~isempty(intersect('biology',paleo_models))

Andy Ridgwell (UC-Riverside)


#jesuisJimZachos

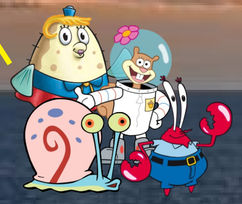

ICP13
~isempty(intersect('biology',paleo_models))

~isempty(intersect('biology',paleo_models))

('some thoughts and perspectives on modelling paleo biology and ecology')

('given the short notice, whatever was on my computer harddrive at the time')

~isempty(intersect('biology',paleo_models))



Paul Bown (UCL)
Sam Gibbs (NOCS, Southampton)
Sarah Alvarez (Bristol)
Daniela Schmidt (Bristol)

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Ben Ward (NOCS, Southampton)

Jamie Wilson (Bristol)

biology/ecology

MATLAB

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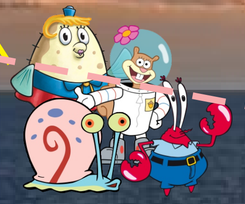

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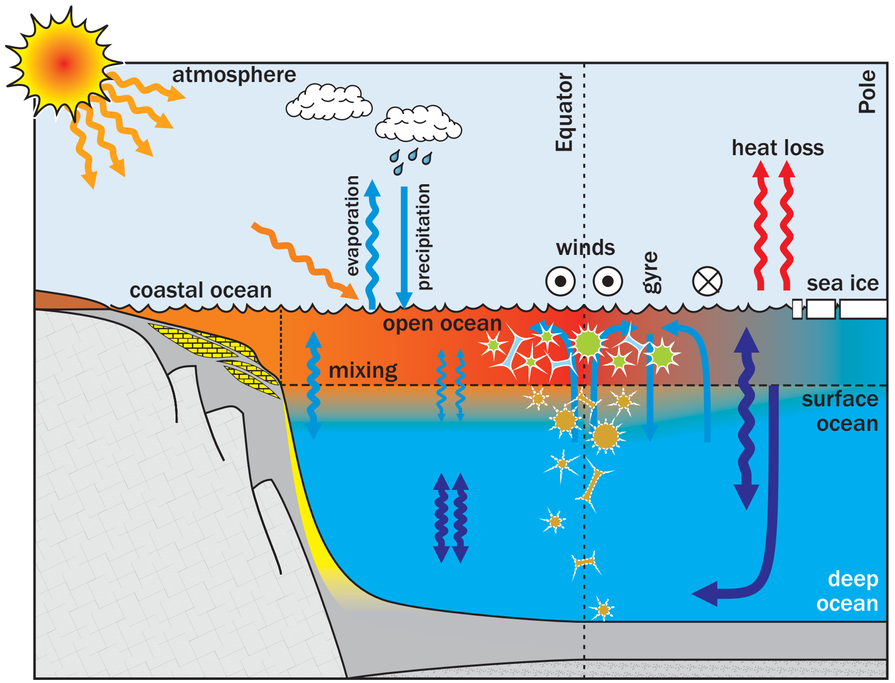
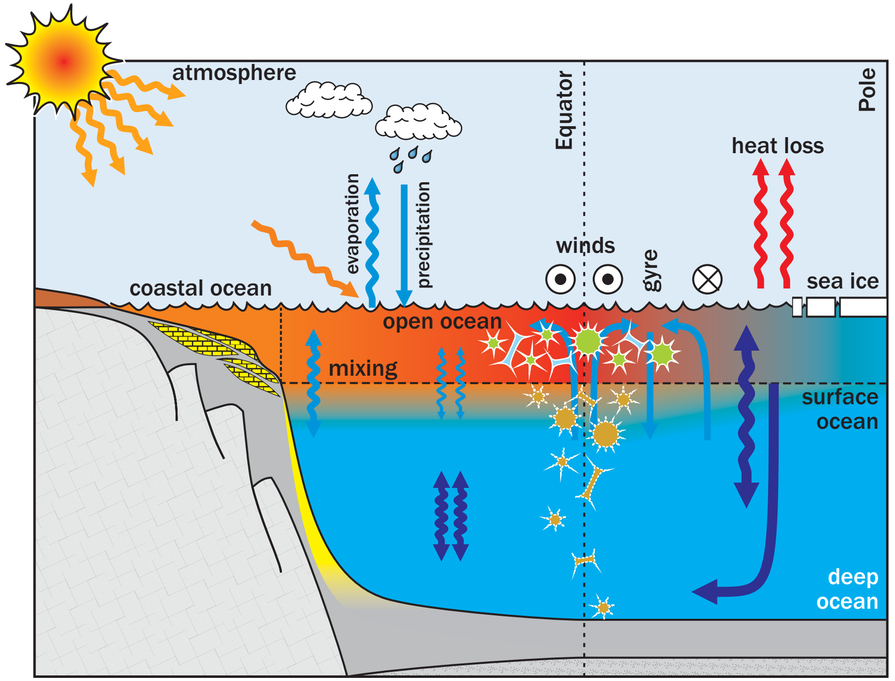
$R^2 = 0.718$

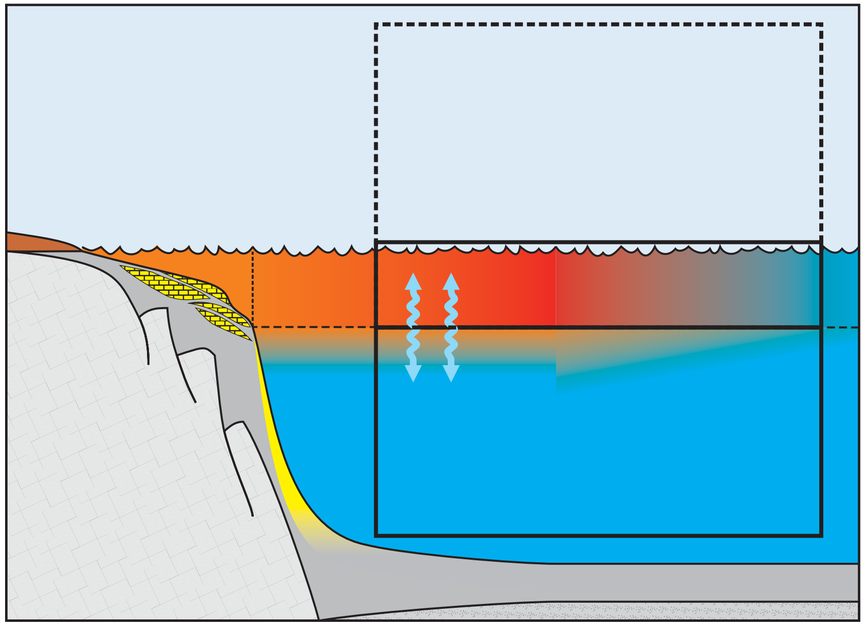
biology/ecology

MATLAB

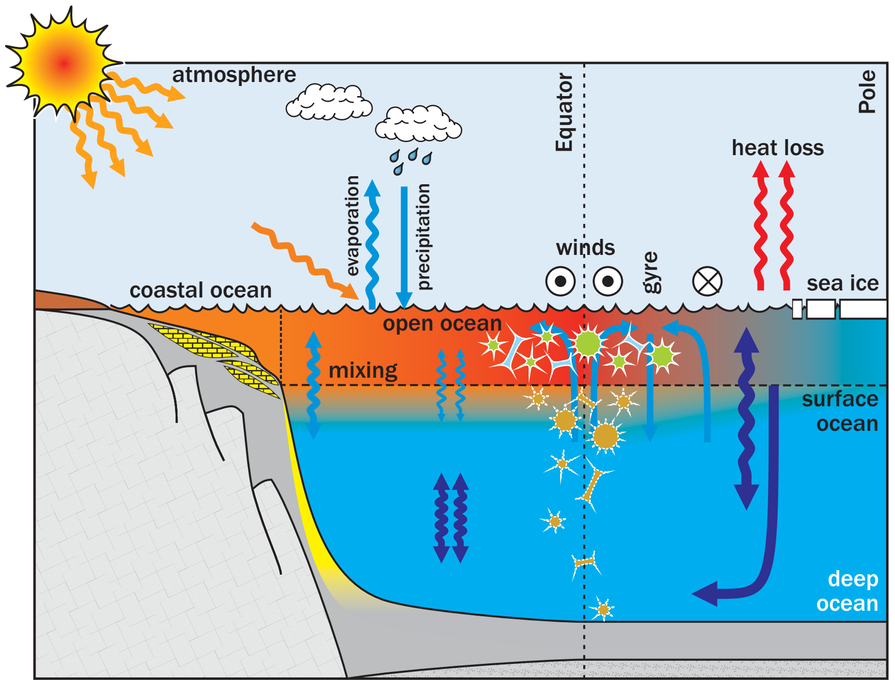

atmosphere
Equator
Pole
heat loss
evaporation
precipitation
winds
gyre
coastal ocean
sea ice
open ocean
mixing
surface ocean
deep ocean



Creating models is effectively, the art of encapsulationing one's understanding (or preconceptions) of a system, numerically (and within computational constraints). Typically such understanding is rooted in modern observations.



strategies for modelling complex marine systems



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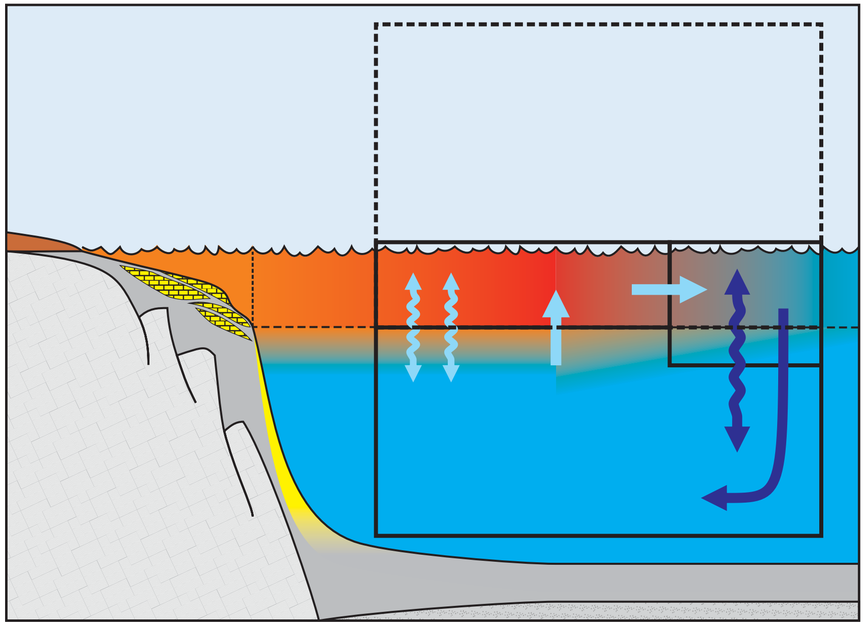
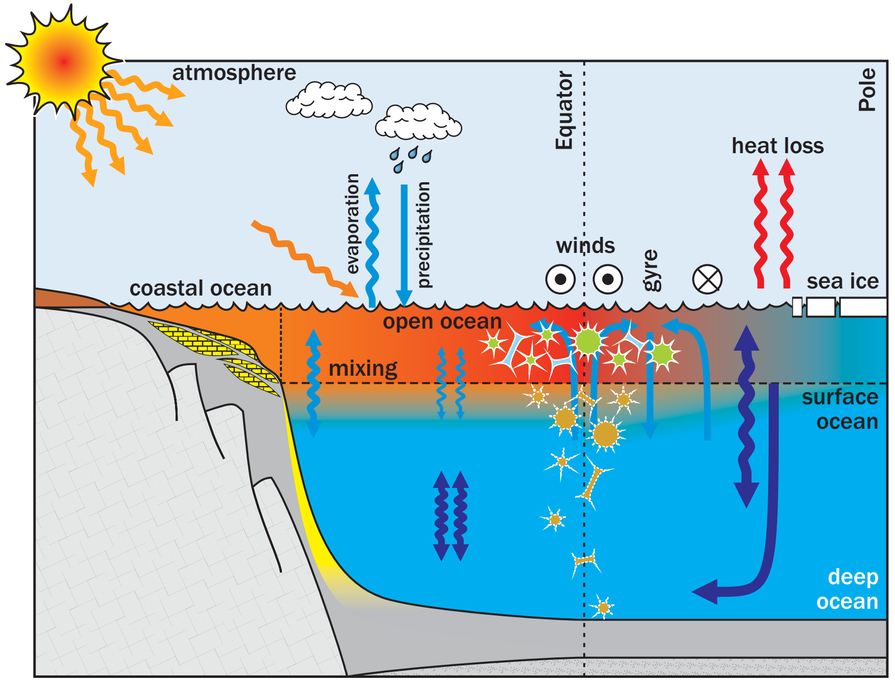
But ...

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 in the first place?





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But ...

What happens under climate change?
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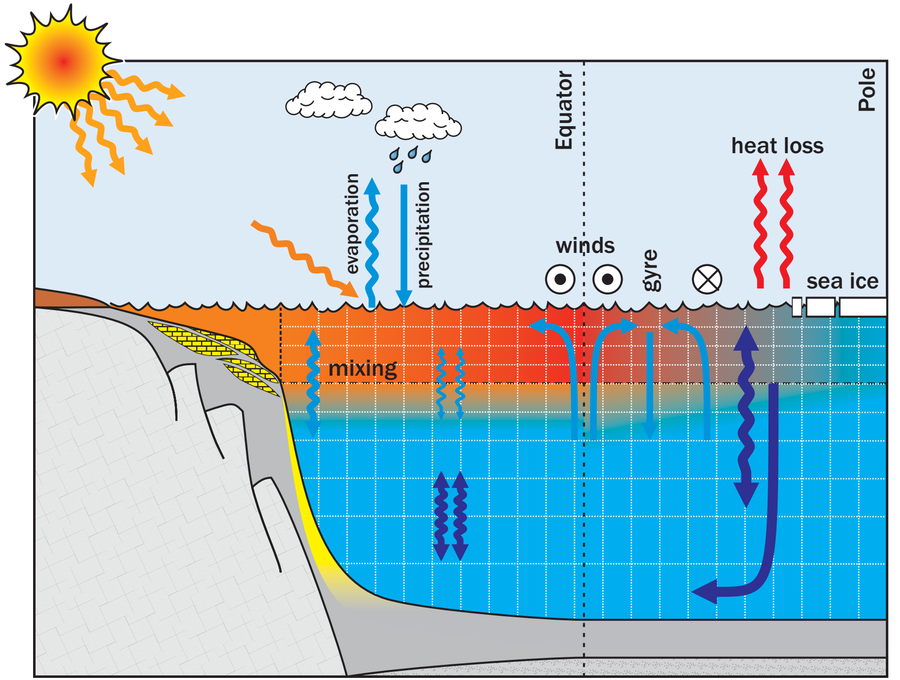
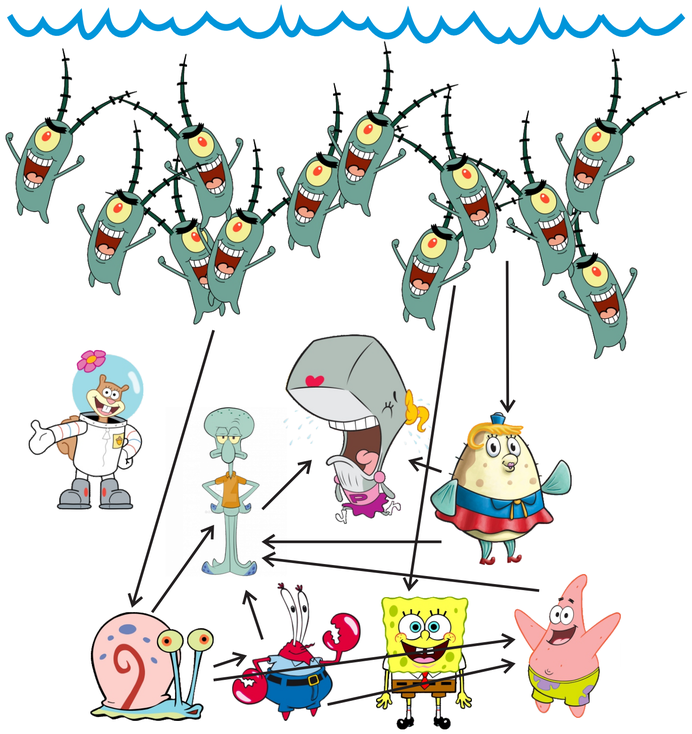
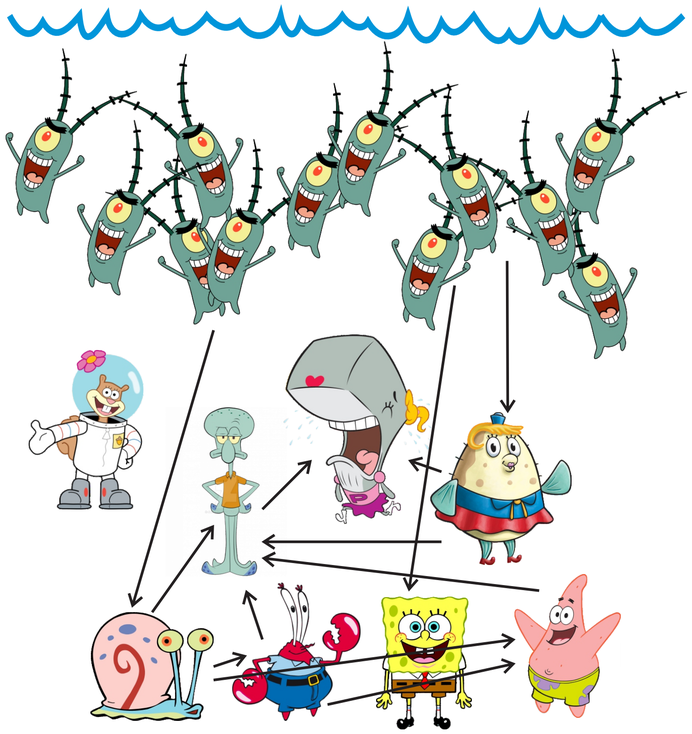
Enter ...

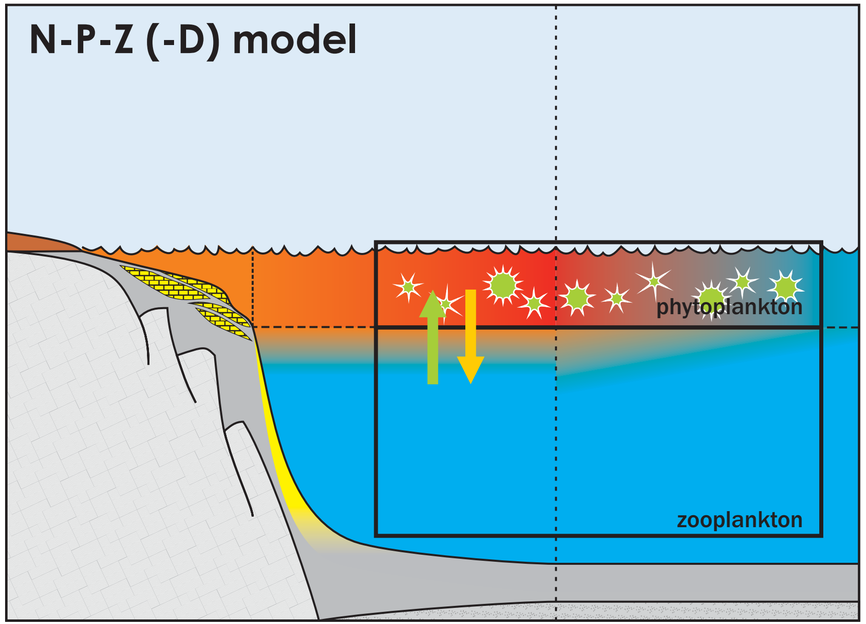
Ocean general circulation models (O-GCMs): Ocean circulation now becomes an **emergent** *rather than a prescribed property of the system.*



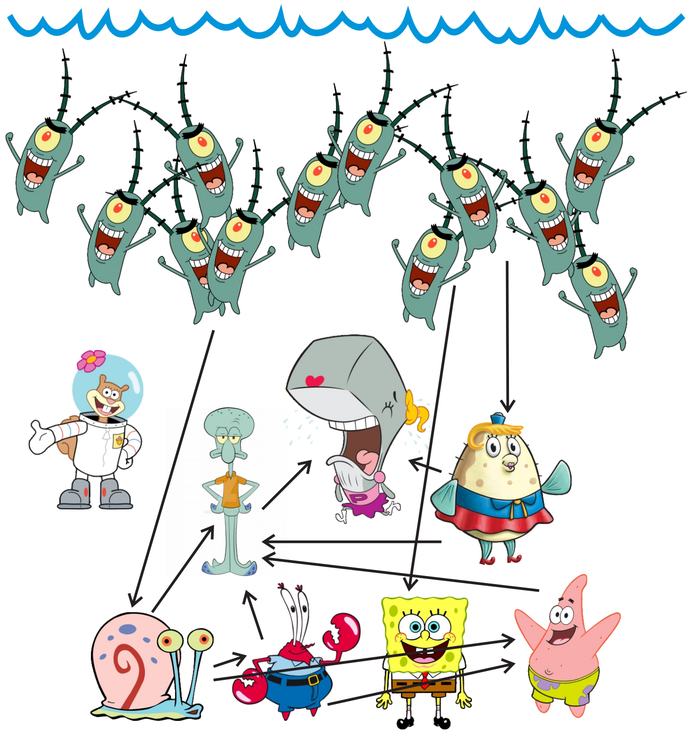
strategies for modelling complex marine systems






N-P-Z (-D) model
phytoplankton
zooplankton

strategies for modelling complex marine systems



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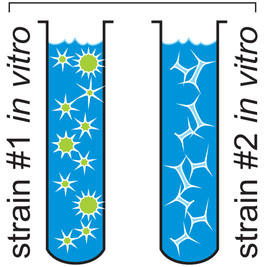
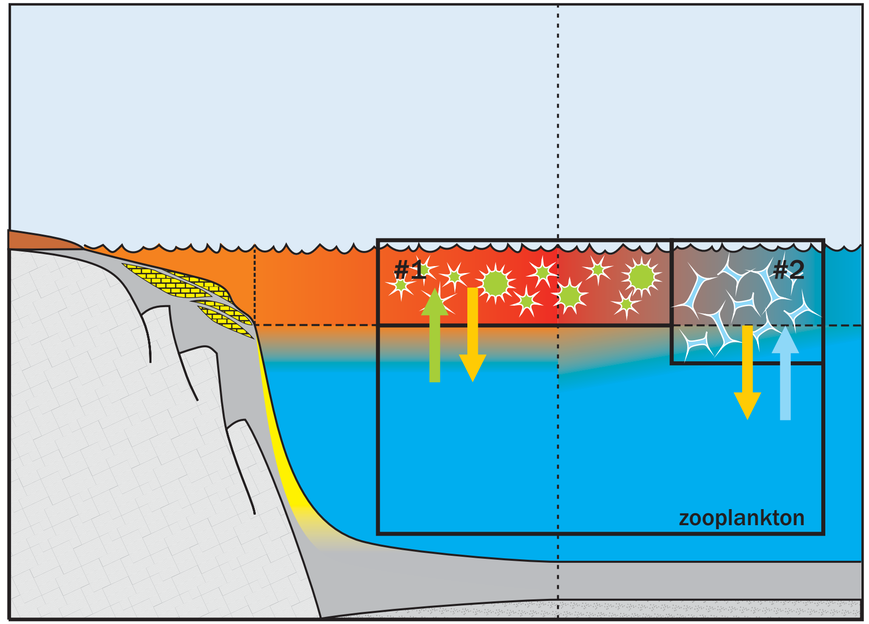
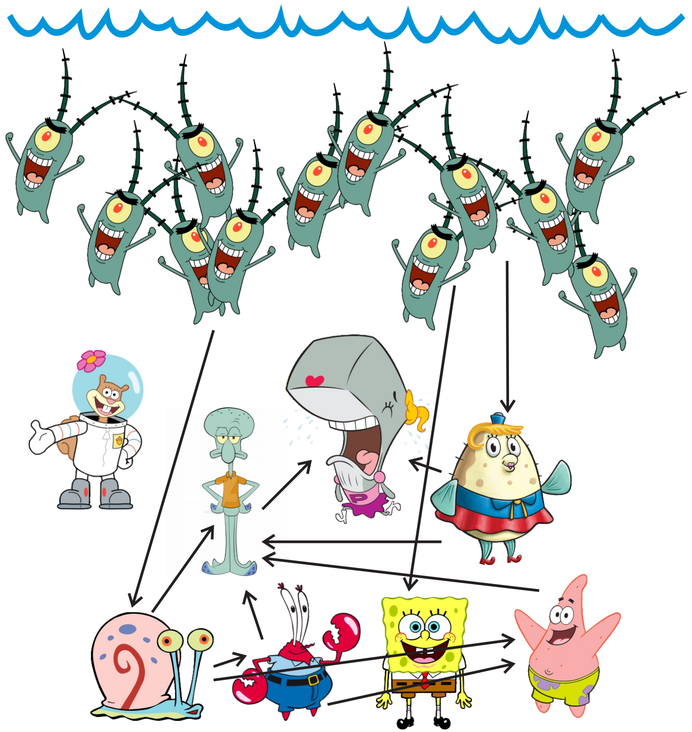
predominantly short-term laboratory perturbation experiments





strategies for modelling complex marine systems



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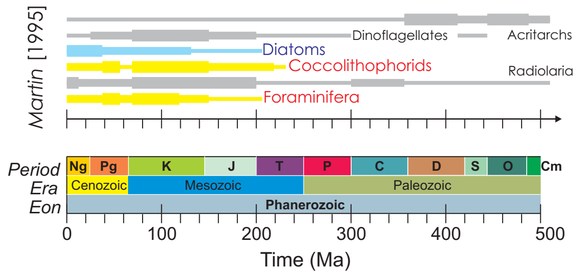
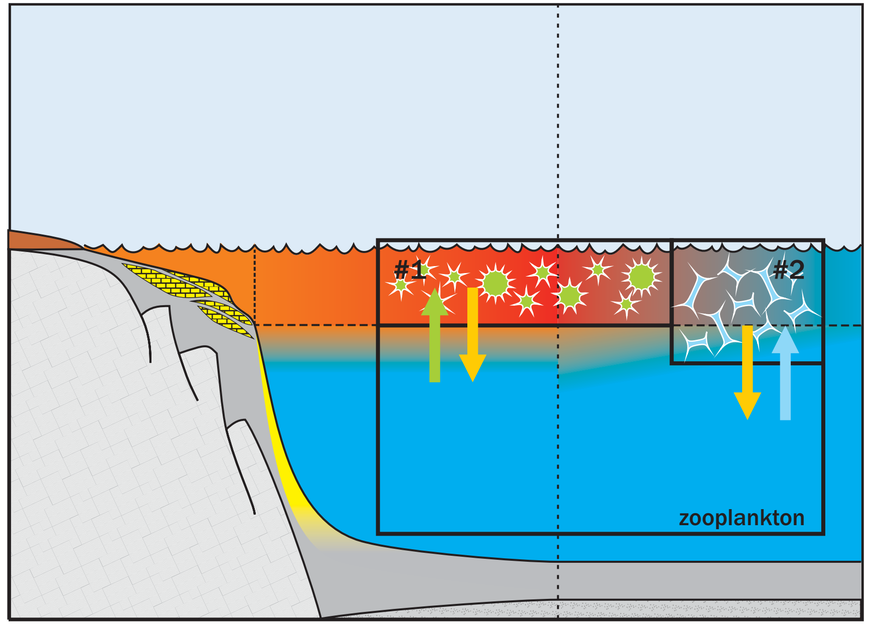
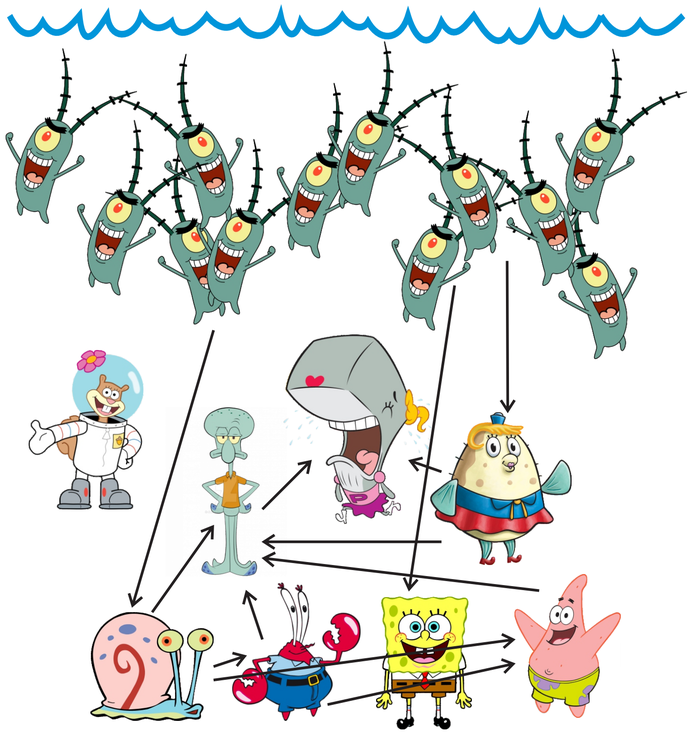
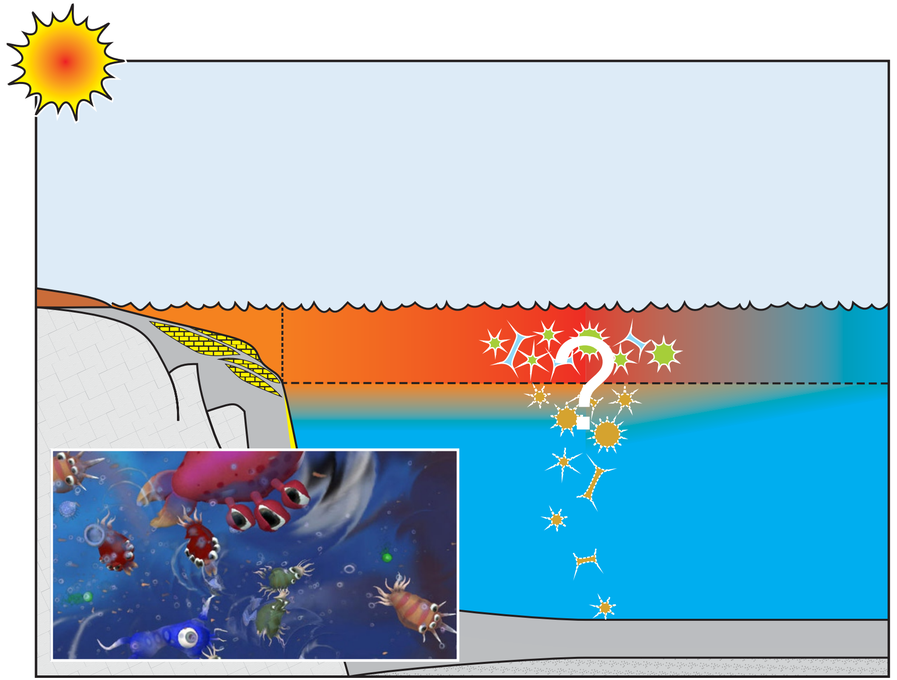






(Ocean) General Ecology Models?
(O-GEMs?)

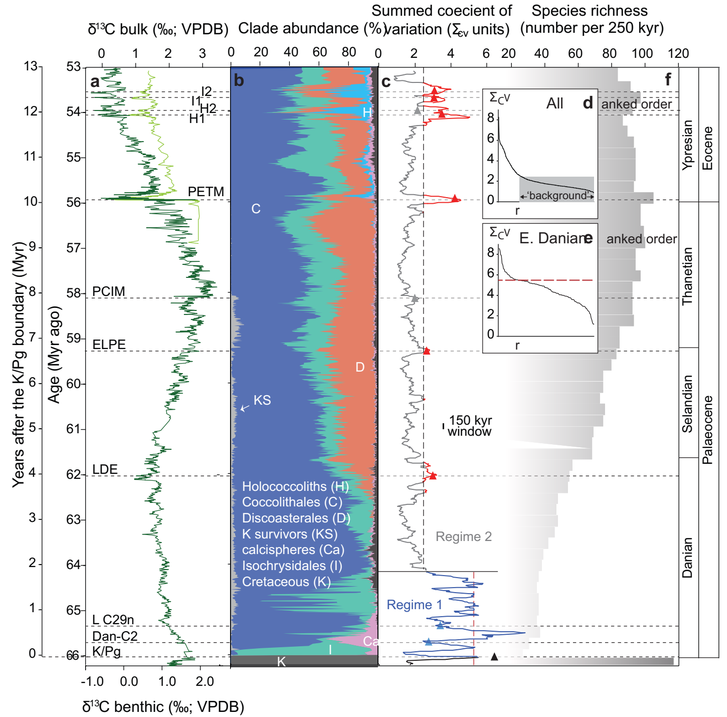
Marine ecology becomes an **emergent** *rather than a prescribed property of the system.*



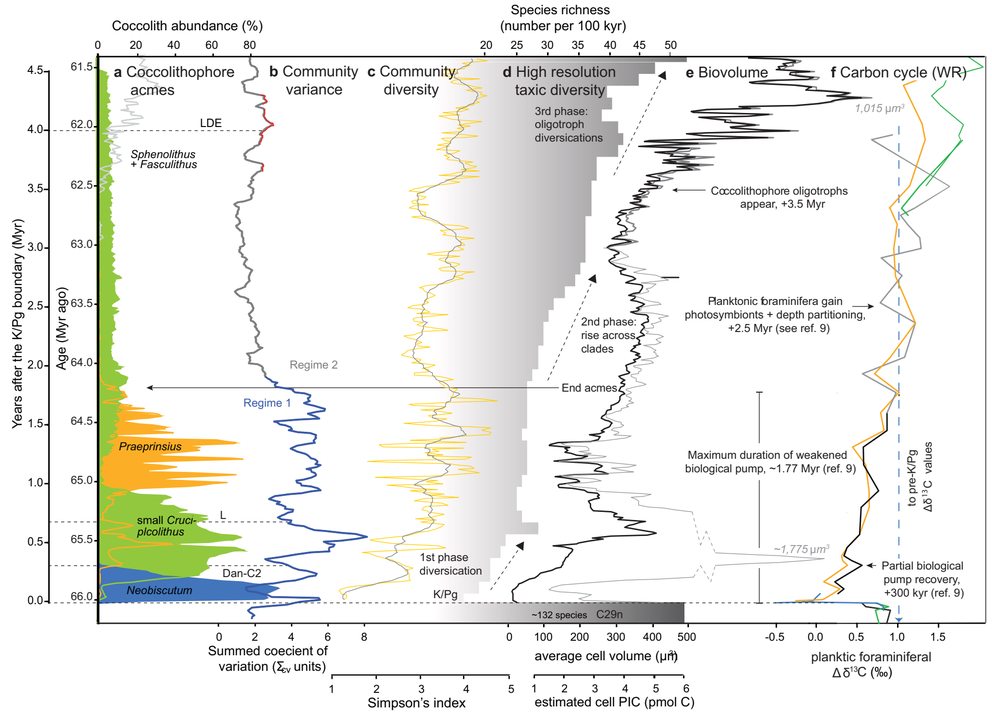
strategies for modelling complex marine systems

Dataset comprising a sample every ~13 thousand years, spanning the first 13 million years of the Cenozoic and total around 700,000 fossil counts -- an unprecedented time-series of key community parameters, including abundance, diversity, taxic richness, variance, dissimilarity and body size ...

Accepted ('in a journal you all read') as Alvarez et al. – 'Diversity decoupled from ecosystem function and resilience during mass extinction recovery'.



real and fake paleo marine ecology



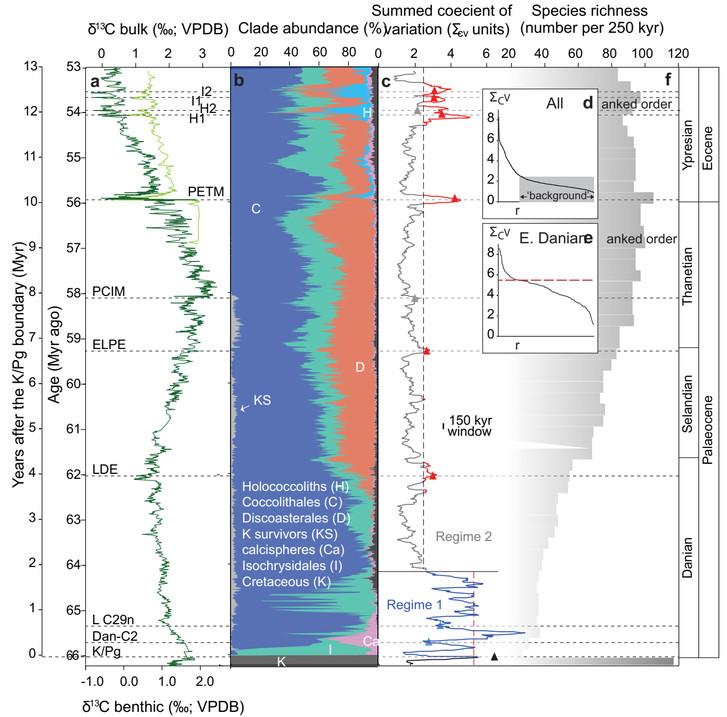
What do we know?

Things go extinct ... loss of species richness. Bigger things tend to go extinct more.

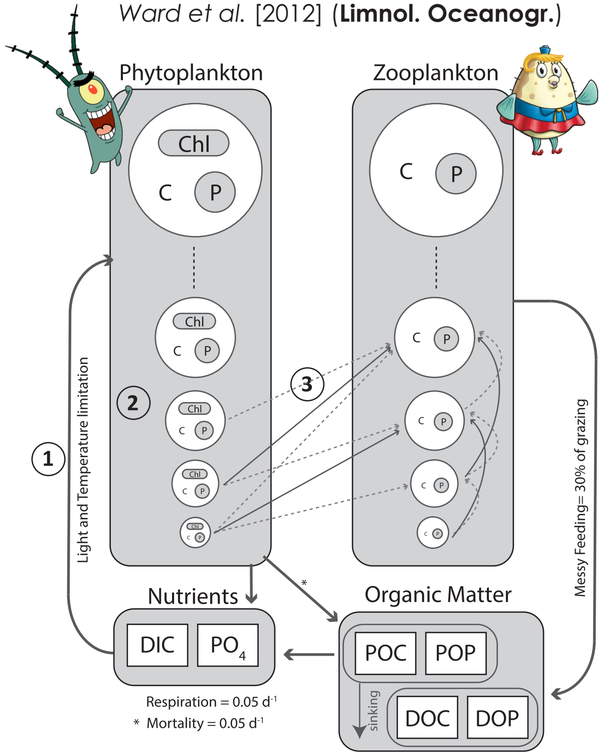
Q. *What are the consequences of drastic changes to marine ecosystems, and how does this and the consequential change in global carbon cycling, relate to observations of e.g. $\delta^{13}C$, carbonate preservation in the deep ocean, etc?*

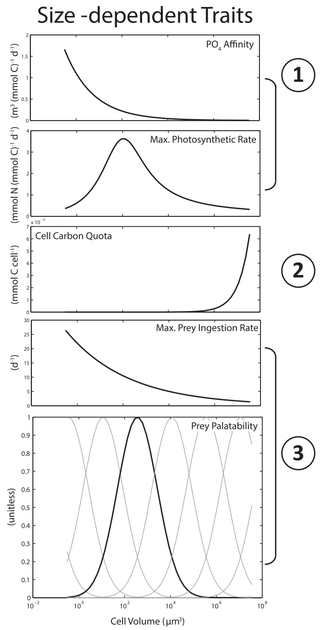
Q. *Conversely, what can observations of e.g. $\delta^{13}C$ changes (and vertical gradients) etc. tell us about extinction and subsequent recovery in marine ecosystems?*

(A classic excuse for models ...)



A size structured food-web model for the global ocean,
Ward et al. [2012] (**Limnol. Oceanogr.**)





Size-structured plankton ecological model.

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

Traits scale with the master variable: cell size.

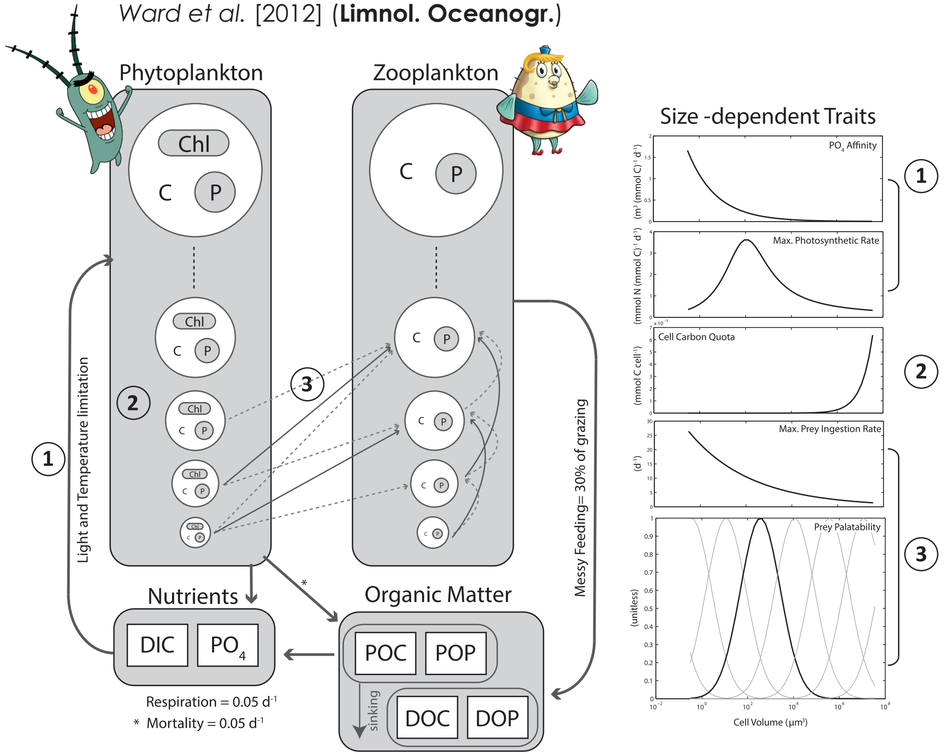
Each plankton has ‘quotas’ for C, N, P, Fe, so variable elemental stoichiometry possible (just C and P used here).
An Ugly Model.

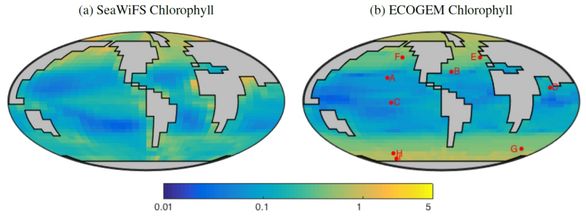
‘Standard’ functional type ecosystem model grazing formulation (with size preference).

(Currently – no other ‘functions’ (or ‘traits’) such as N-fixation, calcification or silicification, are included.)

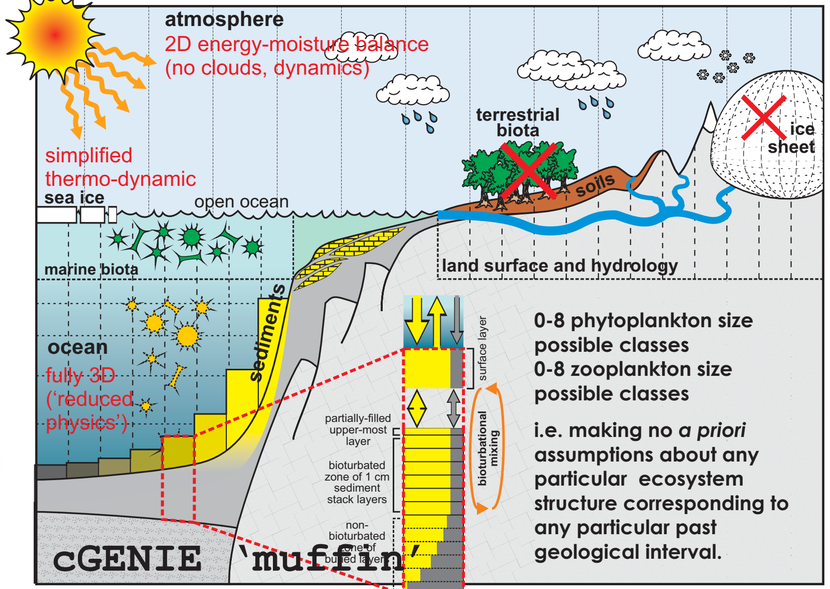
real and fake paleo marine ecology

A size structured food-web model for the global ocean,
Ward et al. [2012] (**Limnol. Oceanogr.**)





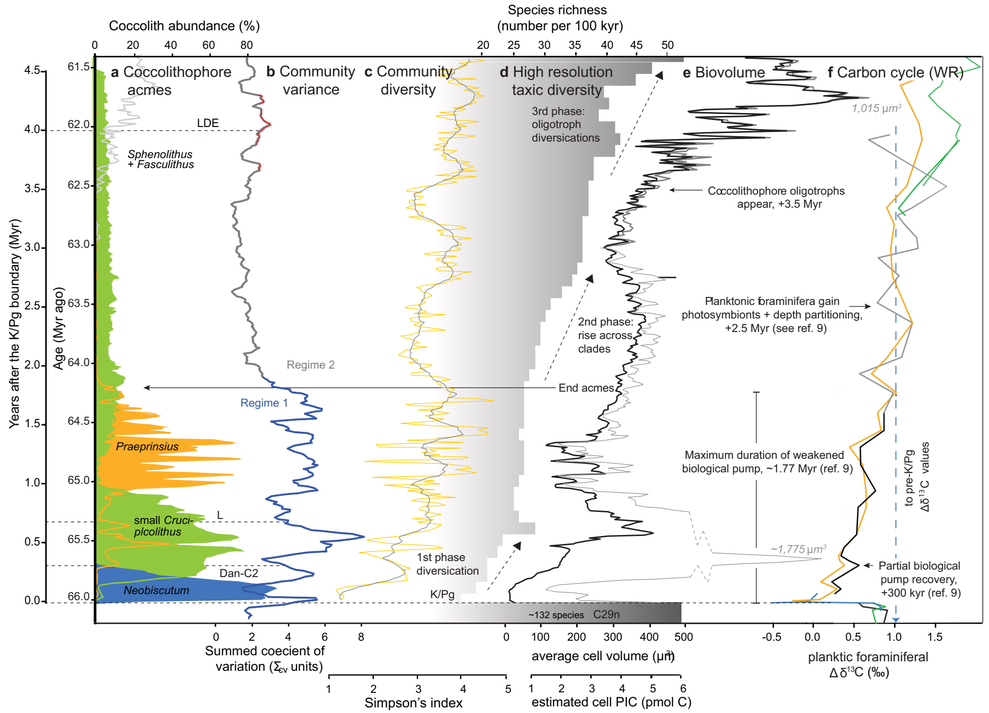
EcoGEnIE 1.0: plankton ecology in the cGEnIE Earth system model
Ward et al. [2018] (**GMD**)



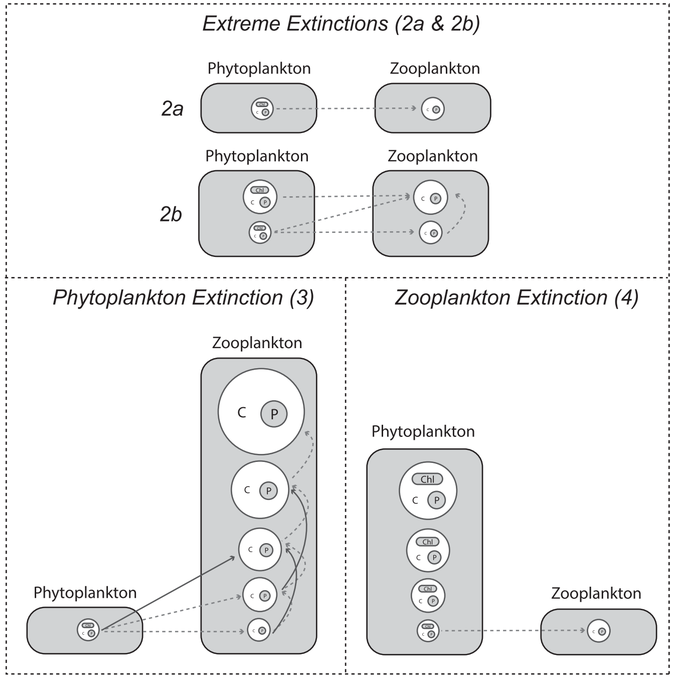
0-8 phytoplankton size possible classes
0-8 zooplankton size possible classes

i.e. making no *a priori* assumptions about any particular ecosystem structure corresponding to any particular past geological interval.

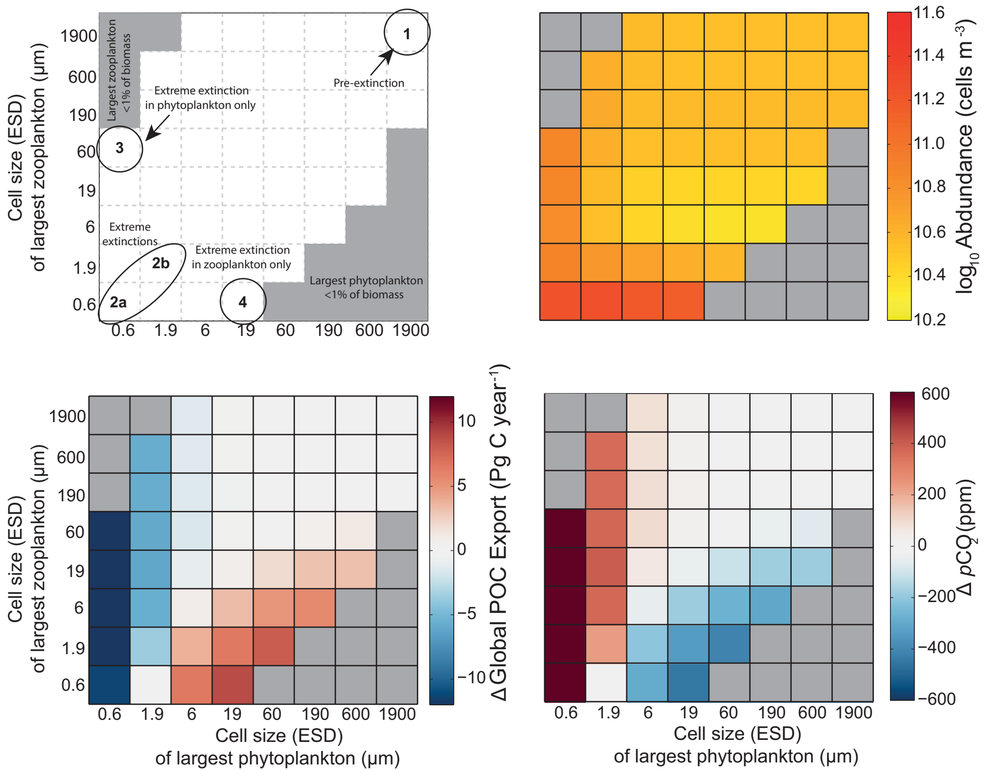
github.com/derpycode/cgenie.muffin



Example Extinction Scenarios in Model



Wilson et al. [in prep.]



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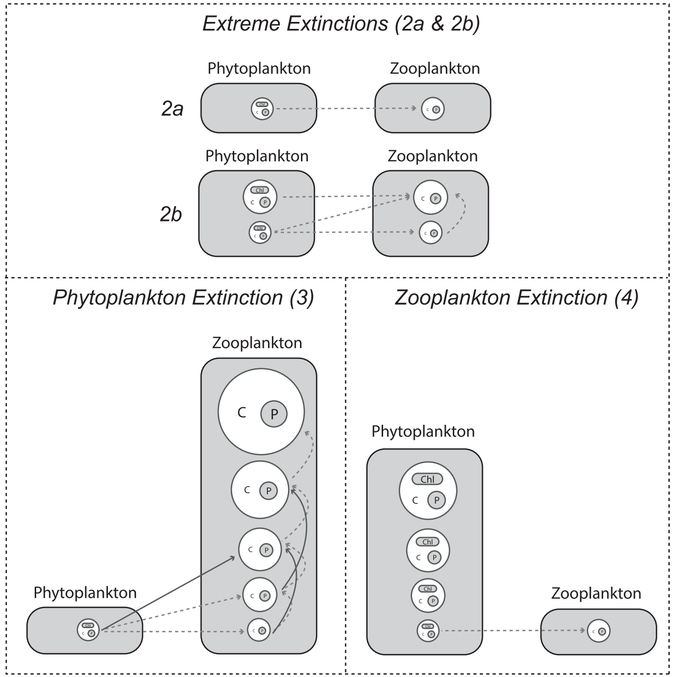

real and fake paleo marine ecology

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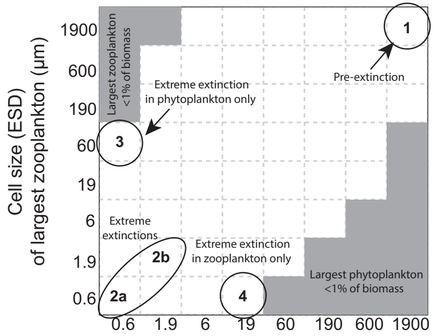
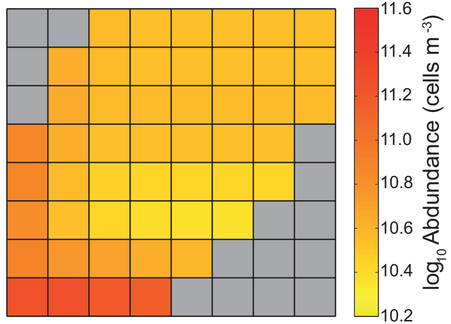
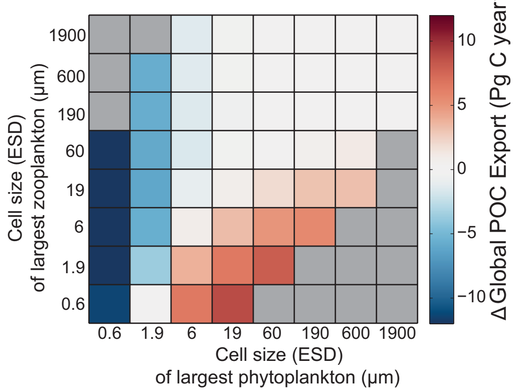
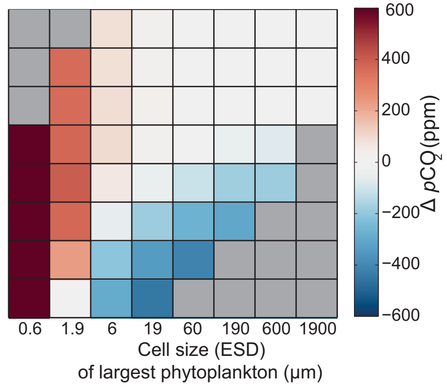
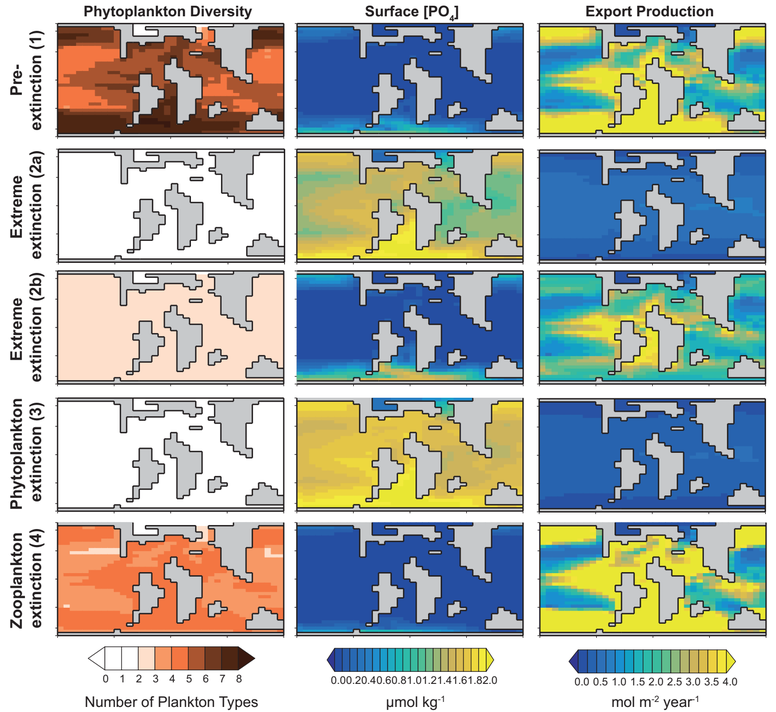
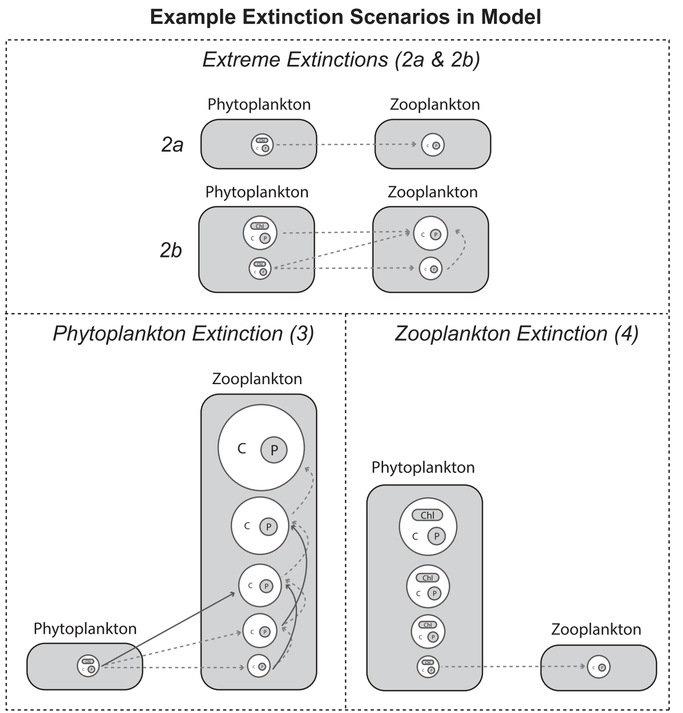






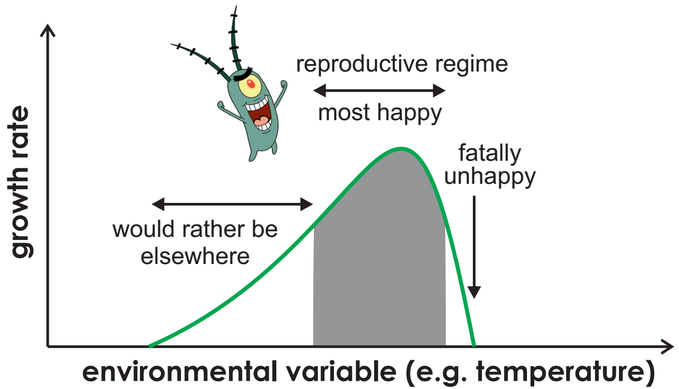






evolution *in silico* (‘fake evolution’) – WHY?

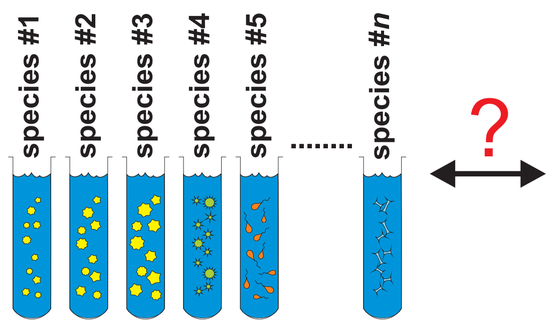
evolution *in silico* ('fake evolution') – WHY?

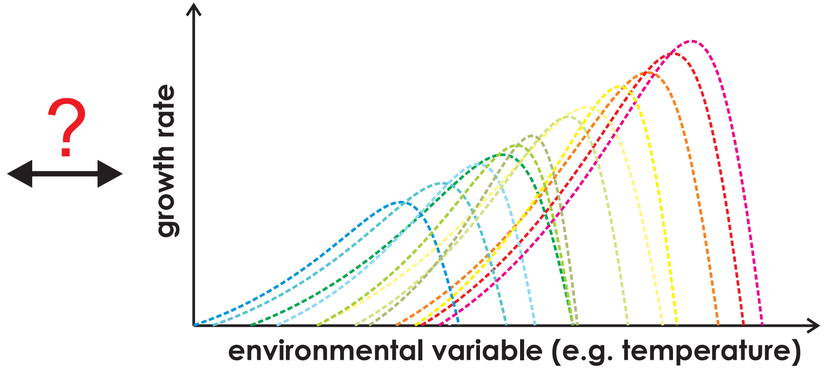


're-drawn' from *Schmidt et al.* [2006]
(with sincere apologies)

evolution *in silico* ('fake evolution') – WHY?

How can a model be constructed when the niches (e.g. temperature optima) occupied by plankton are so numerous and diverse?

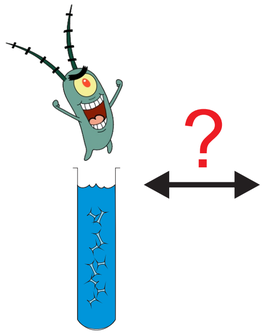




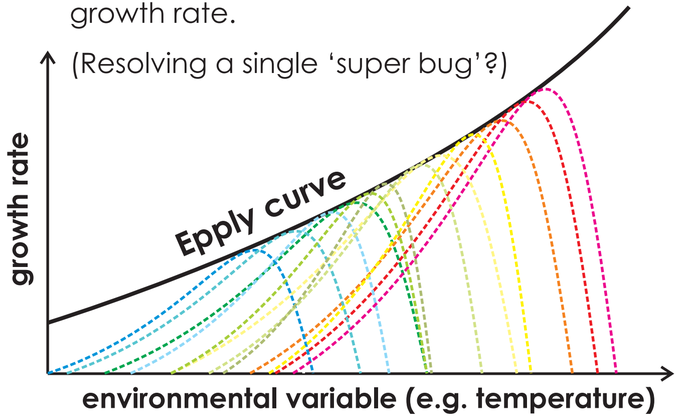
evolution *in silico* ('fake evolution') – WHY?

In traditional 'functional type' ecosystem models, diversity is not resolved, but instead its effects highly parameterized using the Epply curve in the case of temperature and growth rate.

(Resolving a single 'super bug'?)



?



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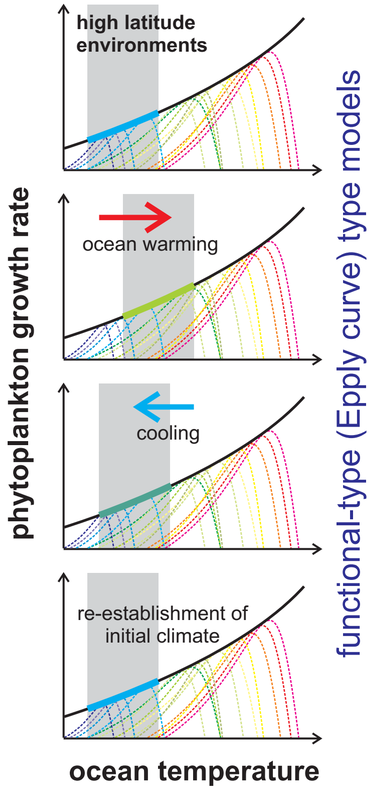
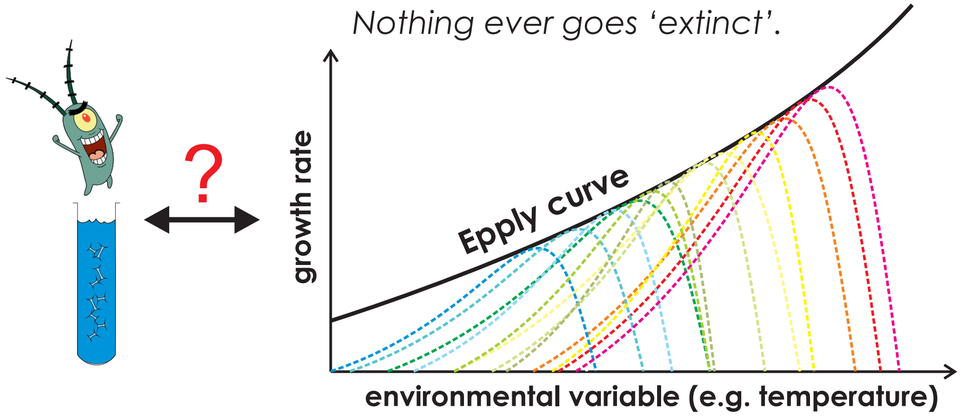


The response to a change in climate is then instantaneous and fully reversible.

Nothing ever goes 'extinct'.



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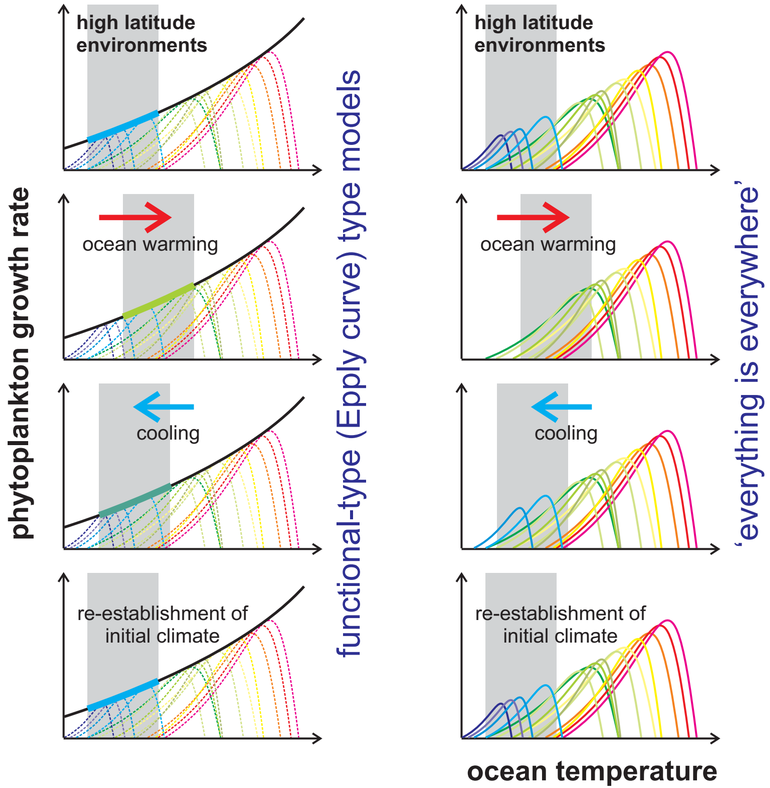

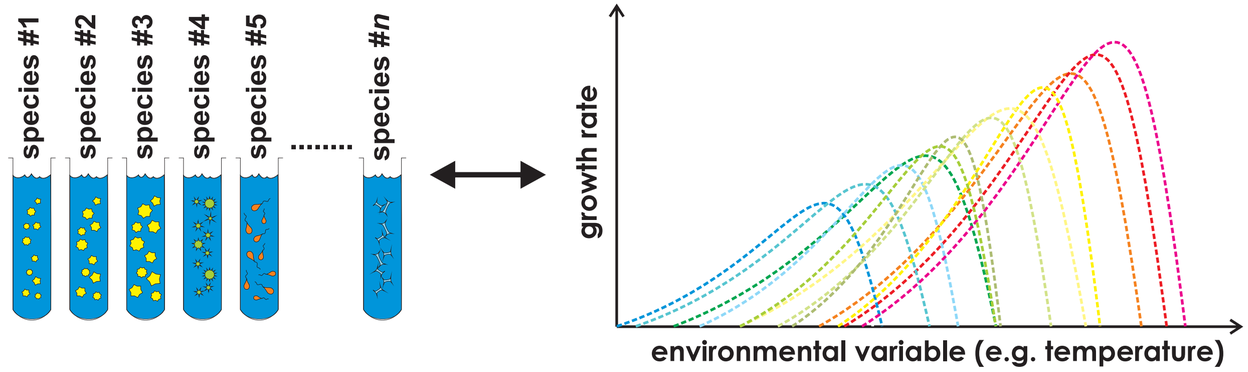

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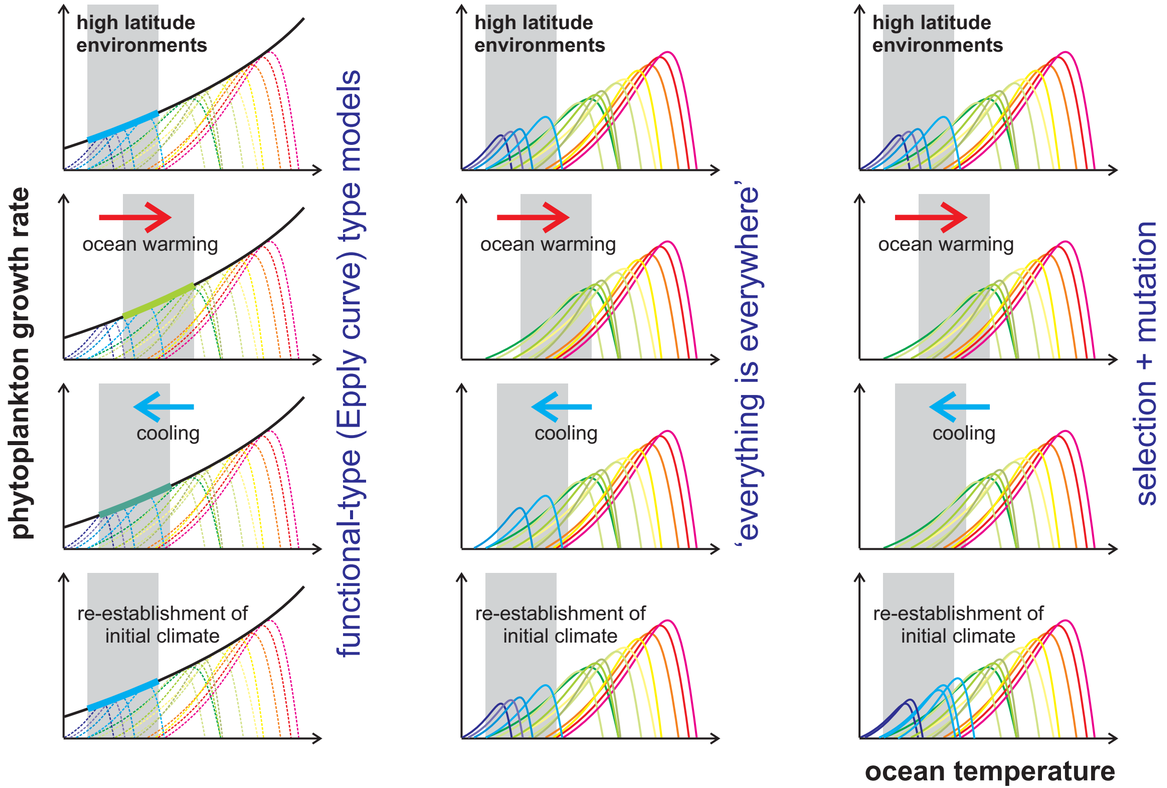
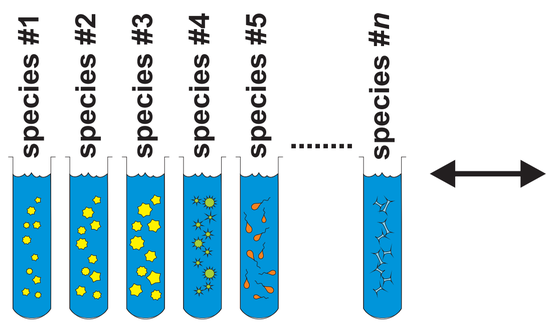
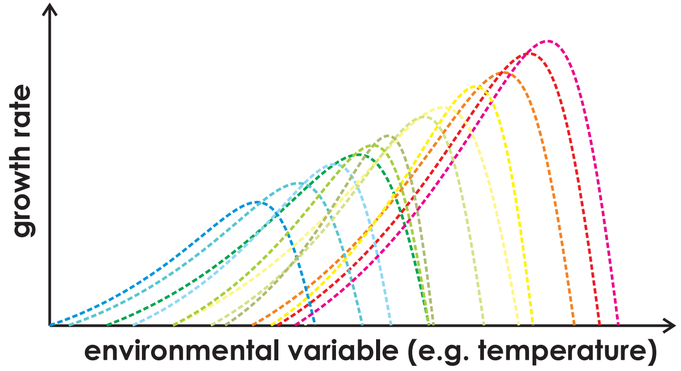
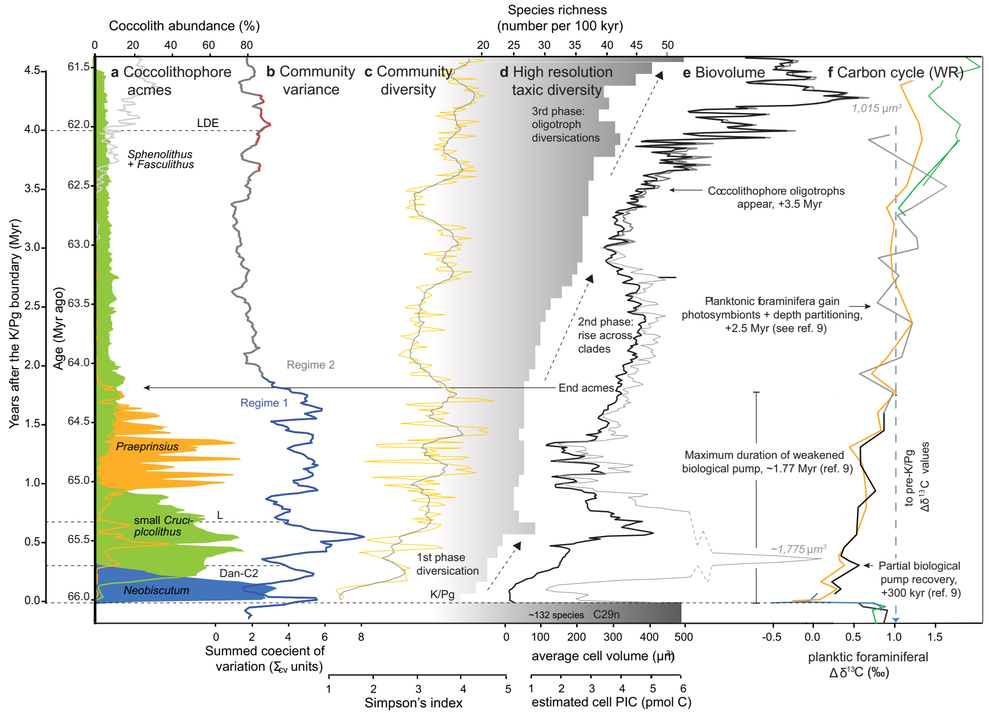




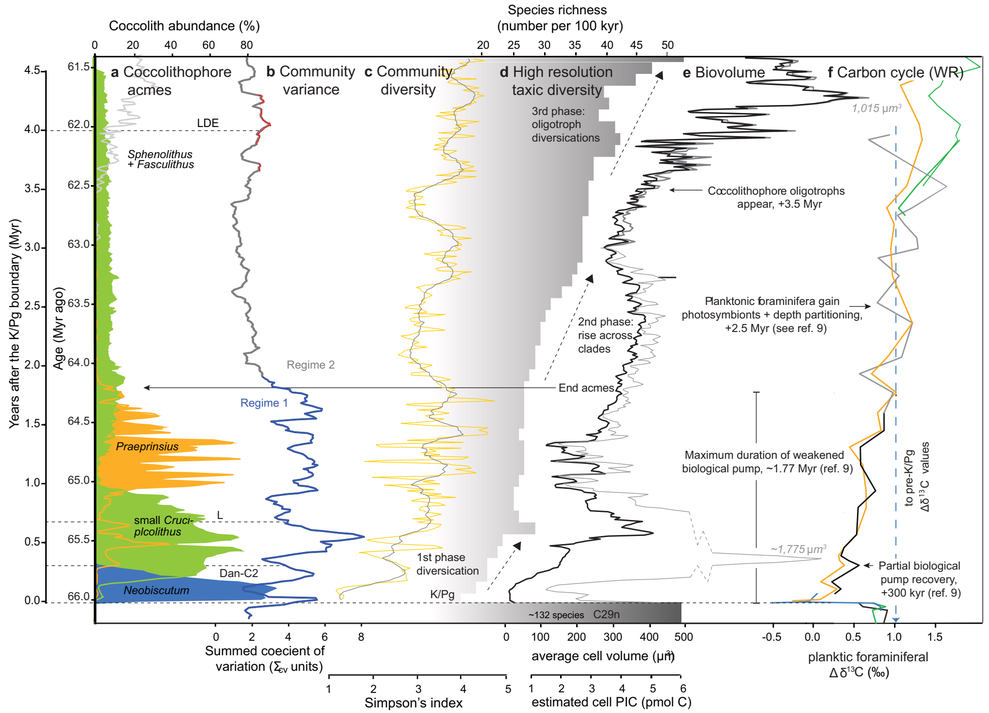


evolution *in silico* ('fake evolution') - WHY?

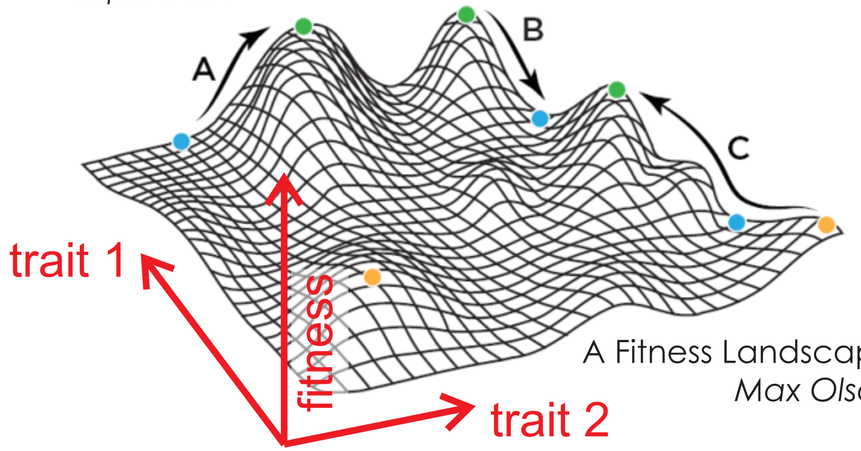


Diversity decoupled from ecosystem function and resilience during mass extinction recovery
Alvarez et al. [accepted]

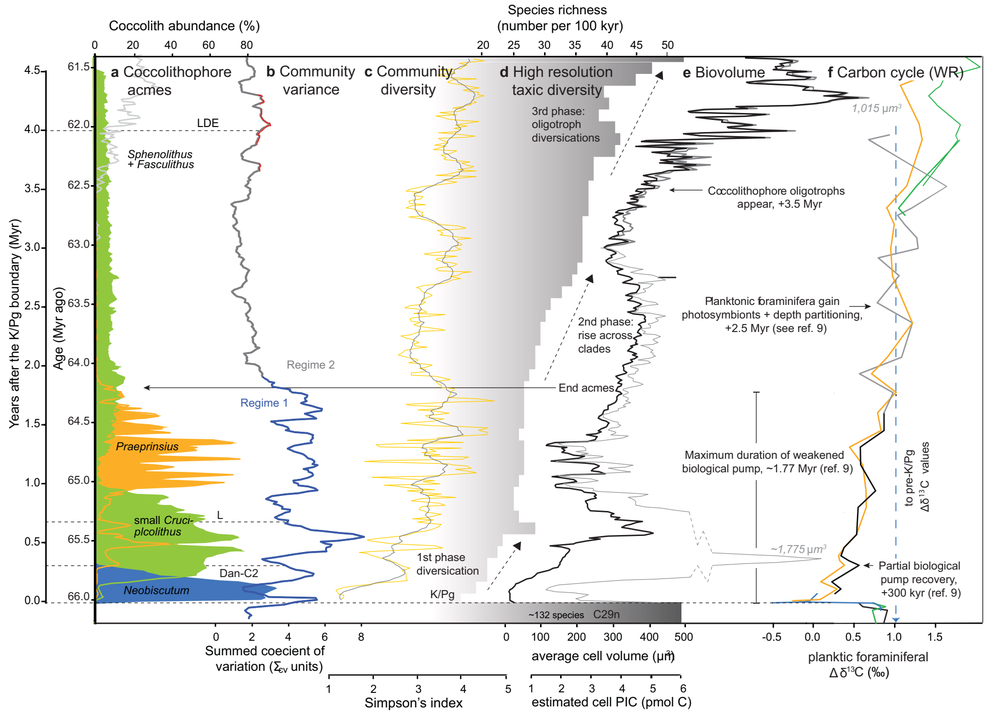
evolution *in silico* ('fake evolution') – WHY?



The traits here could be e.g. (terrestrial) plant height and ability to fix nitrogen and the peak represents being able to grow above the existing canopy in a nutrient (nitrogen) deplete soil.



A Fitness Landscape
Max Olson



evolution *in silico* ('fake evolution') – WHY?

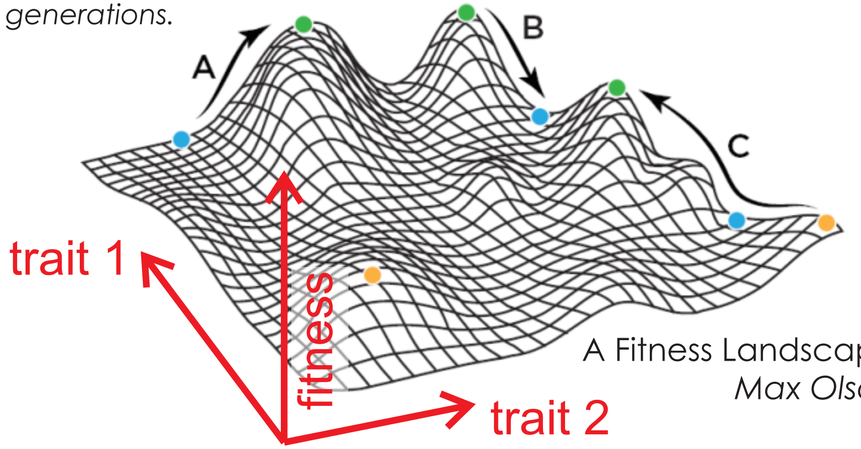
Consider:

(1) A typical phytoplankton cell, under non-limiting growth conditions, divides avery ca. 1 day. So 365 (.25) generations per year on average.

(2) Evolution has been observed (coccolithophores) to occur in vito, within a single year.

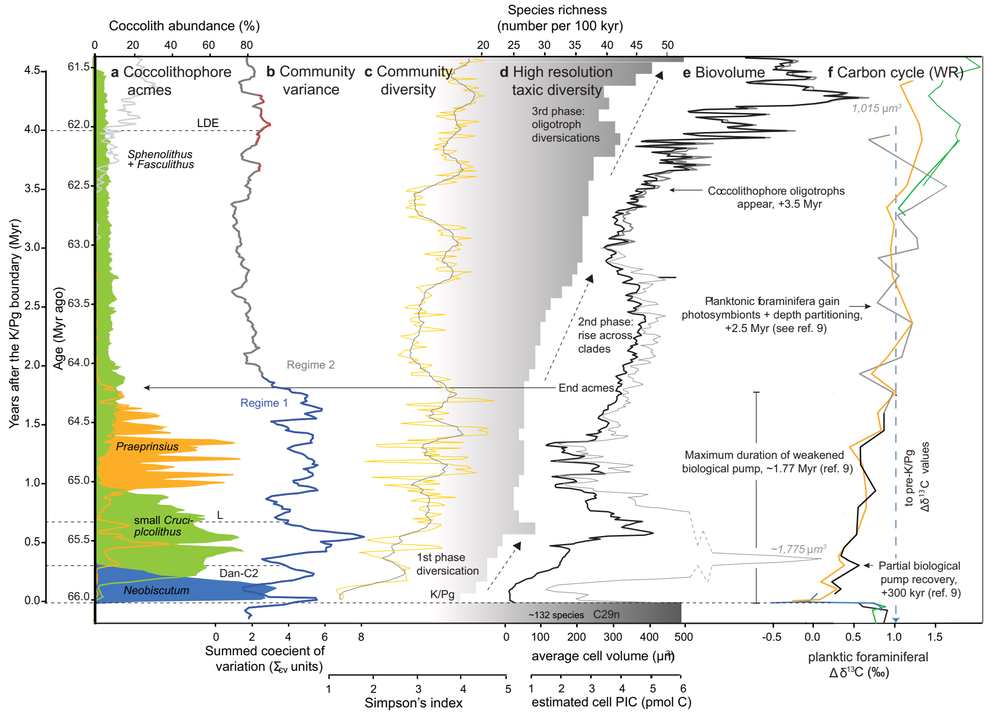
(3) Recovery, post-impact, took ca. 2 Myr to re-establish ecosystem 'function' (global carbon cycling) and stability.
That equates to almost 2 billion generations.

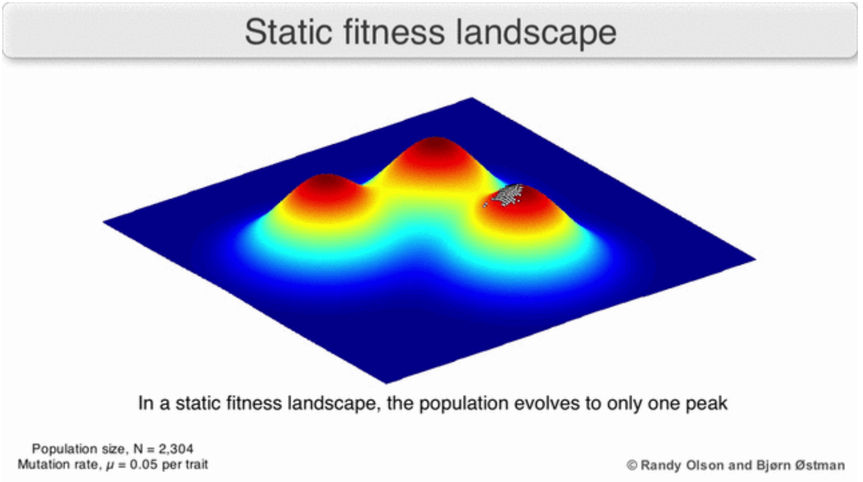
WHY?



A Fitness Landscape
Max Olson

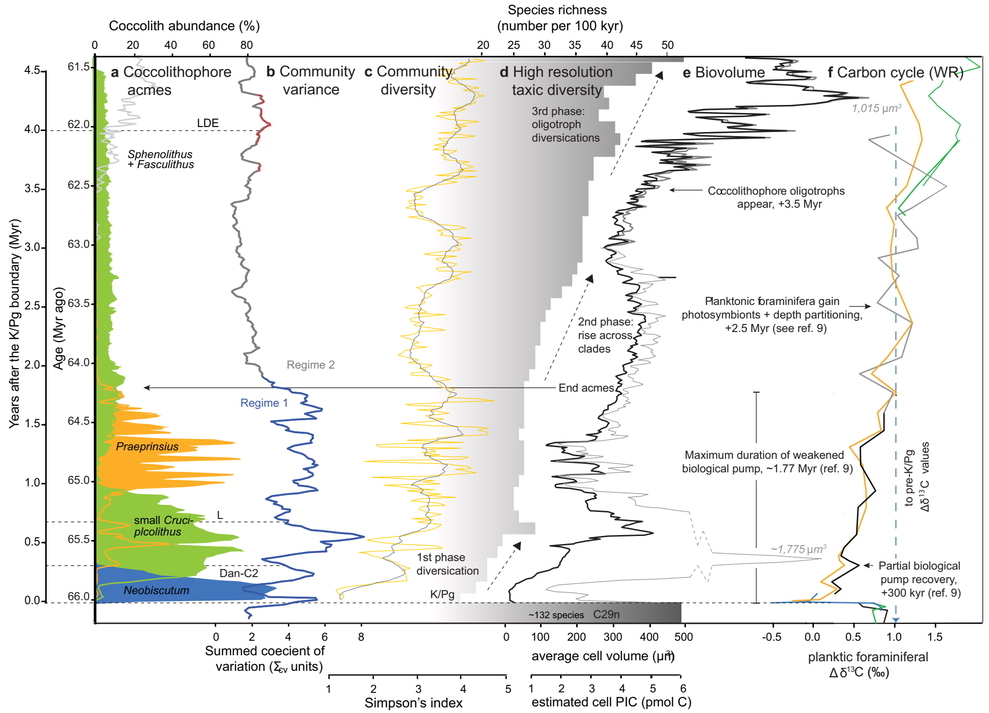
evolution *in silico* ('fake evolution') – WHY?

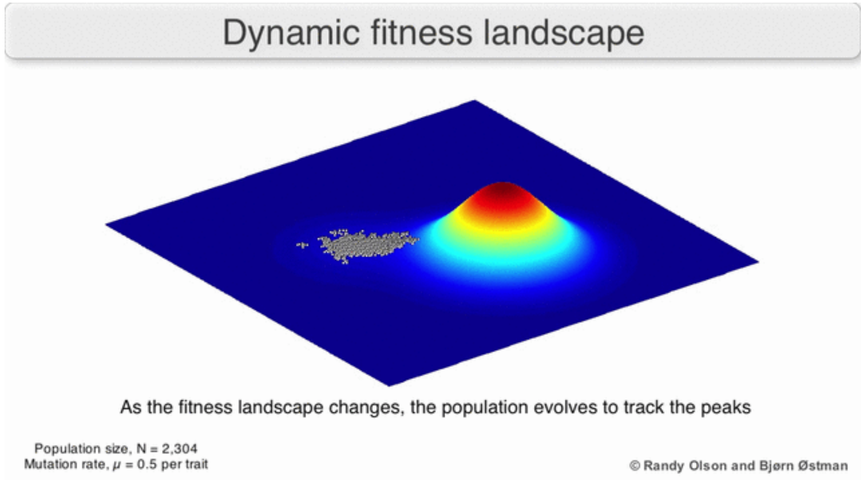




Randy Olson and Bjørn Østman
Visualization of a population evolving in a static fitness landscape

evolution *in silico* ('fake evolution') – WHY?





Randy Olson and Bjørn Østman
Visualization of a population evolving in a dynamic fitness landscape

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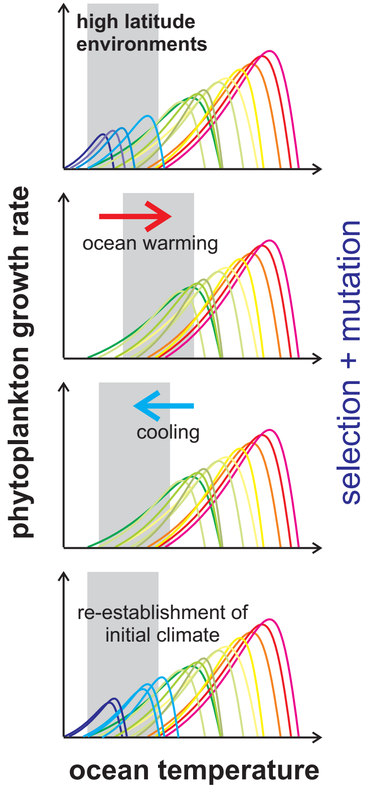
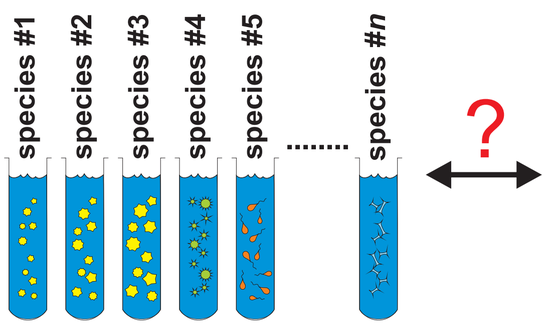
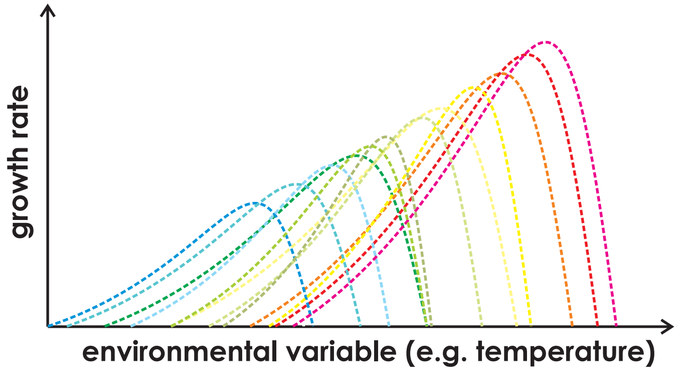


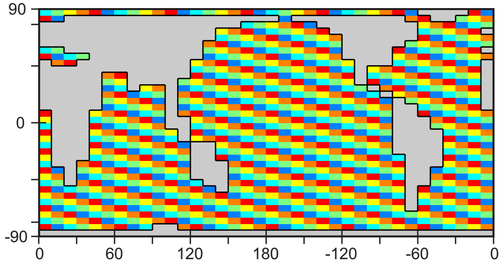




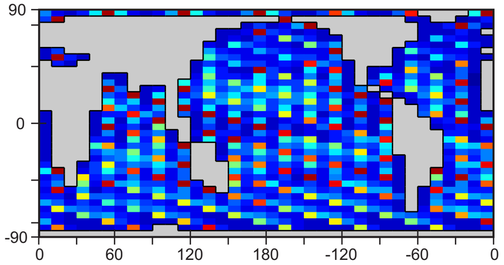
evolution *in silico* ('fake evolution') – HOW?

1. Diagnose the ocean transport in an Earth system model

'Color' tracer pattern to unambiguously diagnose surface ocean transport



Dispersal of a single 'color' after 1 year



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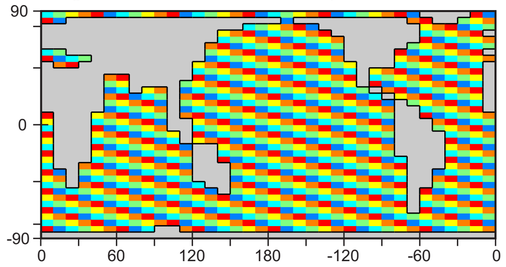

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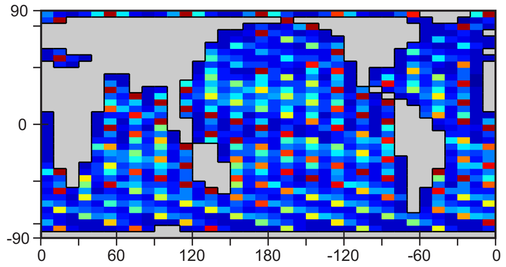
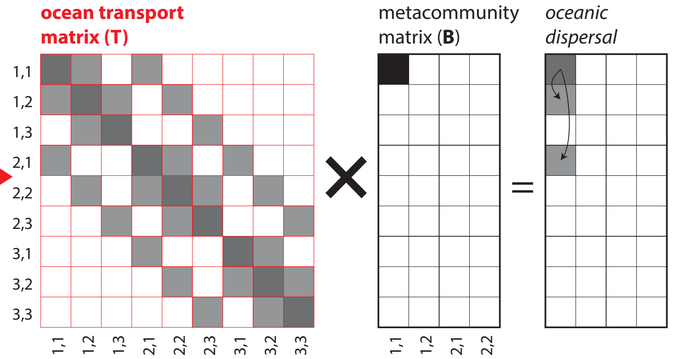
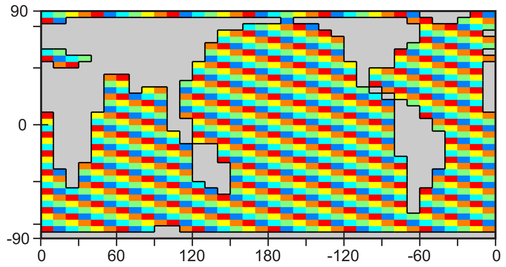




2. Create matrix (of ocean transport)

evolution *in silico* ('fake evolution') - HOW?

'Color' tracer pattern to unambiguously diagnose surface ocean transport



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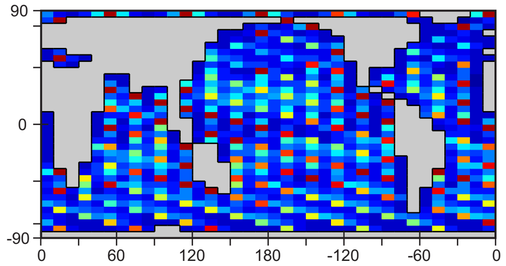
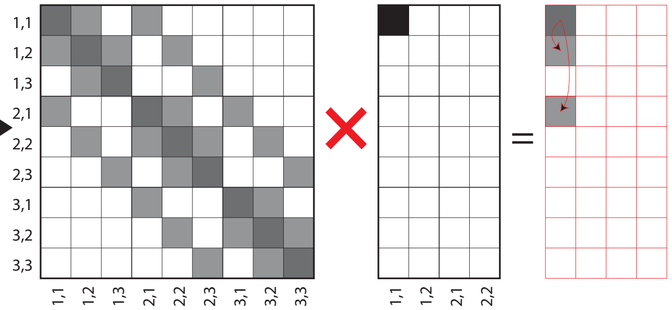


ocean transport matrix (T)

metacommunity matrix (**B**)

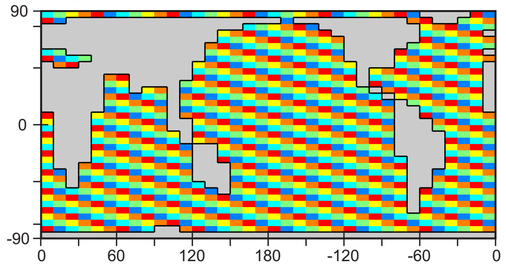
oceanic dispersal



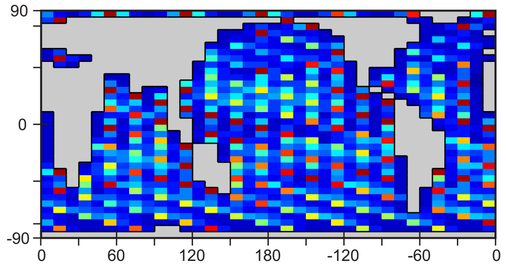
3. Apply matrix to 3D field of plankton

evolution *in silico* ('fake evolution') - HOW?

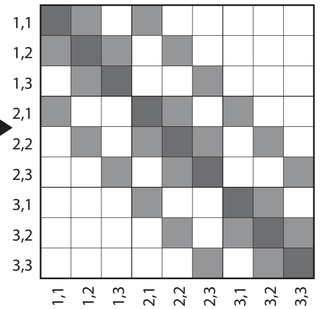
'Color' tracer pattern to unambiguously diagnose surface ocean transport



Dispersal of a single 'color' after 1 year



ocean transport matrix (T)



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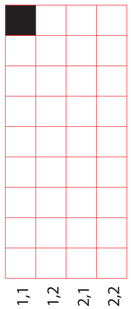
metacommunity matrix (B)



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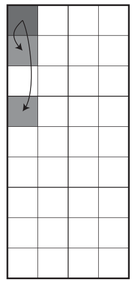
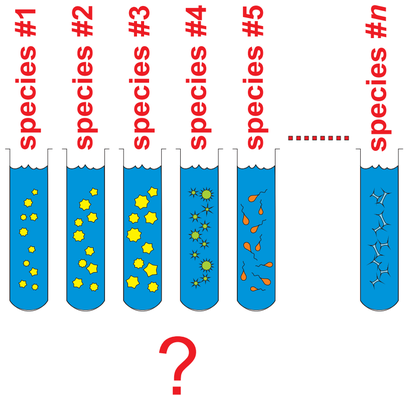
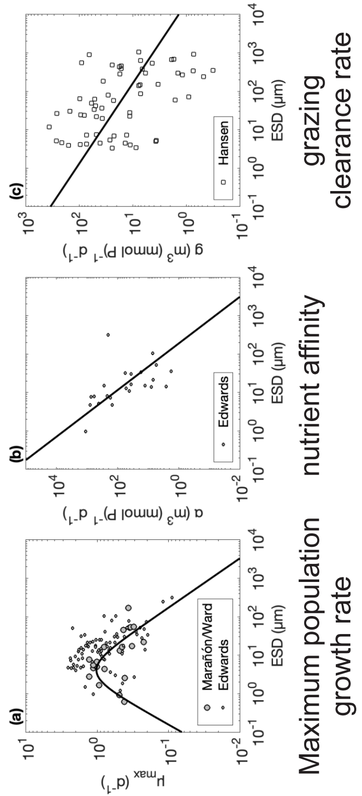
oceanic dispersal

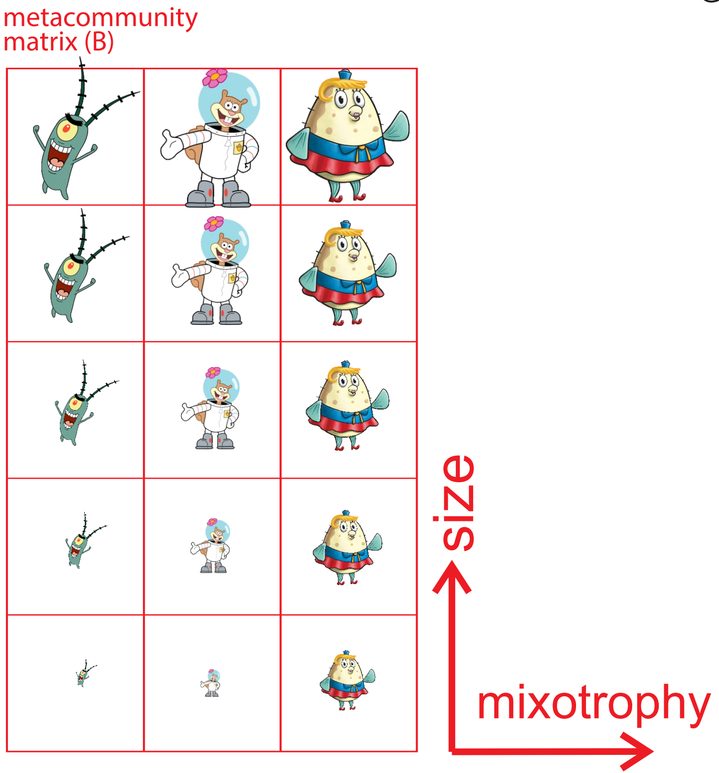




evolution *in silico* ('fake evolution') – HOW?



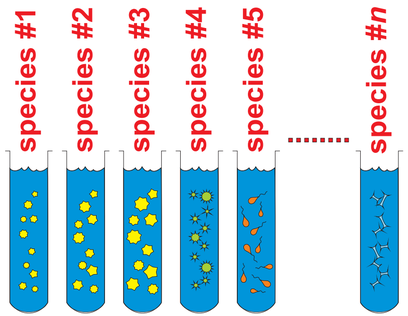
A Matrix Metacommunity Model: ecological and evolutionary emergence of a global plankton metacommunity
Ward, Wilson, et al. [in prep]



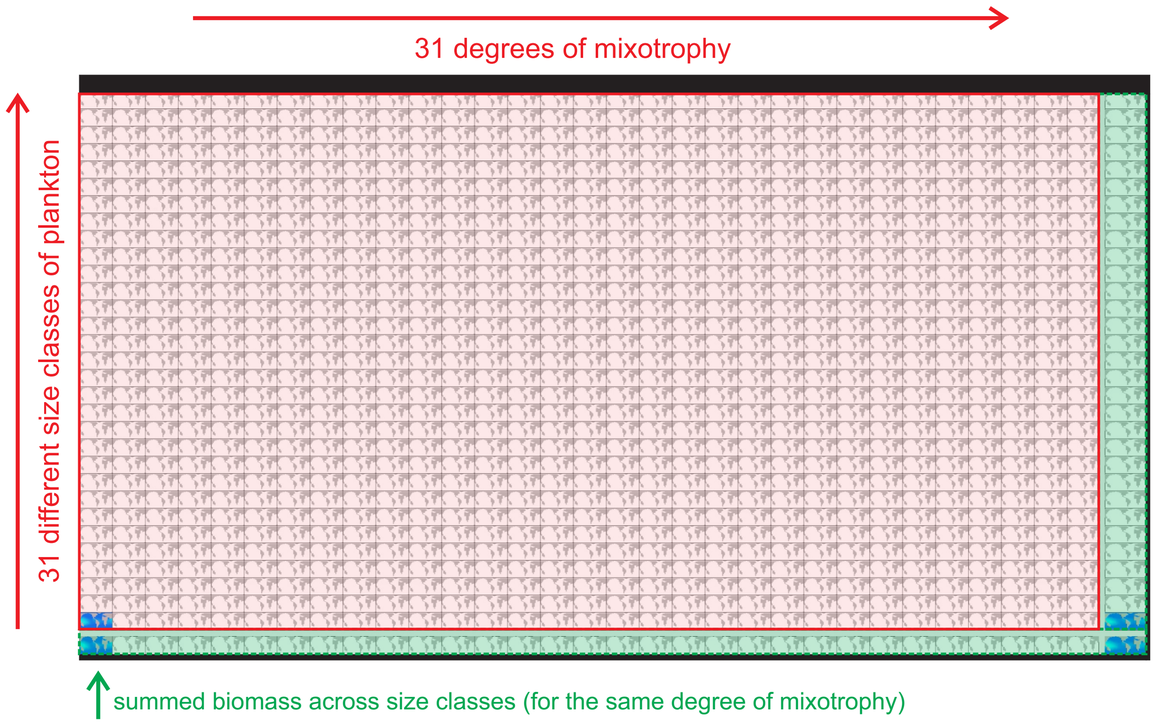
A Venus Flytrap with trigger hairs. Photo: Noah Elhardt / Wikipedia

Potential species are pre-defined. They may never exist anywhere in the ocean or at any time.
(NOT: 'everywhere is everywhere and the environment selects')

Biomass 'diffuses' from one 'species' (trait combination) to another.



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



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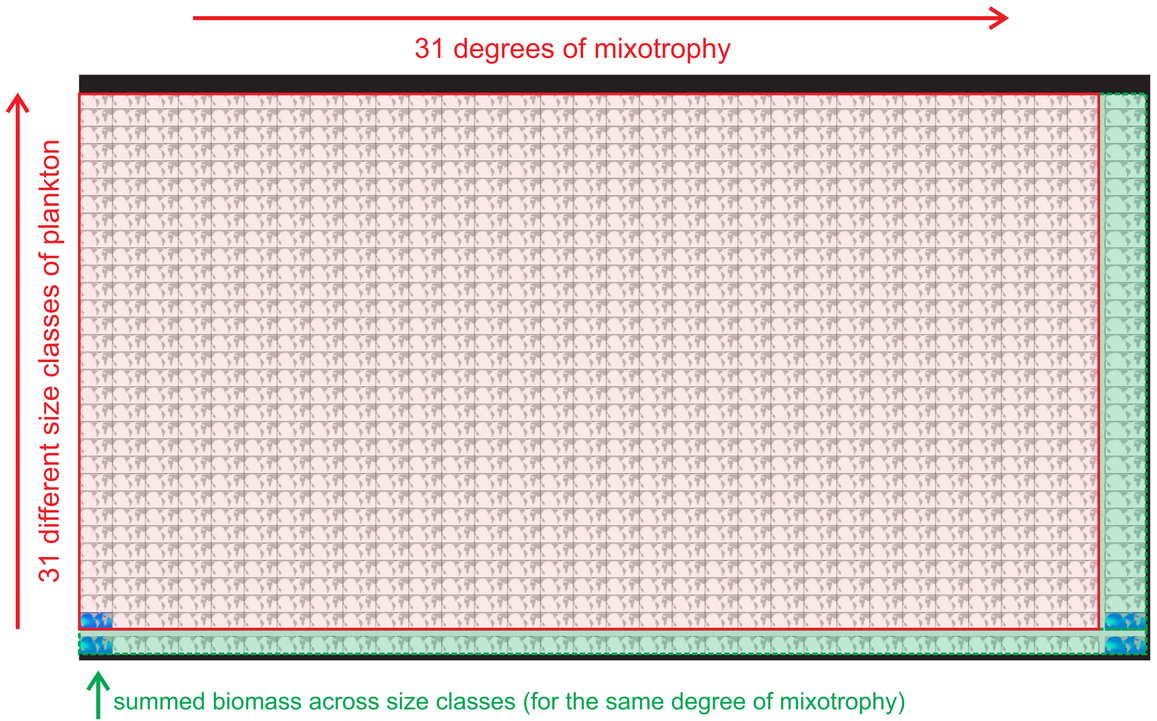


evolution *in silico* ('fake evolution')

This simulation **does not 'mean' anything** *per se*. It is conducted with a modern continental configuration and under modern ocean circulation (and a modern PO_4 inventory) but is not intended to correspond to any specific event or observation (yet), whether paleo, modern, or future.
It is a best viewed as a technical illustration of what can be done. Many questions are currently unanswered ...

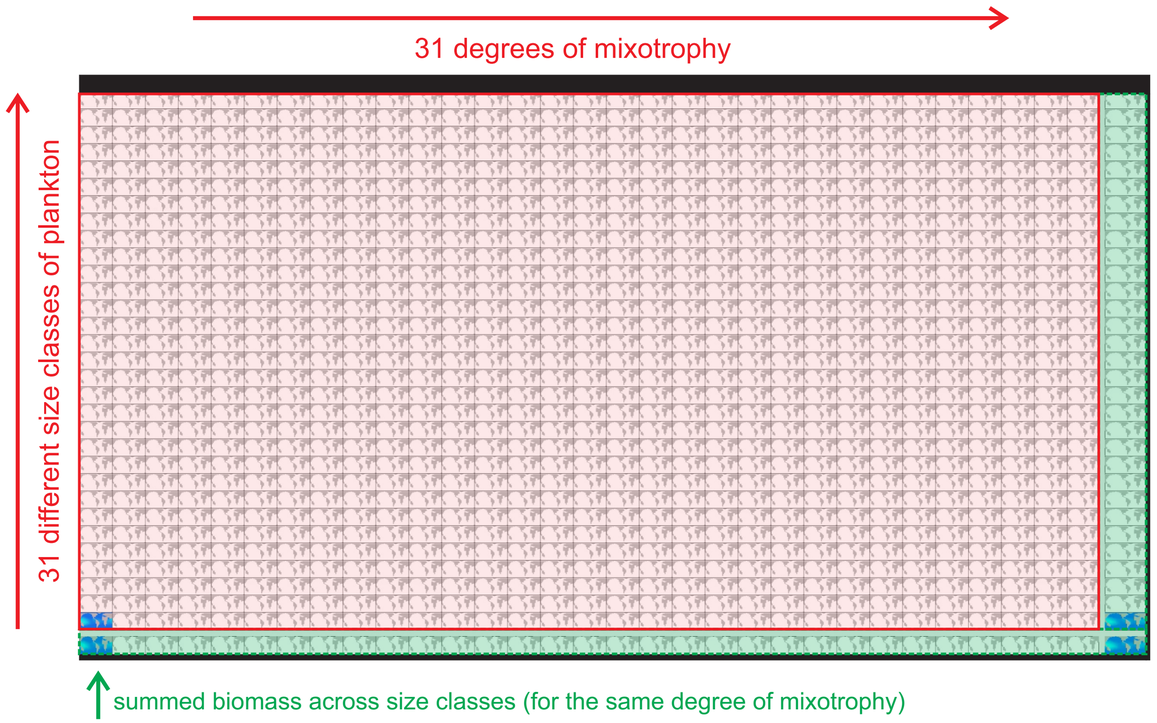
Q. How do you know how large and frequent a mutation to make?
(**A.** There are no specific mutations, but rather diffusion of biomass in trait space.)

Q. What would happen if a single species of phytoplankton was seeded elsewhere in the ocean? Is the final state of global ecology dependent on the initial conditions?
(**A.** Don't know.)

Q. What would happen if climate and ocean circulation changed, e.g. in feedback with the evolving carbon cycle, or if the ocean PO_4 field was prescribed rather than free to evolve?
(**A.** Something different.)

Q. Can I take the gorgeous evolving global ecology home for my children?
(**A.** Of course. Would you like the evolving global ecology gift-wrapped?)

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



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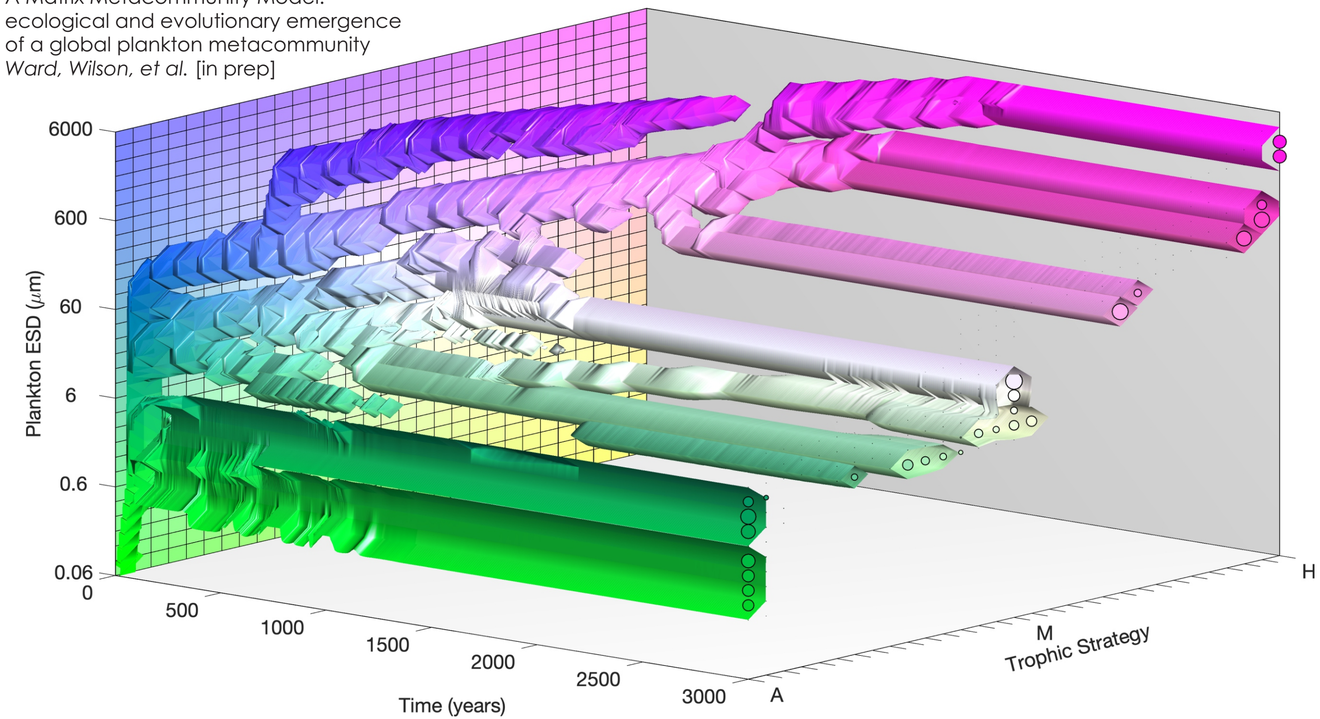
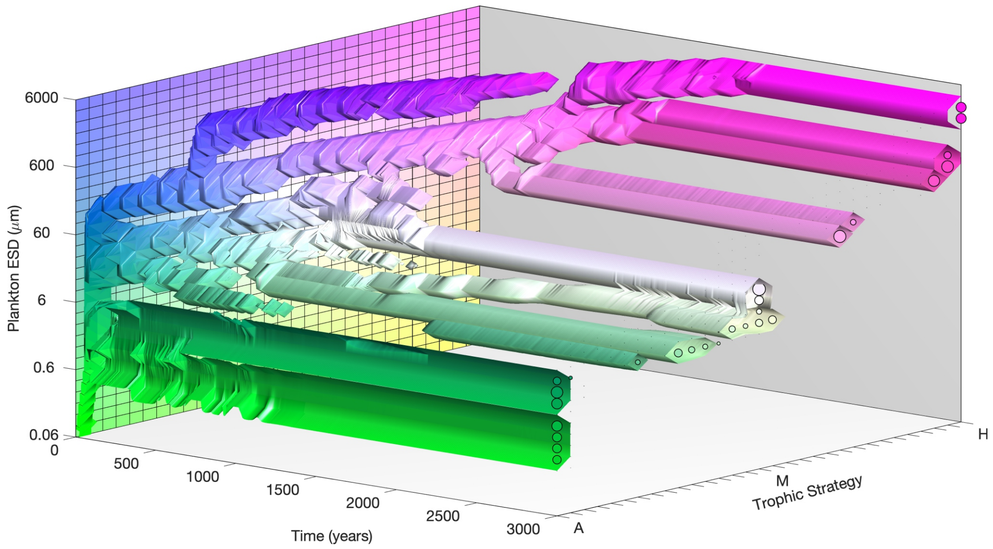
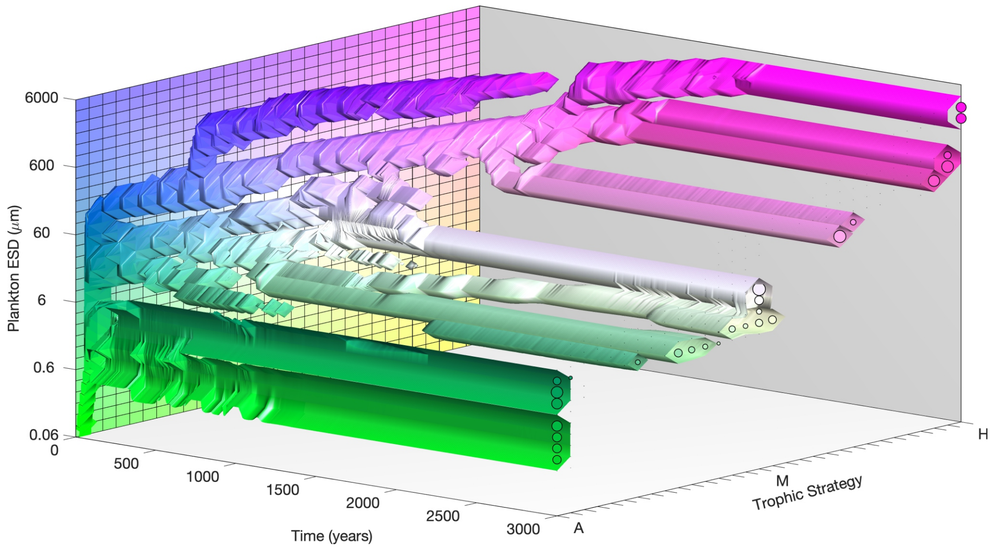



6000
600
60
6
0.6
0.06
Plankton ESD (μm)
0
500
1000
1500
2000
2500
3000
Time (years)
A
M
H
Trophic Strategy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Trophic Strategy

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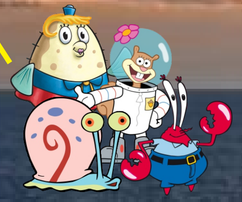

Paul Bown (UCL)
Sam Gibbs (NOCS, Southampton)
Sarah Alvarez (Bristol)
Daniela Schmidt (Bristol)

Fanny Monteiro (Bristol)

Ben Ward (NOCS, Southampton)

Jamie Wilson (Bristol)

biology/ecology

MATLAB


ICP13
~isempty(intersect('biology',paleo_models))
Andy Ridgwell (UC-Riverside)
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