Using dynamic biomes and a climate model to describe the responses of the North Pacific to climate change over the 21st Century

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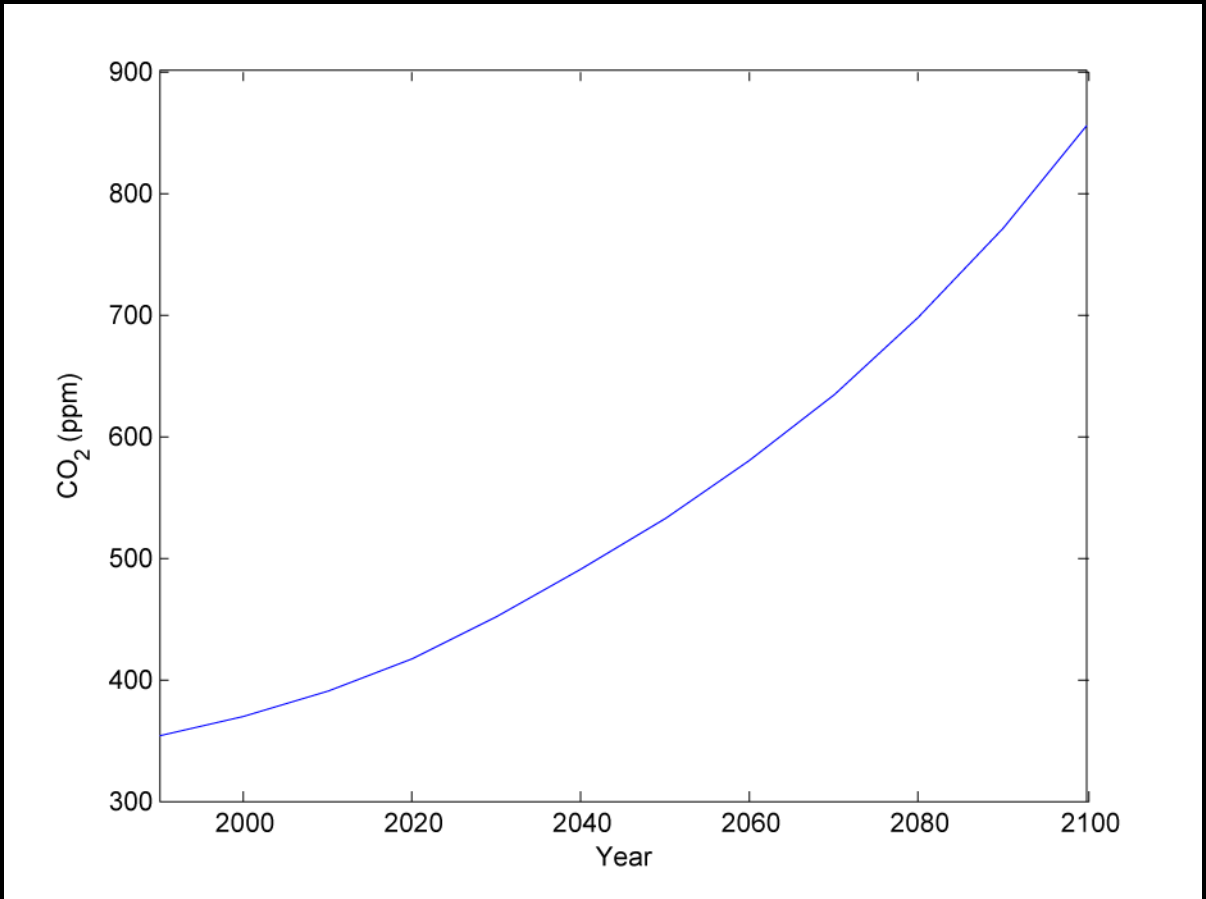
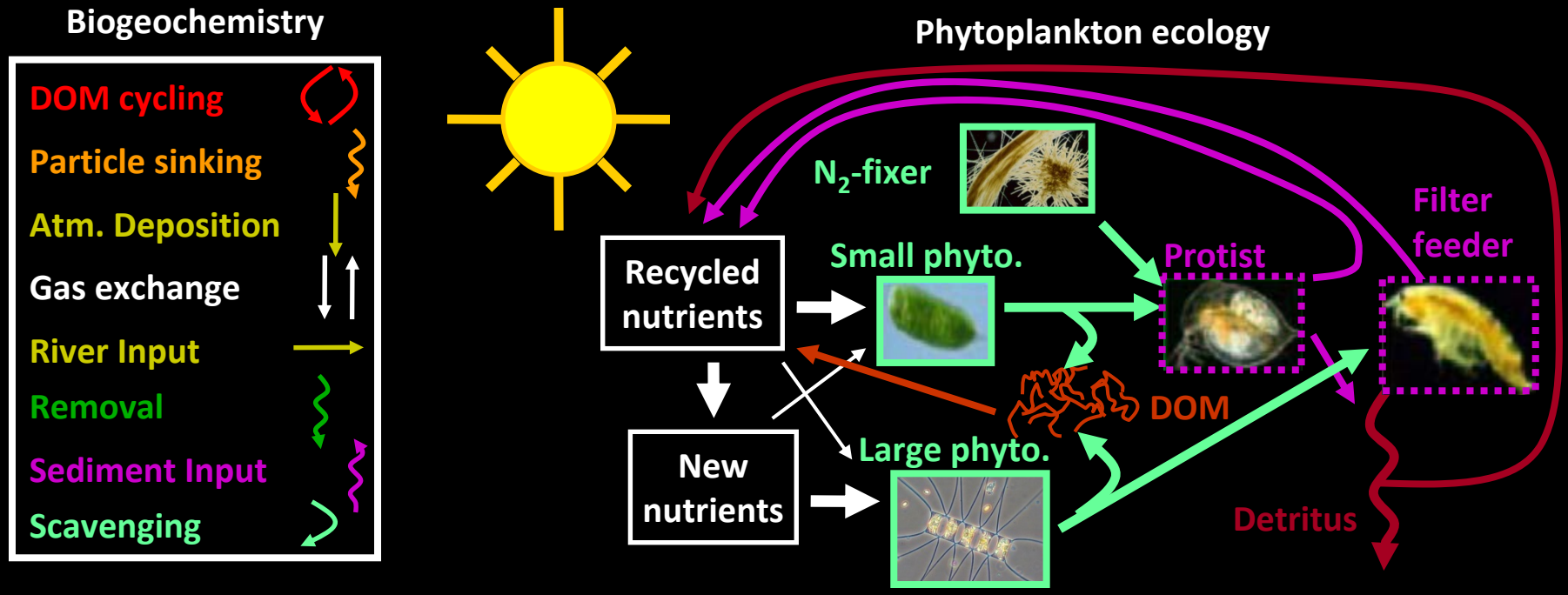
NOAA GFDL Earth System Model 2.1 (ESM2.1)

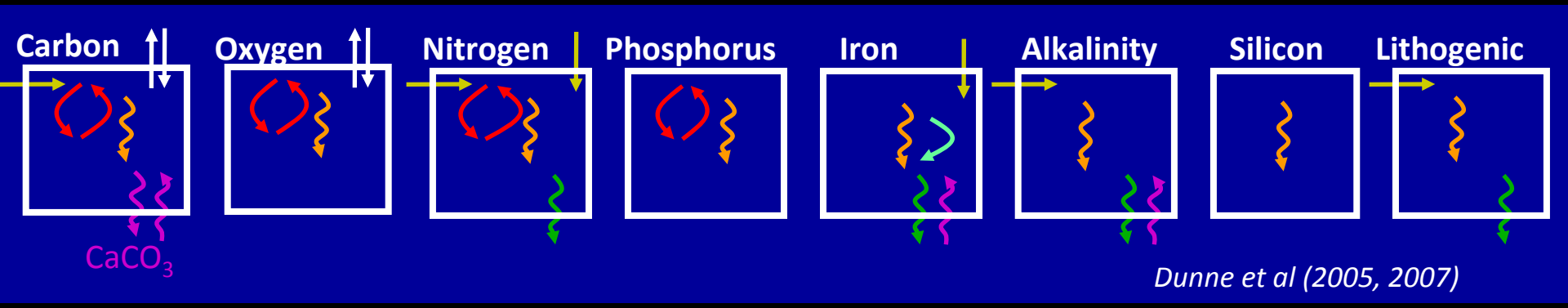
- Coupled climate and biogeochemical model
  - Global coupled climate model CM2.1
    - Atmosphere, ocean, land, sea ice
  - Tracers of Phytoplankton with Allometric Zooplankton (TOPAZ)
    - Major nutrients and four phytoplankton classes
- Horizontal resolution in ocean:
  - 1° x 1° north of 30°N, with 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

CO_2 Forcing Trajectory (Scenario A2)



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

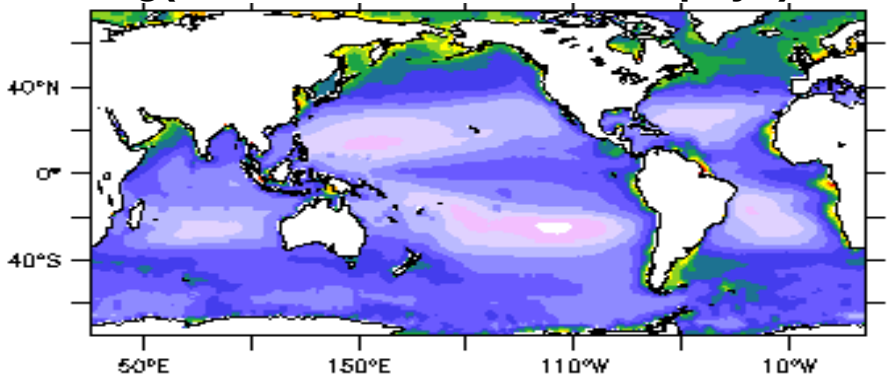




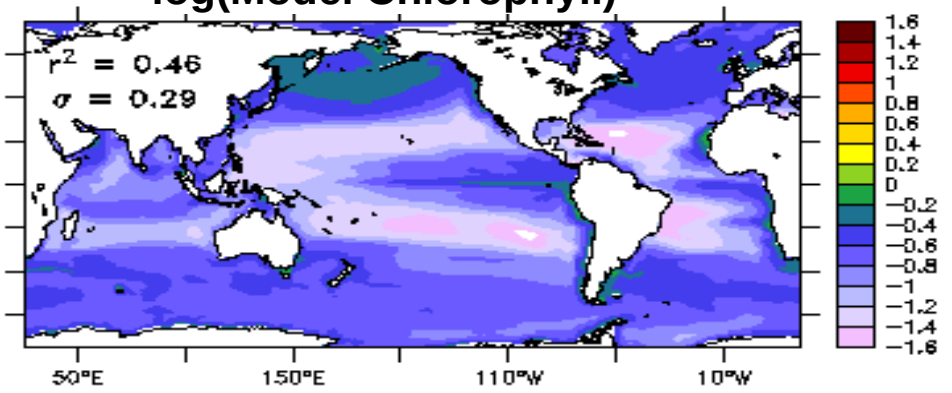
Dunne et al (2005, 2007)

HISTORICAL simulation reproduces SeaWiFS chlorophyll variability and puts it in a mutidecadal context

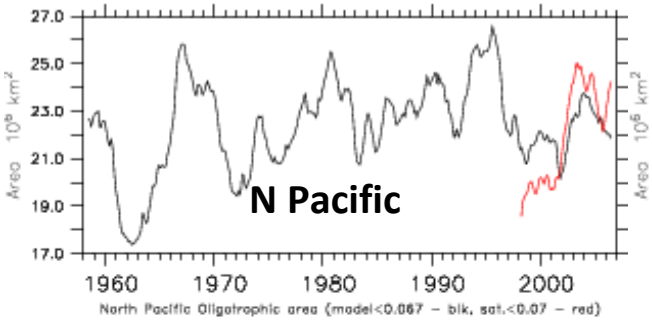
log(SeaWiFS satellite Chlorophyll)

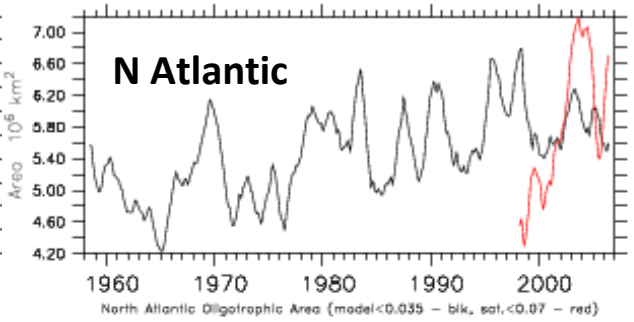


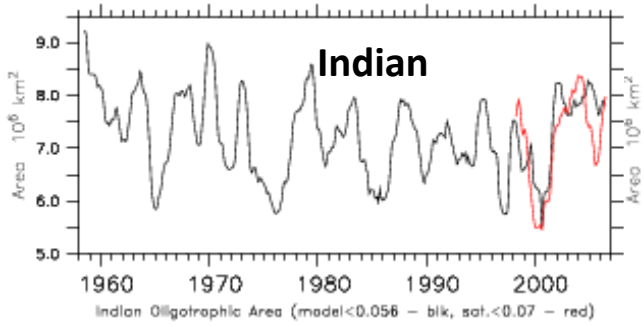
log(Model Chlorophyll)

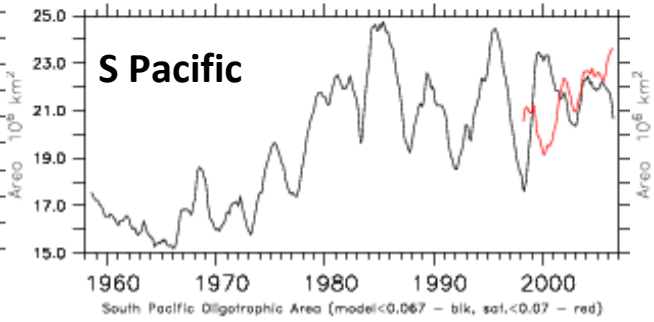


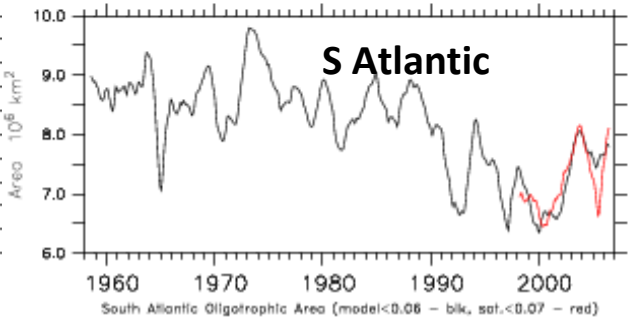
Simulated expansion of oligotrophic gyres (ocean deserts) is similar to **SeaWIFS** (Polovina et al. 2008) and within a large, multidecadal envelope.









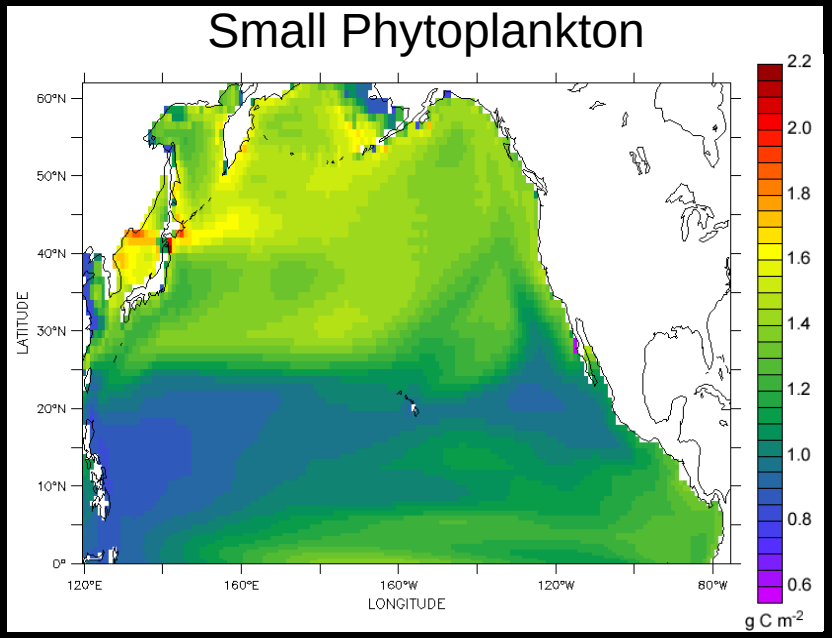


Biomes

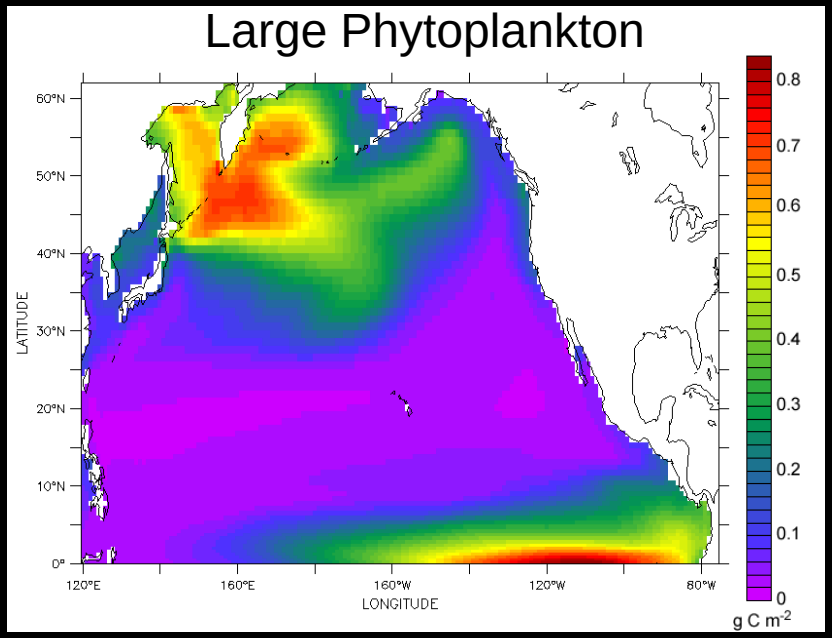
- Longhurst (1995) based on physical forcing defined 4 Biomes: (Polar, Westerlies, Trade-wind,Coastal boundary) further refined to 10 per ocean basin.
- Dynamic biomes and climate model - Sarmiento et al. (2004) biomes based on physical forcing (marginal sea ice, subpolar, subtropical seasonal, subtropical permanent, low-latitude upwelling).
- Hardman-Mountford et al. (2008) defined 6 based on SeaWiFS surface Chl levels- very high to very low.

20-Year Mean Phytoplankton Biomass (1998 – 2017)

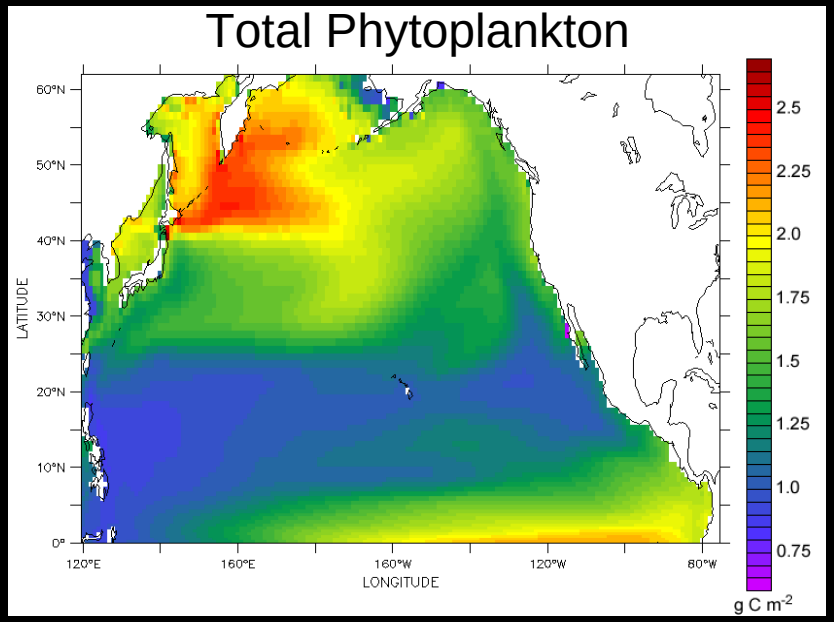
Small Phytoplankton



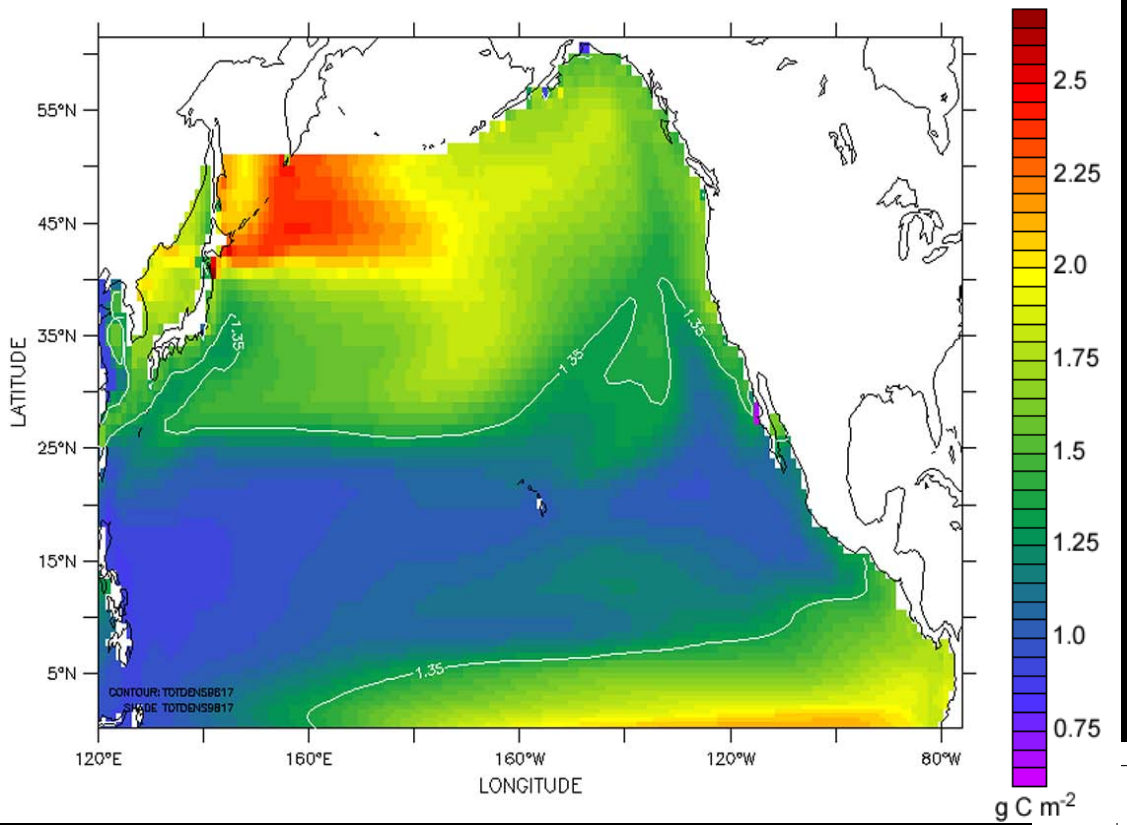
Large Phytoplankton



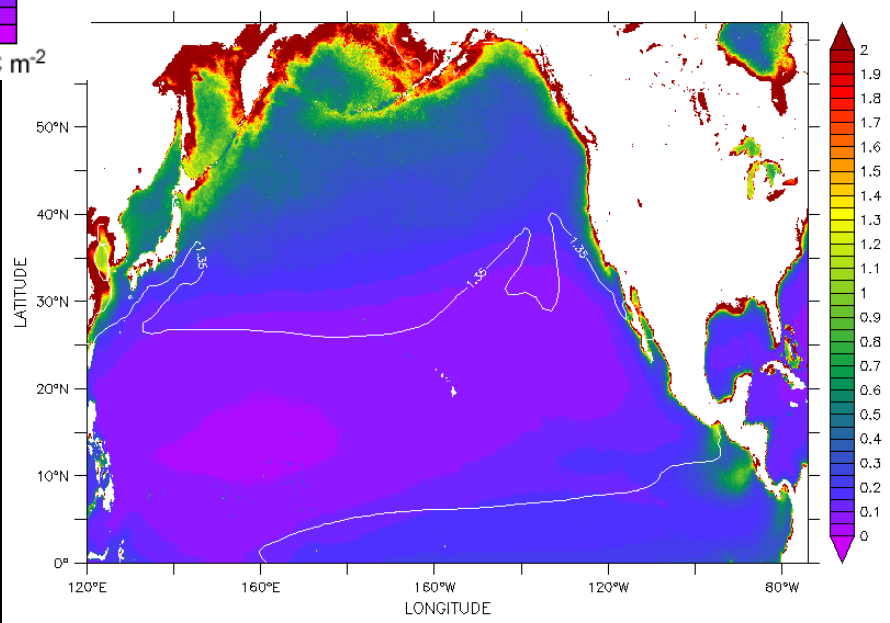
Total Phytoplankton



Total Phytoplankton



Model-derived Biome Boundaries Overlaid on SeaWiFS Climatology



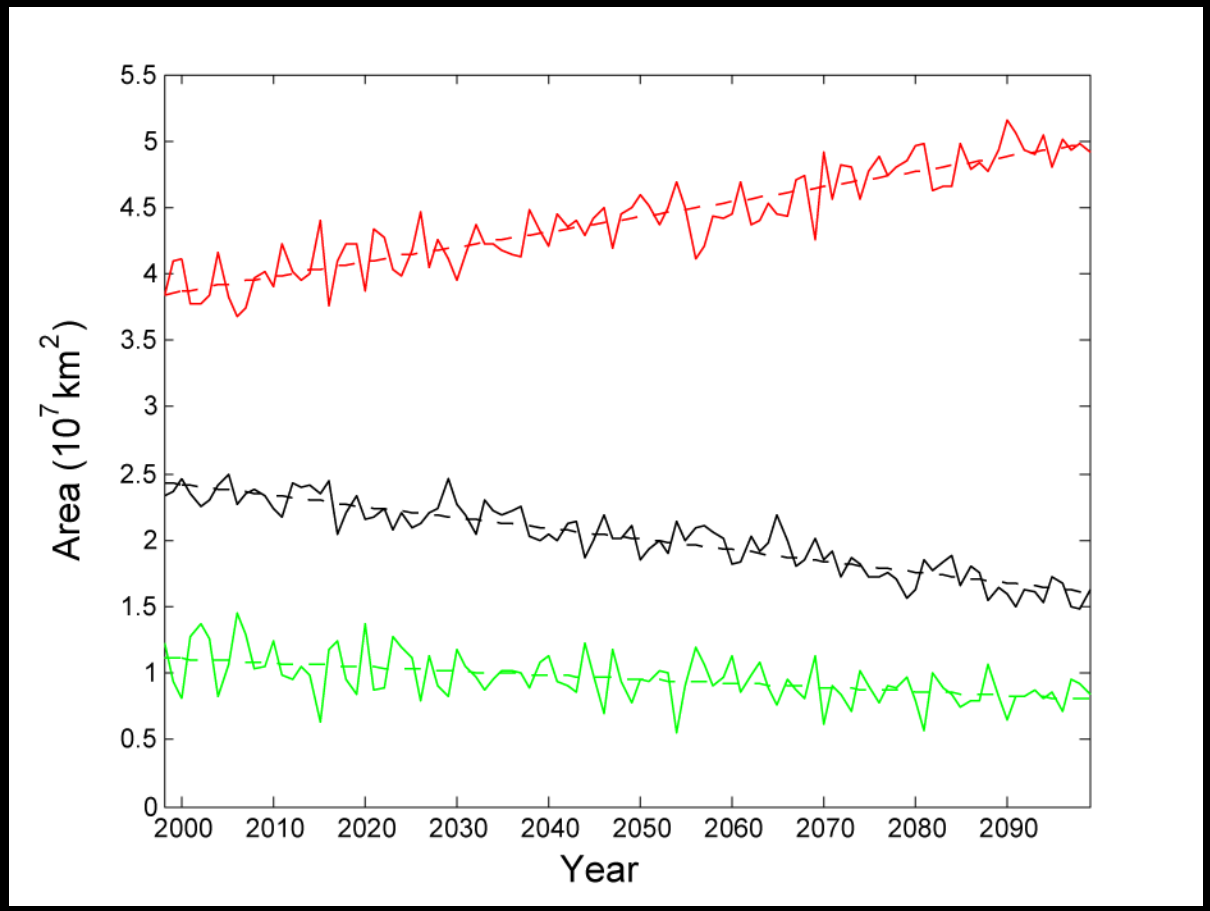
Biome definitions

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

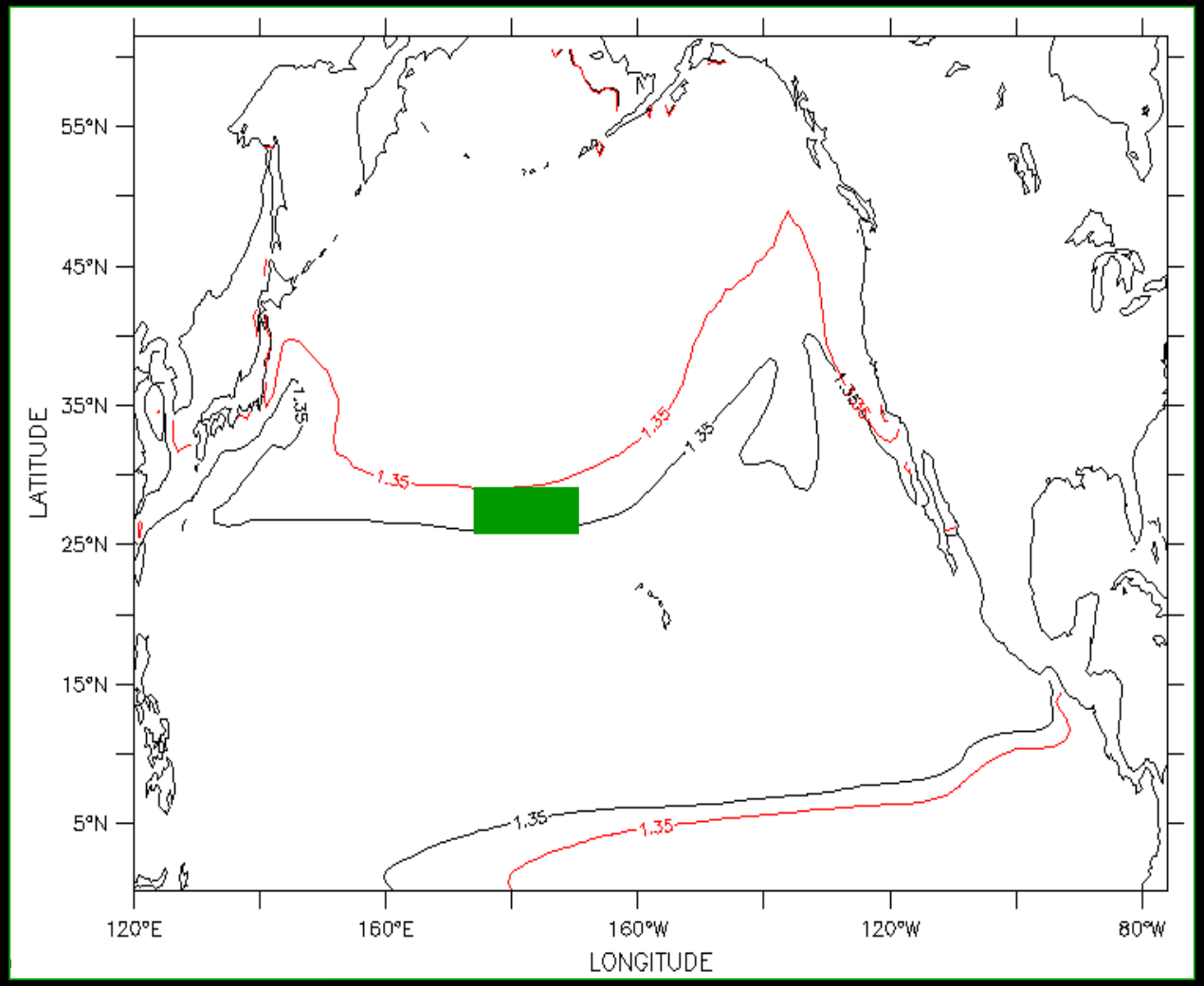


Temperate:
- **Area decreases 35%/100 yr**

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

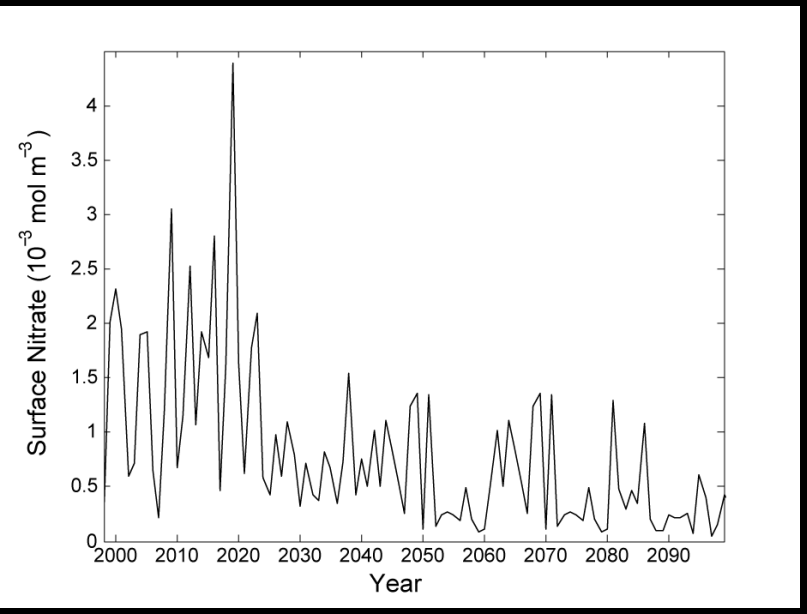
Equatorial Upwelling
Area decreases **27.7%/100yr**

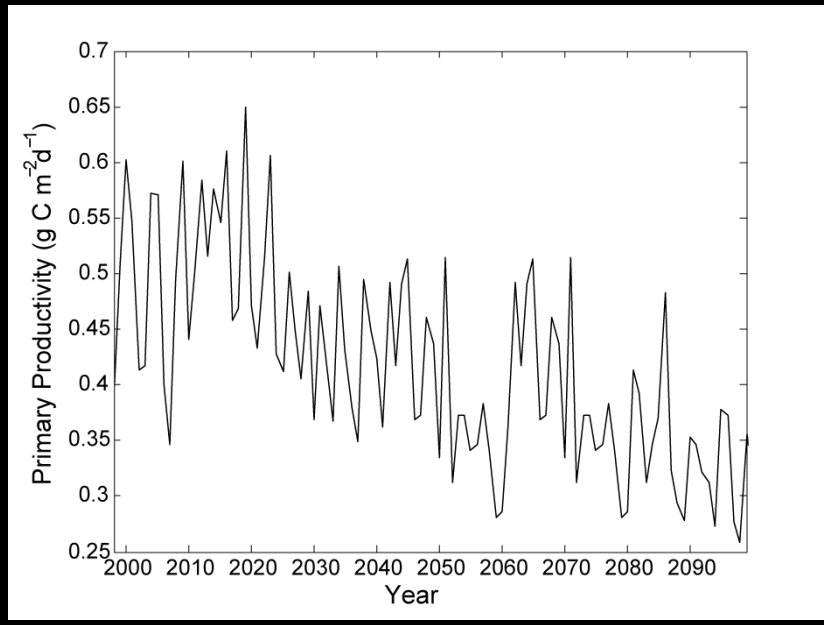
Biome Boundaries at beginning and end of the 21st Century

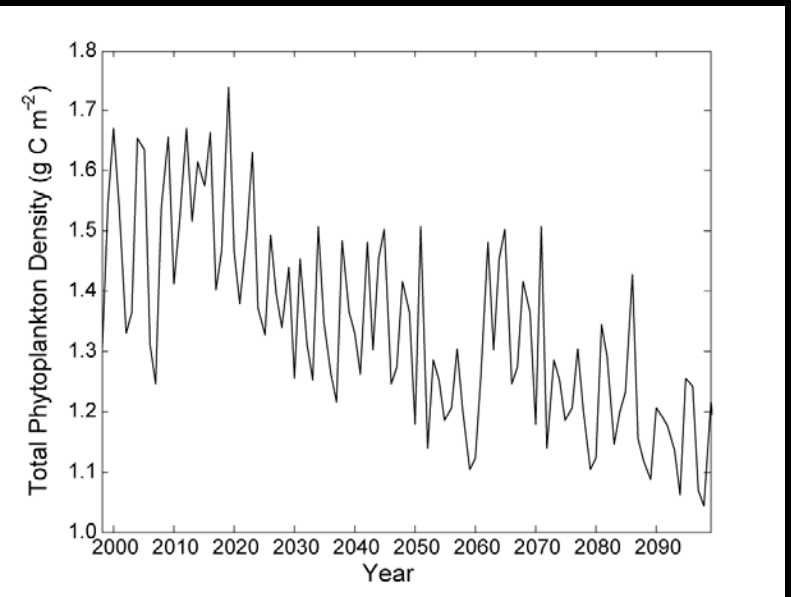


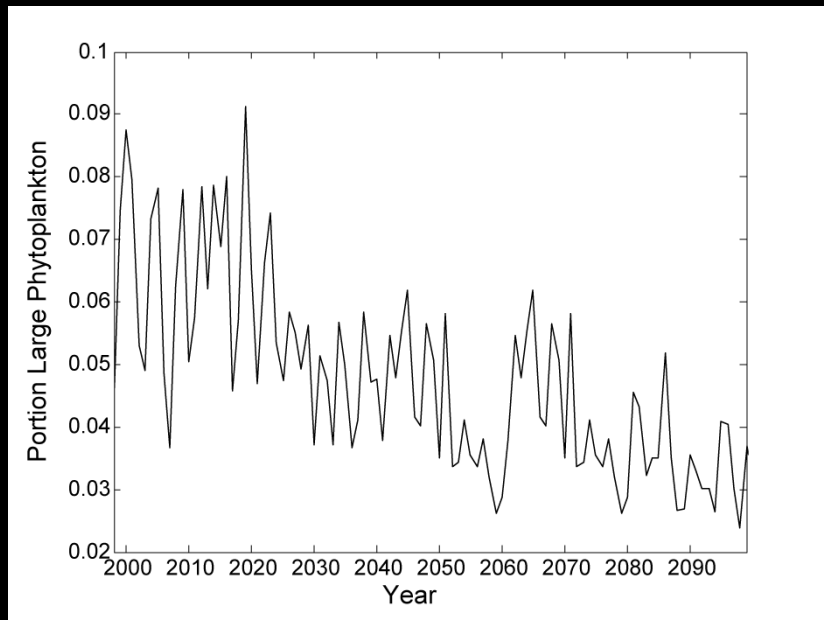
Boundary box:
27° - 29°N, 175°E - 170°W

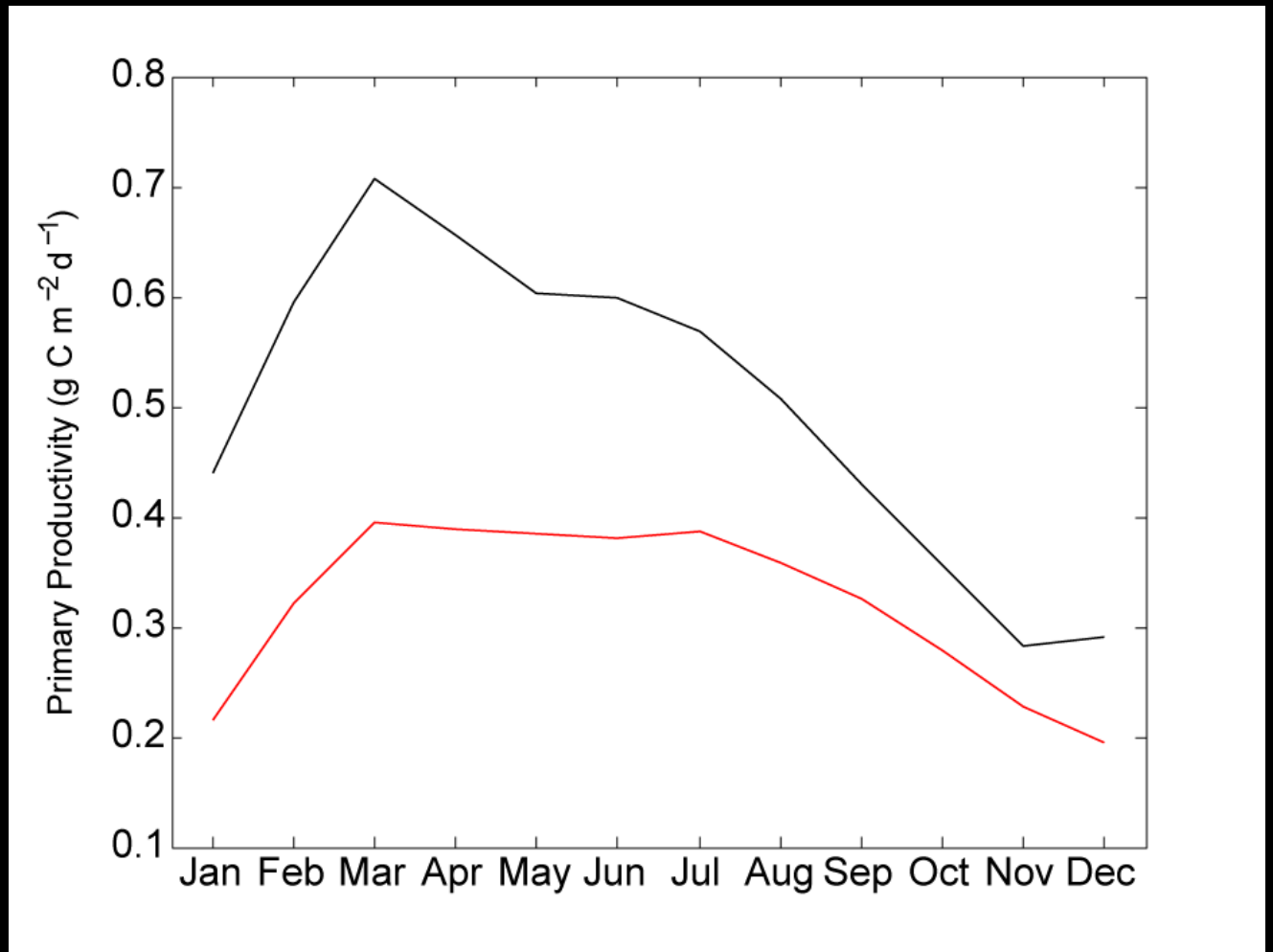
Time series of Nitrate, Primary Production, Phytoplankton biomass, and proportion of large Phytoplankton in the boundary box: 27°- 29°N, 175°E - 170°W, 1998-2100










1998 – 2017
2080 – 2099
20-Year Median Monthly Primary Productivity in the Boundary box at beginning and end of the 21st Century
Primary Productivity (g C m-2 d-1)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Annual Biome Primary Production and Total Biome Primary Production, 1998-2100

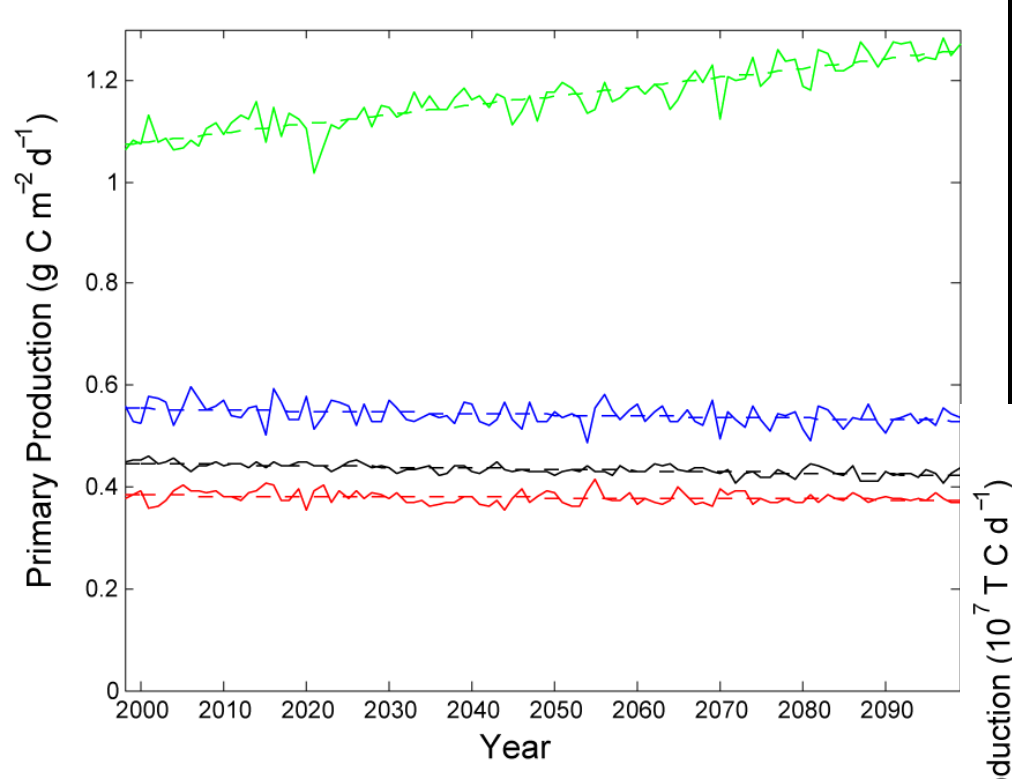
Change in pp density/100yr

Temperate	-5%
Subtropical	-2%
Equatorial Upwelling	17%
Total North Pacific	-5%

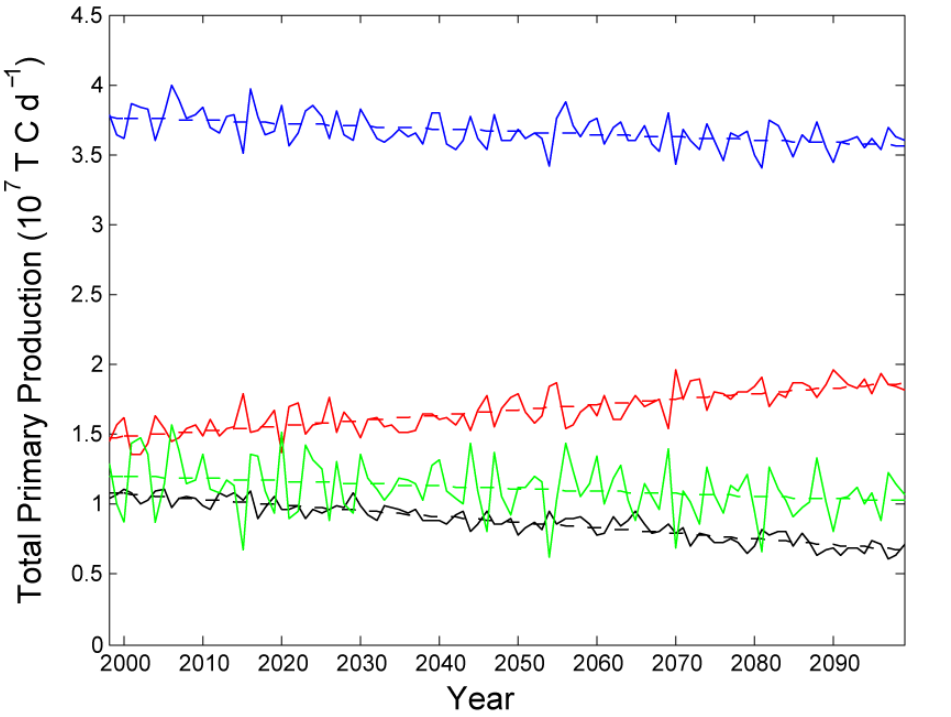
Change in total pp/100yr

Temperate	-38%
Subtropical	26%
Equatorial Upwelling	-15%
Total North Pacific	-5%

Mean annual Biome Primary Production Density

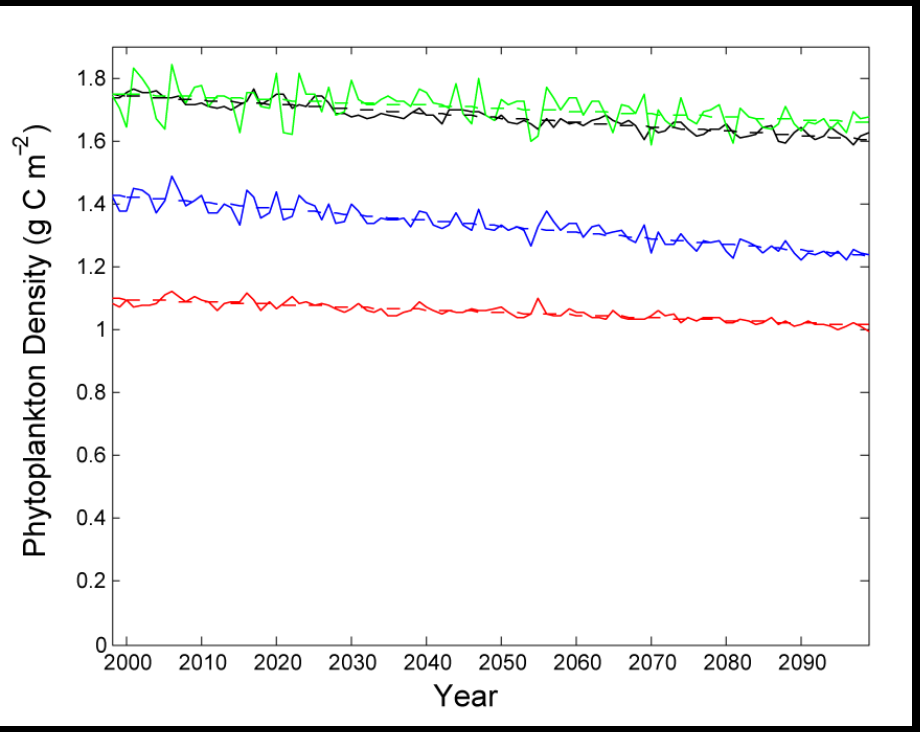


Total annual Biome Primary Production



Annual Biome Phytoplankton and Proportion of Large Phytoplankton, 1998-2100

Mean annual Biome Phytoplankton Density



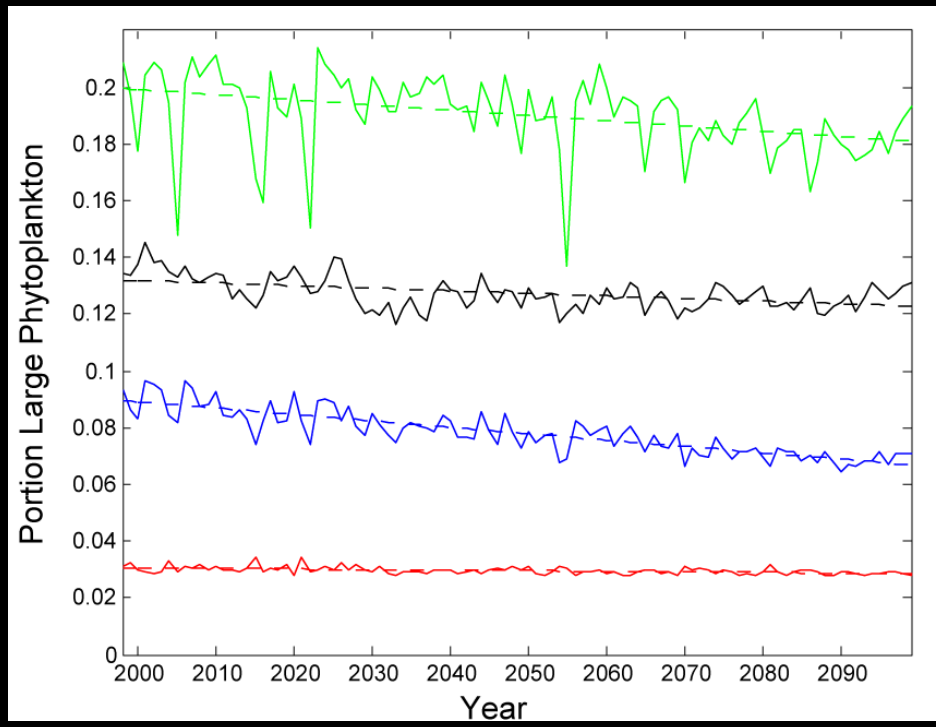
Change in P density/100/yr

Temperate	-8%
Subtropical	-7%
Equatorial Upwelling	-5%
Total North Pacific	-13%

Change in Large P/100/yr

Temperate	-12%
Subtropical	-7%
Equatorial Upwelling	-10%
Total North Pacific	-27%

Biome Proportion of Large Phytoplankton

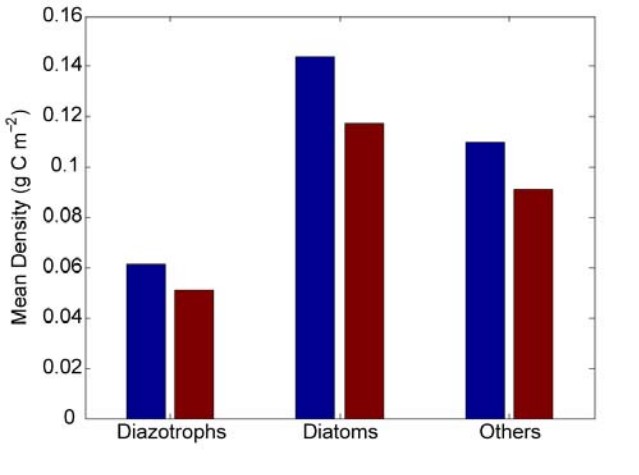


Mean Biome Phytoplankton Density for Large Phytoplankton Groups in 1998-2017 and 2080-2099

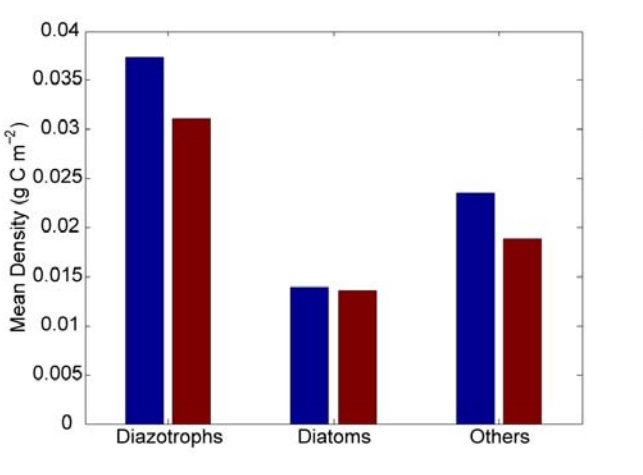
1998 – 2017

2080 – 2099

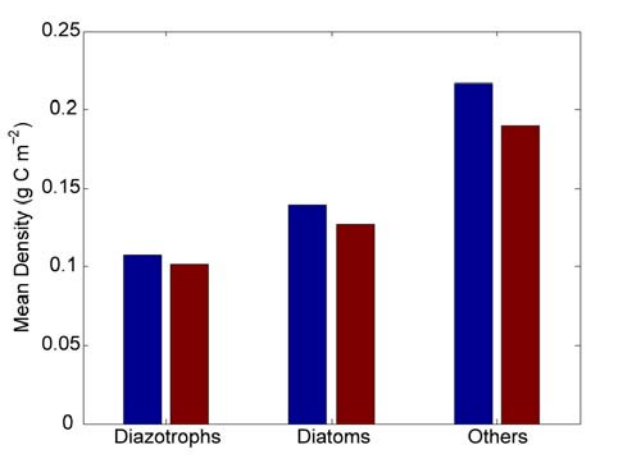
Temperate



Subtropical



Equatorial Upwelling



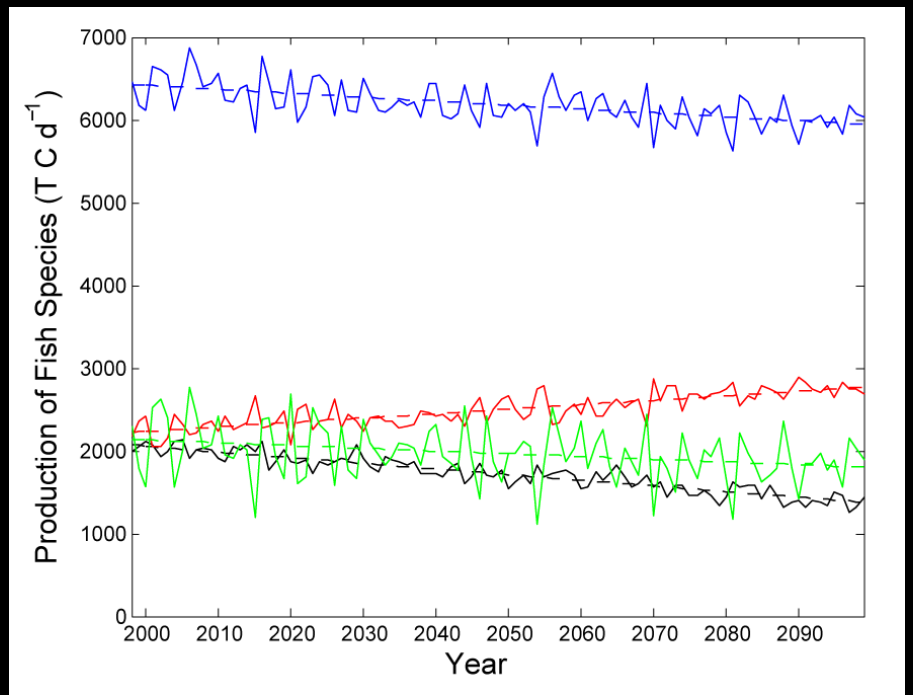
Change in Fish Production

Fish Production = PPx(Trophic Efficiency)**(TL-1) (Iverson 1990)

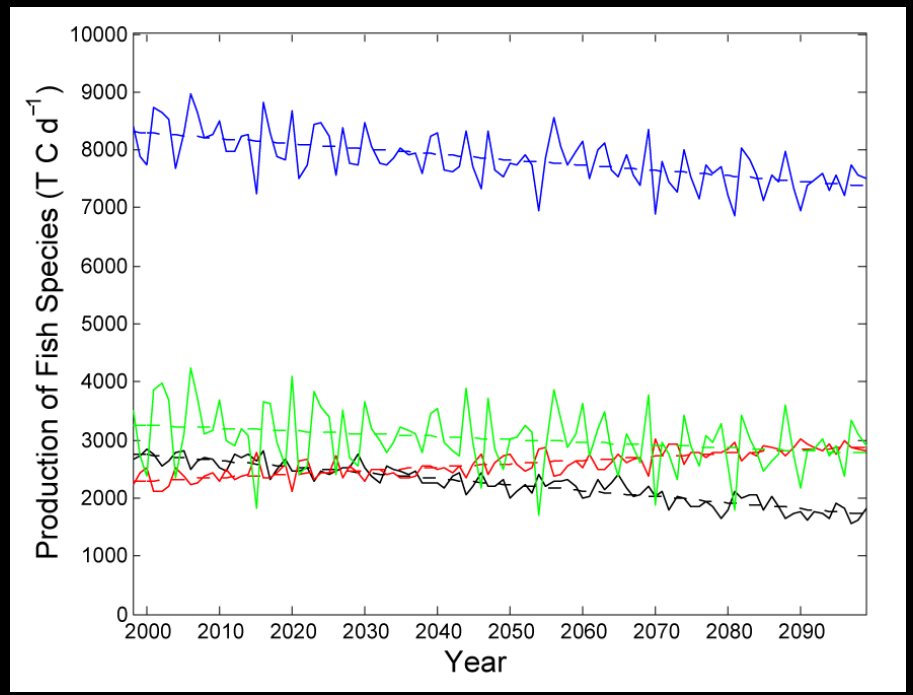
Approach 1: Use 10% TE and Jennings et al TLs (4.8 for Temperate and Subtropic, and 4.7 for EU)

Approach 2: Use TE for transfer from phytoplankton to zooplankton 10% for Subtropic, 15% for Temperate and Equatorial and same TL as Approach 1.

Approach 1, 10% TE, NP fish -7%/100yr



Approach 2, 10,15% TE, NP Fish -11%/100yr



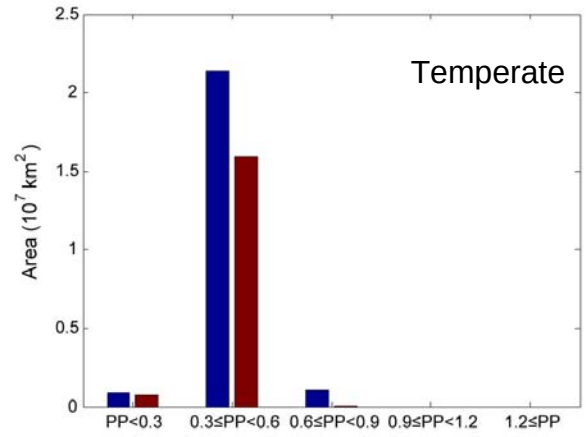
Summary table of percent change over 100 years of physical and biological variables for each biome and total North Pacific, 1998-2100

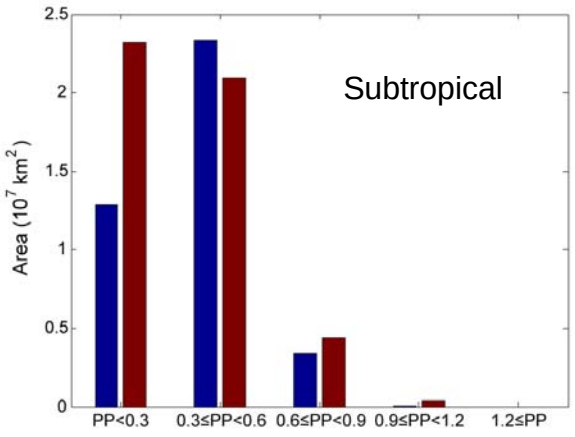
	Temp	ST	EU	North Pacific
Area	**-34.0**	**29.5**	**-27.7**	**-**
Mean PP	**-5.47**	**-2.42**	**17.12**	**-4.33**
Total PP	**-37.70**	**26.38**	**-15.09**	**-4.33**
Fish Production	**-37.7 Mean TL 4.8**	**26.38 Mean TL 4.8**	**-15.09 Mean TL 4.7**	**-6.69 (10% TE) -11.23 (10,15%TE)**
Phytoplankton Biomass	**-8.04**	**-7.64**	**-5.20**	**-13.40**
% Large	**-12.08**	**-7.29**	**-10.01**	**-26.92**
SST	**4.66**	**7.67**	**9.58**	**13.47**

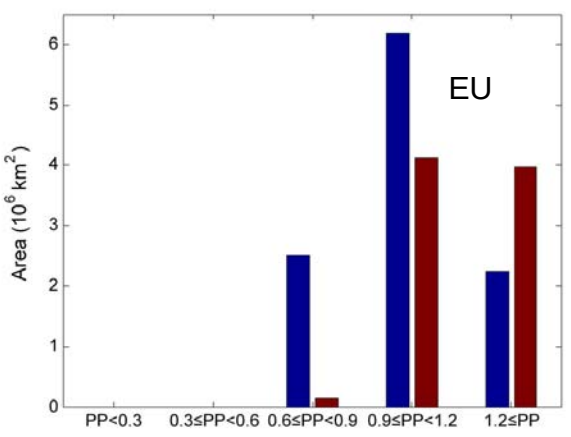
Primary Production and SST changes within the Biomes

Depth-Integrated Primary Productivity by Biome

1998 – 2017
2080 – 2099

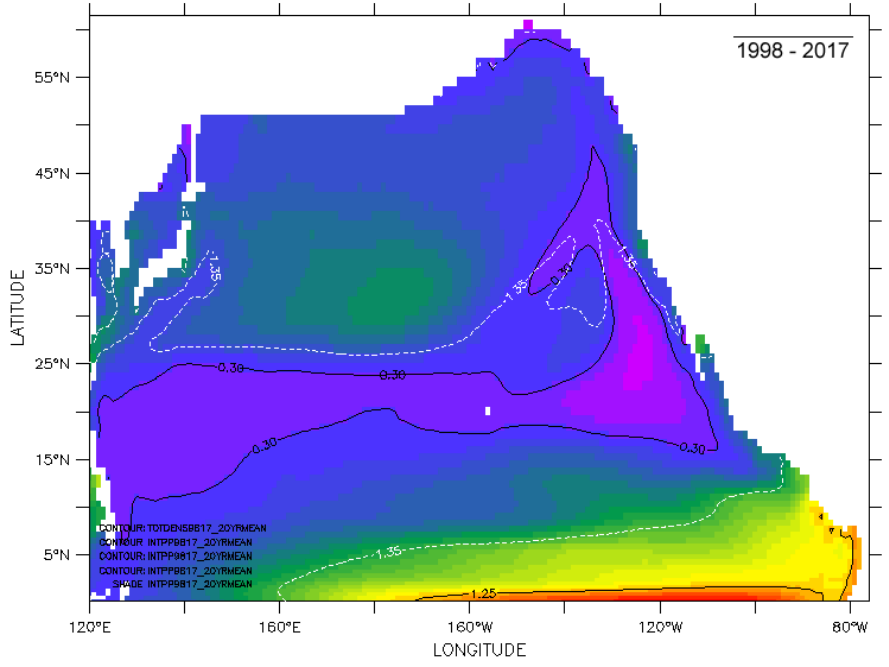


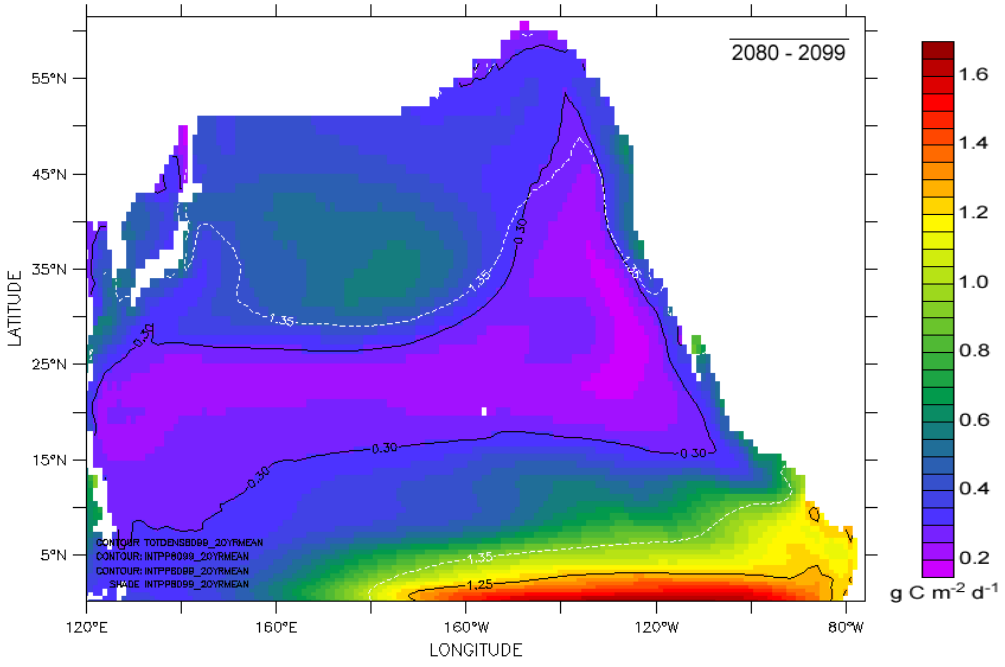




20-Year Mean Depth-Integrated Primary Productivity

0.3 and 1.25 g C m^{-2} d^{-1} contours drawn

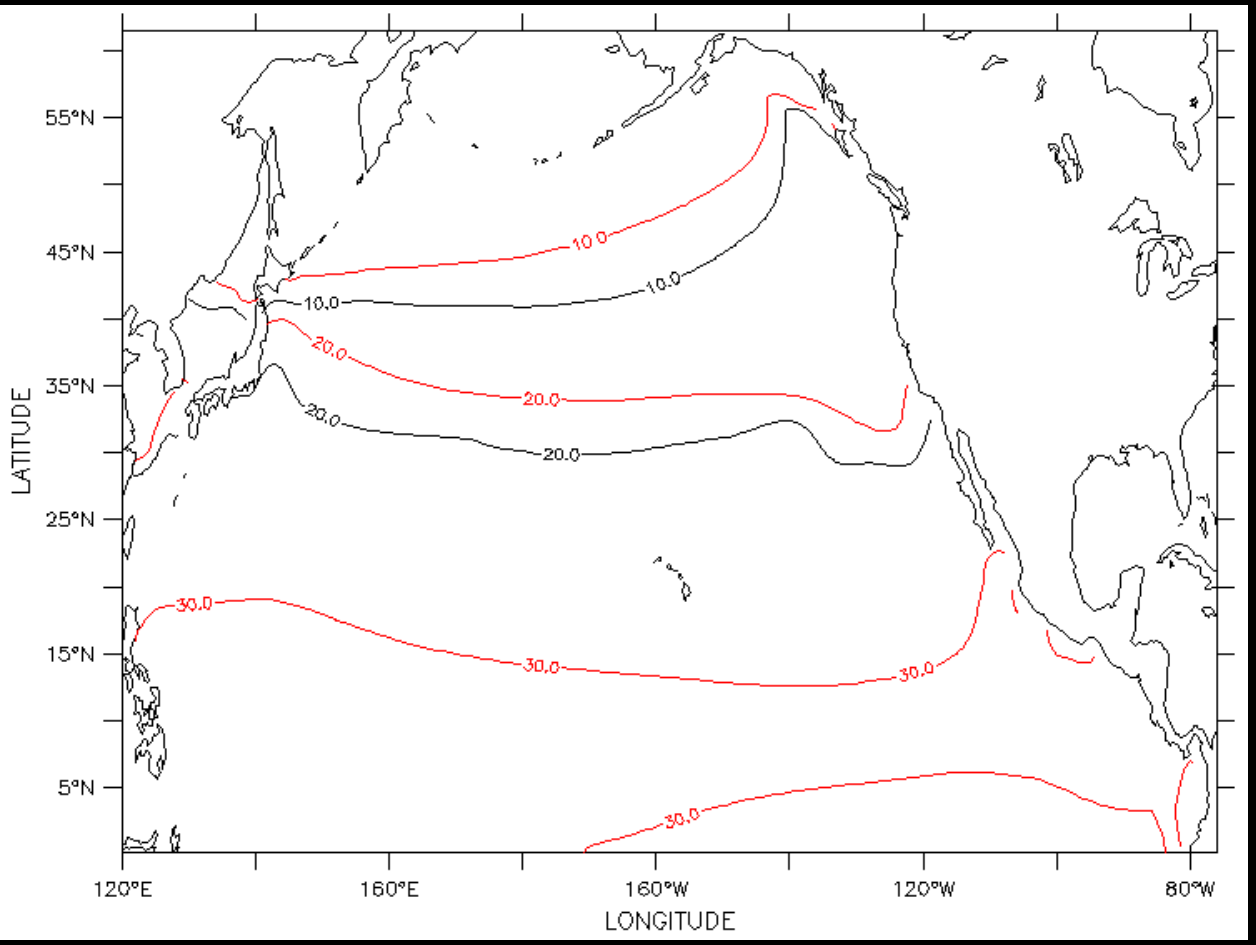


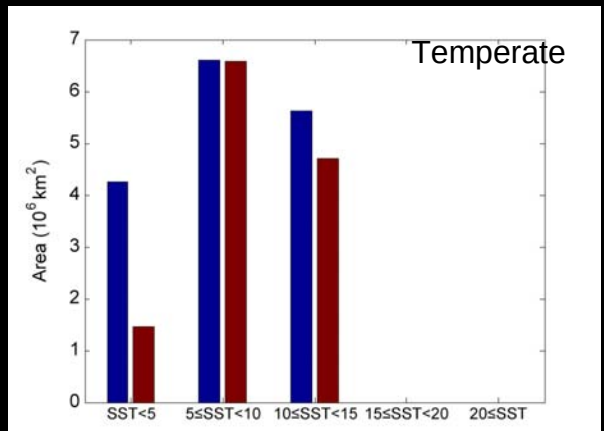


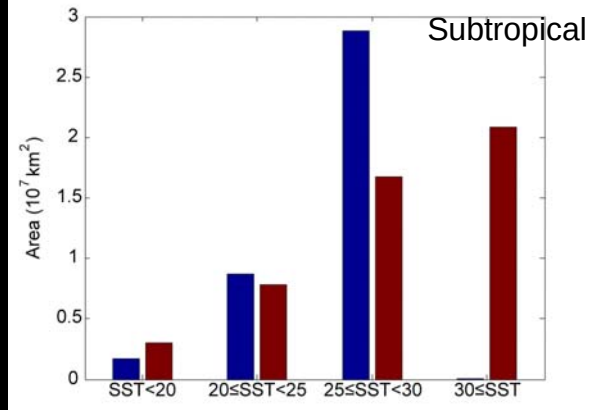
SST Histograms by Biome

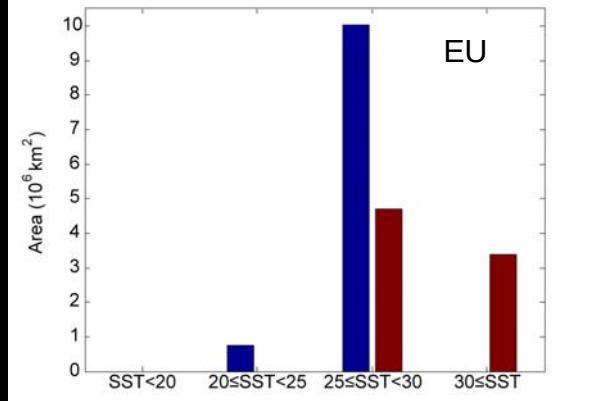
1998 – 2017
2080 – 2099

20-Year Mean SST (°C) Isotherms

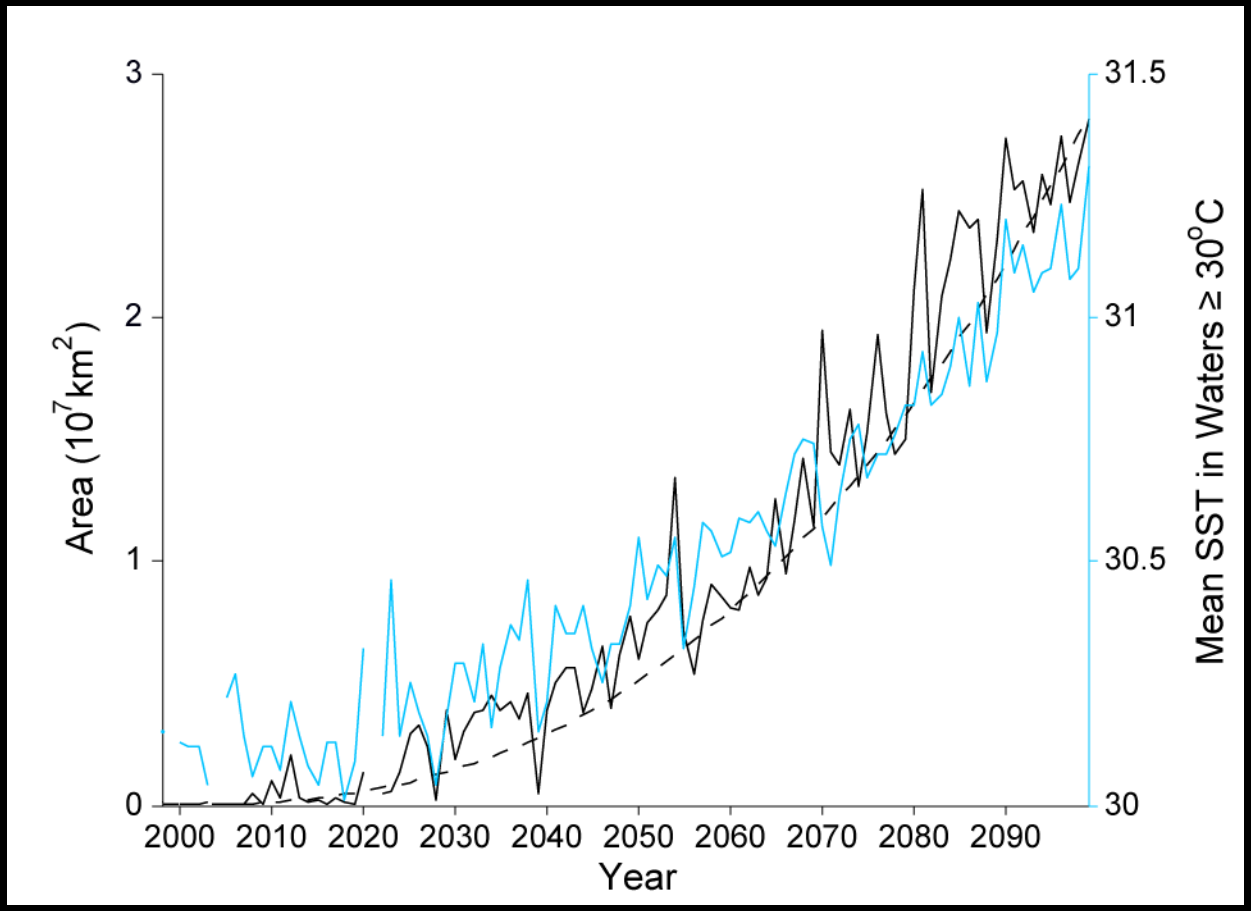


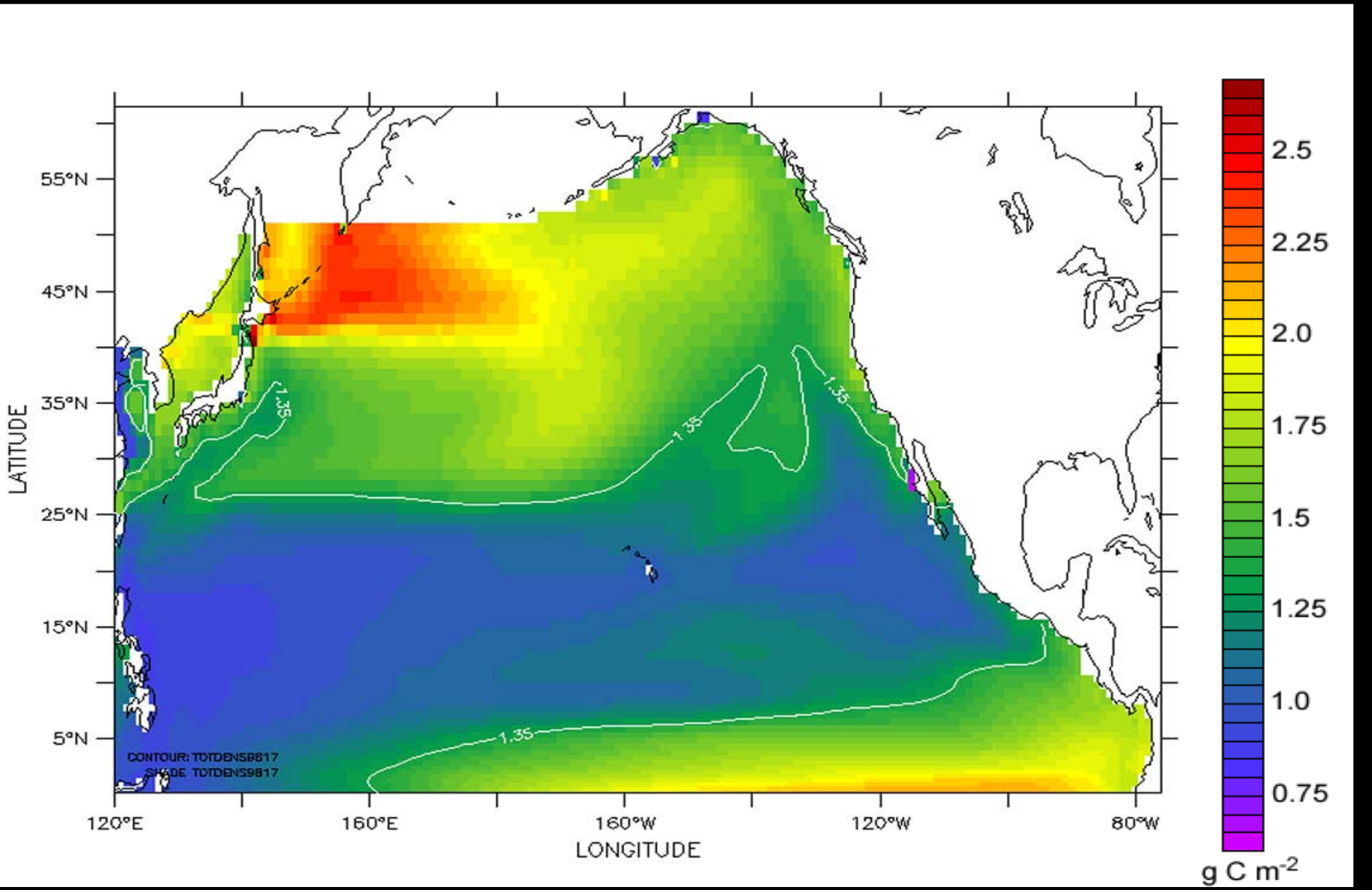






Annual Trend of Warmest Waters




55°N
45°N
35°N
25°N
15°N
5°N
LATITUDE
120°E
160°E
160°W
120°W
80°W
LONGITUDE
1.35
1.35
1.35
1.35
CONTOUR: TOTDENS9817
SHADE TOTDENS9817
2.5
2.25
2.0
1.75
1.5
1.25
1.0
0.75
g C m-2

Model-estimated changes over next 100 years

- North Pacific as a whole:
  - 6% decline in primary productivity
  - 13% decline in phytoplankton biomass
  - 27% decline in the fraction of large phytoplankton
- Dynamic Biome Approach provides useful insights on basin-wide changes and locations to monitor changes
- Subtropical habitat grows in area by 30% while temperate and EU shrink by 34% and 28%, respectively
- Total primary production :
  - In 2000 Temperate, ST, and EU biomes each accounted for about 1/3 of N Pacific PP. In 2100 ST will account for about 50% and Temperate and EU each 25% of N Pacific PP.

Model-estimated changes over next 100 years

- Total Fish production:
  - North Pacific total fish production declines 7% with TE of 10% or 11% under biome-specific TE

- Area of *lowest* primary production in the subtropical biome and *highest* primary production in the EU both expand by roughly 80%

- Area of SST exceeding 30°C goes from negligible to about 40% of subtropical and EU biomes