University of Birmingham 2019

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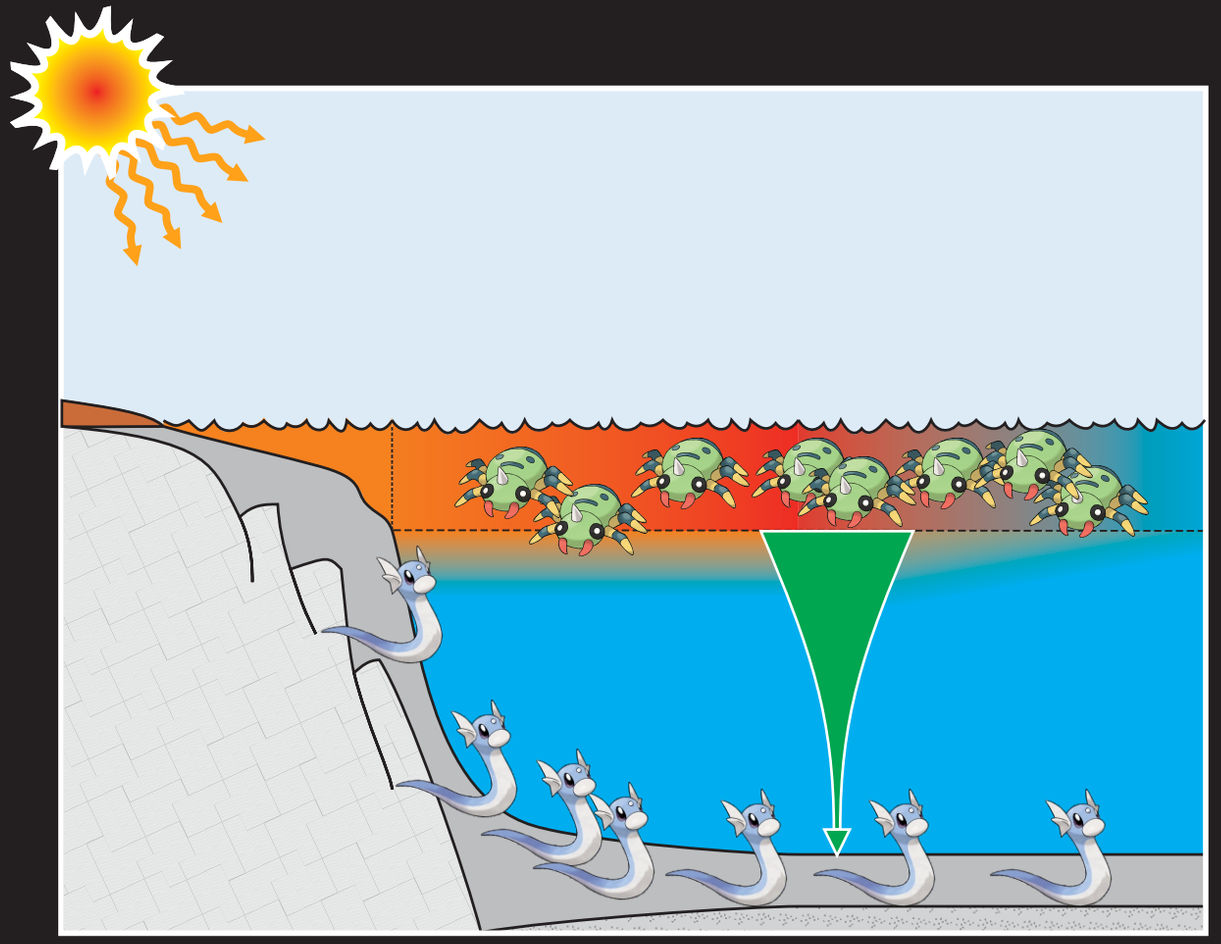
Bugs and worms in models

Andy Ridgwell

University of California – Riverside
University of Bristol



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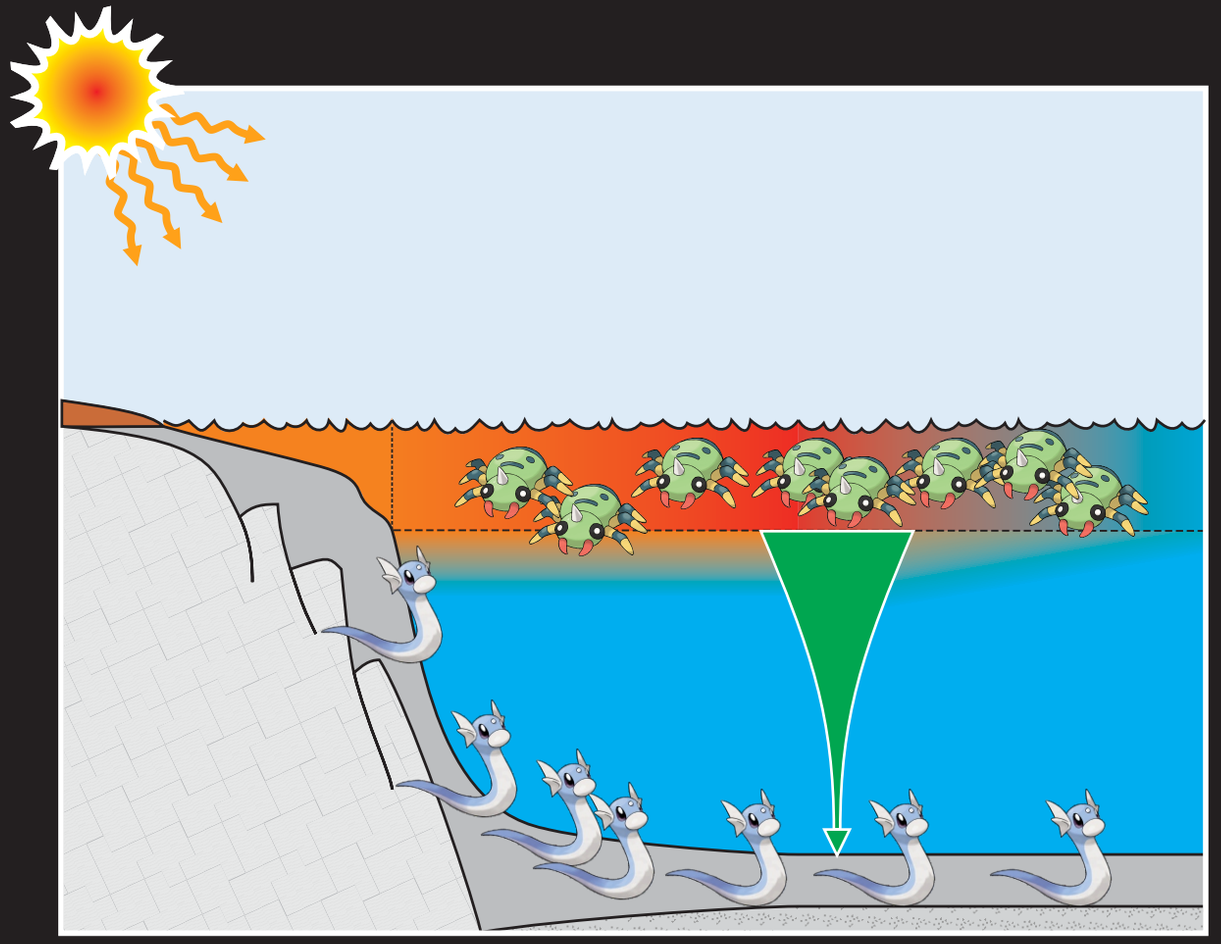


Outline

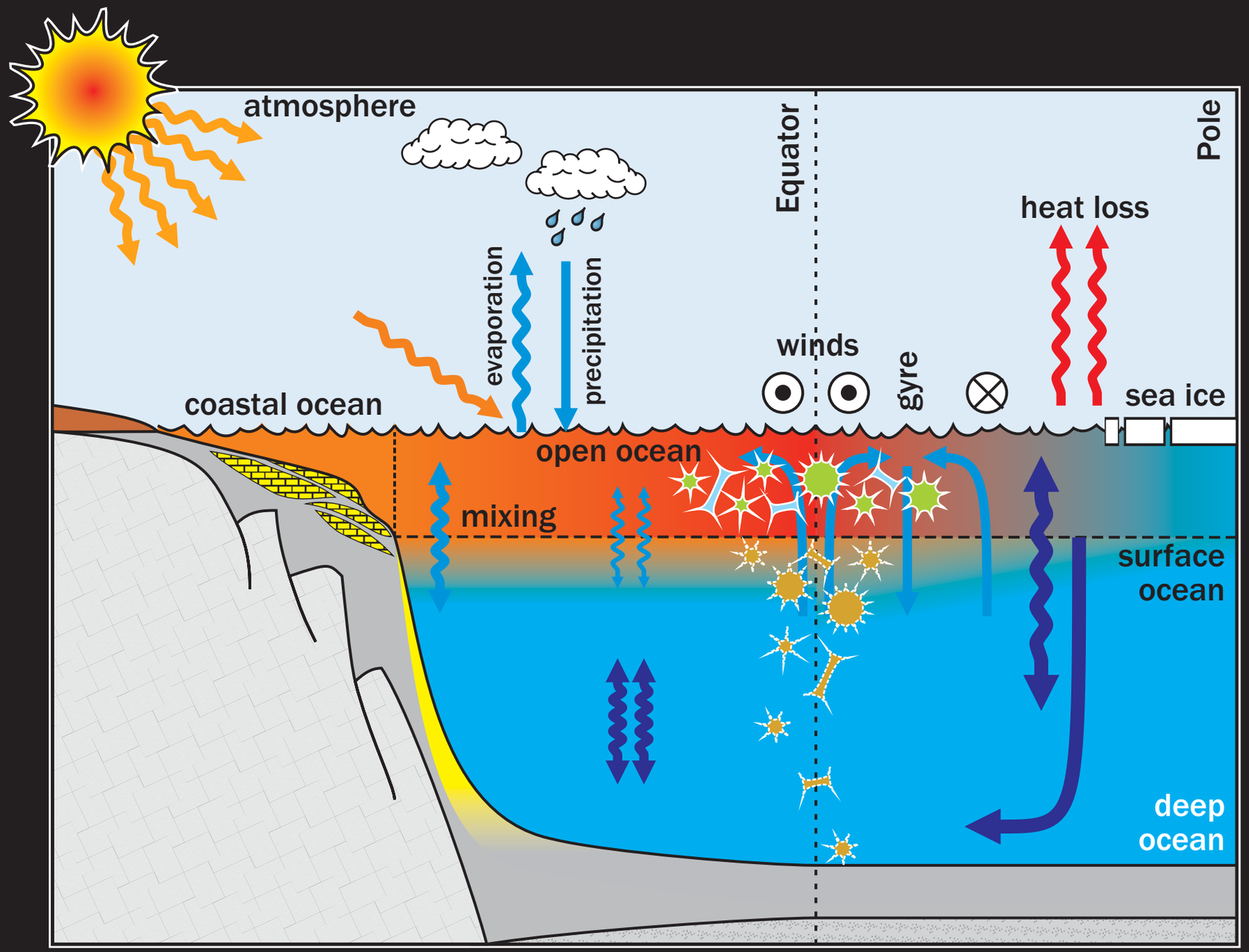
1. 

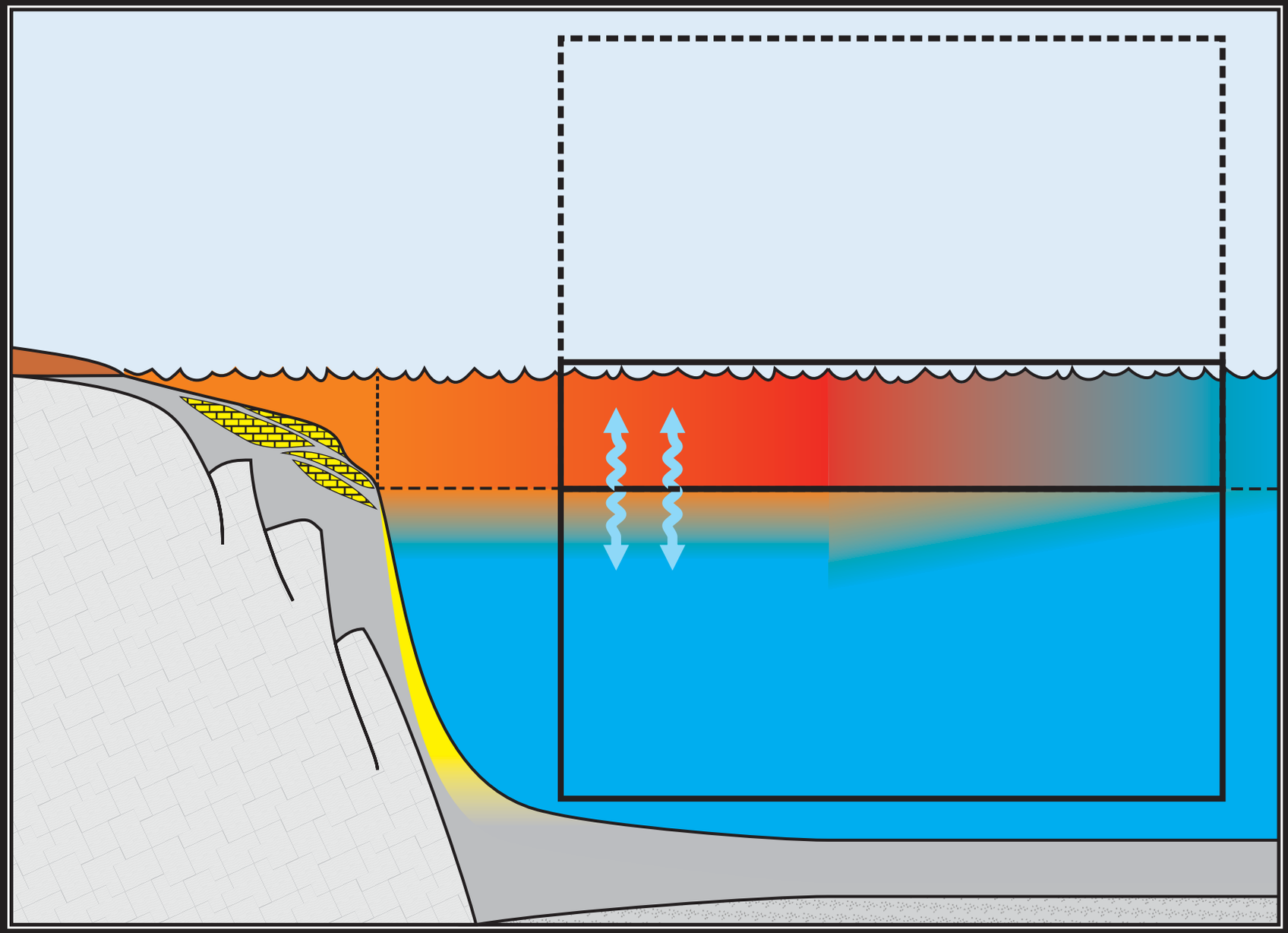
2. 

Ng	Pg	K	J	T	P	C	D	S	O	Cm
Cenozoic		Mesozoic			Paleozoic					
Phanerozoic										

Neoprot.	Mesoprot.	Paleoproterozoic
Proterozoic		

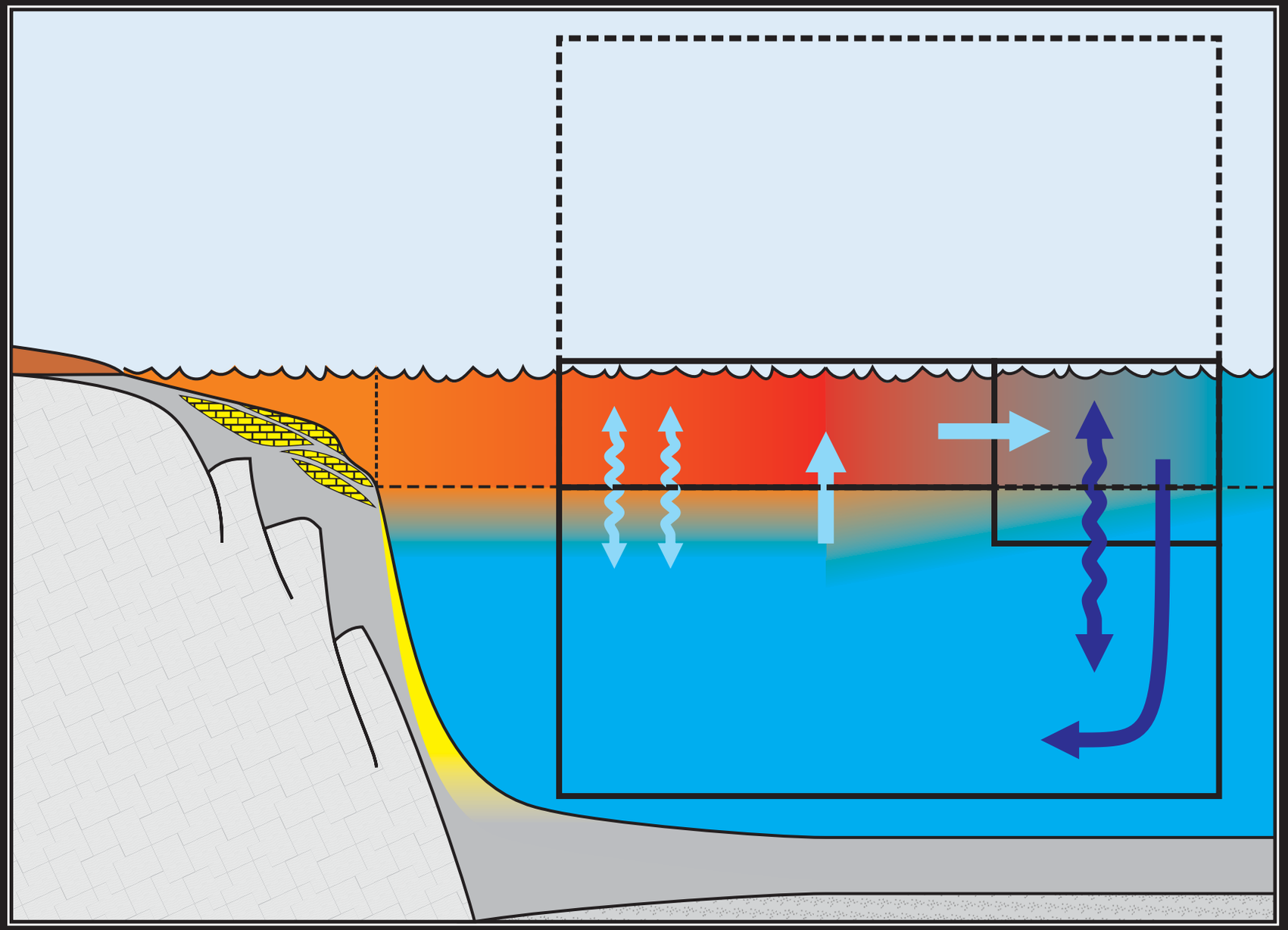
Archean


atmosphere
Equator
Pole
heat loss
evaporation
precipitation
winds
gyre
coastal ocean
sea ice
open ocean
mixing
surface ocean
deep ocean



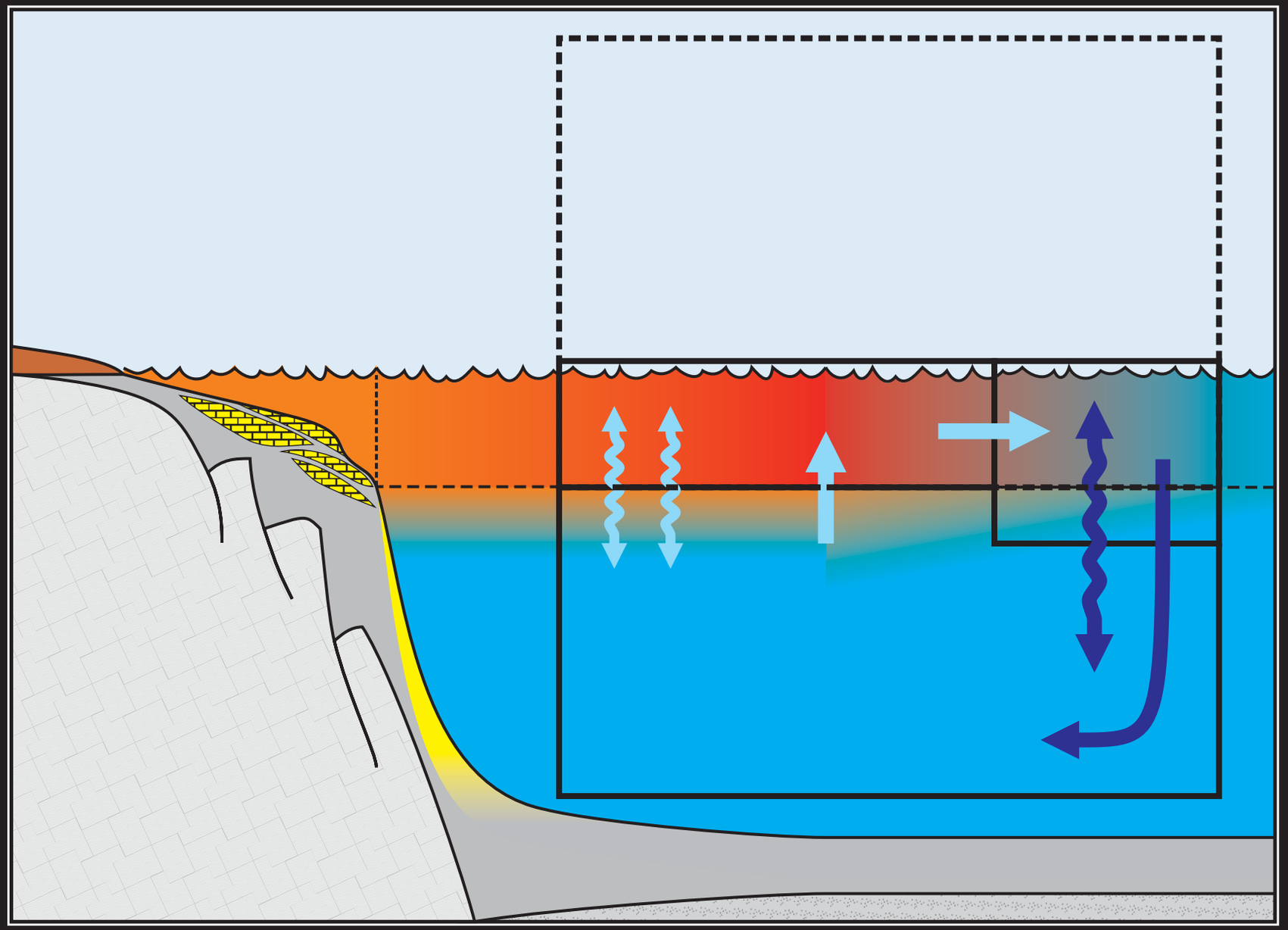
Bugs I – Strategies for modelling complex marine systems

Creating models is effectively, the art of the encapsulation of one's understanding (or preconceptions) of a system, numerically. Typically rooted in modern observations. But ...

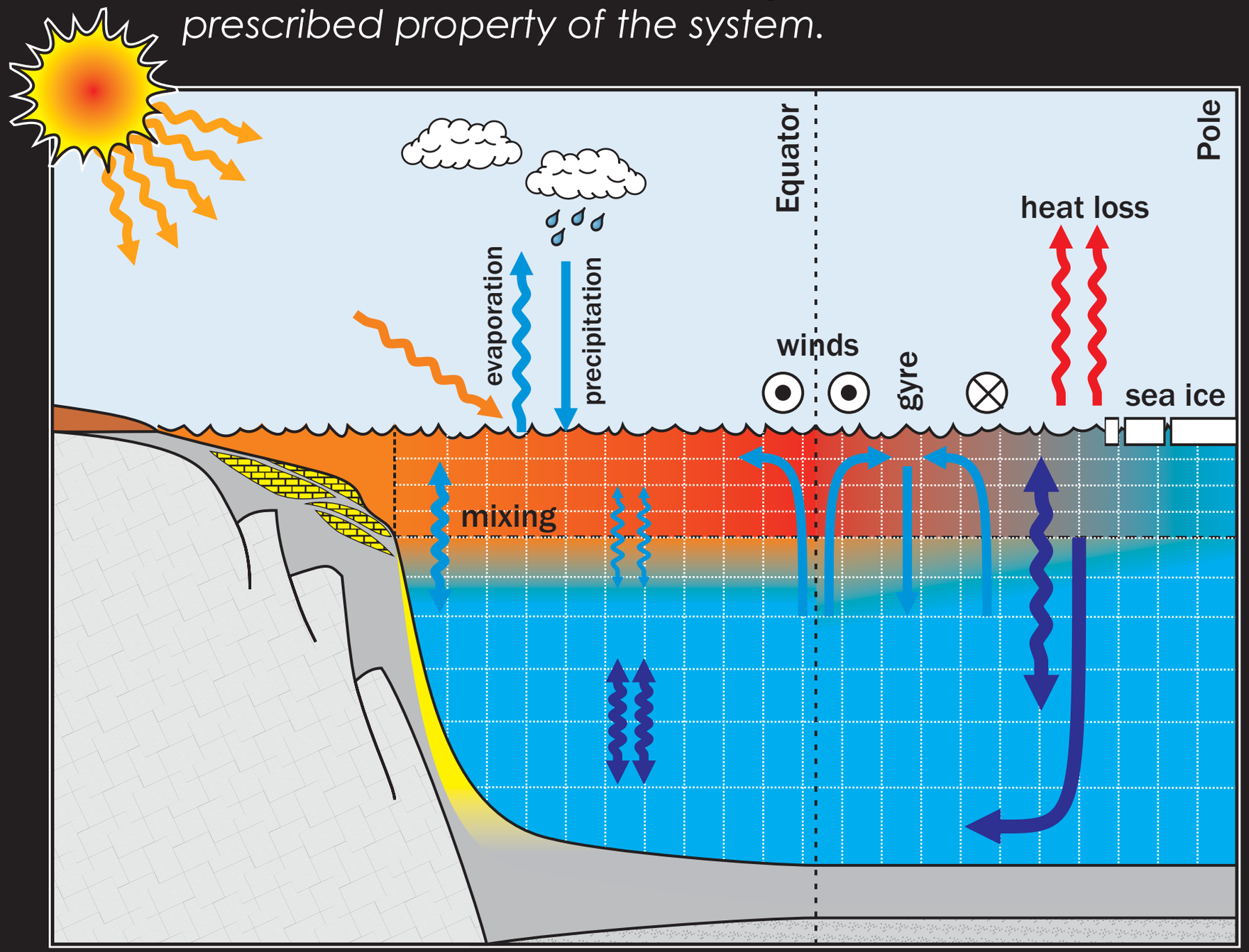


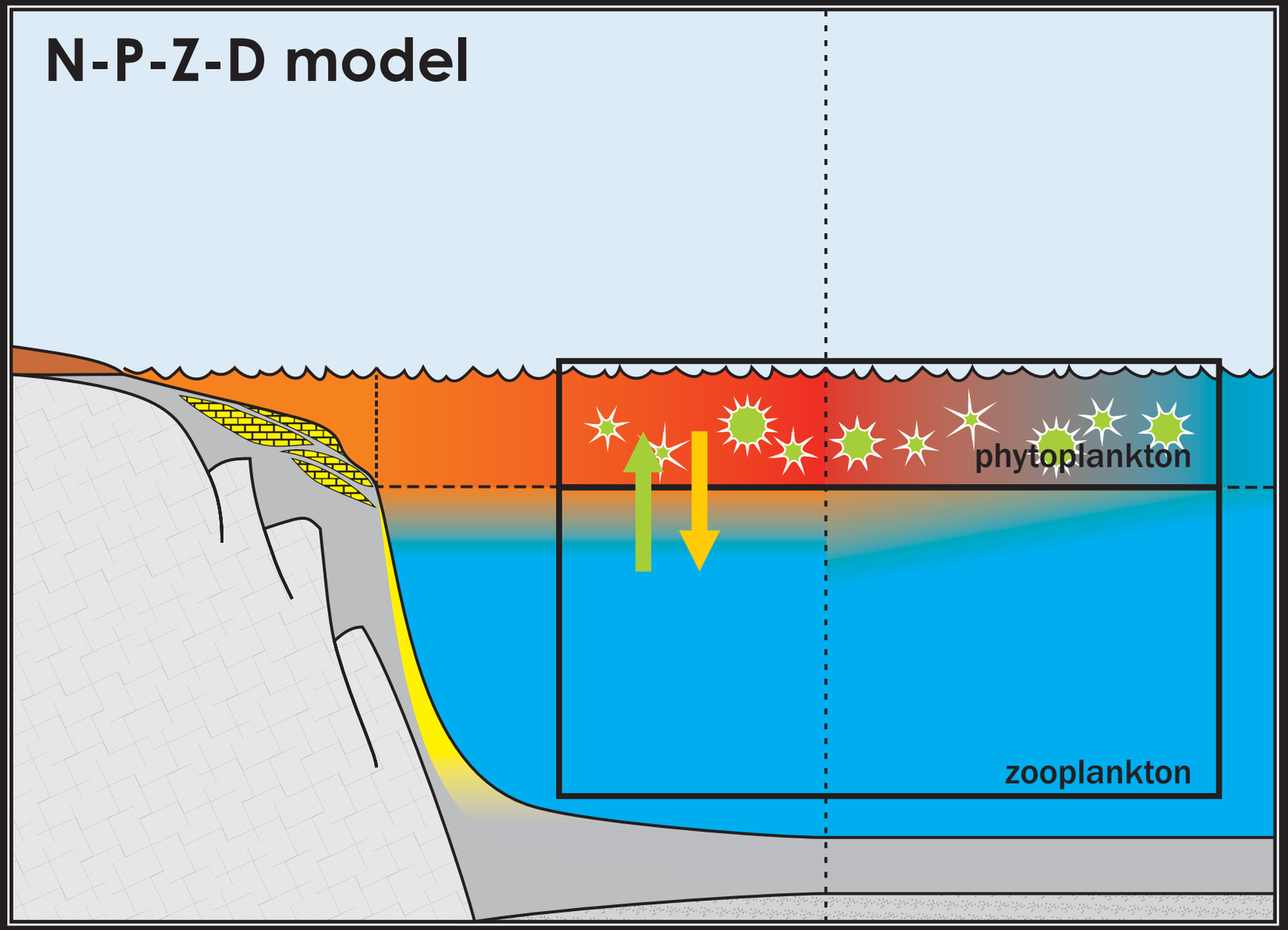
Bugs I – Strategies for modelling complex marine systems

What happens under climate change?
What did the system look like in the past (e.g. Cretaceous)??
What if the structure of the system is not correctly understood???



Ocean <u>general</u> circulation models (O-GCMs):
Ocean circulation becomes an **emergent** *rather than a prescribed property of the system.*




N-P-Z-D model
phytoplankton
zooplankton

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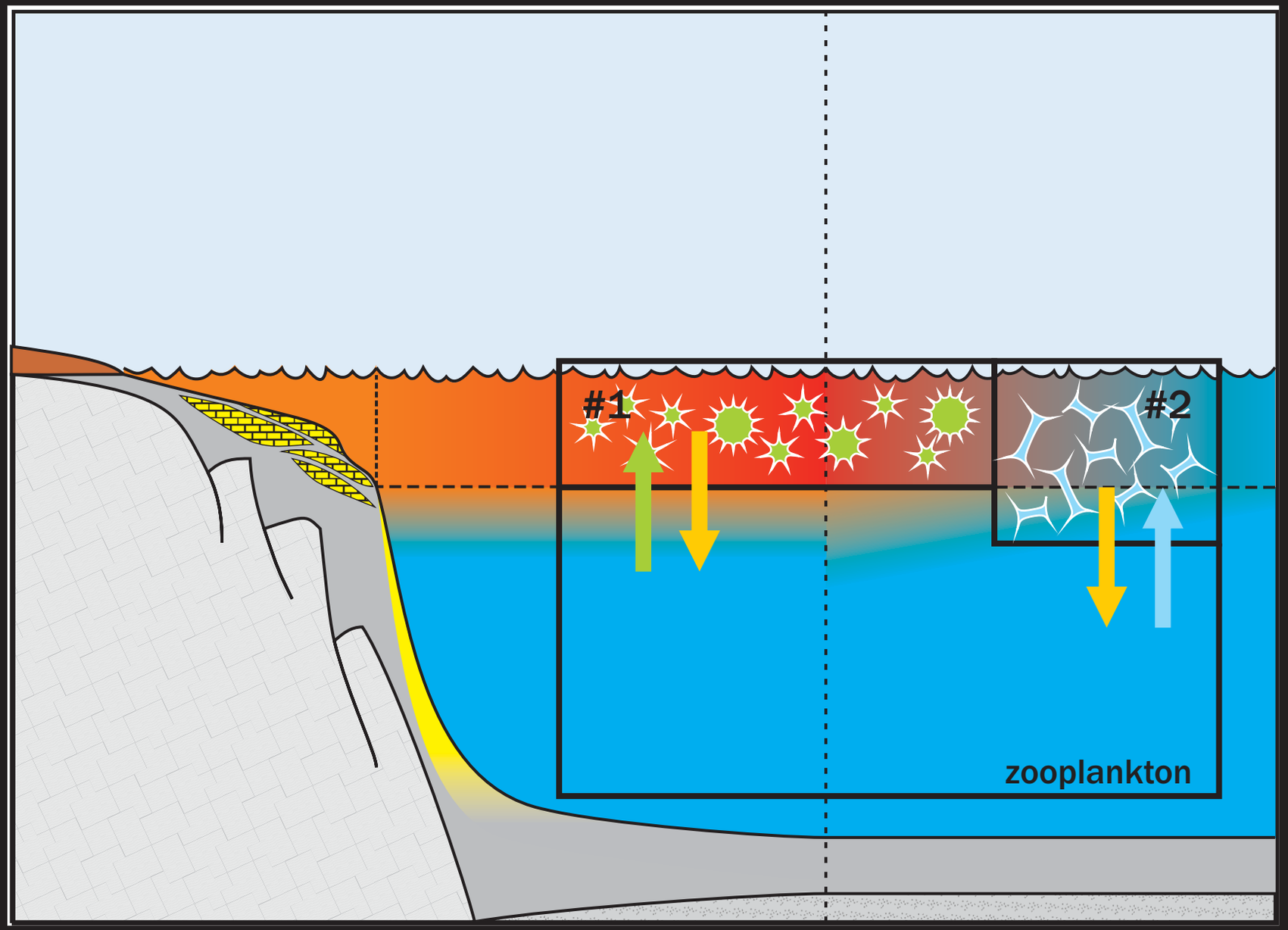
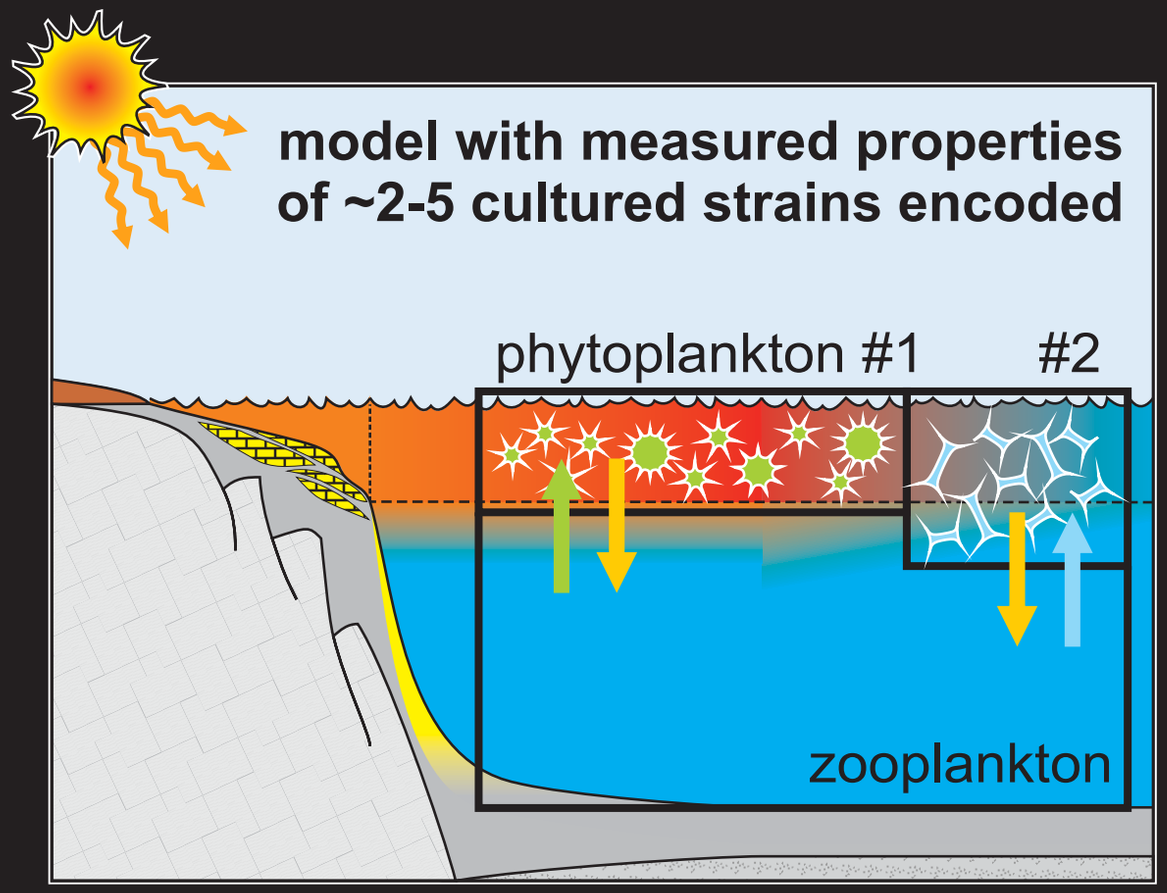
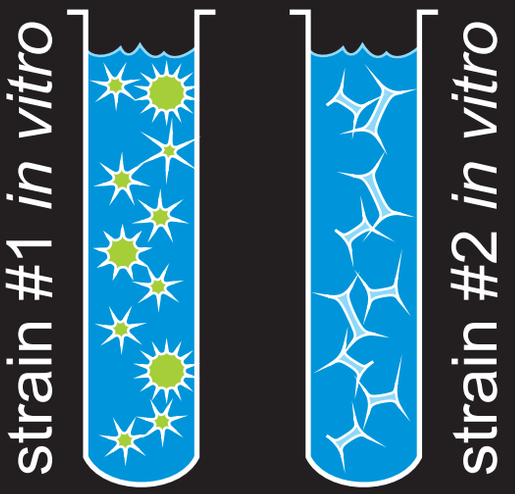


Bugs I – Strategies for modelling complex marine systems



predominantly short-term laboratory perturbation experiments



What happens under climate change?

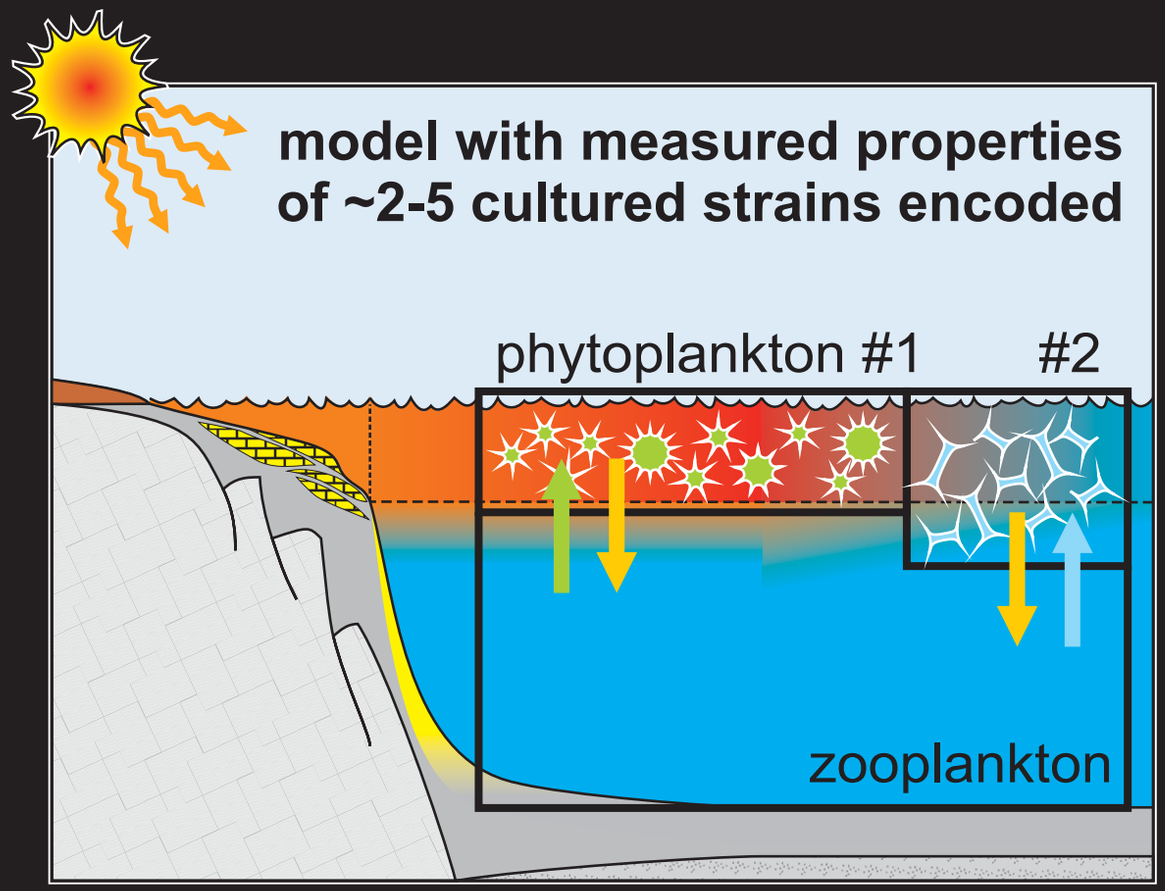
What did the system look like in the past (e.g. Cretaceous)??

What if the structure of the system is not correctly understood???

But also:

What about adaptation (or even evolutionary responses) to global change?

Bugs I – Strategies for modelling complex marine systems



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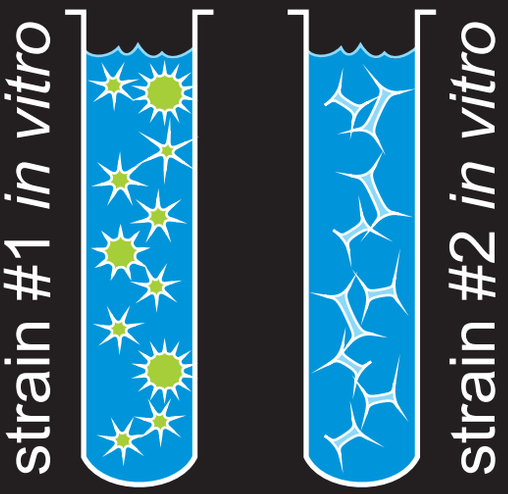
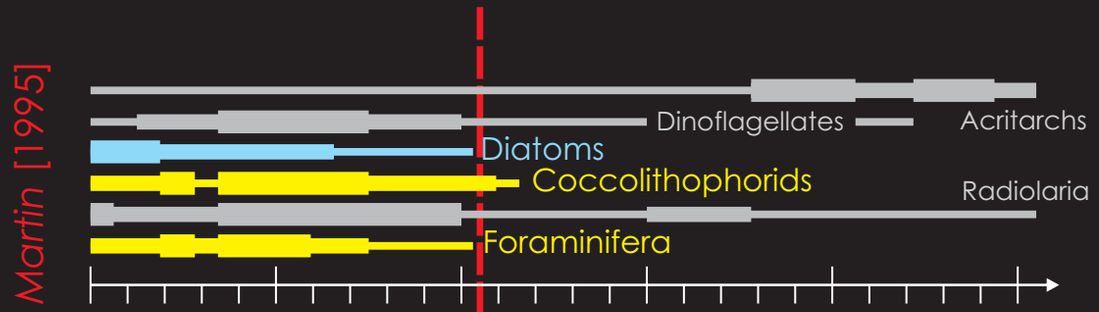
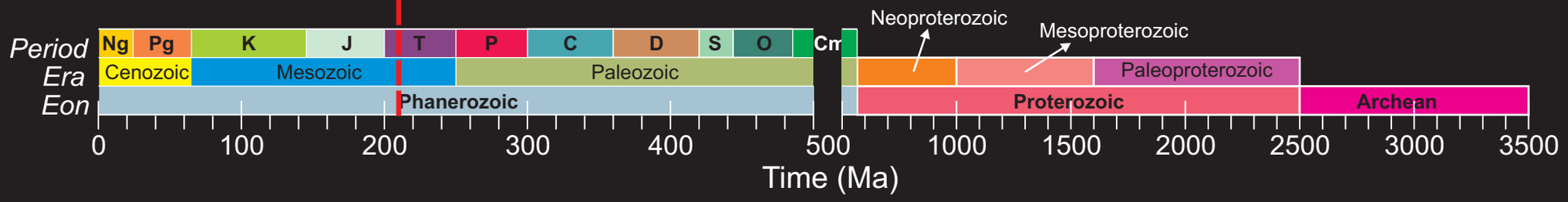
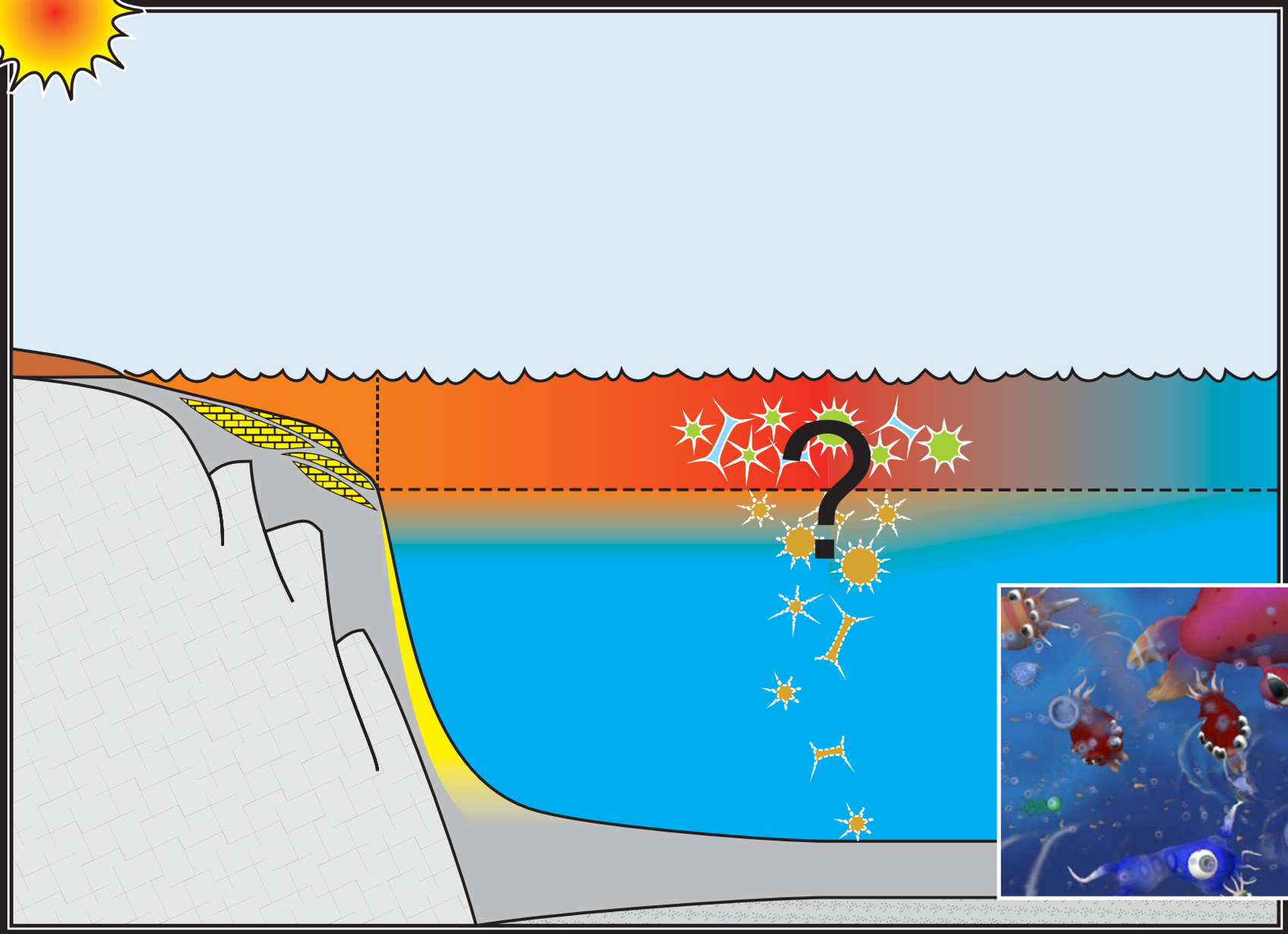


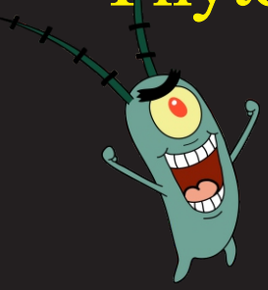




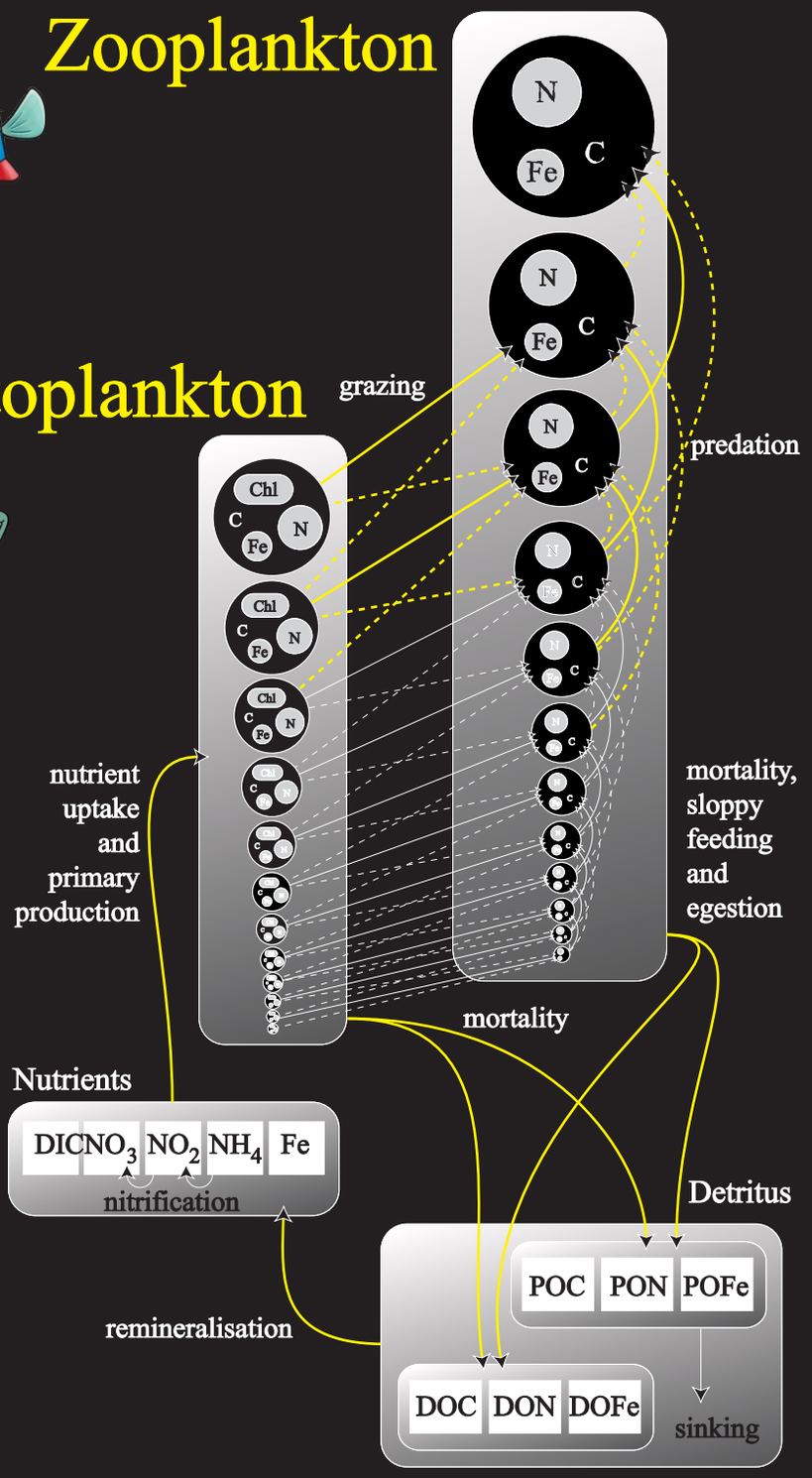
(Ocean) General Ecology Models? (O-GEMs?):
Marine ecology becomes an ***emergent*** *rather than a prescribed property of the system.*



Zooplankton



Phytoplankton



'ECOGEM' size-structured plankton ecological model [*Ward et al.*, 2018 (*GMD*)].

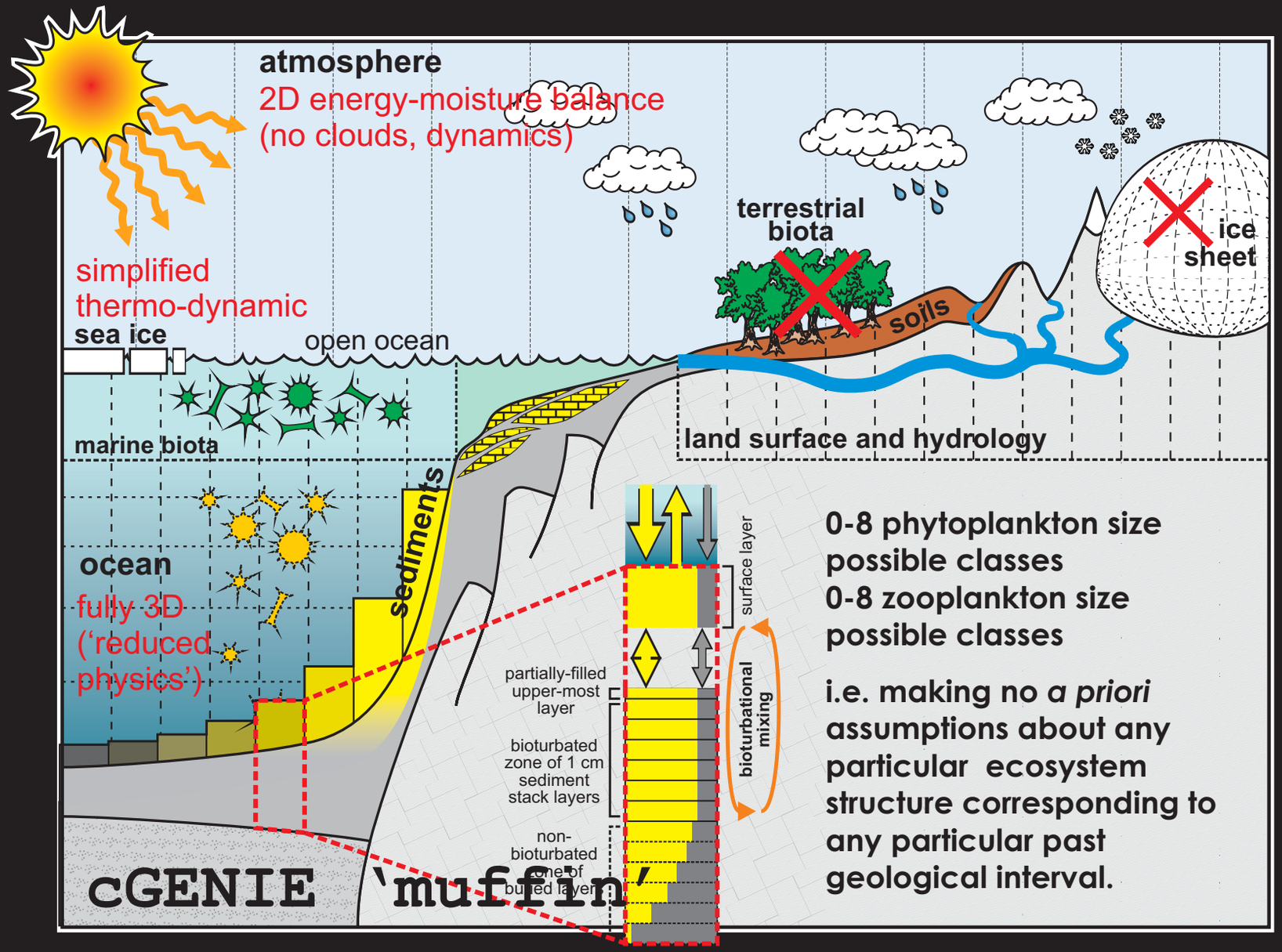
Can define *n* phytoplankton and *m* zooplankton (and/or mixotrophs).

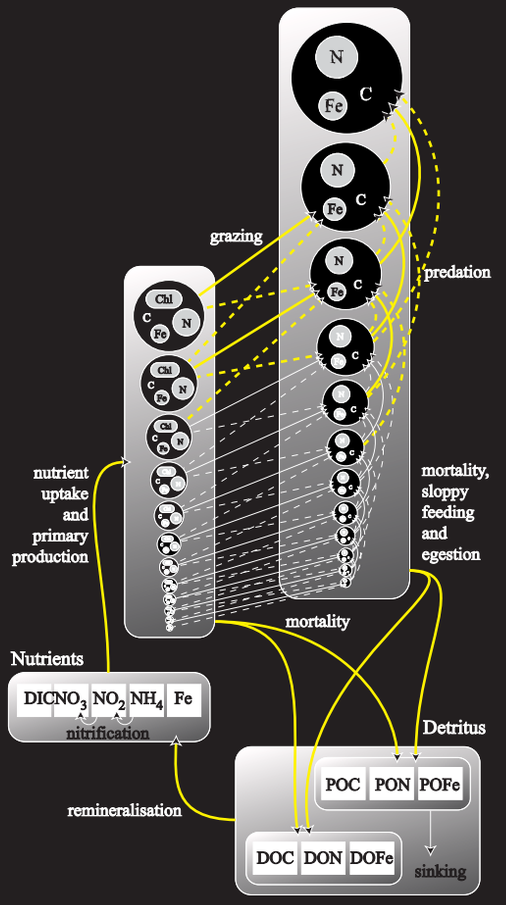
Traits scale with the master variable, cell size.

Each plankton has 'quotas' for C, N, P, Fe, so variable elemental stoichiometry possible (just C and P used here).

'Standard' functional type ecosystem model grazing formulation (with size preference).

Bugs II – Paleo ecological models

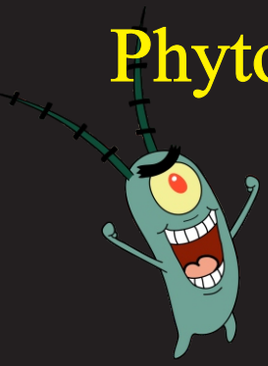




github.com/derpycode/cgenie.muffin

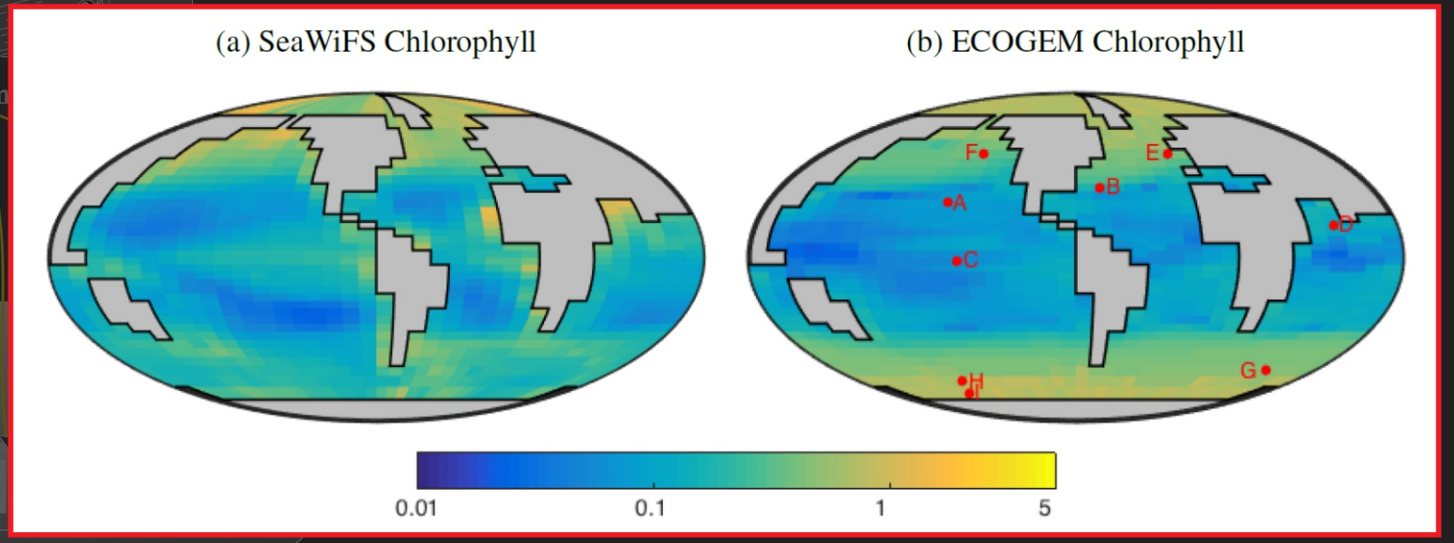
Bugs II – Paleo ecological models

Zooplankton

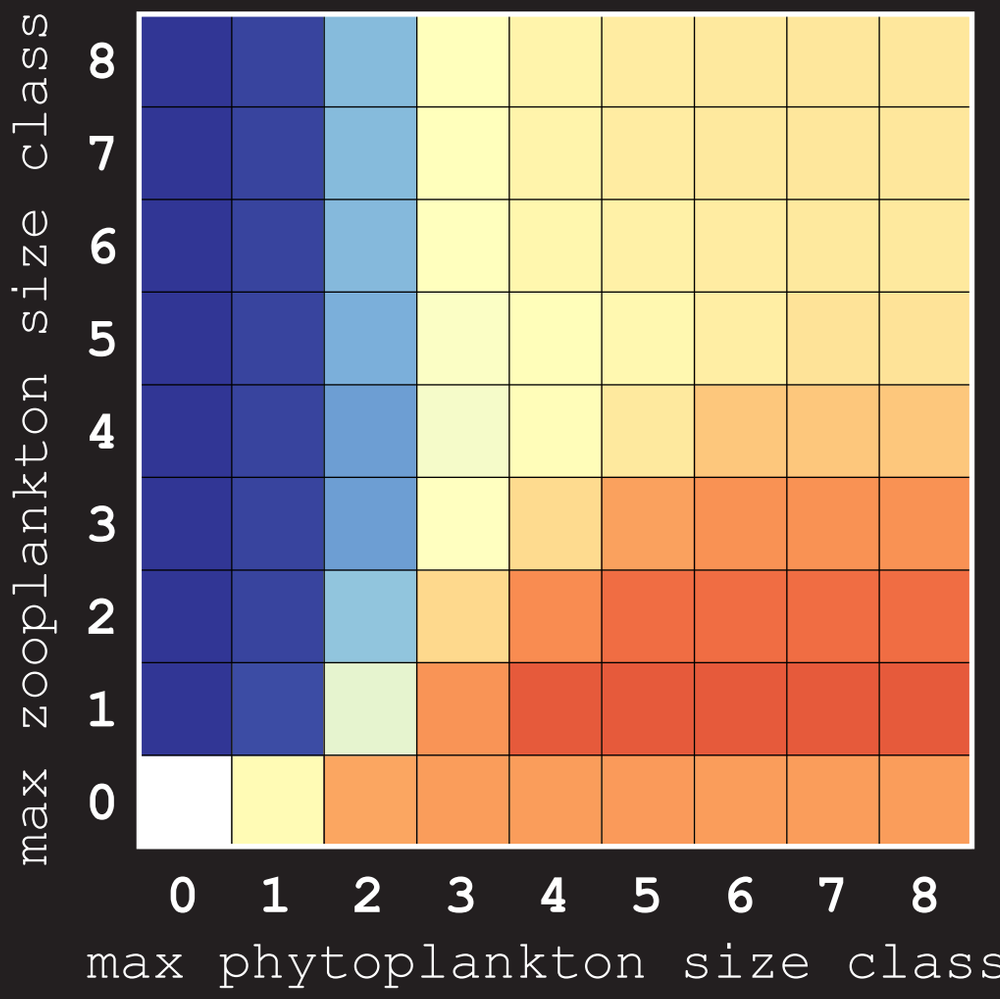


Phytoplankton

[Ward et al., 2018 (GMD)]

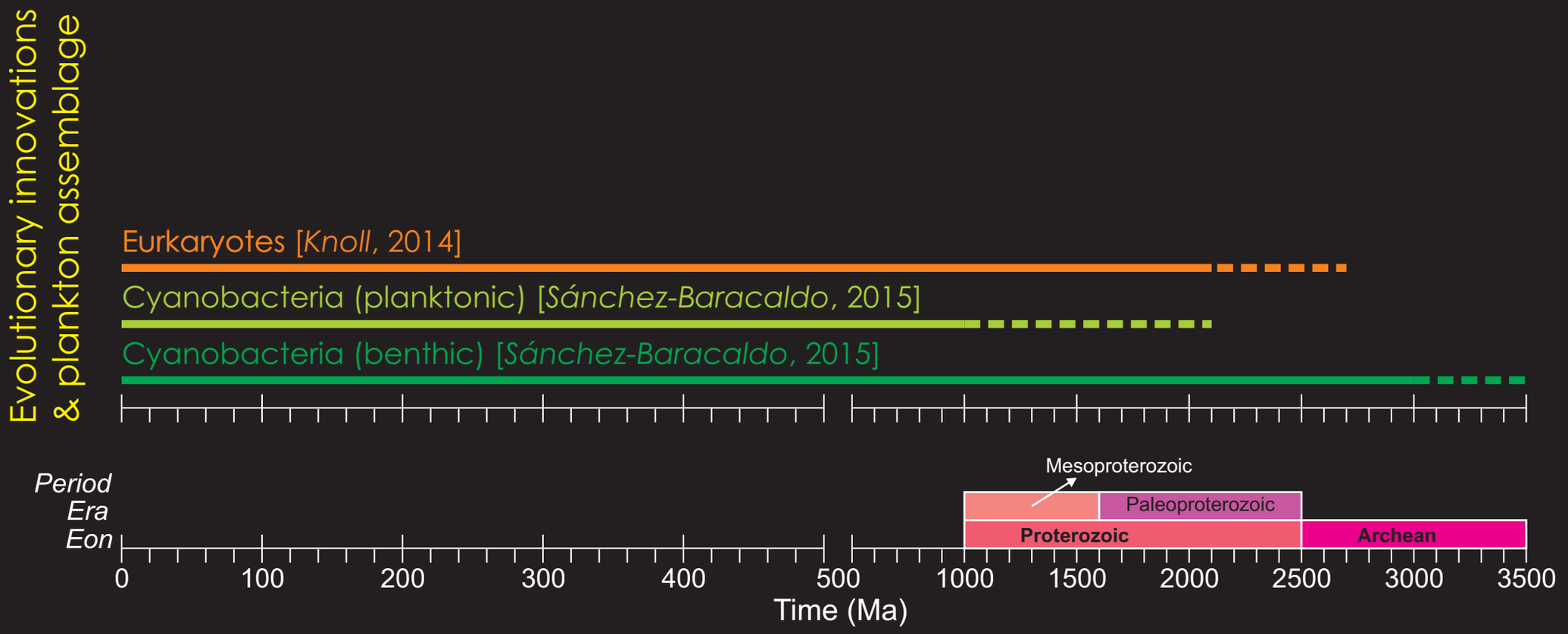


Bugs III – Paleo ecological computer games

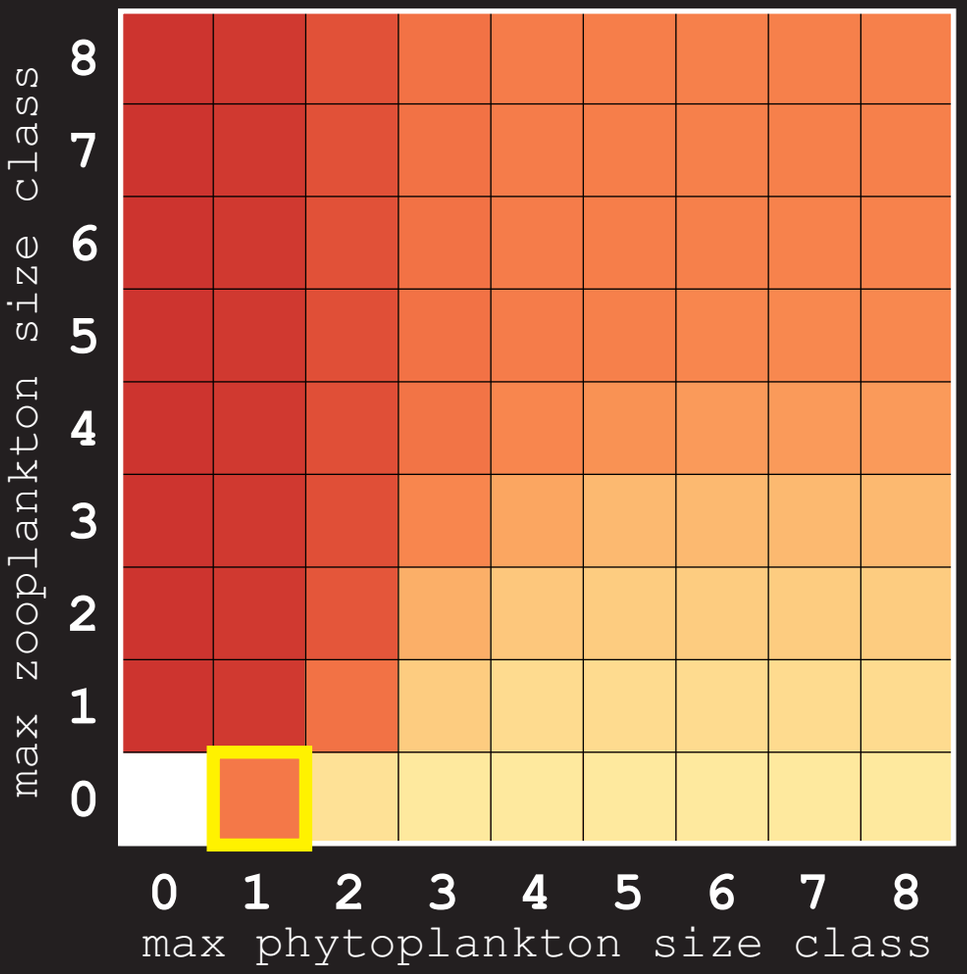


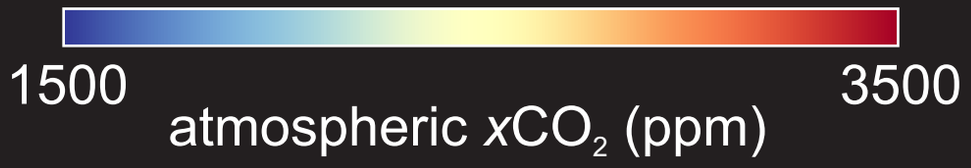
0 == no plankton
1 == 0.6 µm
2 == 1.9 µm
3 == 6.0 µm
4 == 19.0 µm
5 == ...

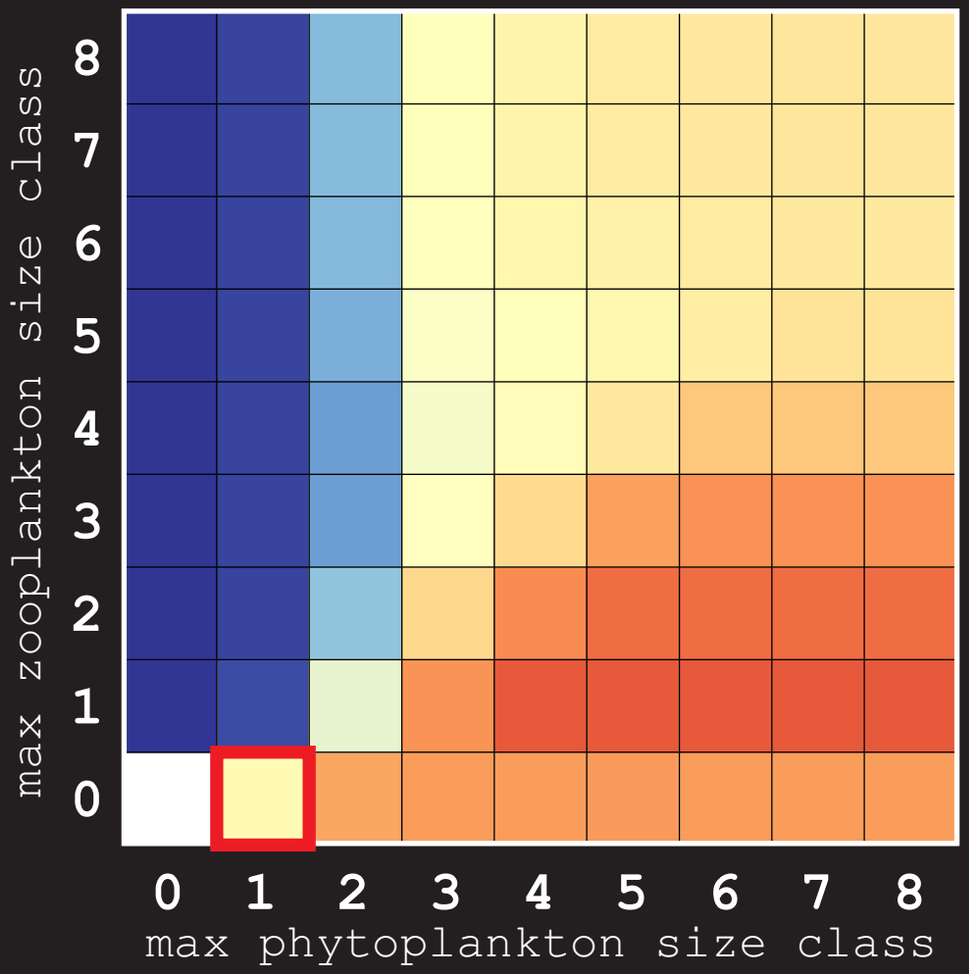
Bugs III – Paleo ecological computer games

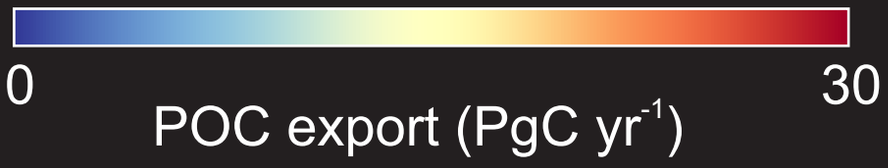


Bugs III – (1) planktonic habitat (small cell size)









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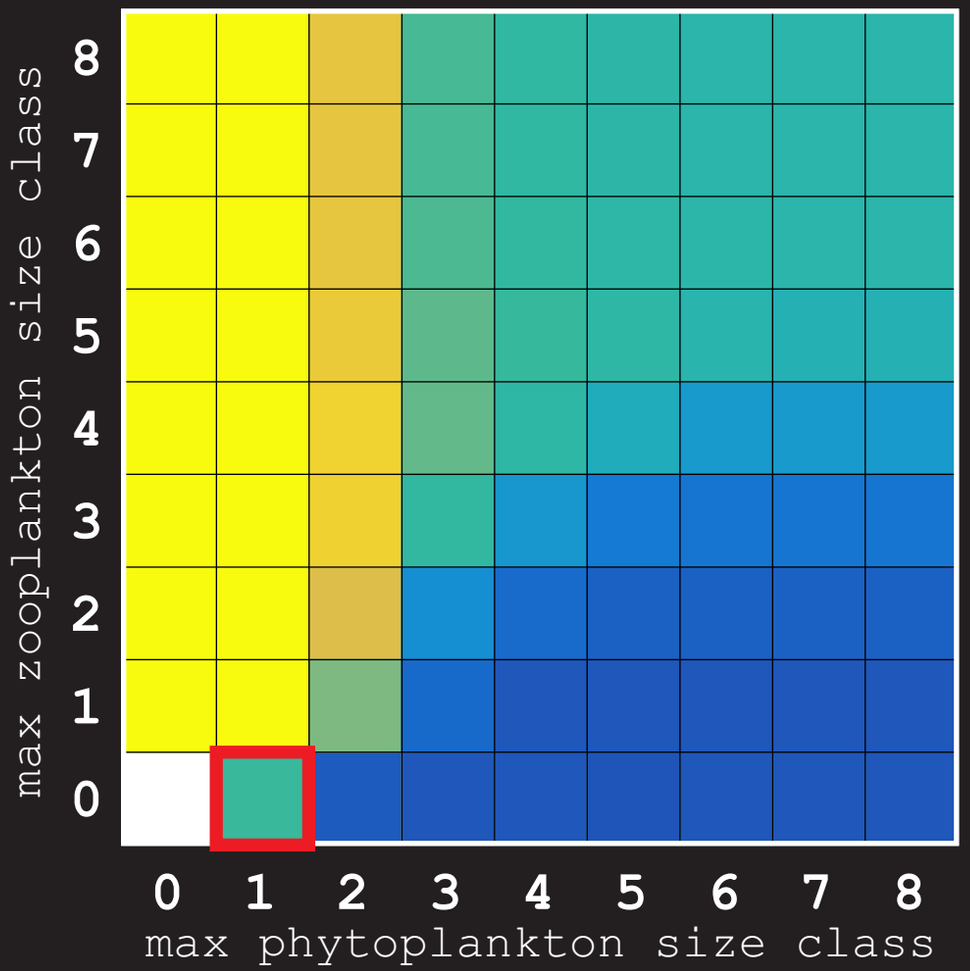
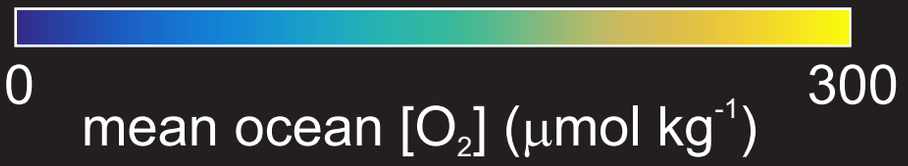
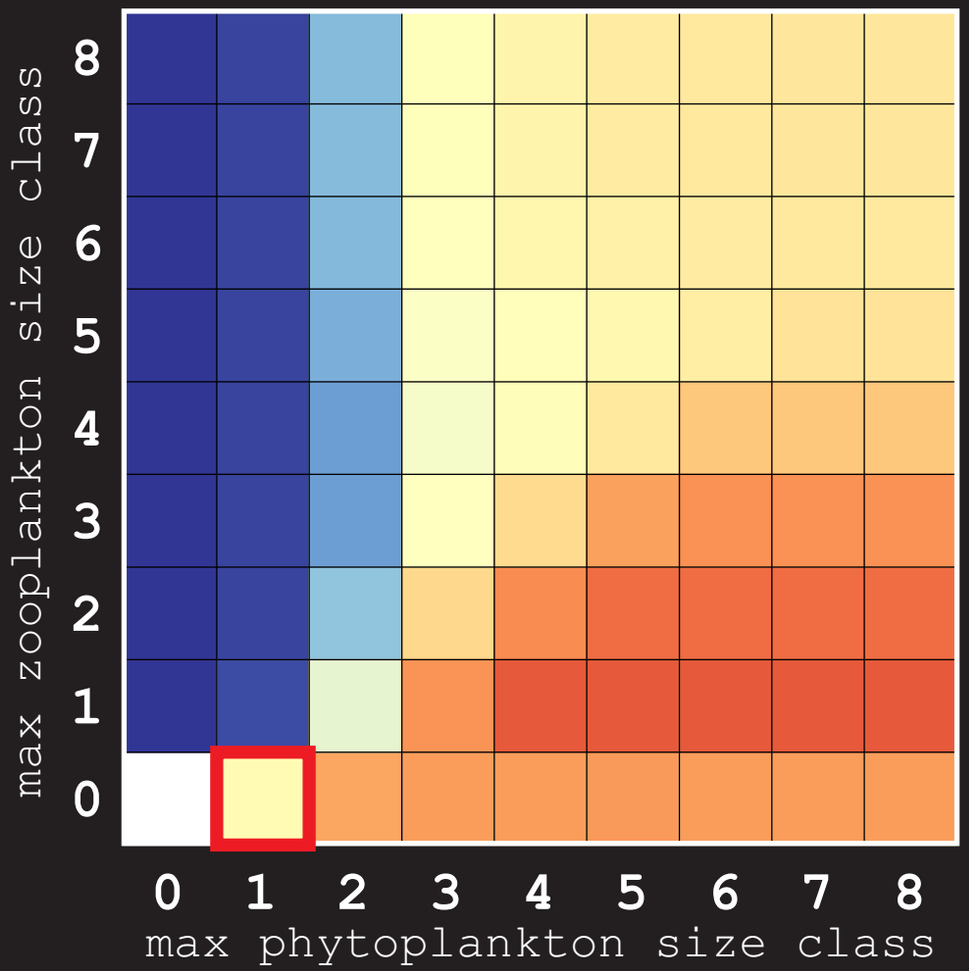
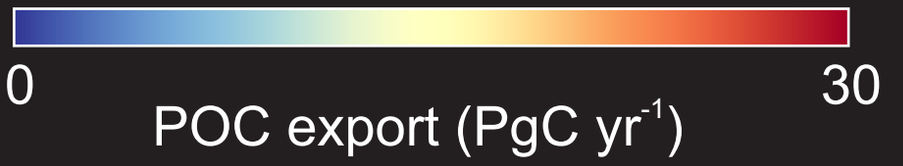
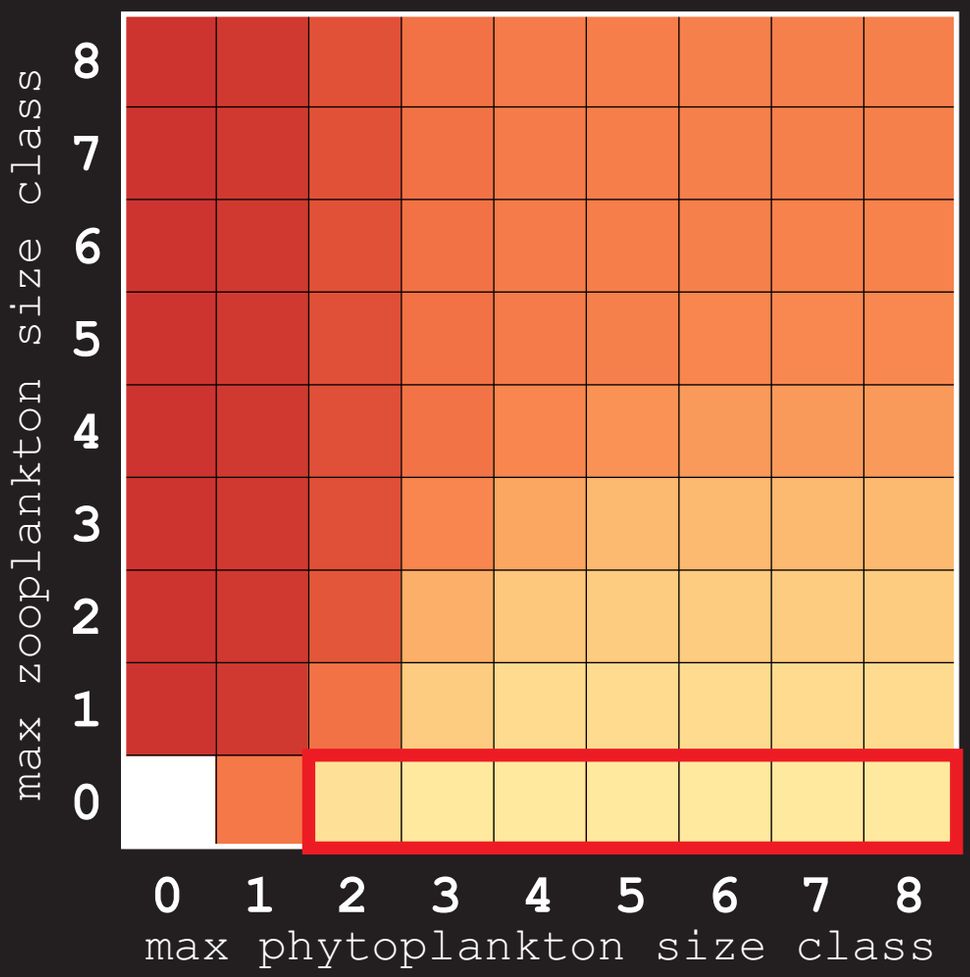


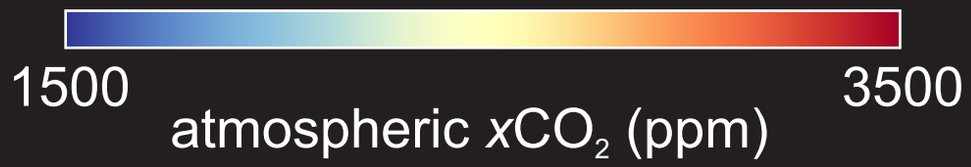


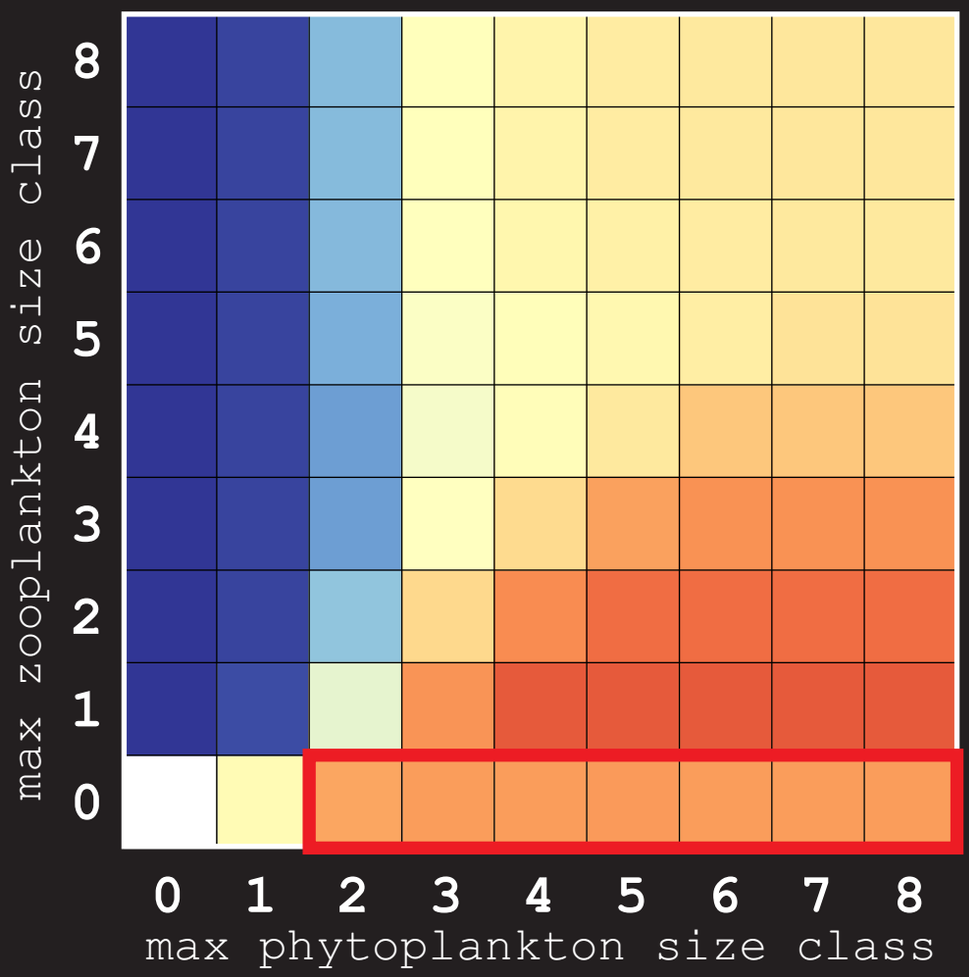


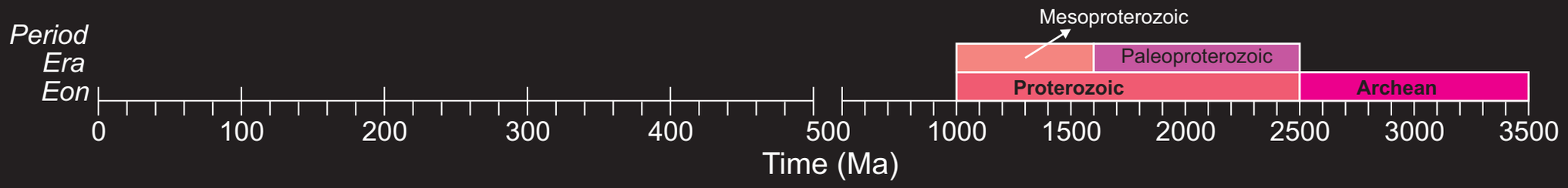


Bugs III – (2) planktonic habitat (large size range)









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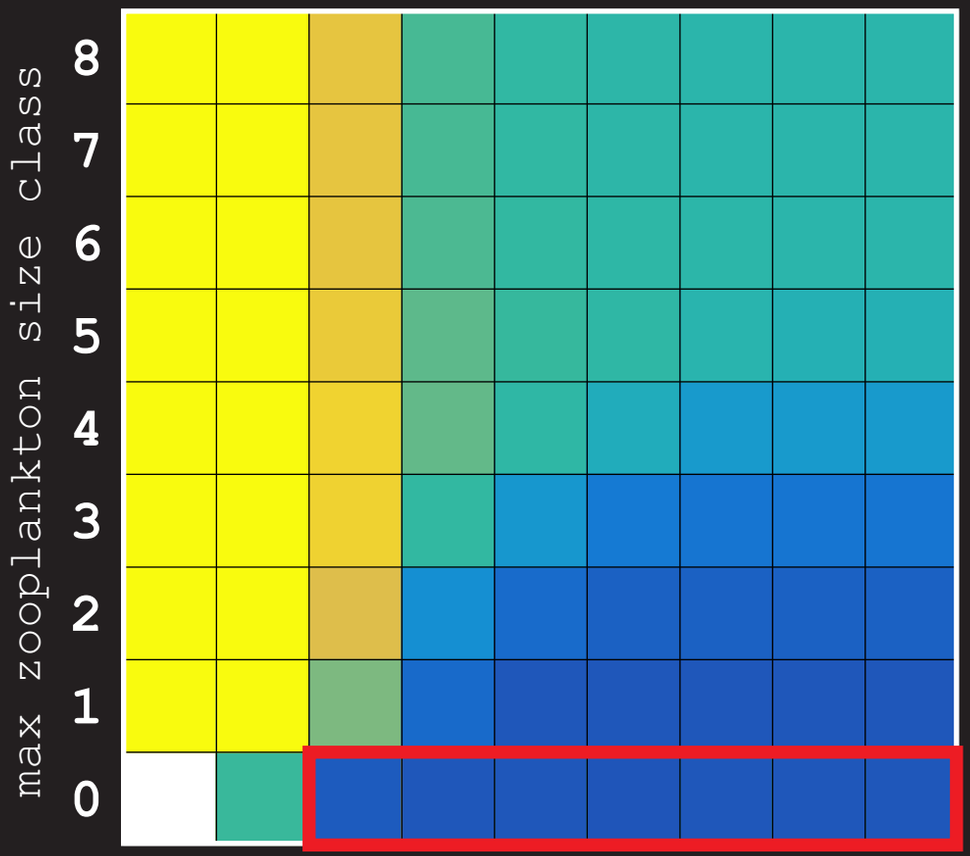

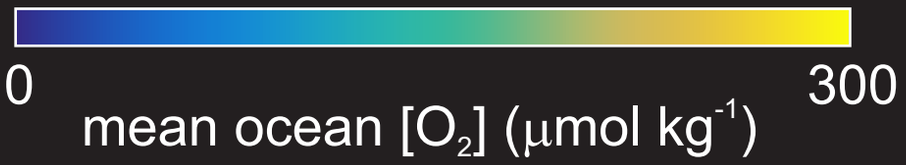

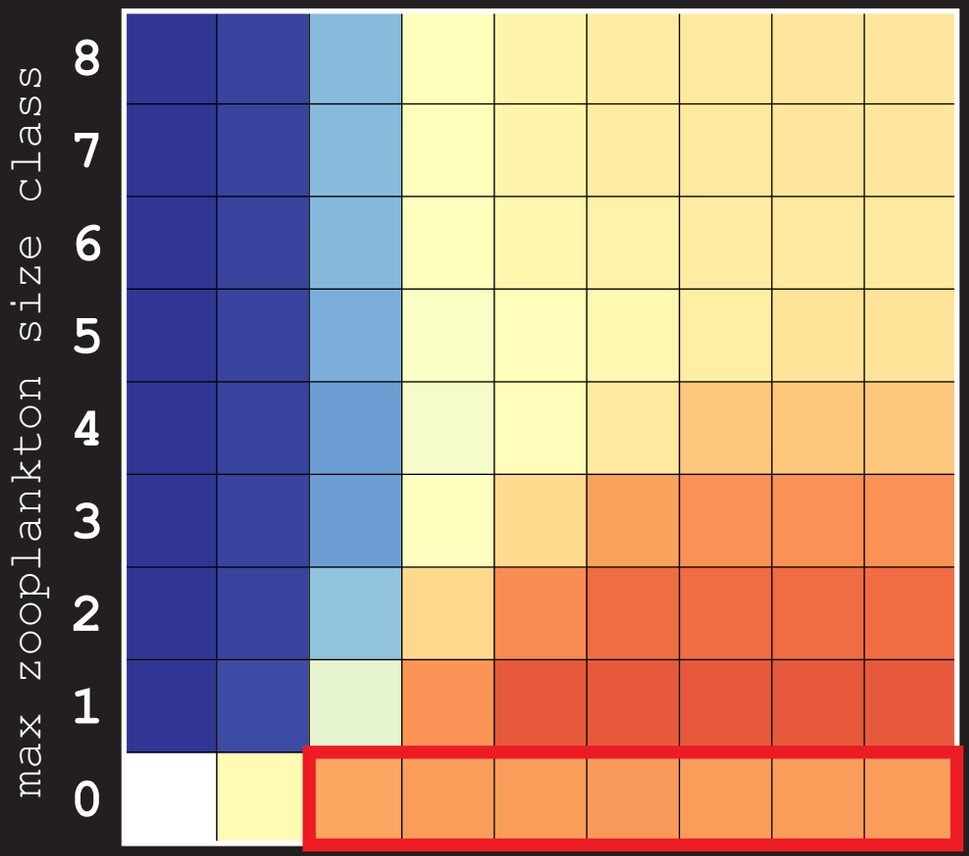

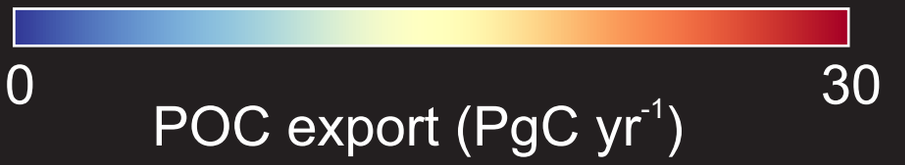

Bugs III – (3) grazing?

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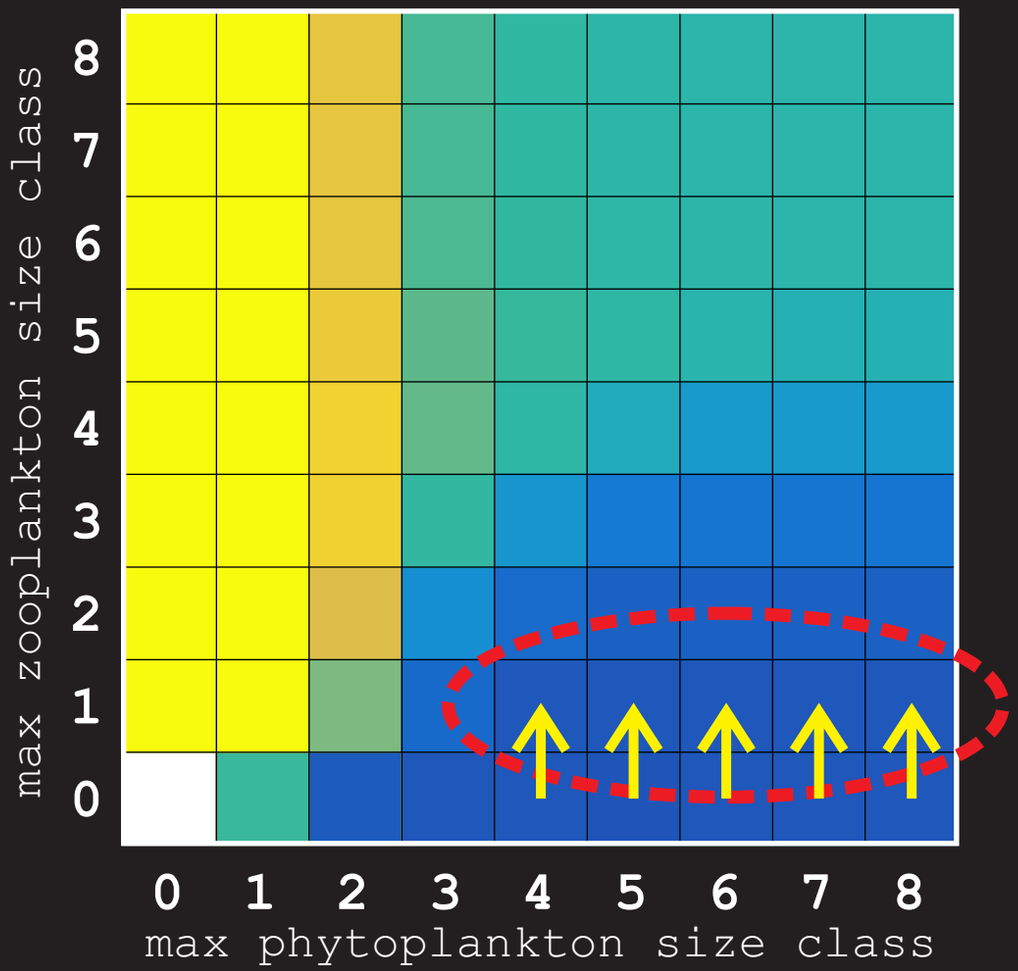

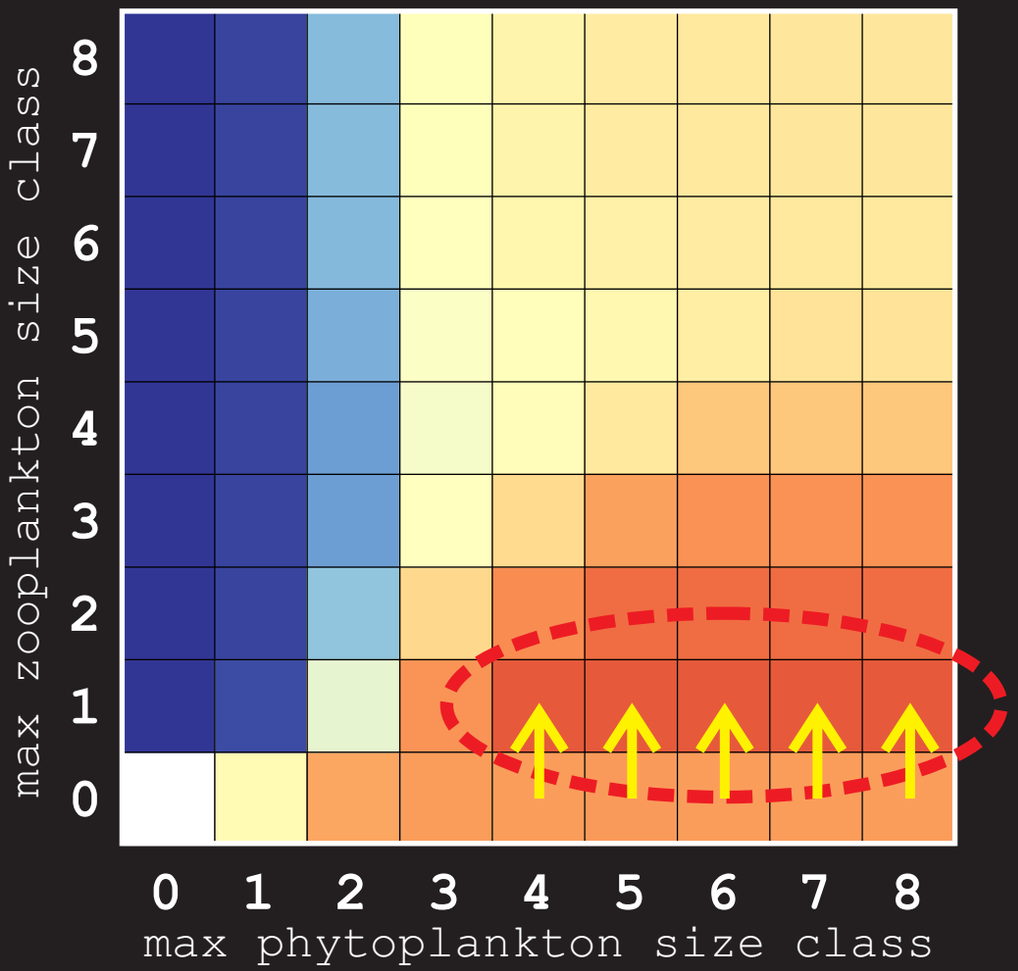

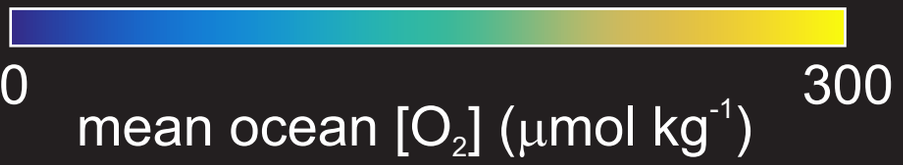

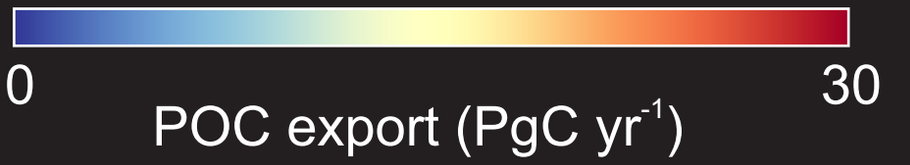

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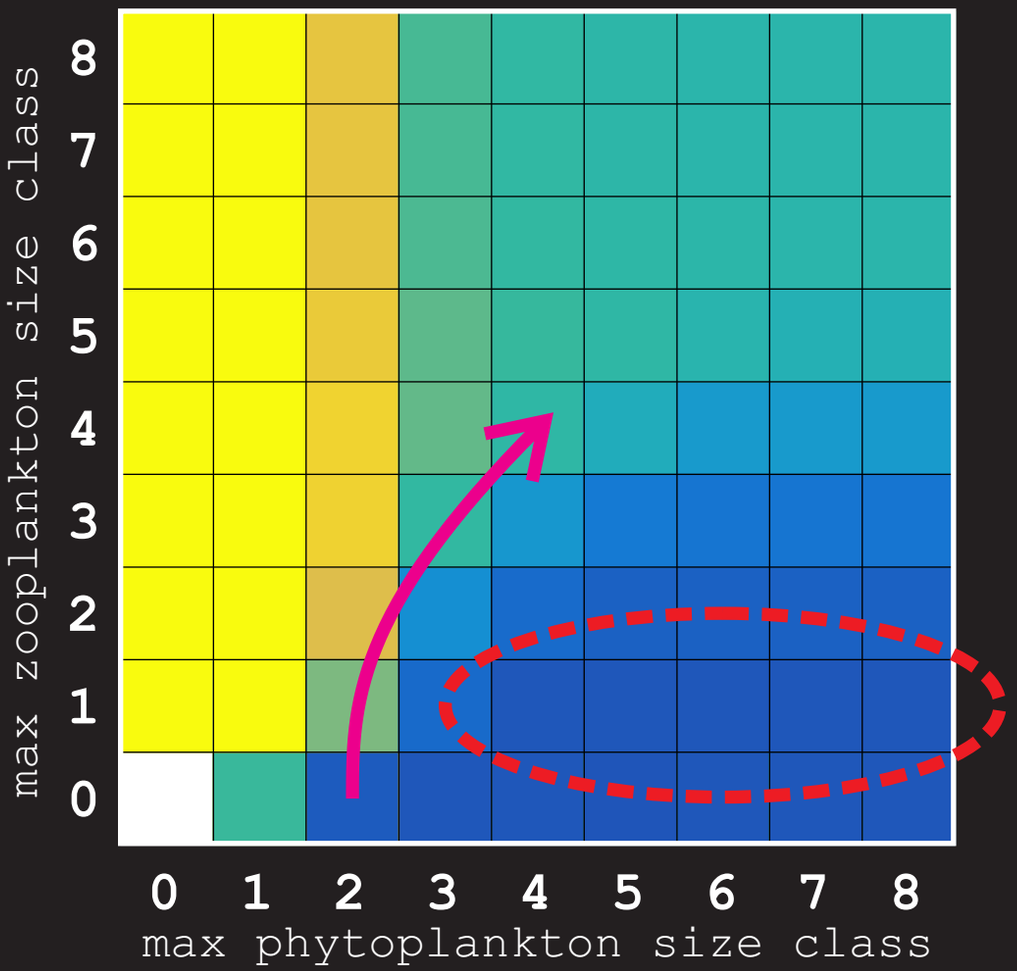

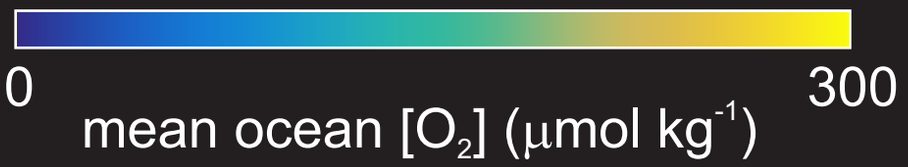

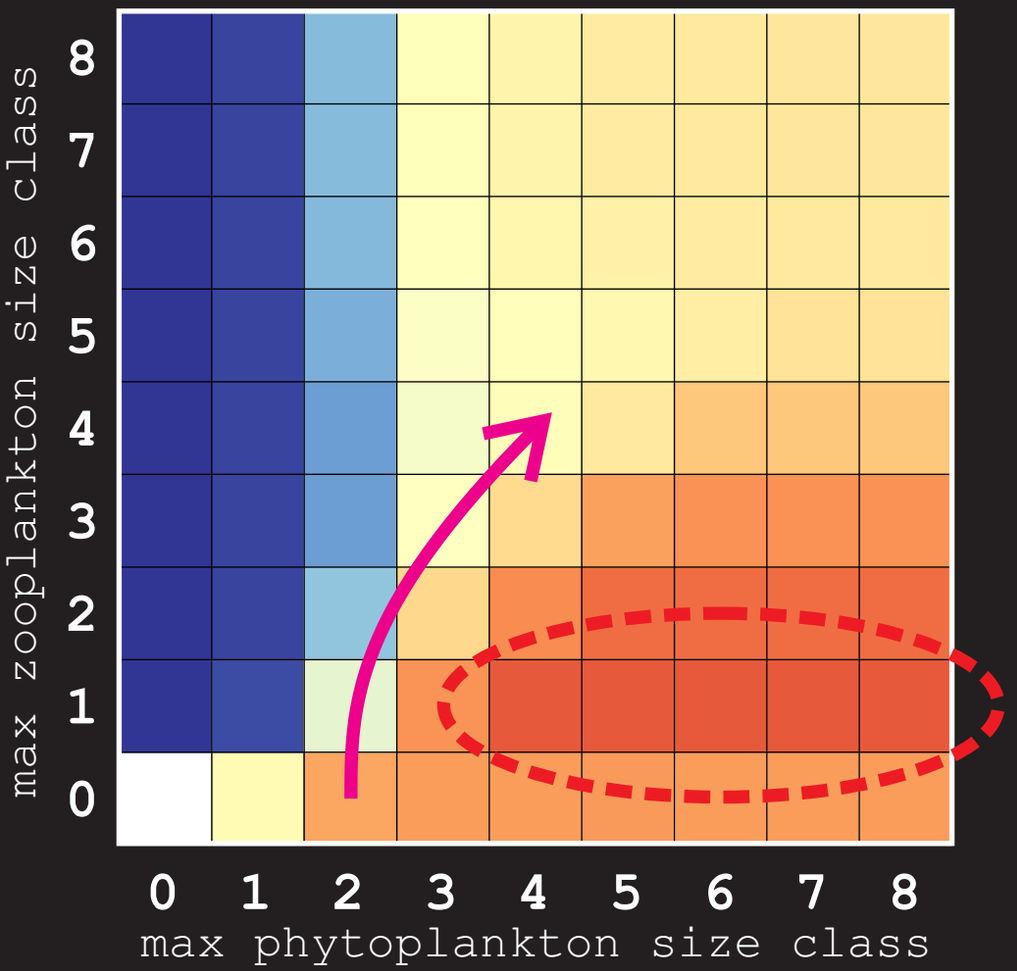

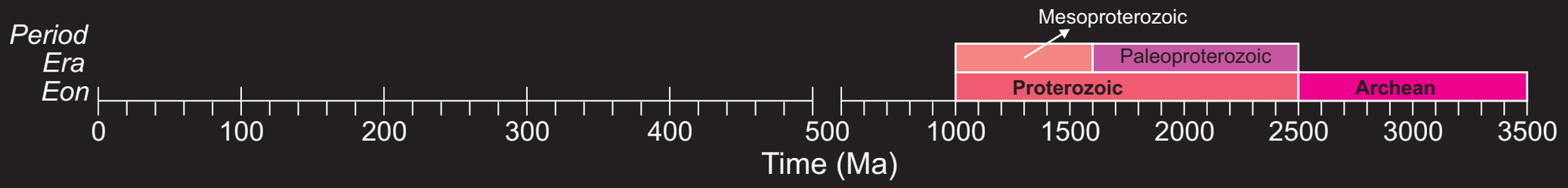

Bugs III – (4) animals (larger grazers)

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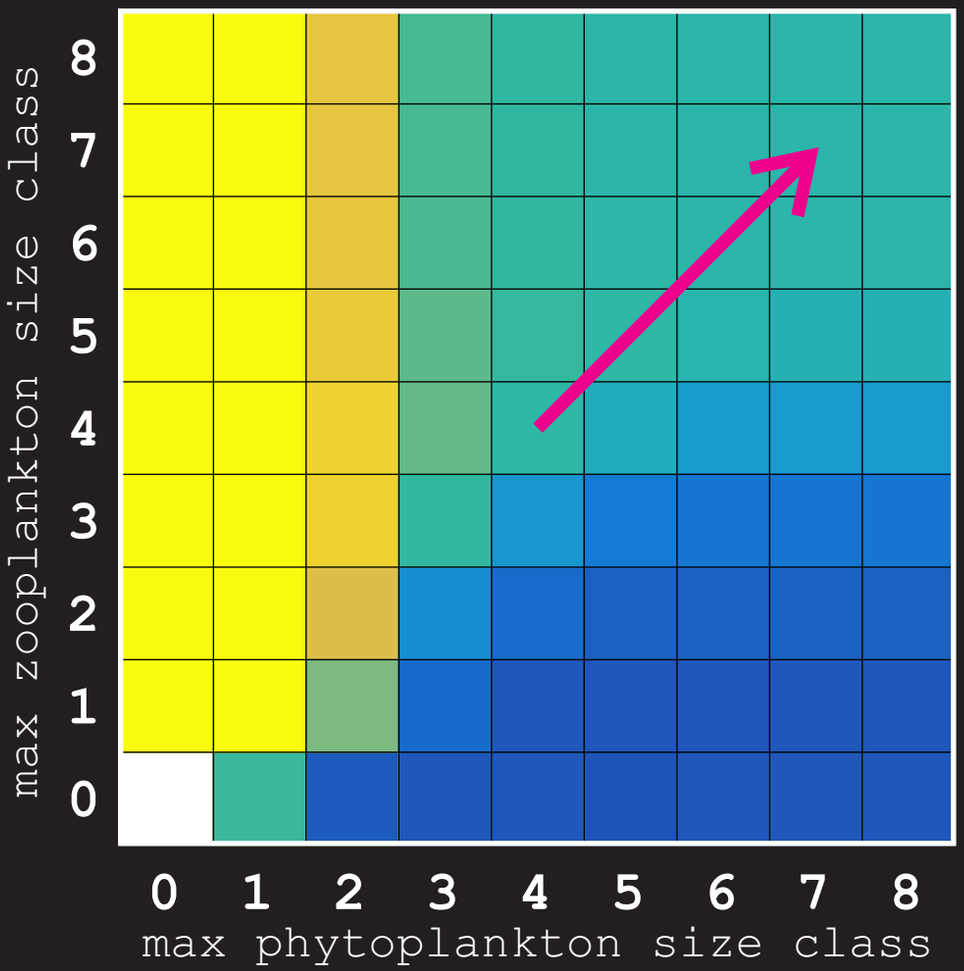

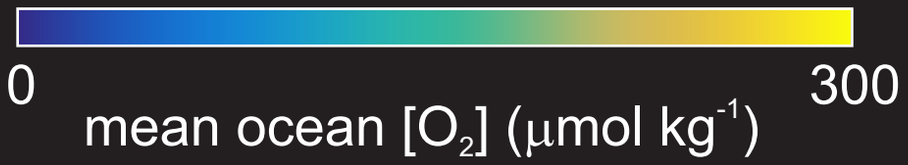

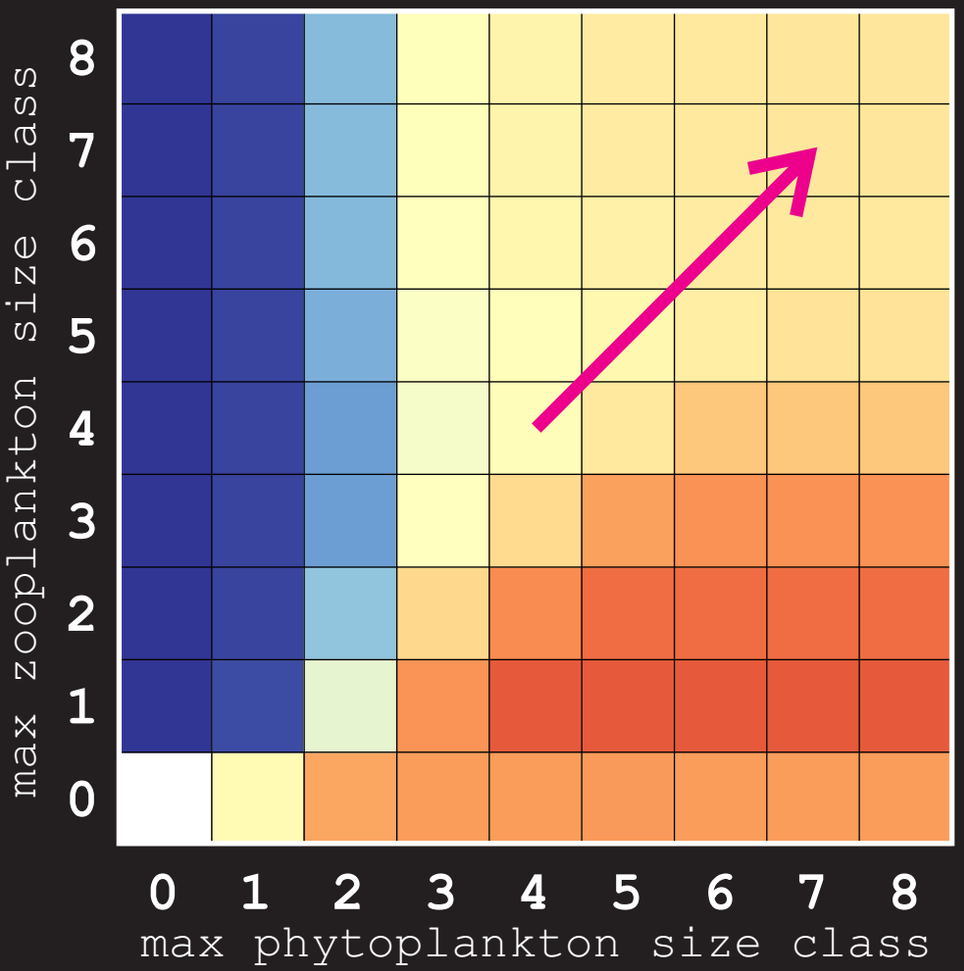

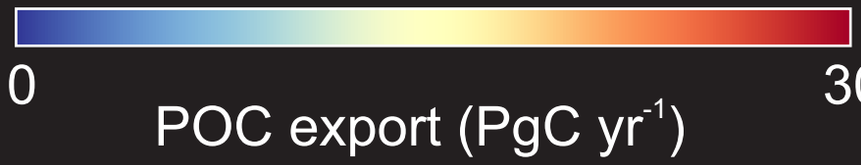

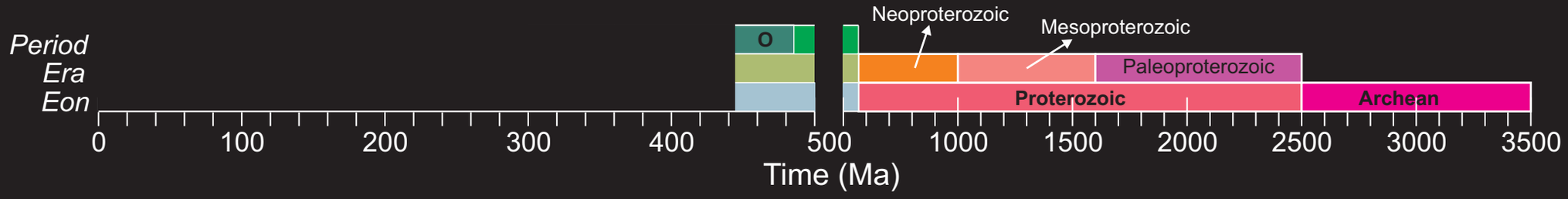

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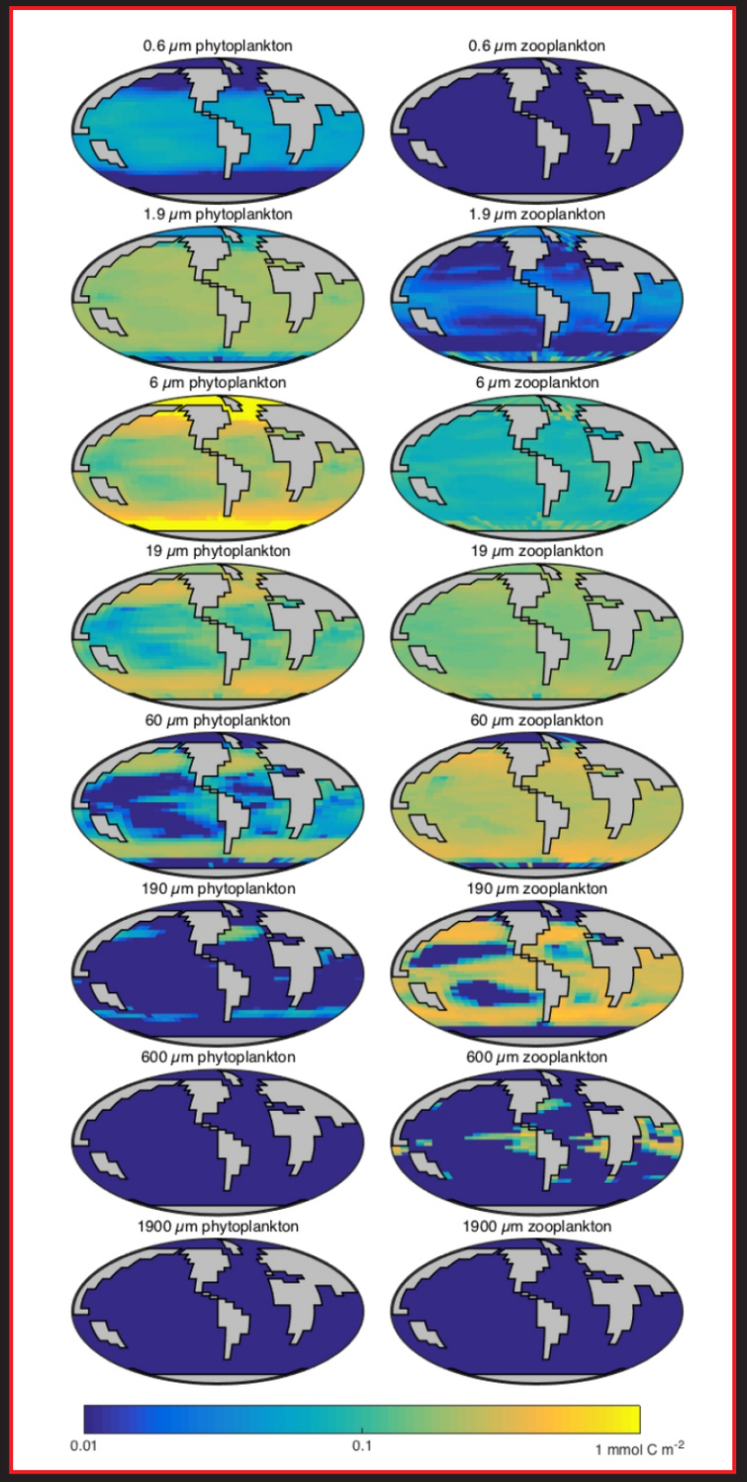
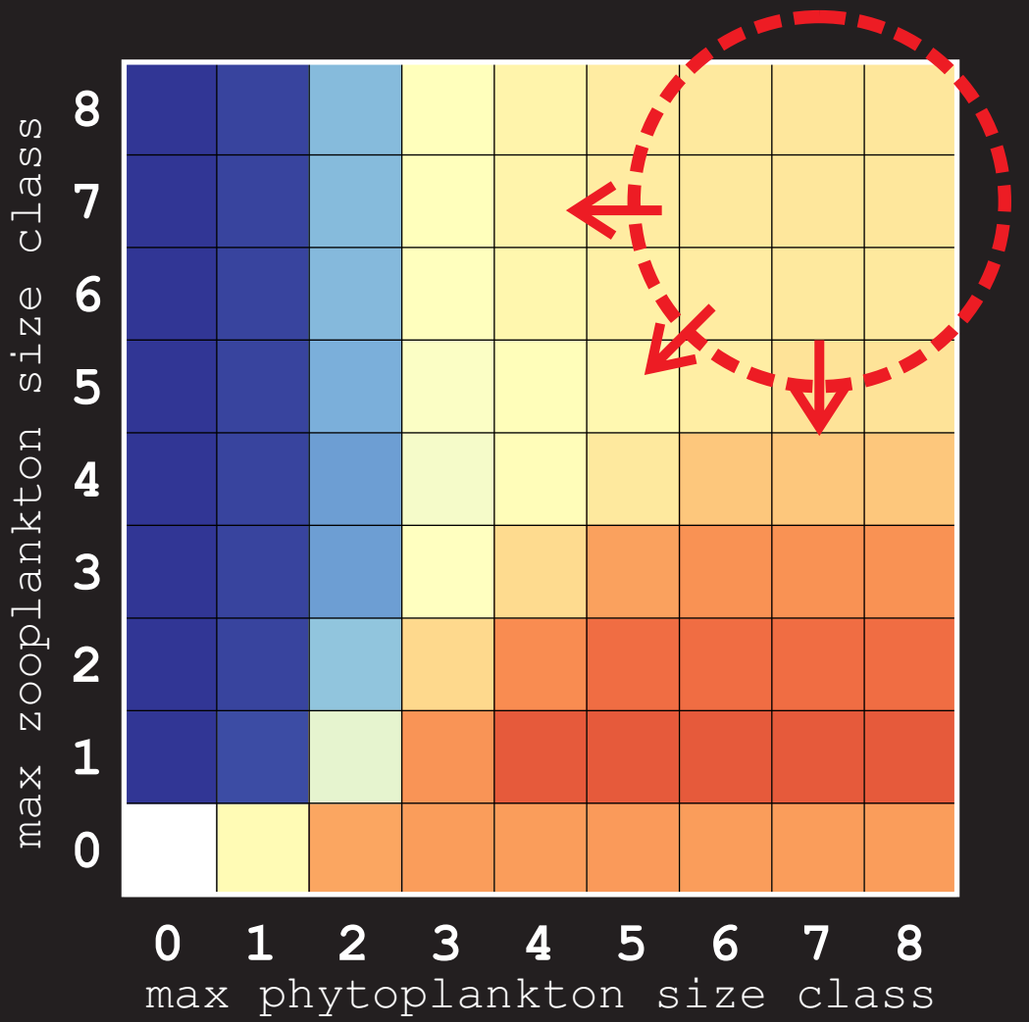
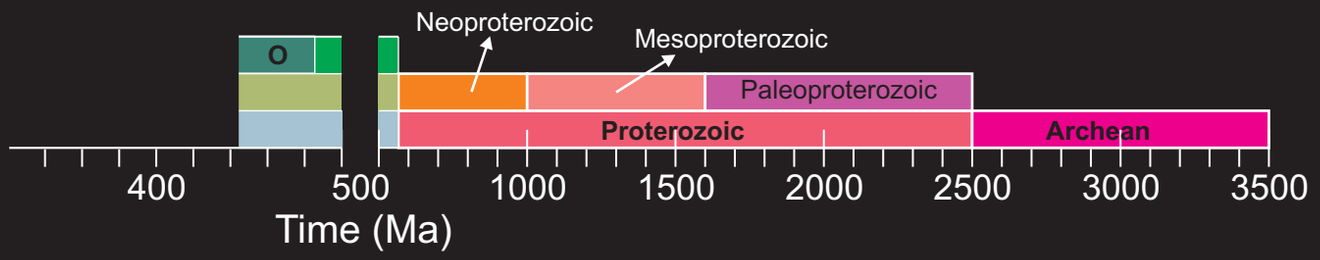
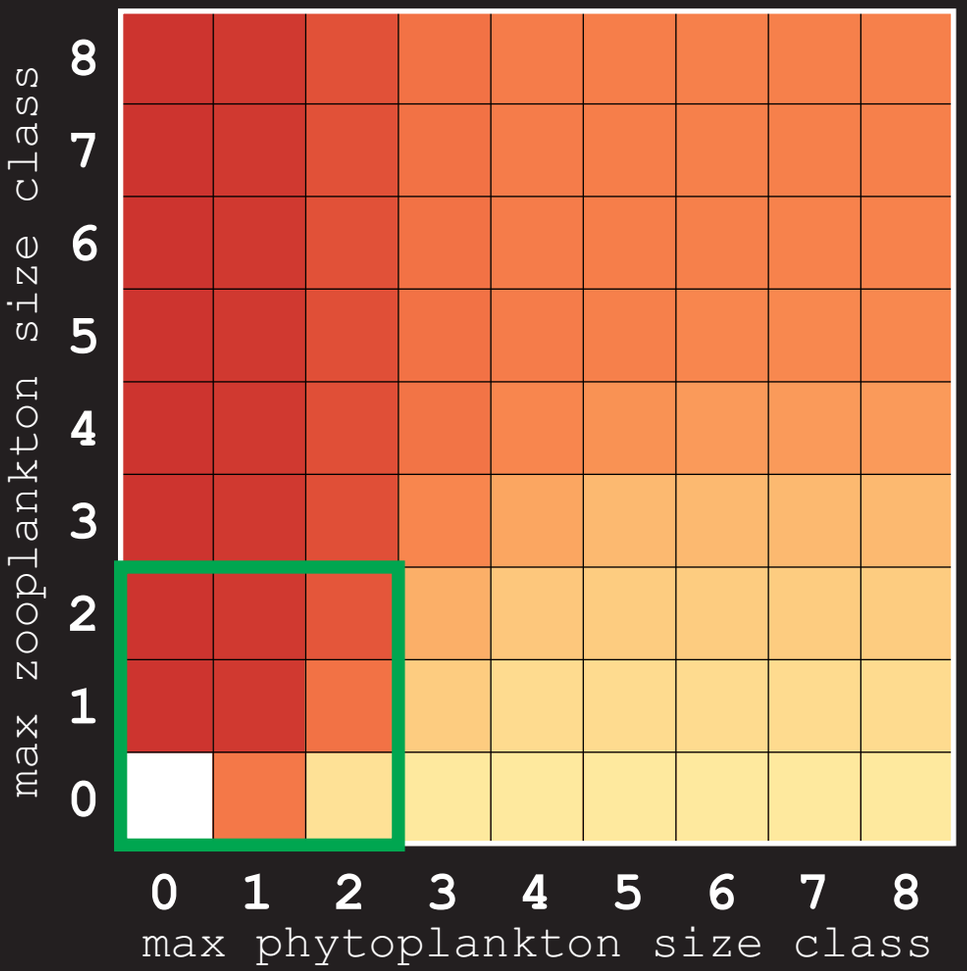
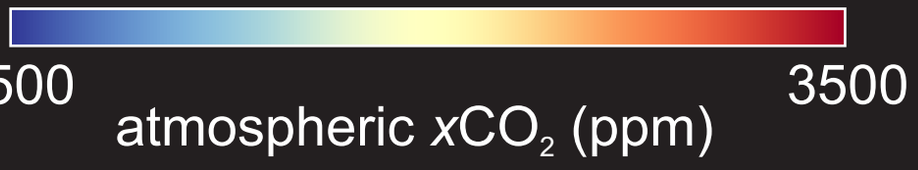


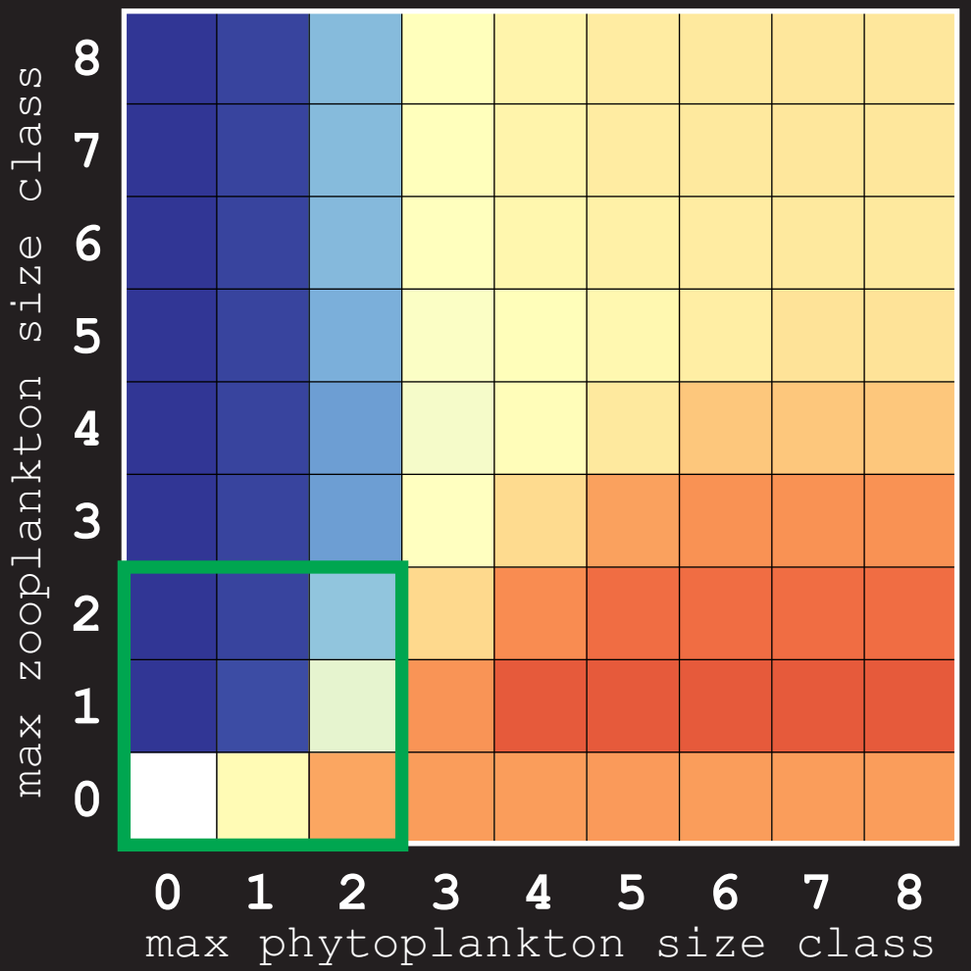


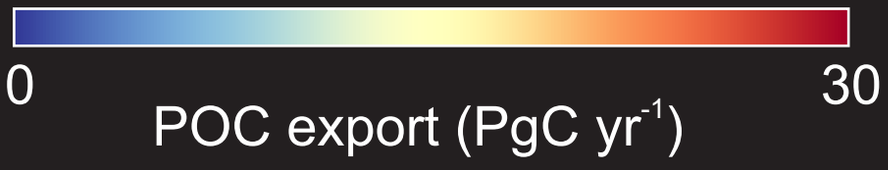


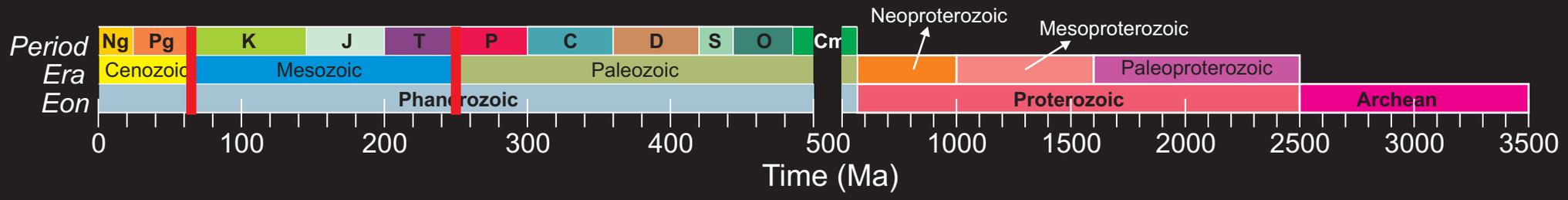
Bugs III – (5) extinctions











Bugs IV – evolution *in silico*

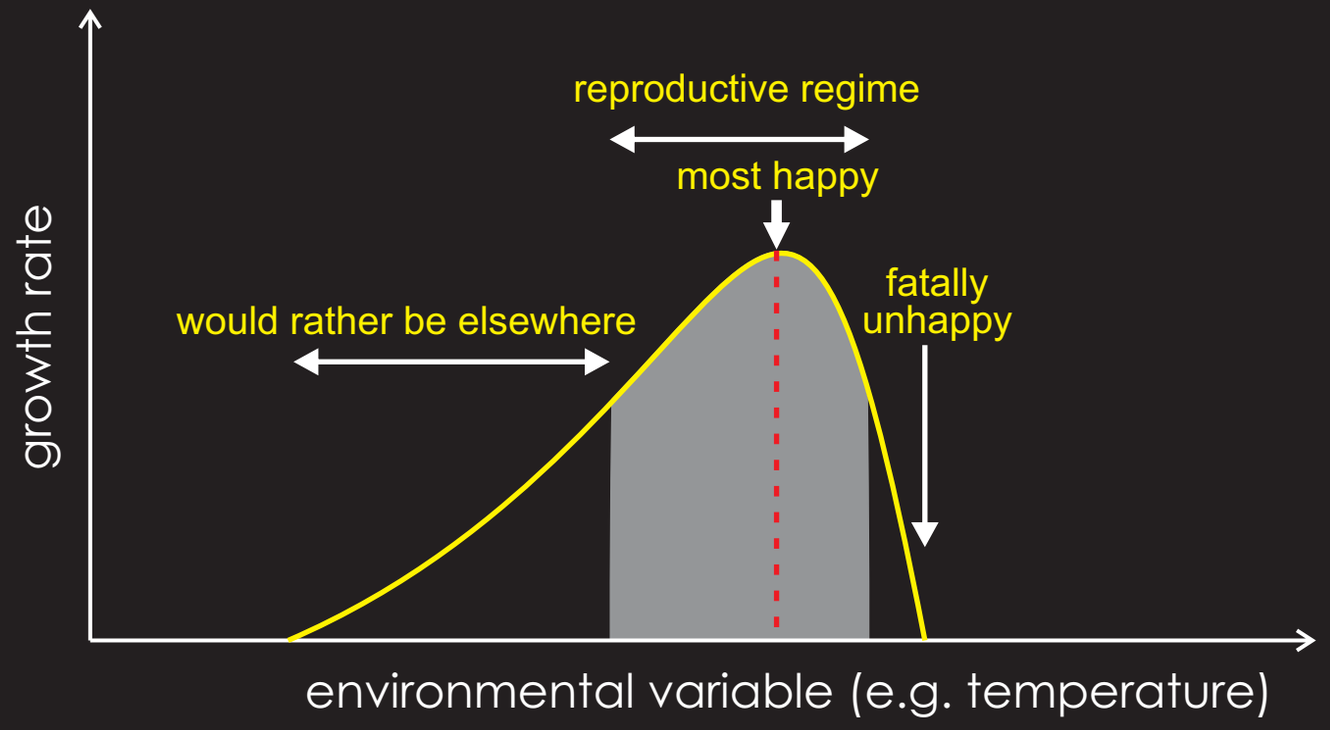
1. 

2. 

Ng	Pg	K	J	T	P	C	D	S	O	Cm
Cenozoic		Mesozoic			Paleozoic					
Phanerozoic										

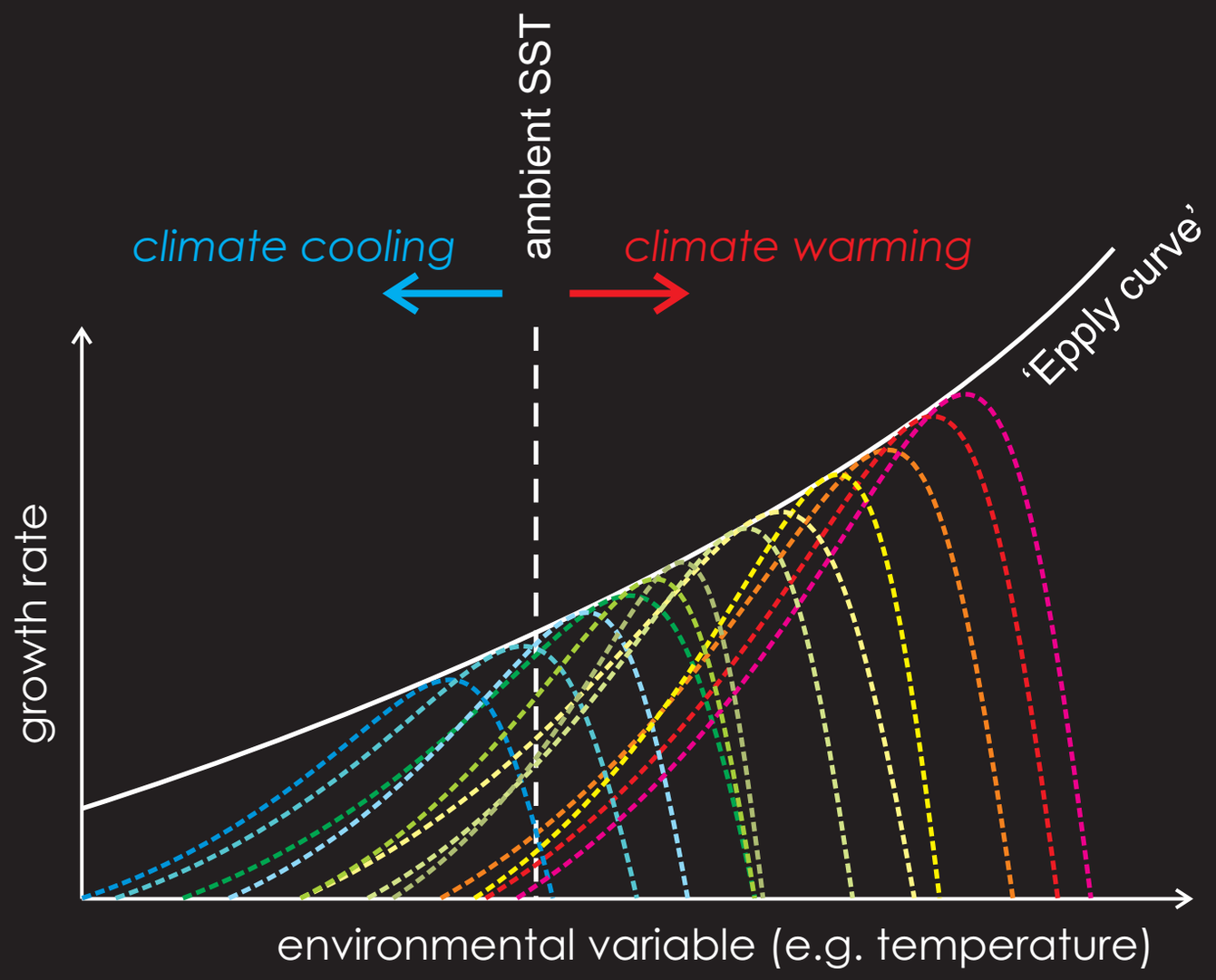
Neoprot.	Mesoprot.	Paleoproterozoic
Proterozoic		Archean

Bugs IV – evolution *in silico*



're-drawn', with sincere apologies, from Schmidt et al. [2006]

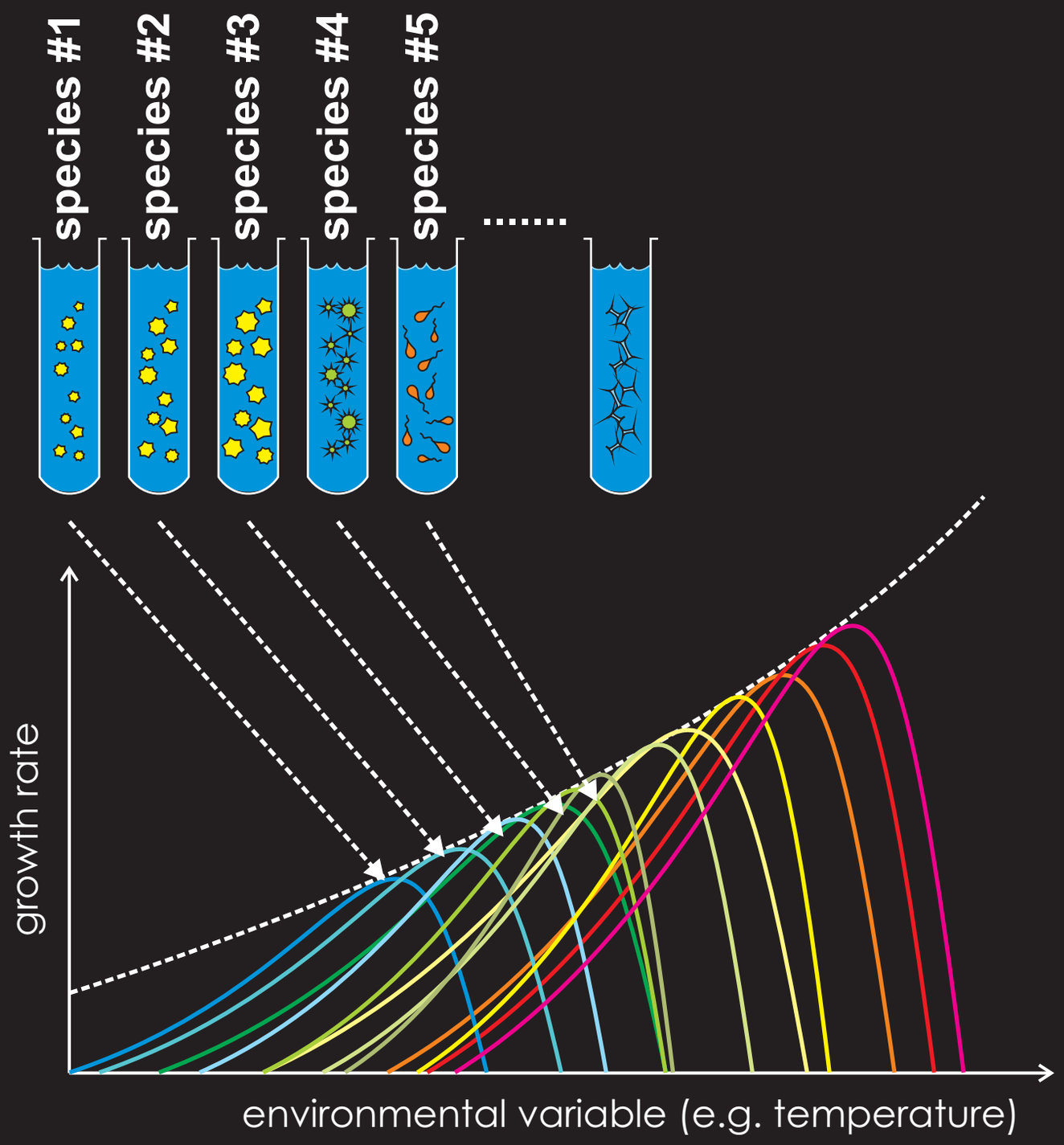
Bugs IV – evolution *in silico*



In traditional 'functional type' ecosystem models, diversity is not resolved, but instead its effects highly parameterized (e.g. the 'Epply curve').

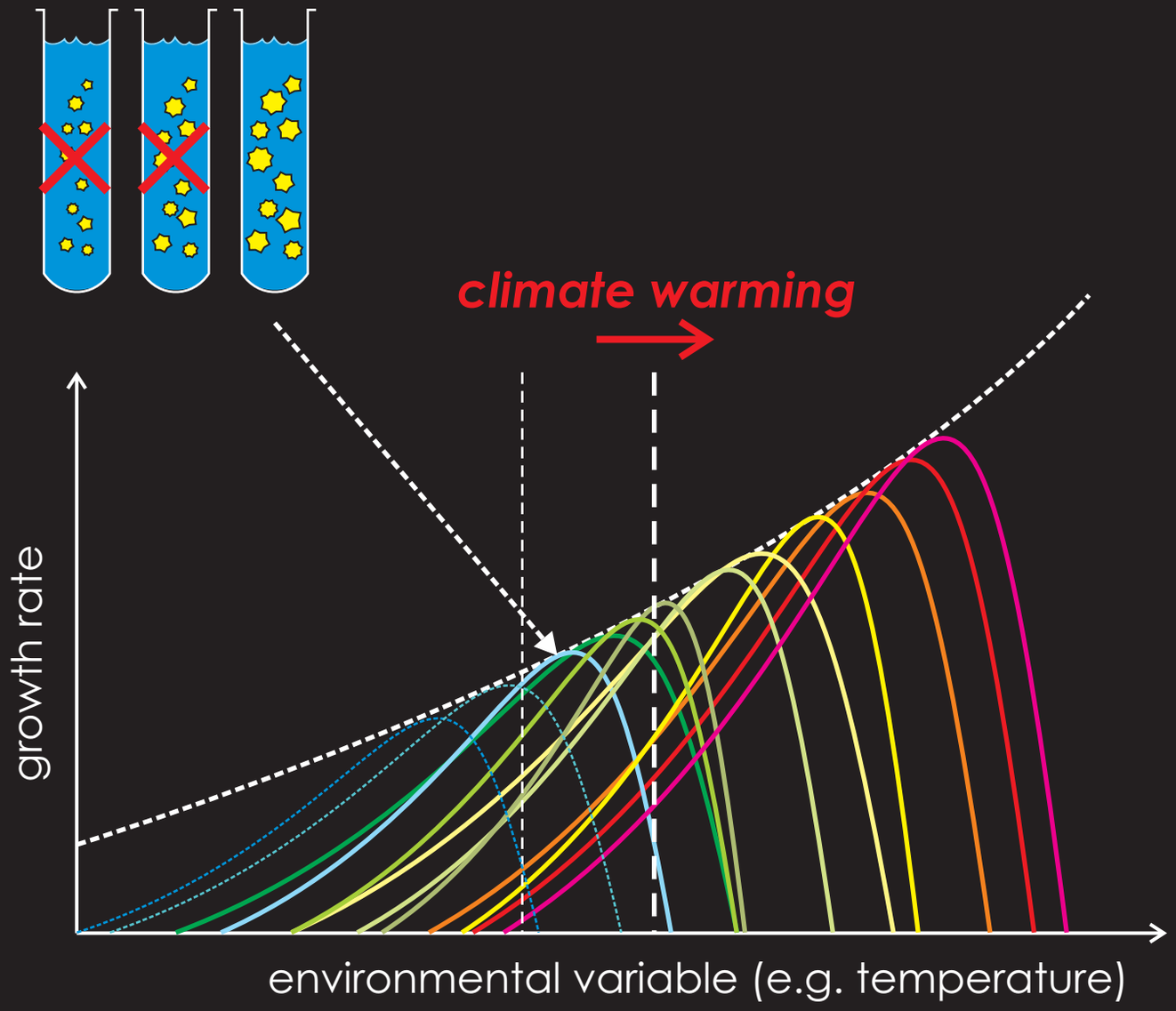
The response to a change in climate is then instantaneous and fully reversible.

Bugs IV – evolution *in silico*



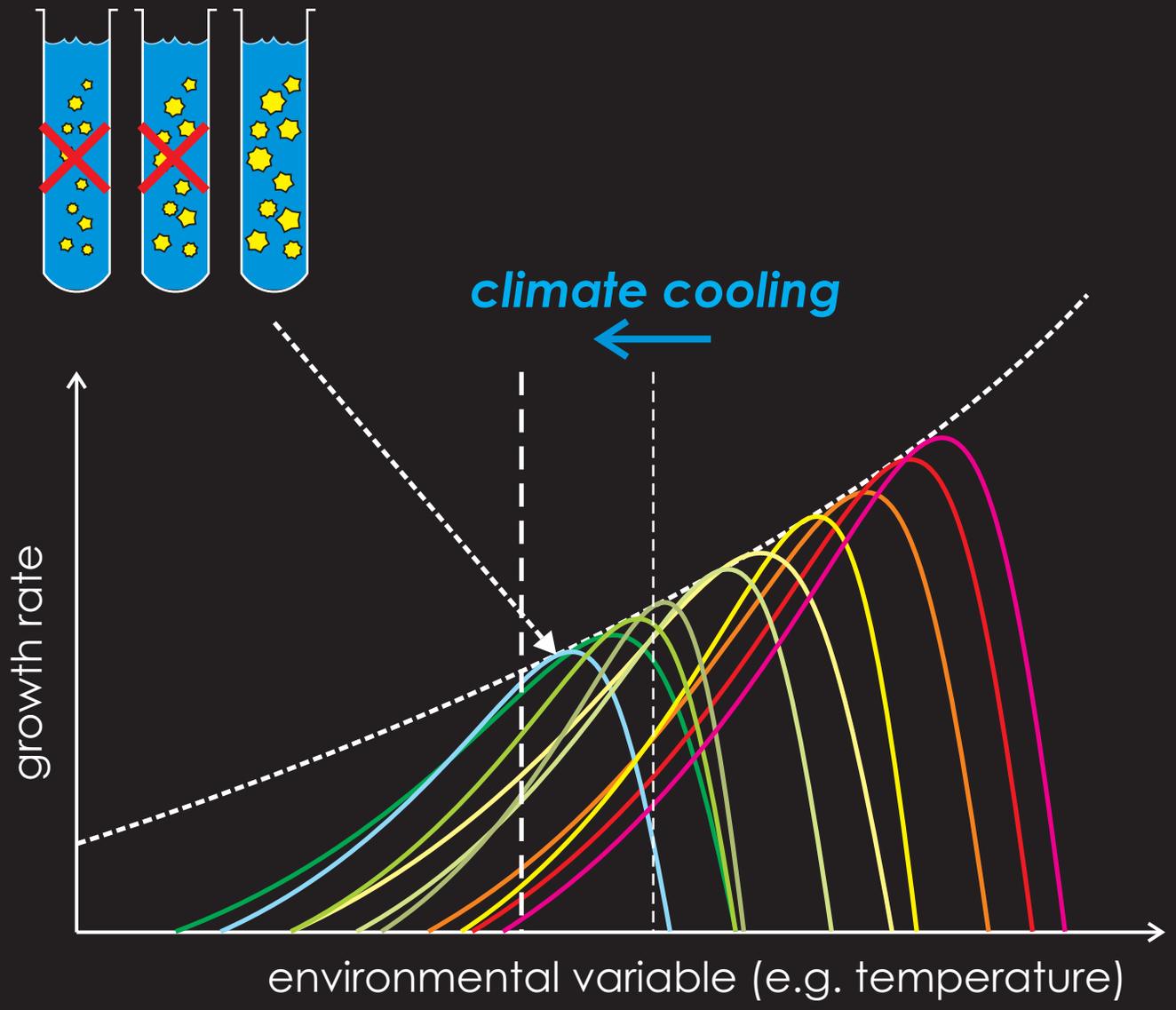
Instead, in a highly diverse model, the environmental response of individual 'species' can be resolved ...

Bugs IV – evolution *in silico*



... and under warming, obligate cryophiles go extinct.

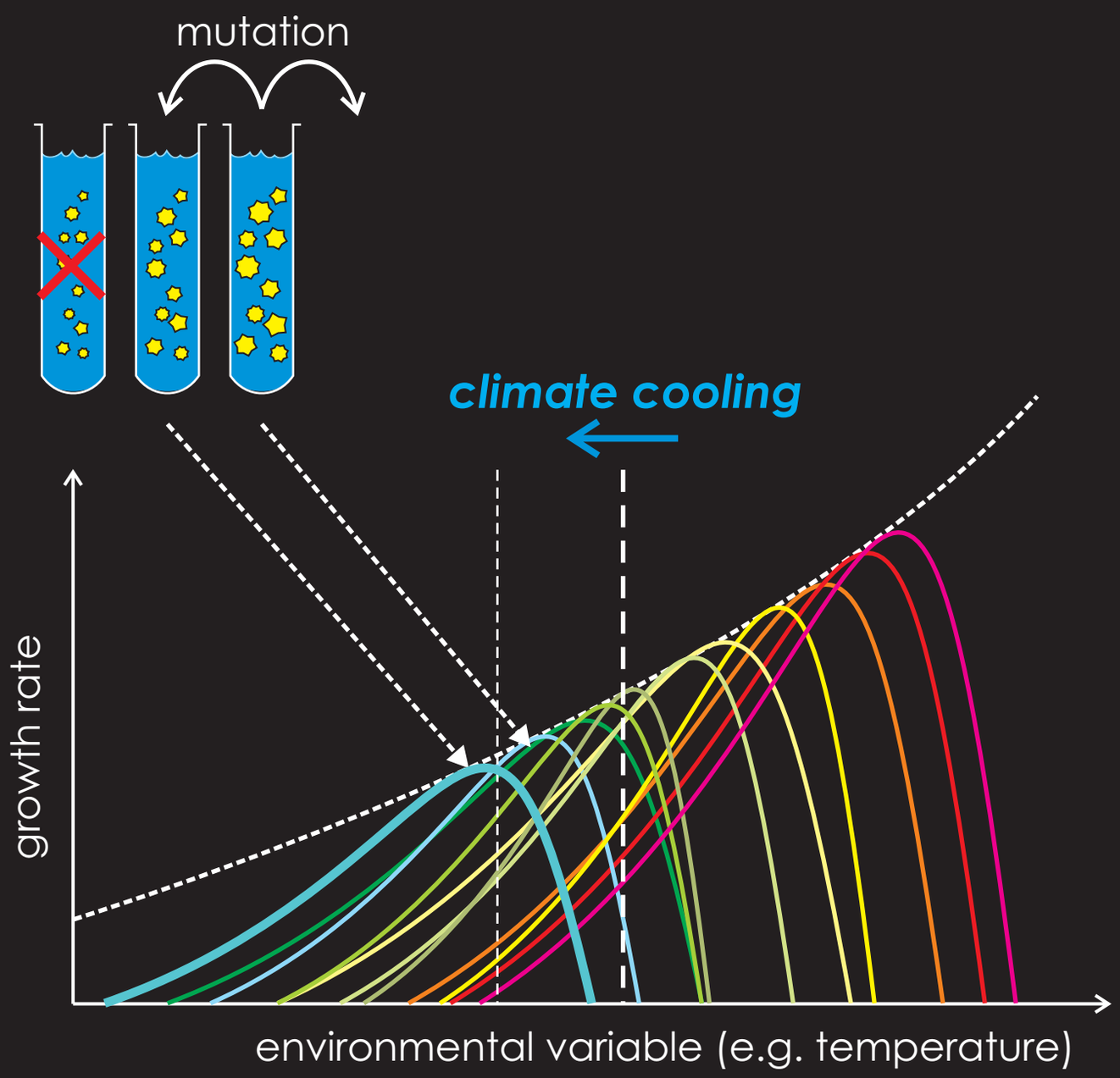
Bugs IV – evolution *in silico*



If climate cools, the low SST optimized species/varients no longer exist. Ecosystem dynamics are presumably different.

Niches are unfilled, so ...

Bugs IV – evolution *in silico*

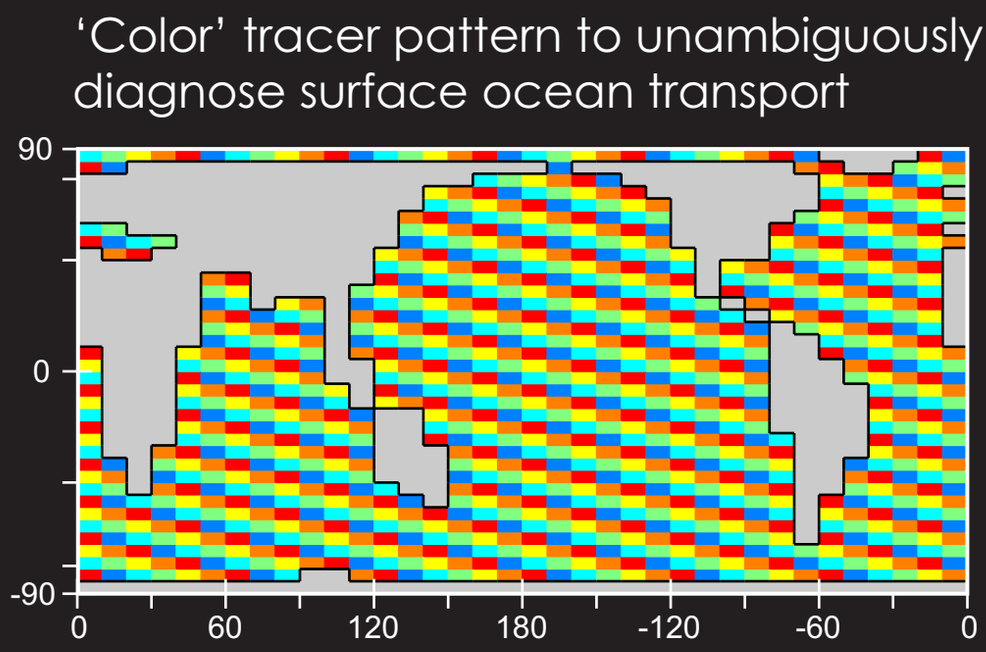


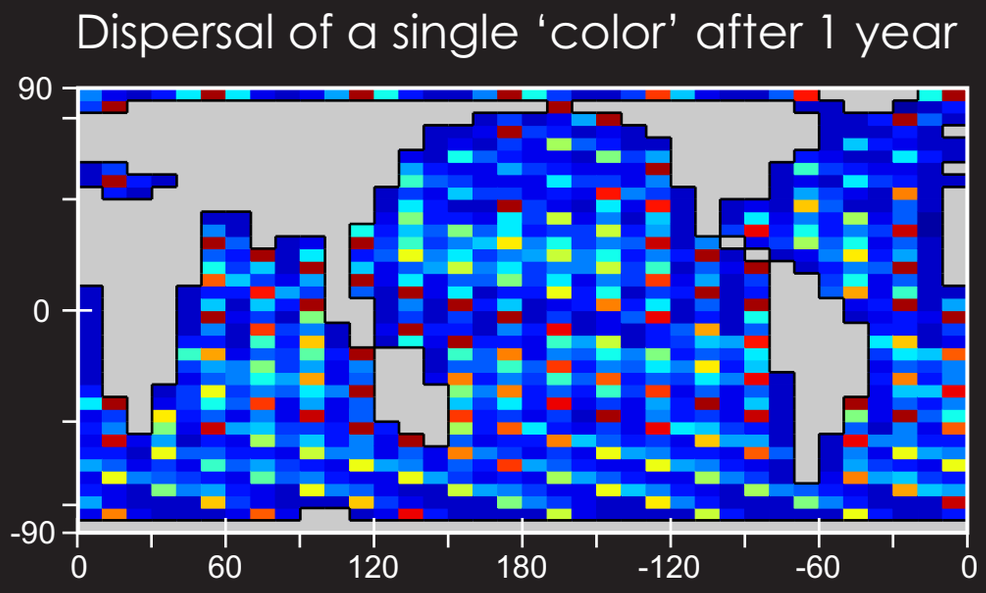
Allow non-viable plankton to be replaced with 'mutations' of surviving species, using the trait based trade-offs.

Q. How 'frequently' to mutate, and as a function of what?

Q. What 'step size' to take for mutation?

Bugs IV – evolution *in silico*





There is clearly a very significant computational expense involved, even if using low resolution/efficient Earth system models such as 'GENIE'.

=> Diagnose full 3D circulation, and employ (sparse) parallelized matrix multiplication or similar ...

Then create new model in MATLAB

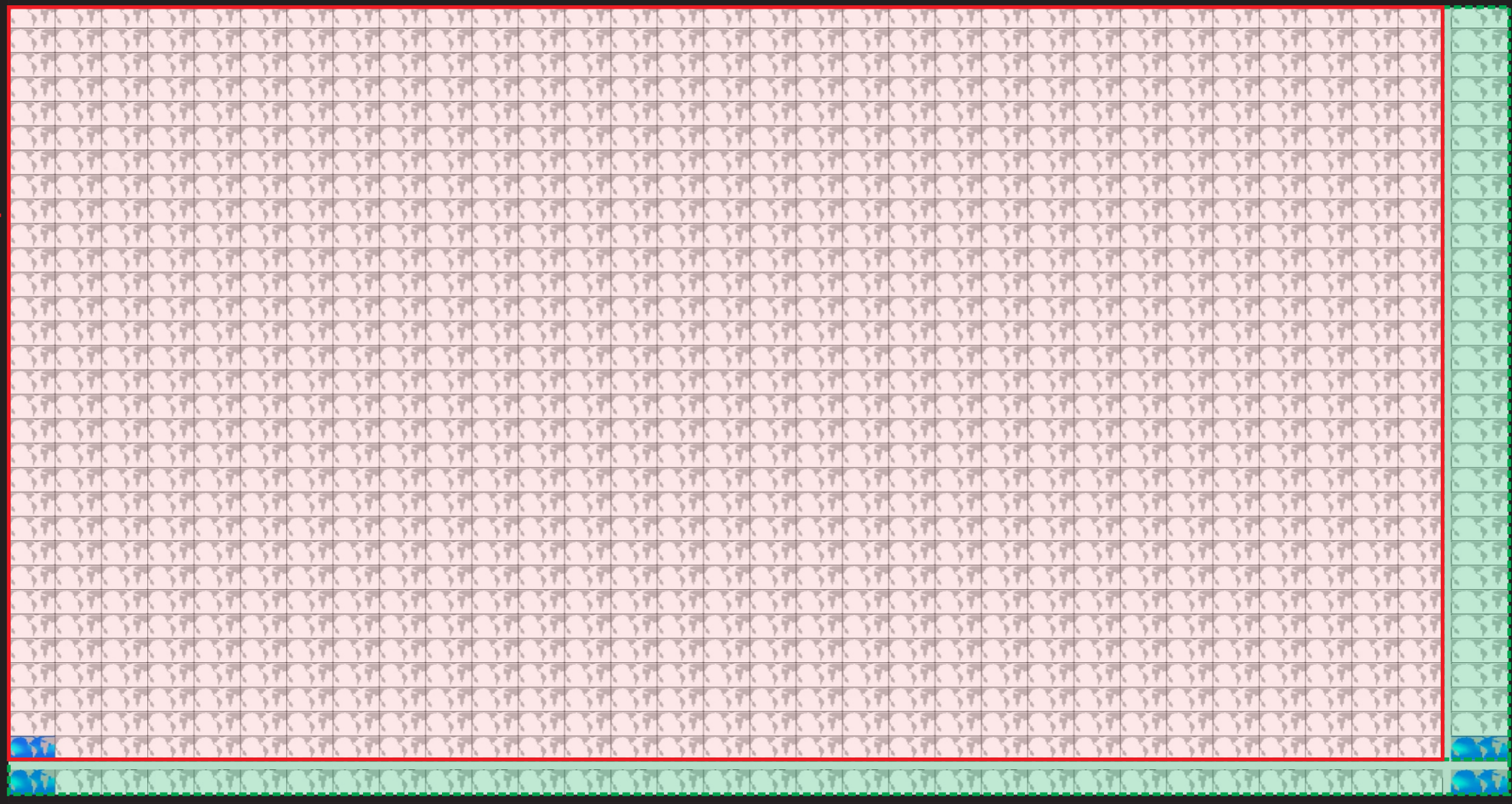
"A Matrix Metacommunity Model: ecological and evolutionary emergence of a global plankton metacommunity" *Ward, Wilson, et al.* [in prep]

Bugs IV – evolution *in silico*

961 global maps of biomass (one for each 'trait' combination == 'species')

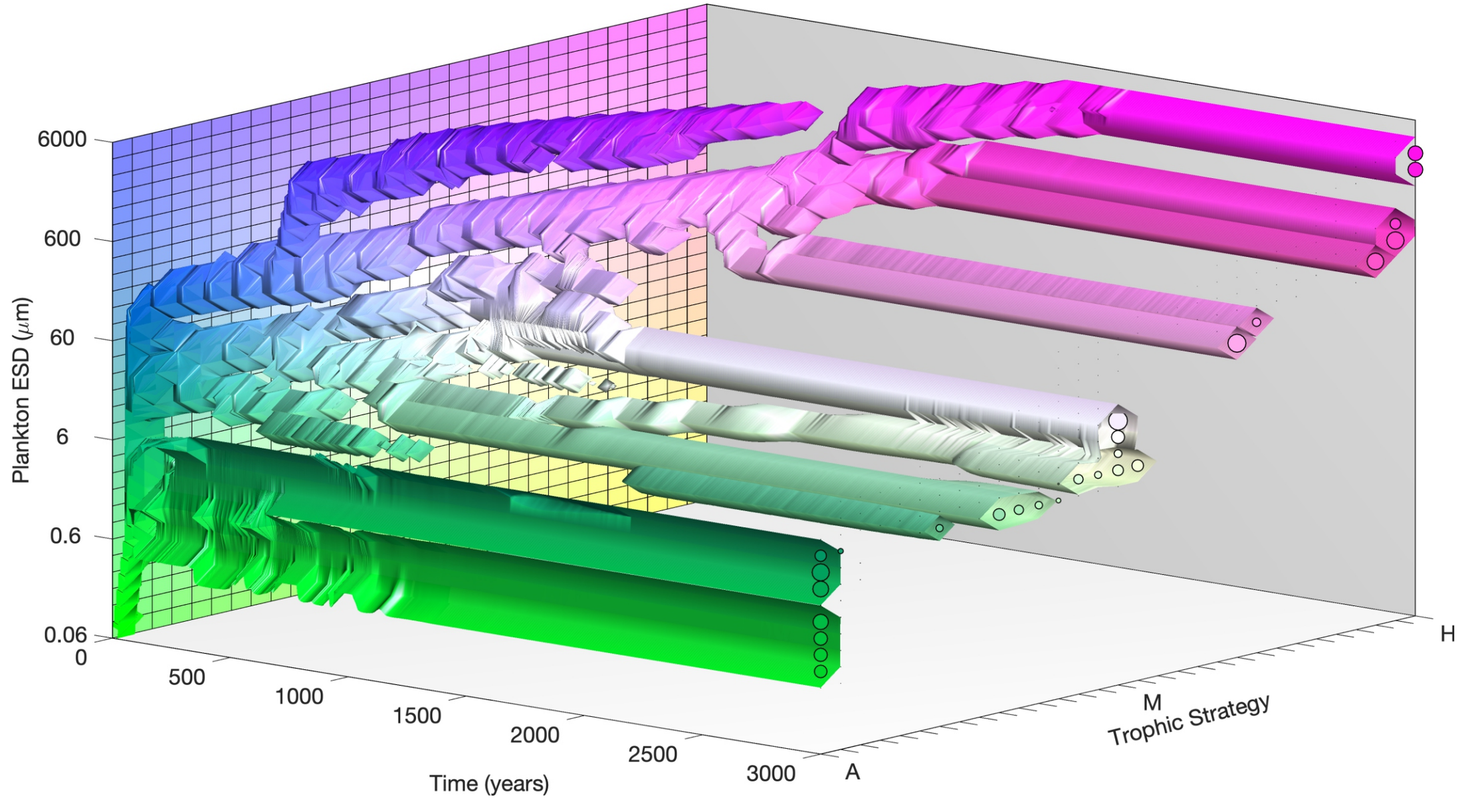
31 degrees of mixotrophy

31 different size classes of plankton



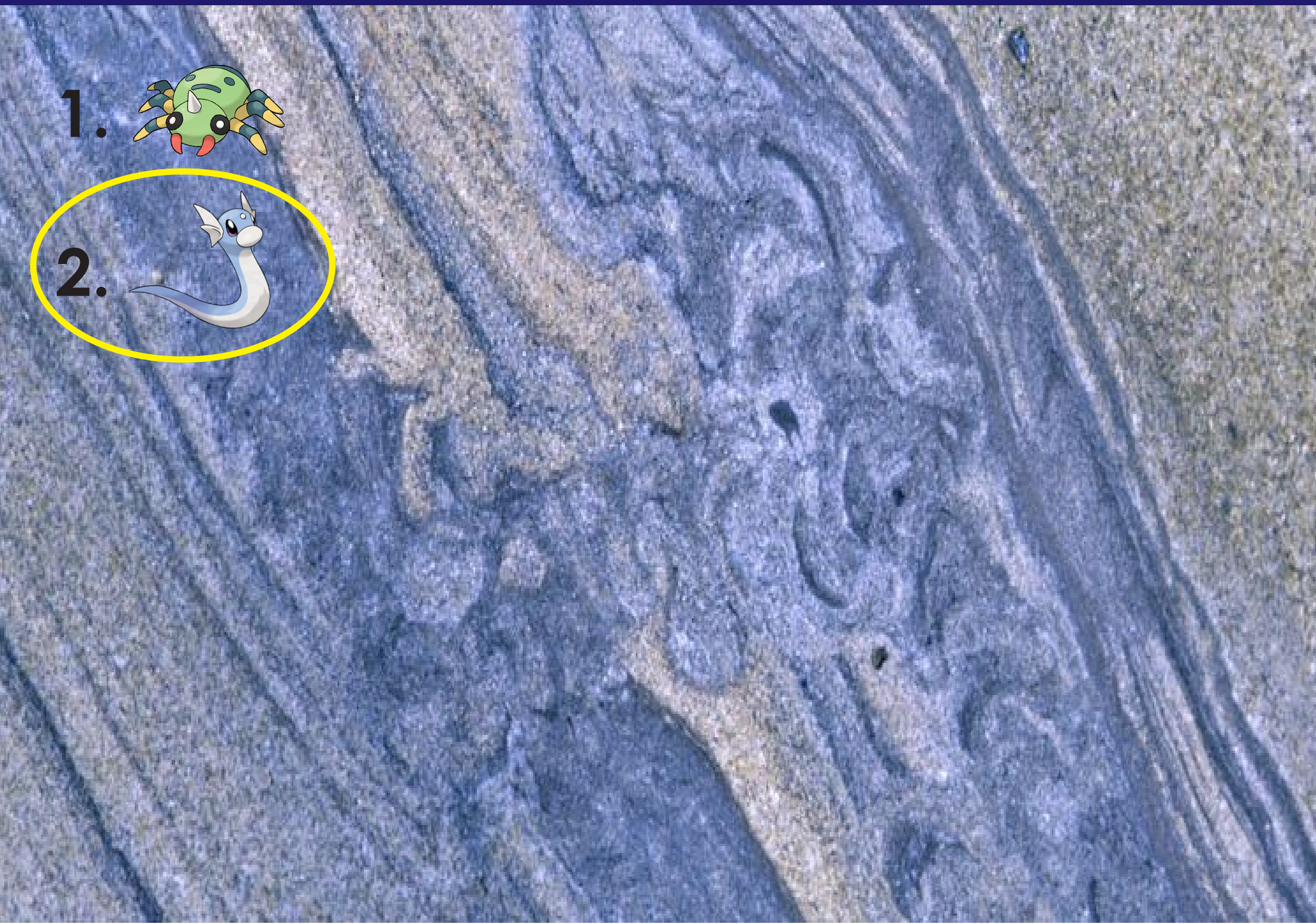
summed biomass across size classes (for the same degree of mixotrophy)

Bugs IV – evolution *in silico*

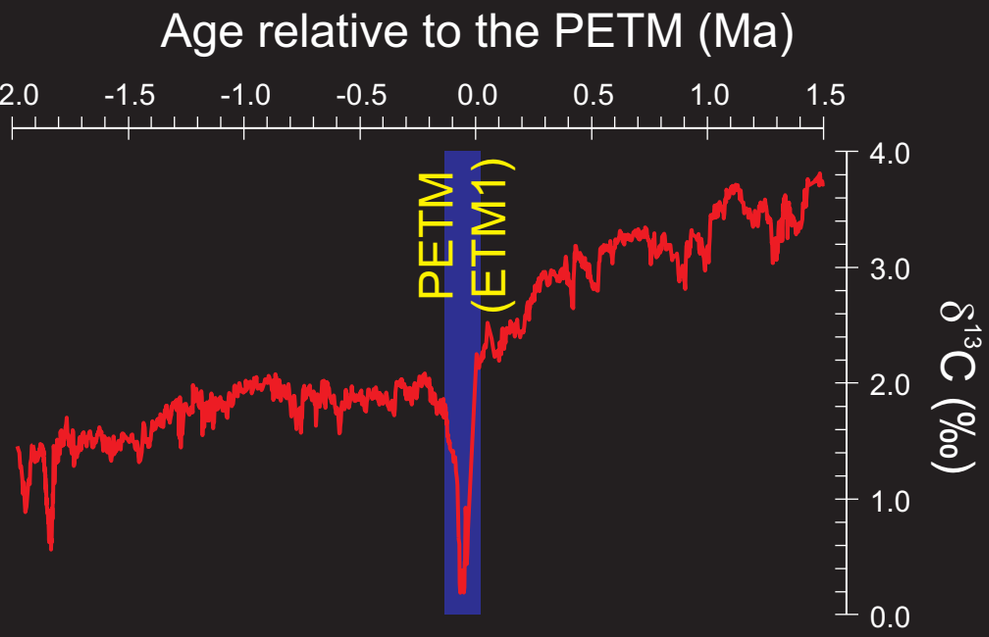


A Matrix Metacommunity Model:
ecological and evolutionary emergence
of a global plankton metacommunity
Ward, Wilson, et al. [in prep]

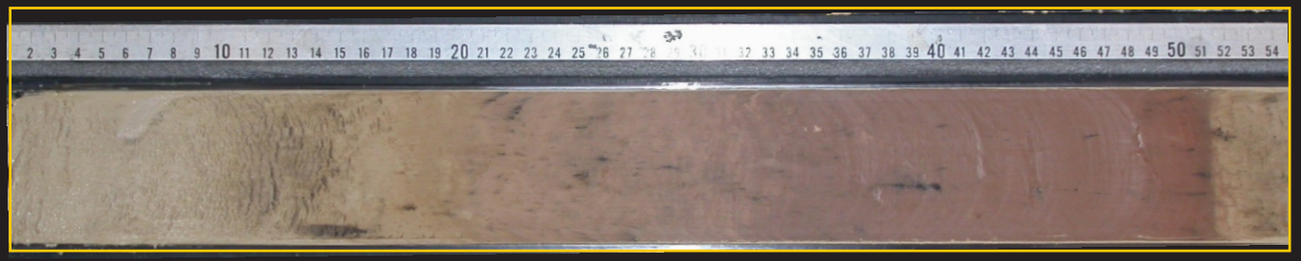
worms



worms – decoding the geological record

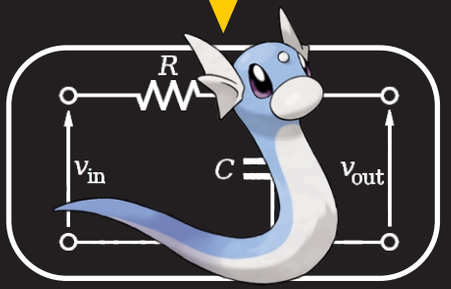


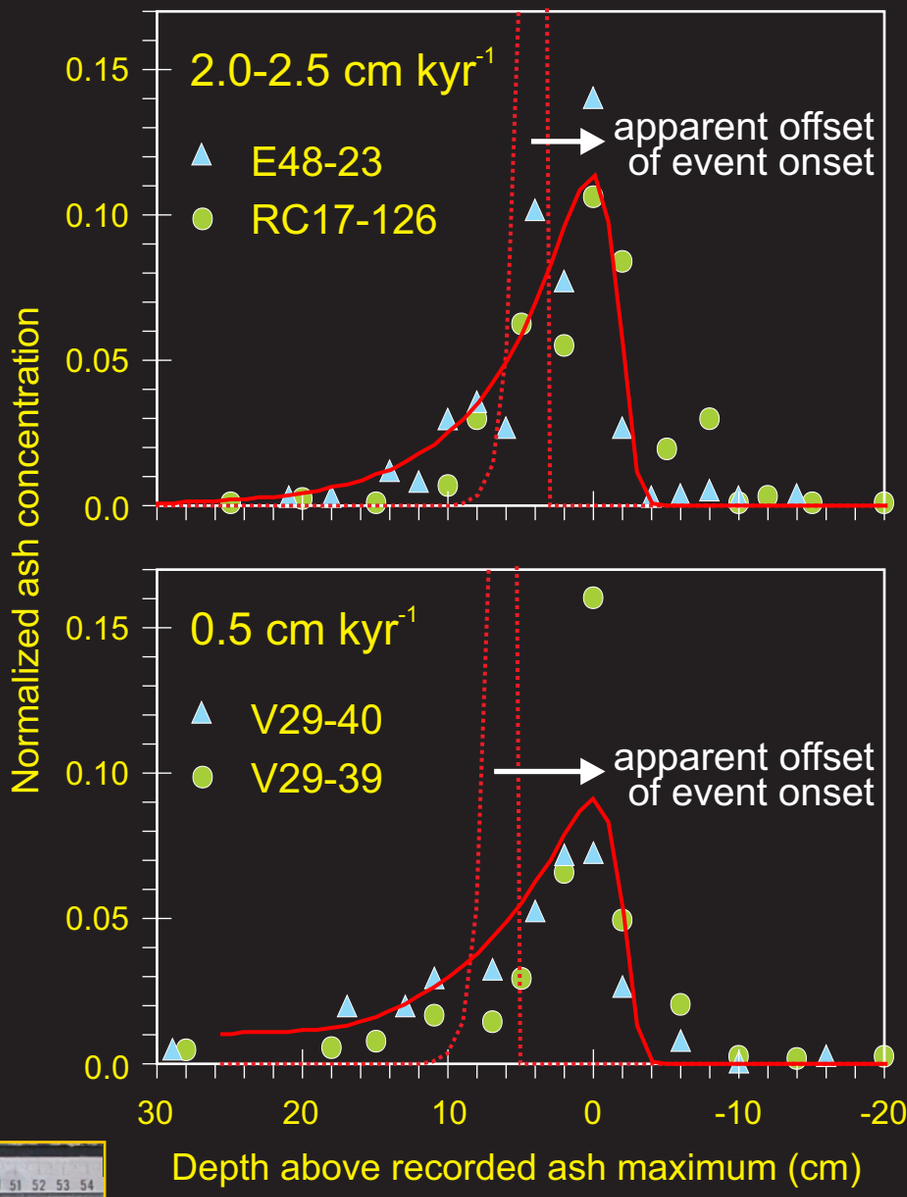
How much carbon?
(=> infer climate,
ecosystem sensitivity etc.)



worms – decoding the geological record

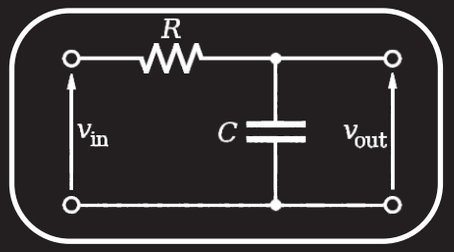
mixing
(bioturbation)



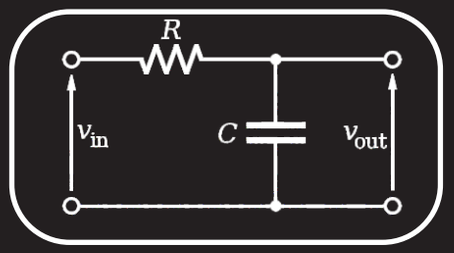


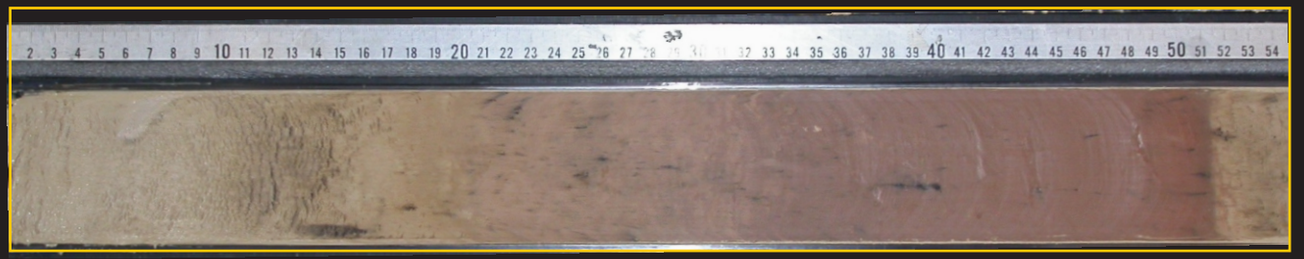
worms – decoding the geological record

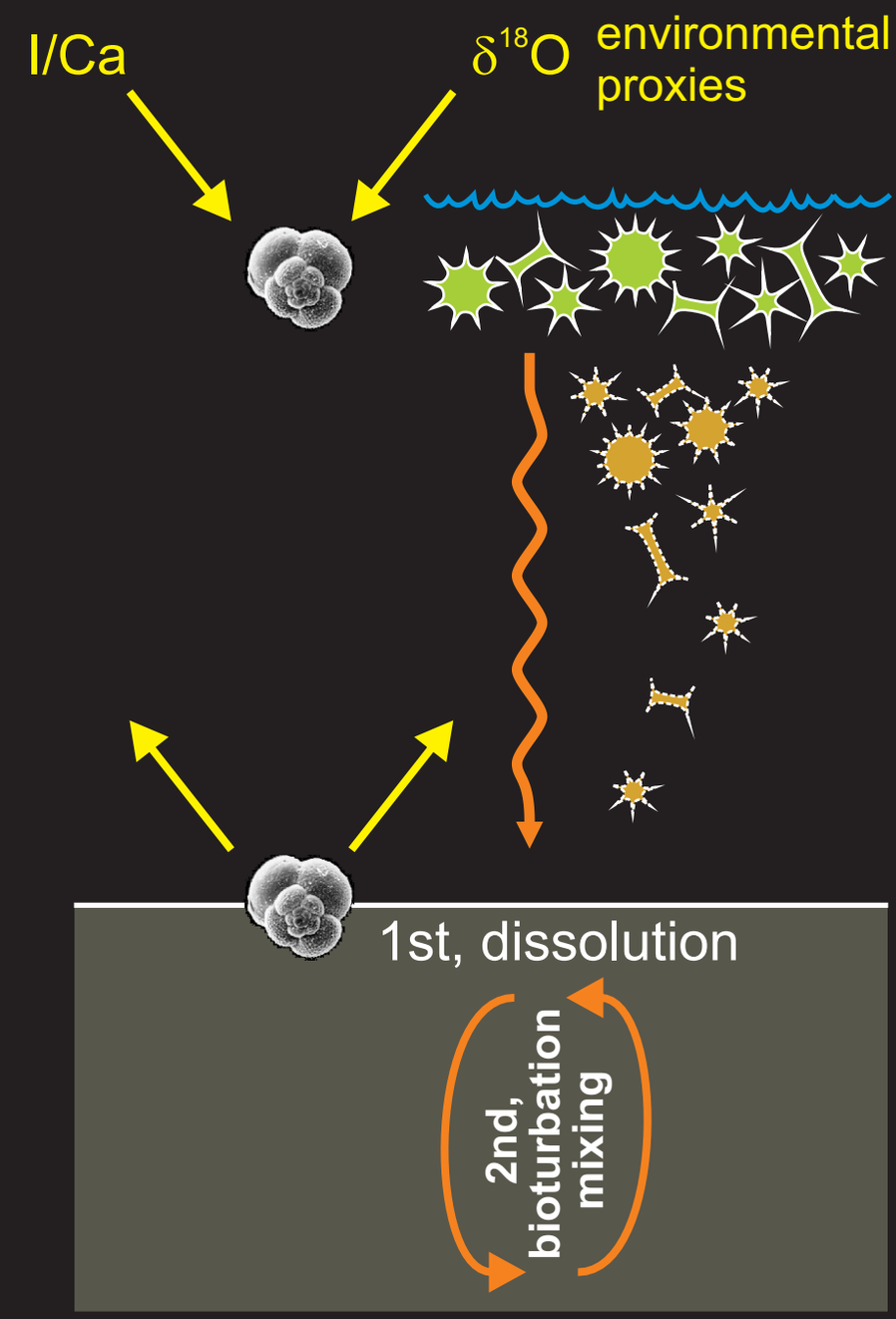
dissolution
(peservation)



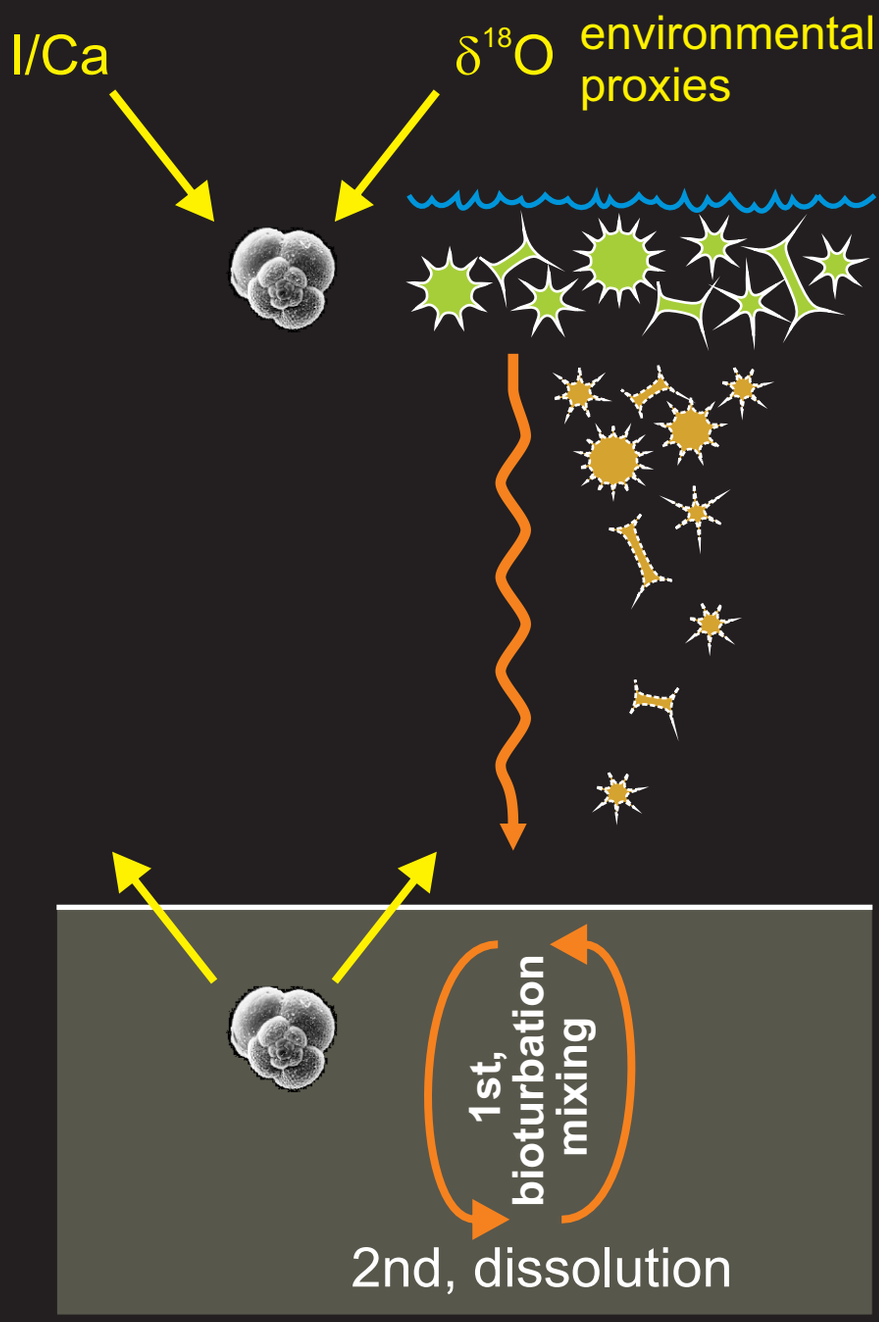
mixing
(bioturbation)





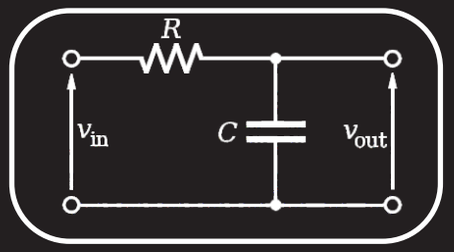

I/Ca
δ18O
environmental proxies
1st, dissolution
2nd, bioturbation mixing

VS.

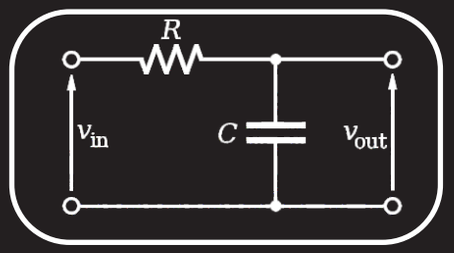

I/Ca
δ18O
environmental proxies
1st, bioturbation mixing
2nd, dissolution

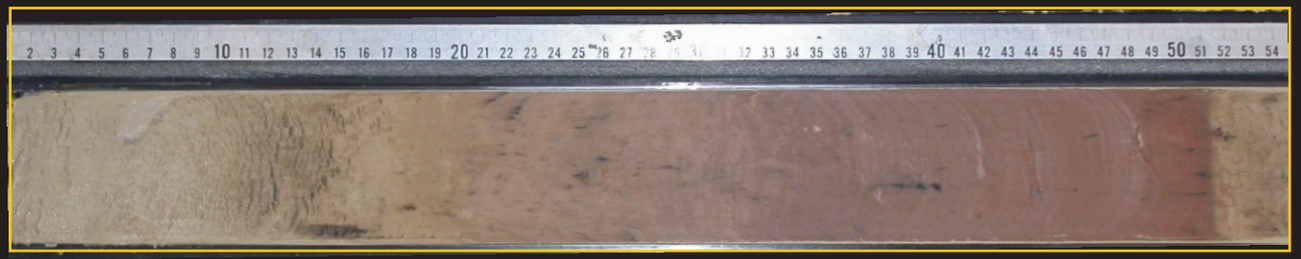
worms – decoding the geological record

dissolution
(peservation)

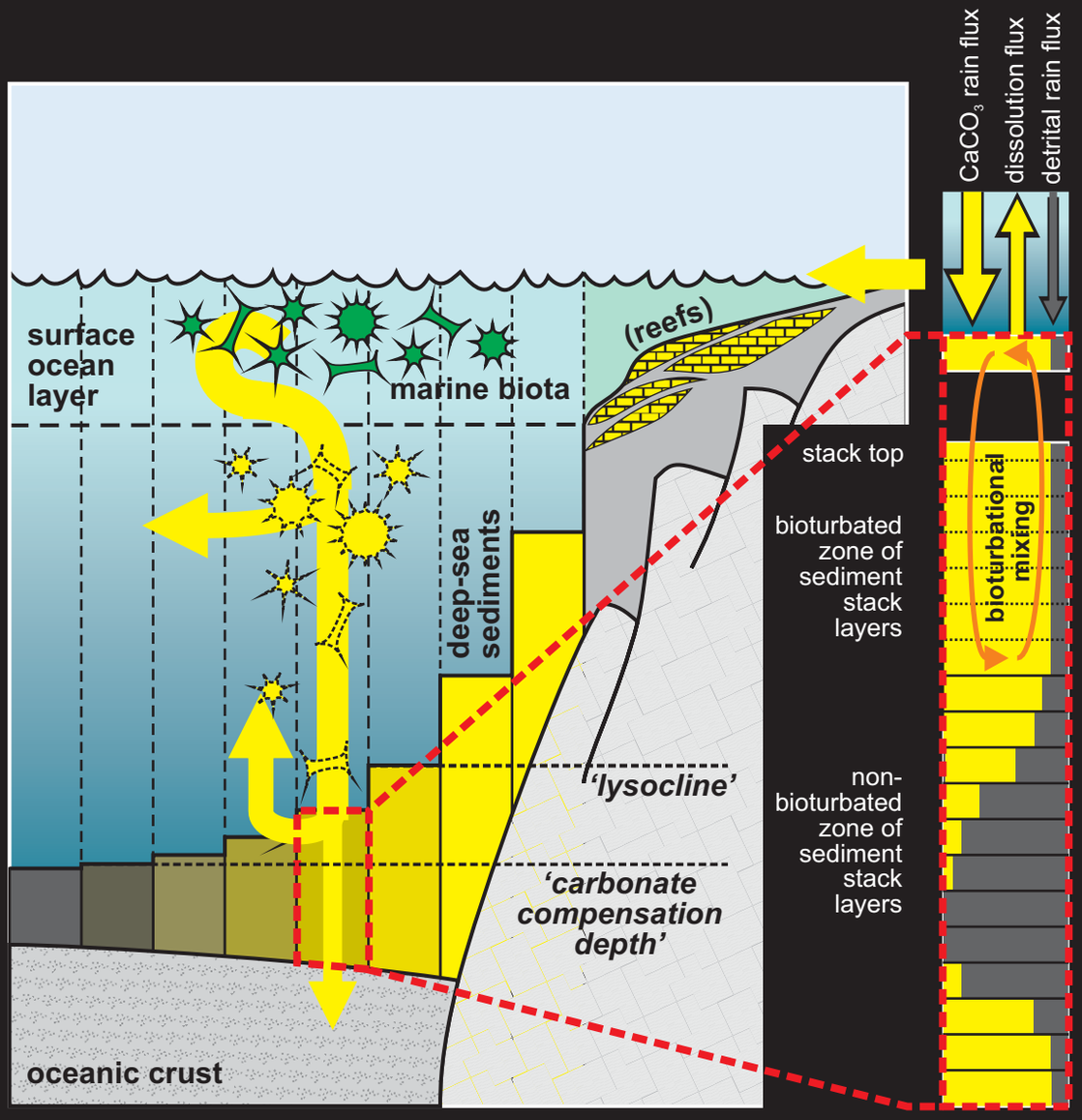


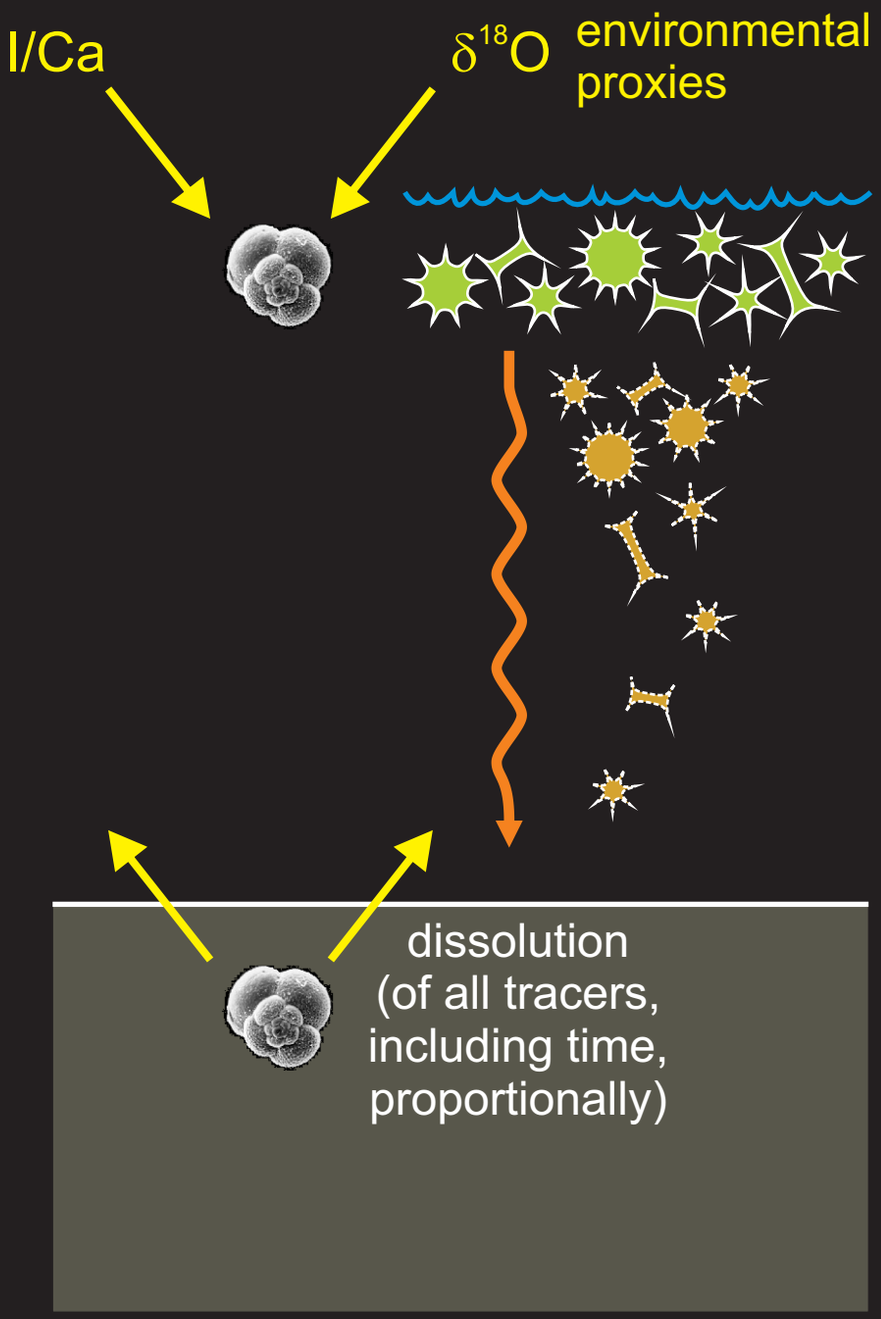
mixing
(bioturbation)



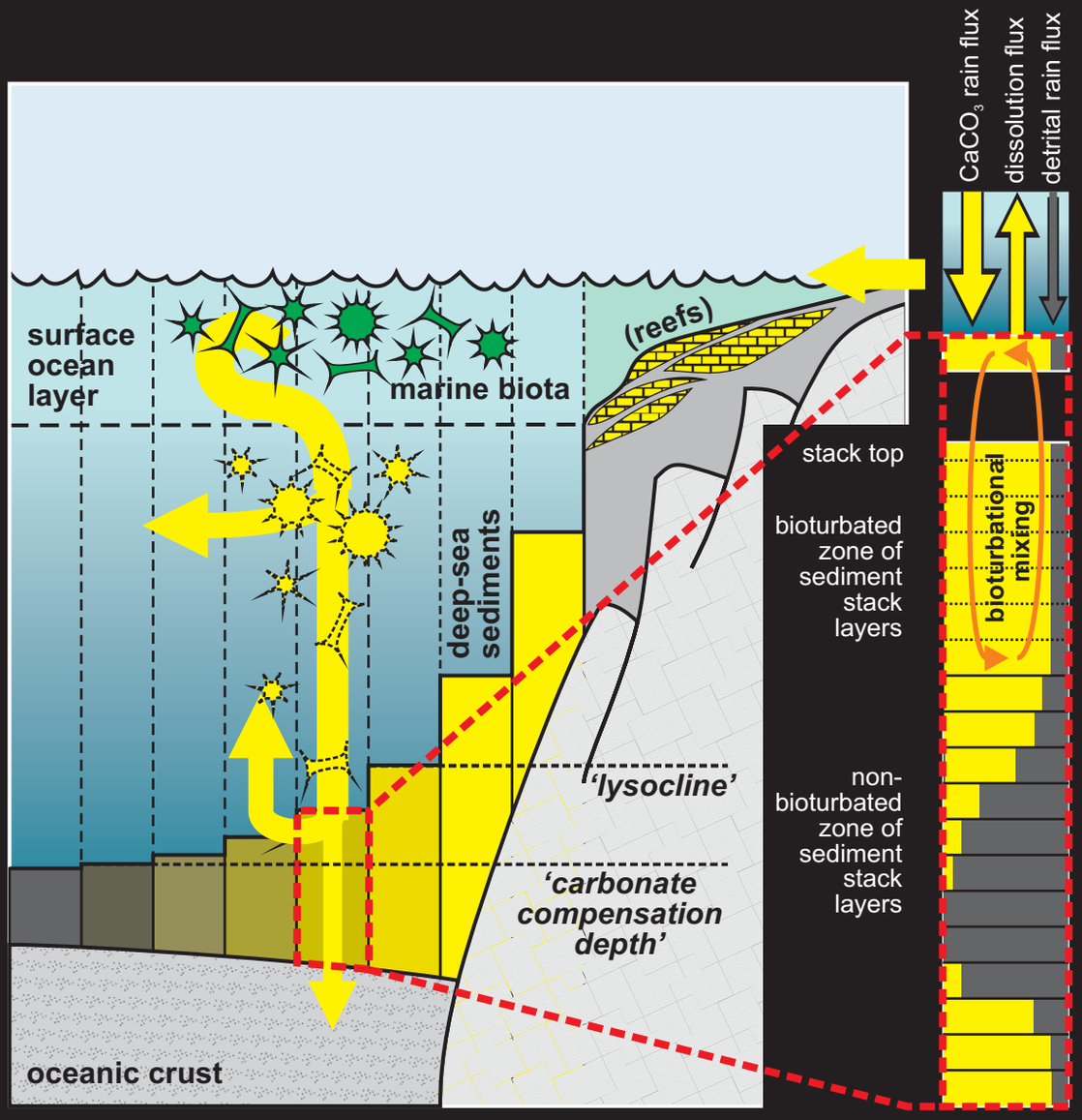


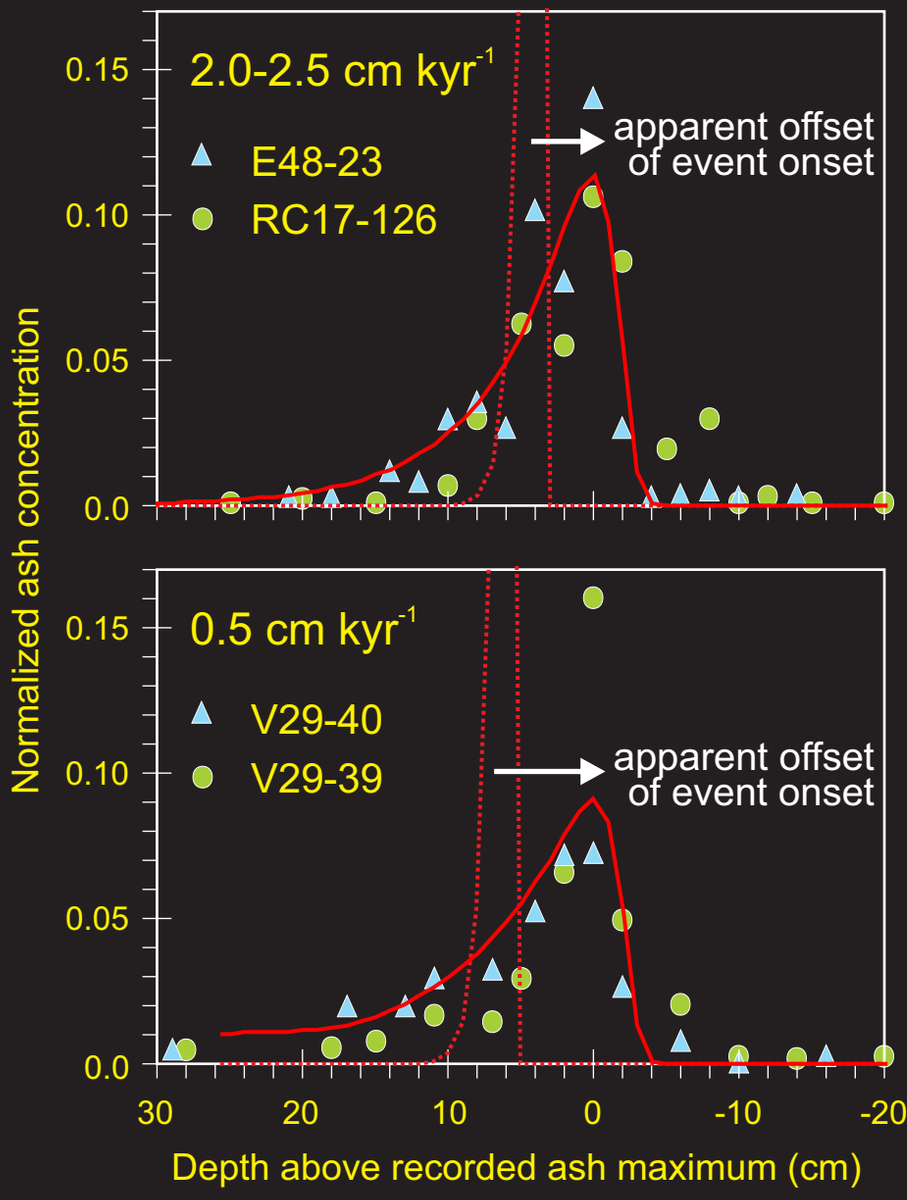
worms – decoding the geological record



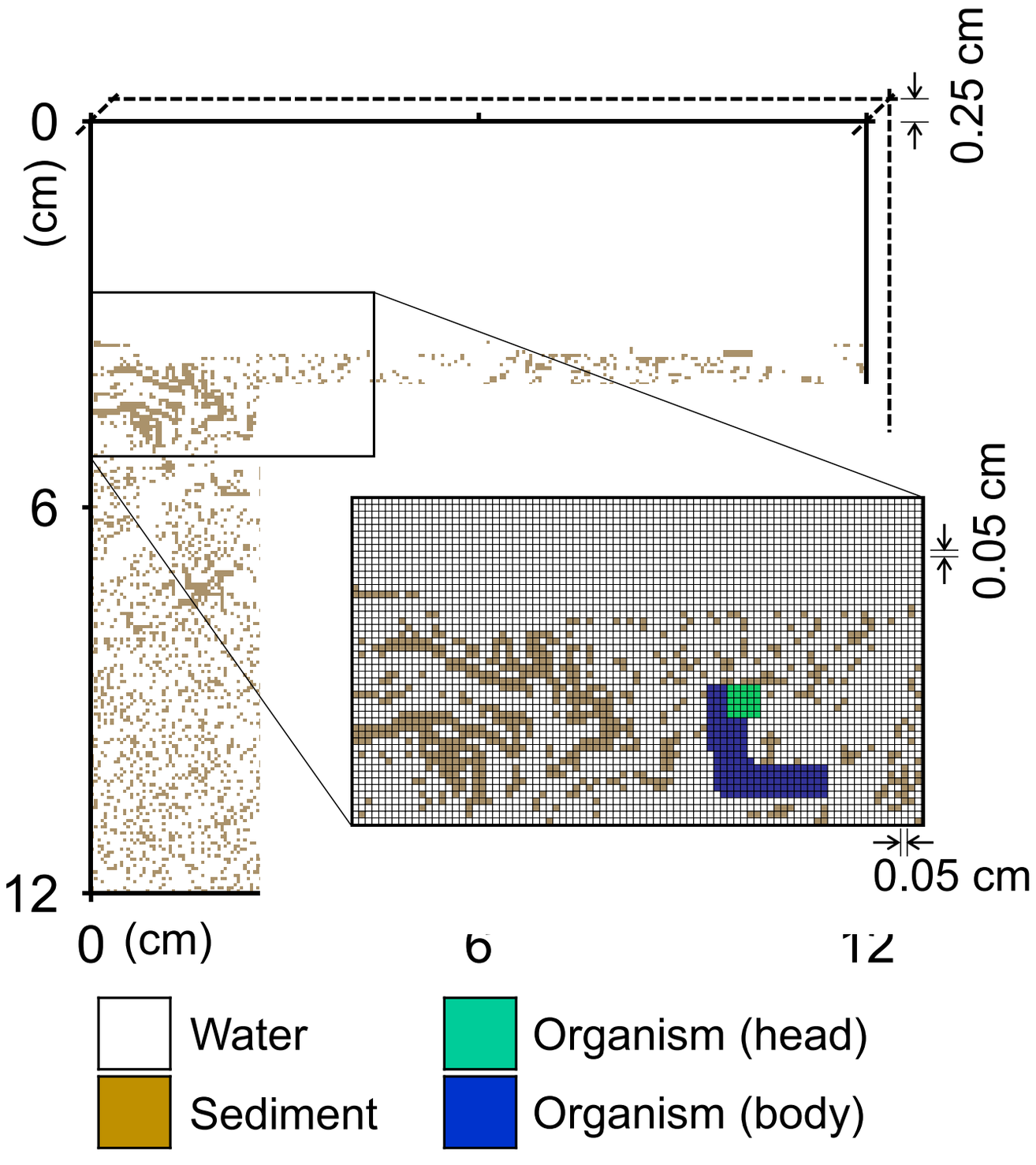


worms – decoding the geological record





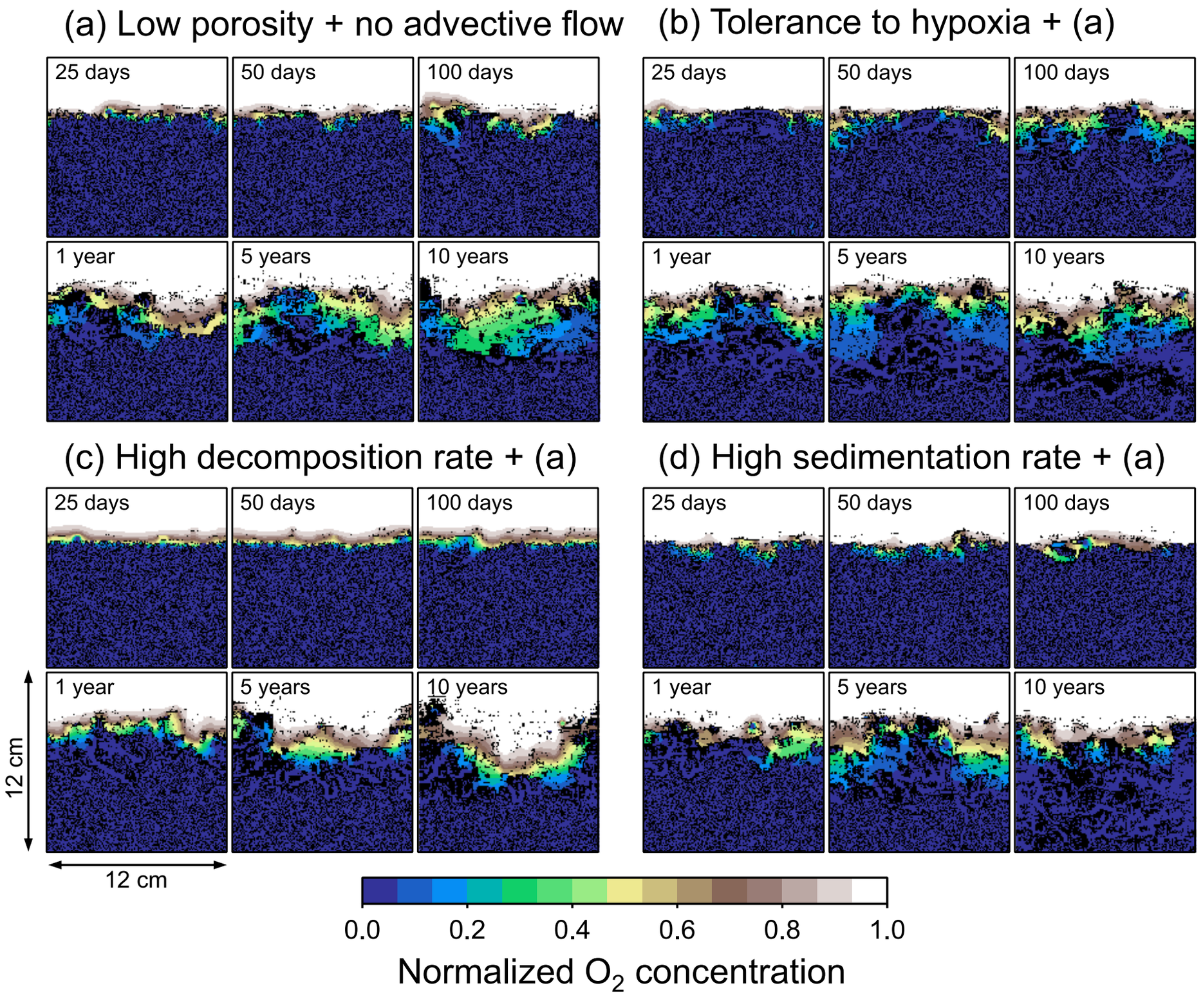
worms – worms *in silico*

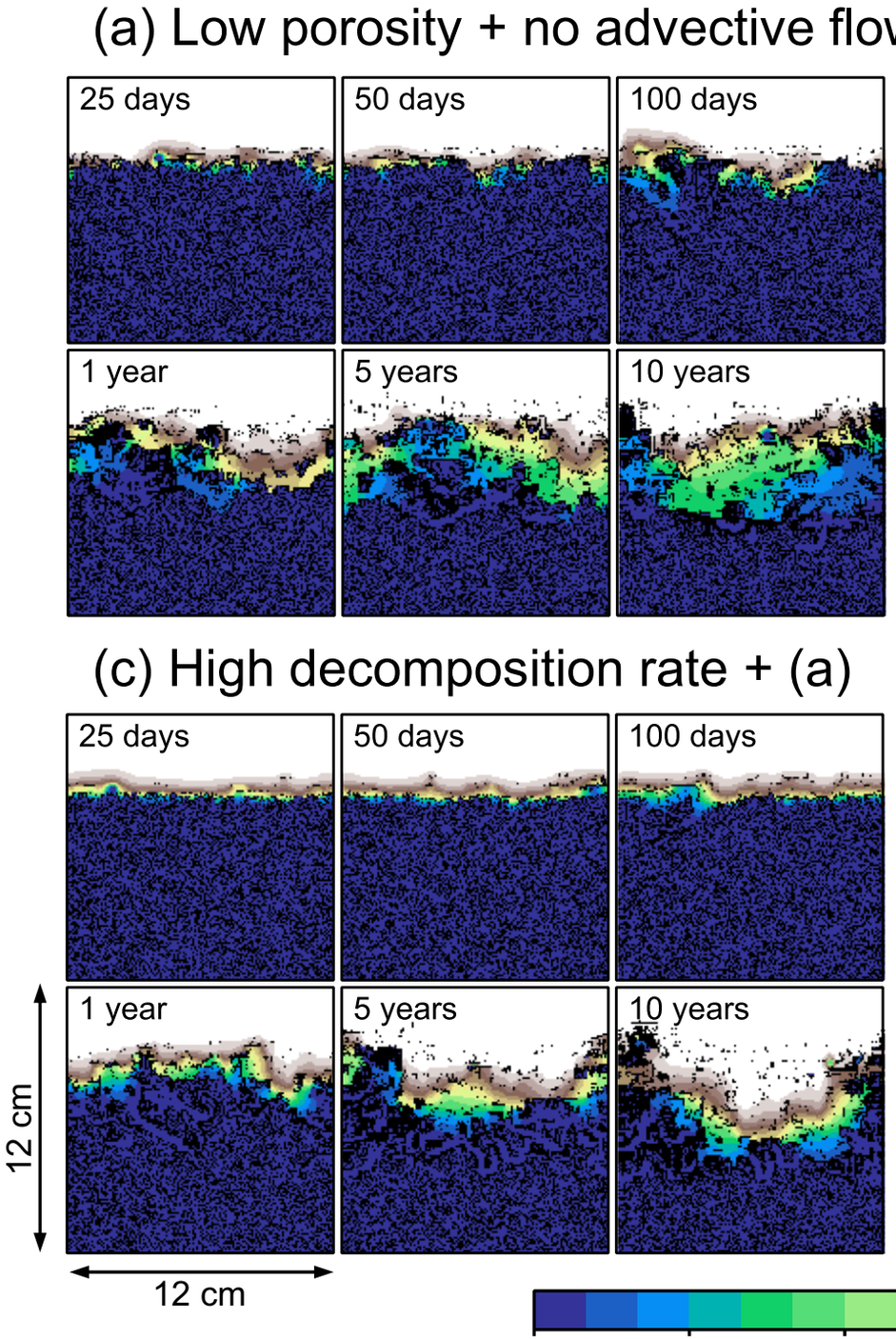


A lattice-automaton bioturbation simulator for the coupled physics, chemistry, and biology of marine sediments 'eLABS'

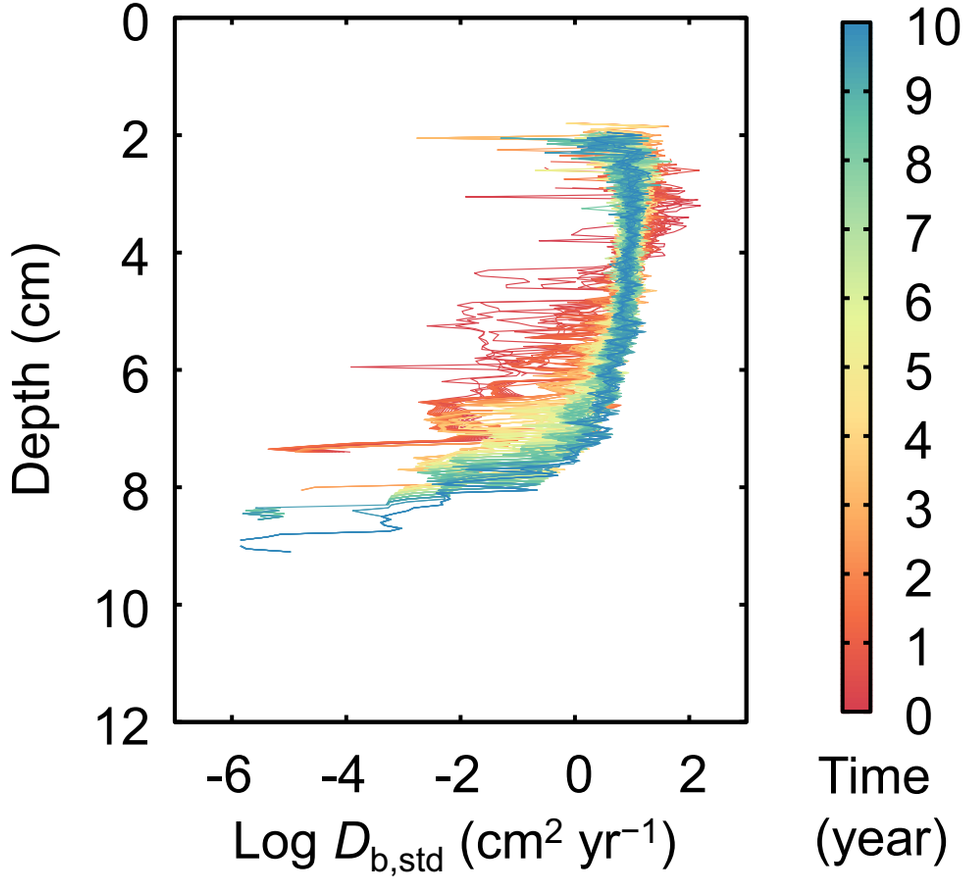
[*Kanzaki et al.*, submitted]
(following *Choi et al.* [2002])

- a numerical grid of inert sediment particles plus organic matter fraction
- constant sedimentation from above
- the presence of 'AI worms' (with defined rules of behaviors)
- pattern and intensity of animal activity and community density can respond to organic matter and/or oxygen availability

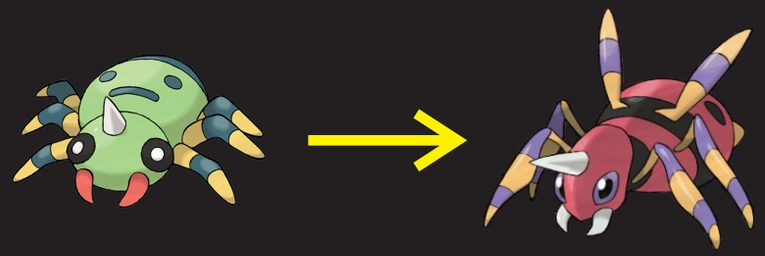

(a) Low porosity + no advective flow
(b) Tolerance to hypoxia + (a)
(c) High decomposition rate + (a)
(d) High sedimentation rate + (a)
25 days
50 days
100 days
1 year
5 years
10 years
12 cm
12 cm
0.0
0.2
0.4
0.6
0.8
1.0
Normalized O_2 concentration



Extract bioturbation profiles (as biodiffusion coefficients), or as a transition matrix (and apply to a 2nd model).



Summary

1. 

2. 


Ng
Pg
K
J
T
P
C
D
S
O
Cm
Cenozoic
Mesozoic
Paleozoic
Neoprot.
Mesoprot.
Paleoproterozoic
Phanerozoic
Proterozoic
Archean

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