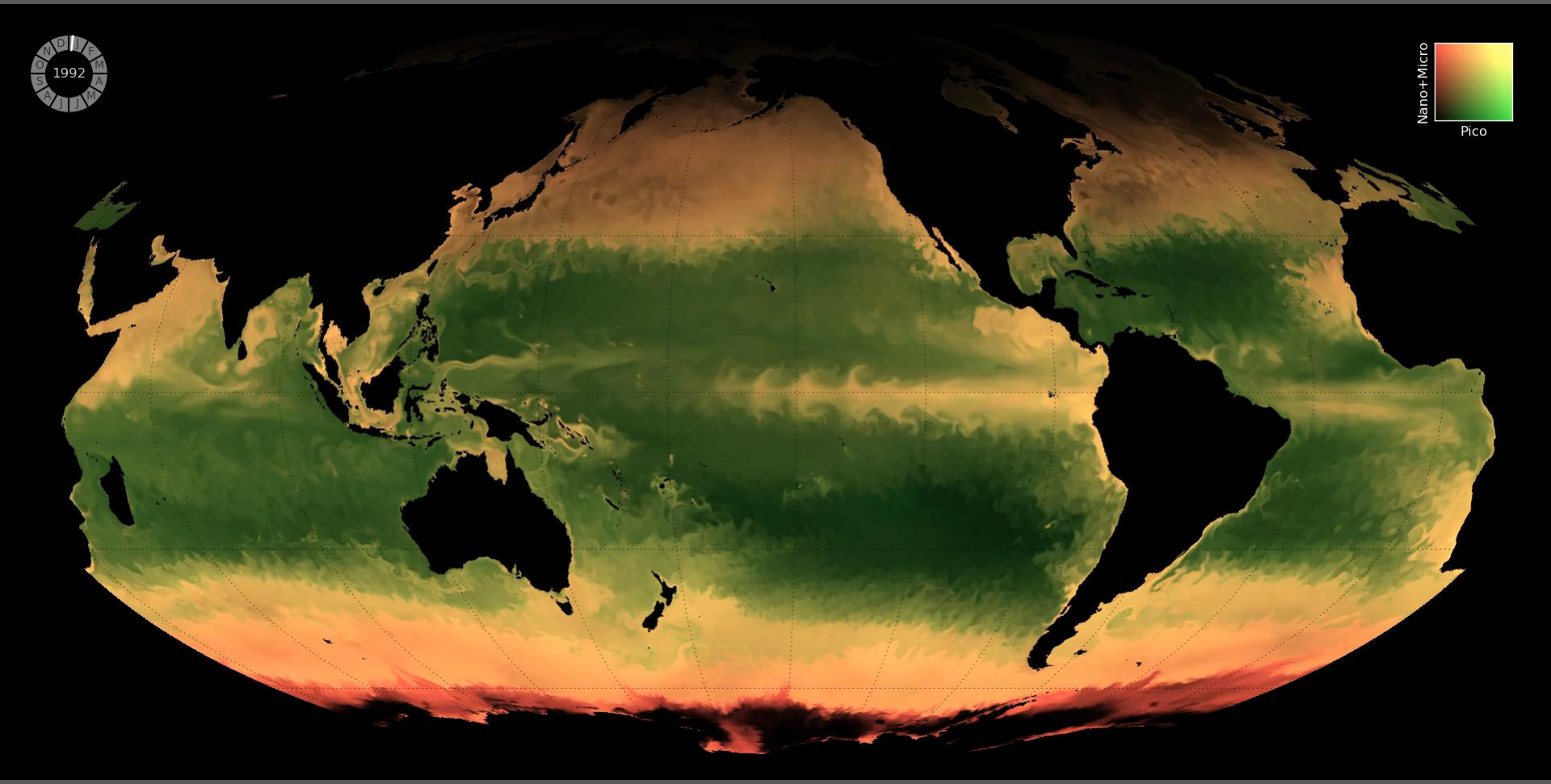
MODELLING DIVERSE PHYTOPLANKTON COMMUNITIES



Stephanie Dutkiewicz

Massachusetts Institute of Technology

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Mick Follows (MIT), **Oliver Jahn** (MIT),
Anna Hickman (U. Southampton), **Ben Ward** (U. Bristol)
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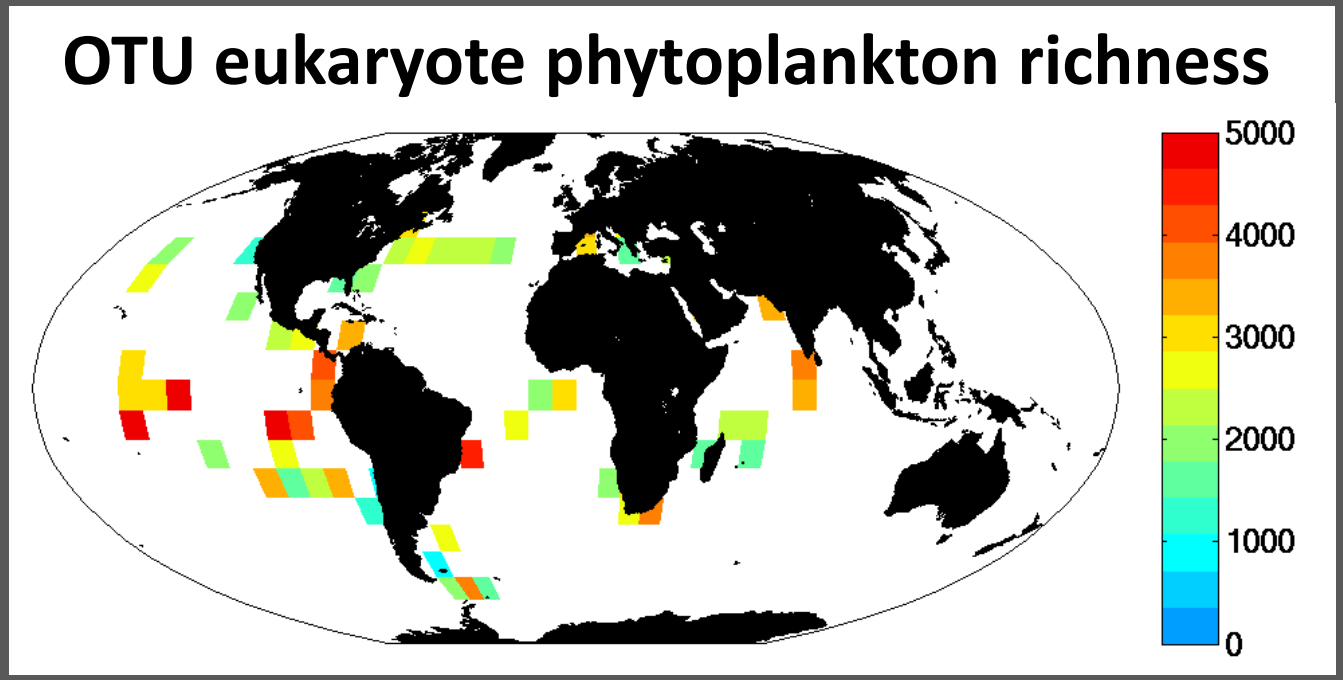
Sergio Vallina (Spanish Institute of Ocean), **Marina Levy** (UPMC)
Fi Prowe (Kiel U.) **Chris Follett** (MIT)

DIVERSITY OF PHYTOPLANKTON

Phytoplankton diversity matters:

- As base of foodweb
- For carbon cycling
- For resilience of ecosystem

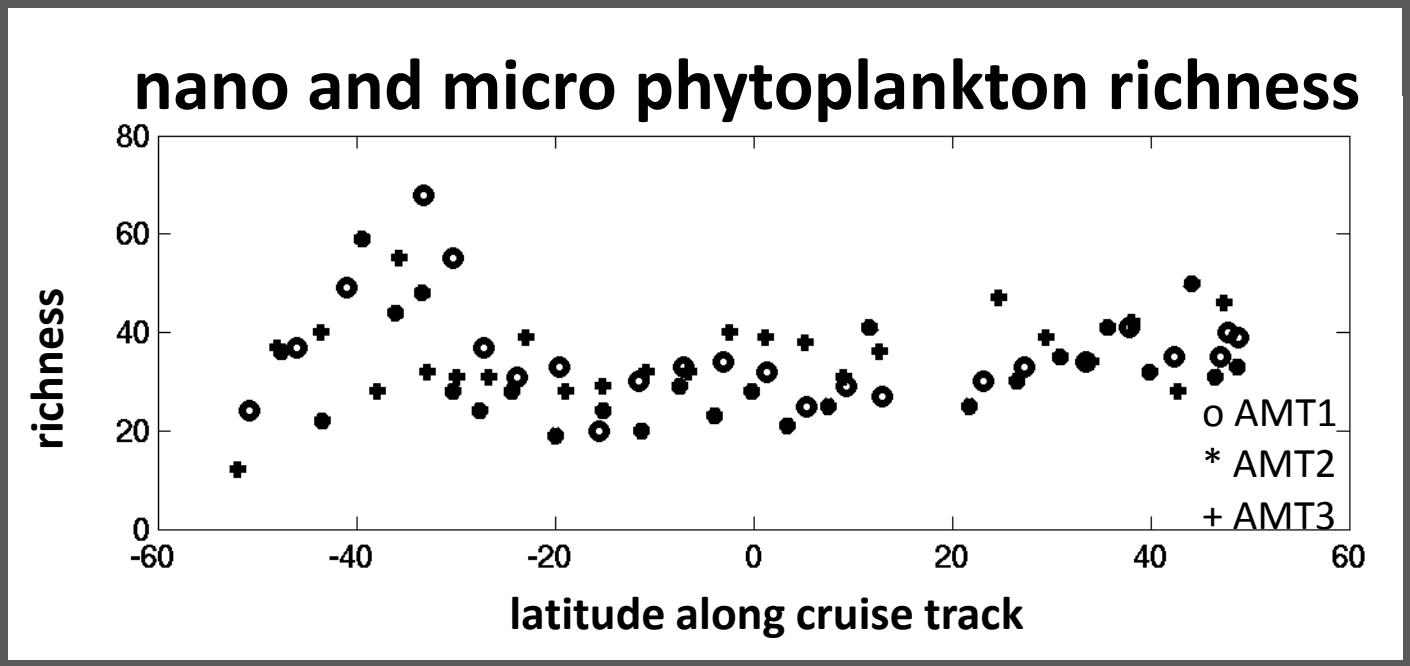
OBSERVING DIVERSITY

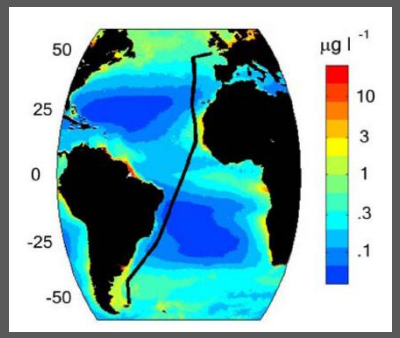


V9 18S rDNA metabarcoding

Unpublished data:
Courtesy of Shruti Malviya, Chris Bowler and the TARA consortium

OBSERVING DIVERSITY





Microscopy from AMT:
Data courtesy of Pedro Cermeno

OBSERVING DIVERSITY

What do observations tell us?

- *Distinct regional variations in diversity*
- *But still too sparse to formalize distinct patterns*

What controls the patterns of diversity?

- *Several theories of universal drivers (e.g. SST, latitude, productivity)*
- *But observations do not show any clear drivers*

(see e.g. Irigoien et al, 2004; Smith, 2007; Fuhrman et al, 2008; Chust et al, 2012; Cermeno et al, 2013; Rodrigues-Ramos et al 2015)

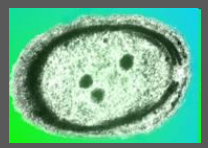
TALK OUTLINE

- Past MIT studies: Controls on diversity*
  (3 approaches exploring diversity)
- Current MIT work: Dimensions of diversity*
- Ongoing and future directions

**Diversity is not the only thing we are working on;*
and we are not the only ones working on this topic

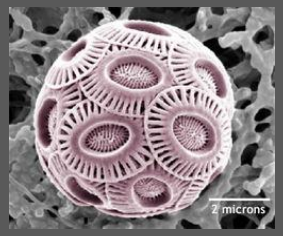
MODELLING DIVERSITY

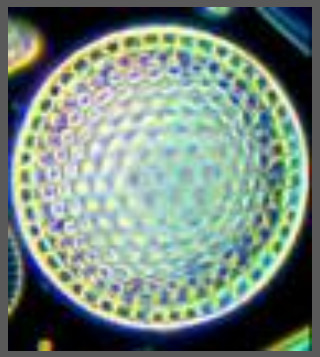
MODELLING DIVERSITY



pico

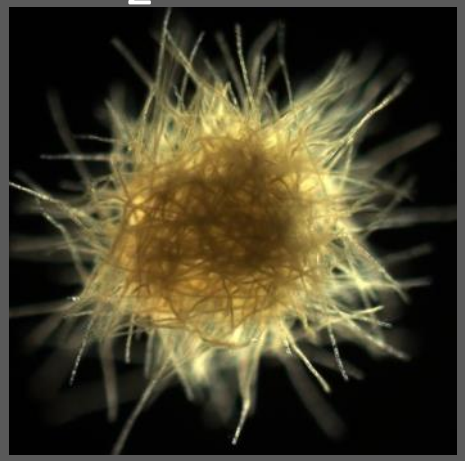
calcifiers

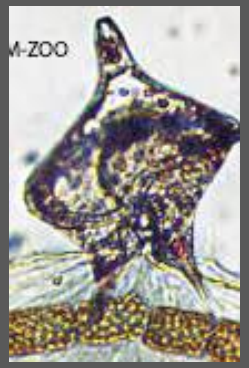




silicifiers

N_2 fixers

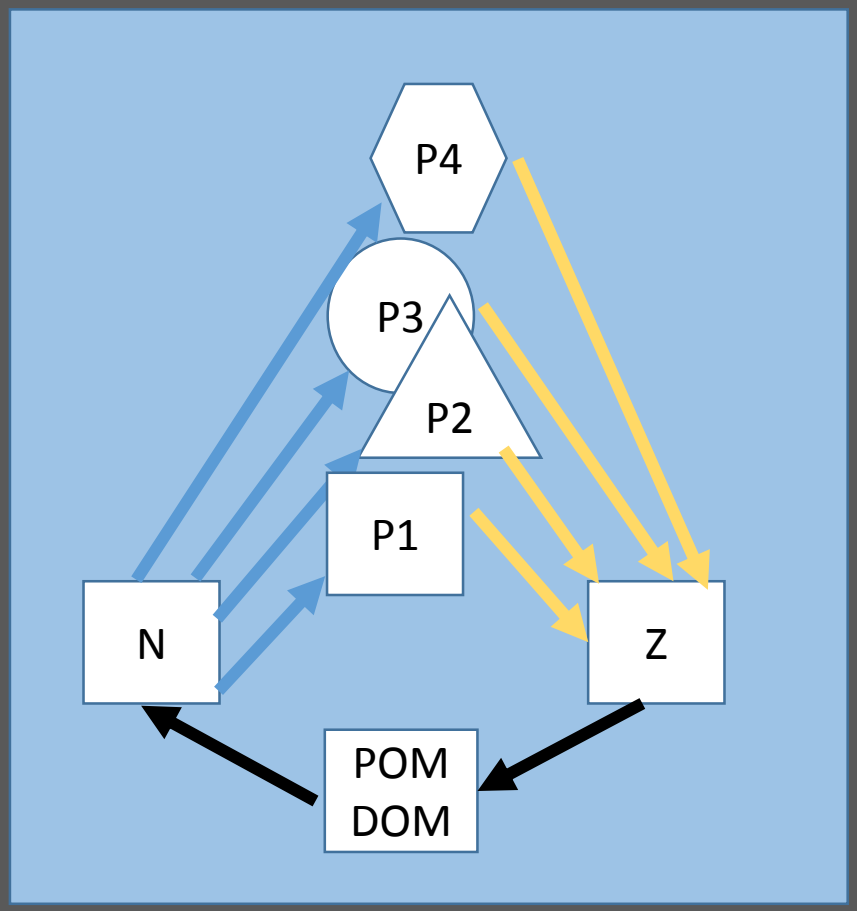




mixotrophs

phytoplankton functional types (PFT)

MODELLING DIVERSITY: PFTs



MIT model examples:
Dutkiewicz et al, GBC, 2001
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phytoplankton functional types

MODELLING DIVERSITY: PFTs

1. What controls co-existence of PFTs?

MODELLING DIVERSITY: PFTs

1. What controls co-existence of PFTs?

Seasonality:	*Dutkiewicz et al., GBC, 2009*
Grazing control:	*Ward et al., L&O, 2012*
Resource Supply ratio:	*Dutkiewicz et al., GBC, 2012*
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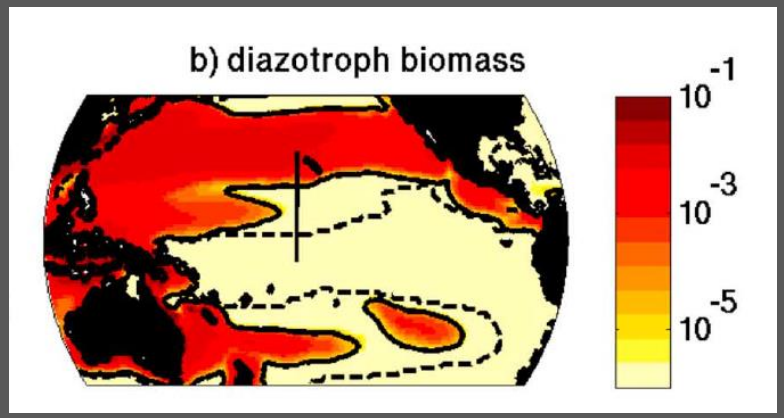
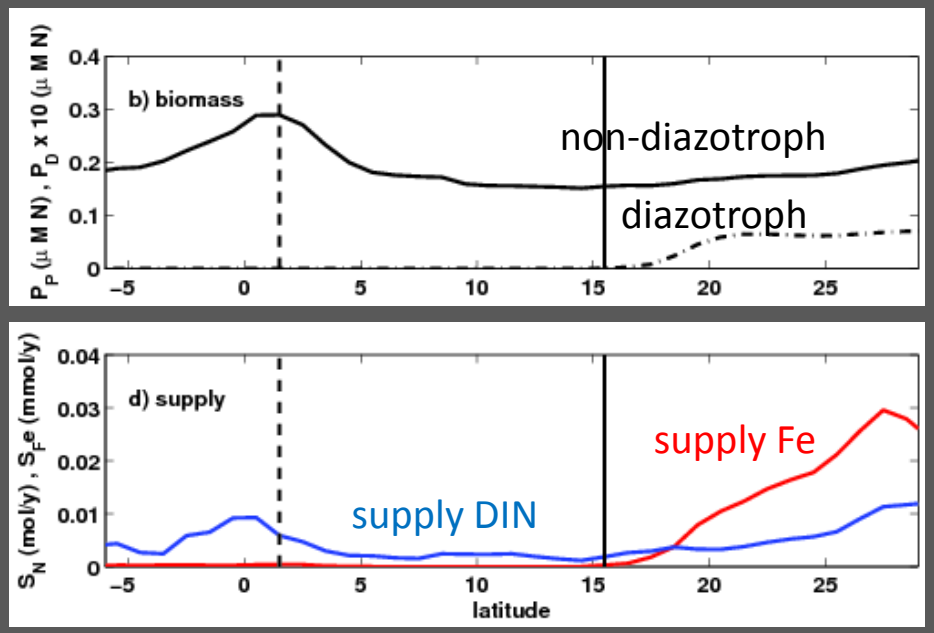
MODELLING DIVERSITY: PFTs

1. What controls co-existence of PFTs?

e.g. diazotrophs and non-diazotrophs *(Dutkiewicz et al., GBC, 2012)*

$$\mu_D < \mu_P$$





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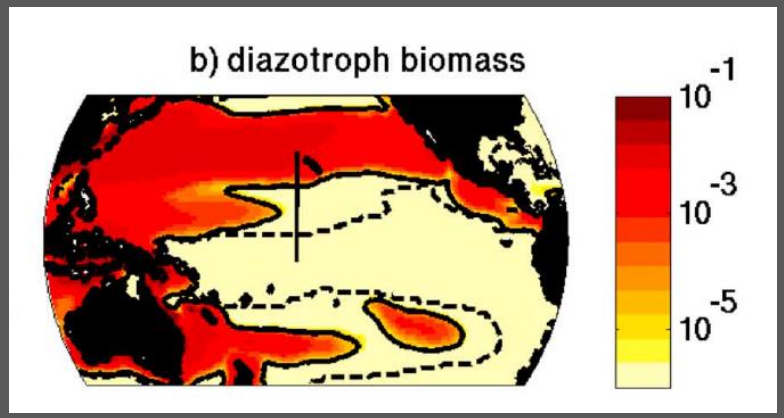
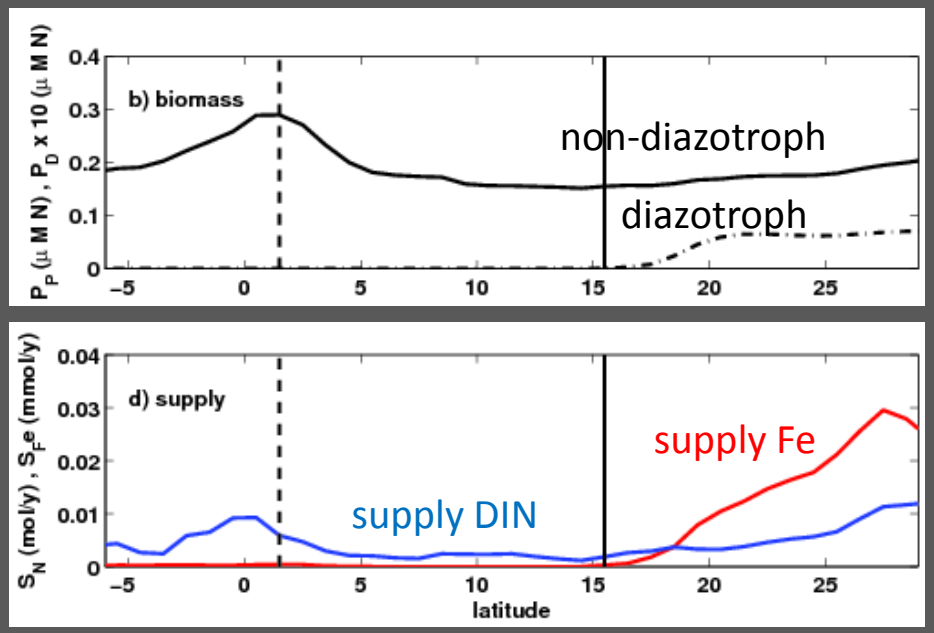
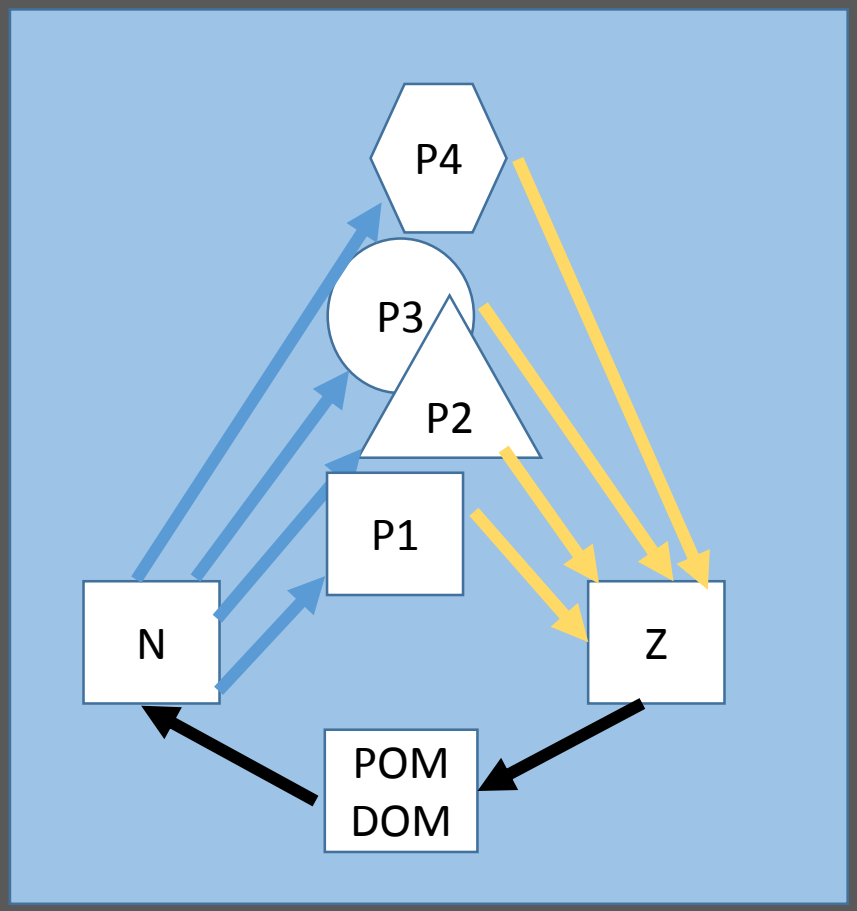




ratio Fe to N supply must be greater than non-diazotroph requirement for N

$$S^*_{Fe} : S^*_N \geq R_P$$

MODELLING DIVERSITY: PFTs



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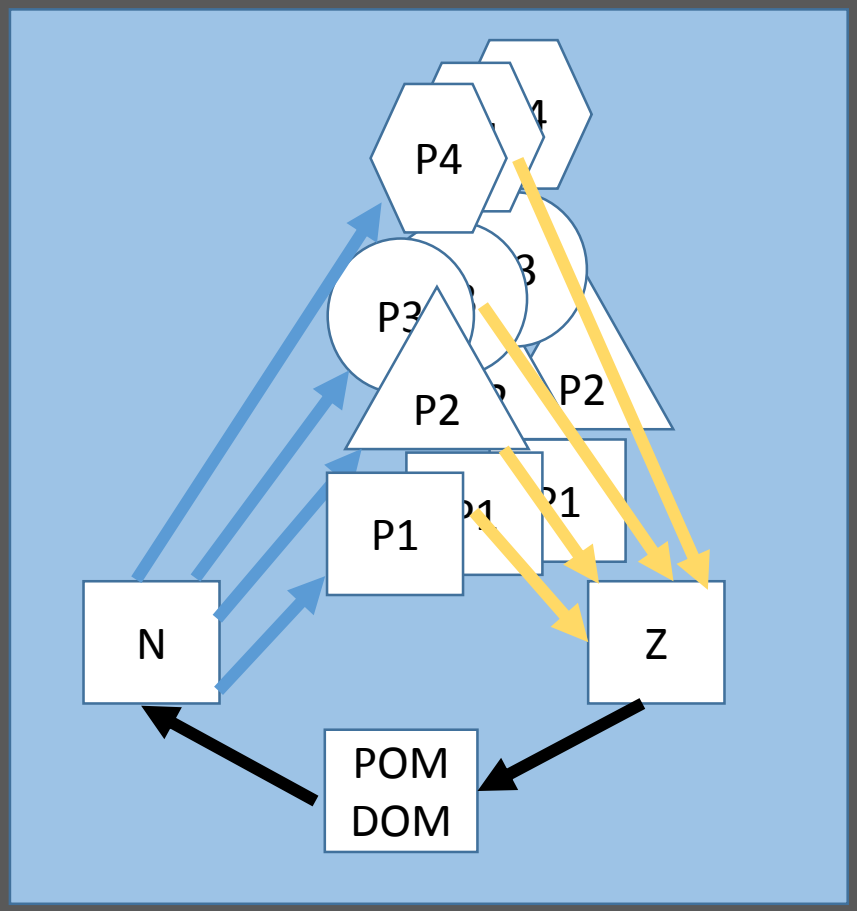
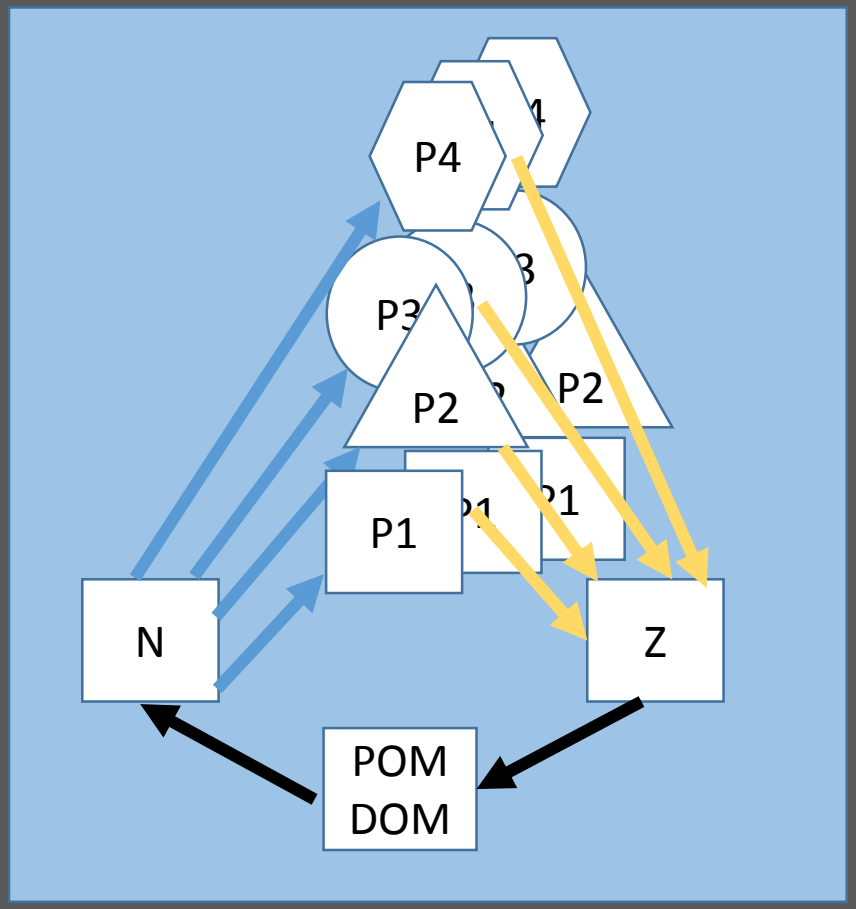
phytoplankton functional types

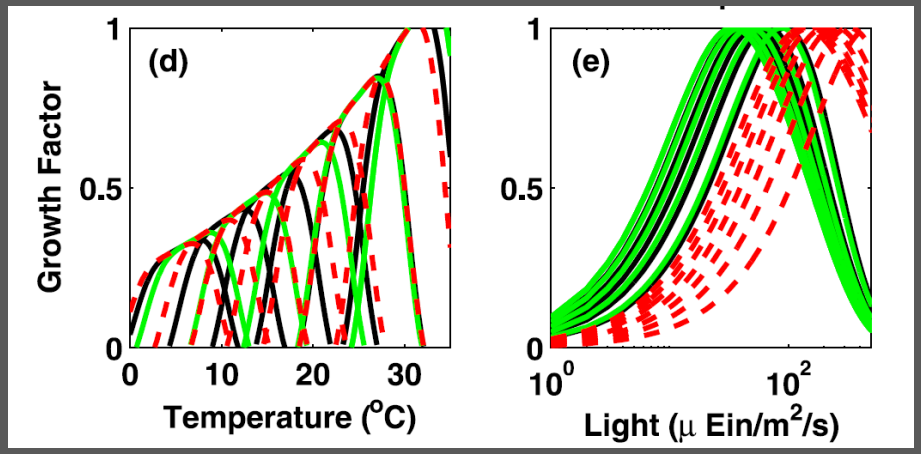
MODELLING DIVERSITY



diversity within functional types

MODELLING DIVERSITY WITHIN PFTs





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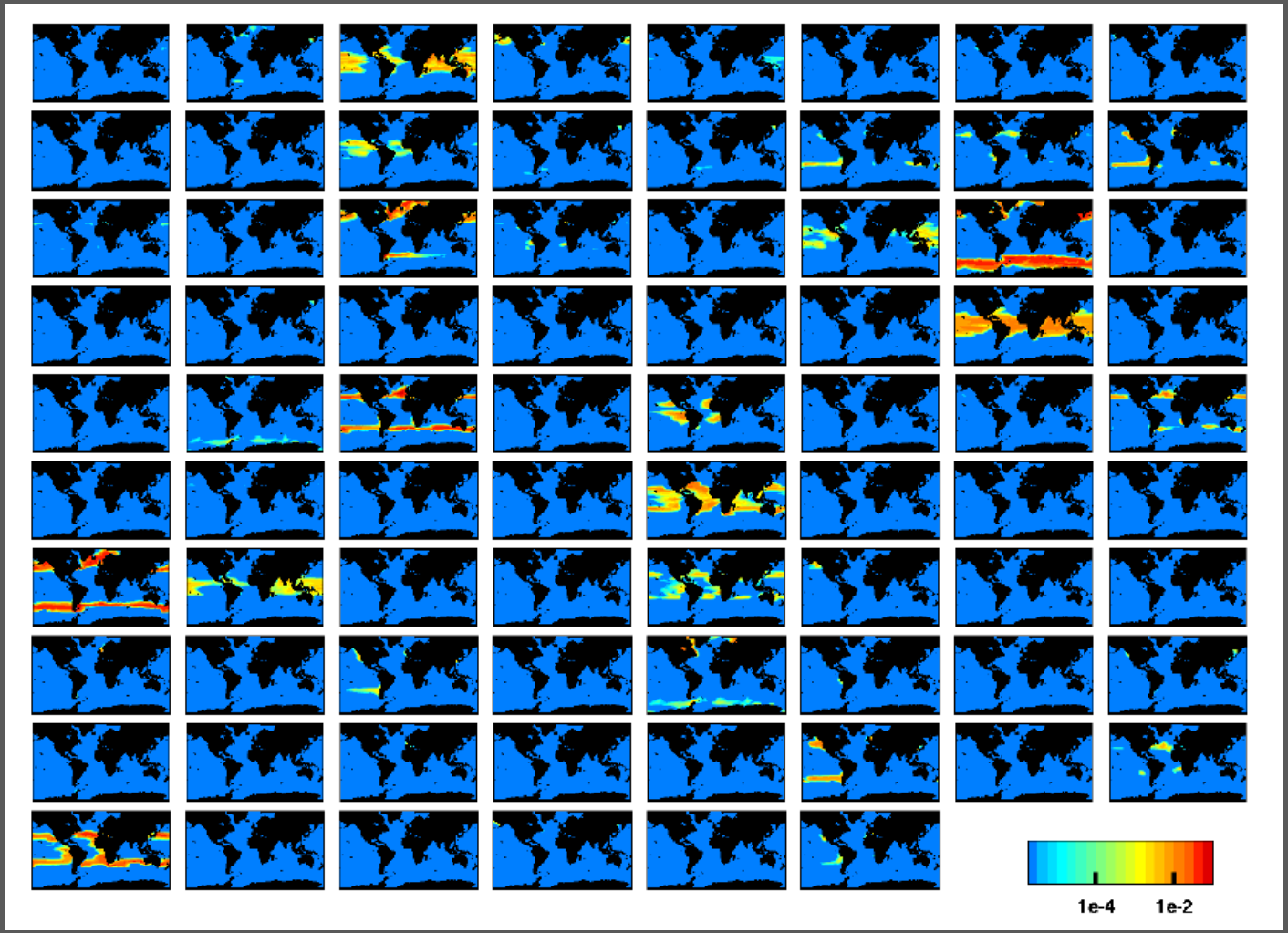
MODELLING DIVERSITY WITHIN PFTs



Follows et al, Science, 2007

MODELLING DIVERSITY WITHIN PFTs

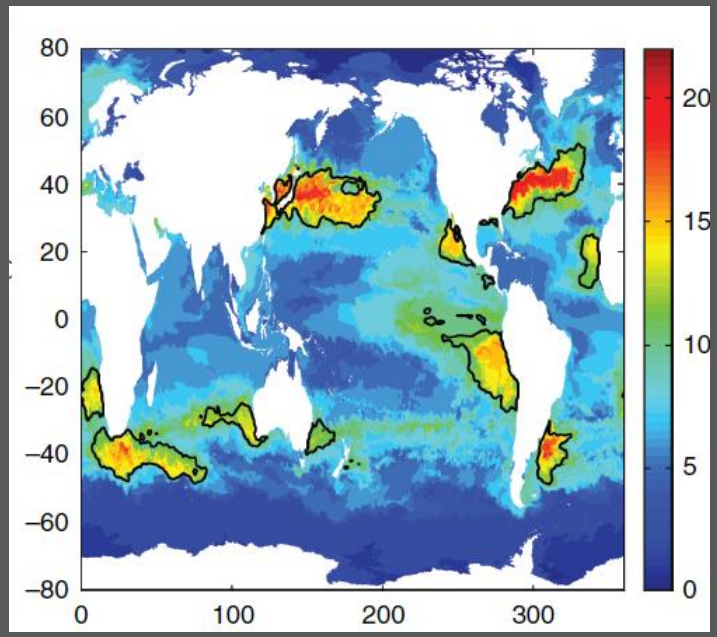
2. What controls diversity:

Neutral Theory: *Barton et al, Science, 2010*

Roles of grazers: *Vallina et al, Prog. Ocean., 2014*
Prowe et al, Prog. Ocean., 2011

Role of transport: *Clayton et al, L&O F&E, 2013*
Levy et al, L&O F&E, 2013
Levy et al, RFIF, 2015

Richness (# phytoplankton types co-existing)



Clayton et al, L&O F&E, 2013

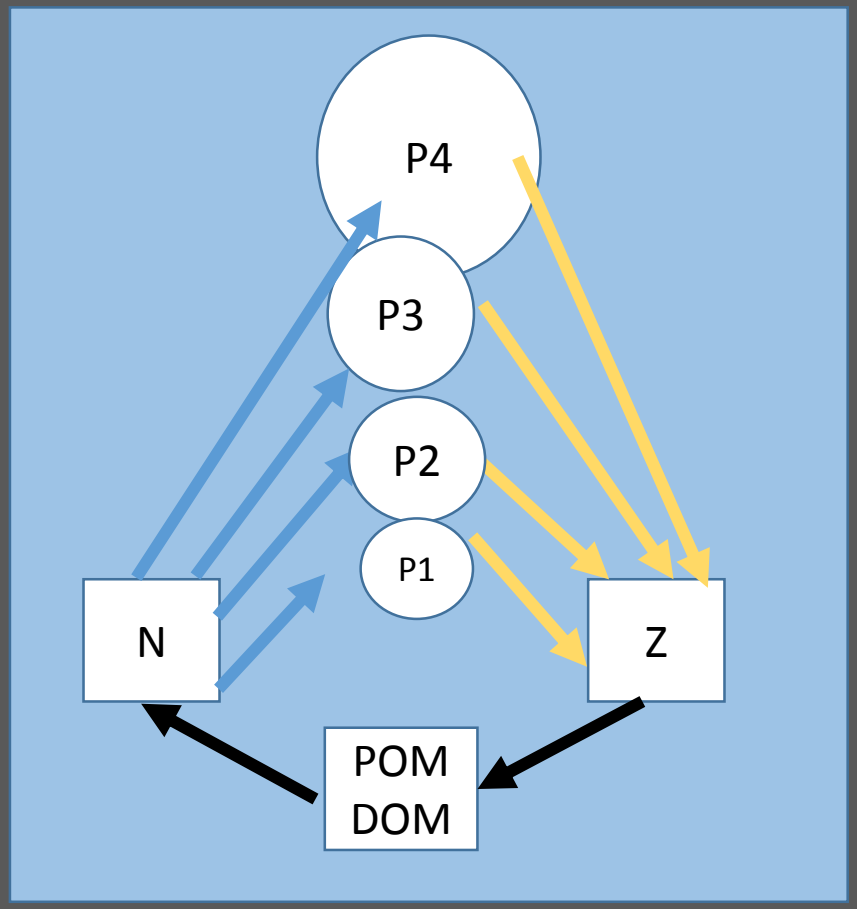
MODELLING DIVERSITY: SIZE CLASSES

MODELLING DIVERSITY: SIZE CLASSES

Many parameters are a function of cell volume:

aV^b

(e.g. max growth rate, affinity, sinking etc)



phytoplankton size classes

MIT model examples:
Ward et al, L&O 2012
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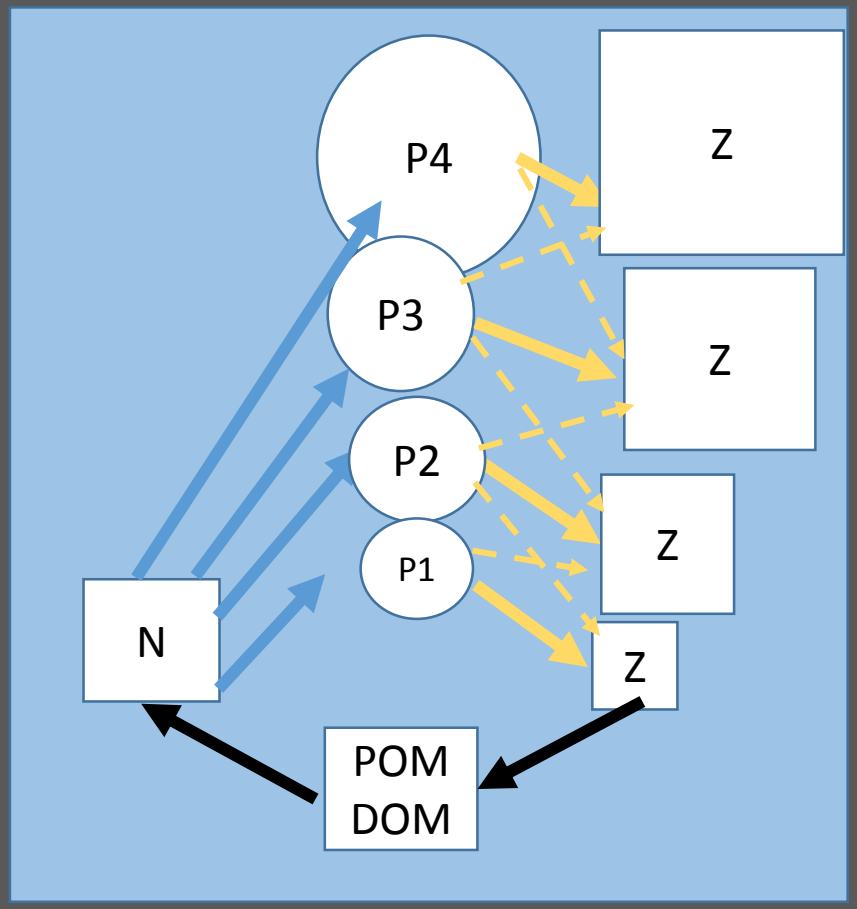

phytoplankton size classes

MIT model examples:
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MODELLING DIVERSITY

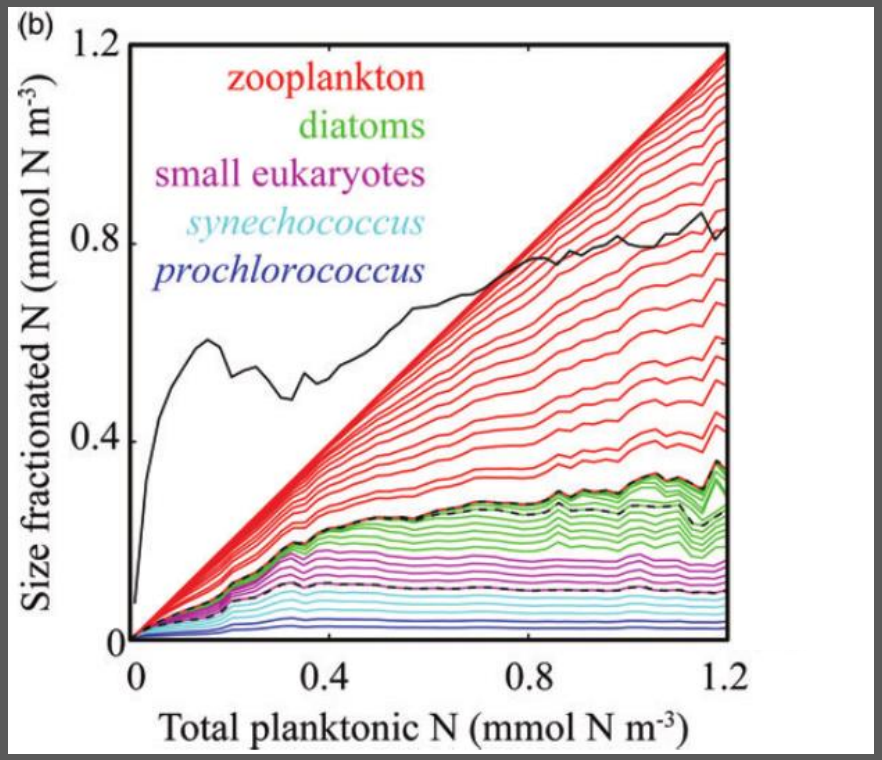
3. What control number of co-existing size classes?

e.g. Roles of nutrient supply rate and grazers: *Ward et al, JPR, 2013*

Rate of supply of nutrient allows increase biomass

Size specific grazing allows different size phytoplankton classes to make up the biomass

(see eg Armstrong 1999)



increased supply of nutrients

MODELLING DIVERSITY

Some lessons learnt:

- We can't model species by species
  (too many unknown parameters)

- Trait based approach can help
  (minimize parameters by having them function of a trait such as size)

- But diversity patterns depends on metric you consider

TALK OUTLINE

- Past MIT studies: Controls on diversity*

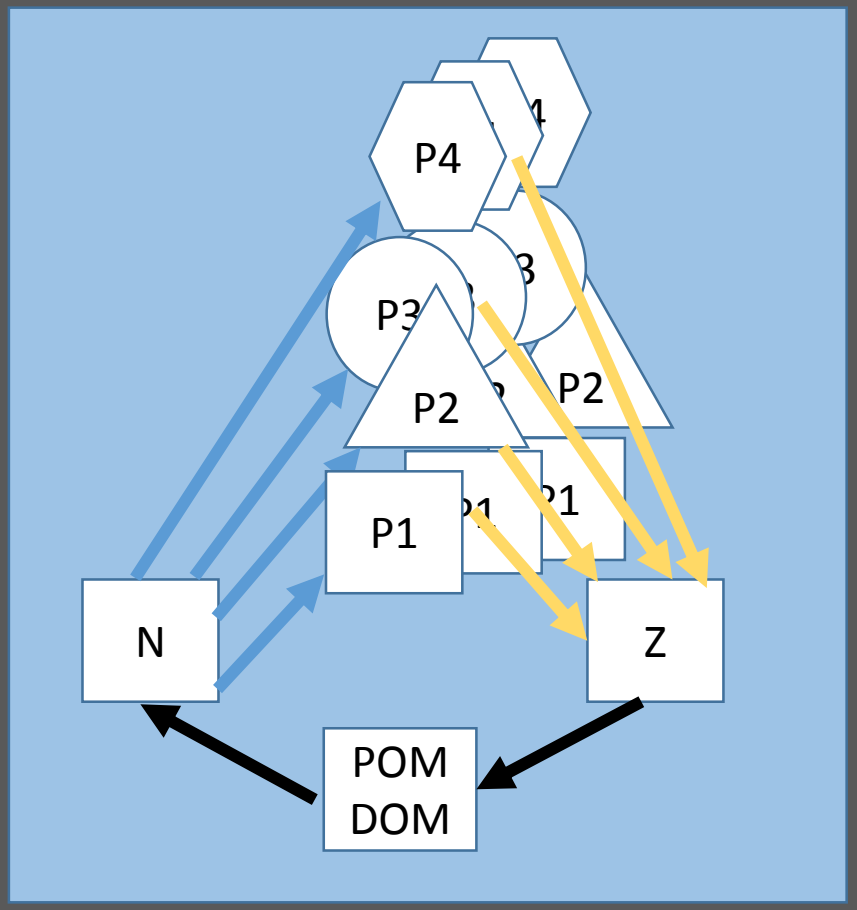
  (3 approaches exploring diversity)

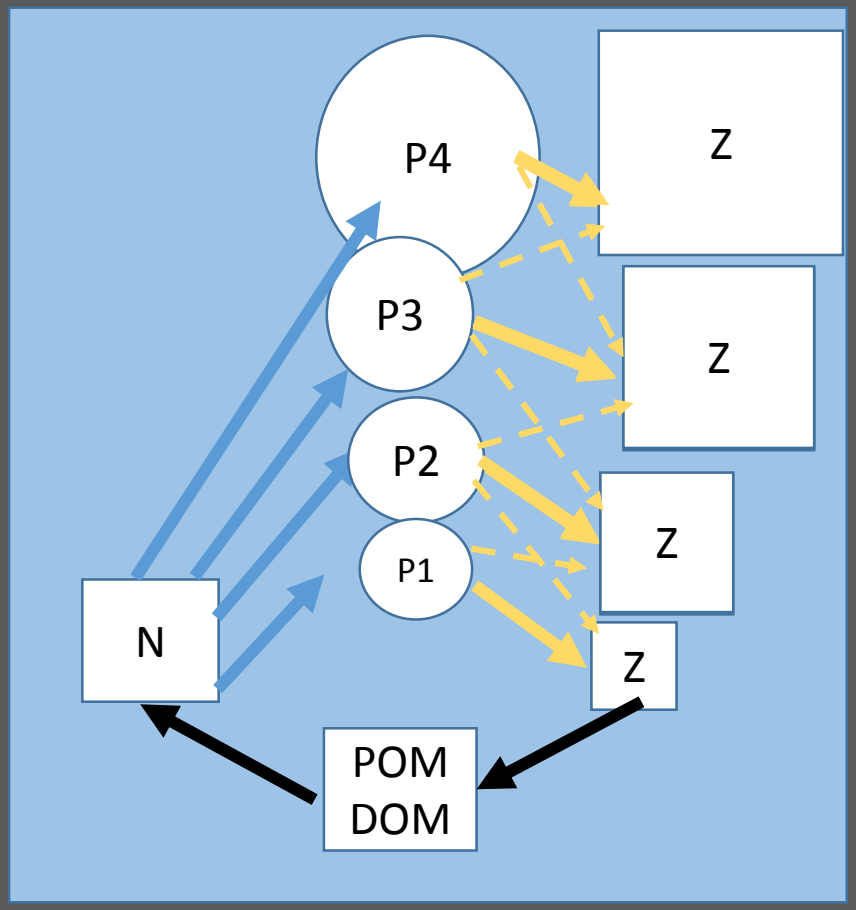
- Current MIT work: Dimensions of diversity*

- Ongoing and future directions

**Diversity is not the only thing we are working on; and we are not the only ones working on this topic*

MODELLING DIVERSITY





DIMENSIONS OF DIVERSITY

Phytoplankton differ in terms of:

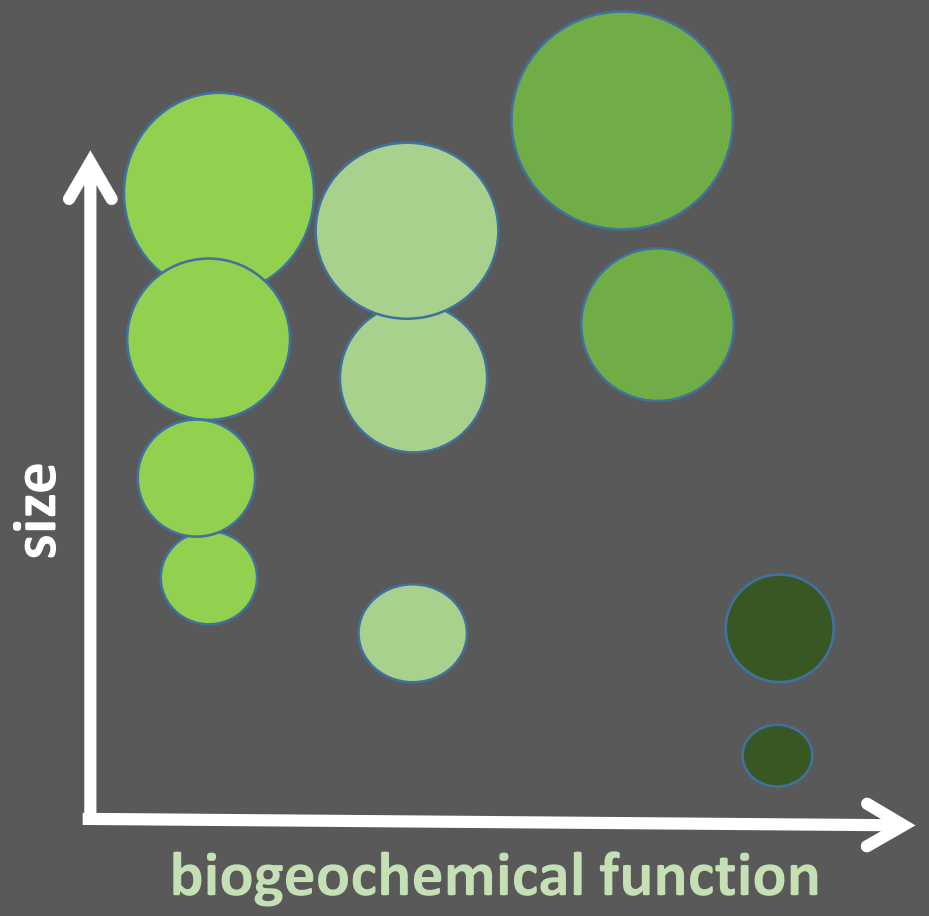
- Size
- etc

DIMENSIONS OF DIVERSITY

Phytoplankton differ in terms of:

- size
- trophic strategy
- biogeochemical function
- accessory pigments

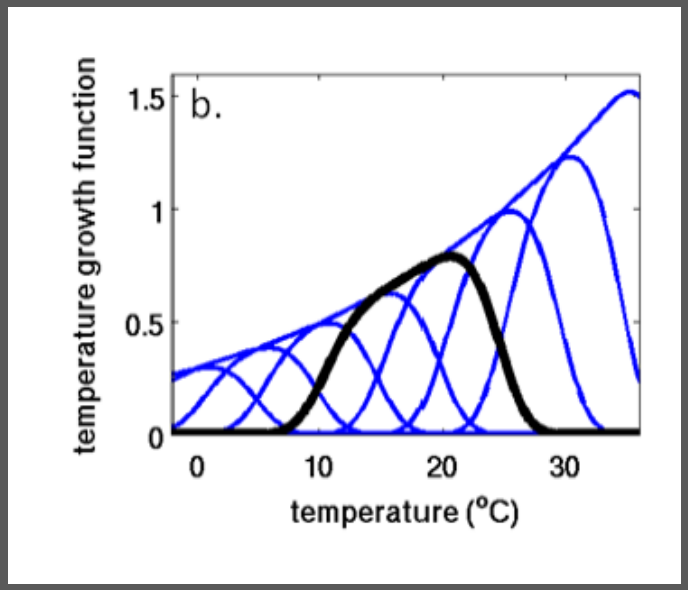
- etc

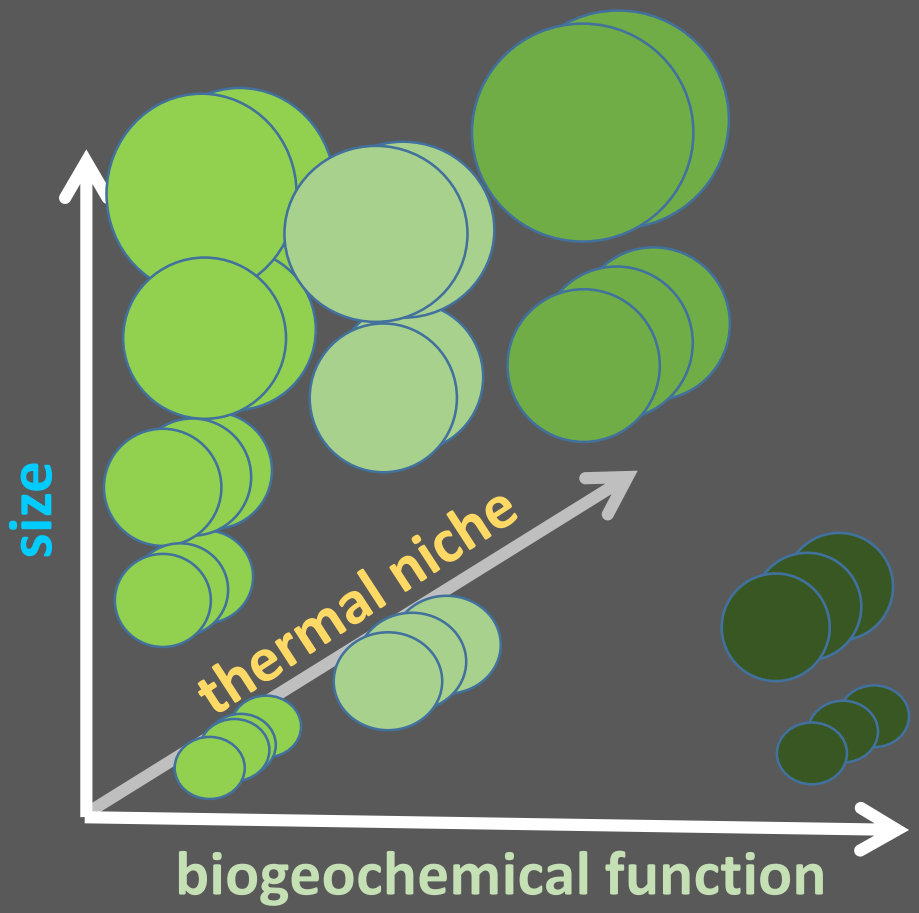


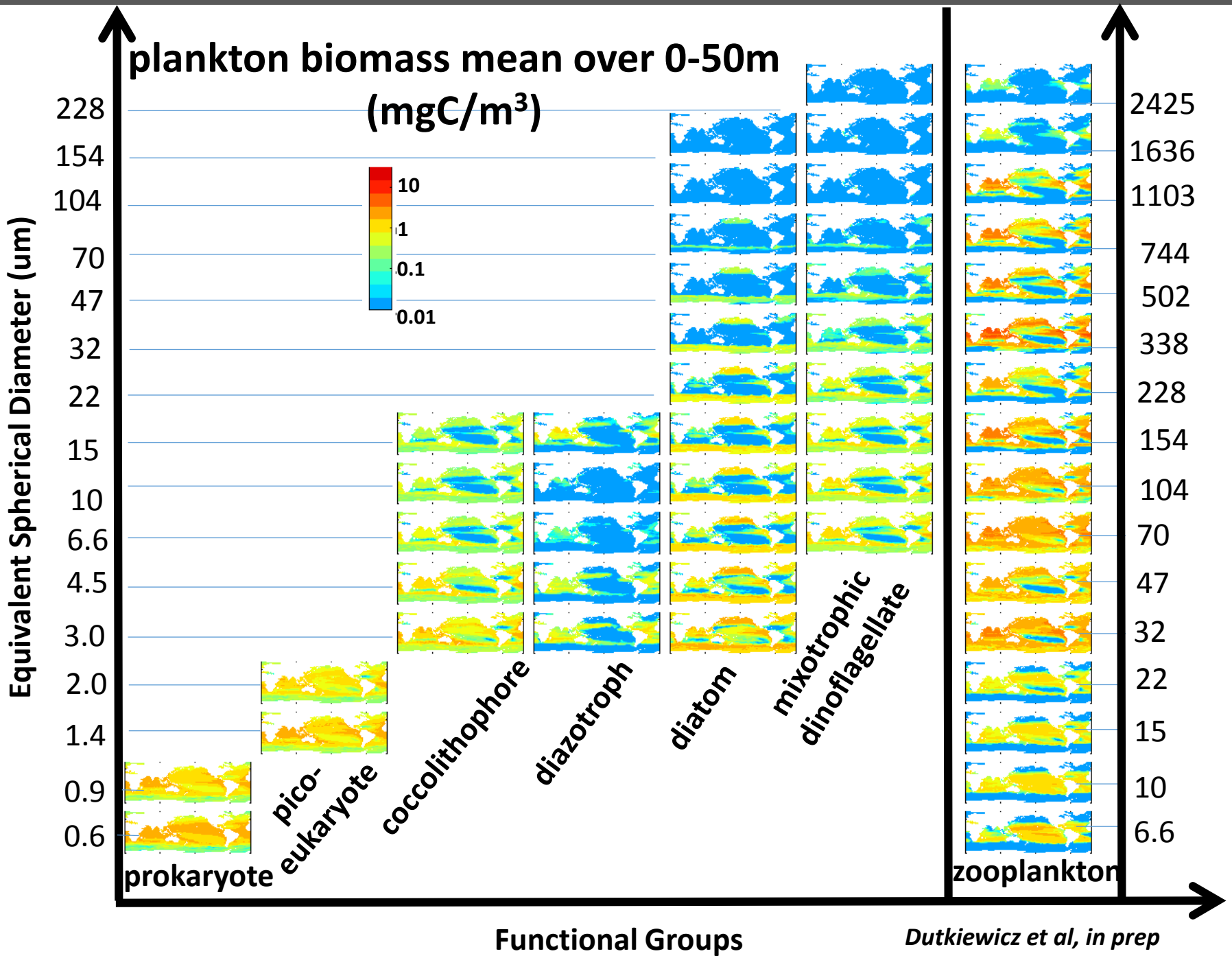
DIMENSIONS OF DIVERSITY

Phytoplankton differ in terms of:

- size
- trophic strategy
- biogeochemical function
- accessory pigments
- thermal niche






plankton biomass mean over 0-50m
(mgC/m³)
10
1
0.1
0.01
Equivalent Spherical Diameter (um)
228
154
104
70
47
32
22
15
10
6.6
4.5
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2.0
1.4
0.9
0.6
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pico-
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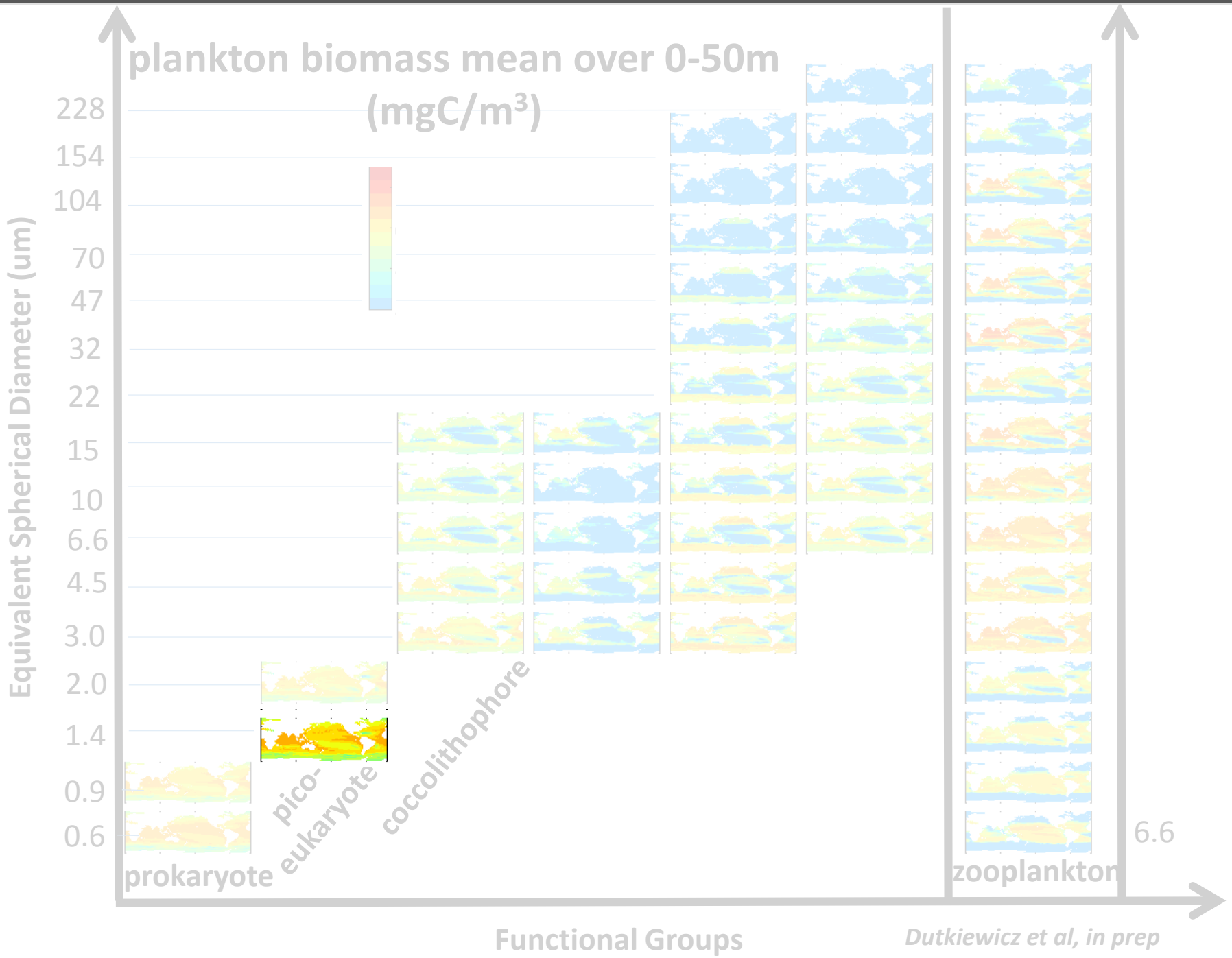
coccolithophore
diazotroph
diatom
mixotrophic
dinoflagellate
zooplankton
Functional Groups
Dutkiewicz et al, in prep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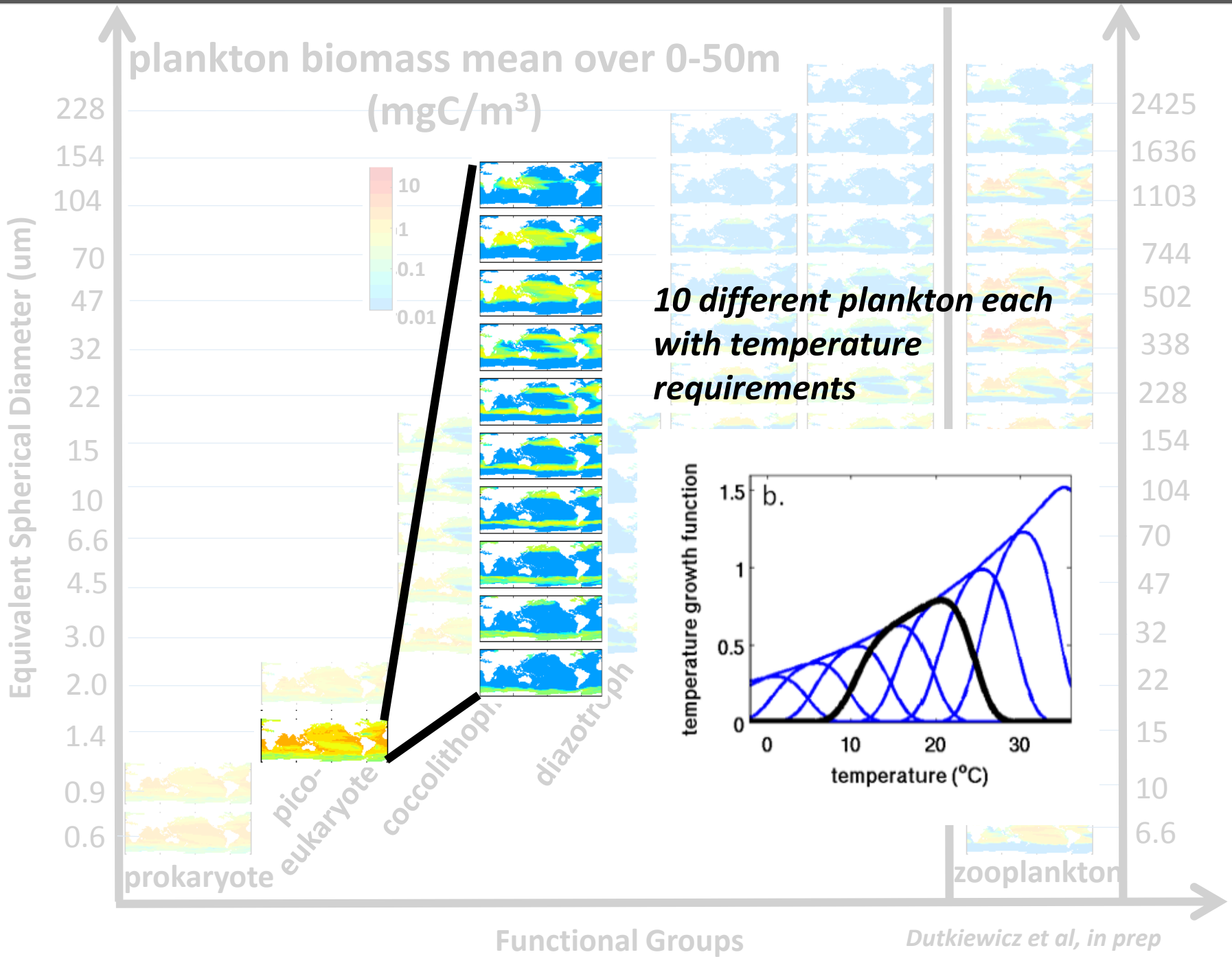
Dutkiewicz et al, in prep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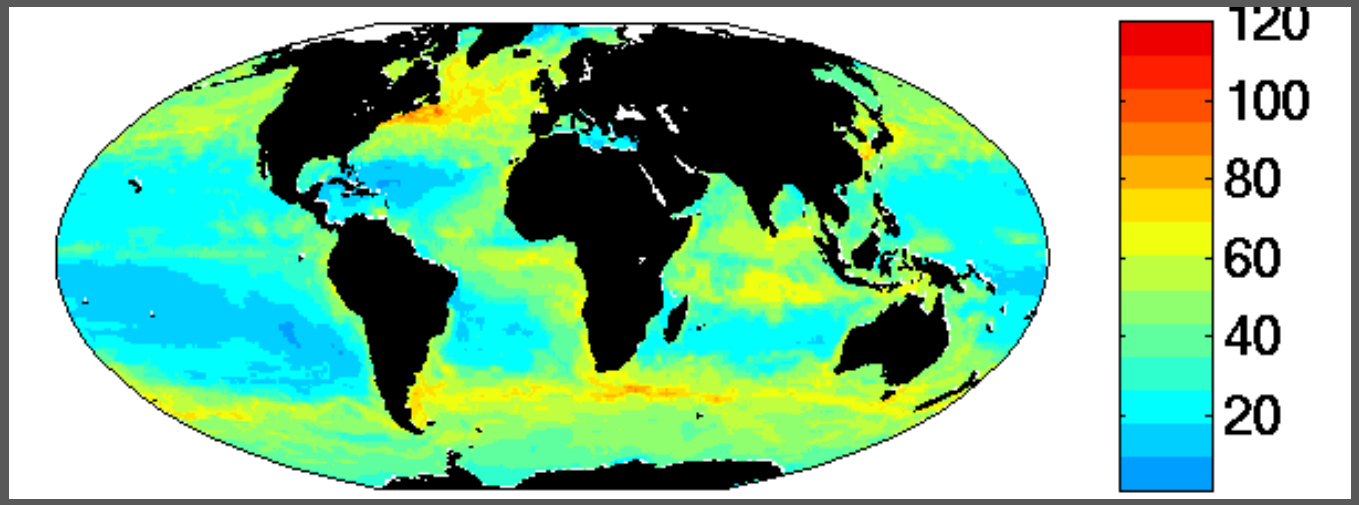
Functional Groups
10 different plankton each with temperature requirements
b.
temperature growth function
1.5
1
0.5
0
0
10
20
30
temperature (°C)
Dutkiewicz et al, in prep

DIMENSIONS OF DIVERSITY

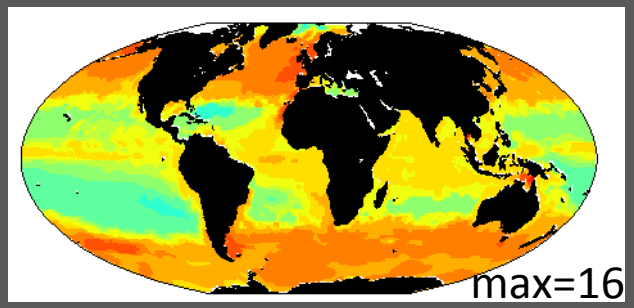
modelled richness (annual)



Dutkiewicz et al, in prep

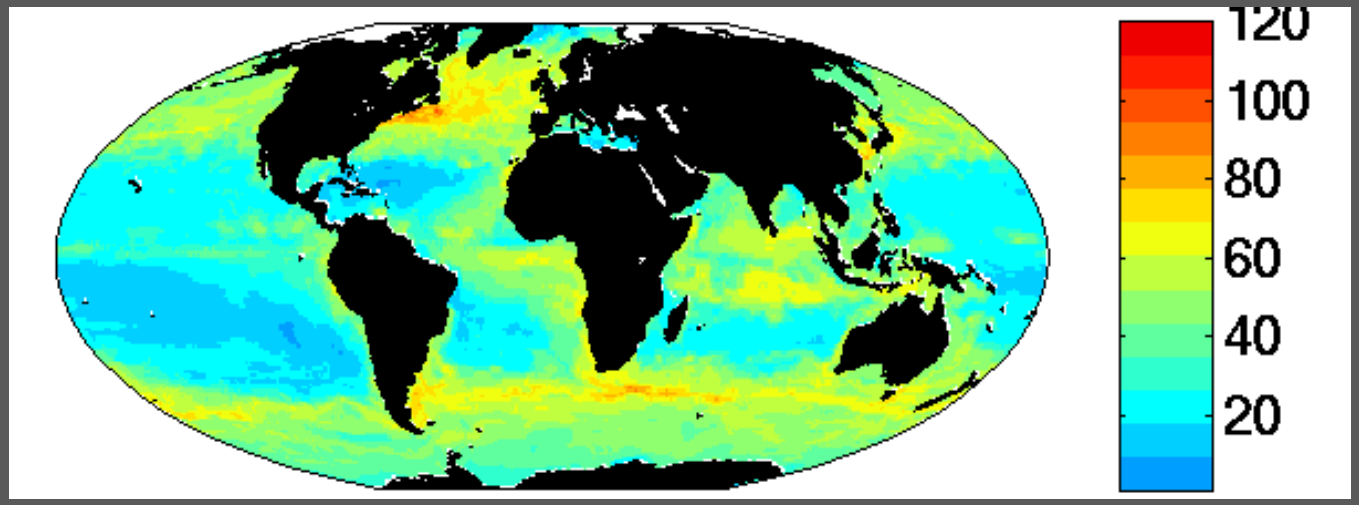
DIMENSIONS OF DIVERSITY

Dimensions: size classes



Richness normalized to maximum within dimension

modelled richness (annual)



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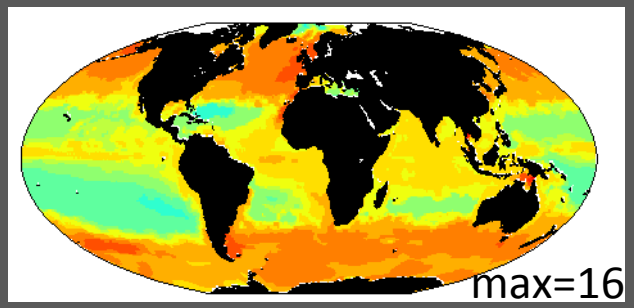
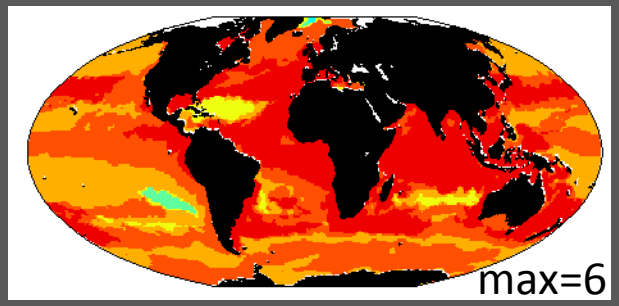
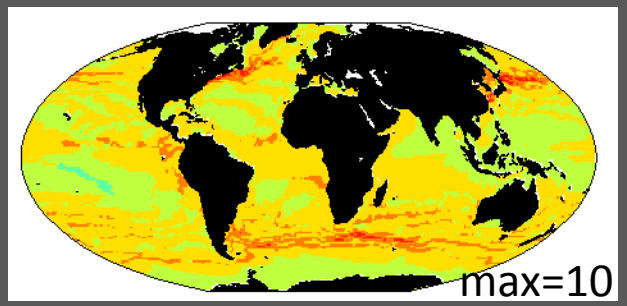


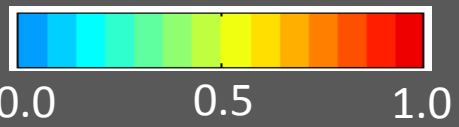
functional groups



thermal niche



Richness normalized to maximum within dimension



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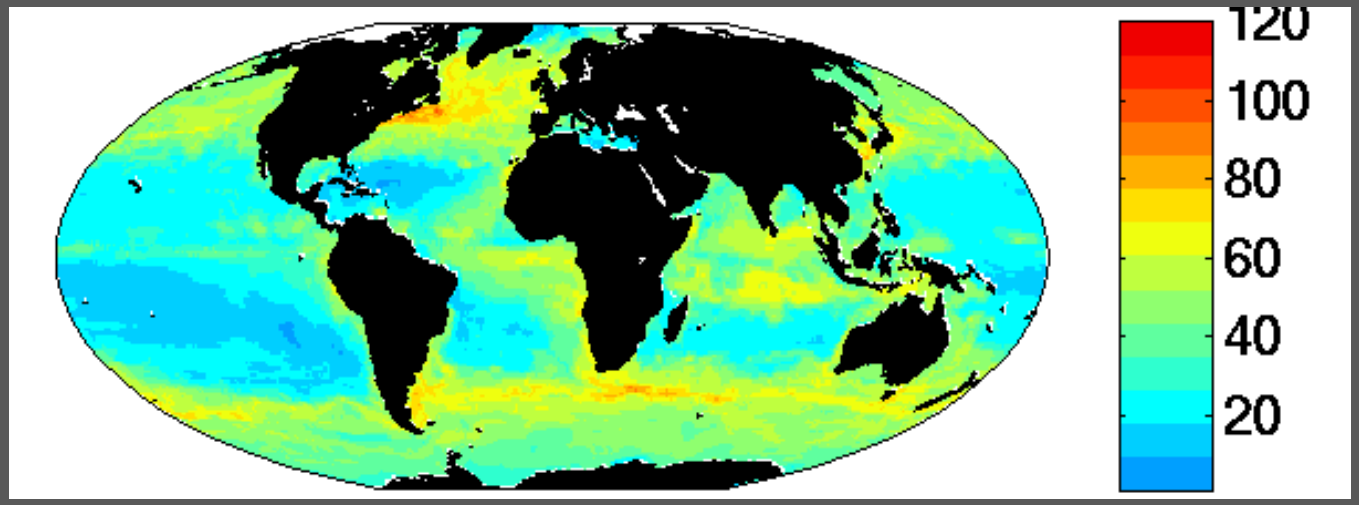

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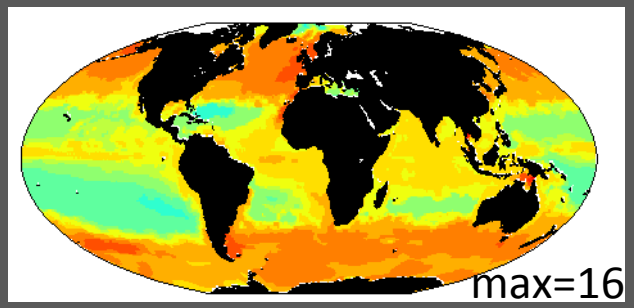
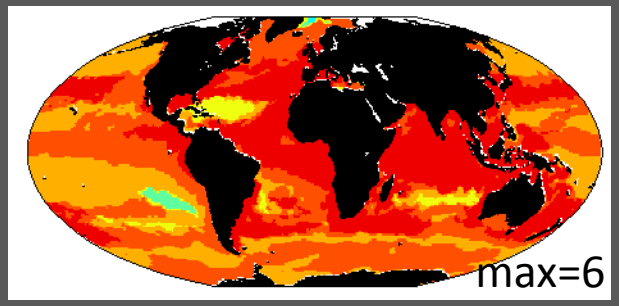
DIMENSIONS OF DIVERSITY

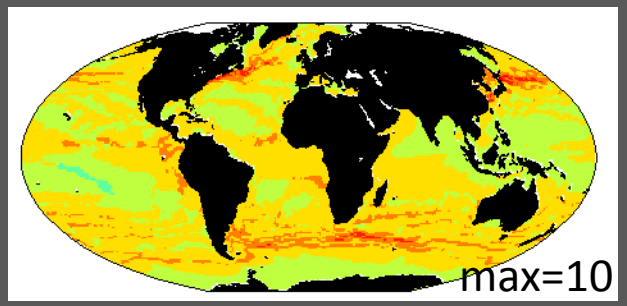
Dimensions: size classes



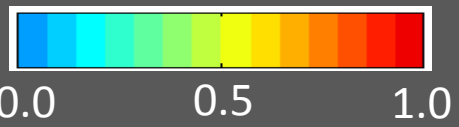
functional groups



thermal niche



Richness normalized to maximum within dimension



Largely controlled by:

rate of supply of limiting resource and size specific grazing

(see e.g. Armstrong, 1999; Ward et al, JPR, 2014)

ratio of supply of different resources

(see e.g. Ward et al, 2013; Dutkiewicz et al, BG, 2014)

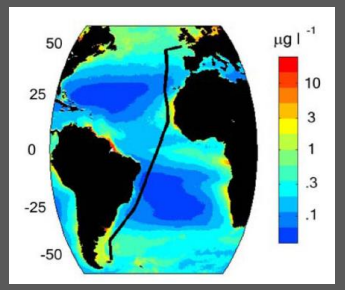
degree of mixing of water masses

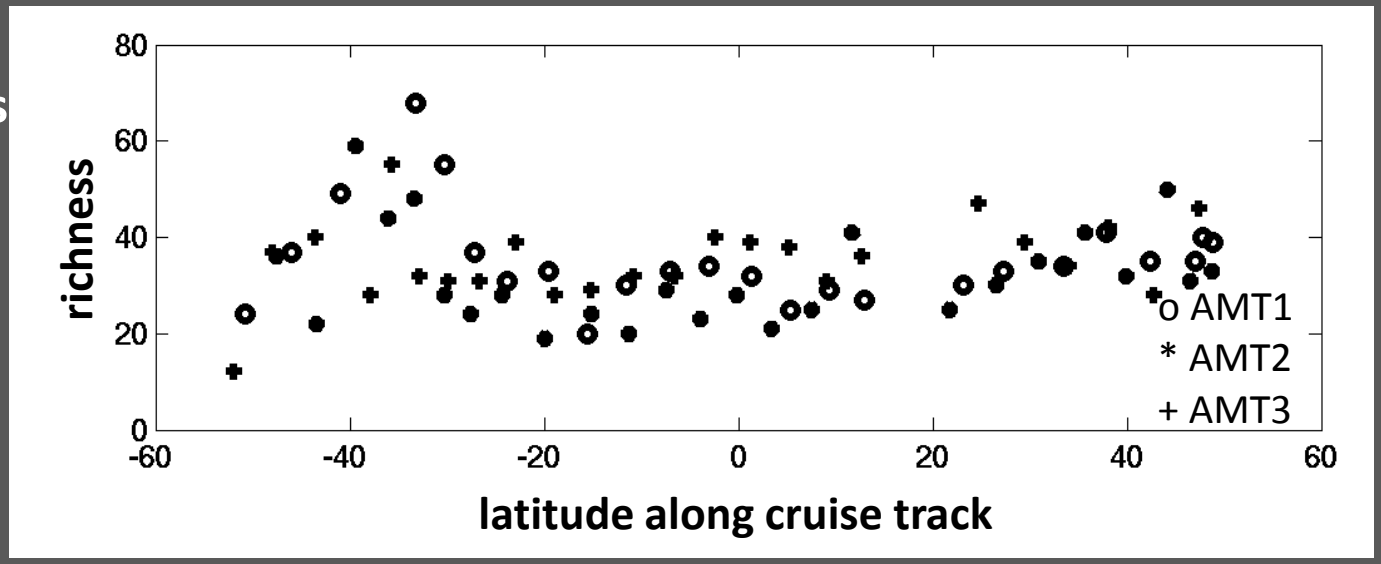
(see e.g. Clayton et al, L&OFE, 2013; Levy et al, L&OFE, 2014)

DIMENSIONS OF DIVERSITY

nano and micro phytoplankton richness

Microscopy from AMT:
Data courtesy of Pedro Cermeno

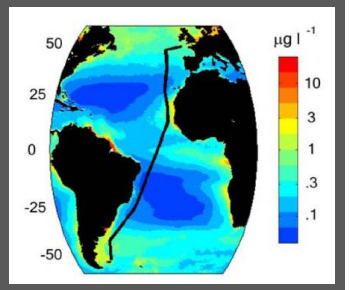


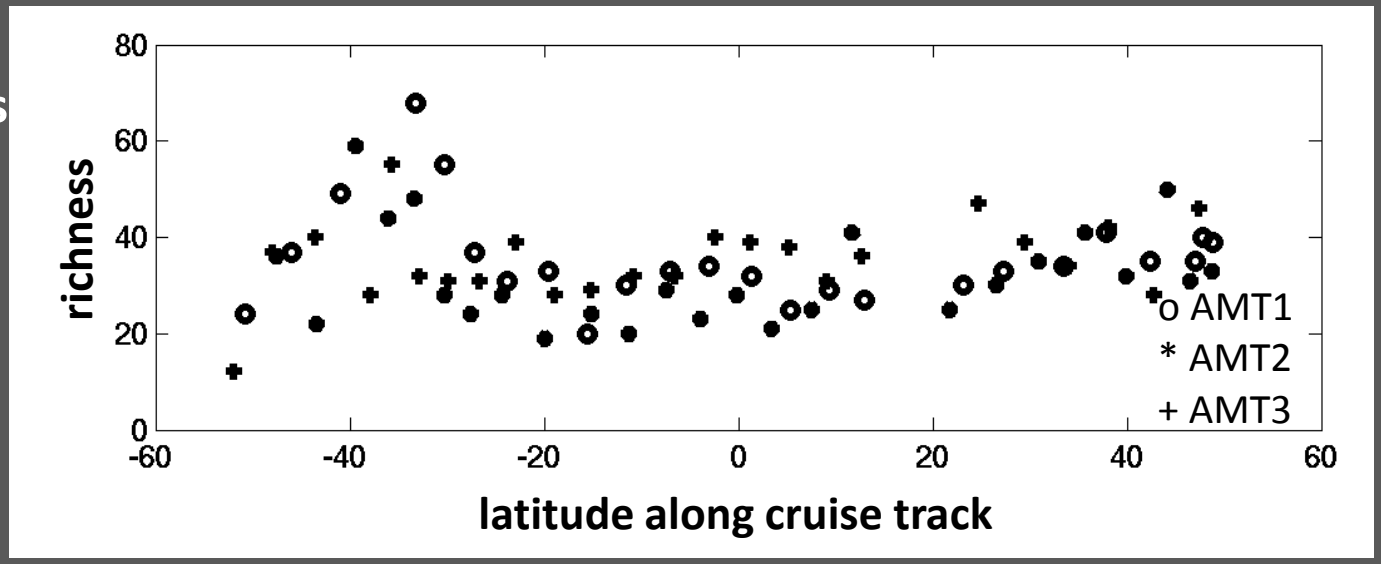


DIMENSIONS OF DIVERSITY

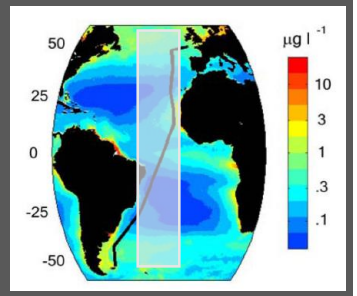
nano and micro phytoplankton richness

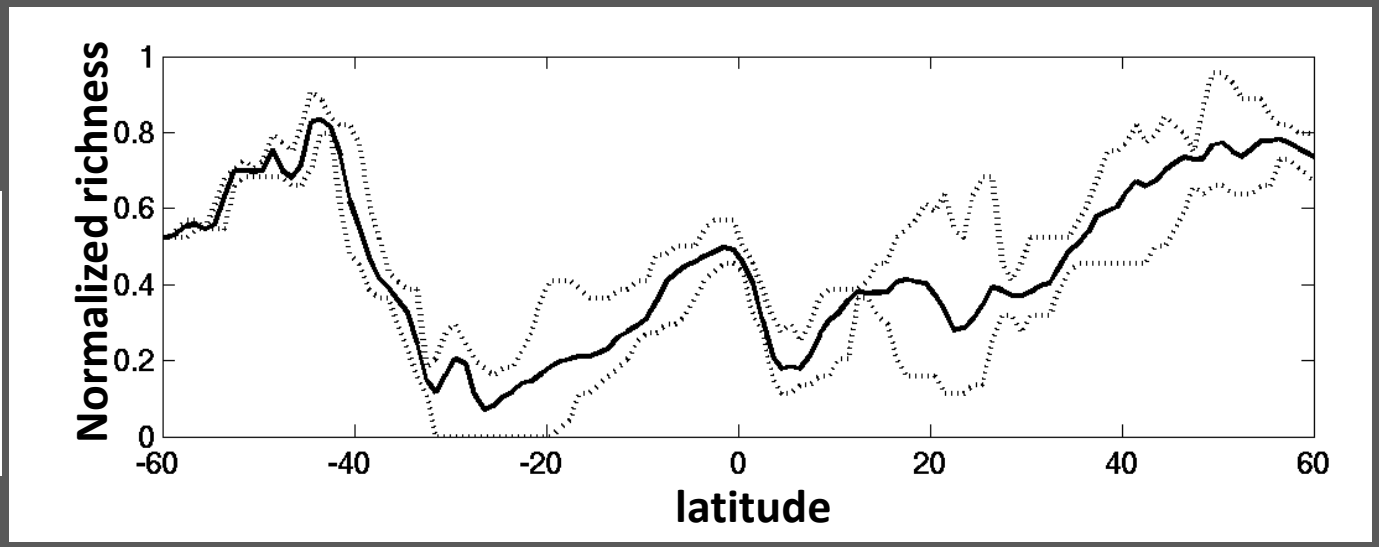
Microscopy from AMT:
Data courtesy of Pedro Cermeno



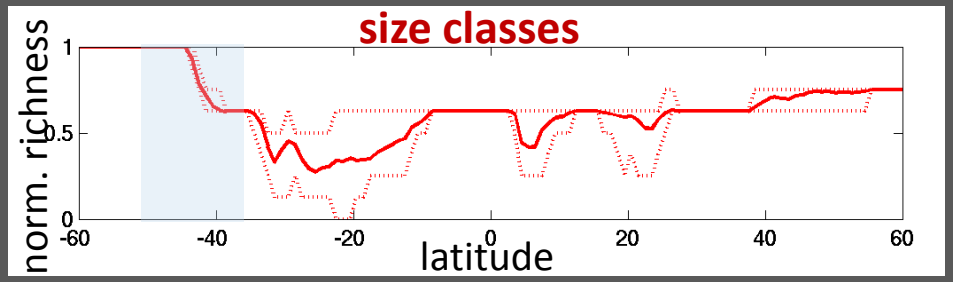


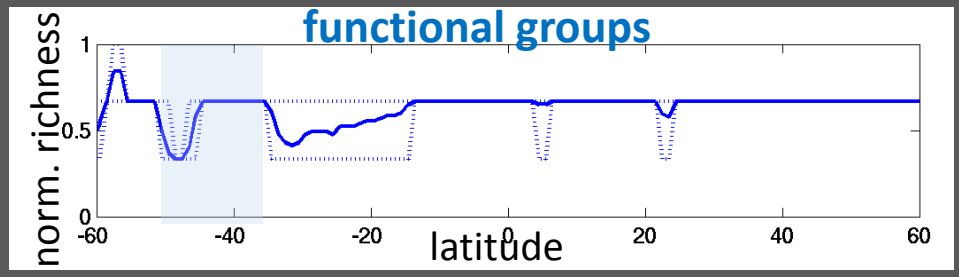
MODEL

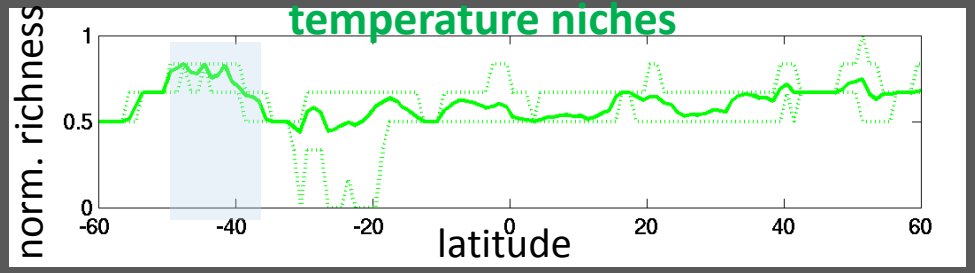




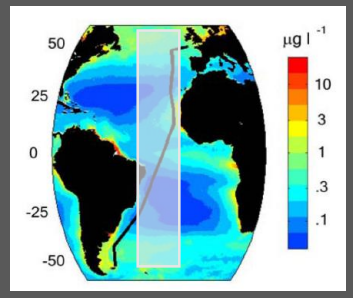
DIMENSIONS OF DIVERSITY

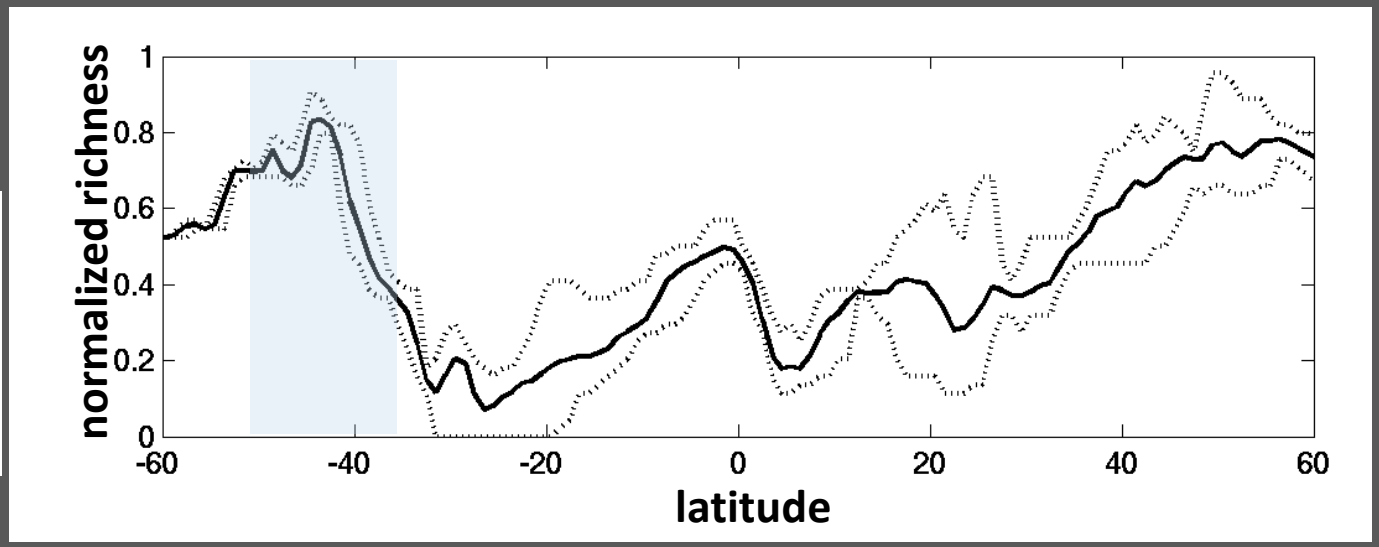






MODEL





DIMENSIONS OF DIVERSITY

Summary:

- Significant regional patterns of diversity
- That are result of combinations of many dimensions of diversity
- Each dimensions has a different set of controls

- *No single driver or theory can explain the patterns*
- *Various measurement of diversity (microscopy, genomics, size fractionation, HPLC) will pick up different patterns*

TALK OUTLINE

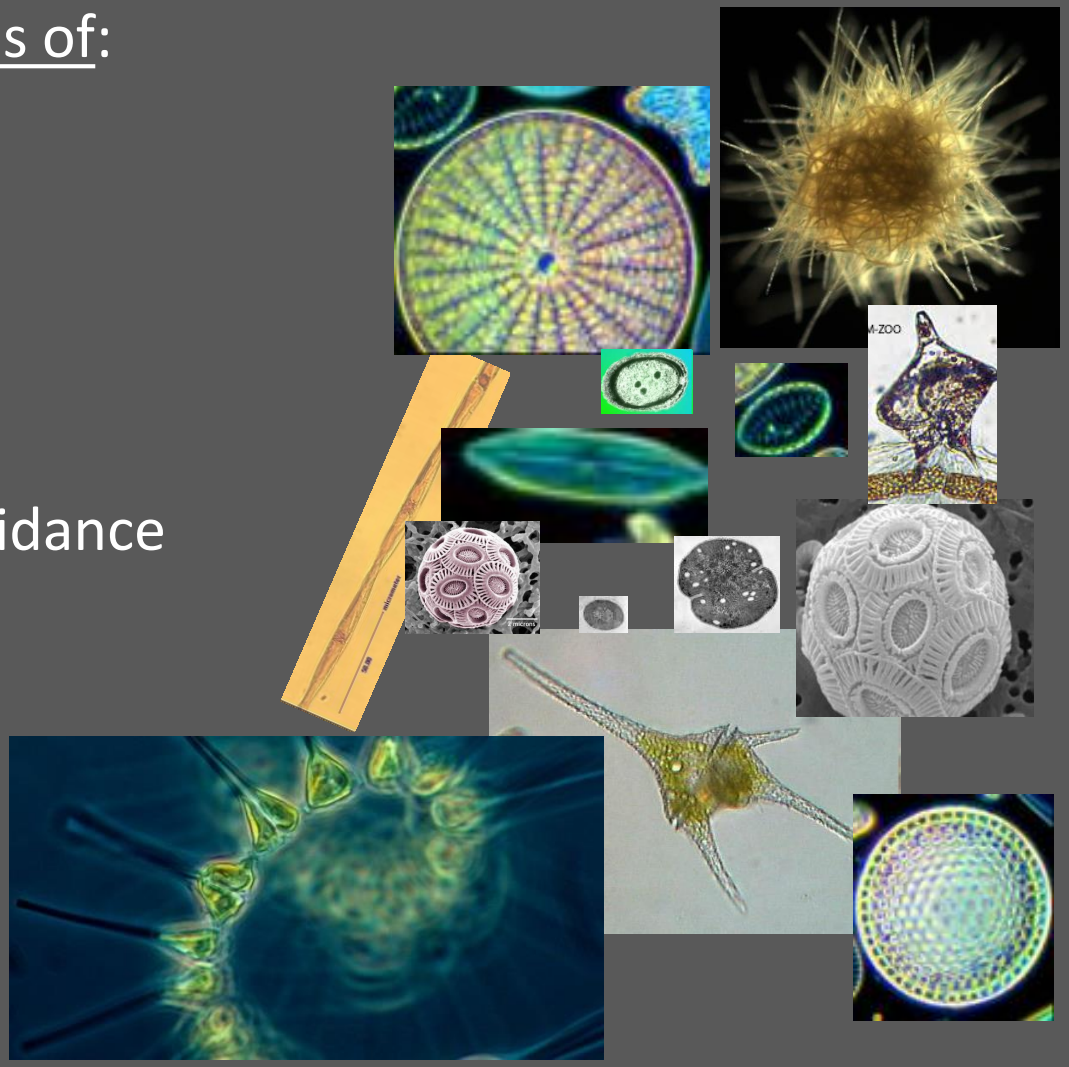
- Past MIT studies: Controls on diversity*
- Current MIT work: Dimensions of diversity*
- Ongoing and future directions

**Diversity is not the only thing we are working on; and we are not the only ones working on this topic*

ONGOING AND FUTURE WORK

Phytoplankton differ in terms of:

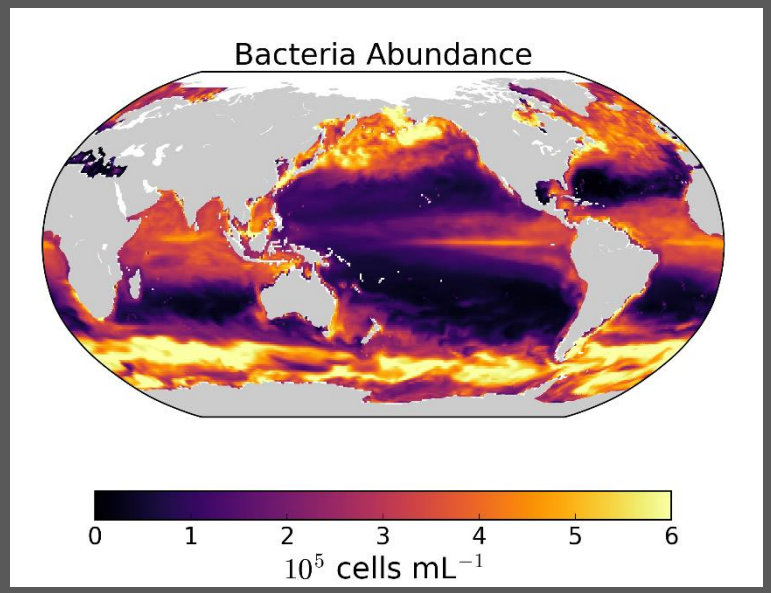
- size
- trophic strategy
- biogeochemical function
- accessory pigments
- thermal niche
- predation protection/avoidance
- morphology
- chain/colony formation
- symbiosis
- etc



ONGOING AND FUTURE WORK

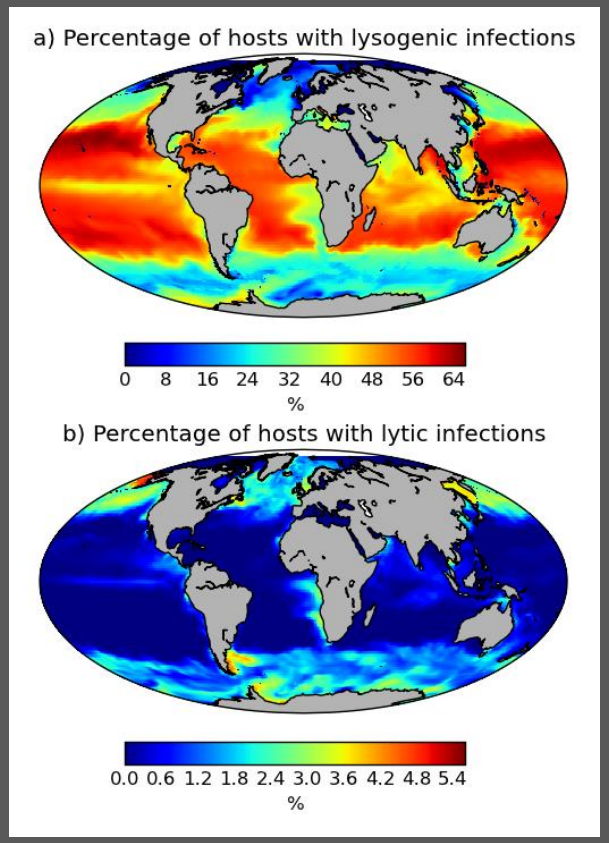
heterotrophic bacteria

Dr Emily Zakem, MIT
(soon to be post-doc at U Southern California)

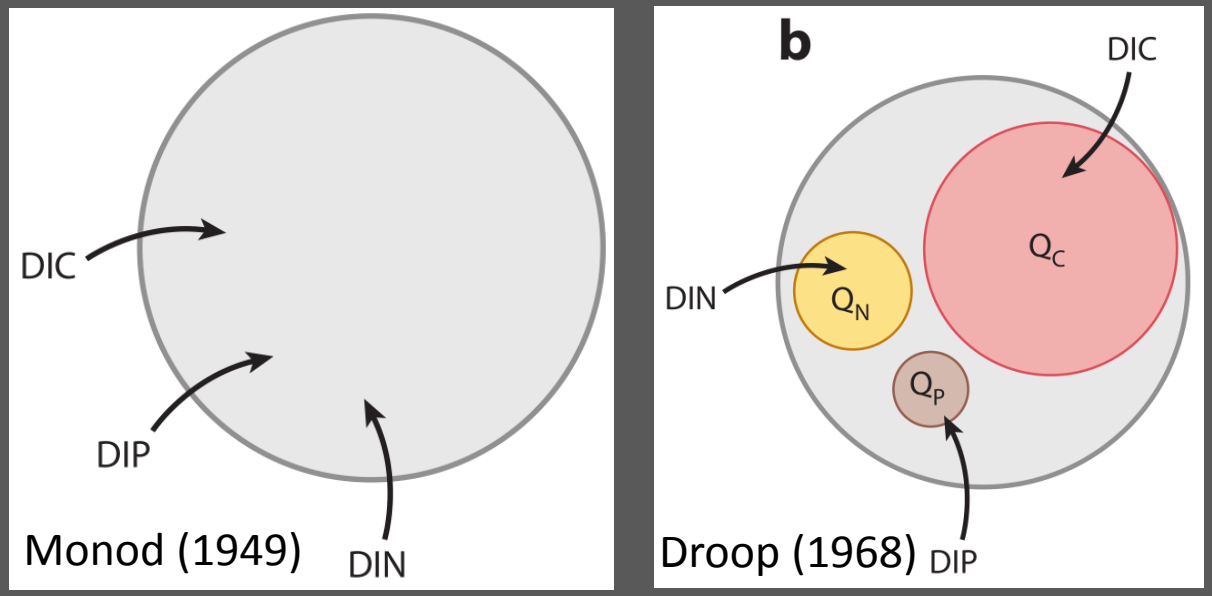


viruses

Dr David Talmy, MIT
(soon to be faculty at U Tennessee)



ONGOING AND FUTURE WORK



Figures from Follows and Dutkiewicz (2011)

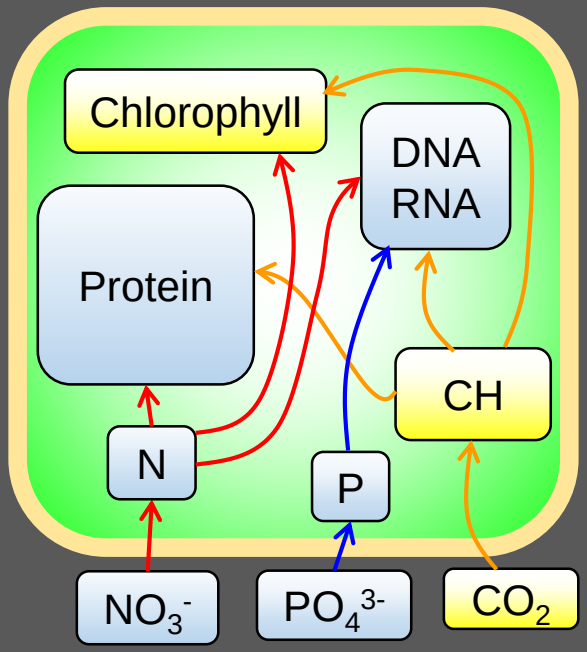
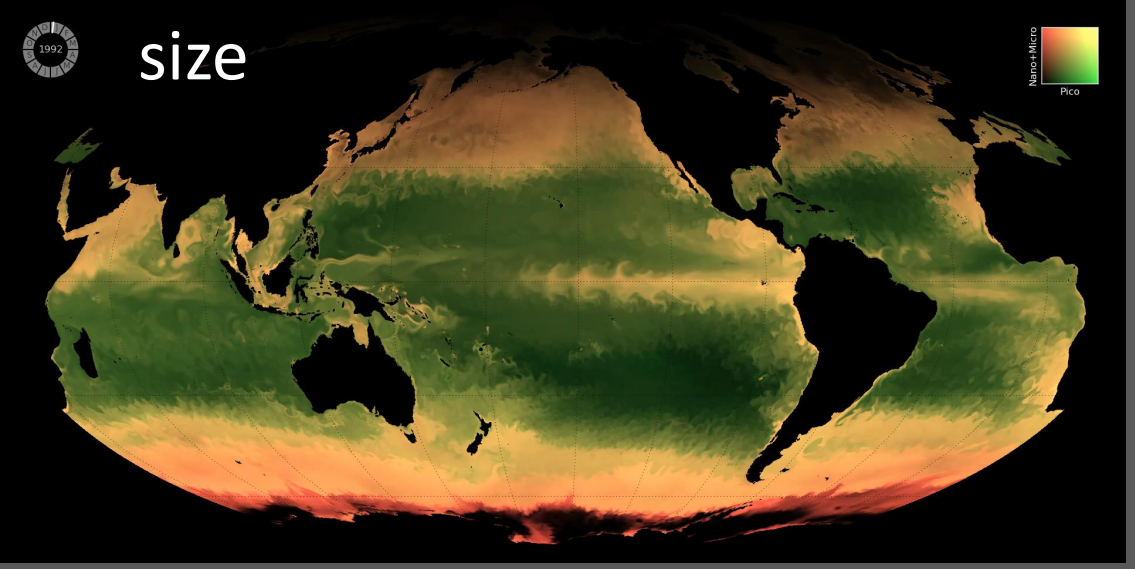
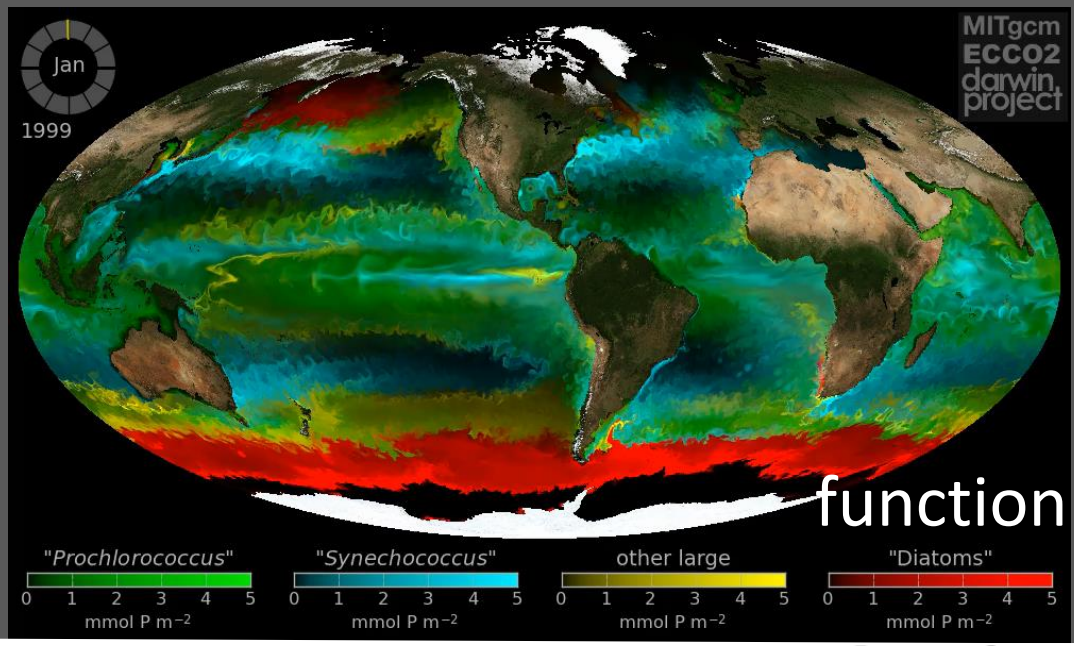


Figure from Kei Inomura

Use macromolecular cell model to parameterize cell growth
Dr Kei Inomura, MIT (soon to be post-doc at U Washington)



DIMENSIONS OF DIVERSITY

What level of diversity do we need for different questions?

What other traits important? (And do we know enough to model them?)