Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming

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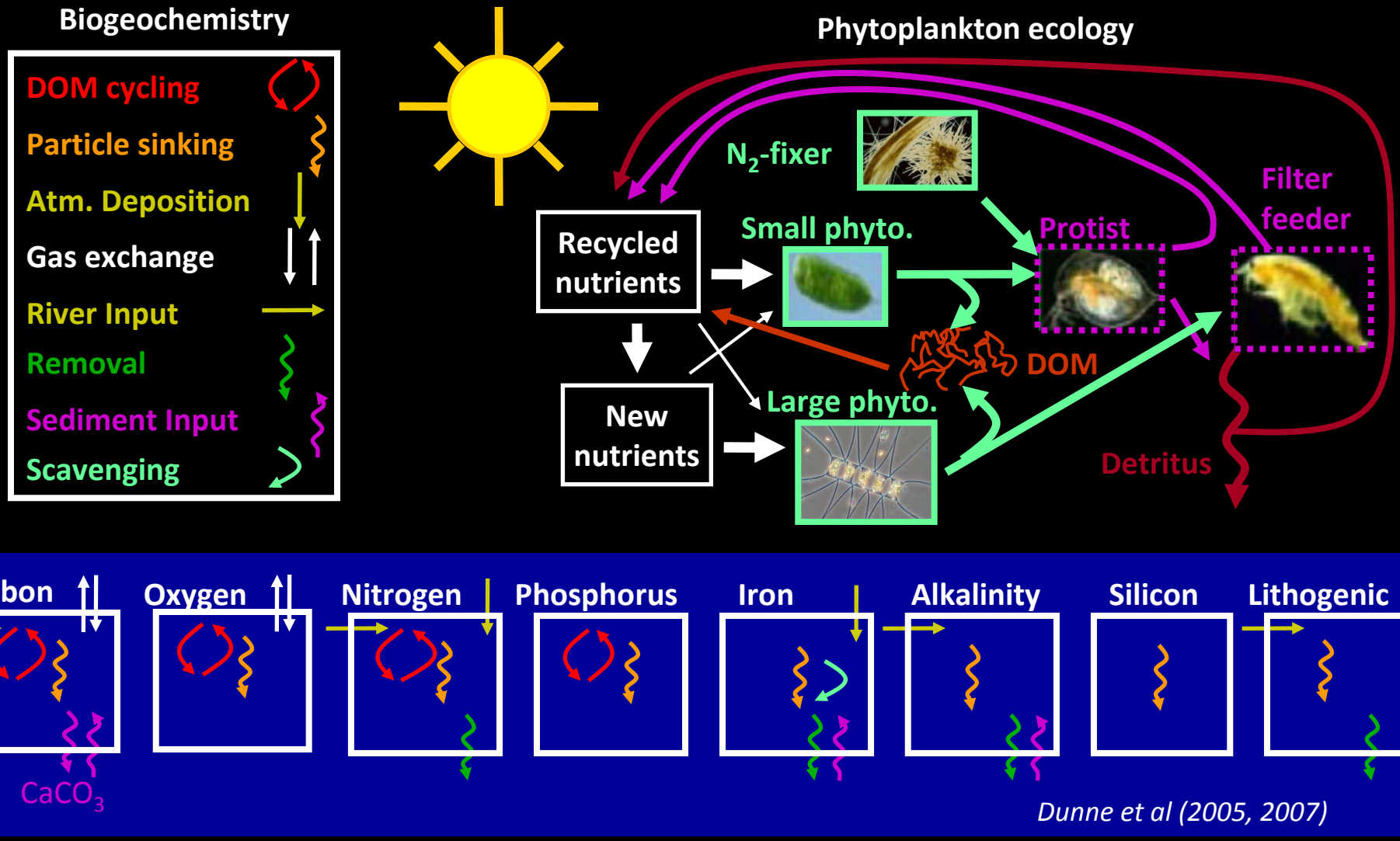
NOAA GFDL Earth System Model 2.1 (ESM2.1)

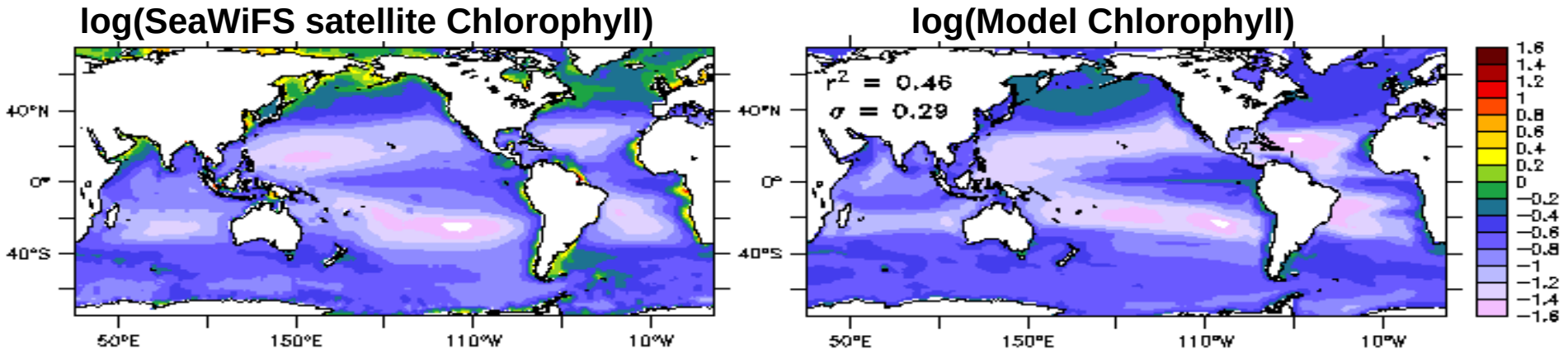
- Coupled climate and biogeochemical model
  - Global coupled climate model CM2.1
    - Atmosphere, ocean, land, sea ice
  - Tracers of Phytoplankton with Allometric Zooplankton (TOPAZ)
    - Major nutrients and four phytoplankton classes
- Horizontal resolution in ocean:
  - 1° x 1° north of 30° N, with latitudinal resolution increasing to 0.33° at equator
- Vertical resolution:
  - Ocean: 50 levels, with 22 10m levels in the upper 220m
  - Atmosphere: 24 levels
- We Used Monthly N Pacific output from 1998 - 2100

Tracers Of Phytoplankton with Allometric Zooplankton (TOPAZ) simulates the mechanisms that control the ocean carbon cycle



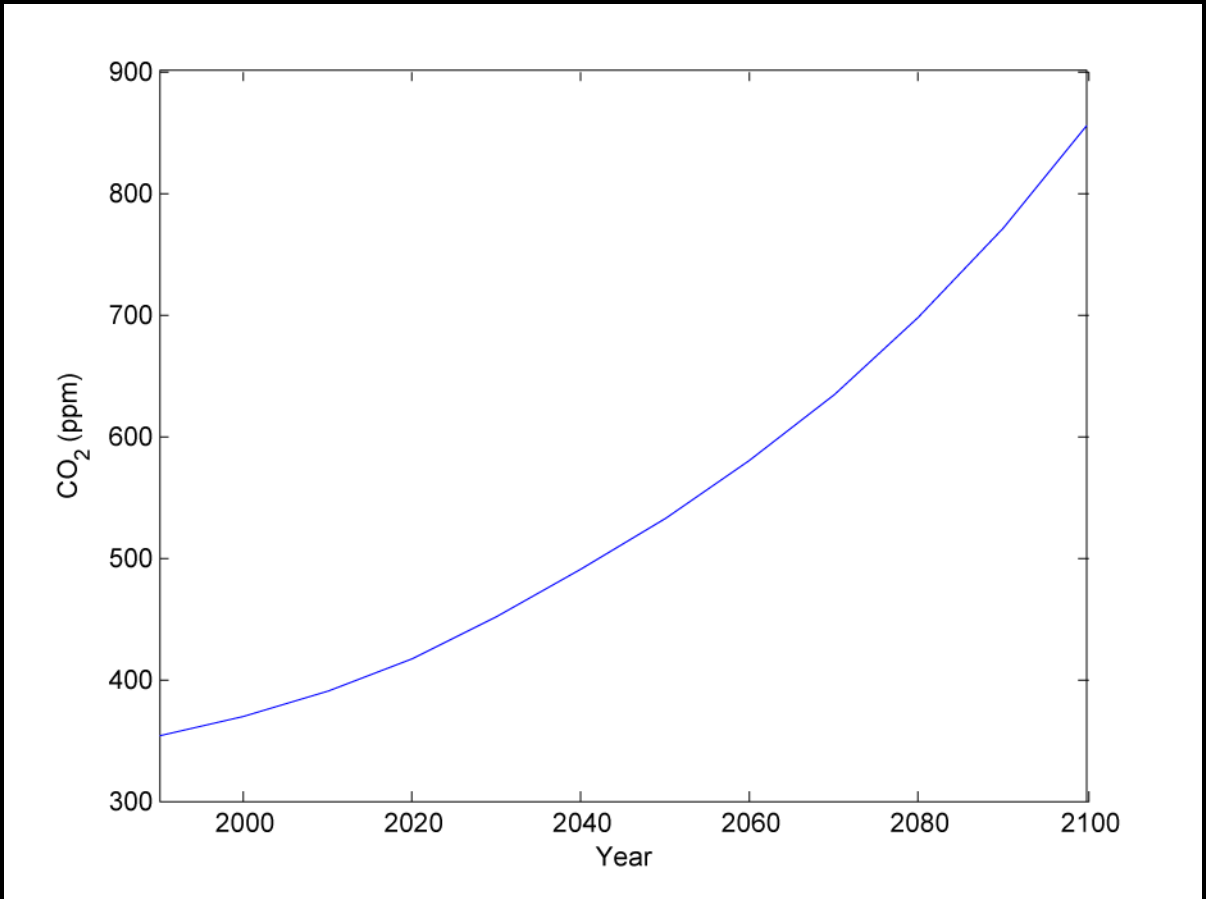
Dunne et al (2005, 2007)

Validation of ESM2.1 with TOPAZ



In historical simulation TOPAZ reproduces SeaWiFS chlorophyll spatial and temporal variability and captures much of the temporal variation in the 50-yr Continuous Plankton Recorder (Henson et al. 2009a, Henson et al. 2009b). However in the North Pacific while the Transition Zone is reproduced, its shape is not as zonal as it should be.

CO_2 Forcing Trajectory (Scenario A2)



Biomes

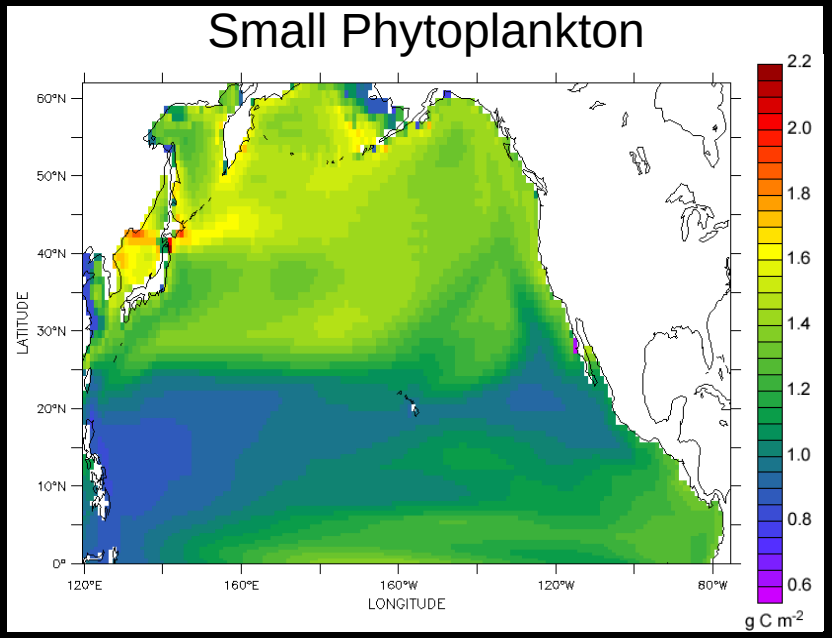
- Longhurst (1995) based on physical forcing defined 4 Biomes: (Polar, Westerlies, Trade-wind,Coastal boundary) further refined to 10 per ocean basin.

- Hardman-Mountford et al. (2008) defined 6 based on SeaWiFS surface Chl levels- very high to very low.

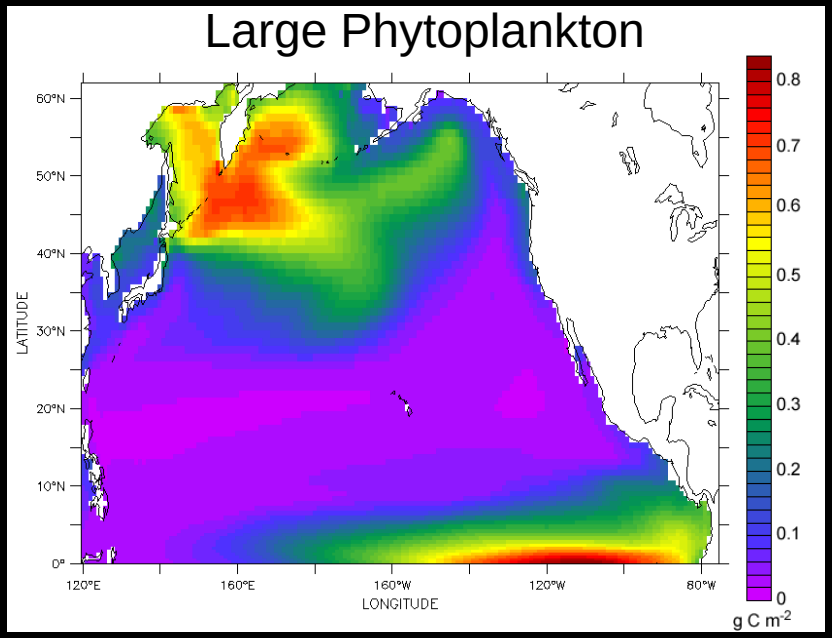
- Dynamic biomes and climate model - Sarmiento et al. (2004) biomes based on physical forcing (marginal sea ice, subpolar, subtropical seasonal, subtropical permanent, low-latitude upwelling).

20-Year Mean Phytoplankton Biomass (1998 – 2017)

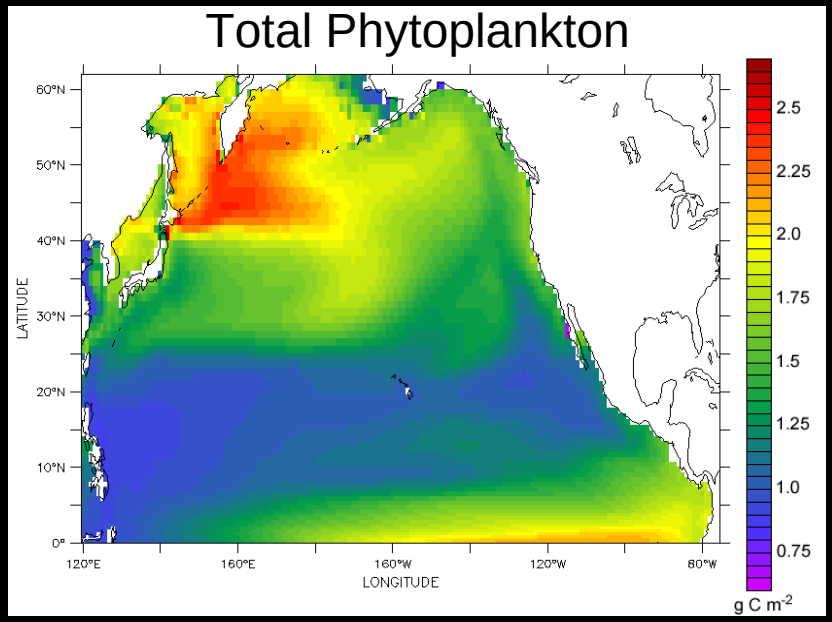
Small Phytoplankton



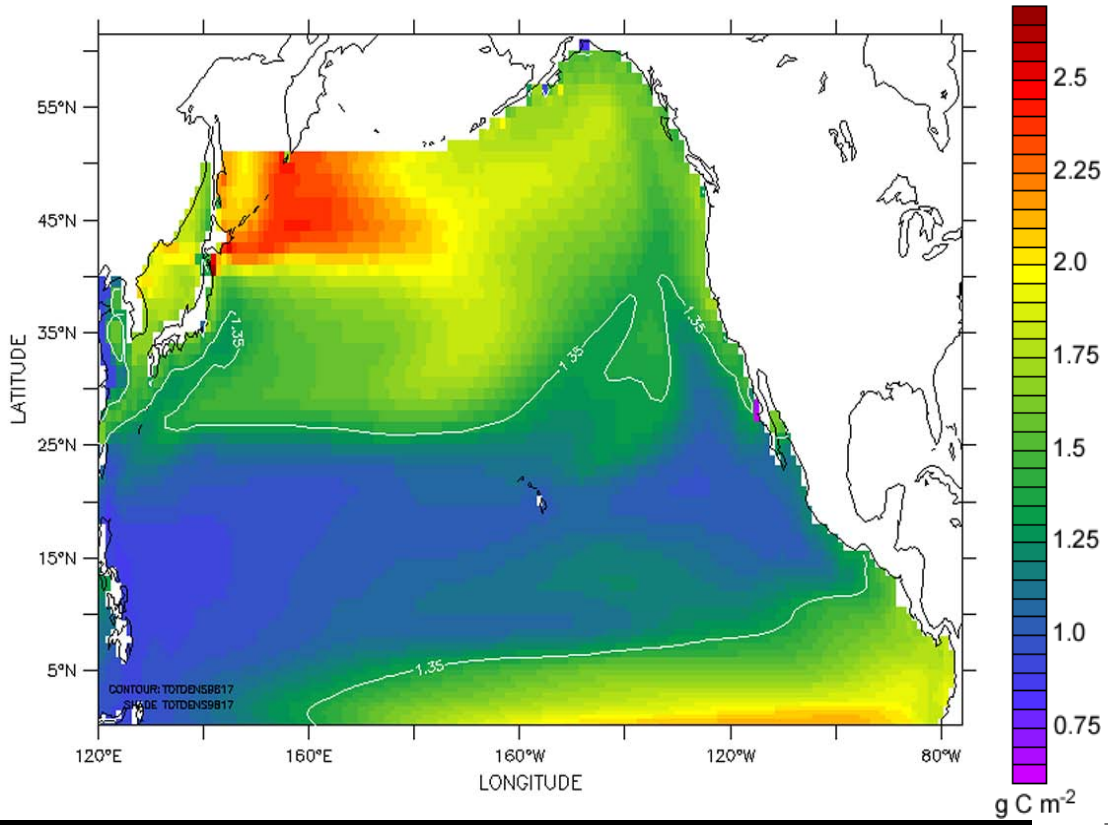
Large Phytoplankton



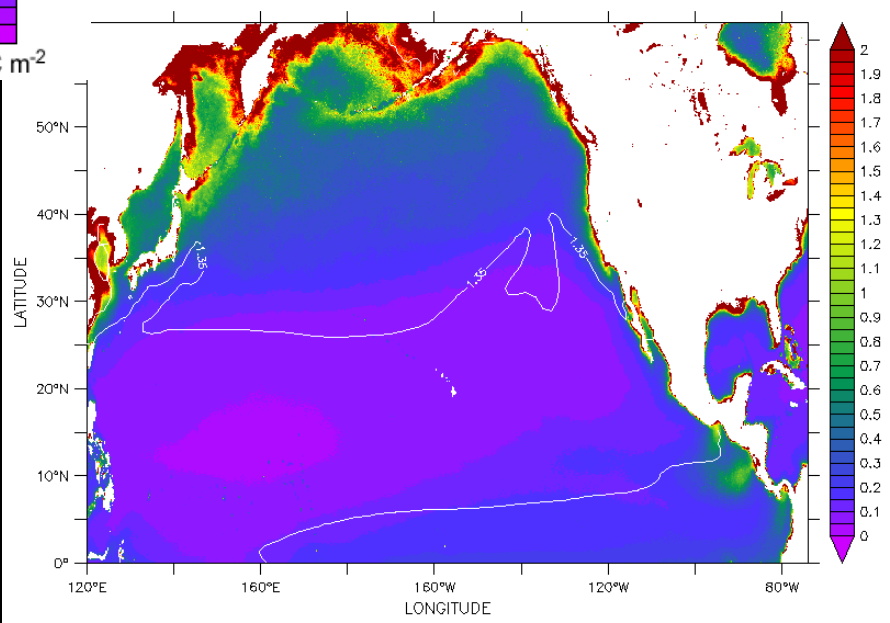
Total Phytoplankton



Total Phytoplankton



Model-derived Biome Boundaries Overlaid on SeaWiFS Climatology



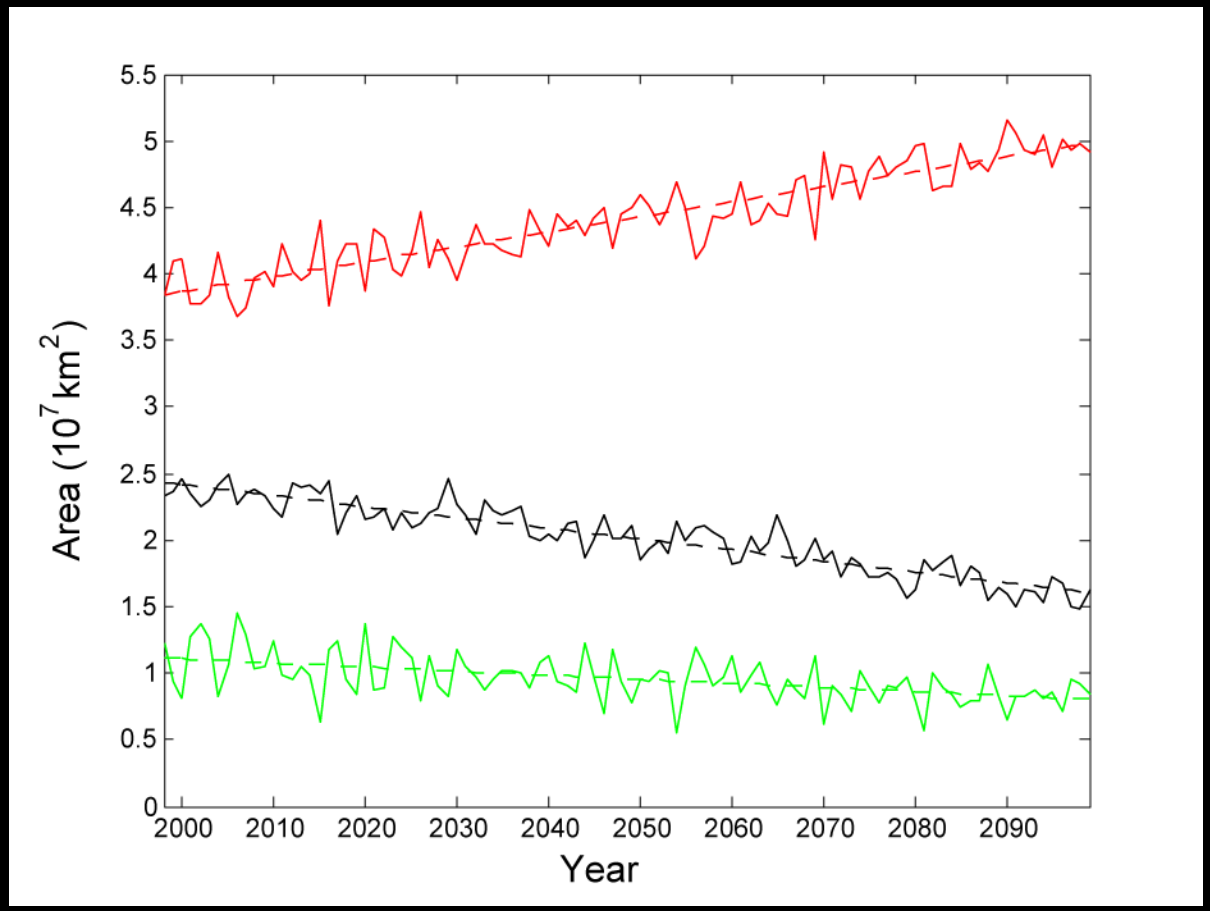
Biome definitions

1. Subtropical: area with phytoplankton not exceeding 1.35 gC/m^2

2. Temperate: Area north of 20^o N lat with phytoplankton exceeding 1.35 gC/m^2

3. Equatorial Upwelling: Area south of 20^o N lat with phytoplankton exceeding 1.35 gC/m2

Annual Mean Biome Area over the 21st Century

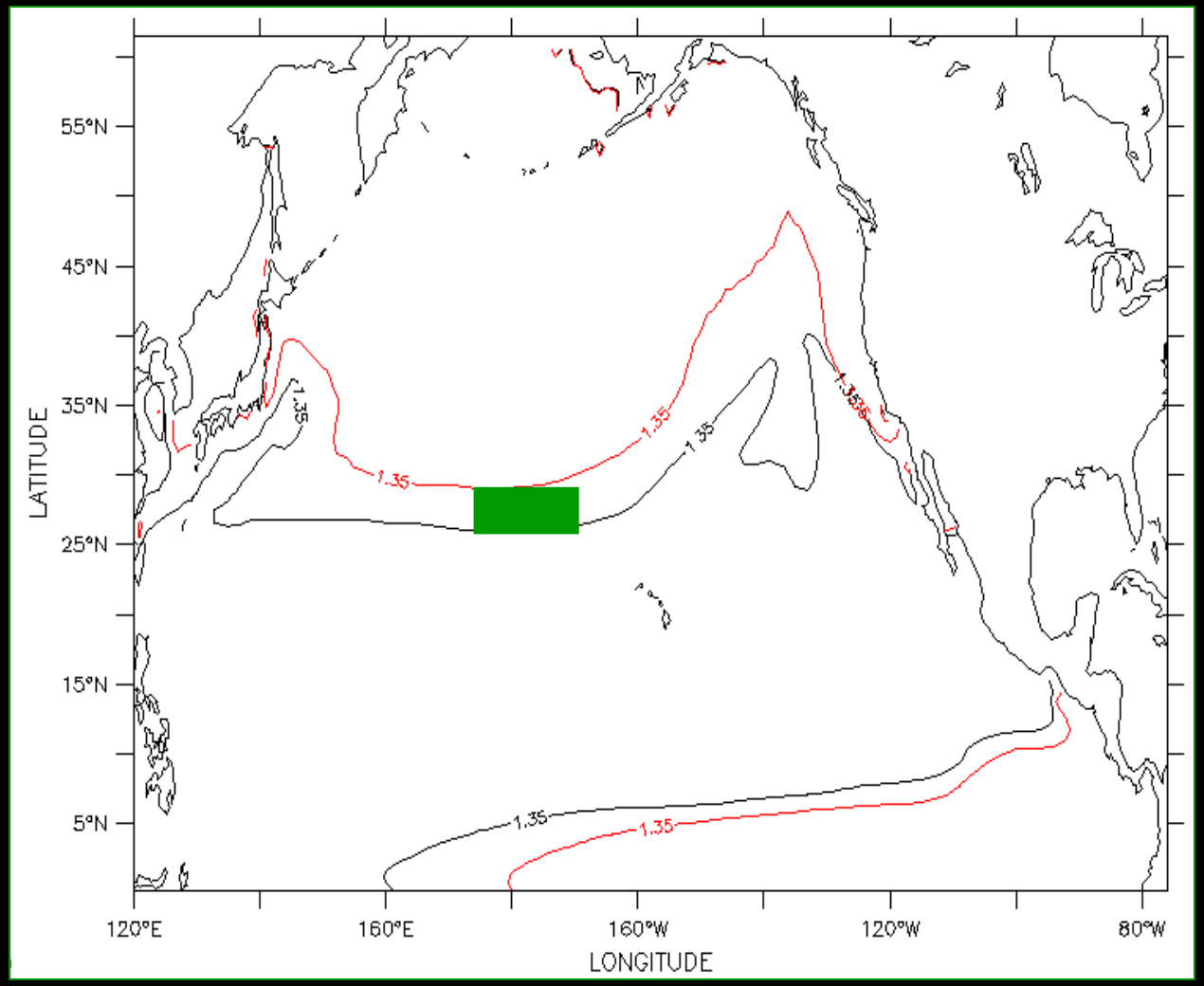


Temperate:
- **Area decreases 34%/100 yr**

Subtropical:
- Area increases **29.5%/100yr**

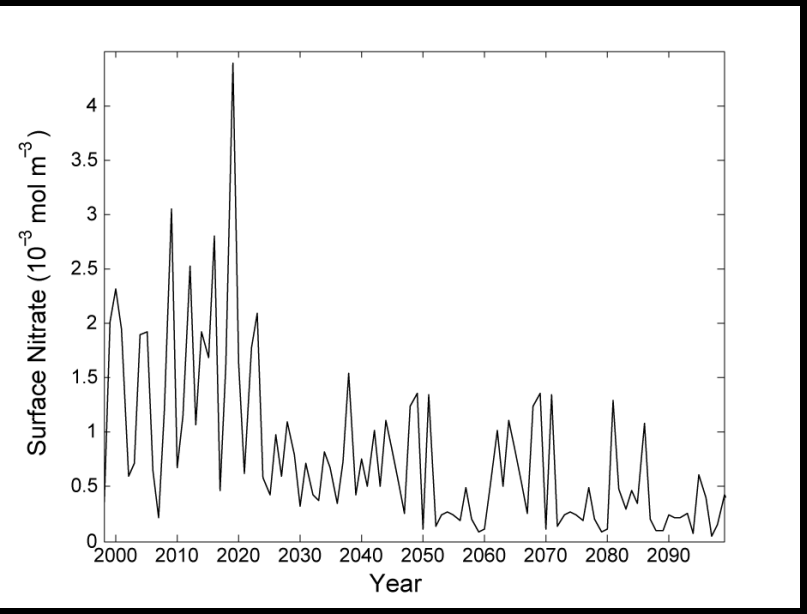
Equatorial Upwelling
Area decreases **27.7%/100yr**

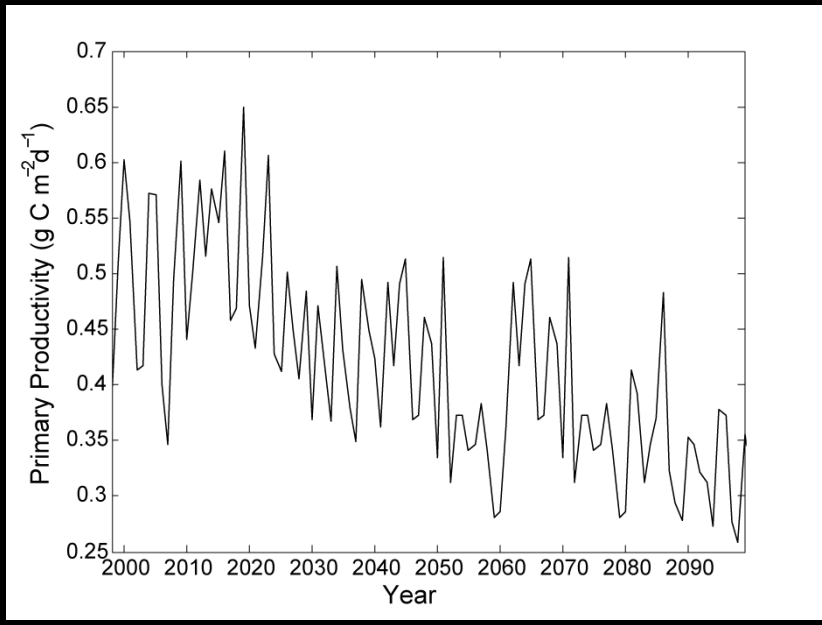
Biome Boundaries at beginning and end of the 21st Century

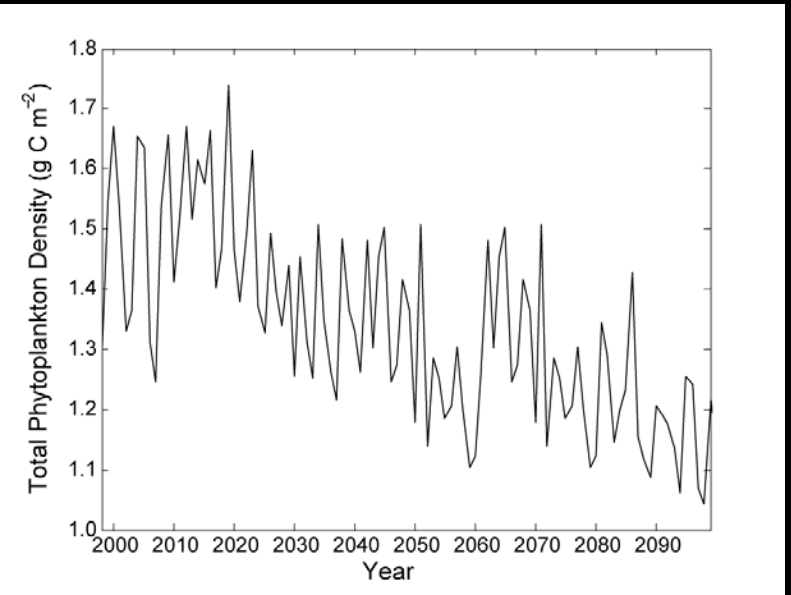


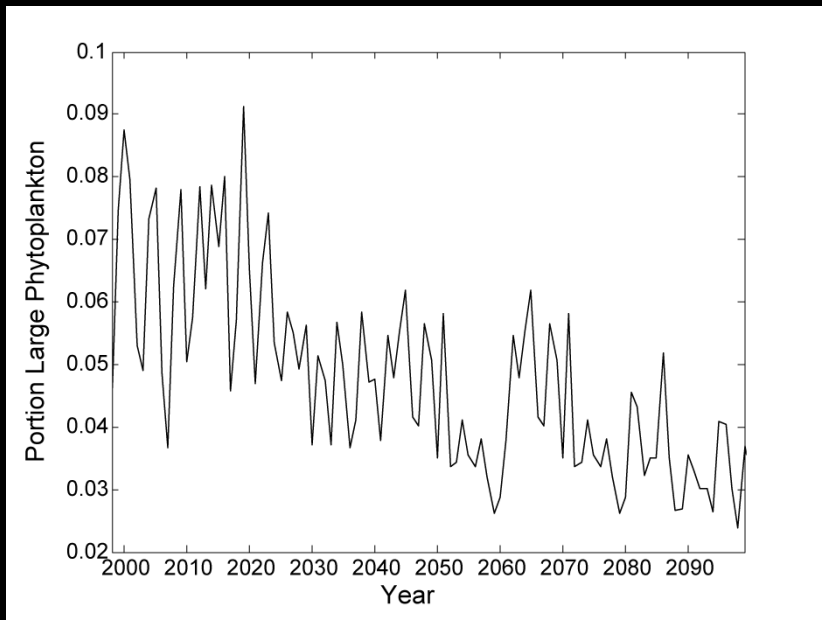
Boundary box:
27˚ - 29˚ N, 175˚ E - 170˚ W

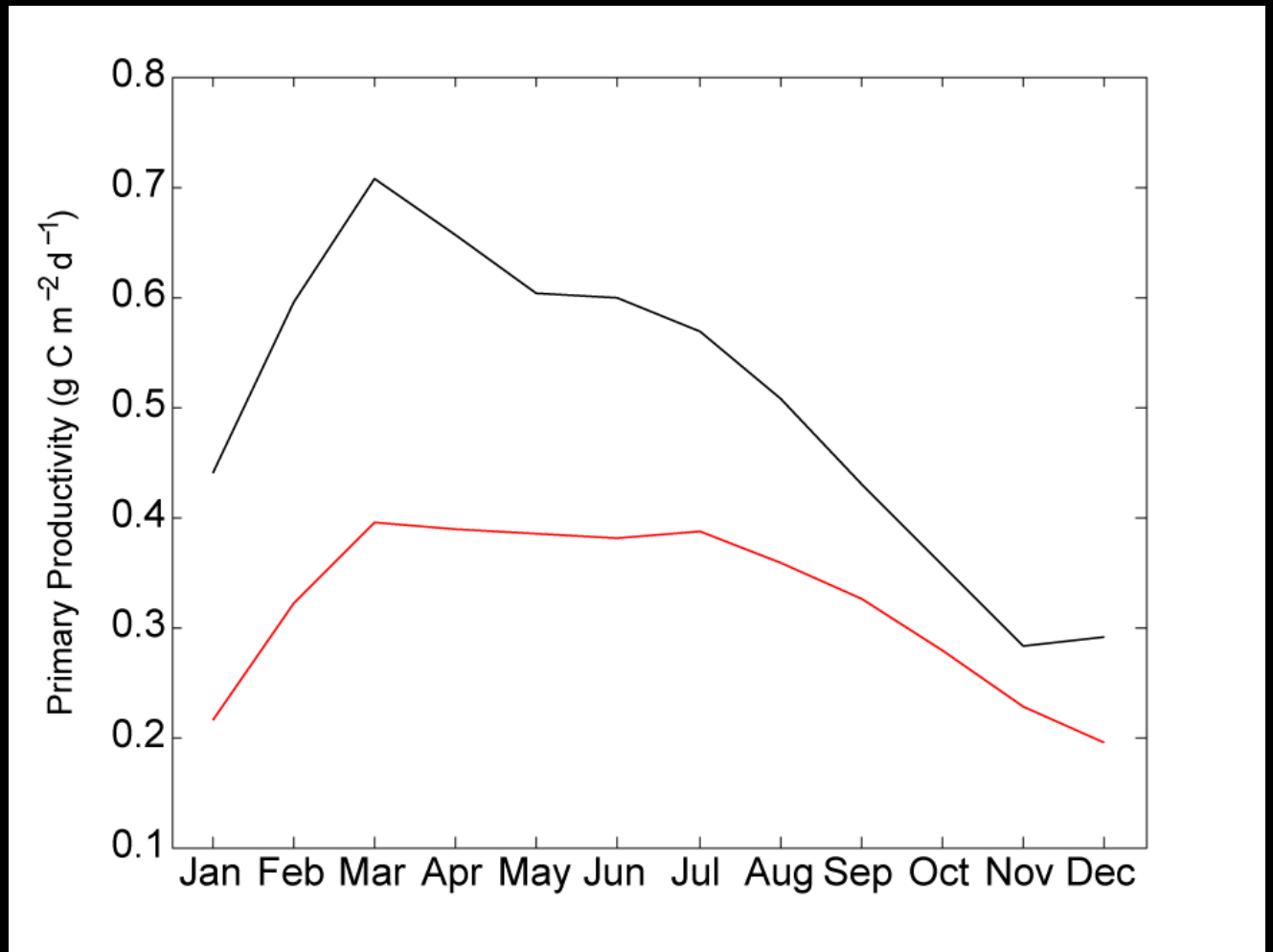
Time series of Nitrate, Primary Production, Phytoplankton biomass, and proportion of large Phytoplankton in the boundary box: 27° - 29° N, 175° E - 170° W, 1998-2100











20-Year Median Monthly Primary Productivity in the Boundary box at beginning and end of the 21st Century

Summary table of percent change over 100 years of physical and biological variables for each biome and total North Pacific, 1998-2100

	Temp	ST	EU	North Pacific
Area	**-34**	**30**	**-28**	**-**
Mean PP	**-6**	**-2**	**17**	**-4**
Total PP	**-38**	**26**	**-15**	**-4**
Phytoplankton Biomass Density	**-8**	**-8**	**-5**	**-13**
% Large	**-12**	**-7**	**-10**	**-27**
SST	**5**	**8**	**10**	**14**

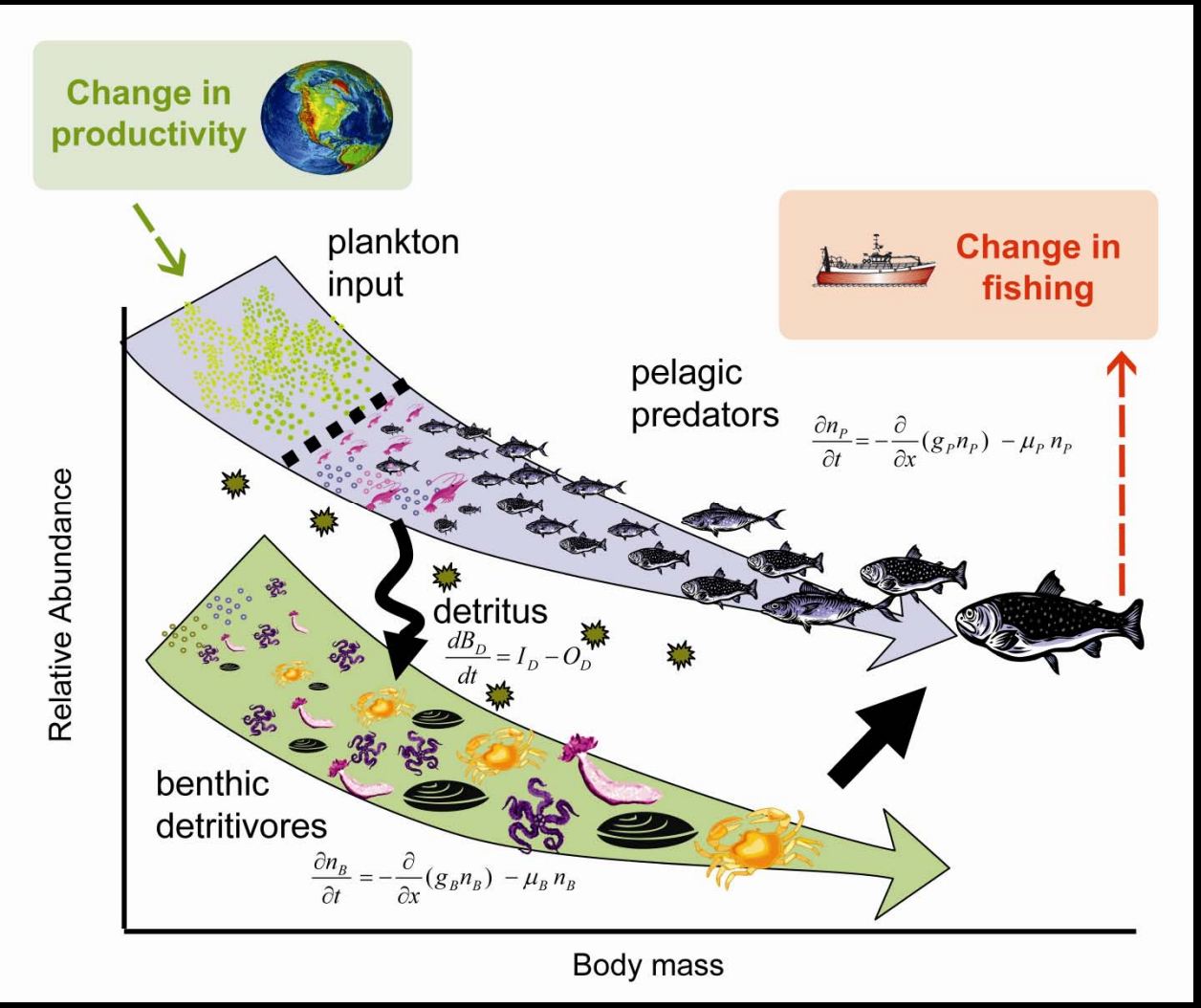
Results from other model studies

- large scale weakening (Vecchi et al., 2006) and poleward shift (Yin, 2005) in northern hemisphere westerlies

- NP basin-scale decreases in the magnitude of vertical velocities in both temperate and subtropical biomes (Rykaczewski and Dunne, accepted).

- Reduced nutrient input to euphotic zone in low and mid-latitudes in response to increased stratification seen in multi-model study (Steinacher et al. 2010)

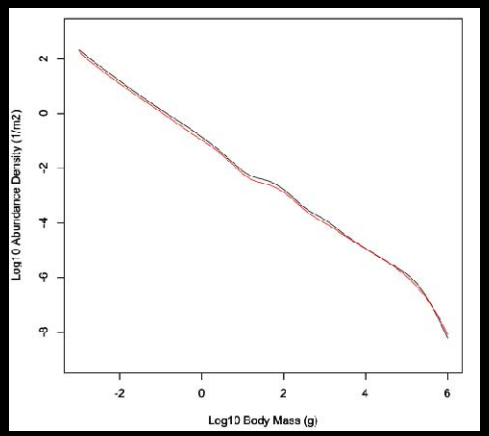
Size-based model



Assumes size-based predation, and size-specific growth and mortality are functions of food availability and SST

Input: monthly plankton size spectrum and SST

Output: monthly population size spectrum



Jennings et al. 2008, *Proc. R. Soc. B;* Blanchard et al. 2009 *J Anim Ecol*; Blanchard et al. 2010 *Theor. Ecol.*

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Phytoplankton Biomass	**-8**	**-8**	**-5**	**-13**
% Large	**-12**	**-7**	**-10**	**-27**
SST	**5**	**8**	**10**	**14**
Pelagic Biomass >2kg	**-39**	**18**	**-29**	**-28**

Current Forecast

- Weakening mid-latitude westerlies, increased vertical statification, reduced deep nutrients into euphotic zone in subtropical and temperate biomes, increased warming and deep nutrients to Calif Current and EU.

- North Pacific as a whole:
  - 4% decline in primary productivity
  - 13% decline in phytoplankton biomass
  - 27% decline in the fraction of large phytoplankton
  - 28% decline in fish biomass

- Subtropical habitat grows in area by 30% while temperate and EU shrink by 34% and 28%, respectively
  * 39% decline in fish biomass in Temperate Biome
  * 18% increase in fish biomass ST Biome
  * 29% decline in fish biomass EU Biome

Challenges in understanding and forecasting change

- Basin-wide ecosystem monitoring to evaluate the climate change forecast/models
- Improving our ability to forecast impacts to top trophic levels. Any hope to forecast species – specific changes? Incorporate error and multi-model ensembles
- Managing fisheries with slow average 0.4% decline/yr