The role of movement in determining the global distribution of marine biomass

James Watson (Princeton: jrwatson@princeton.edu)
Charlie Stock, Jorge Sarmiento

Atmospheric and Oceanic Sciences Program
Dept. Ecology and Evolutionary Biology
Geophysical Fluid Dynamics Laboratory (NOAA)

A. Global Fisheries Production

- How much biomass does the ocean produce?

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Photosynthesis and Fish Production in the Sea

The production of organic matter and its conversion to higher forms of life vary throughout the world ocean.

John H. Ryther

Science, 1969; Pauly & Christensen 1995, Chassot et al. 2010

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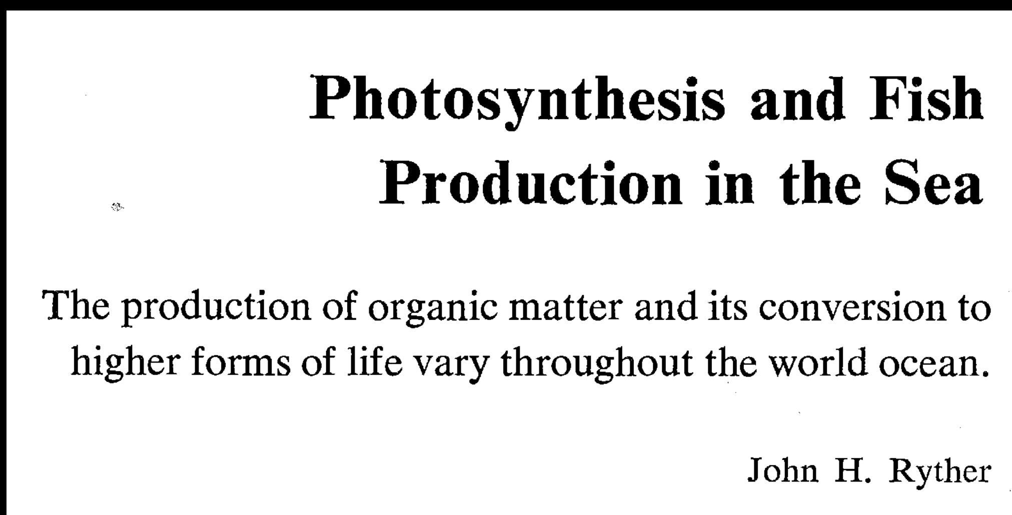

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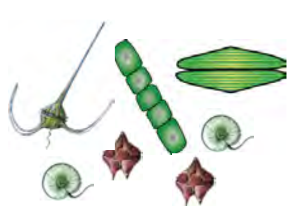

Phytoplankton

Trophic transfer efficiency

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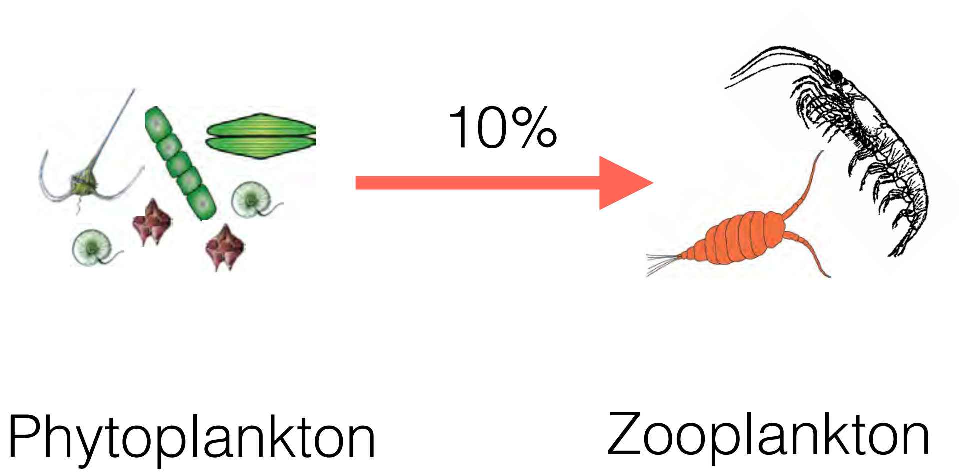

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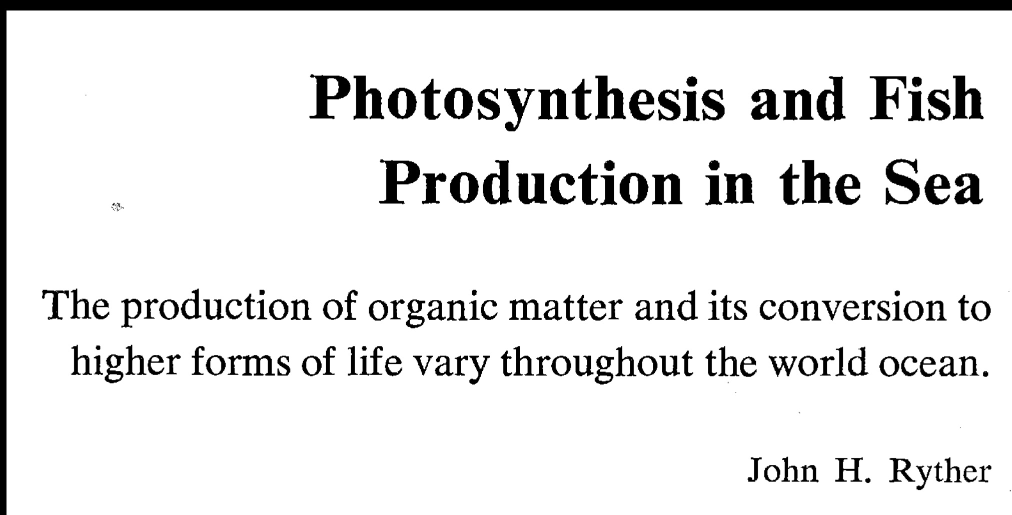

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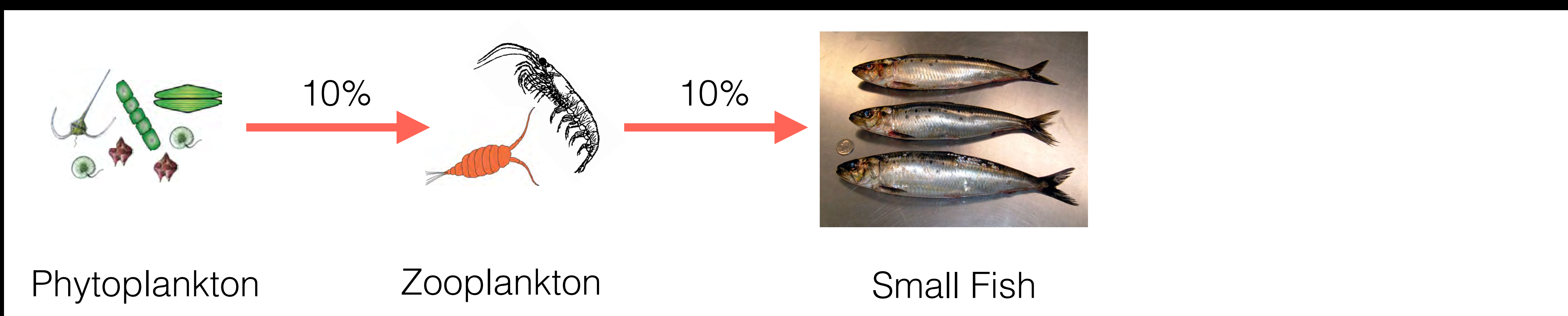

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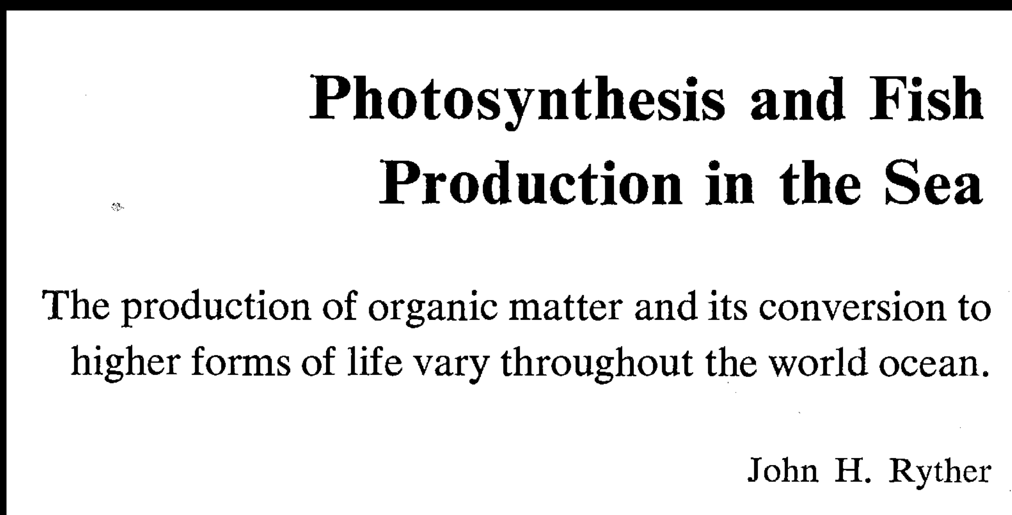

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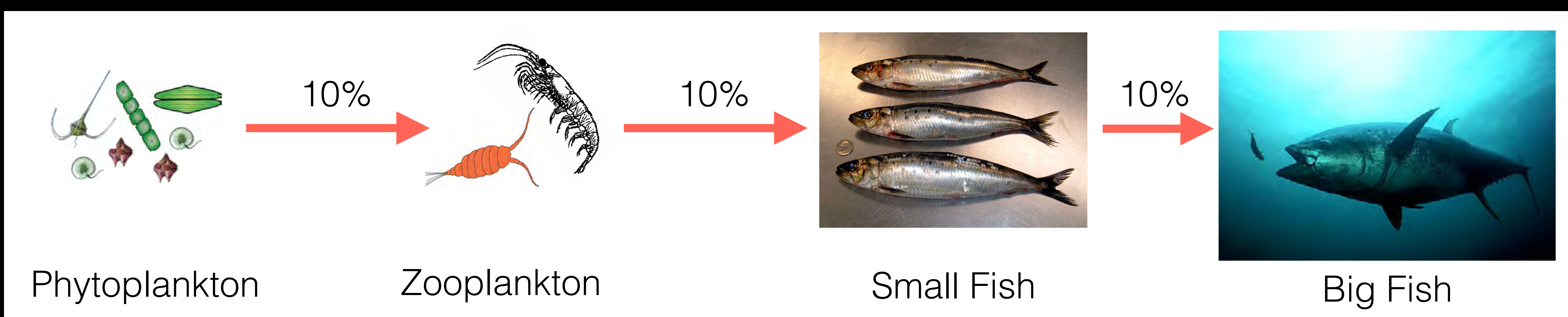

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Table 3. Estimated fish production in the three ocean provinces defined in Table 2.

Province	Primary production [tons (organic carbon)]	Trophic levels	Efficiency (%)	Fish production [tons (fresh wt.)]
Oceanic	16.3×10^9	5	10	16×10^5
Coastal	3.6×10^9	3	15	12×10^7
Upwelling	0.1×10^9	1½	20	12×10^7
Total				24×10^7

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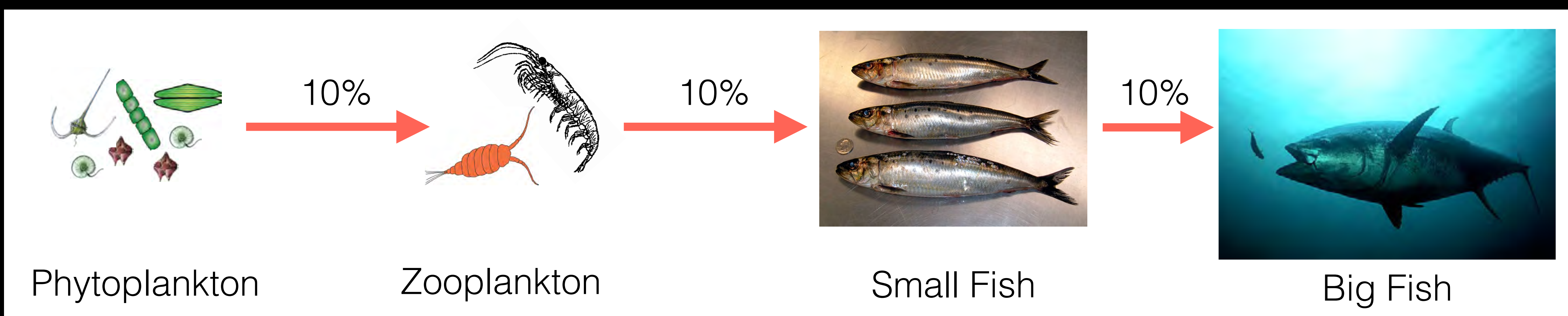

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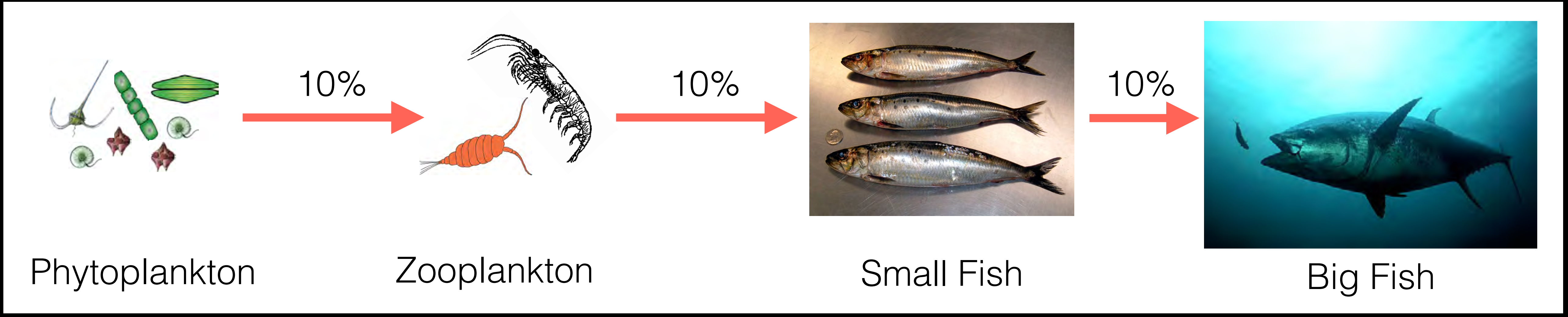

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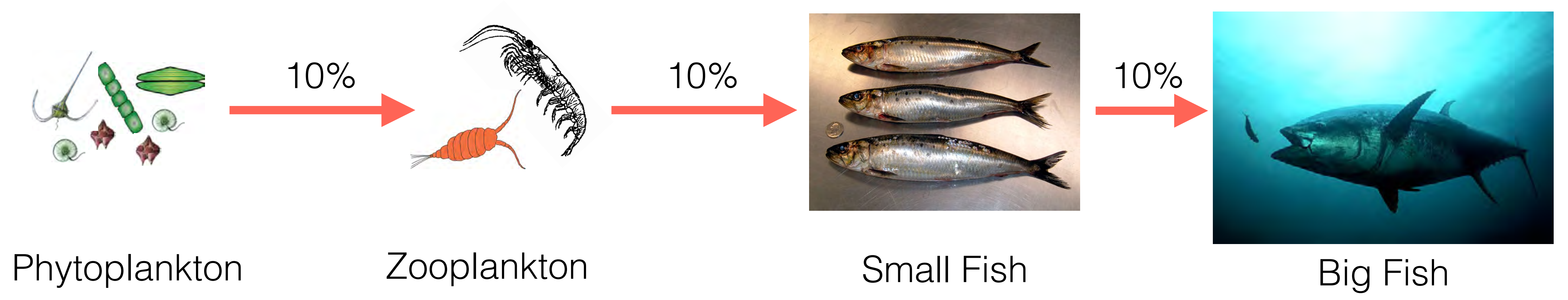
Maximum fisheries production: 240 MT year^{-1}



Trophic transfer efficiency

Global Ecosystem Modeling

- Can we do better than the trophic transfer efficiency (nonlinear relationships, spatial resolution)?

Charles A Stock, John P Dunne, and Jasmin G John. Progress In Oceanography, In press

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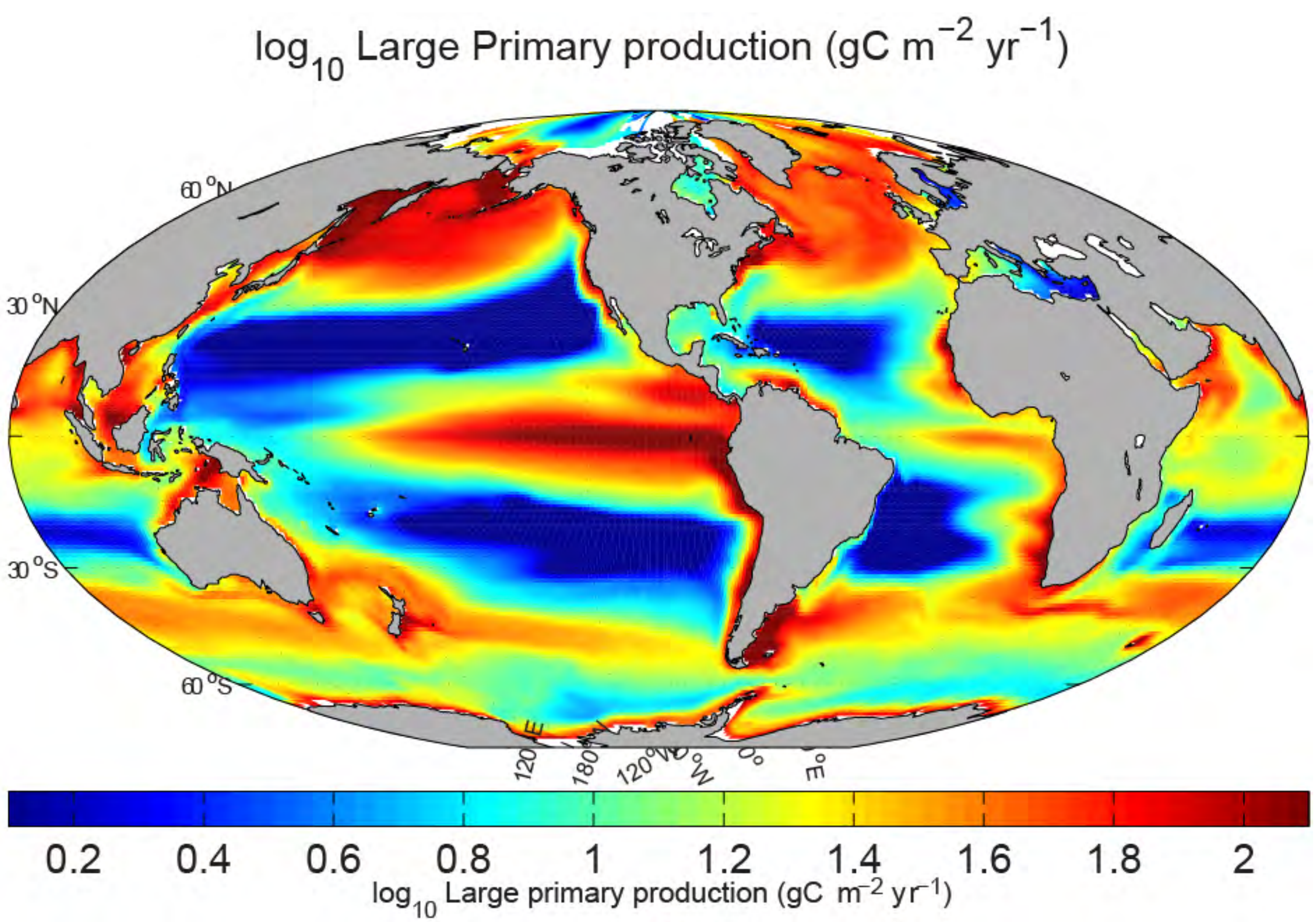
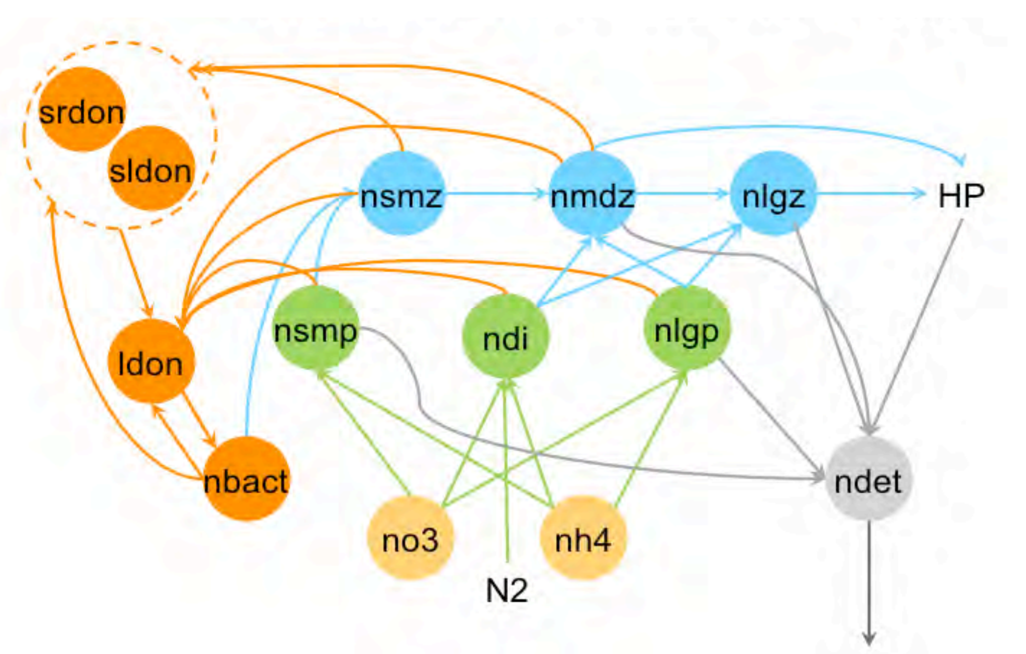


COBALT

Carbon, Ocean Biogeochemistry
and Lower Trophics

Charles Stock, John Dunne, Jasmin John; GFDL



Figs: Charles Stock: COBALT

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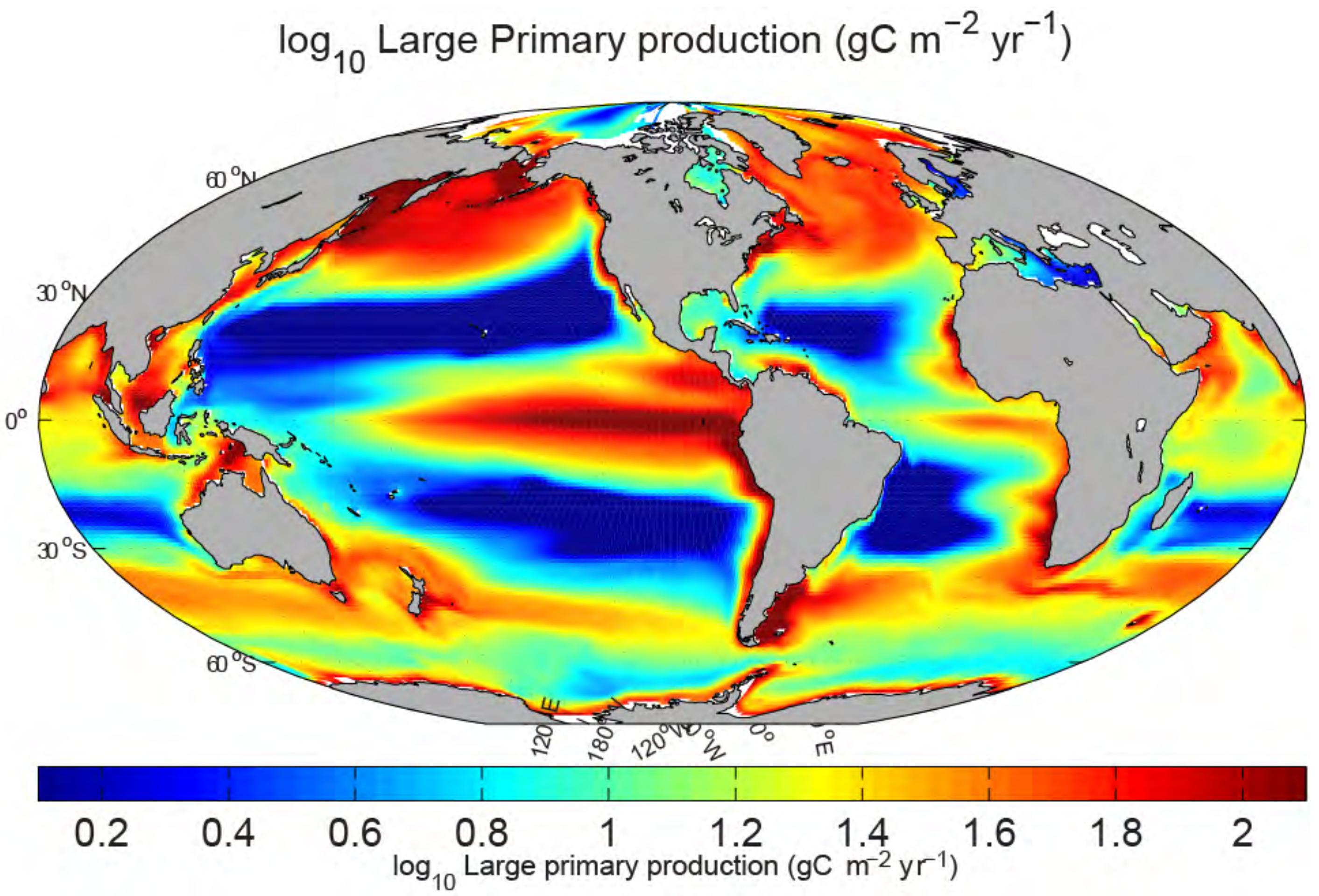

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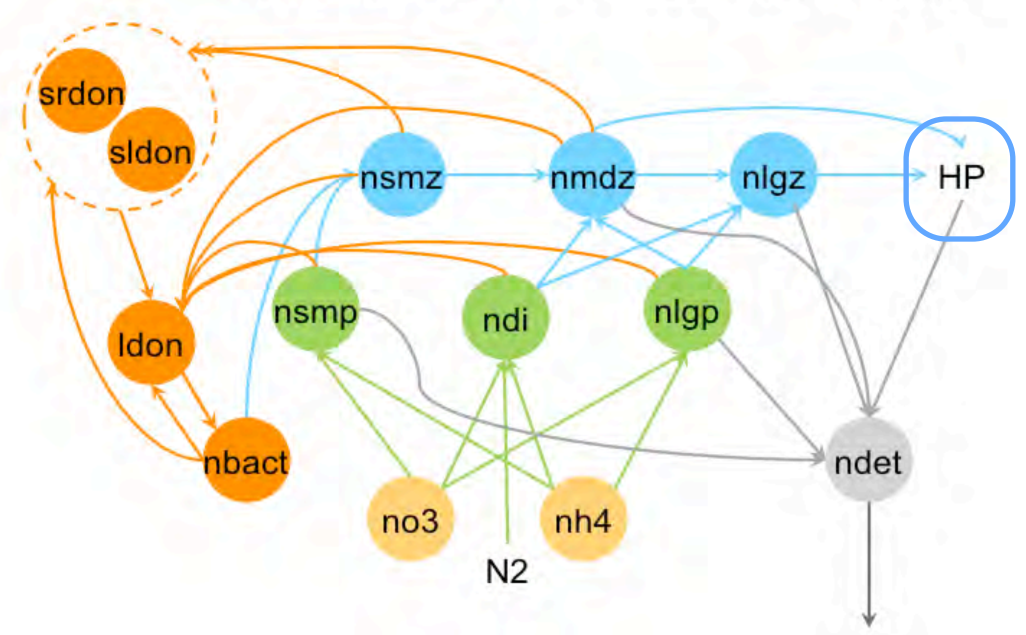


Mortality to higher predators

Charles A Stock, John P Dunne, and Jasmin G John. Progress In Oceanography, In press

The challenge...

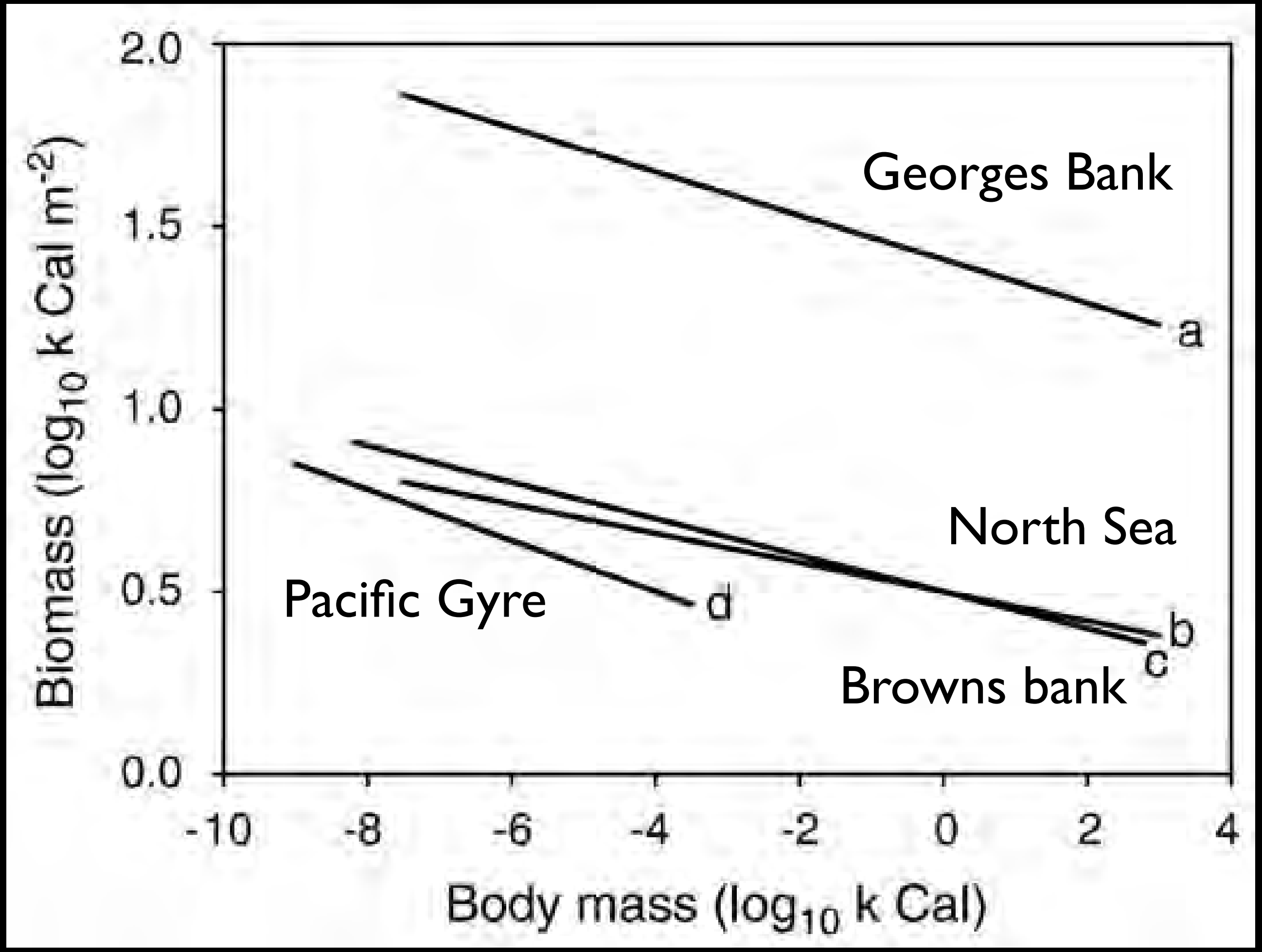
Quantify upper-trophic, or fisheries, production at a global scale...

Like plankton, big things are highly diverse

Unlike plankton, big things move against currents

Size-based Models

A conserved feature of marine systems around the globe:

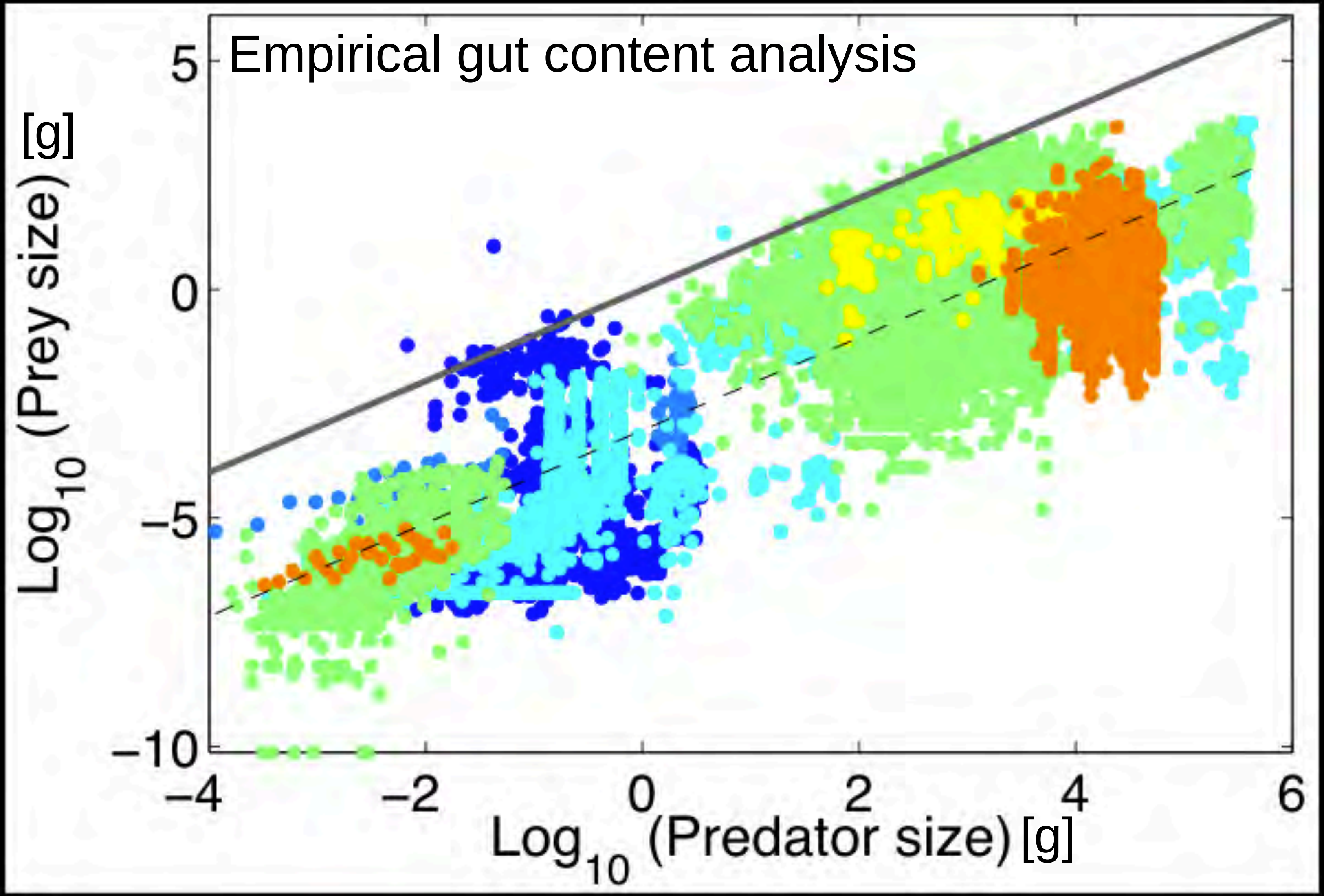


Jennings & Brander 2010,
originally from Boudreau & Dickie 1992

Big, medium, small... size simplifies

Many things scale with size

- e.g. swimming speed, metabolic rates and predator-prey relationships
- Metabolic Theory of Ecology (Jim Brown @ U. New Mexico)



Barnes et al. 2009

A Size-based Model: formulation

Model the rate of change of biomass of a particular size-class:

$$\frac{dB_i}{dt} =$$

i = medium fish

Images not to scale

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Type II feeding function (PPMR, volume searched)

Allometric power law ... as_i^b

Gradient ascent $J = f(dB_j/dx)$

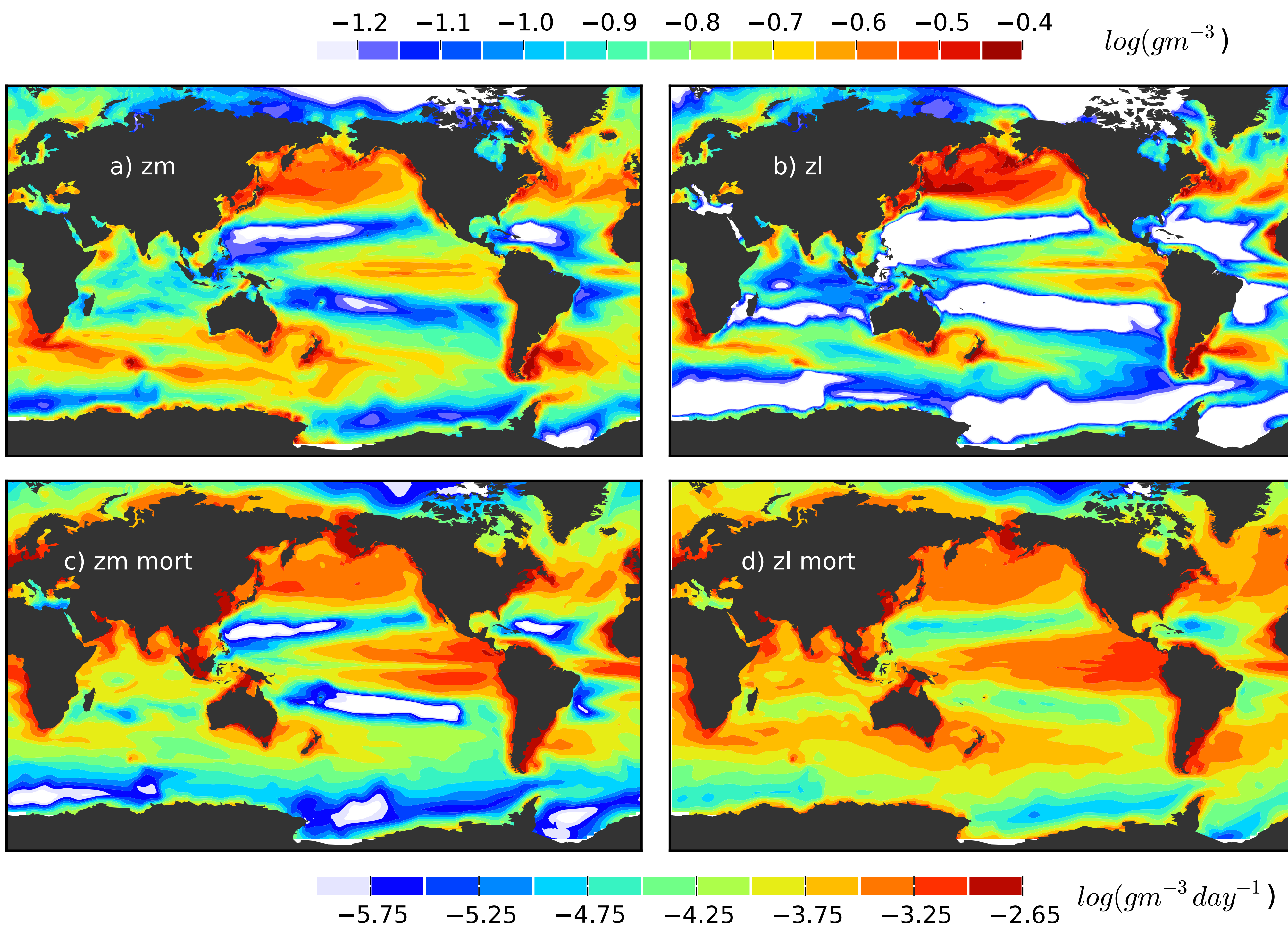
j = small fish

i = medium fish

k = large fish

Images not to scale

A Size-based Model: results



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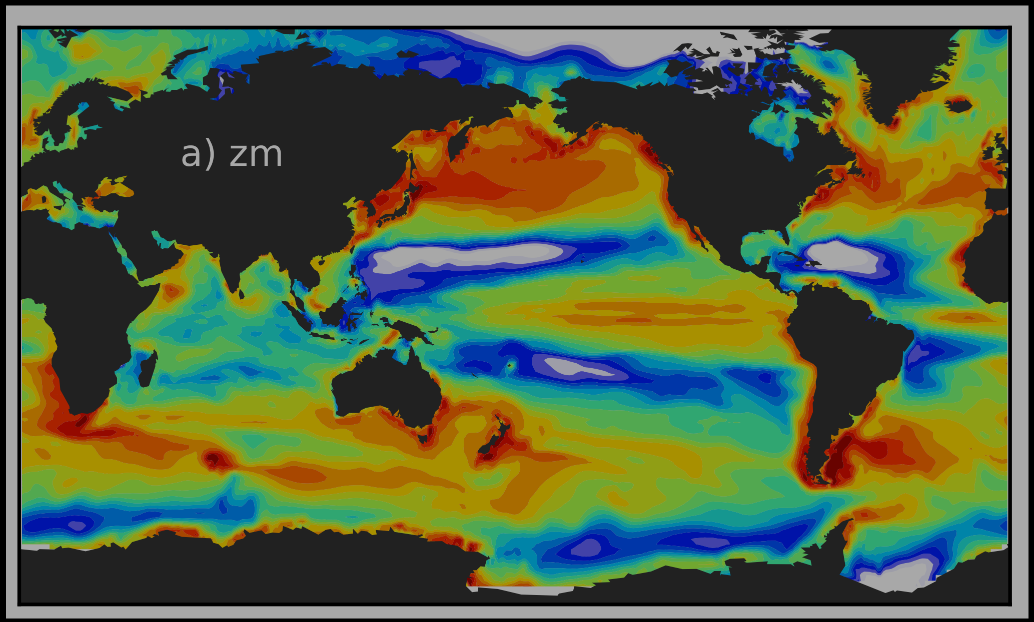

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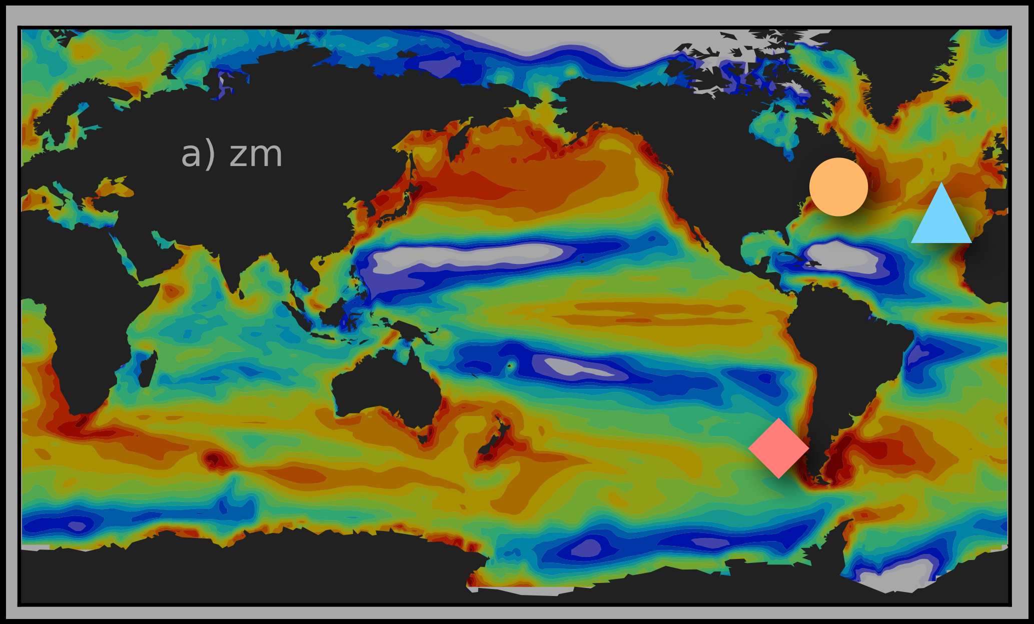

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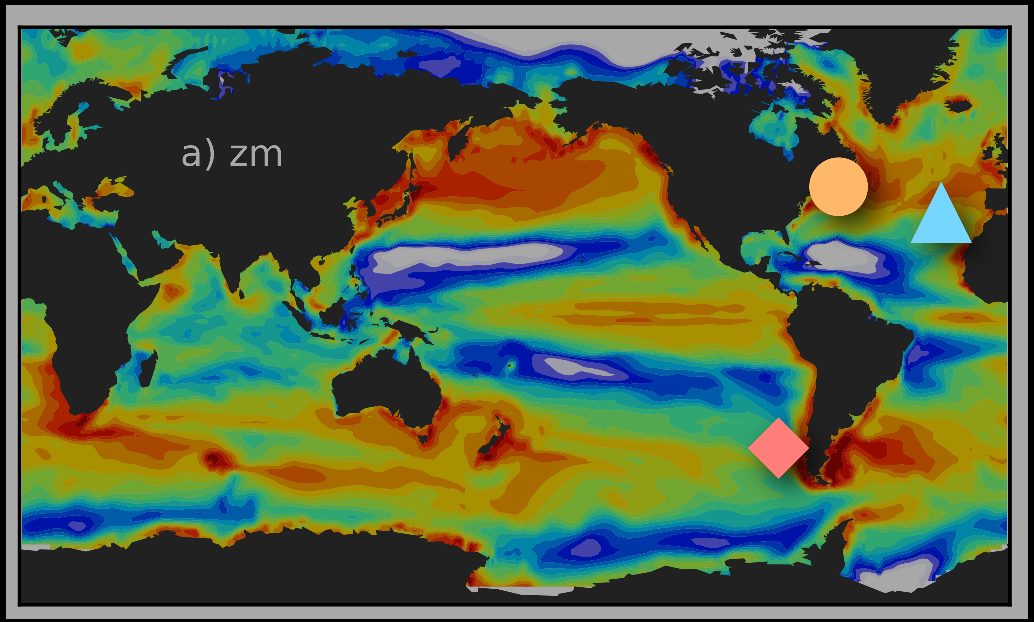

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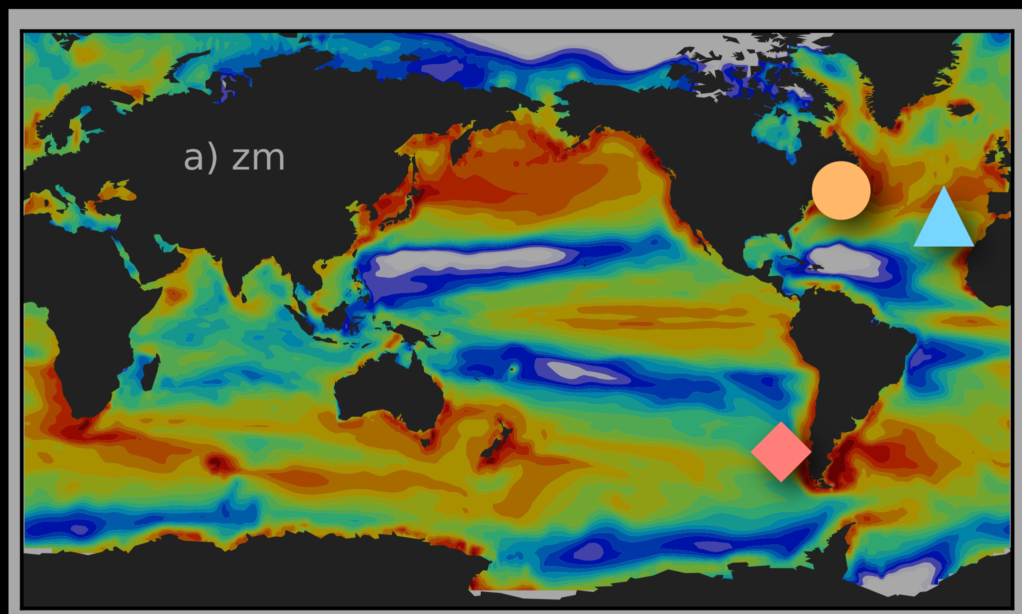

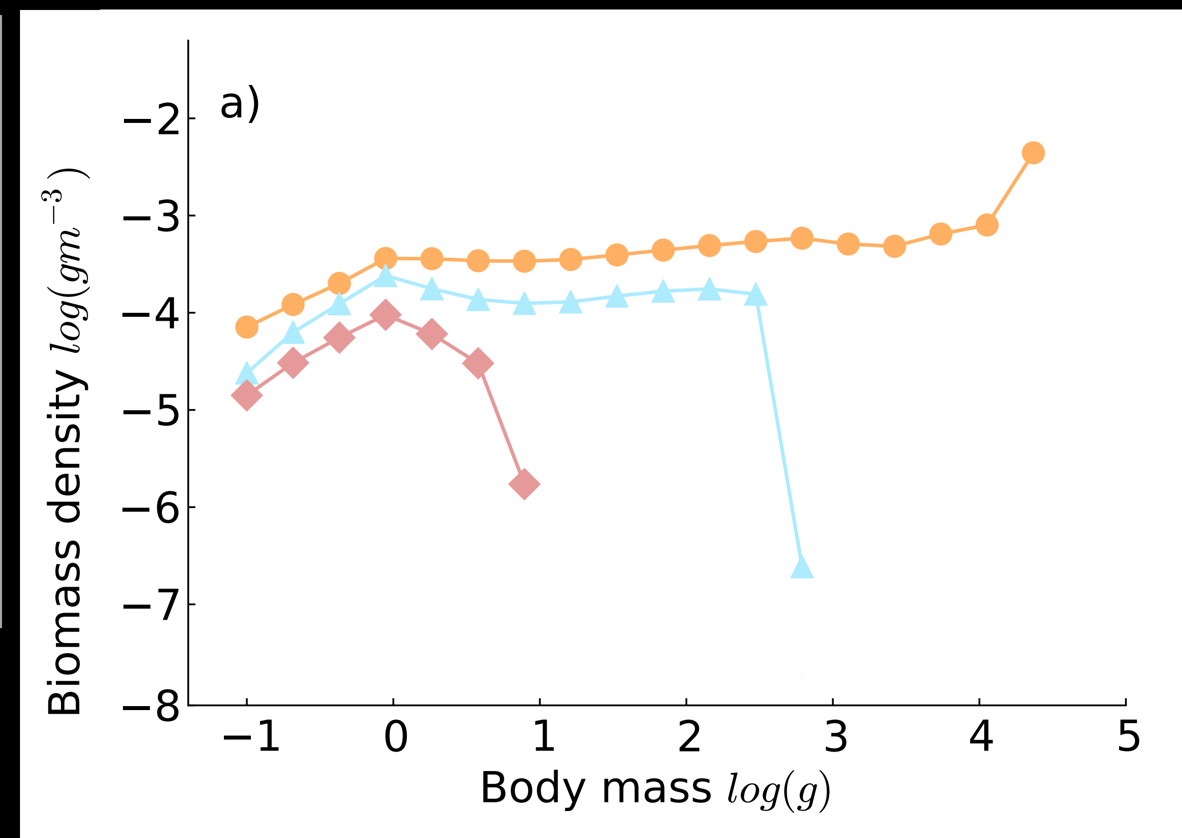

Size-based model estimates biomass size spectra...

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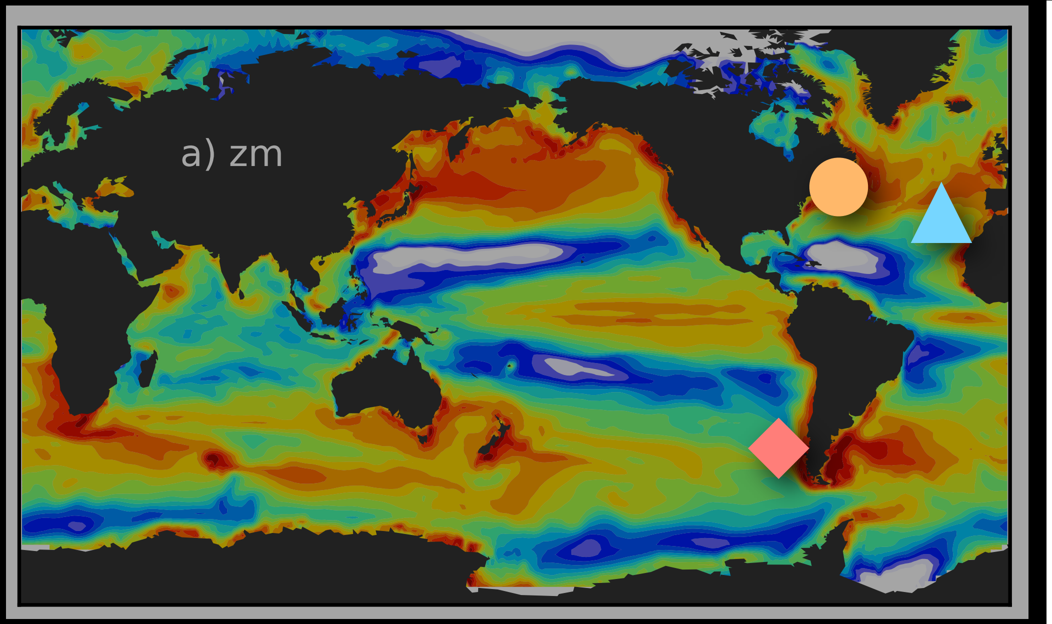

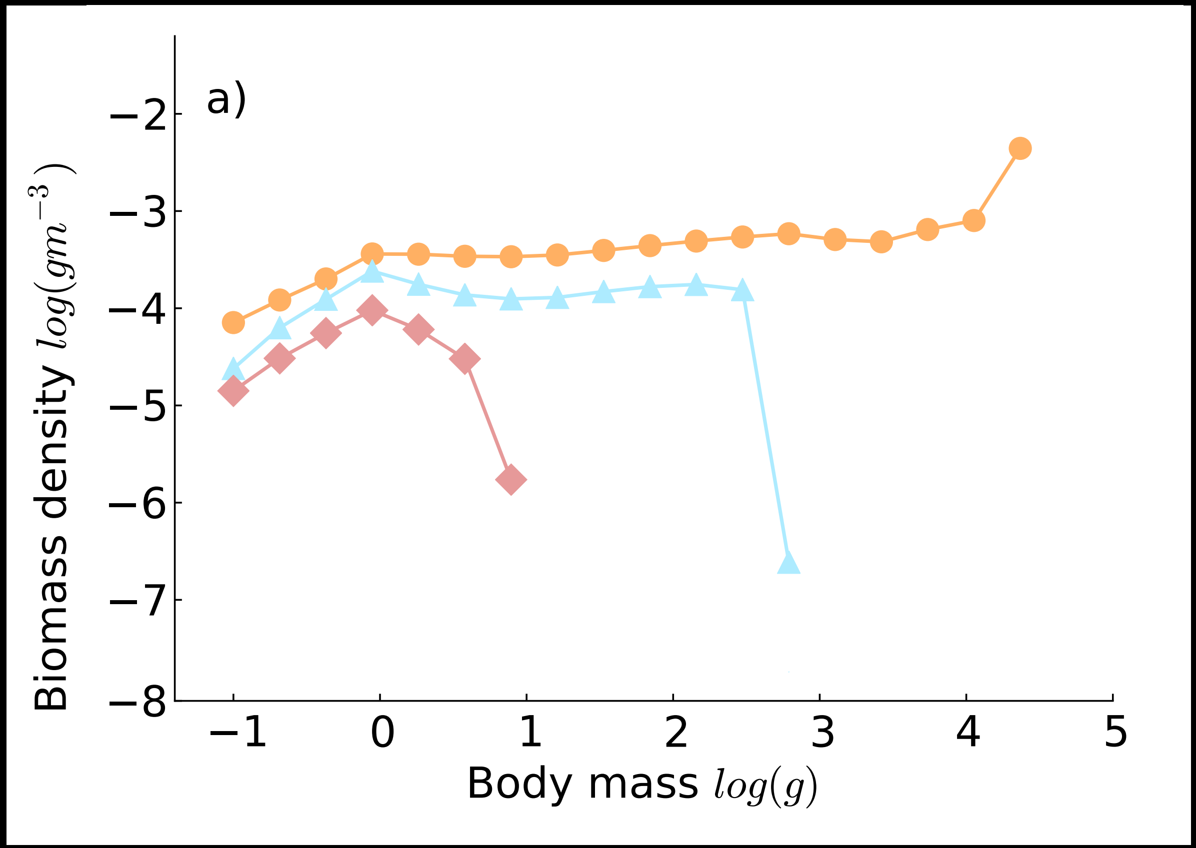

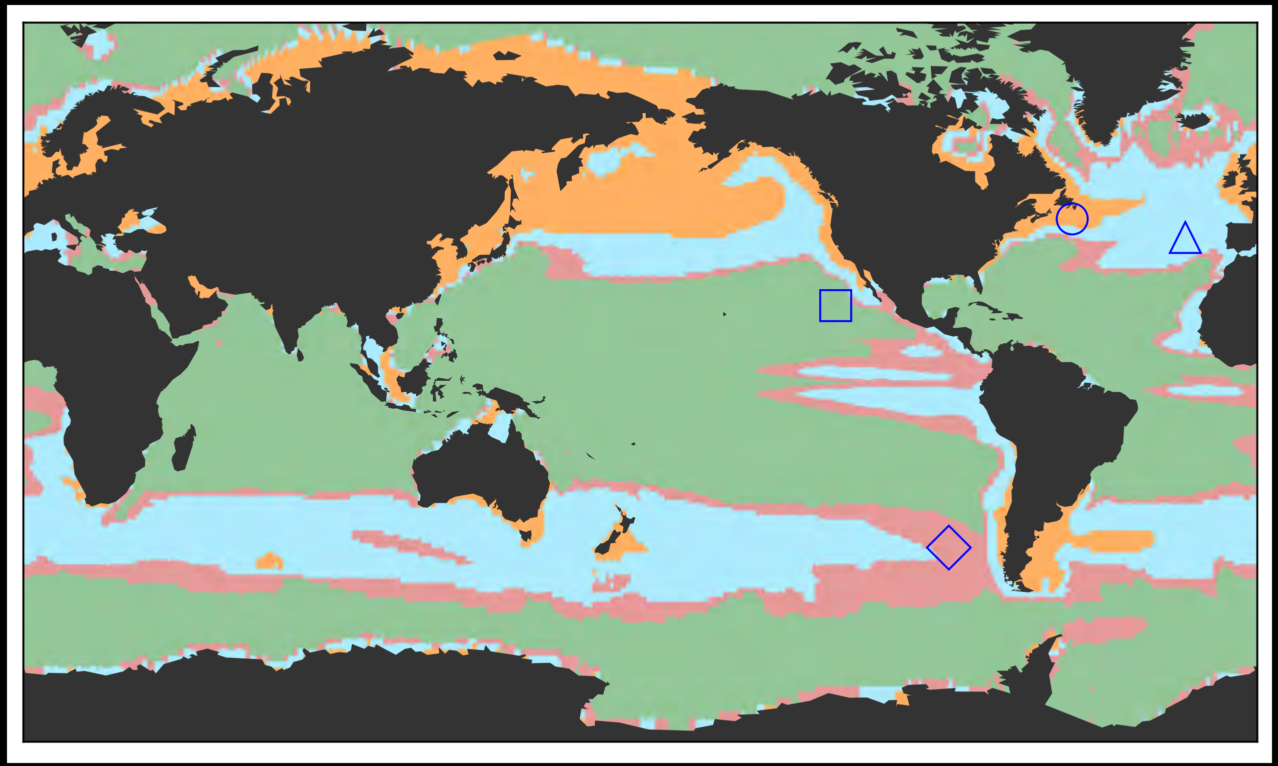

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Forage fish 

~100g

>1kg

 Top predator

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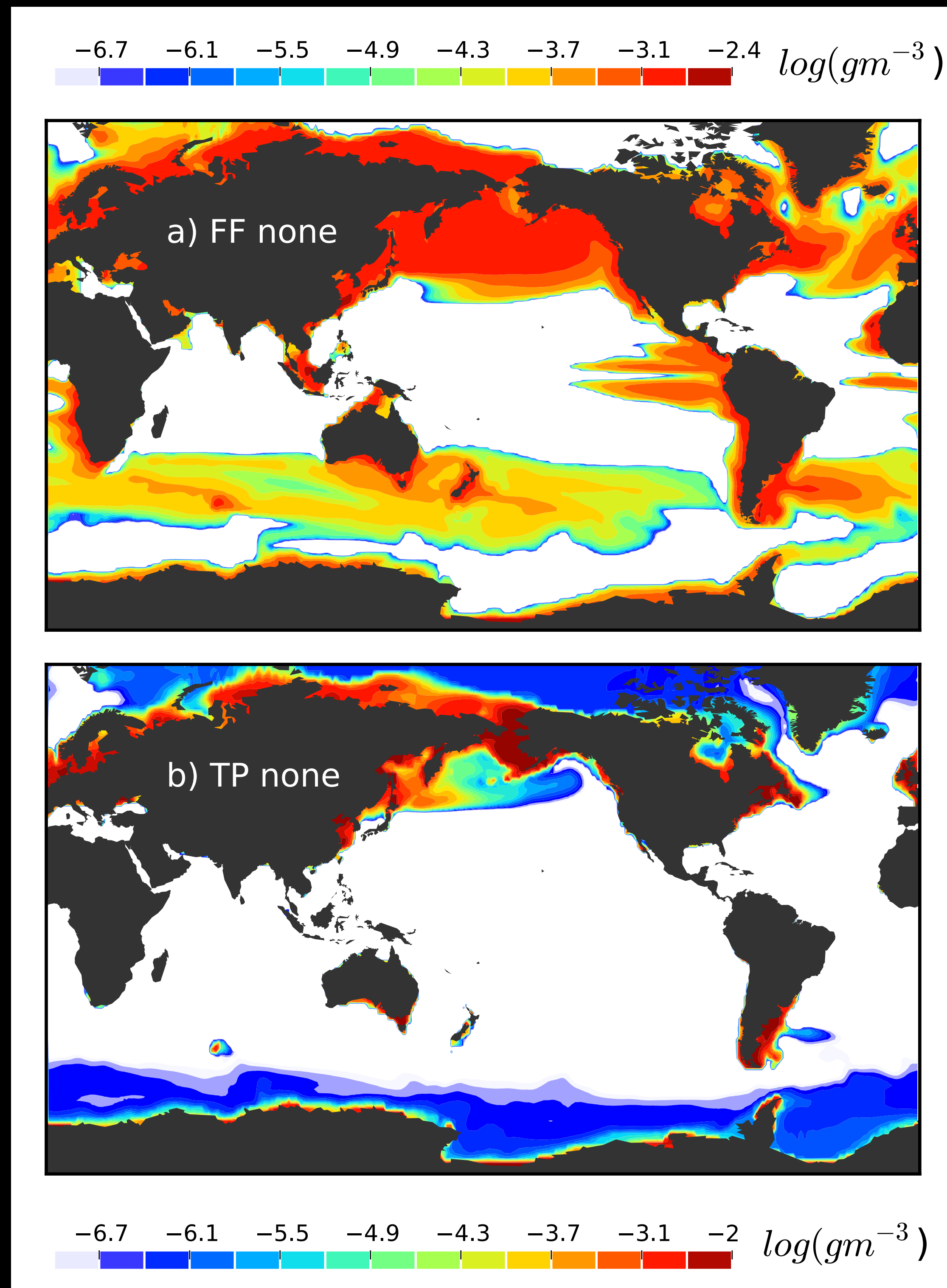

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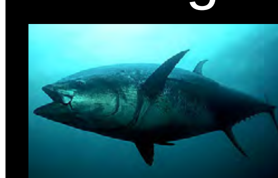

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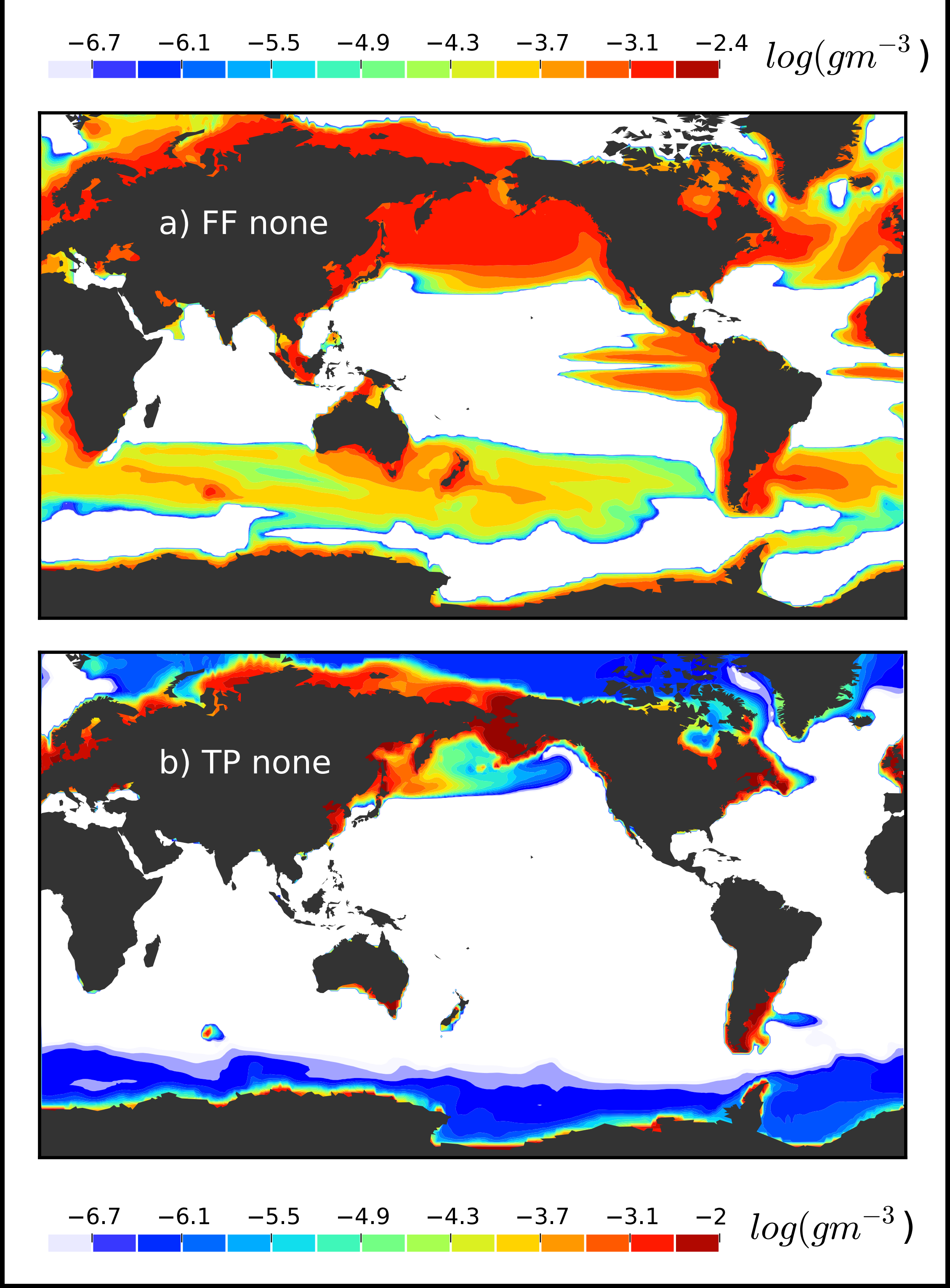


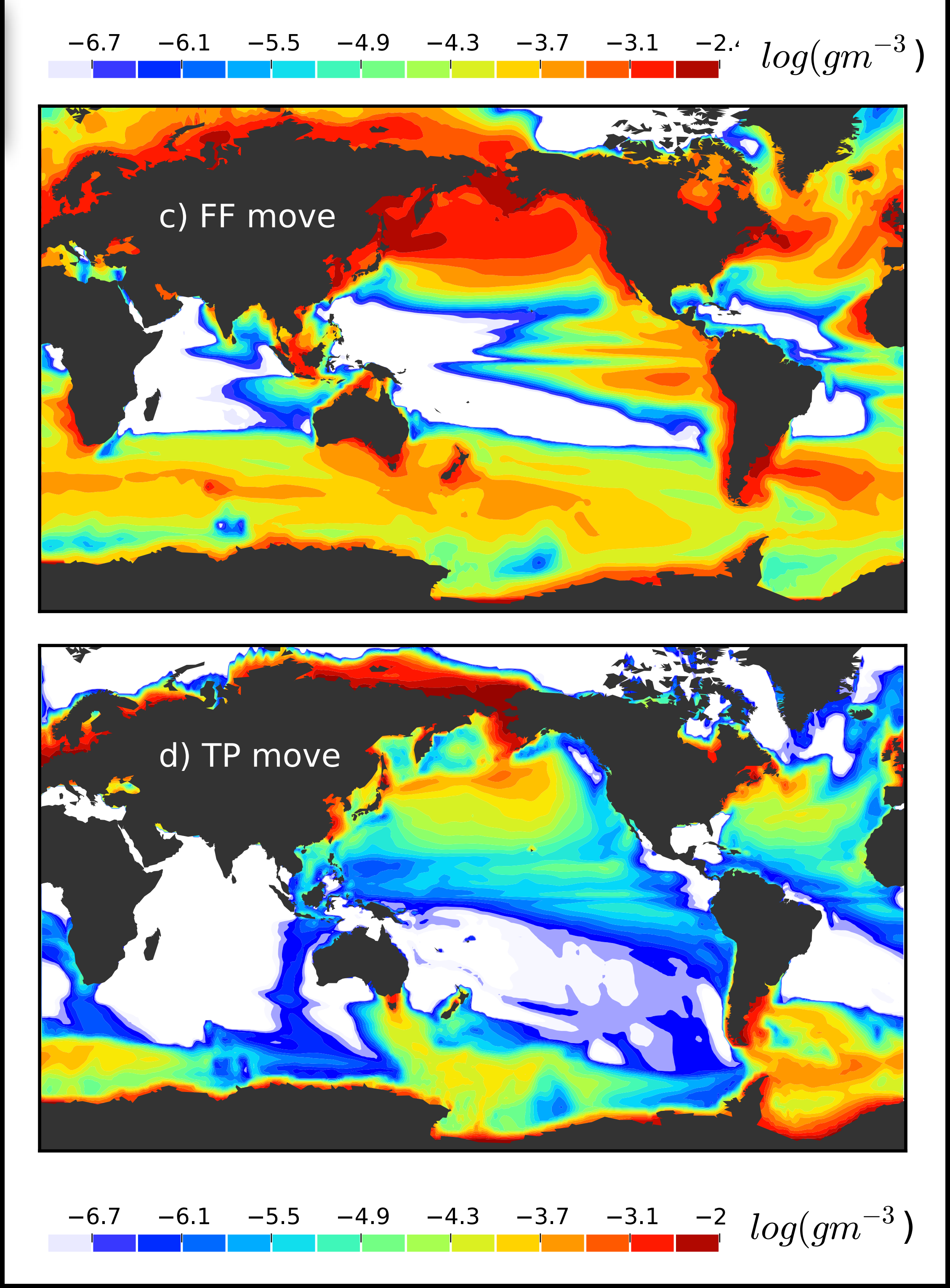
No movement

>1kg

Top predator

A Size-based Model: results

Forage fish



With net-growth following movement

Top predator

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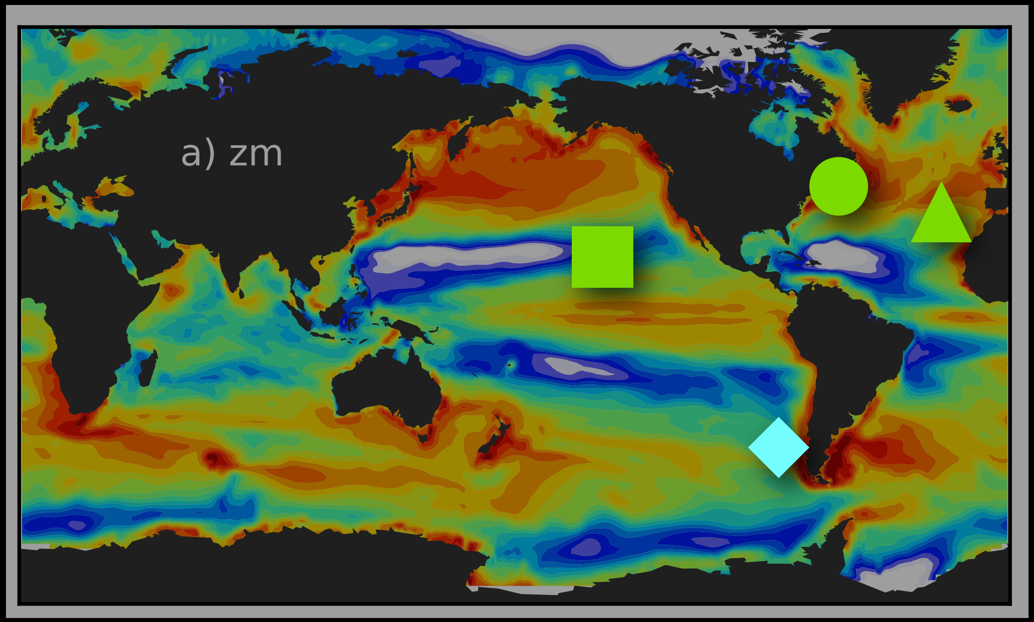

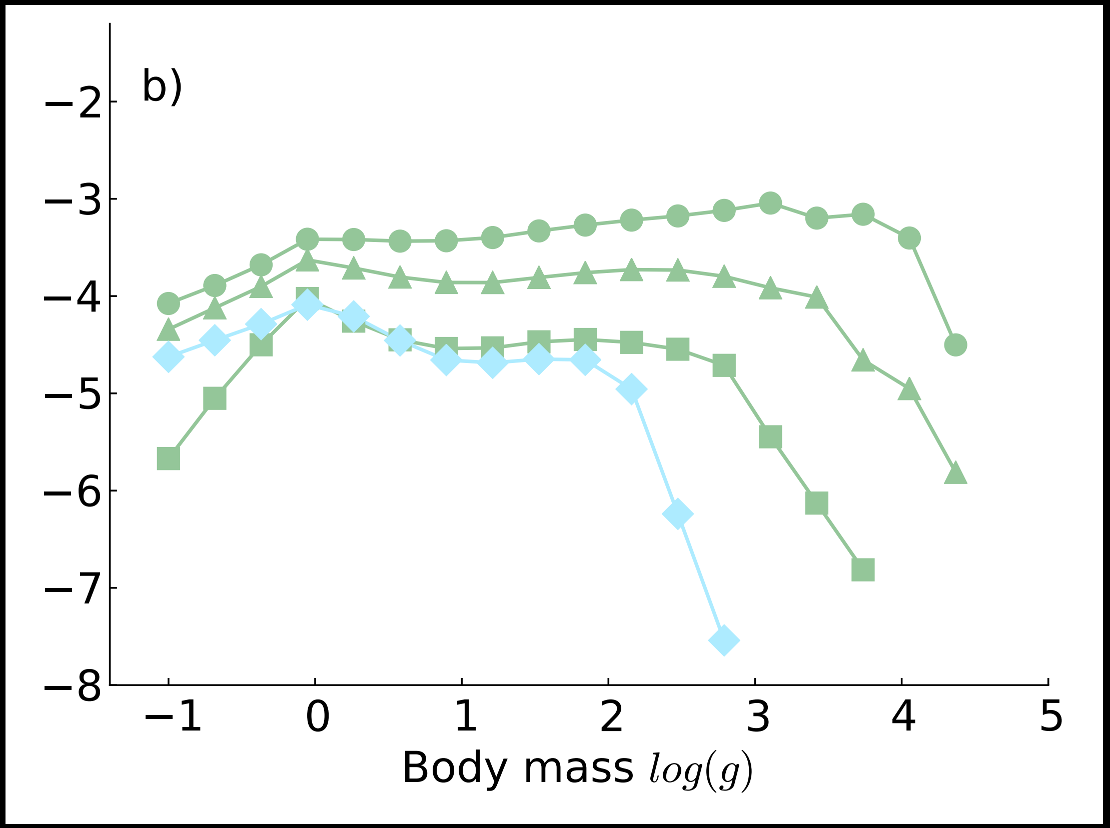

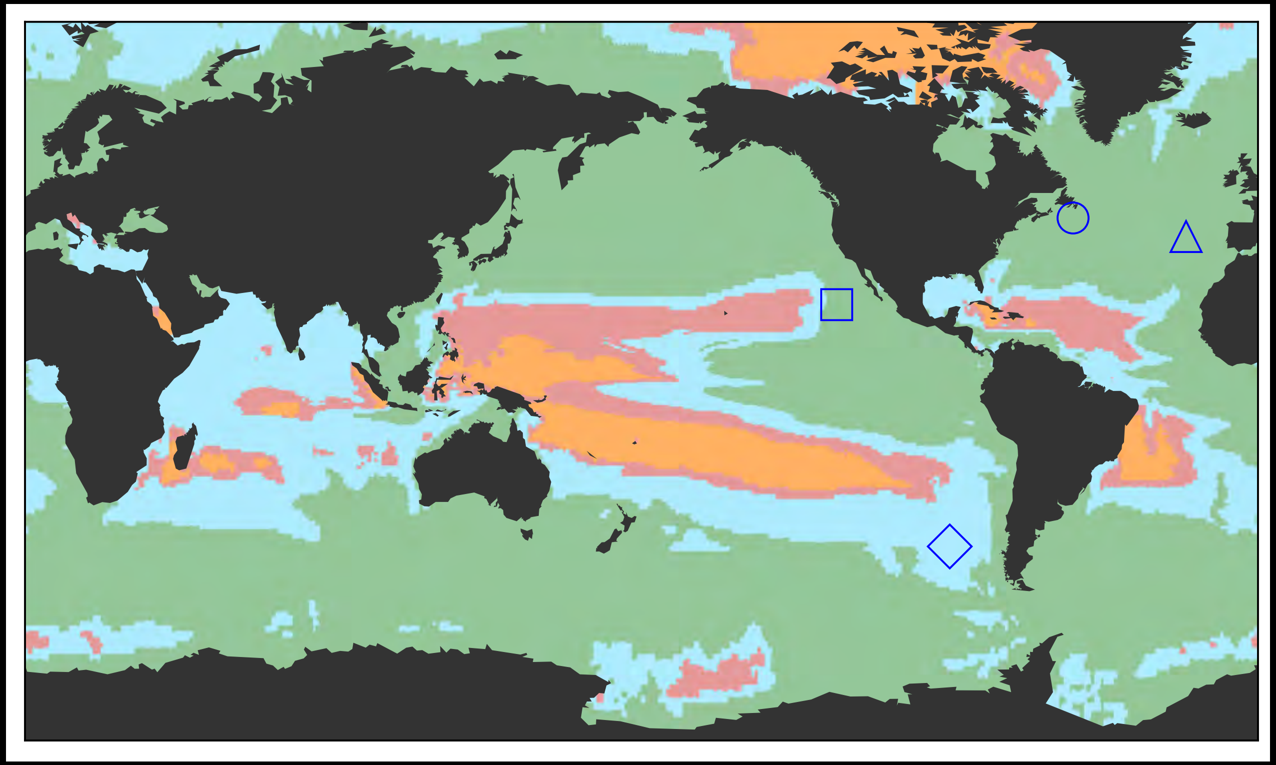

Ecoregions with net-growth following movement

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Lacks species specific details:

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- No complex migration, no “extreme” parameters

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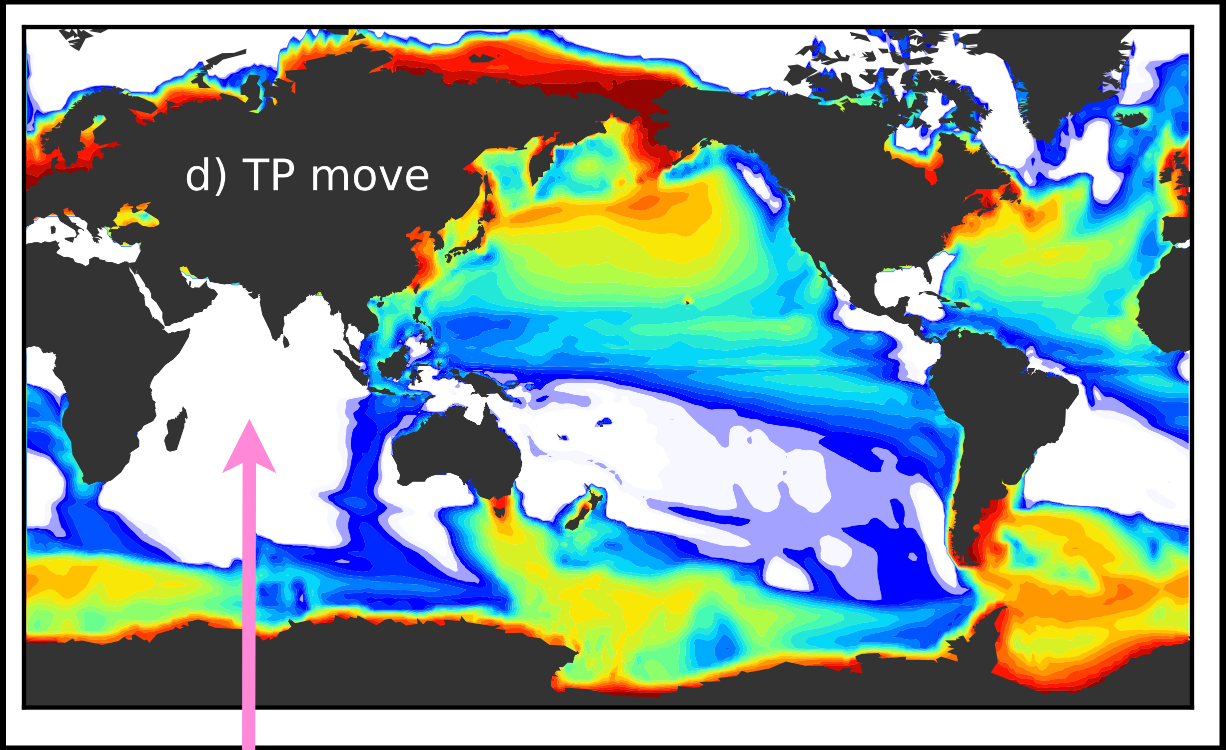


No big fish!

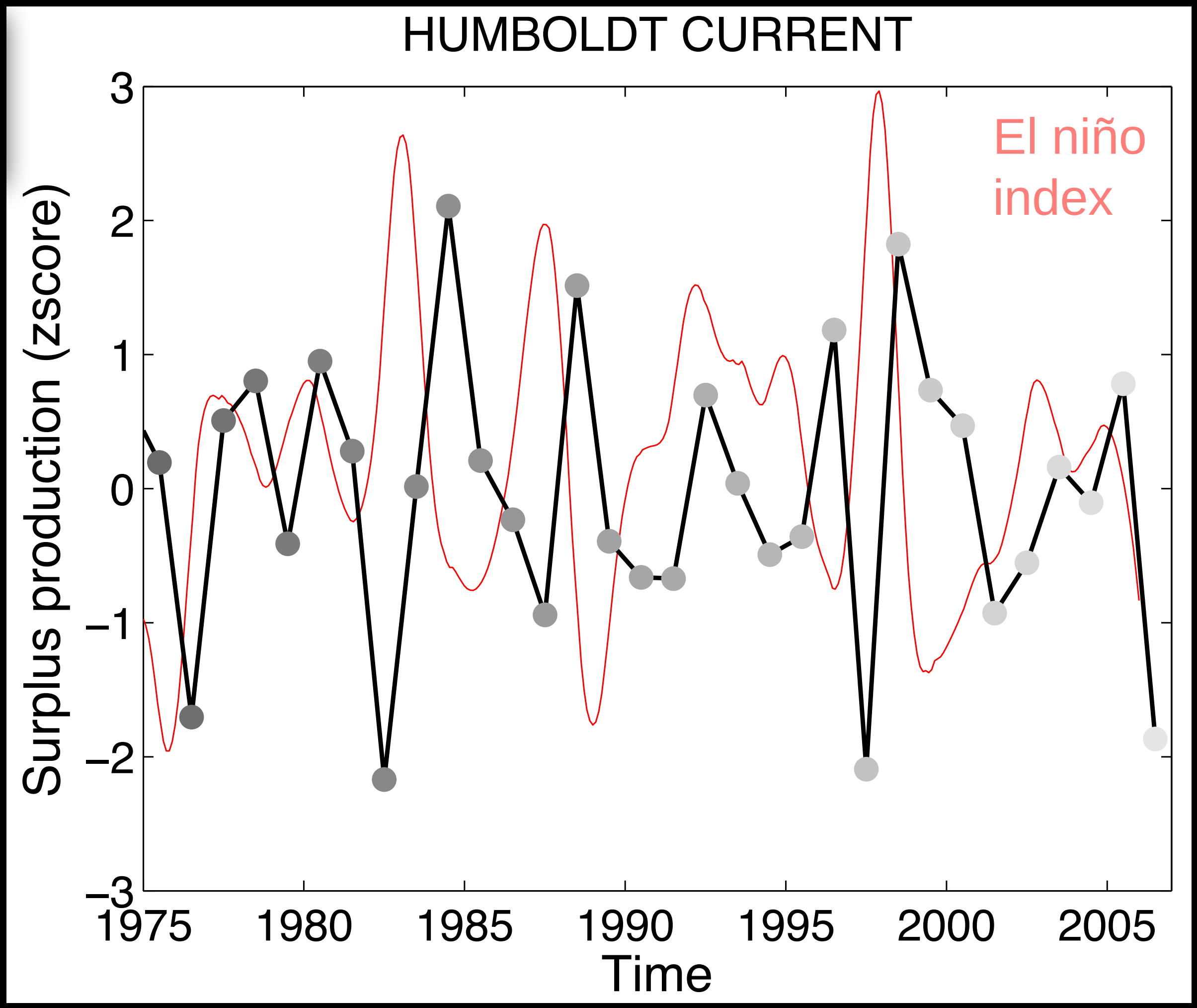
Top predator

Limitations

Lack species specific details

- It can't resolve sardine and anchovy (only "forage fish")

~100g



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Highly sensitive to parameters

Global ocean biomass (tonnes): ~ 86.2×10^{9} (x30 Jennings et al. 2009)
Biomass production ($gm^{-2}yr^{-1}$): ~ 0.5×10^{10} (x0.5 Jennings et al. 2009)

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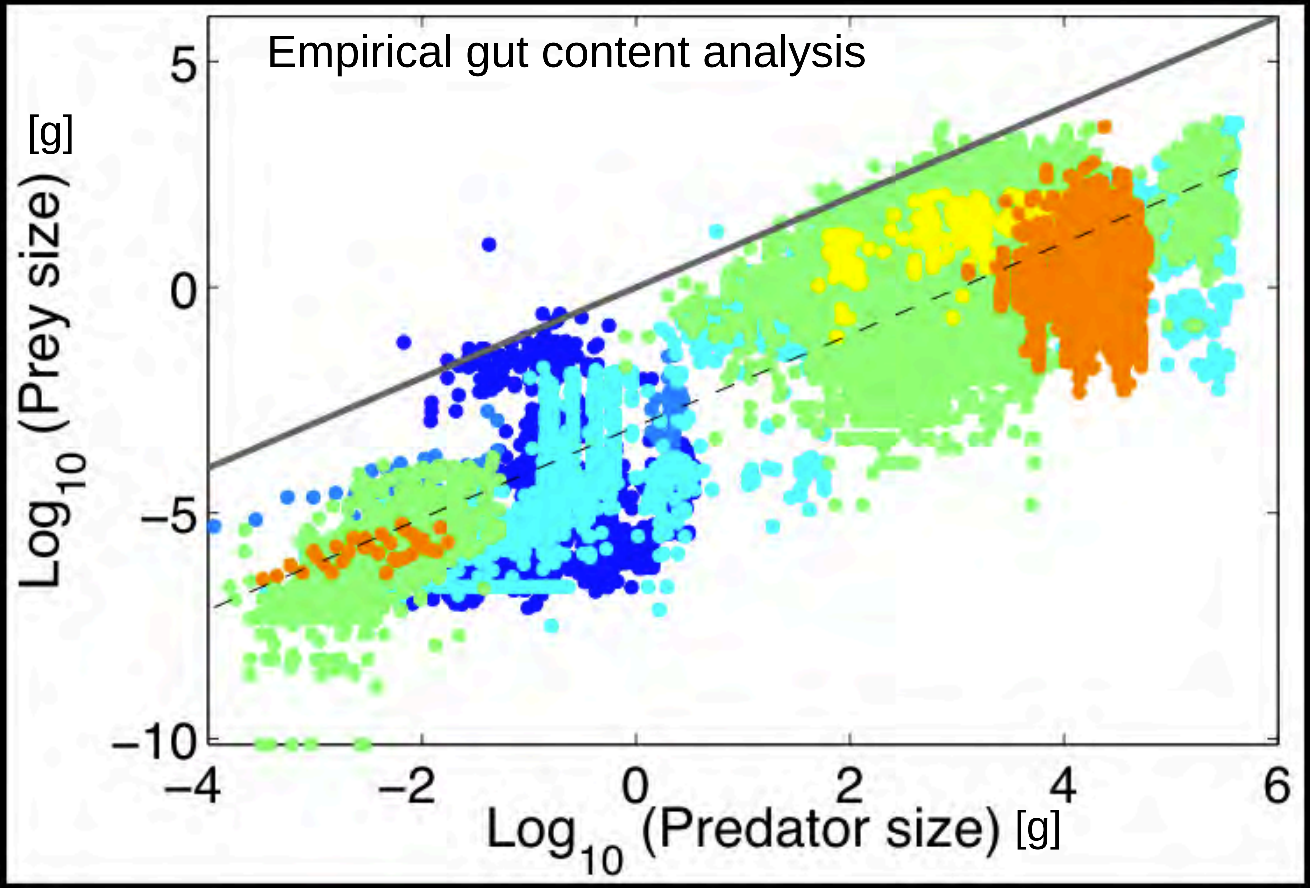

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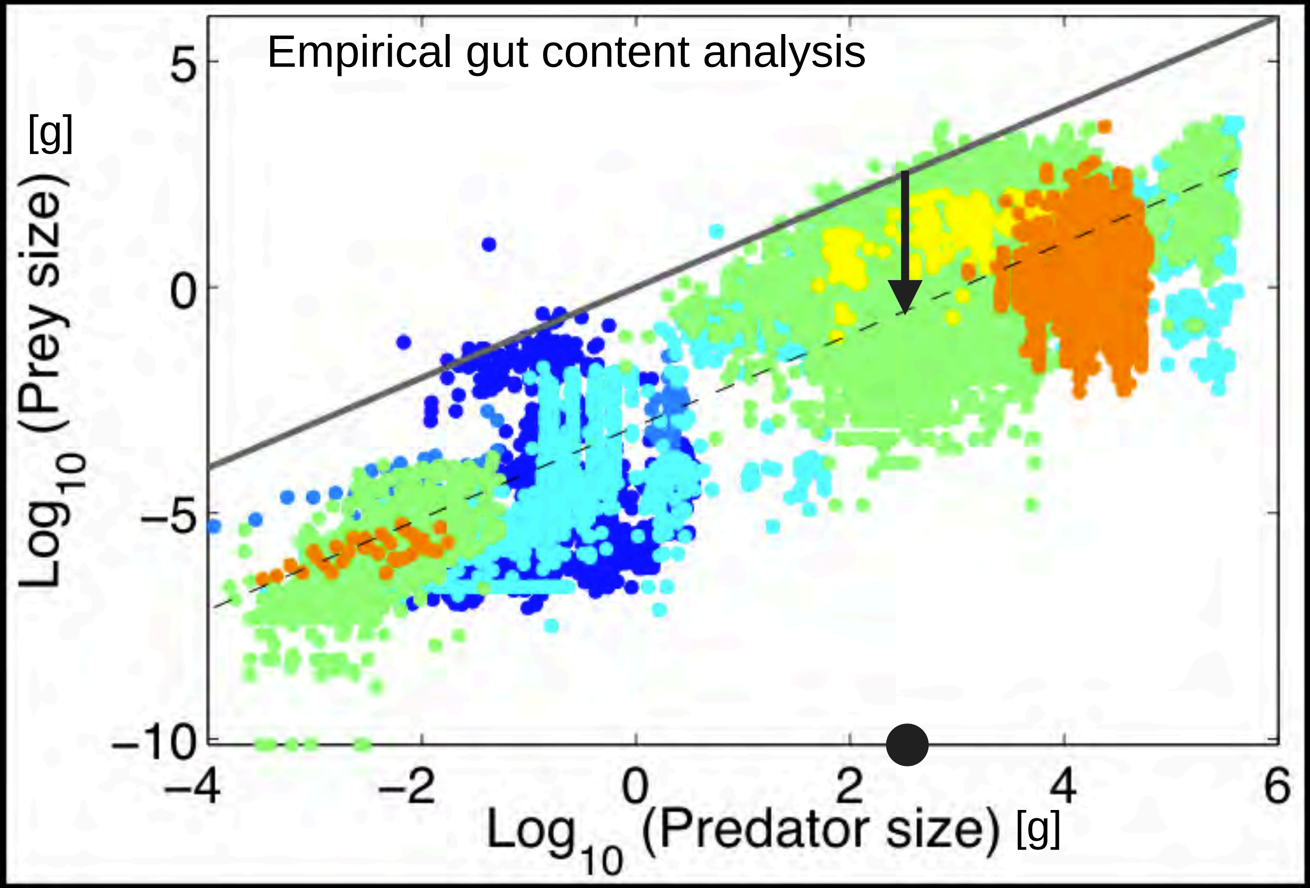

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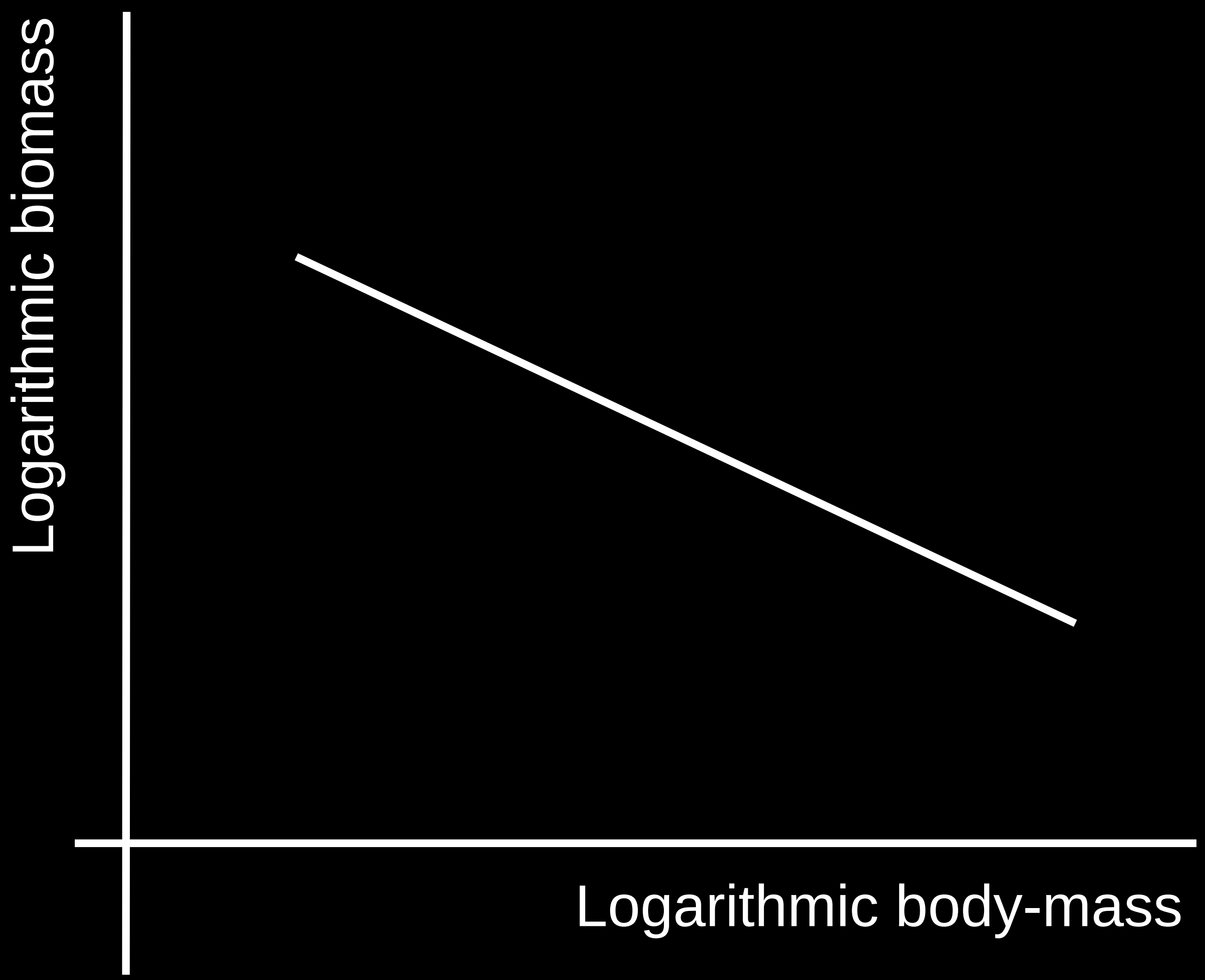
Comparison

No ontogeny (not “size-structured”),

- poor estimates of recruitment

Size-based population model



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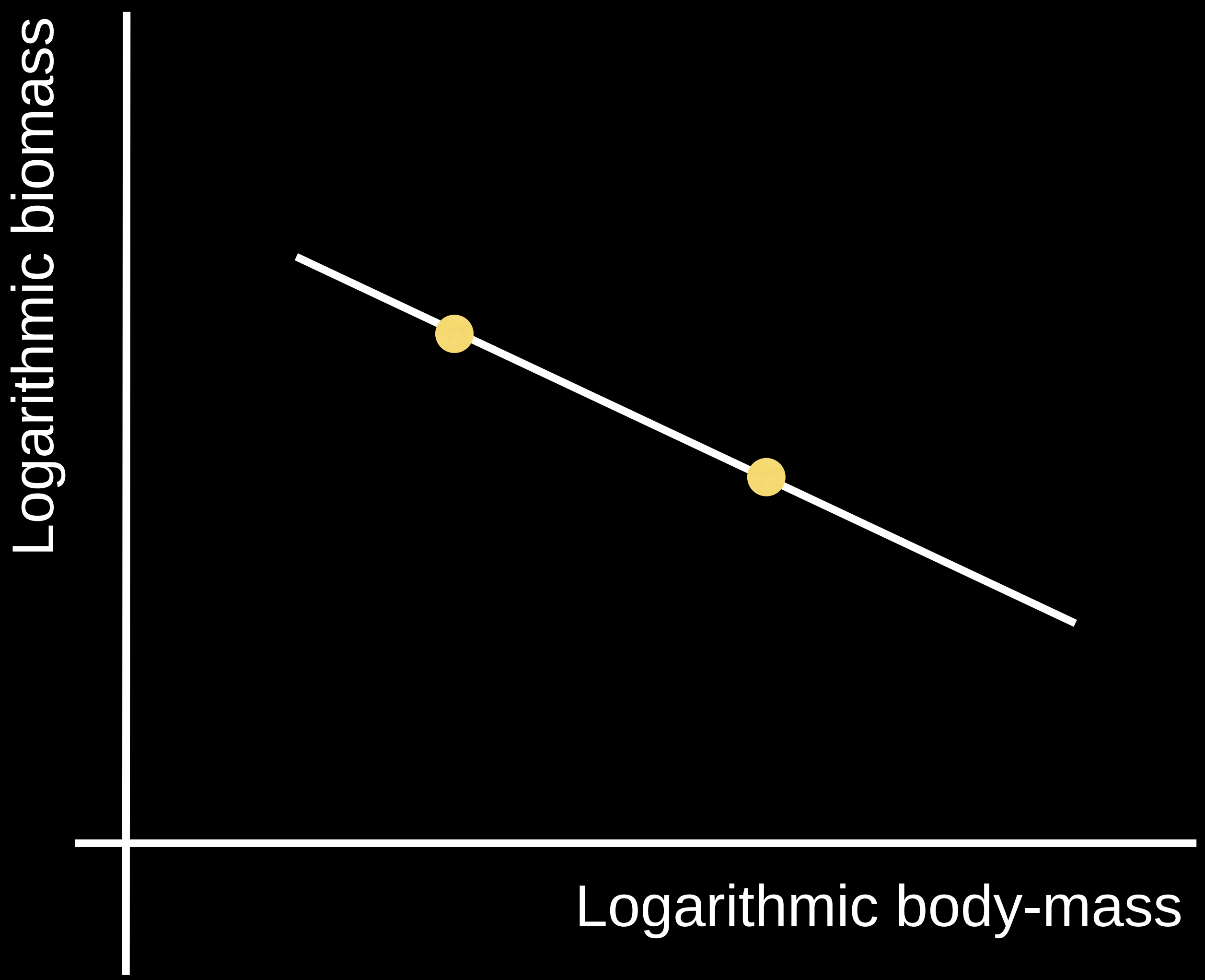

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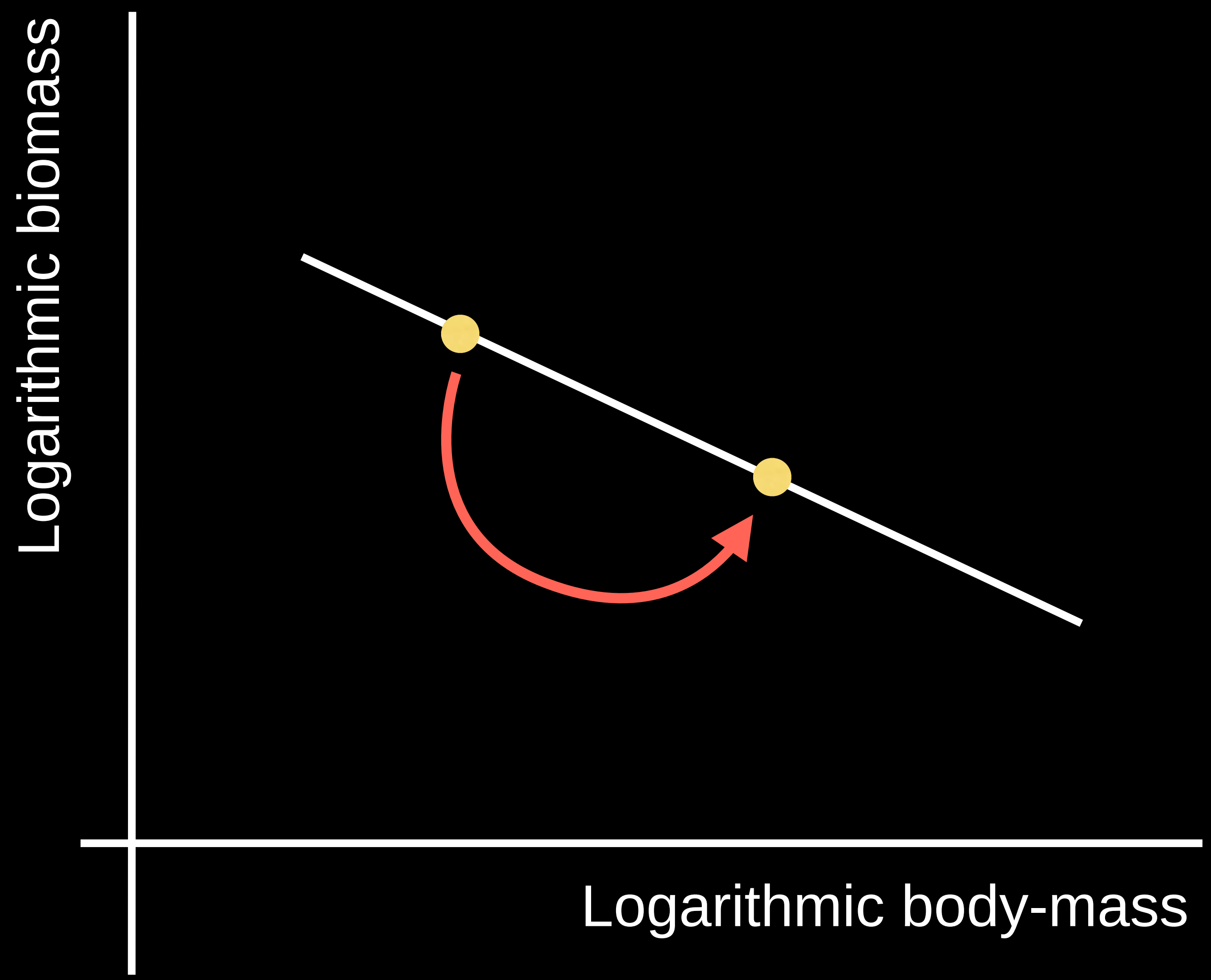

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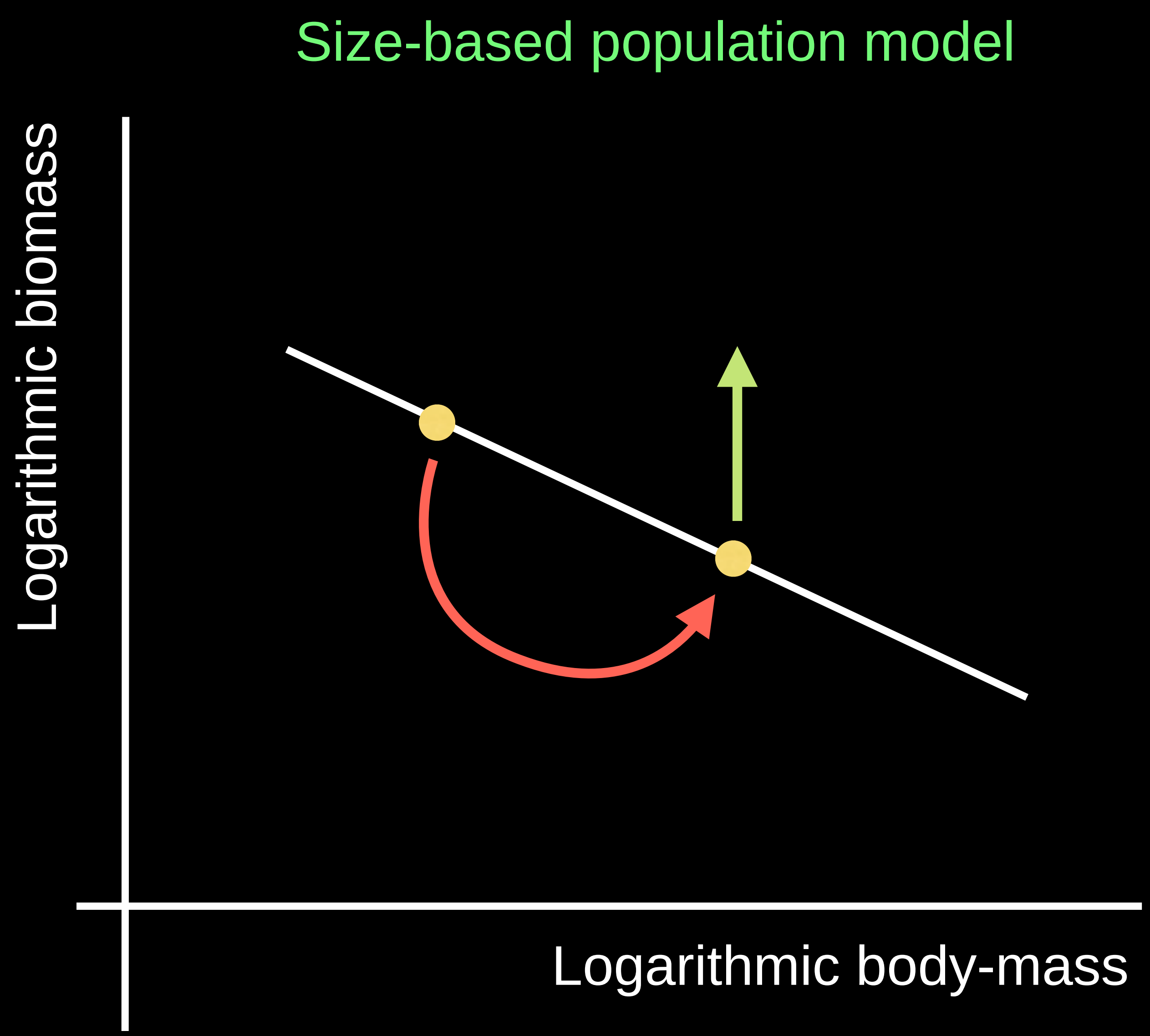

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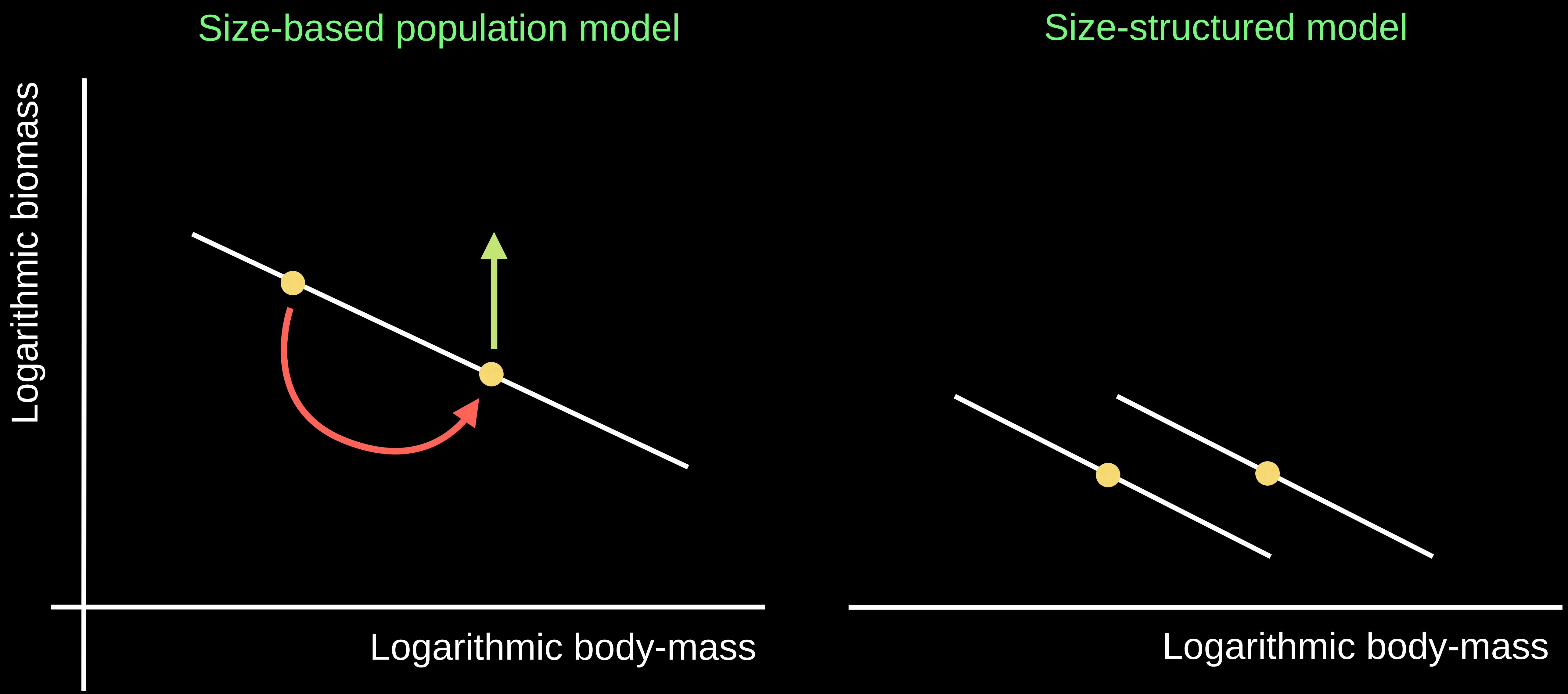

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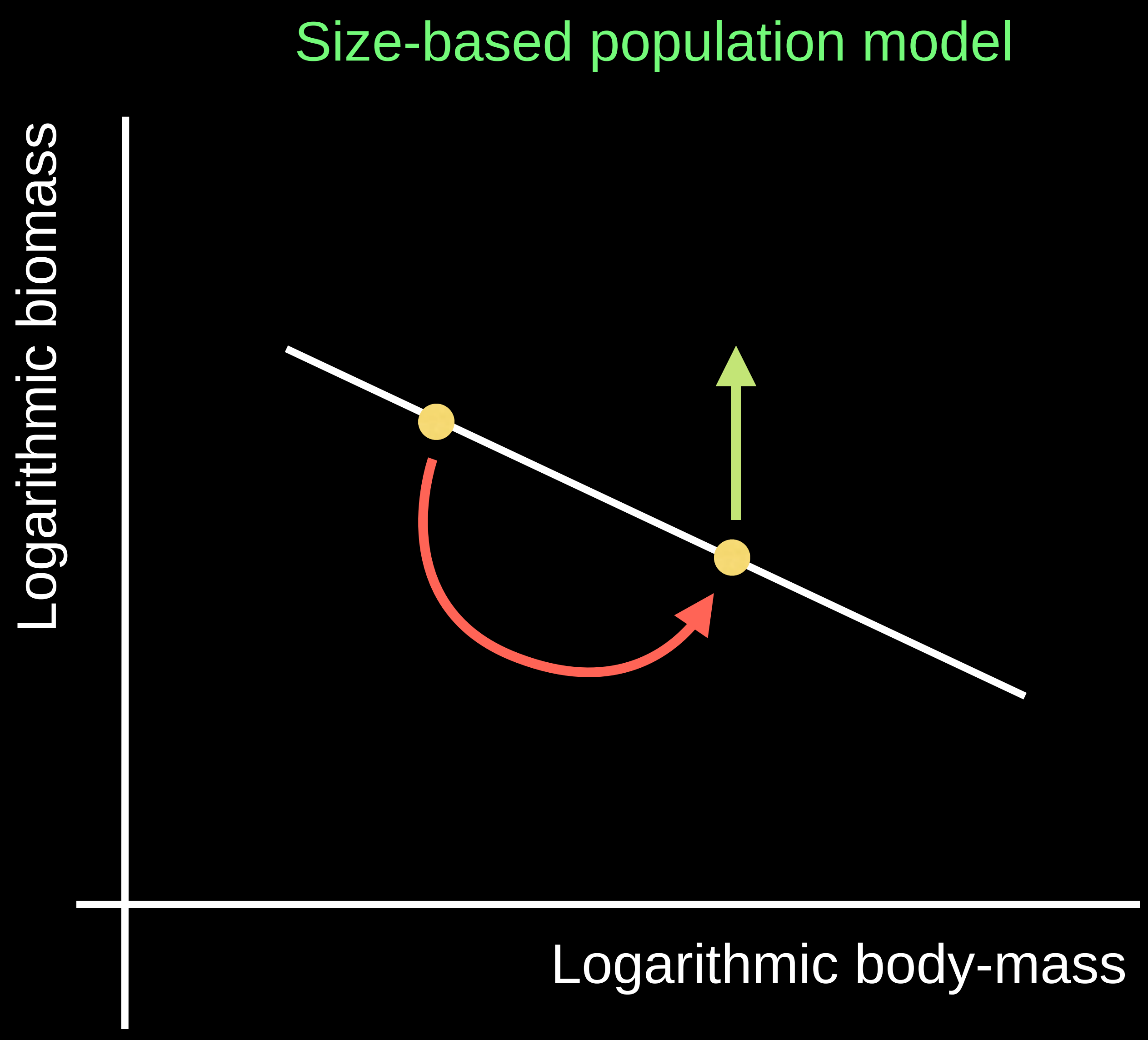

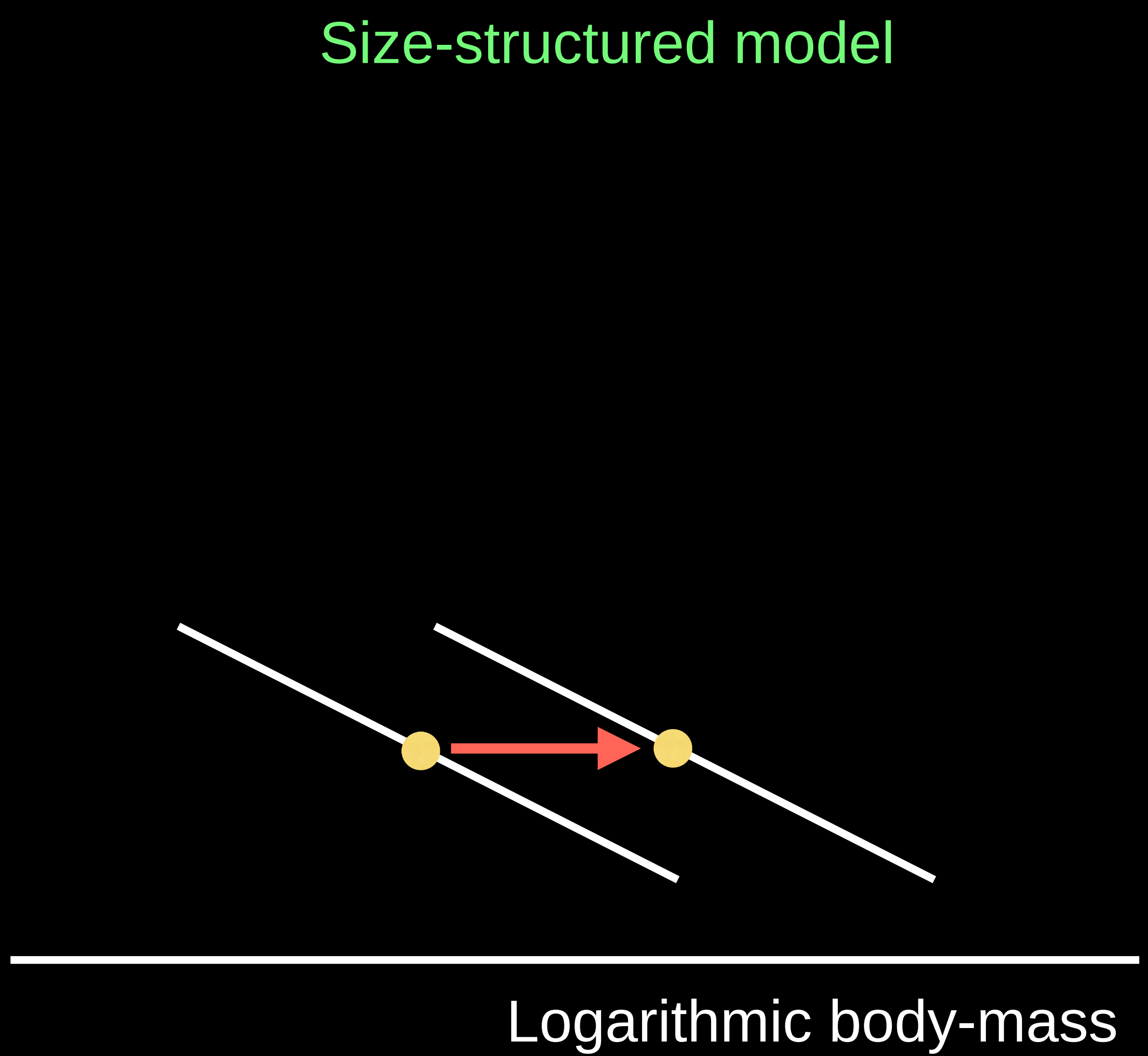

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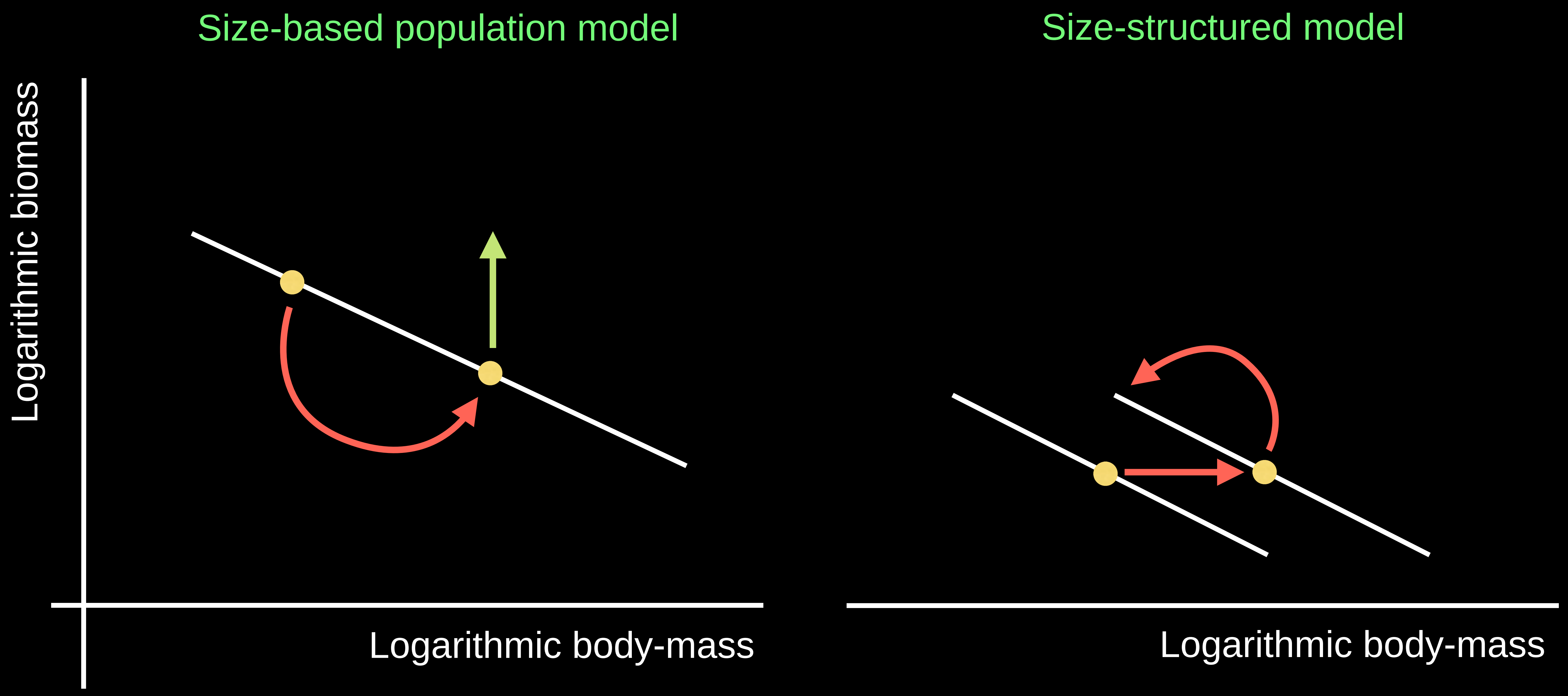

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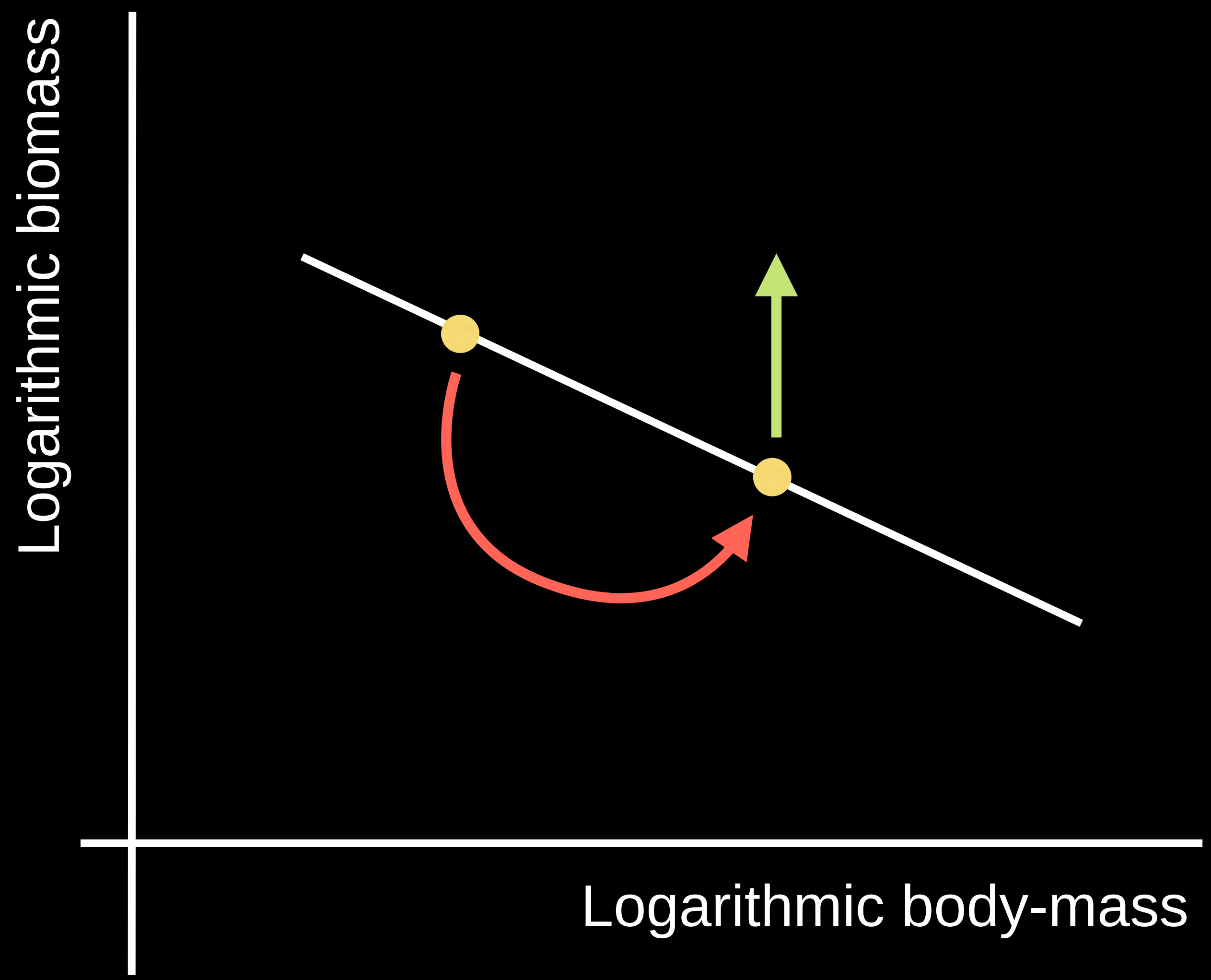
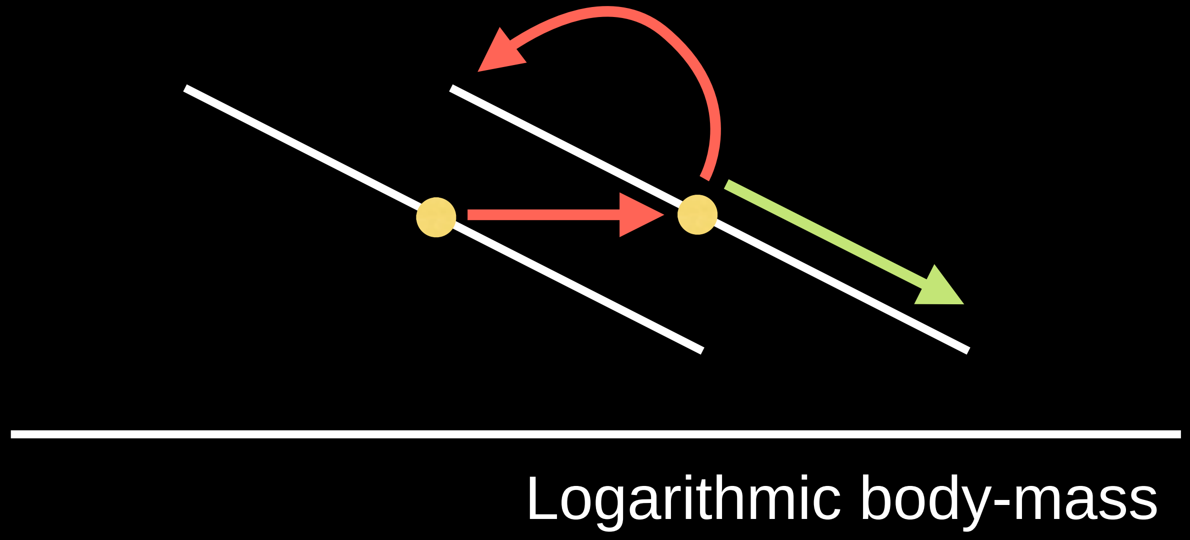


Size-structured model



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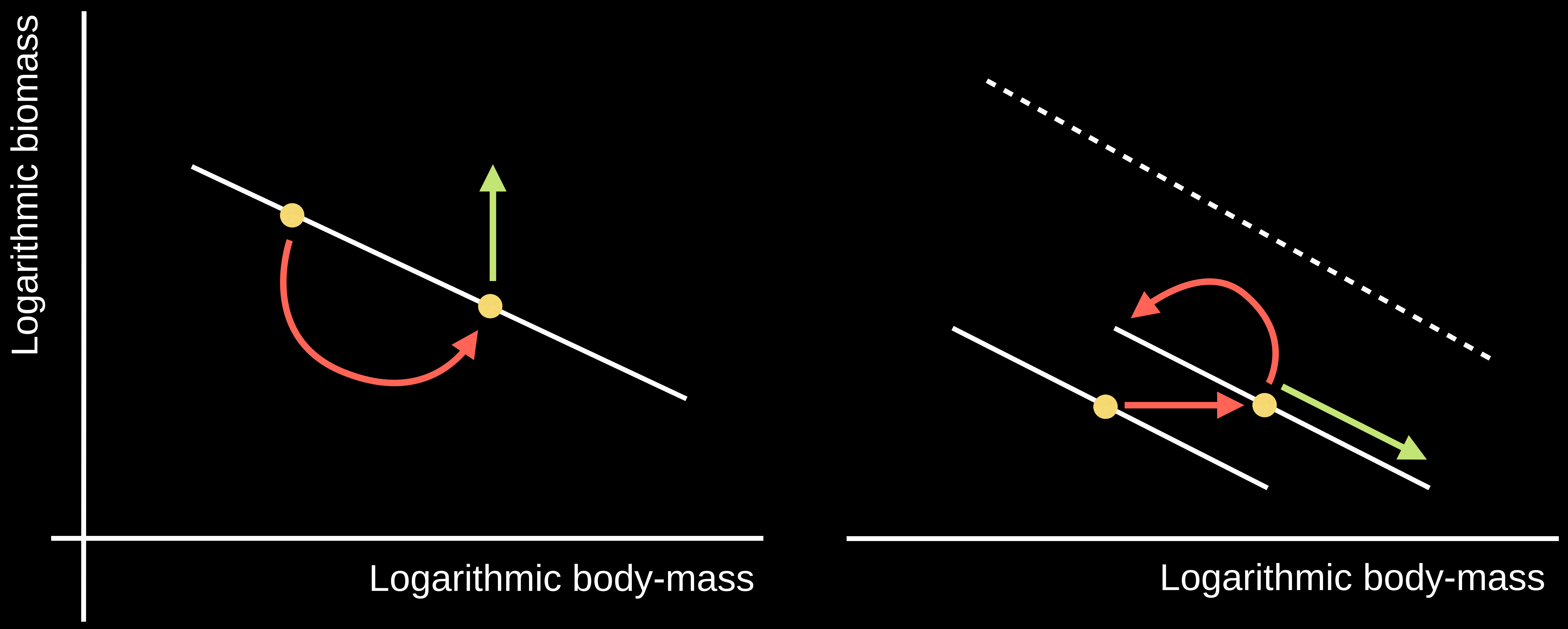

Summary

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Size based models:

- ecological understanding: yes, movement is important
- prediction? useful given the conditions

Jorge Sarmiento (Princeton)
Simon Levin (Princeton)
Charlie Stock (NOAA / GFDL)

Emma Fuller (Princeton)
Andrew Tilman (Princeton)
Malin Pinsky (Rutgers)

... and many others

James Watson
jrwatson@princeton.edu

Thank you

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