Investigating marine food-web dynamics in the Community Earth System Model (CESM)

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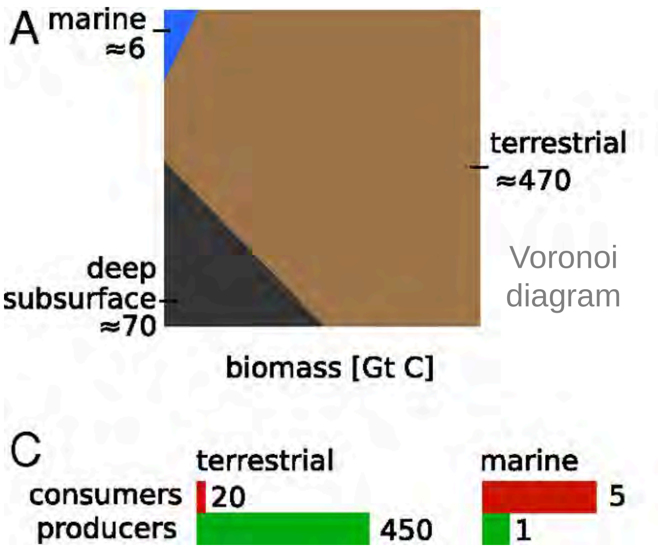
NCAR

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Predicting climate impacts on marine food-webs and the biological pump

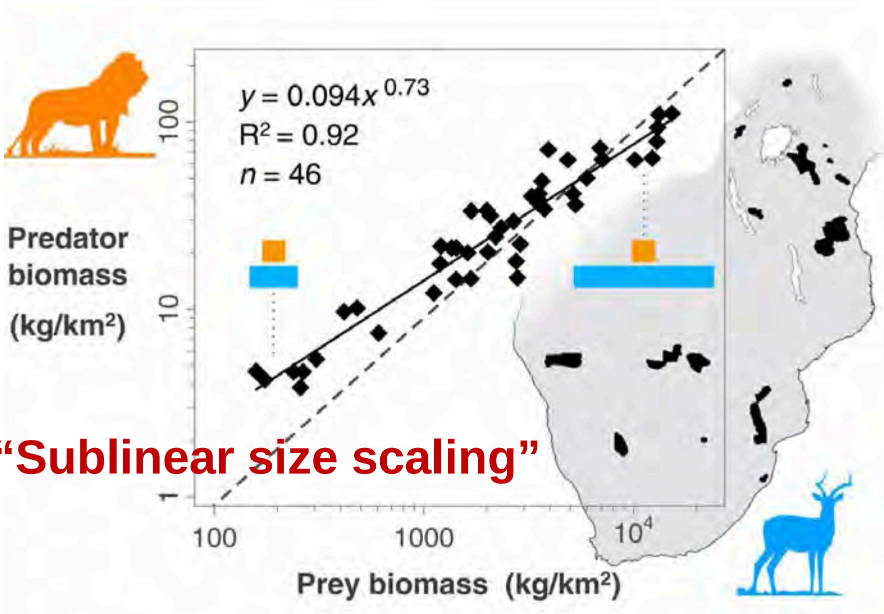
Q: How does energy transfer up the marine food chain?



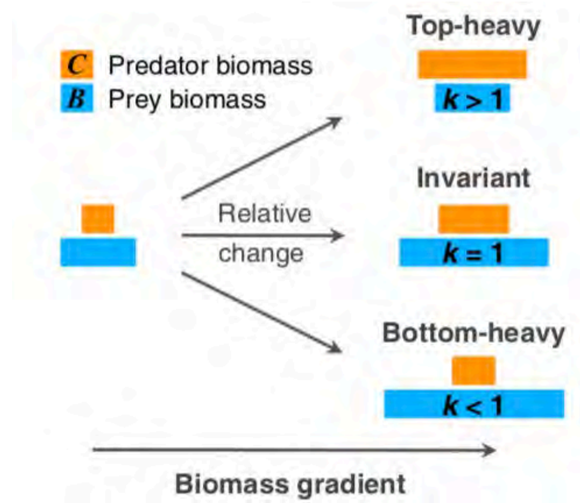
inverted pyramid

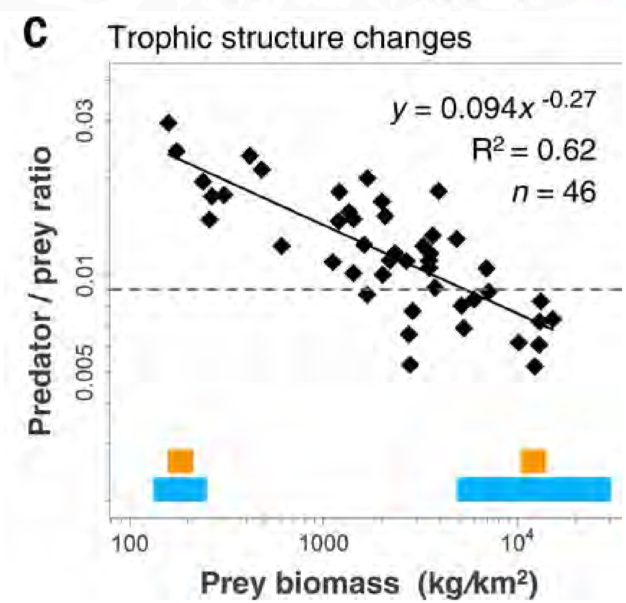
Bar-On et al. 2018, PNAS

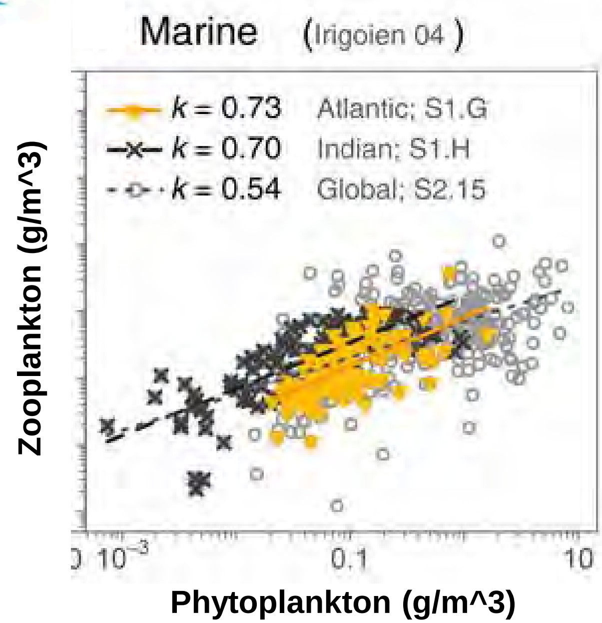
Universal ecosystem-level trophic structure?



"Sublinear size scaling"



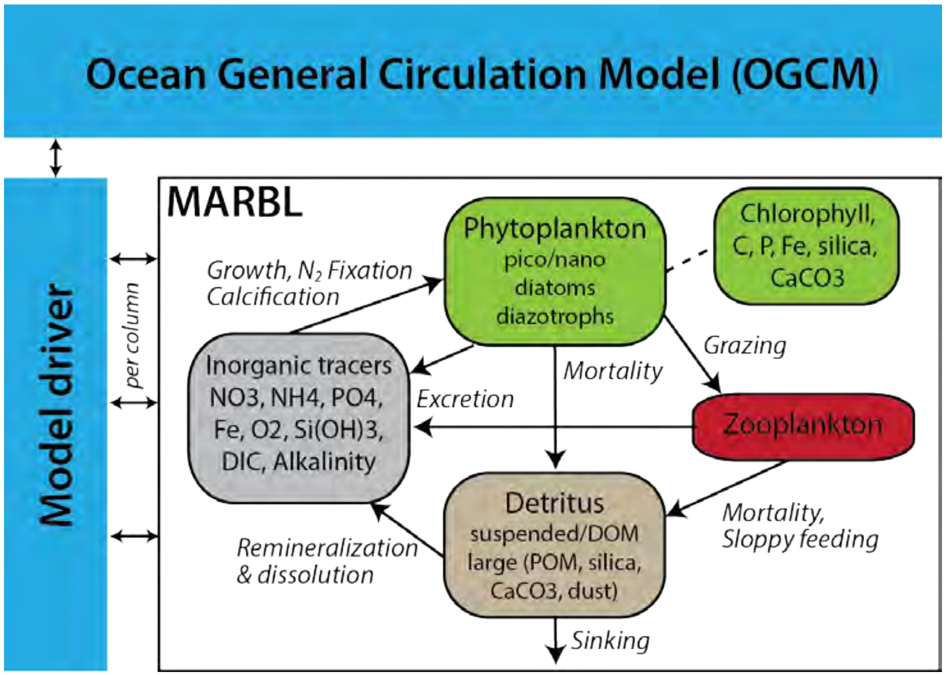




How does the marine 'inverted pyramid' arise?

Hatton et al. 2015 *Science*

Marine Biogeochemistry Library (MARBL)

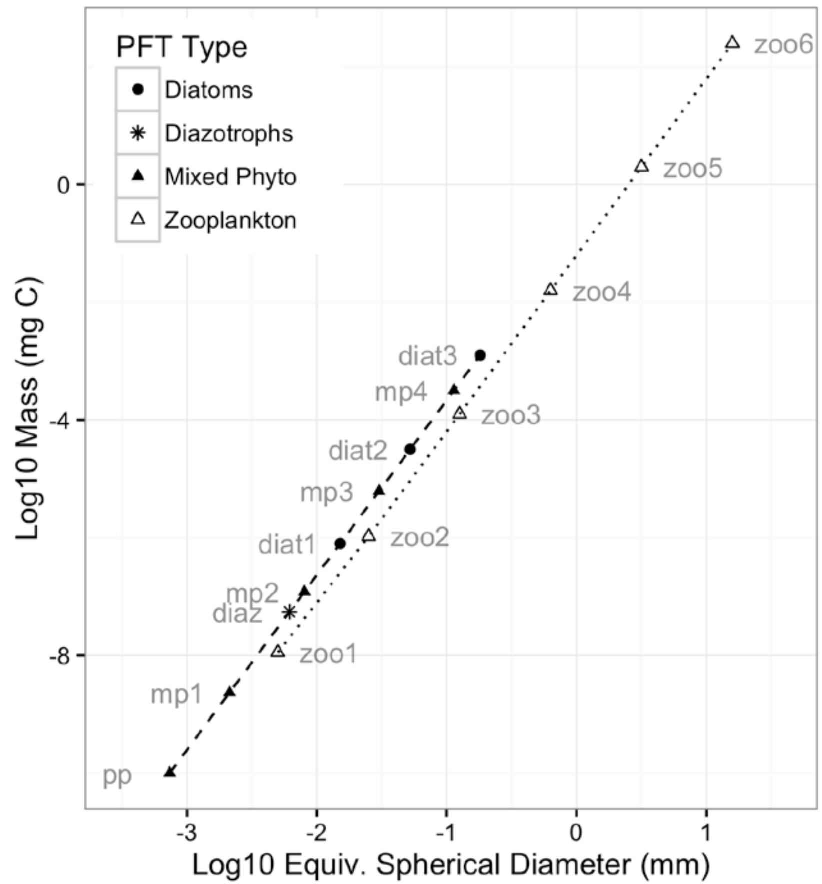


- Modular ocean biogeochemistry model
- Default: 3 phytoplankton and 1 zooplankton
- Now enables flexible number of plankton groups

Size-based Plankton Ecological Traits model (SPECTRA)

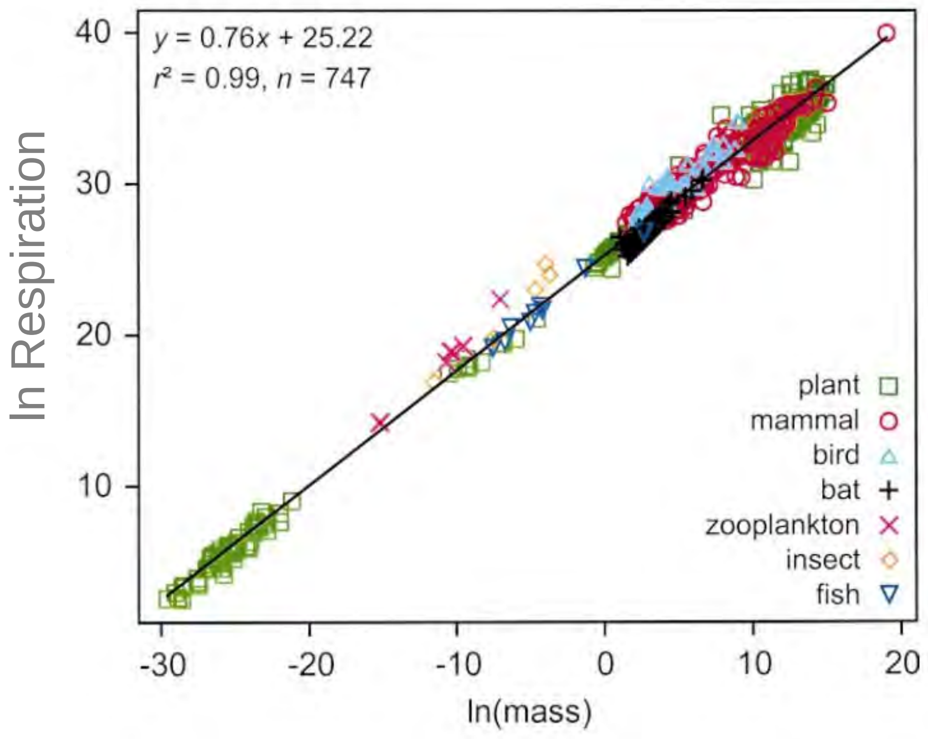
9 phytoplankton

6 zooplankton



Size as a ‘master trait’ for describing marine organisms

Physiological processes scale with mass



Kleiber’s law

Brown et al. 2004

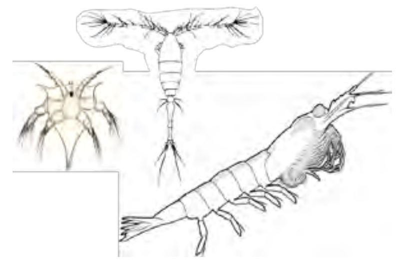
Allometric scalings

Phytoplankton

NASA EOL

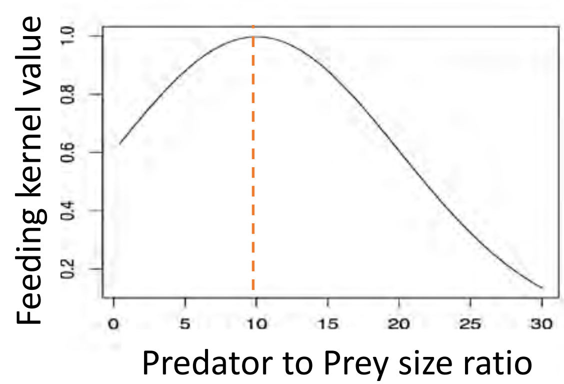
- Max photosynthesis rate ↓
- Initial growth-irradiance slope ↓
- Chl *a*:N ratio ↓
- Fe:C ratio ↓
- P:C ratio ↑
- Half-saturation constants:
  - NO_3 ↑
  - NH_4^+ ↑
  - PO_4^{3-} ↑
  - DOP ↑
  - SiO_3 ↑
  - Fe ↑

Zooplankton



- Max grazing rate ↓
- Grazing half-saturation constant ↓
- Respiration rate ↑
- Mortality rate ↓
- Fraction of losses to detritus ↑

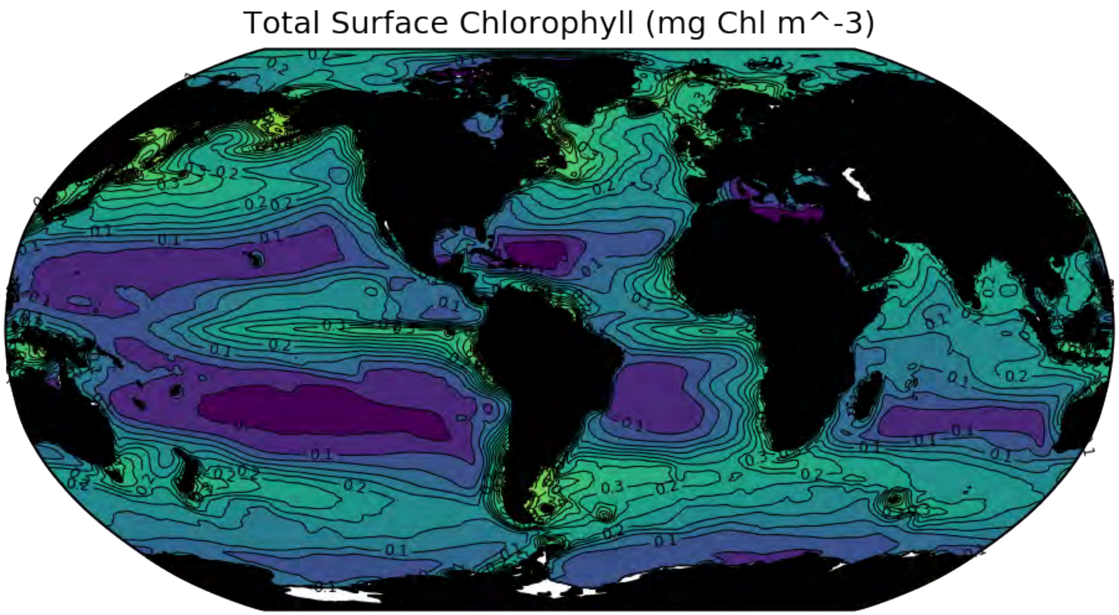
Optimal predator-prey size ratio = 10:1



Feeding kernel width ↑

Model validation – chlorophyll

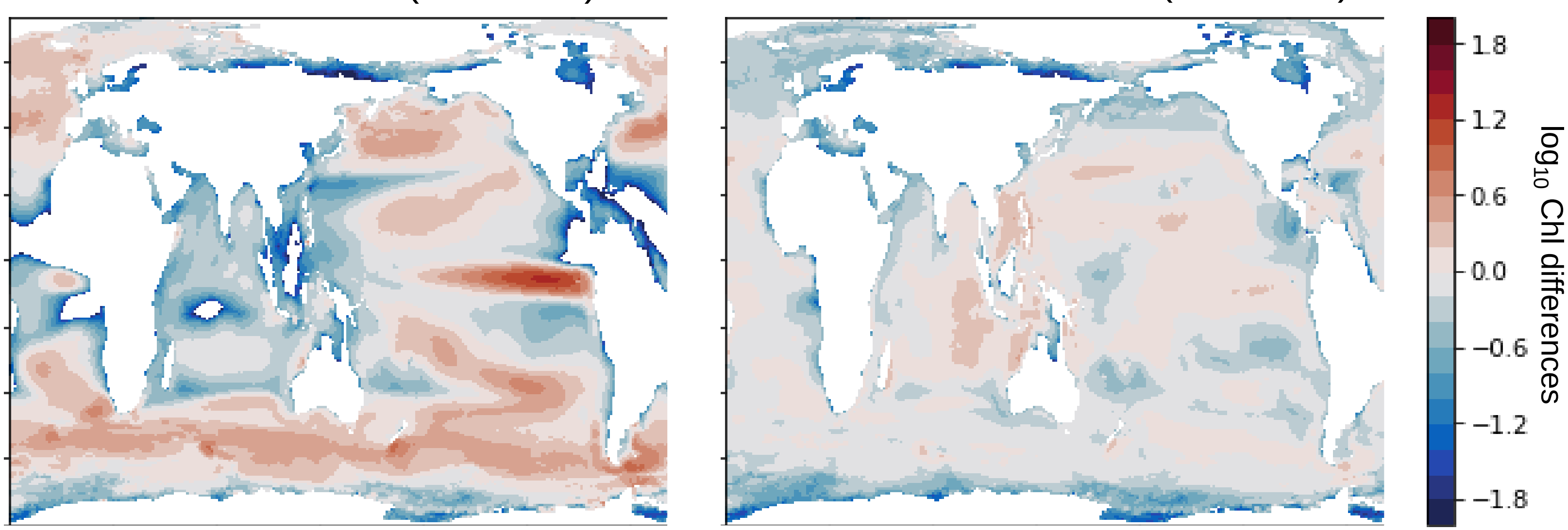
NPP:
48 Pg C y^{-1}



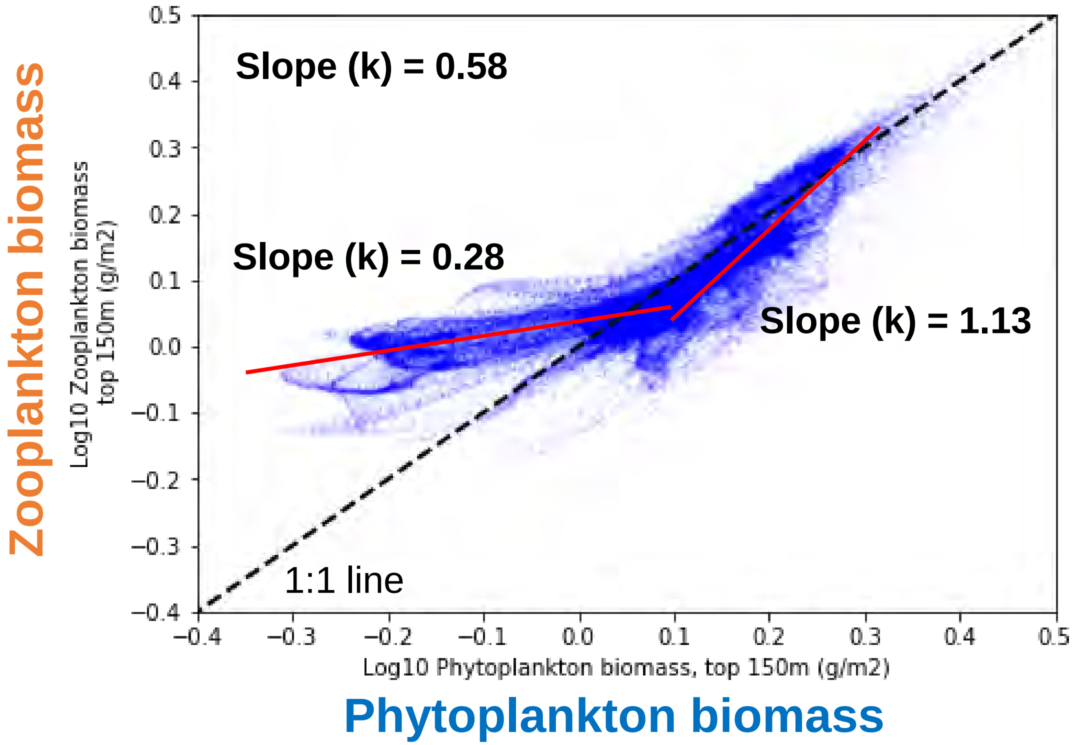
Model:
CORE II forced
Ocean-Ice case
1-degree POP + CICE
62-year hindcast
Results shown are years
32-62 (1981-2011)

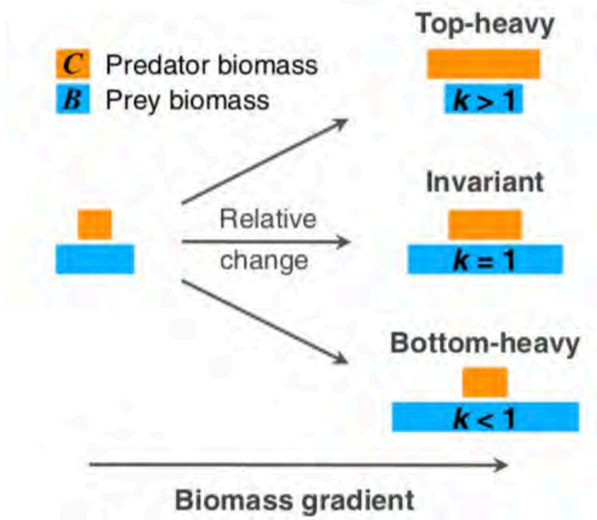
Model improvement of 40-50%

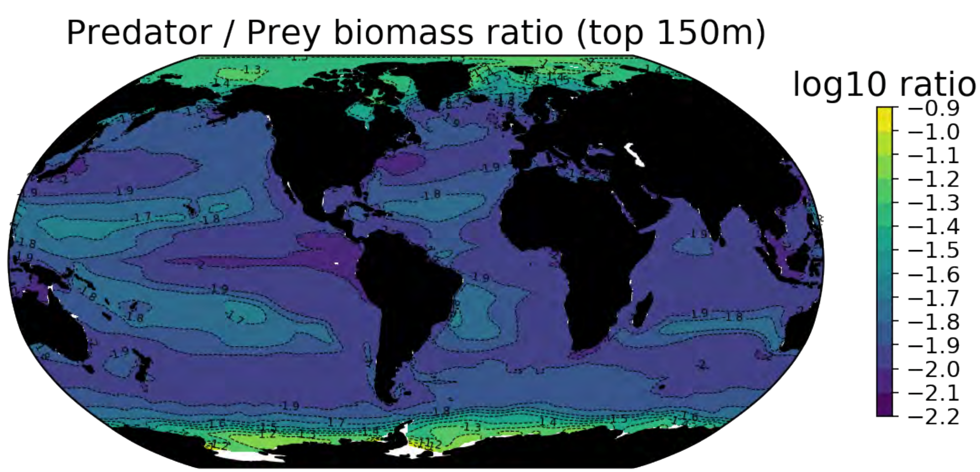
BEC Model – Obs (SeaWiFS)   SPECTRA Model – Obs (SeaWiFS)



Modeled predator-prey biomass scaling



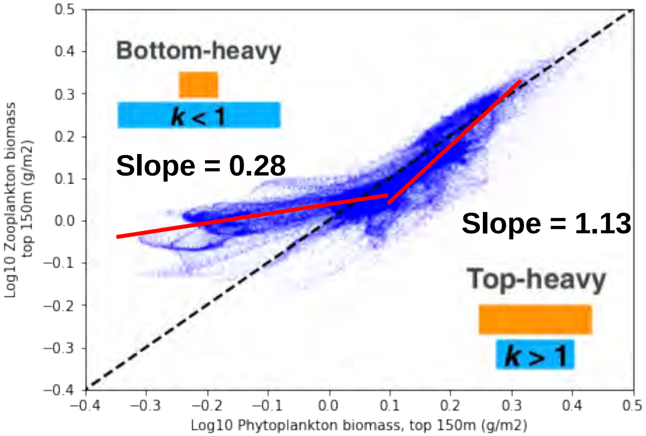




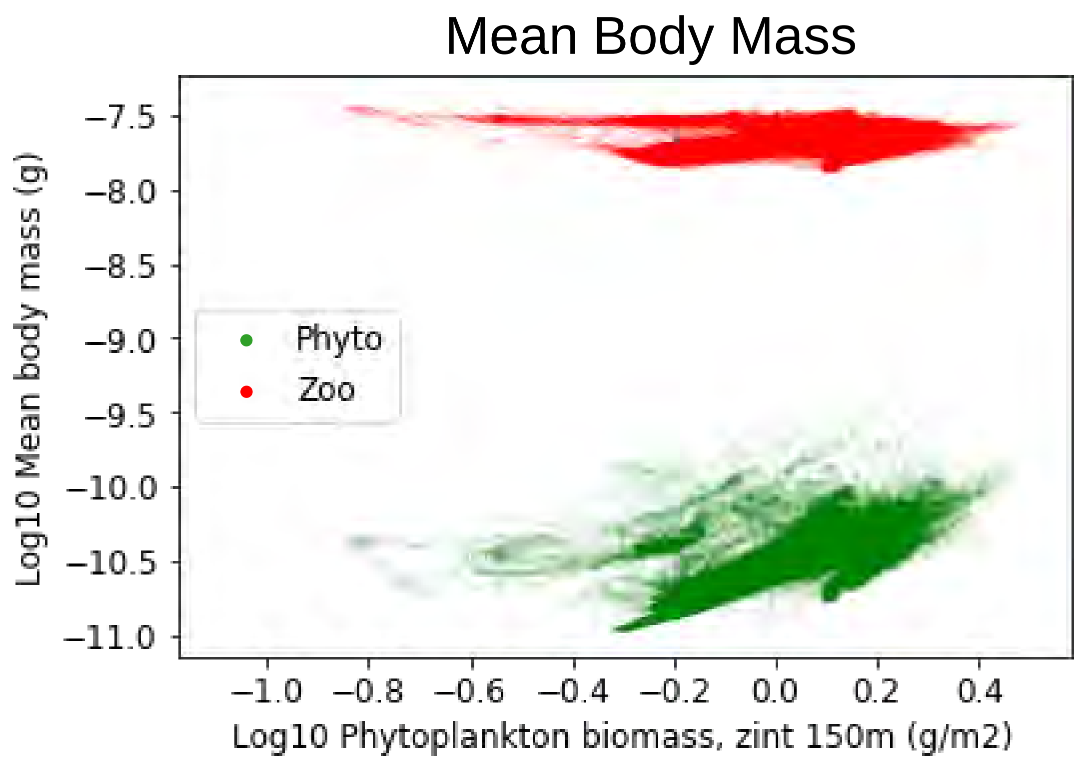
HYPOTHESES:

1. Zooplankton mean size increases at high phytoplankton biomass.
2. Productivity of large zooplankton increases relative to small zooplankton due to large-sized phytoplankton food.

Why does trophic biomass scaling increase at high biomass?



1. Zooplankton mean size increases at high phytoplankton biomass. X
2. Productivity of large zooplankton increases relative to small zooplankton due to large-sized phytoplankton food.



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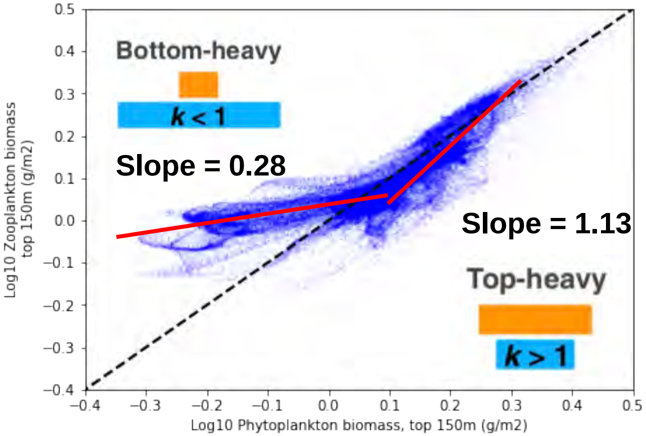
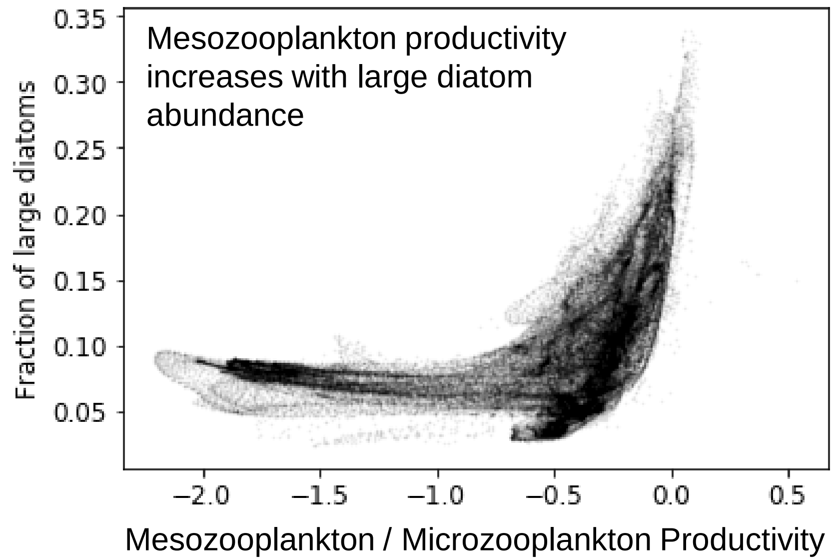
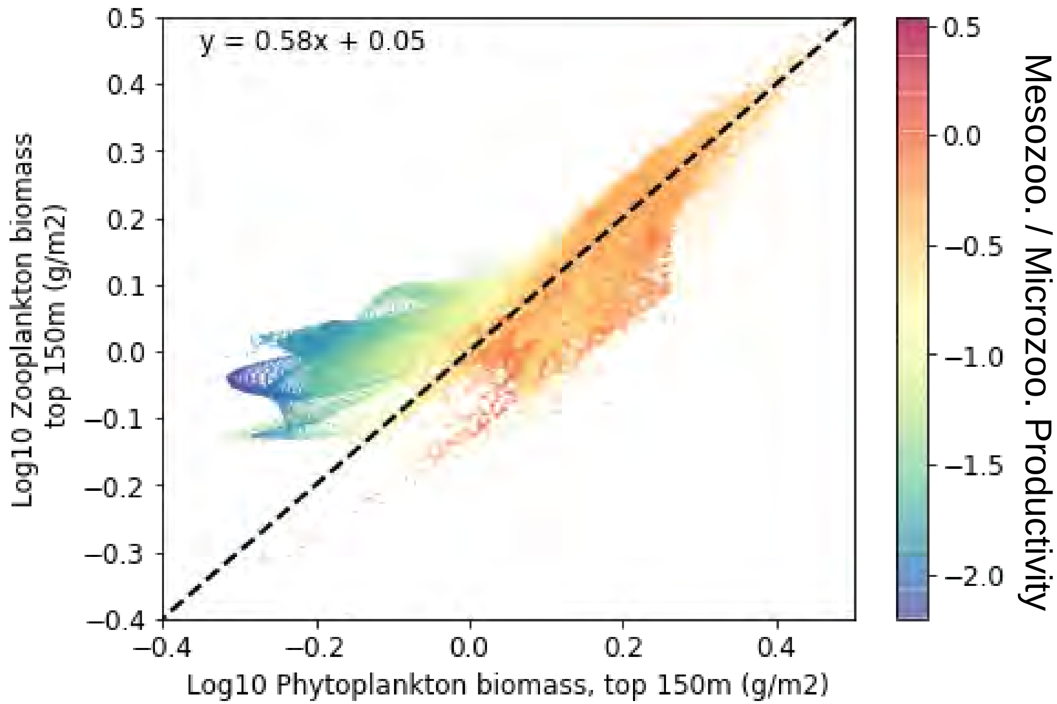




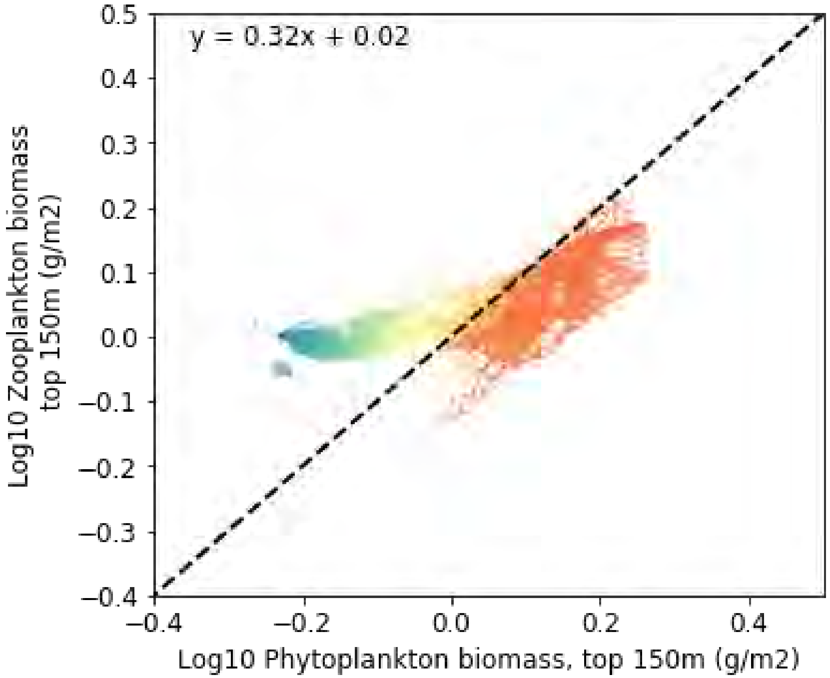
1. Zooplankton mean size increases at high phytoplankton biomass. X

2. Productivity of large zooplankton increases relative to small zooplankton due to large-sized phytoplankton food. ✓

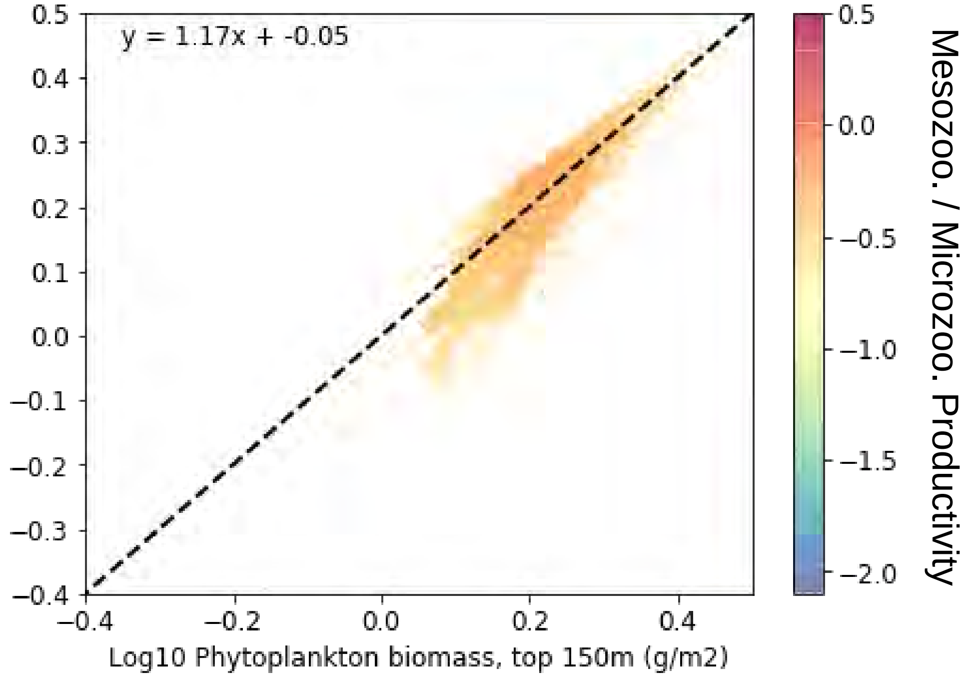


Spatial Patterns

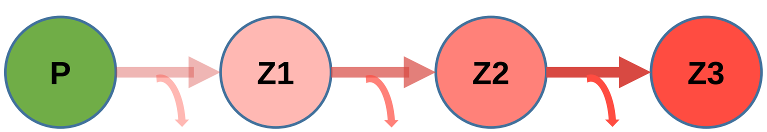
Equatorial and lower latitude regions



Subpolar regions



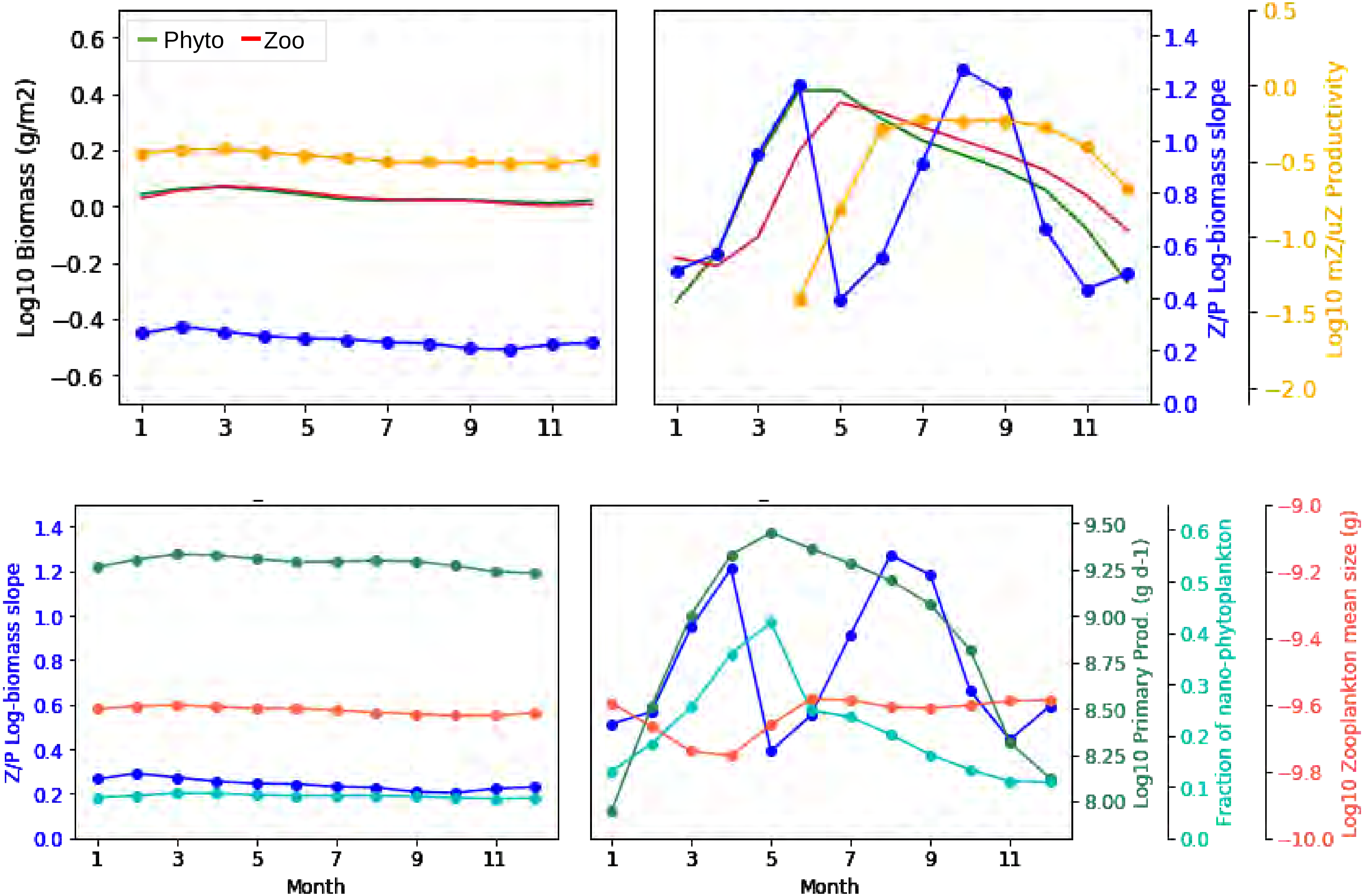
- Food web lengthens as phytoplankton biomass increases
- Spatially heterogeneous
- Trophic links are leaky



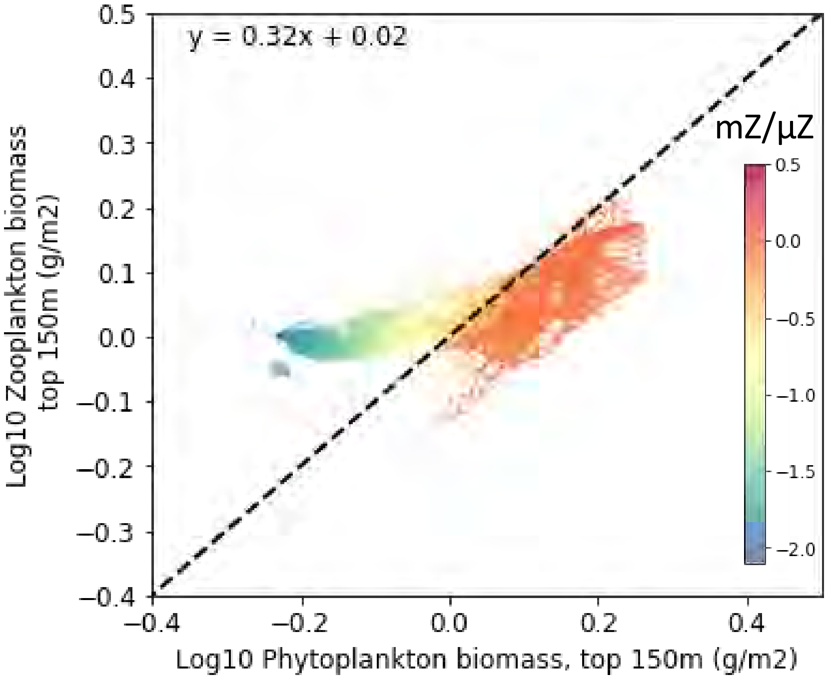
- Trophic transfer efficiency does not change with phytoplankton biomass
- Strong bottom-up control (tightly coupled food webs)
- High benthic fluxes
- Less large mesozooplankton (why?)

Temporal Patterns

Equatorial and lower latitude regions | **Subpolar regions**

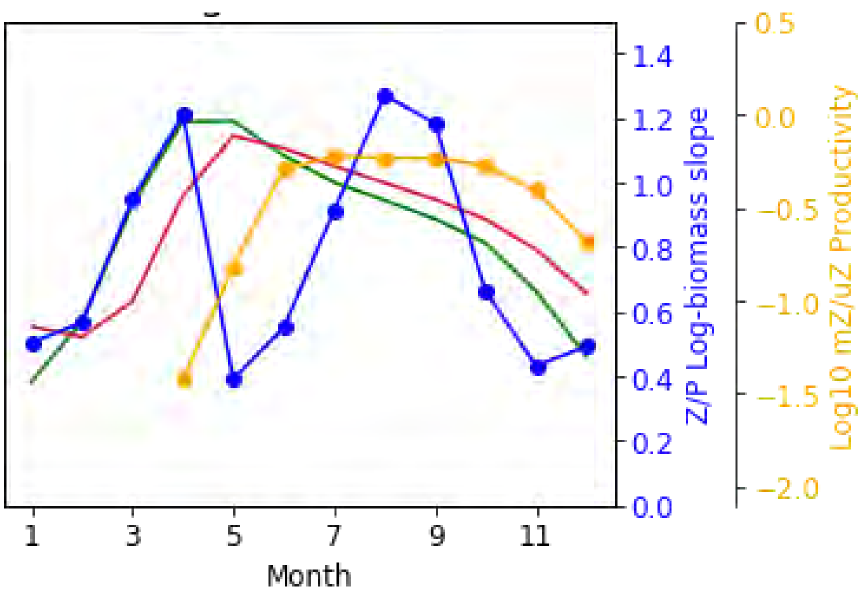


Equatorial and lower latitude regions



- Spatially heterogeneous
- Long food chains
- Supports low densities of highly mobile species (e.g., tunas)?

Subpolar regions



- Seasonal dynamics dominate
- Strongly coupled trophic levels
- Supports opportunistic, less mobile species (e.g., groundfish)?

Summary

- **A size-structured plankton model is a parsimonious method of adding ecosystem complexity**
  - Allometric relationships are key
  - Enables future integration with size-resolved detritus groups
  - Potential for development into a continuous size-based model
- **Predator-prey biomass scaling for examining food-web shifts**
  - Average scaling is sublinear over the global ocean
  - High latitude areas can have super-linear scaling
  - Sublinear areas: food web lengthens as biomass increases
  - Time and space variations on dominant processes controlling trophic biomass scaling
- **How does the predator-prey biomass scaling extend to higher trophic levels?**

Acknowledgments

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Comments?

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