

Virtual absence of first principles, have to rely on empirical models

- Comprehensive model calibration and sensitivity analysis is essential!
- Calibration tools are available (TMM, Andersen acceleration, (Uvic),…)
- Need comprehensive data sets (culture studies, mesocosm, field)

Single ‘average’ species models or adaptive models? MOPS vs OPEM?

- UVic-OPEM: promising first results,
  more variables (13 vs 9) but fewer free parameters (~20 vs ~30) than MOPS
- Which concept of ‘optimality’ is optimal?
  Timescales; species vs ecosystems; memory; biodiversity;…