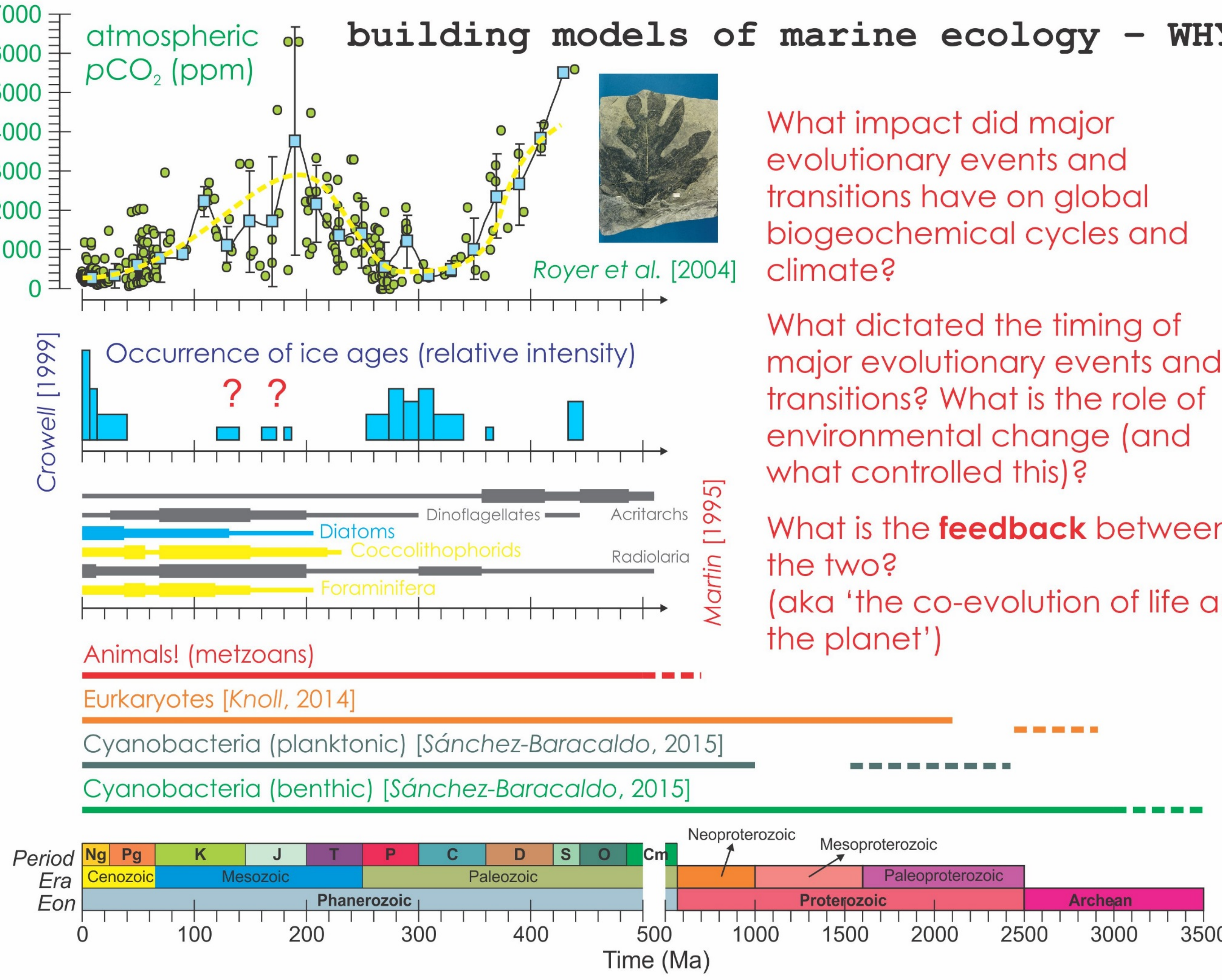
Numerical recipes for a marine biosphere

Andy Ridgwell (UC-Riverside)

building models of marine ecology – WHY?

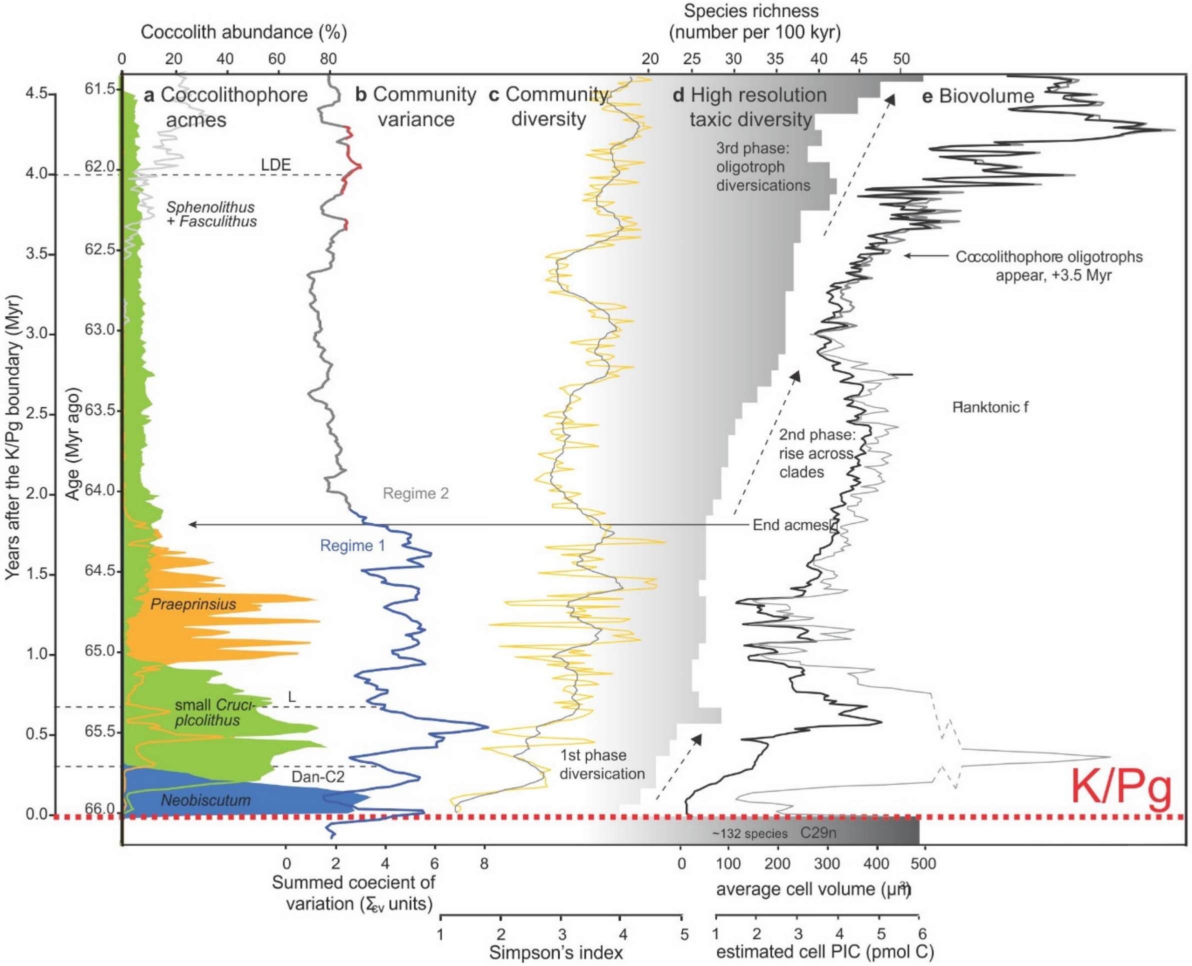


What impact did major evolutionary events and transitions have on global biogeochemical cycles and climate?

What dictated the timing of major evolutionary events and transitions? What is the role of environmental change (and what controlled this)?

What is the **feedback** between the two?
(aka 'the co-evolution of life and the planet')

building models of marine ecology - WHY?



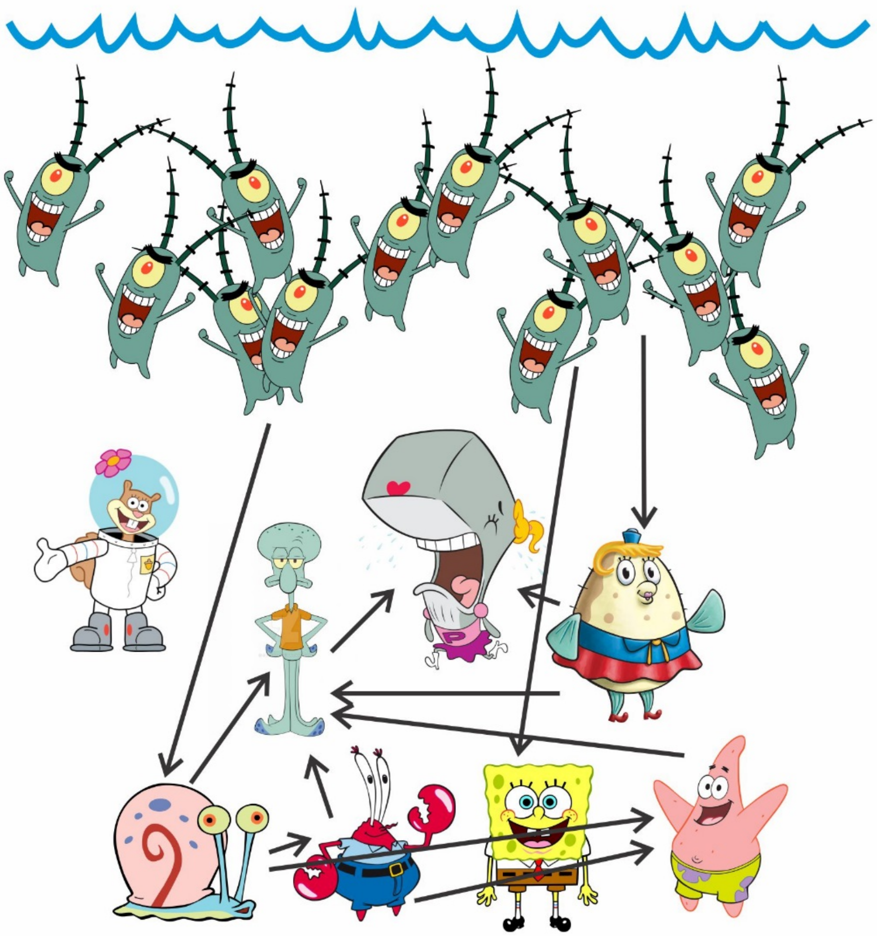
Alvarez et al. – 'Diversity decoupled from ecosystem function and resilience during mass extinction recovery' (Nature)

RIP dinosaurs at the end of the Cretaceous ...

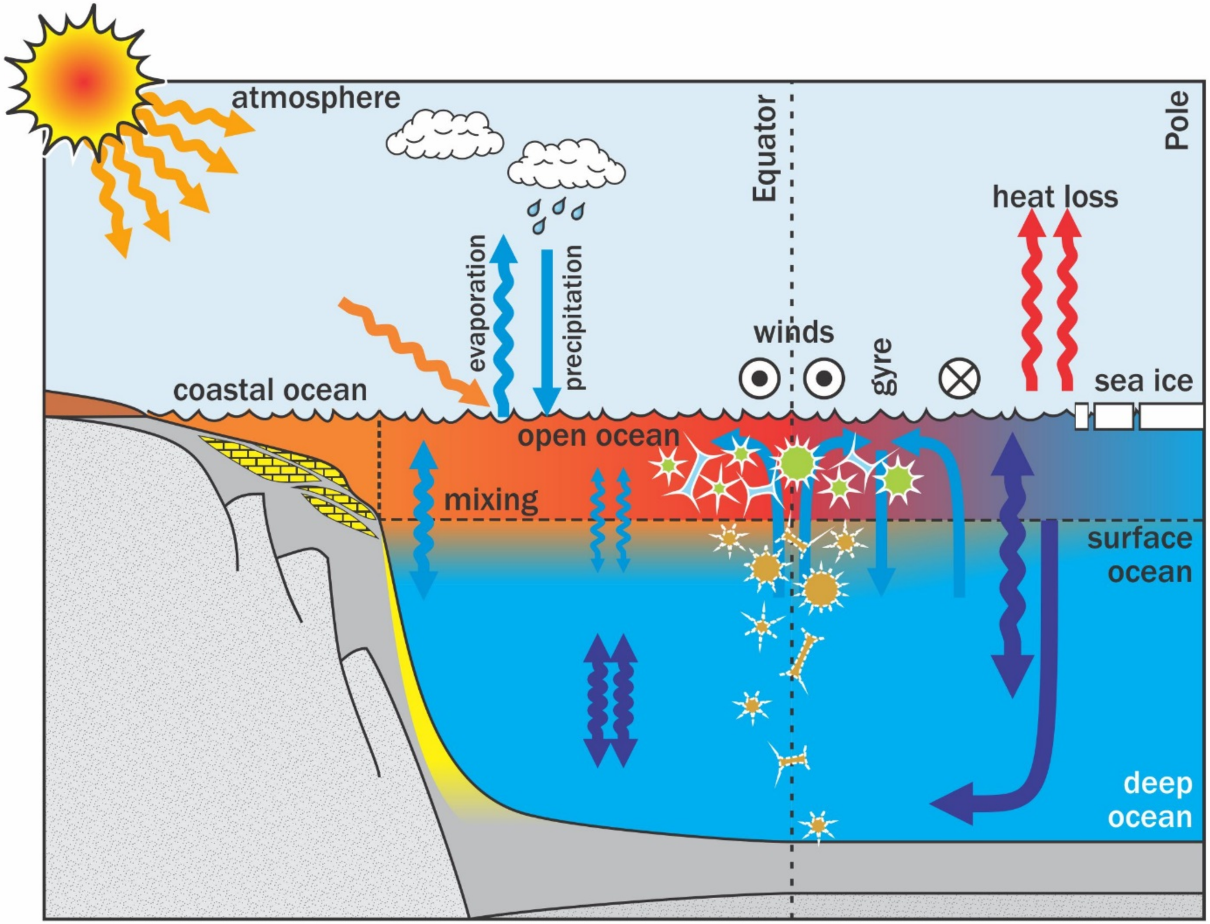
... but marine sediment data also tells us that in the ocean things also go extinct at the impact ... loss of species richness ... bigger things tend to go extinct more than smaller ones ...

... a 'working' marine biosphere takes several million years to re-establish (WHY?) ... a fully diverse marine biosphere takes 10 million years (WHY??) ...

building models of marine ecology – HOW?

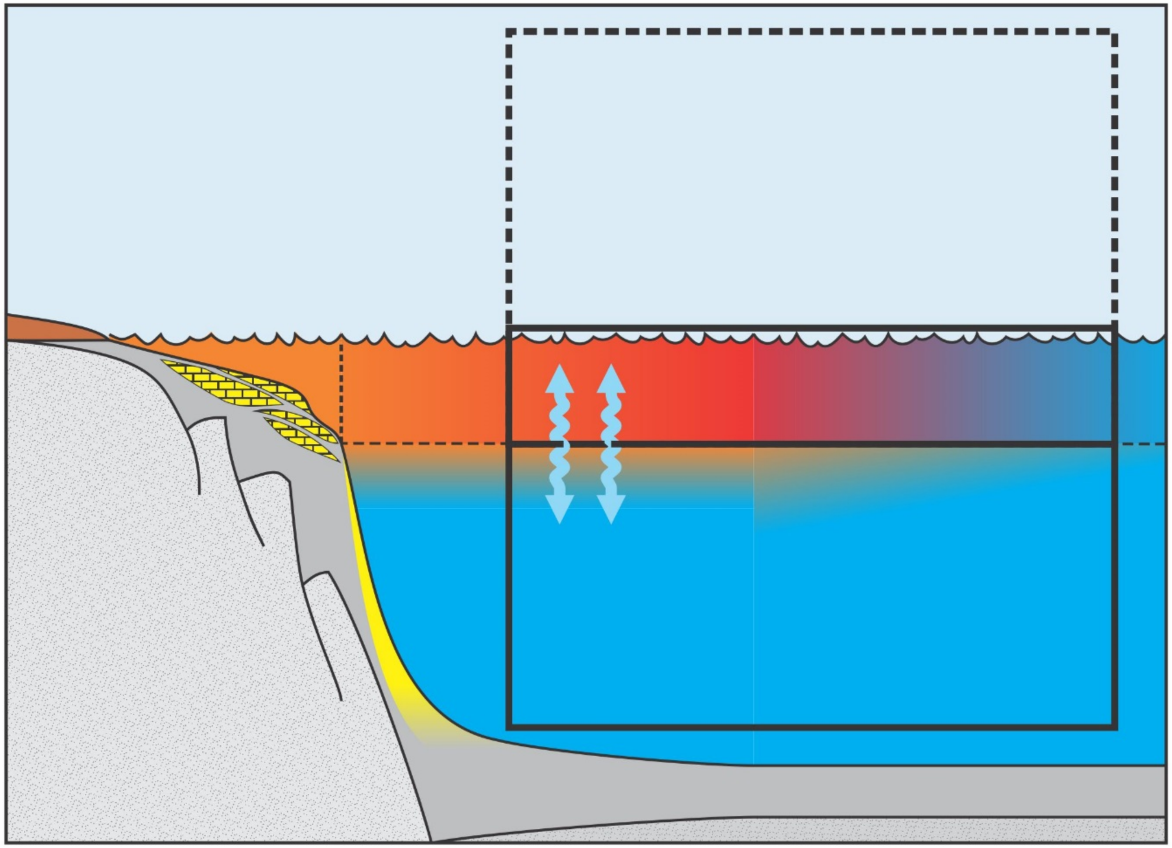


strategies for modelling complex marine systems



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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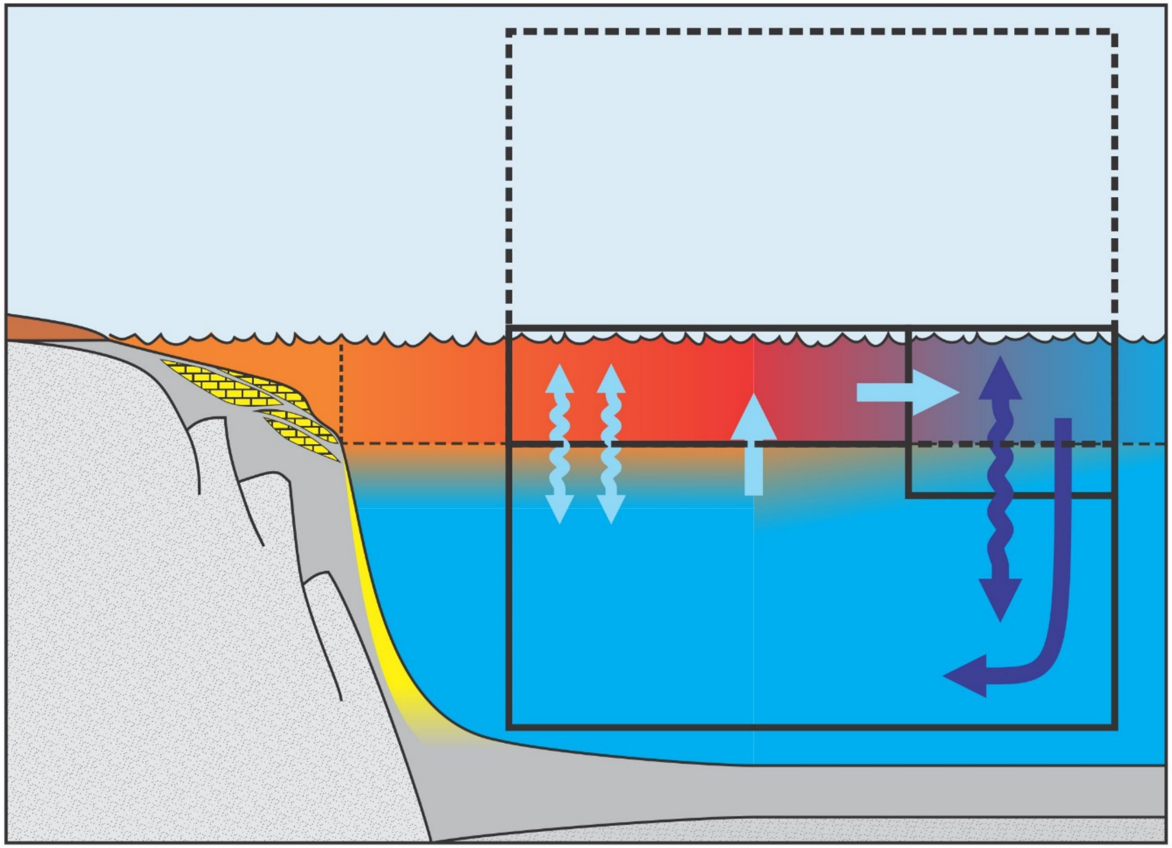

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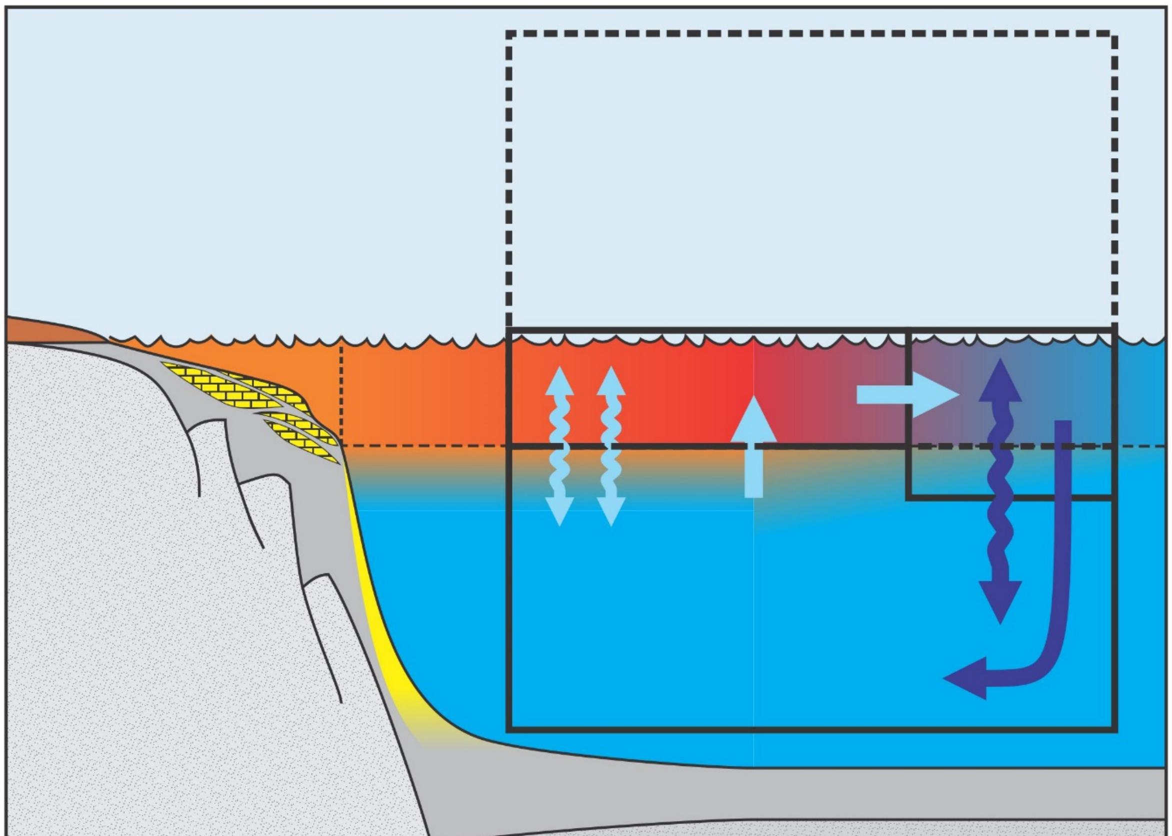

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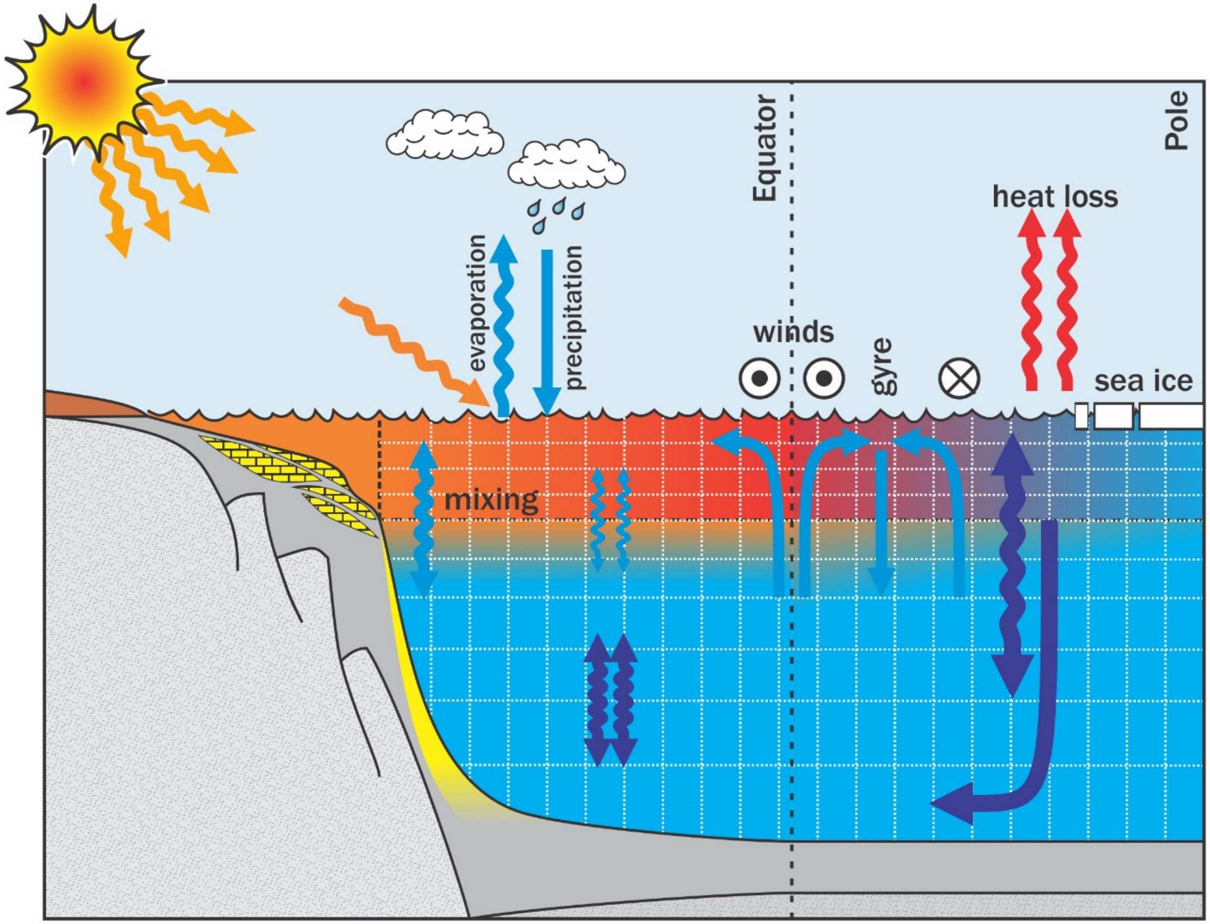
But ...

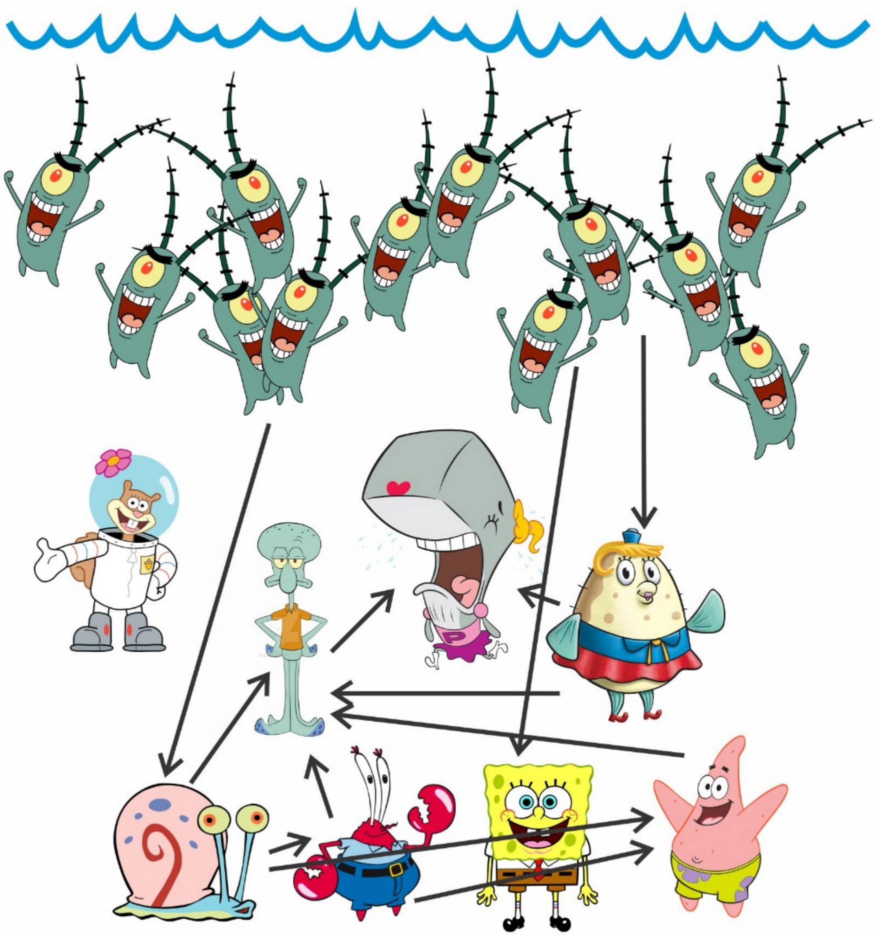
What happens under climate change?
What did the system look like in the past (e.g. Cretaceous)?
What if the structure of the system is not correctly understood in the first place?



Enter ...

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

numerical recipes for a marine biosphere(?)



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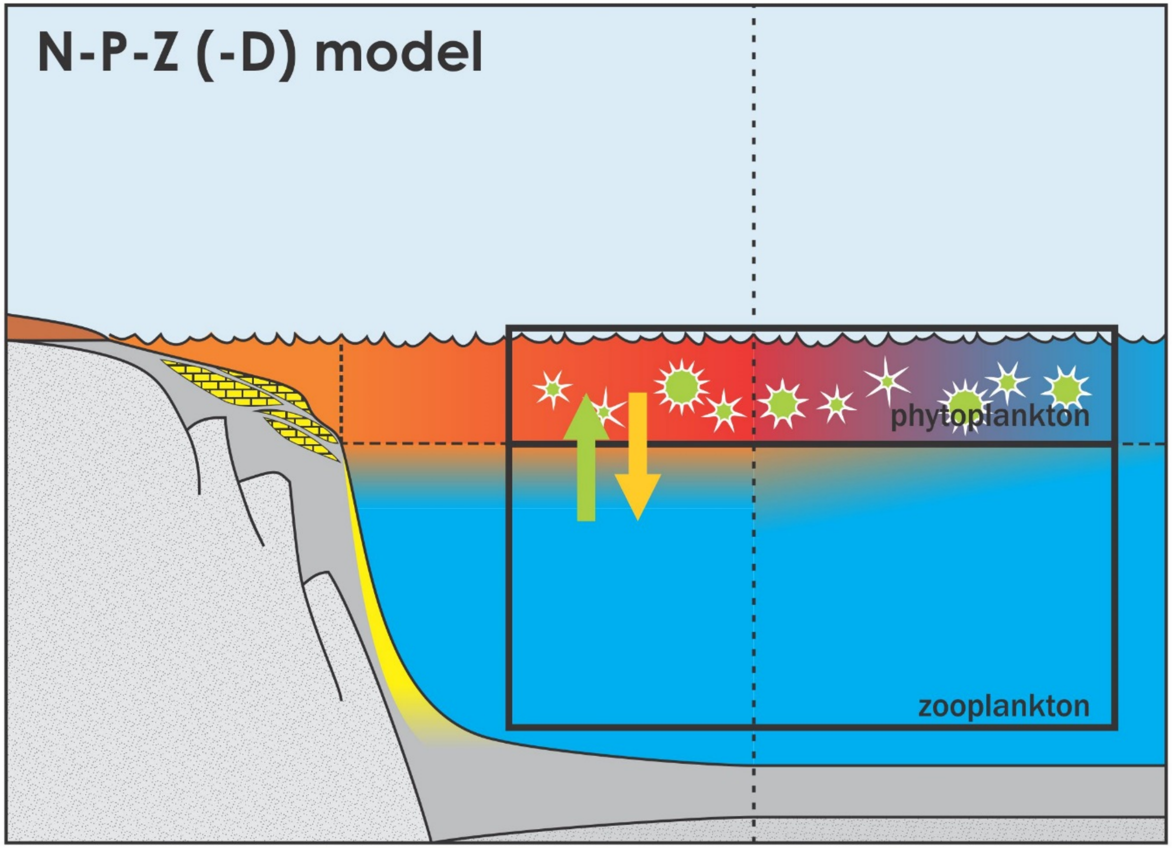

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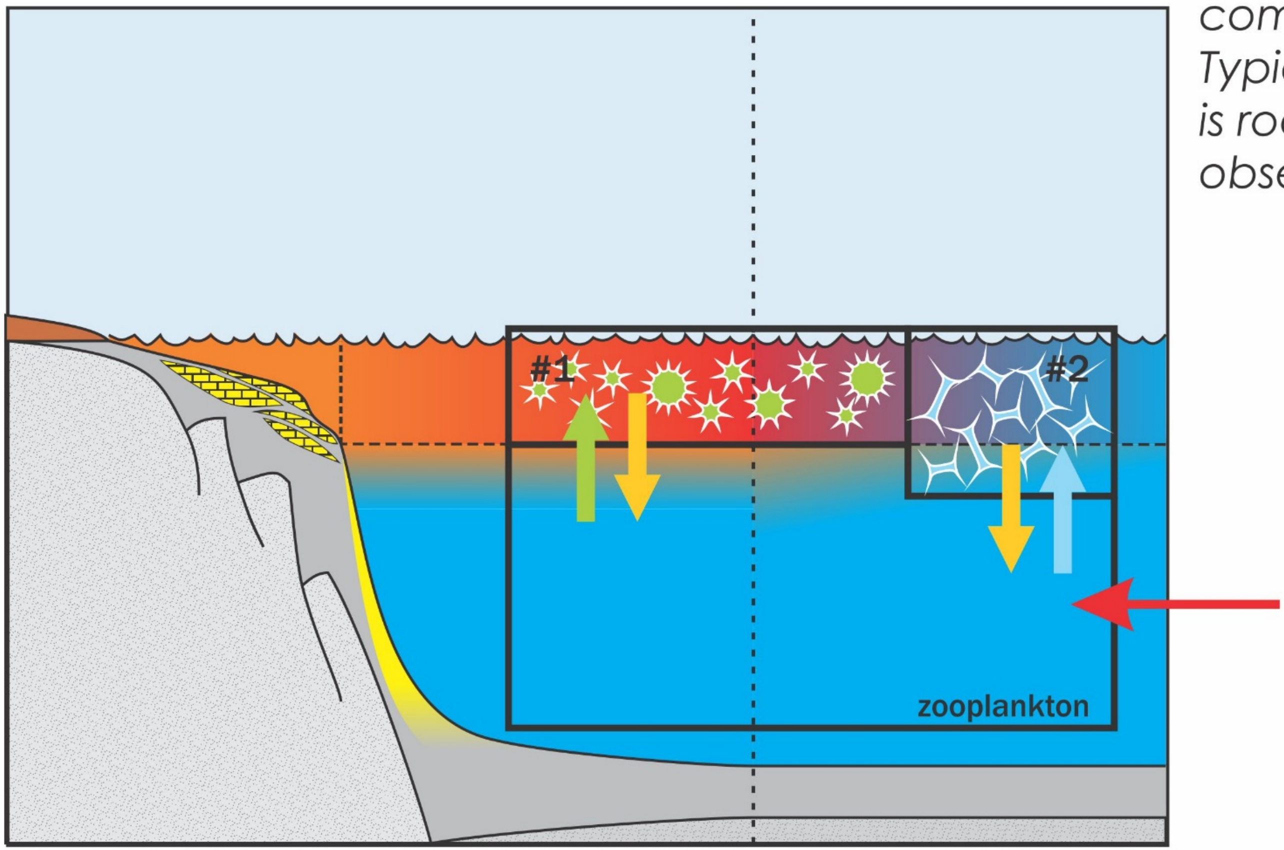
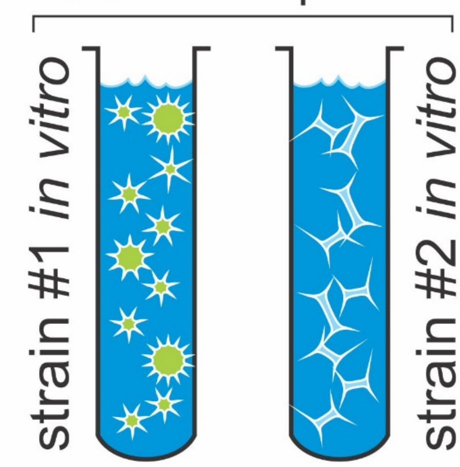


short-term laboratory perturbation experiments



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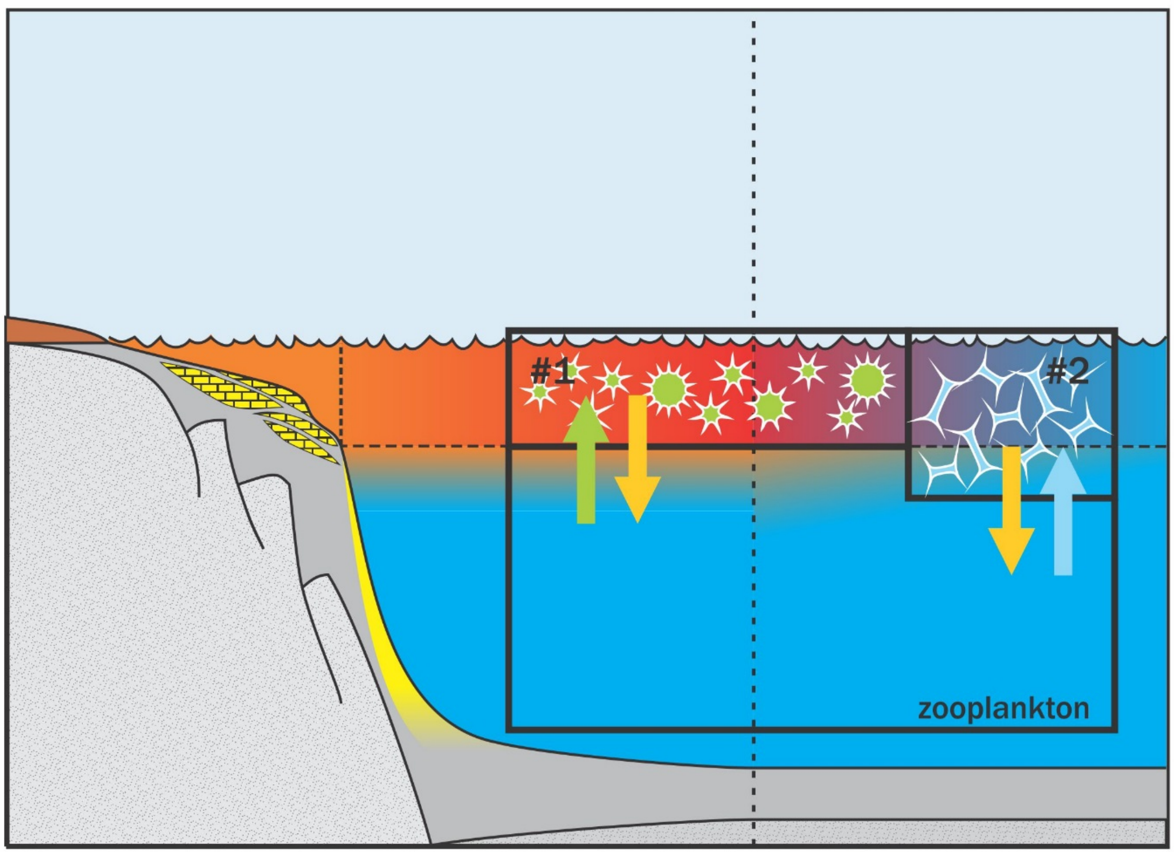

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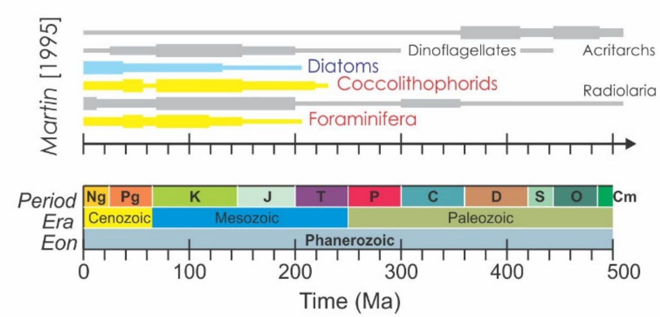

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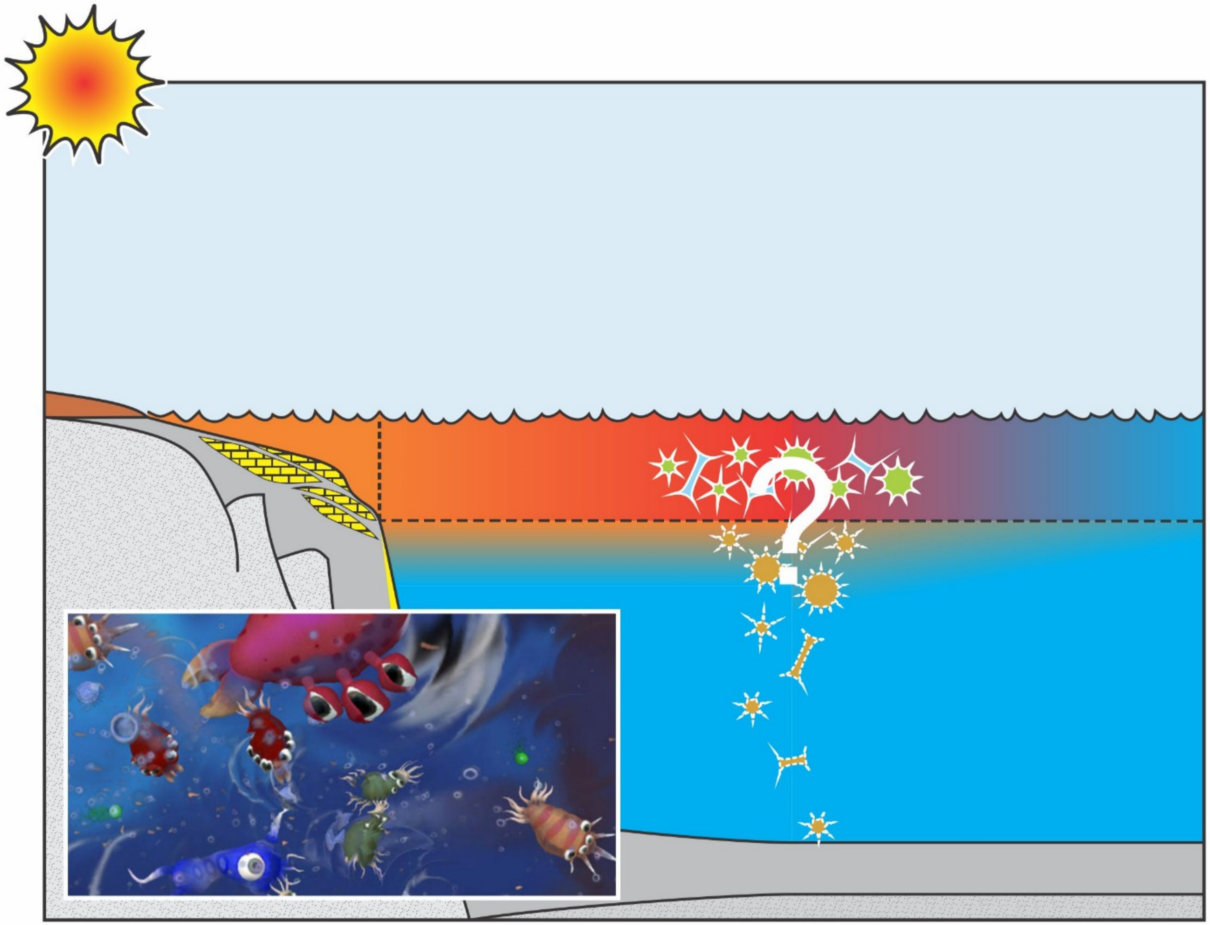
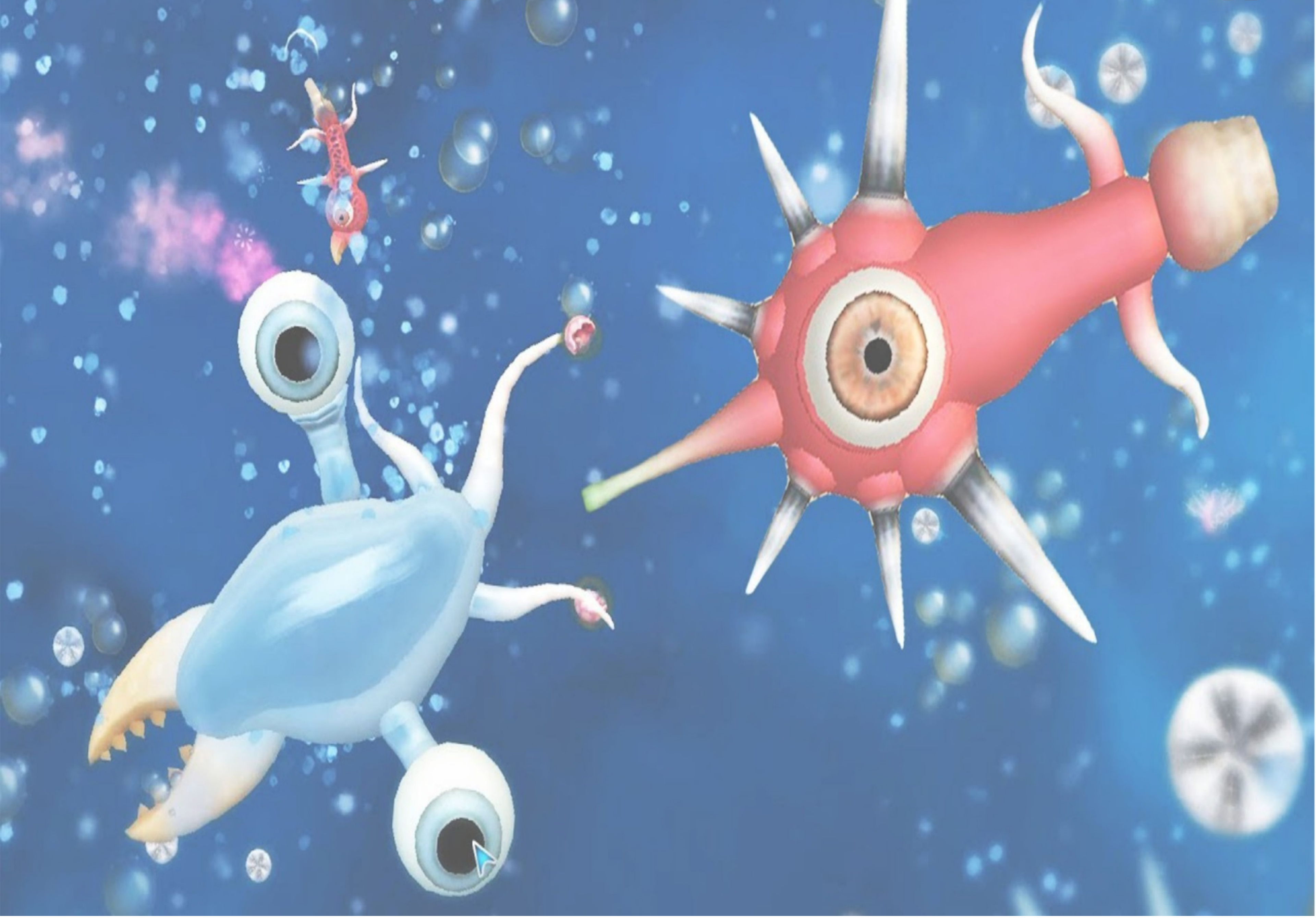


(Ocean) General Ecology Models?
(O-GEMs?)

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

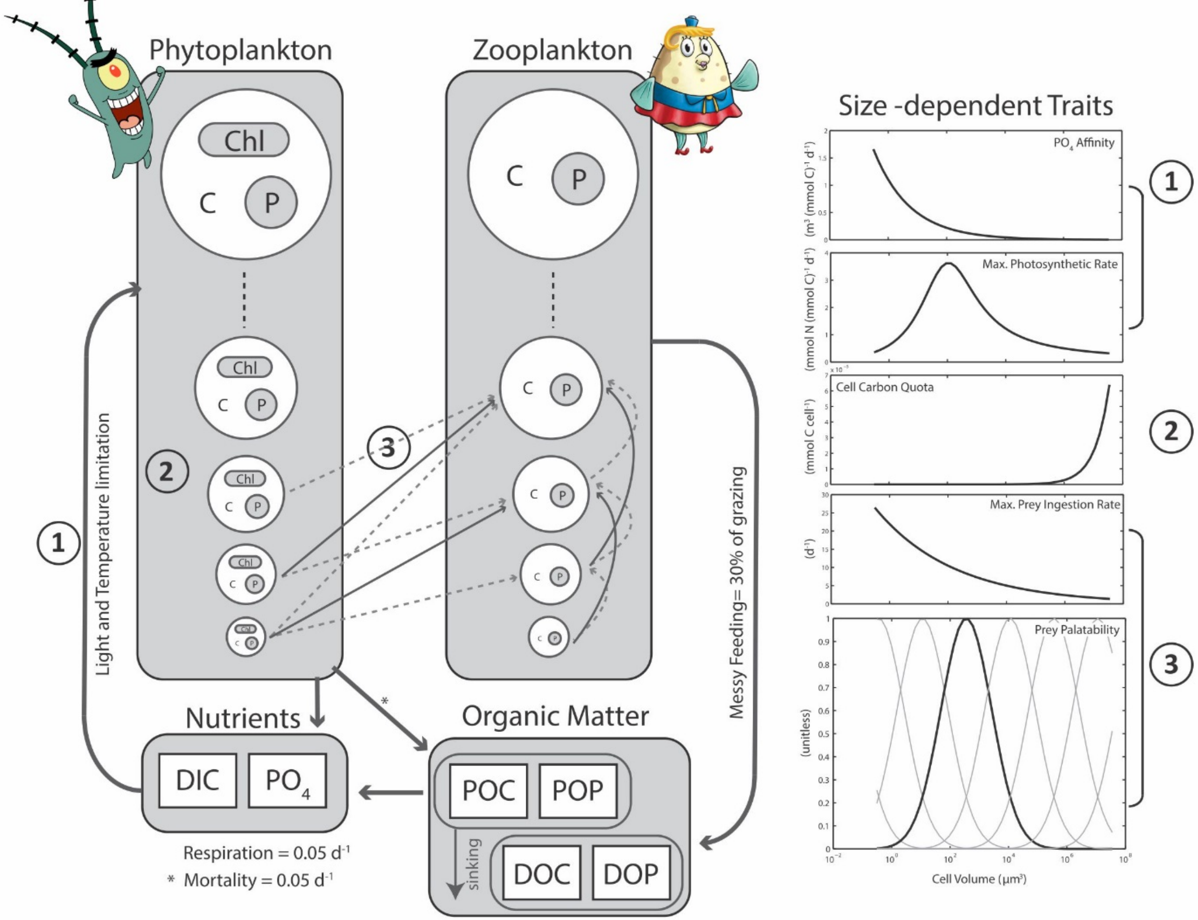
what are the 'physics' (rules) of marine ecology?




big fish eat little fish
ECCE
Hieronymus Bos. inuentor
COCK·EXCV·1557·
GRANDIBVS EXIGVI SVNT PISCES PISCIBVS ESCA·
Siet sone dit hebbe ick zeer langhe ghewetent / dat die groote vissen de cleyne eten

numerical recipes for a marine biosphere(?)

A size structured food-web model for the global ocean,
Ward et al. [2012] (**Limnol. Oceanogr.**)
(figure from: *Wilson et al.* [2018])



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).

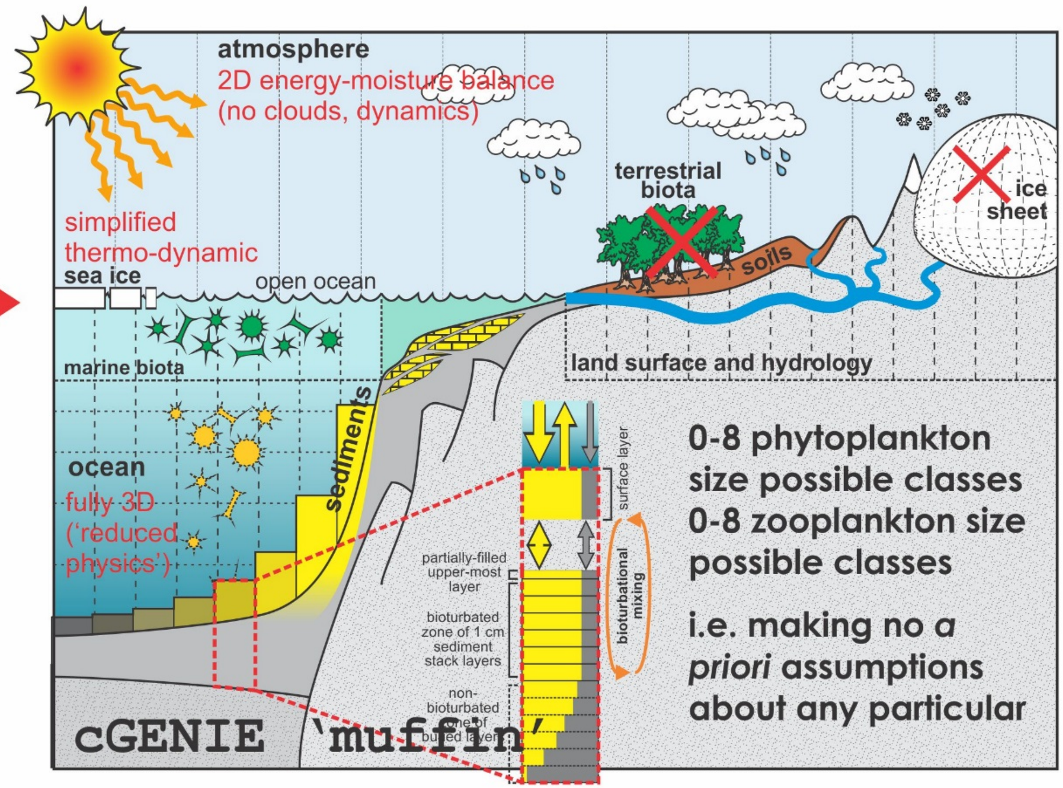
'Standard' functional type ecosystem model grazing dynamics (with size preference).

(Currently (not published), no other 'functions' (or 'traits') such as N-fixation, calcification or silicification, are included.)

numerical recipes for a marine biosphere(?)

... then embedded in an Earth system model ...

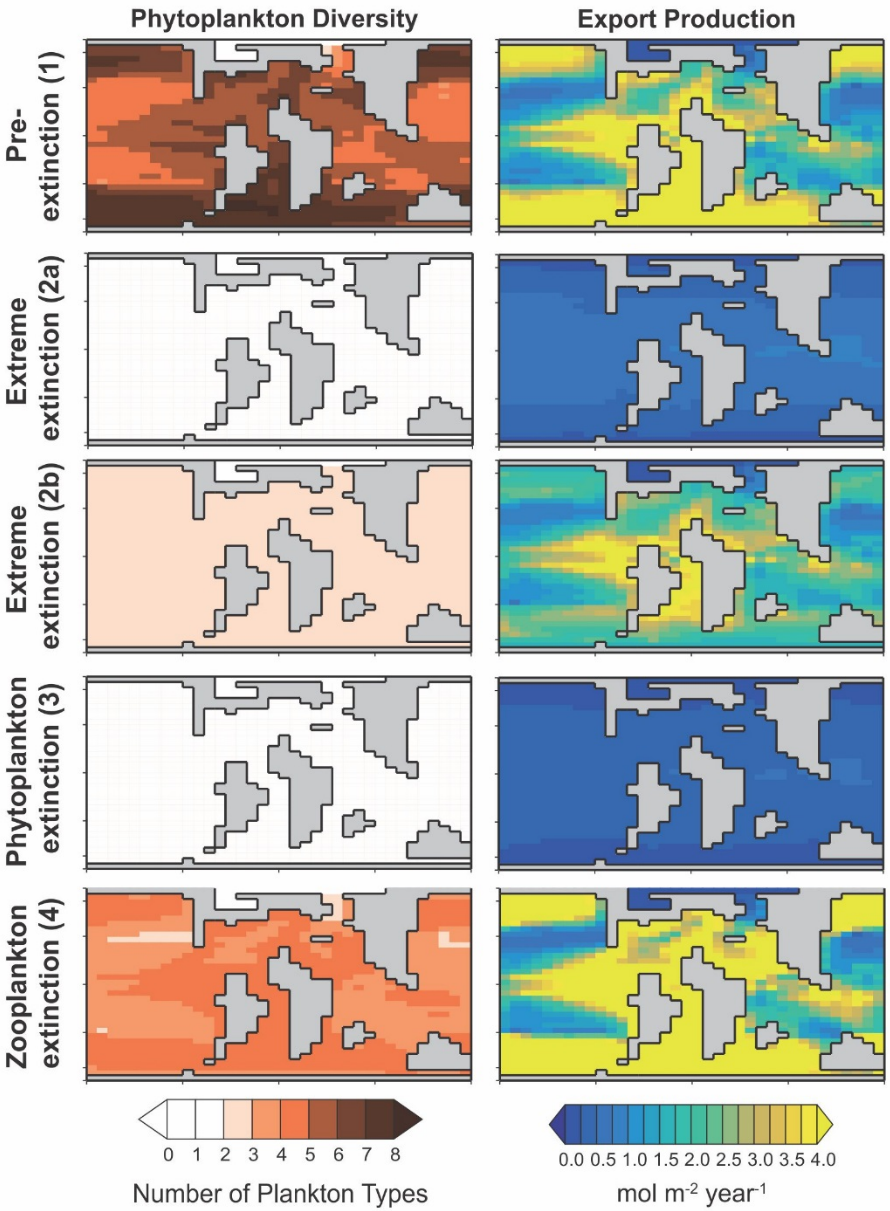
EcoGEnIE 1.0: plankton ecology in the cGEnIE Earth system model
Ward et al. [2018] (**GMD**)

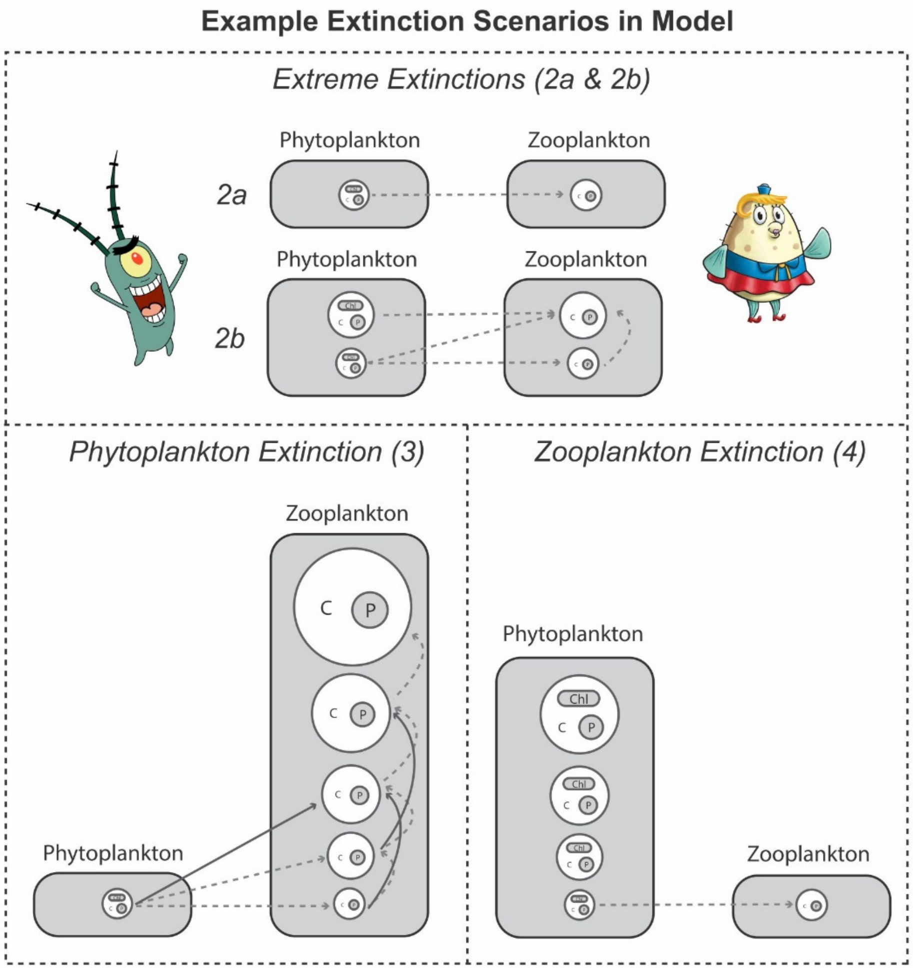


github.com/derpycode/cgenie.muffin

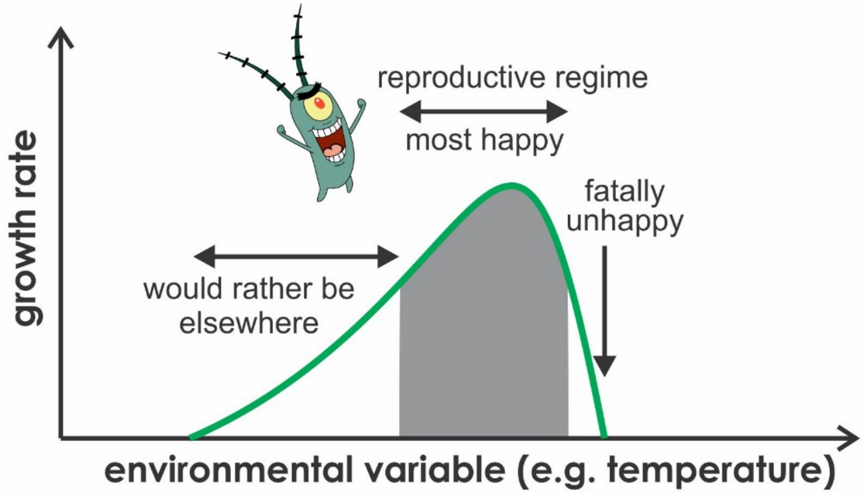
numerical recipes for a marine biosphere(?)

Wilson et al. [in prep.]
'The response of the oceans biological carbon pump to ecological disruption'



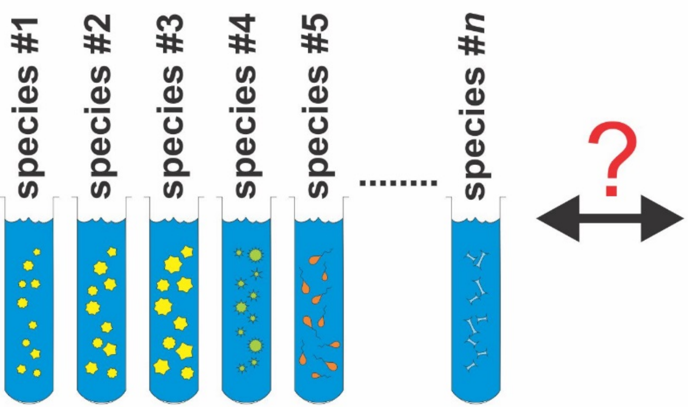


numerical recipes for a marine biosphere(?)

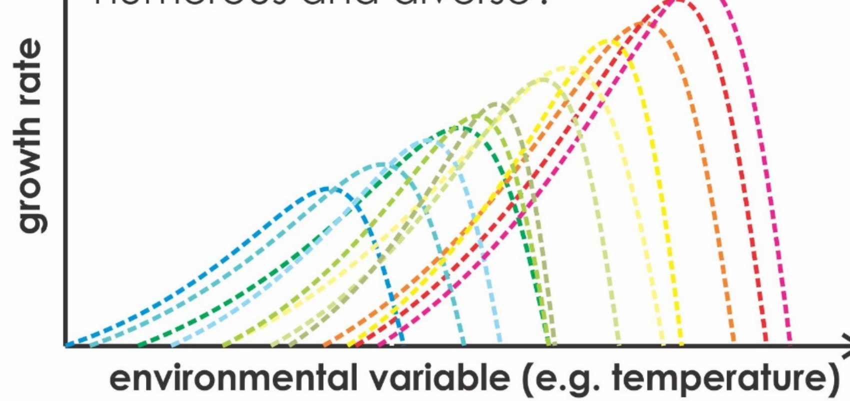


're-drawn' from *Schmidt et al.* [2006]
(with sincere apologies)

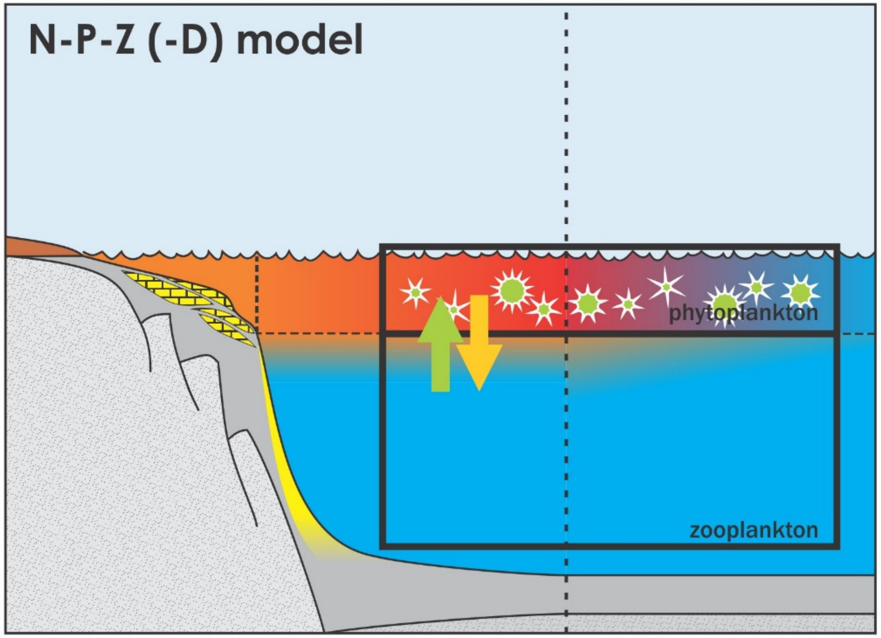
numerical recipes for a marine biosphere(?)



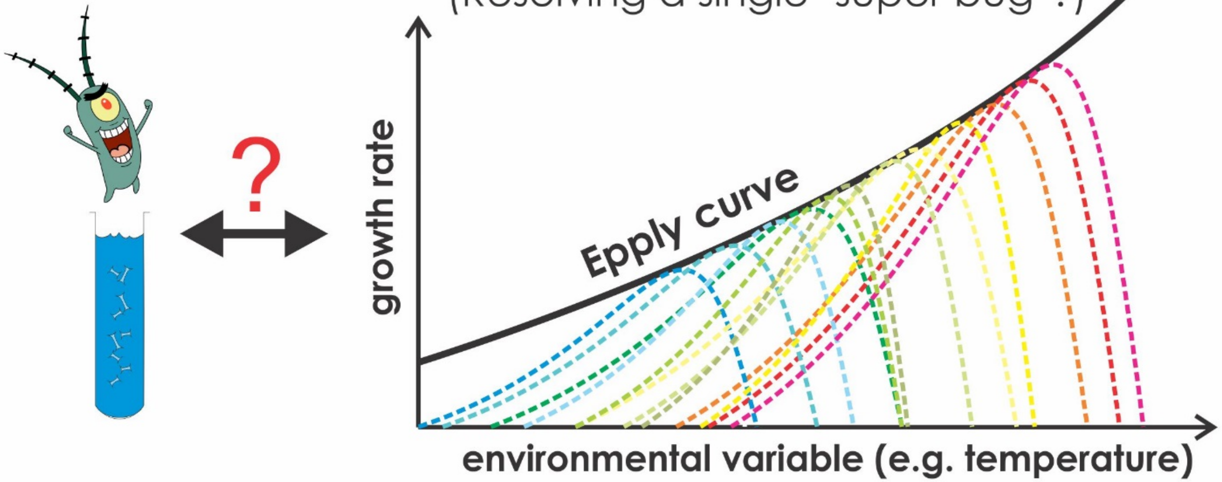
How can a model be constructed when the niches (e.g. temperature optima) occupied by plankton are so numerous and diverse?

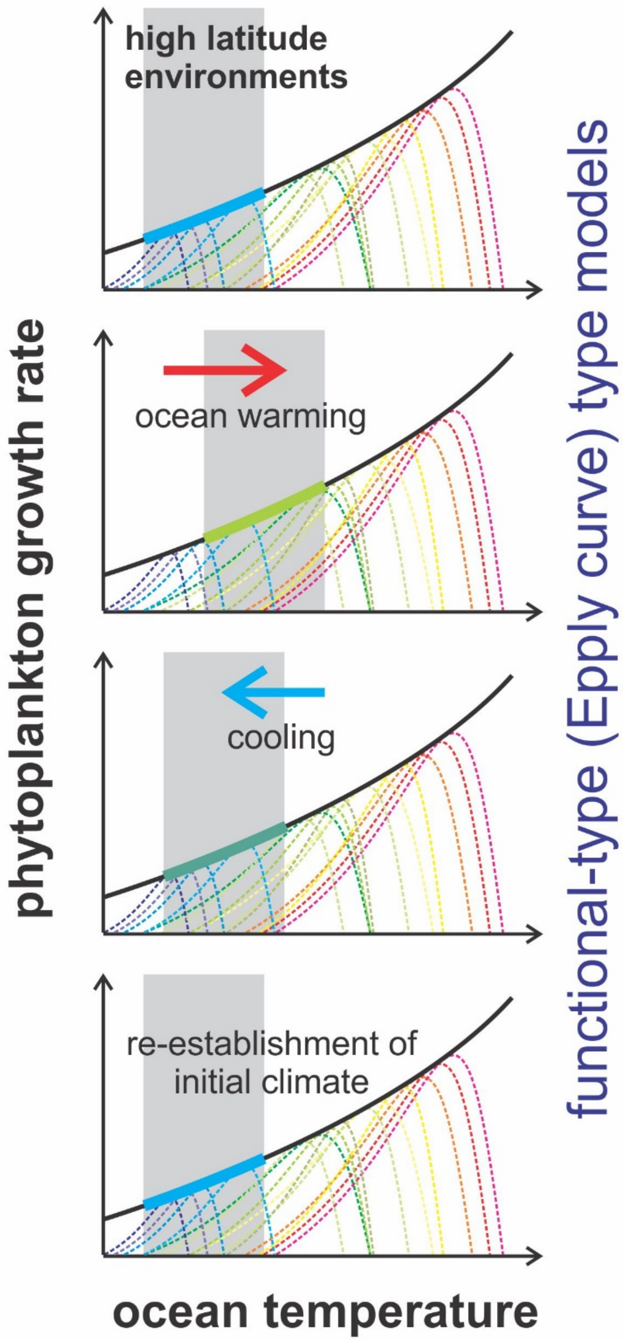


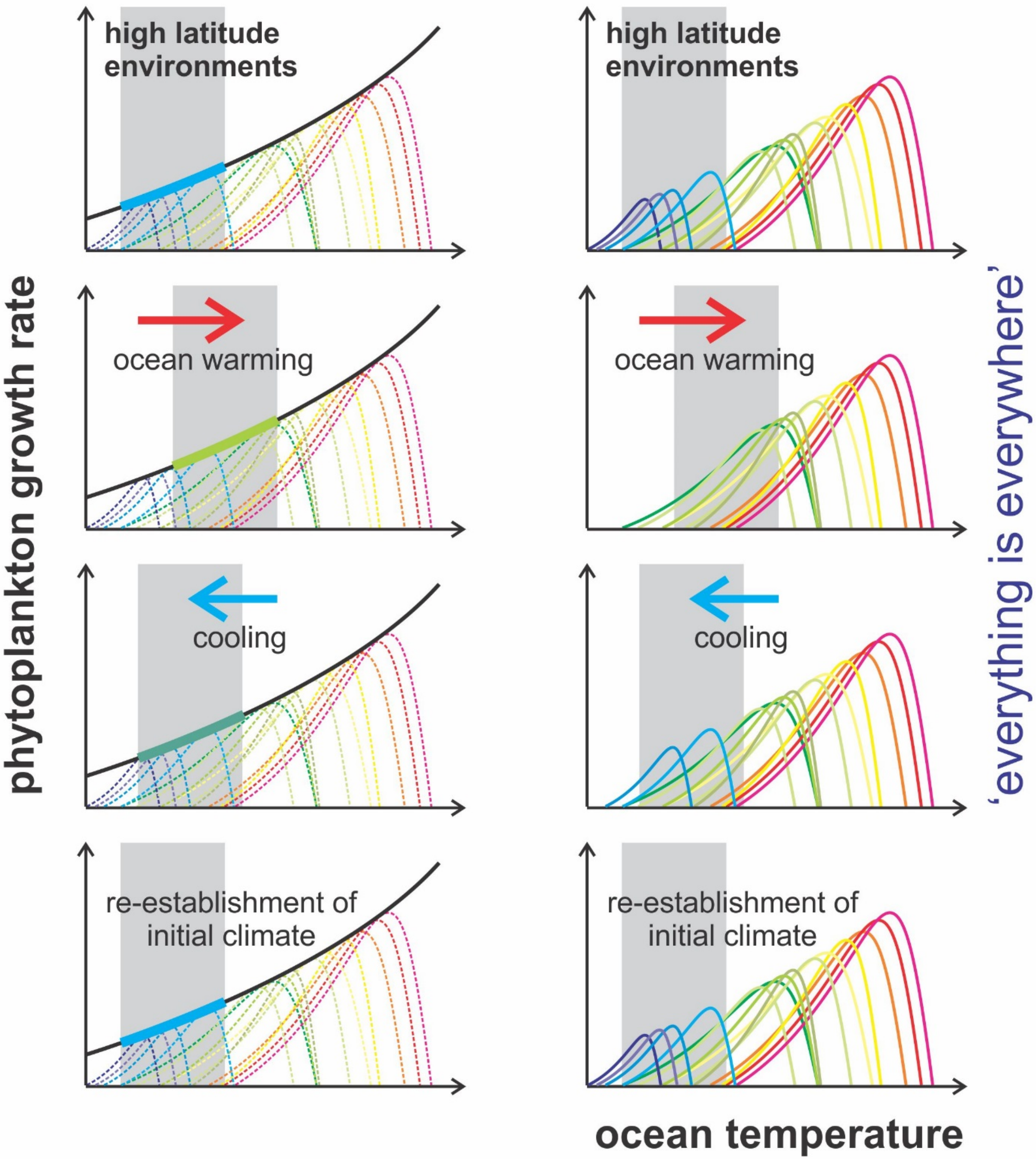
numerical recipes for a marine biosphere(?)



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'?)




high latitude environments
ocean warming
cooling
re-establishment of initial climate
phytoplankton growth rate
ocean temperature
functional-type (Epply curve) type models


phytoplankton growth rate
high latitude environments
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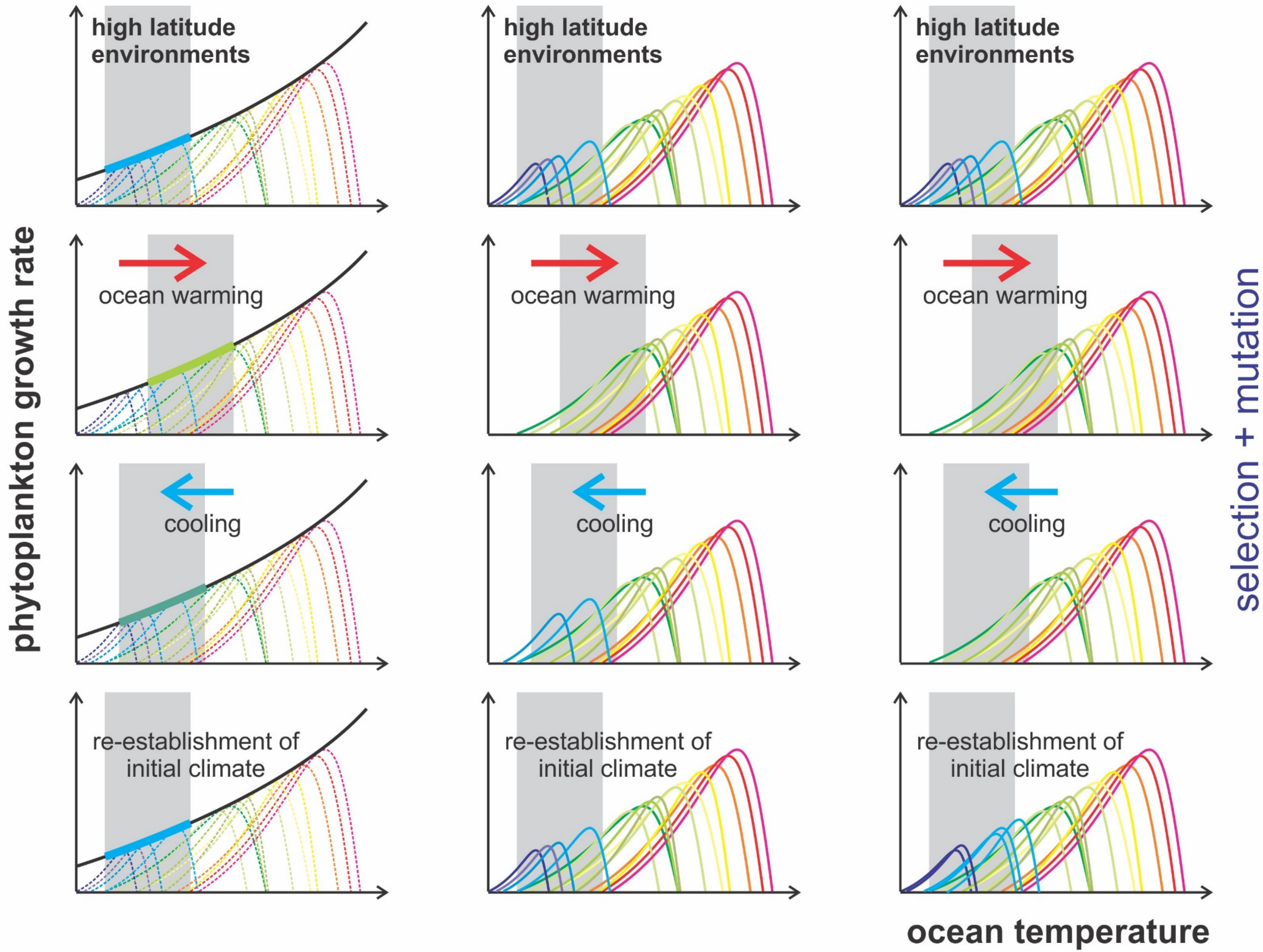
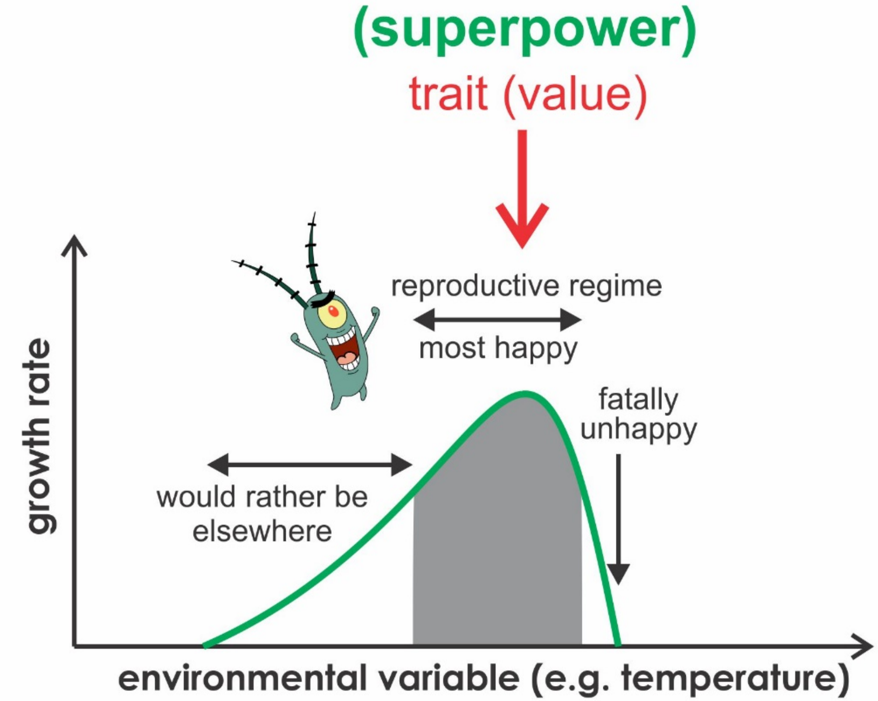
ocean warming
cooling
cooling
re-establishment of initial climate
re-establishment of initial climate
'everything is everywhere'
ocean temperature


phytoplankton growth rate
high latitude environments
high latitude environments
high latitude environments
ocean warming
ocean warming
ocean warming
cooling
cooling
cooling
re-establishment of initial climate
re-establishment of initial climate
re-establishment of initial climate
selection + mutation
ocean temperature

evolution *in silico* ... 'fitness landscapes'

For a plankton, trait values could include the temperature optima for growth, as well as a property describing the width or skew of the growth distribution.



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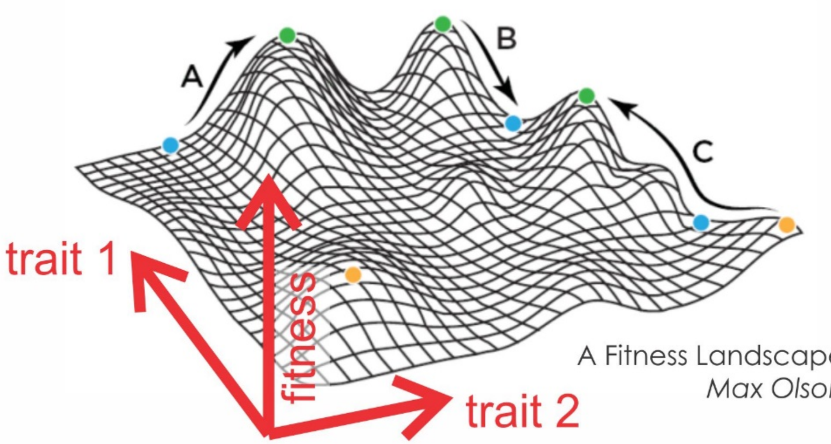


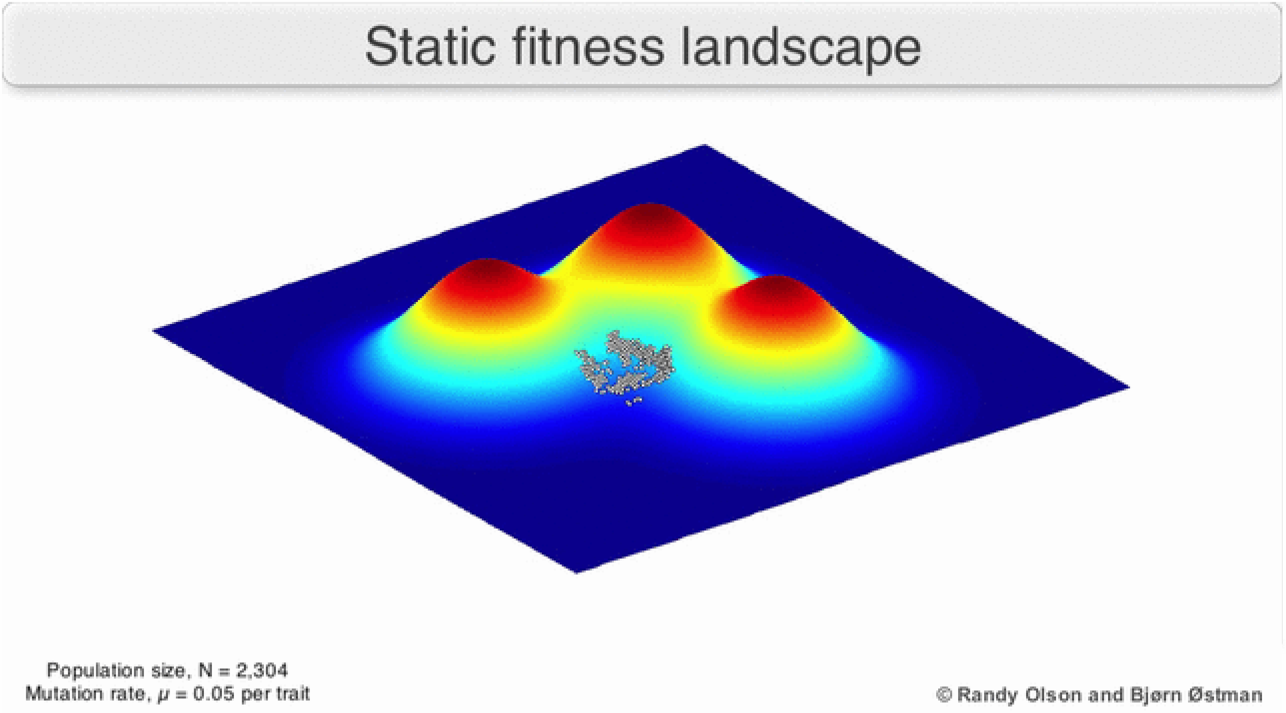
A Fitness Landscape
Max Olson

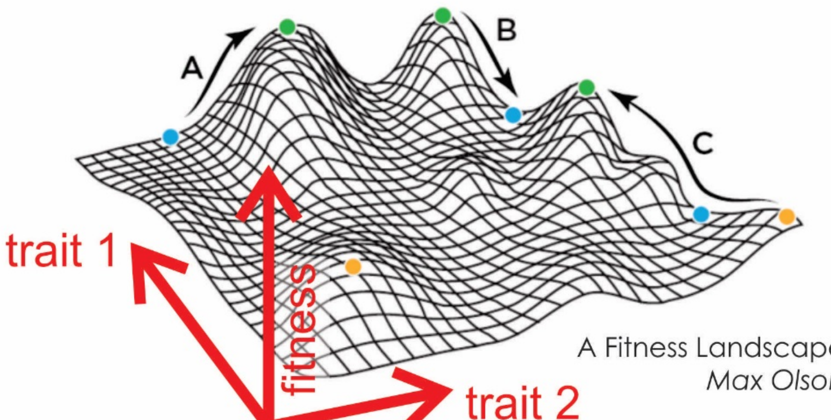
Fitness or adaptive landscapes (types of evolutionary landscapes) visualize the relationship between genotypes (the set of responsible for a particular trait) and reproductive success.

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 deplete soil (and hence be more competitive ... 'fit').

evolution *in silico* – WHY? – **fitness landscapes**

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





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evolution *in silico* – WHY? – **fitness landscapes**

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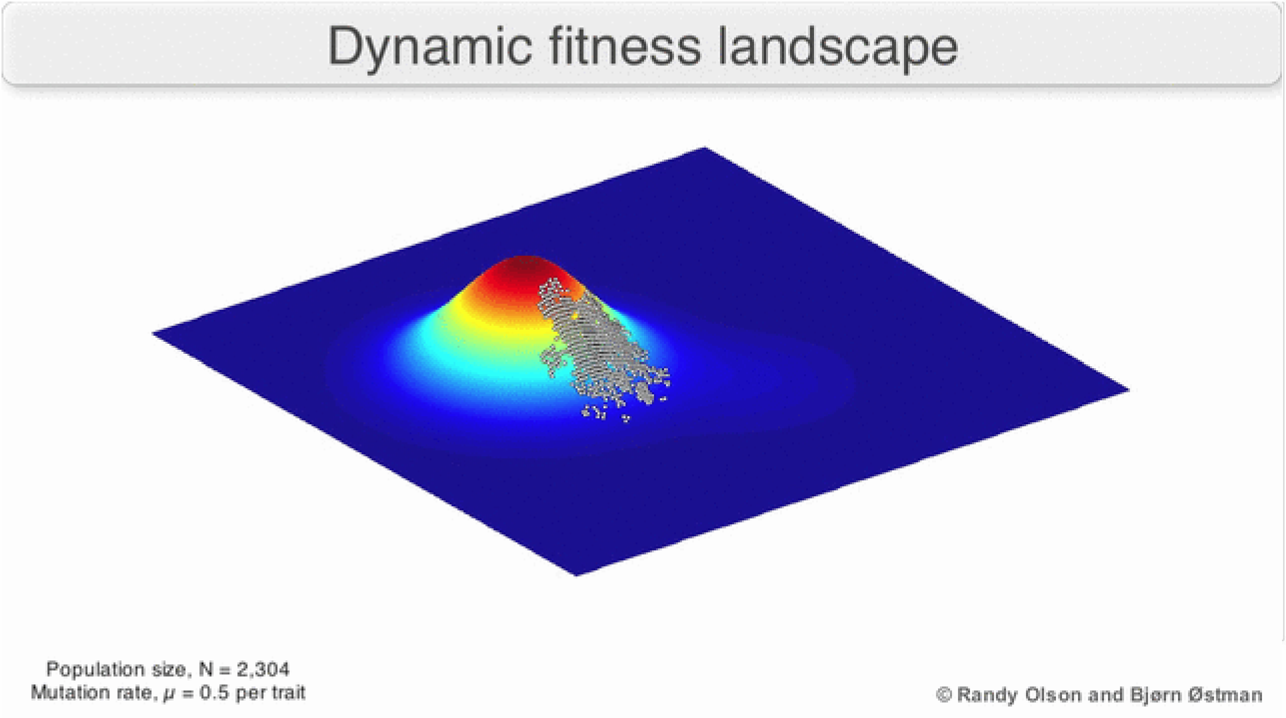
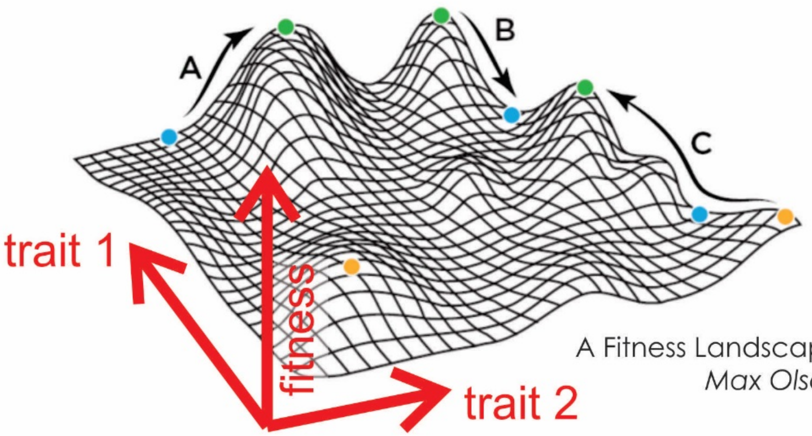




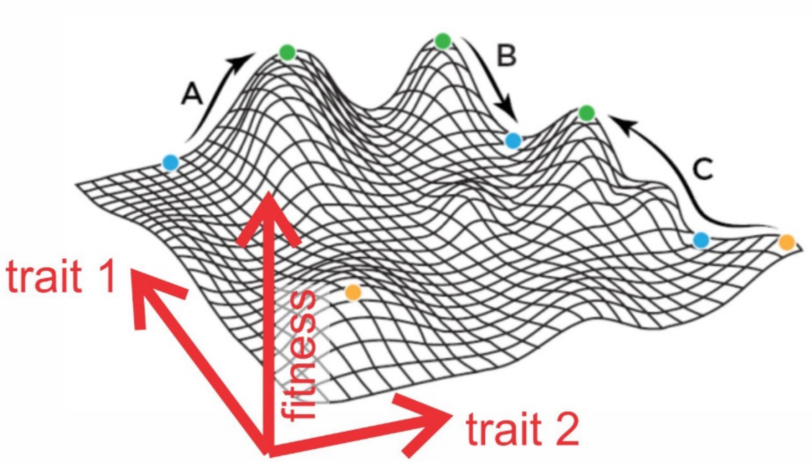
A Fitness Landscape
Max Olson

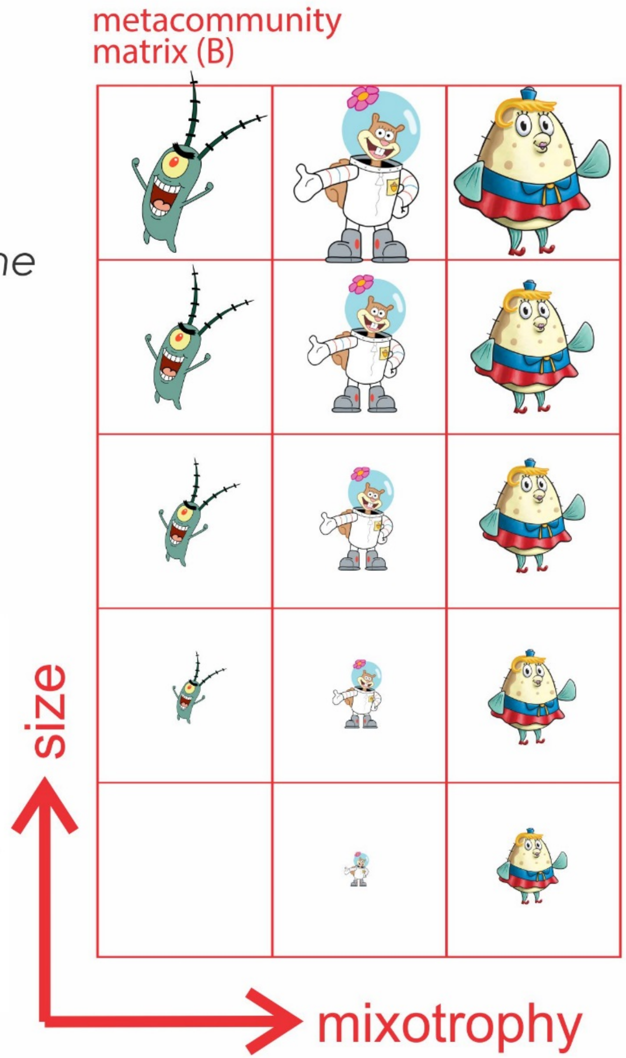
evolution *in silico* ... ‘fitness landscapes’

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

*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’.)*

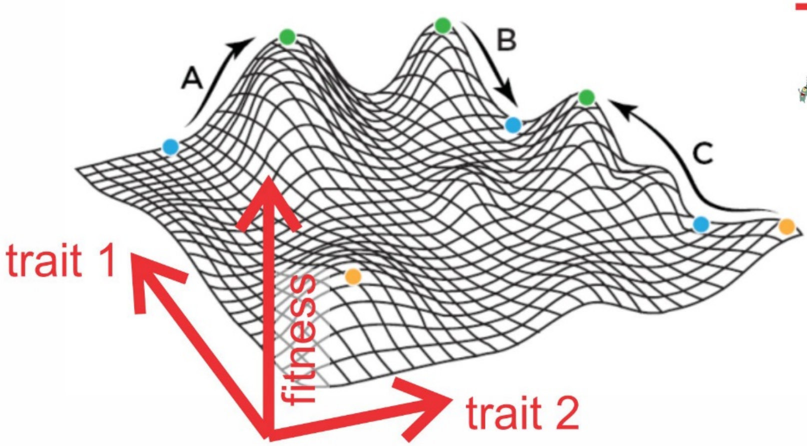
Biomass ‘diffuses’ from one ‘species’ (trait combination) to another.





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

numerical recipes for a marine biosphere(?)



numerical recipes for a marine biosphere(?)

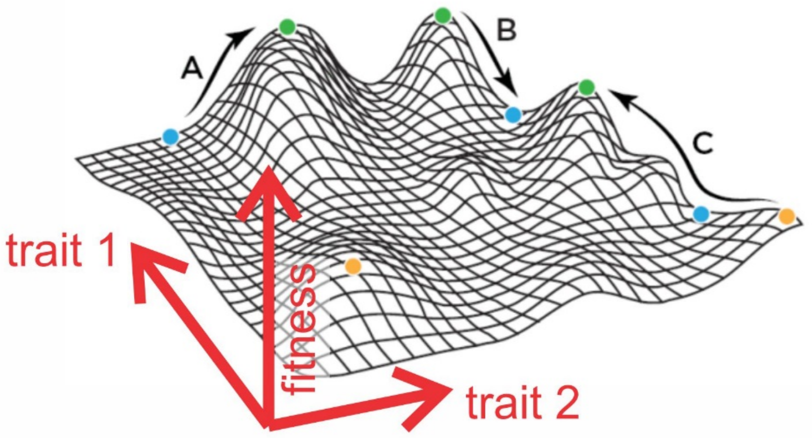
This simulation does not 'mean' anything *per se*. It is conducted with a modern continental configuration and under modern ocean circulation (and a modern PO_4 inventory) but is not intended to correspond to any specific event or observation (yet), whether paleo, modern, or future. It is a best viewed 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?)



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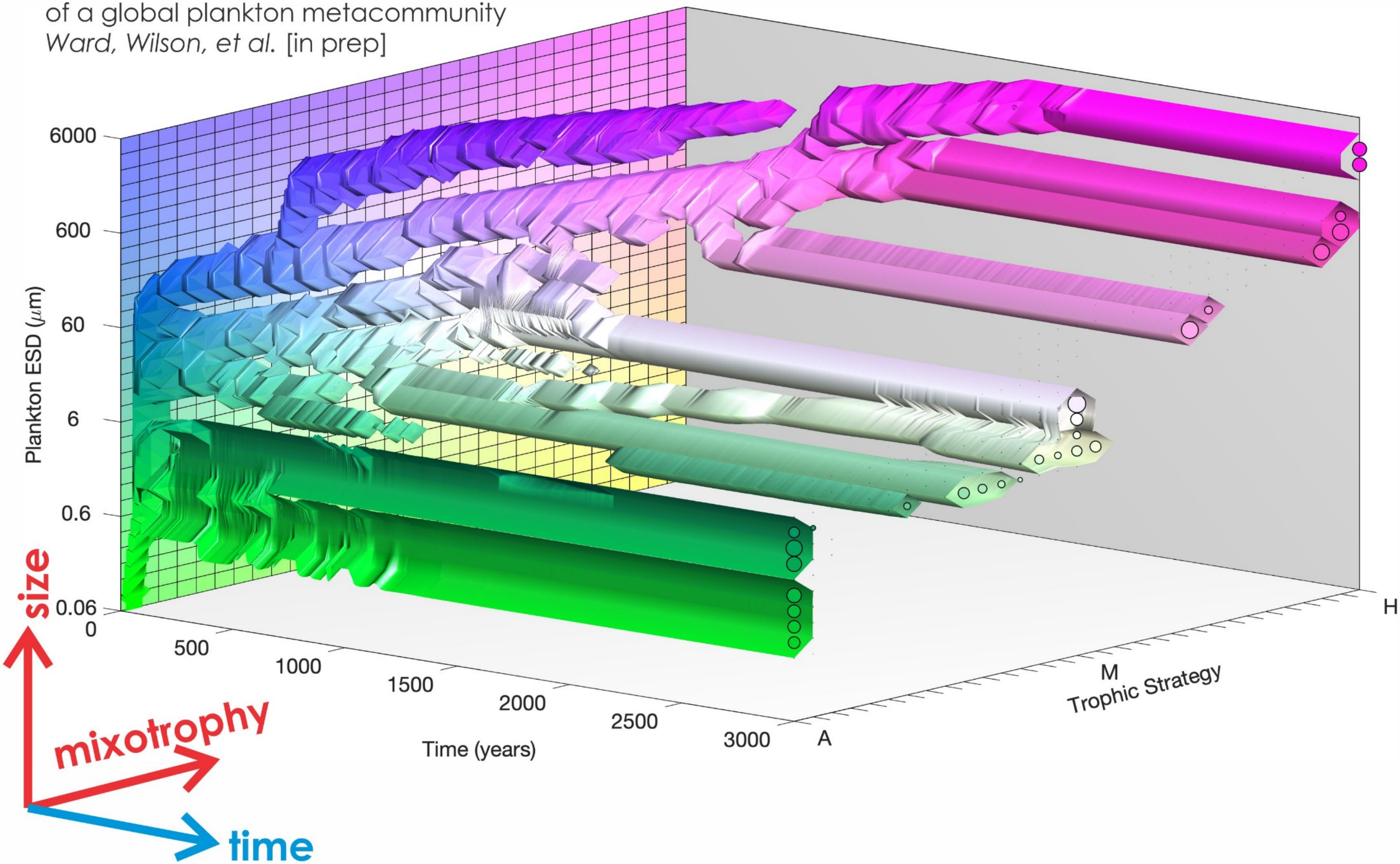

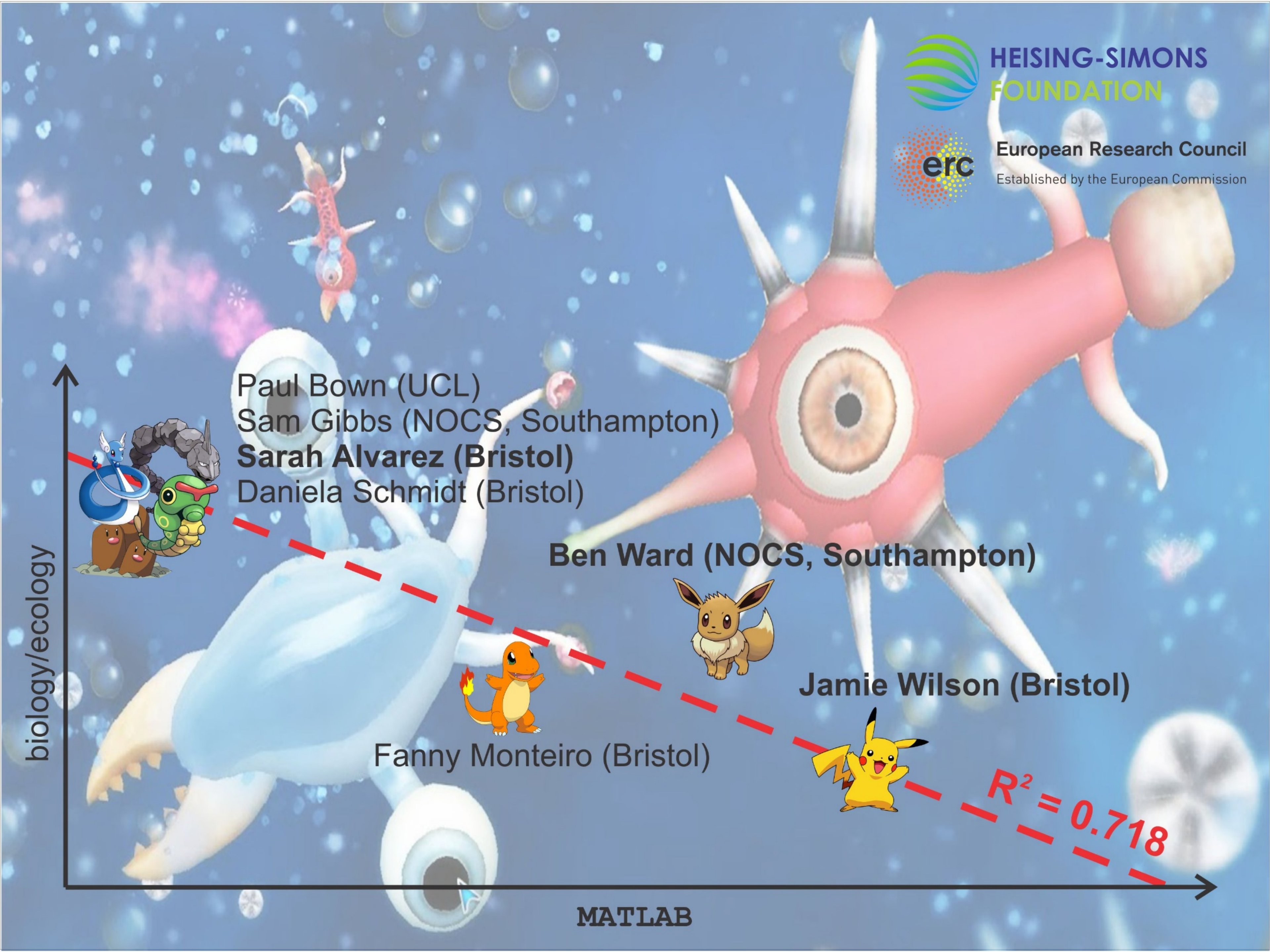
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Fanny Monteiro (Bristol)
$R^2 = 0.718$
biology/ecology
MATLAB