North Pacific climate change impacts as projected by a suite of CMIP5 model output

Phoebe Woodworth-Jefcoats

NOAA Fisheries – Pacific Islands Fisheries Science Center

University of Hawaii at Manoa

Jeffrey J. Polovina

NOAA Fisheries – Pacific Islands Fisheries Science Center

Introduction

- Climate Model Intercomparison Project Phase Five – CMIP5 (pcmdi9.llnl.gov)
- Model selection criteria:
  - Historical and Future Projection RCP8.5
  - Monthly output
  - Phytoplankton and zooplankton carbon
  - First simulation (r1i1p1) only
  - Most recent version
- Resulted in 14 simulations output by 8 models
  - Regridded to a common 1° × 1° grid

Taylor *et al*. 2012

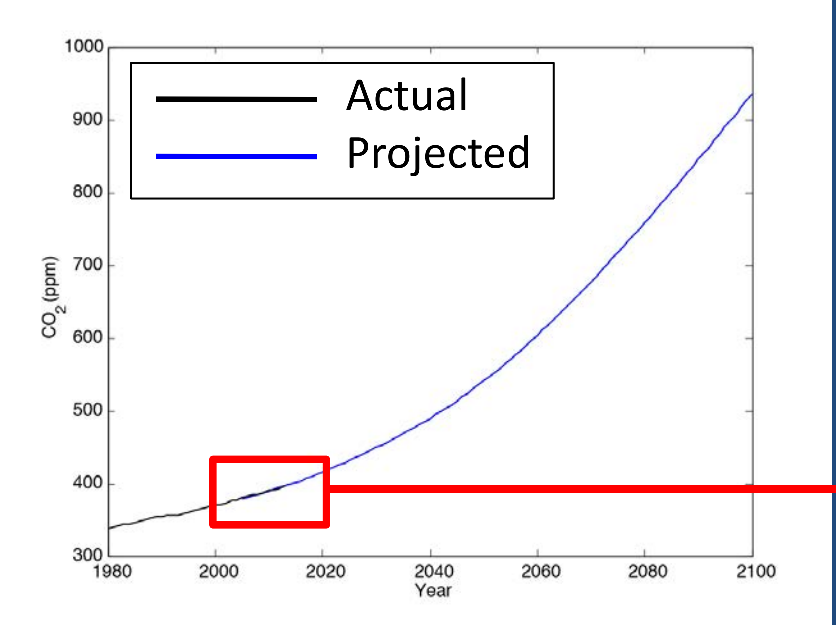
Model Suite

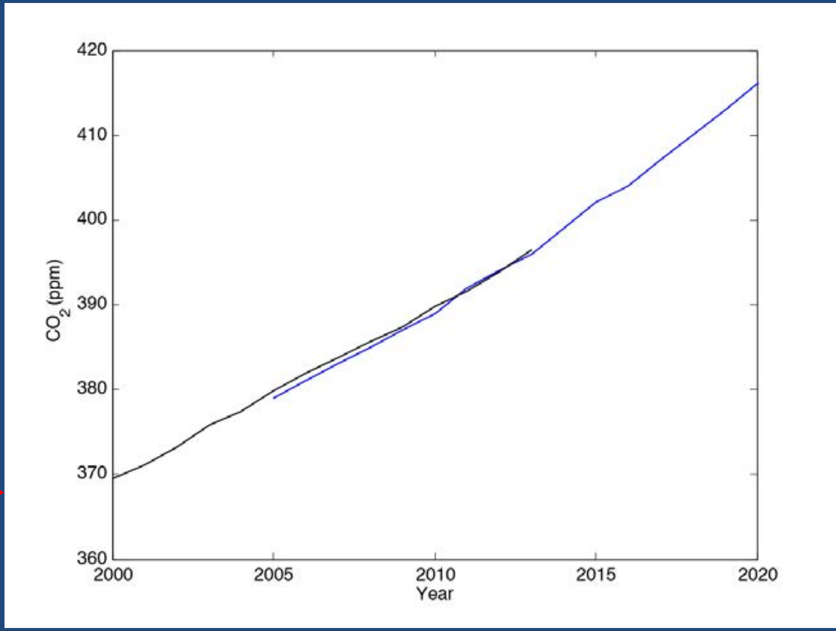
- Canadian Center for Climate Modeling and Analysis Earth system model (**CanESM2**)
- Community Earth System Model, version 1 - Biogeochemistry (**CESM1**)
- Geophysical Fluid Dynamics Laboratory Earth System Model
  - Modular Ocean Model 4 (**GFDL-ESM2G**)
  - Generalized ocean layer dynamics (**GFDL-ESM2M**)
- NASA Goddard Institute for Space Sciences ModelE2 Earth System Model
  - Carbon cycle coupled to the HYCOM ocean model (**GISS-E2-H-CC**)
  - Carbon cycle coupled to the Russell ocean model (**GISS-E2-R-CC**)
- HadGEM2 of the Met Office Unified Model
  - Coupled Carbon Cycle (**HadGEM2-CC**)
  - Full Earth System (**HadGEM2-ES**)
- Institut Pierre Simon Laplace
  - Low resolution CM5A (**IPSL-CM5A-LR**)
  - Medium resolution CM5A (**IPSL-CM5A-MR**)
  - Low resolution CM5B (**IPSL-CM5B-LR**)
- Max-Planck-Institute Earth System Model
  - Low resolution (**MPI-LR**)
  - Medium resolution (**MPI-MR**)
- Meteorological Research Institute Earth System Model Version 1 (**MRI**)

Christian *et al*. 2010, Dufresne *et al*. 2013,
Dunne *et al*. 2013, Gent *et al*. 2011, Giorgetta *et al*. 2013, Long *et al*. 2013, Martin *et al*. 2011, Romanou *et al*. 2014, Schmidt *et al*. 2014

Representative Concentration Pathway (RCP) 8.5

- RCP8.5 simulates radiative forcing reaching 8.5 W m^{-2} by 2100
- "… a relatively conservative business as usual case with low income, high population and high energy demand due to only modest improvements in energy intensity." *Riahi et al. 2011*





Meinhausen *et al*. 2011, NOAA ESRL, Riahi *et al*. 2011, Taylor *et al*. 2012

Projections from Previous Work

Basin-wide warming

Tropical easterlies weaken

Westerlies and polar easterlies weaken and shift poleward

Reduced wind-stress curl

Weakened vertical velocities and increased stratification

Nutrient redistribution

Expansion of the oligotrophic North Pacific Subtropical Gyre

Declines in large phytoplankton density, shift in size structure

Decline in large fish biomass

Spatial shifts in suitable habitat

Conditions favorable for smaller body sizes

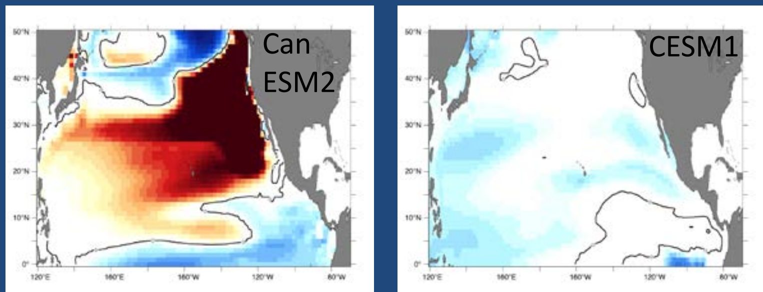
Bopp *et al*. 2013; Cheung *et al*. 2010, 2012; Daufresne *et al*. 2009; Dueri *et al*. 2014; Lefort *et al*. 2014;
Polovina *et al*. 2011; Rykaczewski and Dunne 2010; Sarmiento *et al*. 2004; Vecchi *et al*. 2006; Woodworth-Jefcoats *et al*. 2013; Yin 2005

Focus of Talk

- Areas of greatest change in phytoplankton densities over the 21st century
- Ecosystem implications of bottom-up change
  - Why look at phytoplankton density rather than primary production or chlorophyll?
    - Lack of simple relationship between large phytoplankton biomass and chlorophyll or primary production
    - Small phytoplankton biomass may not be well represented by chlorophyll concentrations
    - Suggested relationship between phytoplankton biomass and large fish biomass
    - Models differ in exact geographic placement of features

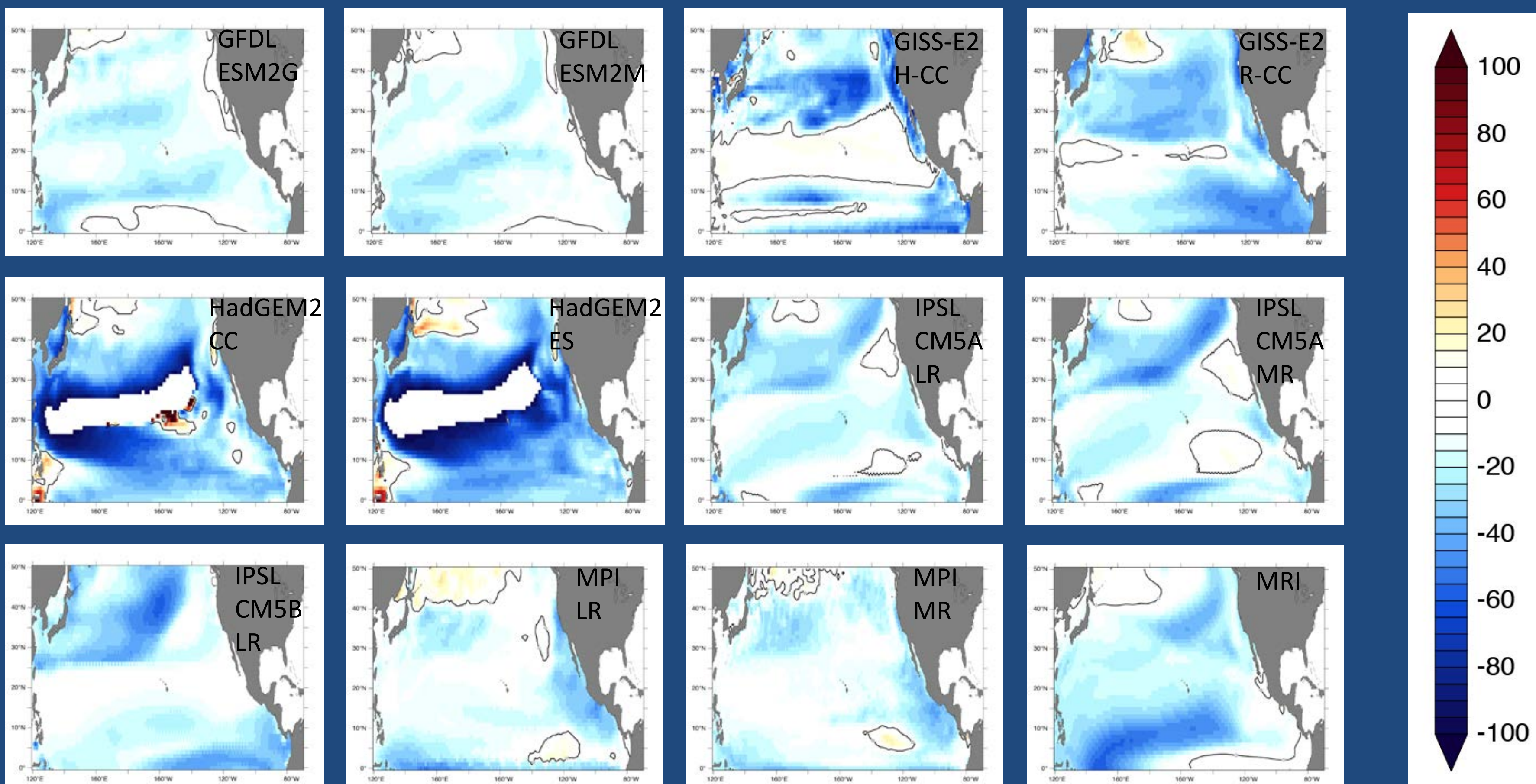
Gnanadesikan *et al*. 2011, Morán *et al.* 2010, Woodworth-Jefcoats *et al*. 2013

Percent Change in Phytoplankton Density

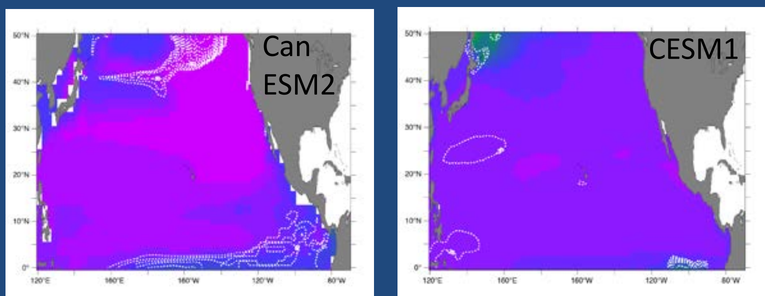


Last 20 years for the 21st century (2081 – 2100) relative to

Last 20 years of the historical run (1986 – 2005)

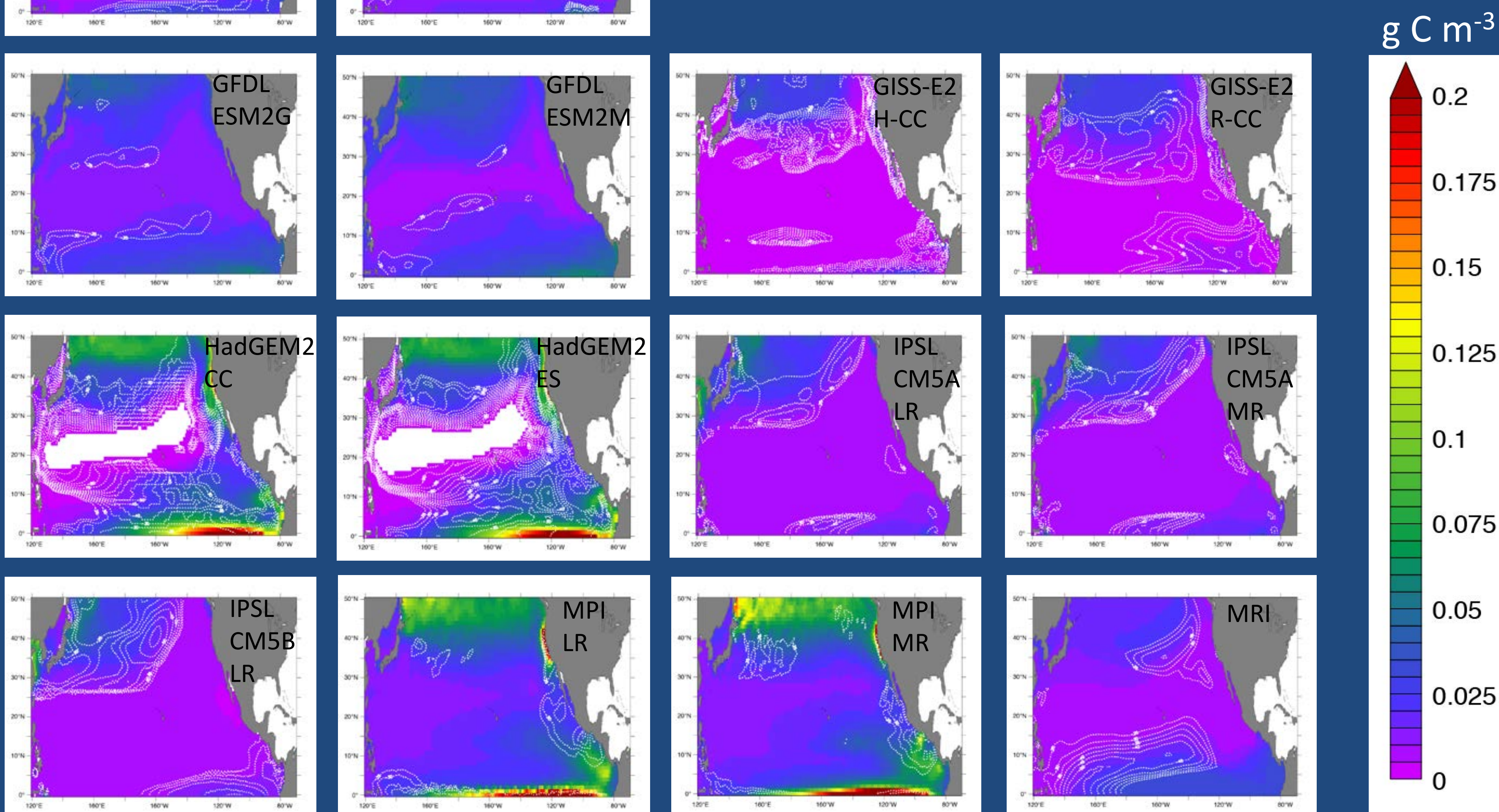


Phytoplankton Density and Areas of Greatest Change

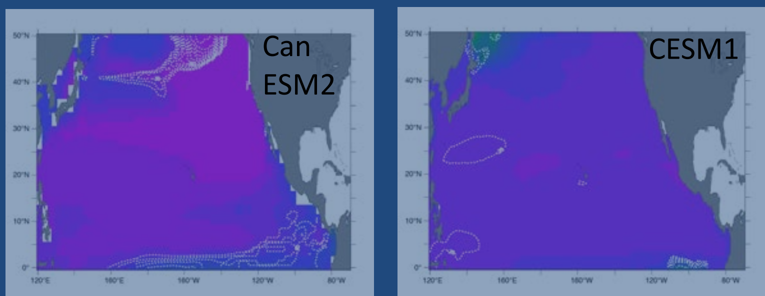


Mean phytoplankton density for 1986 – 2005

Declines of ≥ 25% over the 21st century outlined

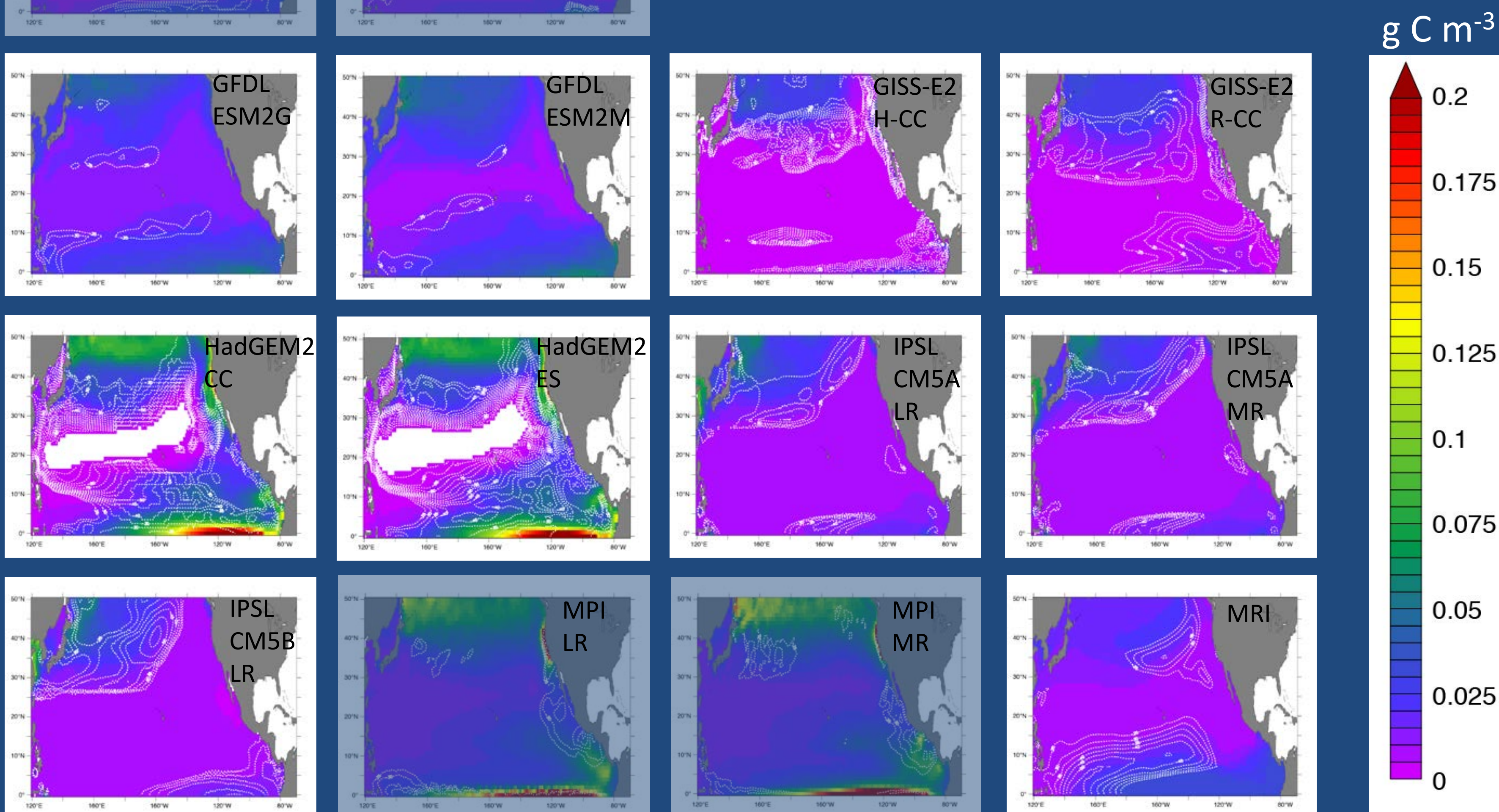


Phytoplankton Density and Areas of Greatest Change



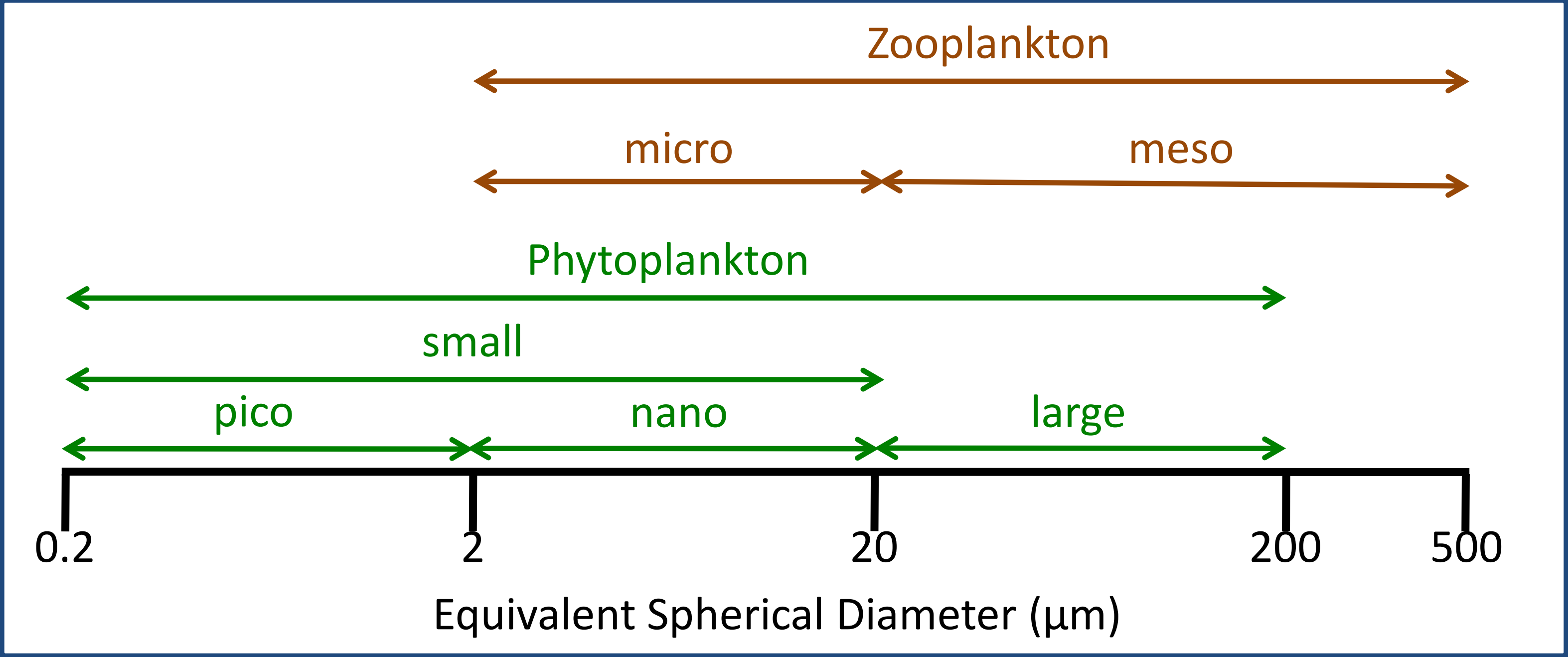
Mean phytoplankton density for 1986 – 2005

Declines of ≥ 25% over the 21st century outlined



Determining Plankton Spectra

Plankton output by the models span various size classes:



Discretize biomass evenly across size class (0.1 $\log_{10}$ grams wet weight)

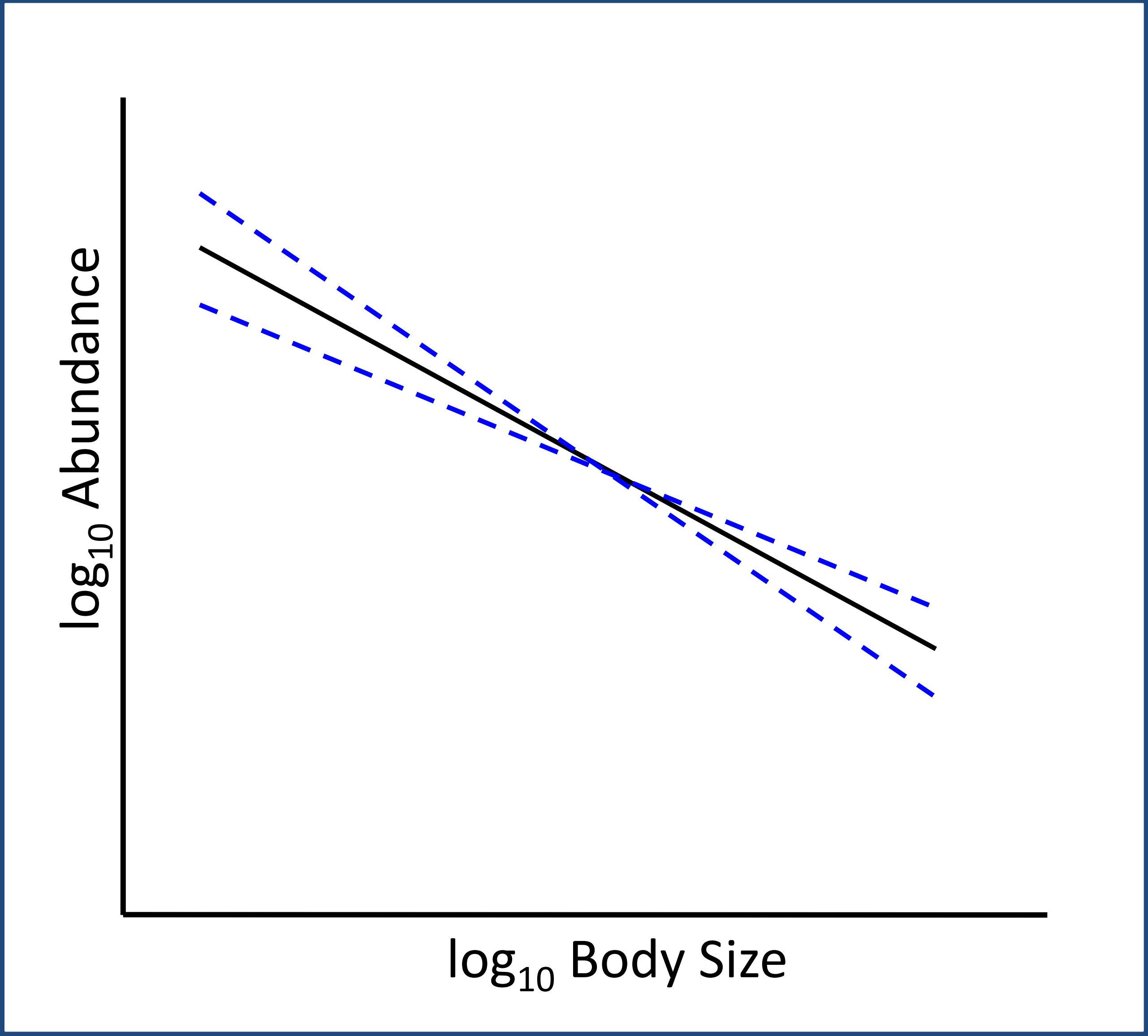
Divide biomass at size by cell volume to get abundance at size

Anh *et al*. 1992; Aumont and Seferian *et al*.2012; Bopp 2006; Bricaud *et al*. 1983; Bricaud and Morel 1985; Chistian *et al*. 2010; Collins *et al*. 2011; Dufresne *et al*. 2013; Dunne *et al*. 2005, 2012, 2013; Gregg and Casey 2007; Ilyina *et al*. 2013; Moore *et al*. 2002, 2004, 2013; Sathyendranath *et al*. 1987; Yukimoto *et al*. 2011; Zahariev *et al*. 2008

Changing Plankton Spectra

Jennings and Brander 2010

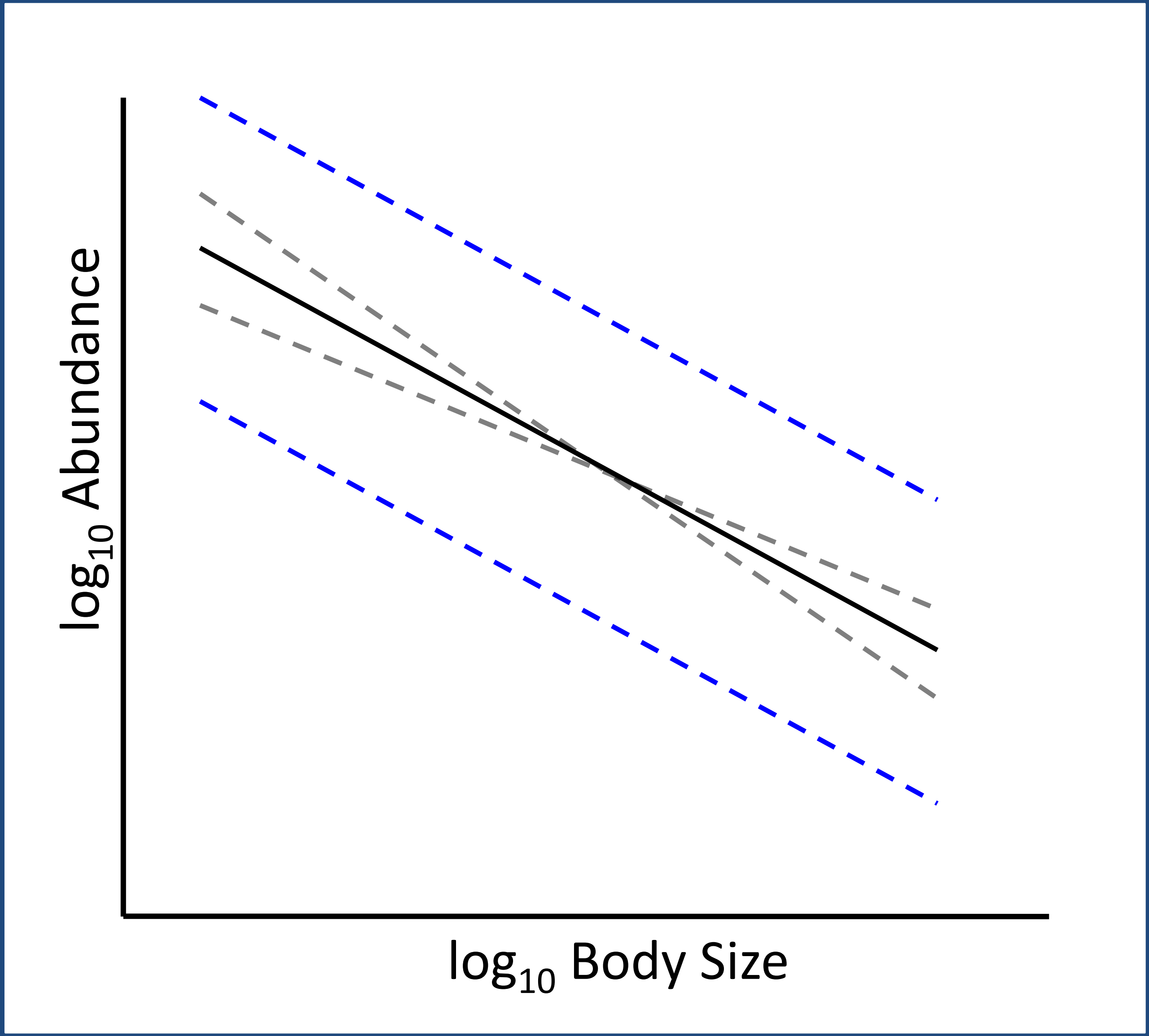
Changing Plankton Spectra



Δ Slope
Composition

Jennings and Brander 2010

Changing Plankton Spectra

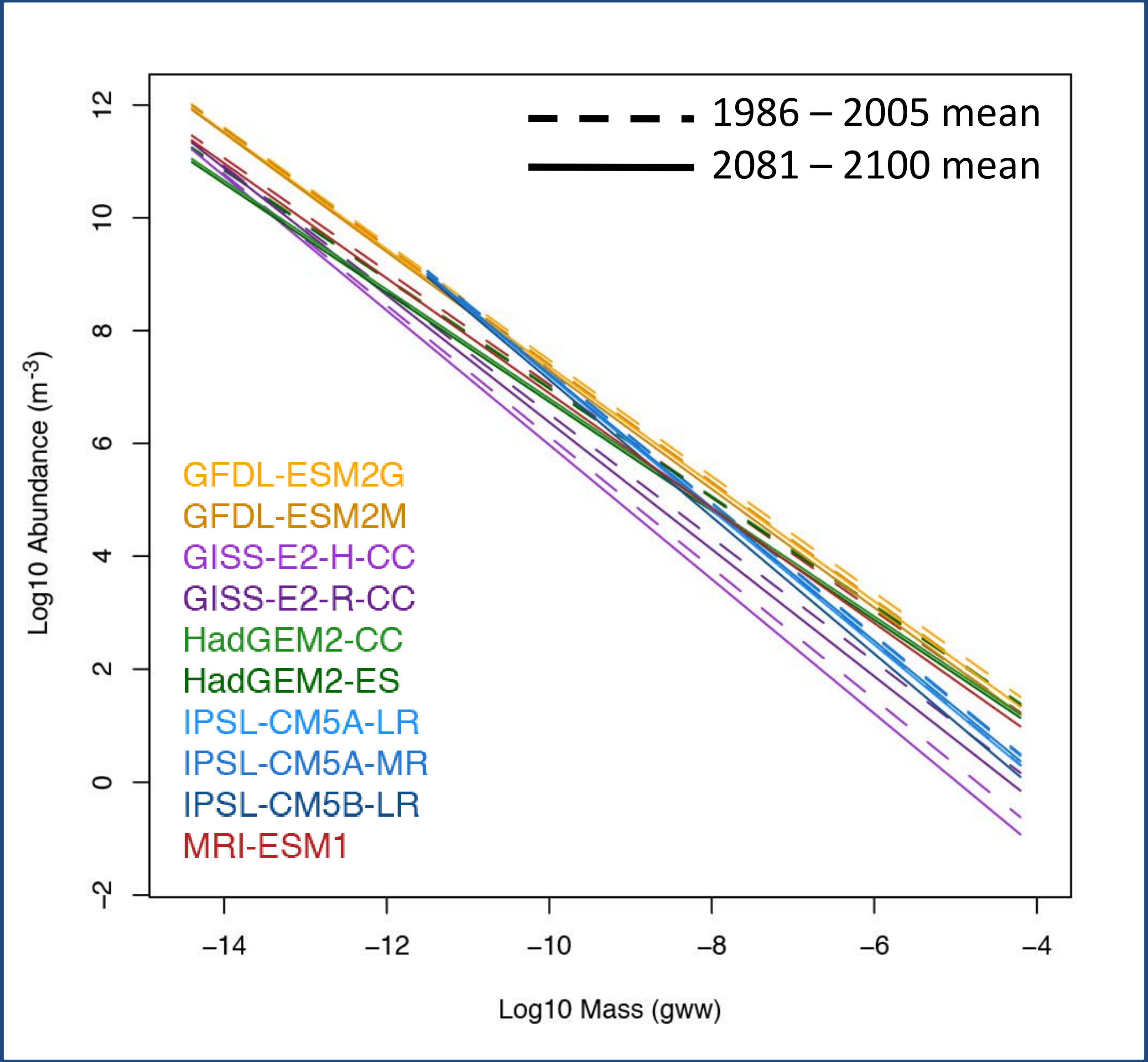


Δ Slope
- Composition

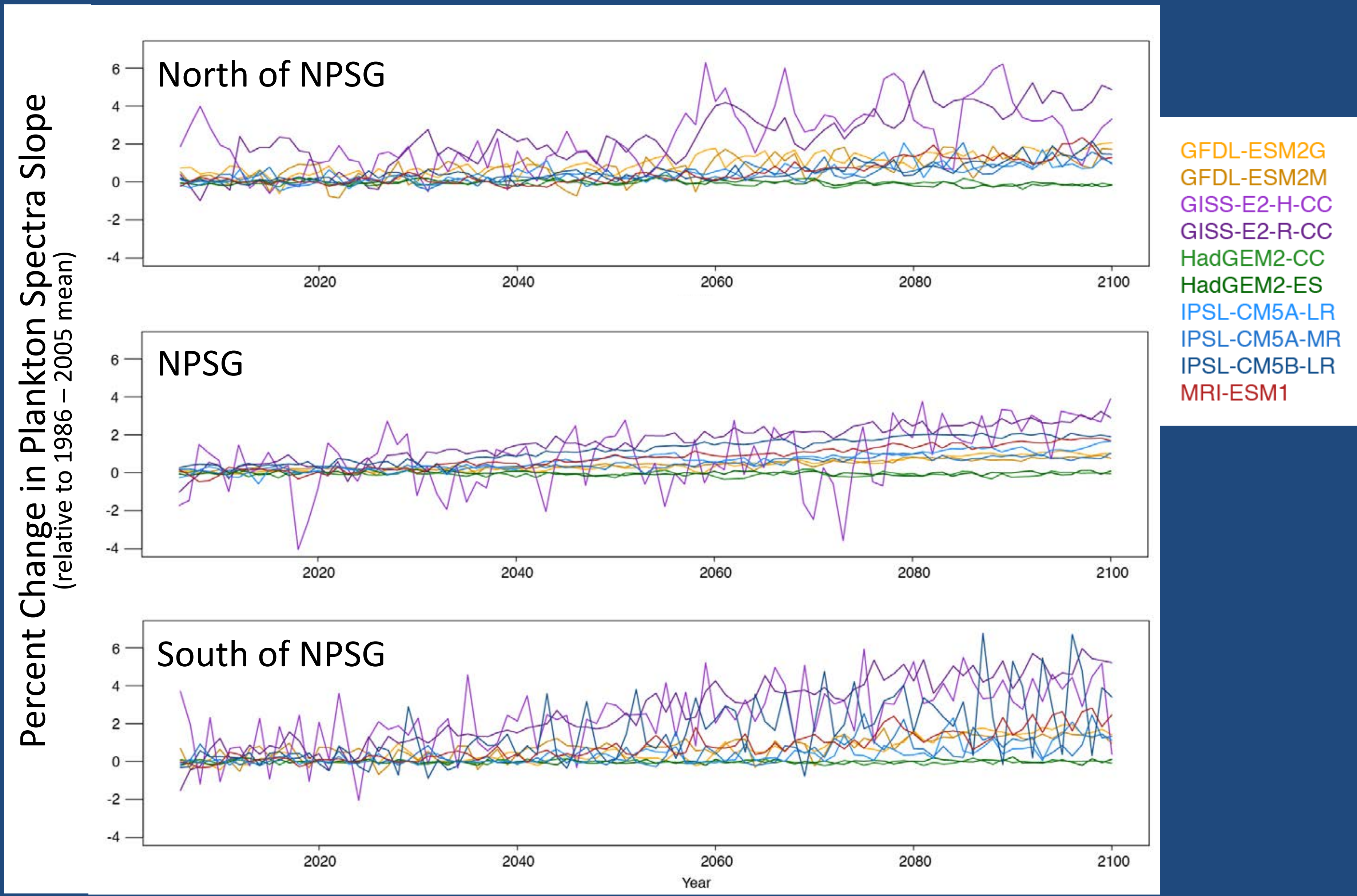
Δ Intercept
- Abundance
- Composition

Jennings and Brander 2010

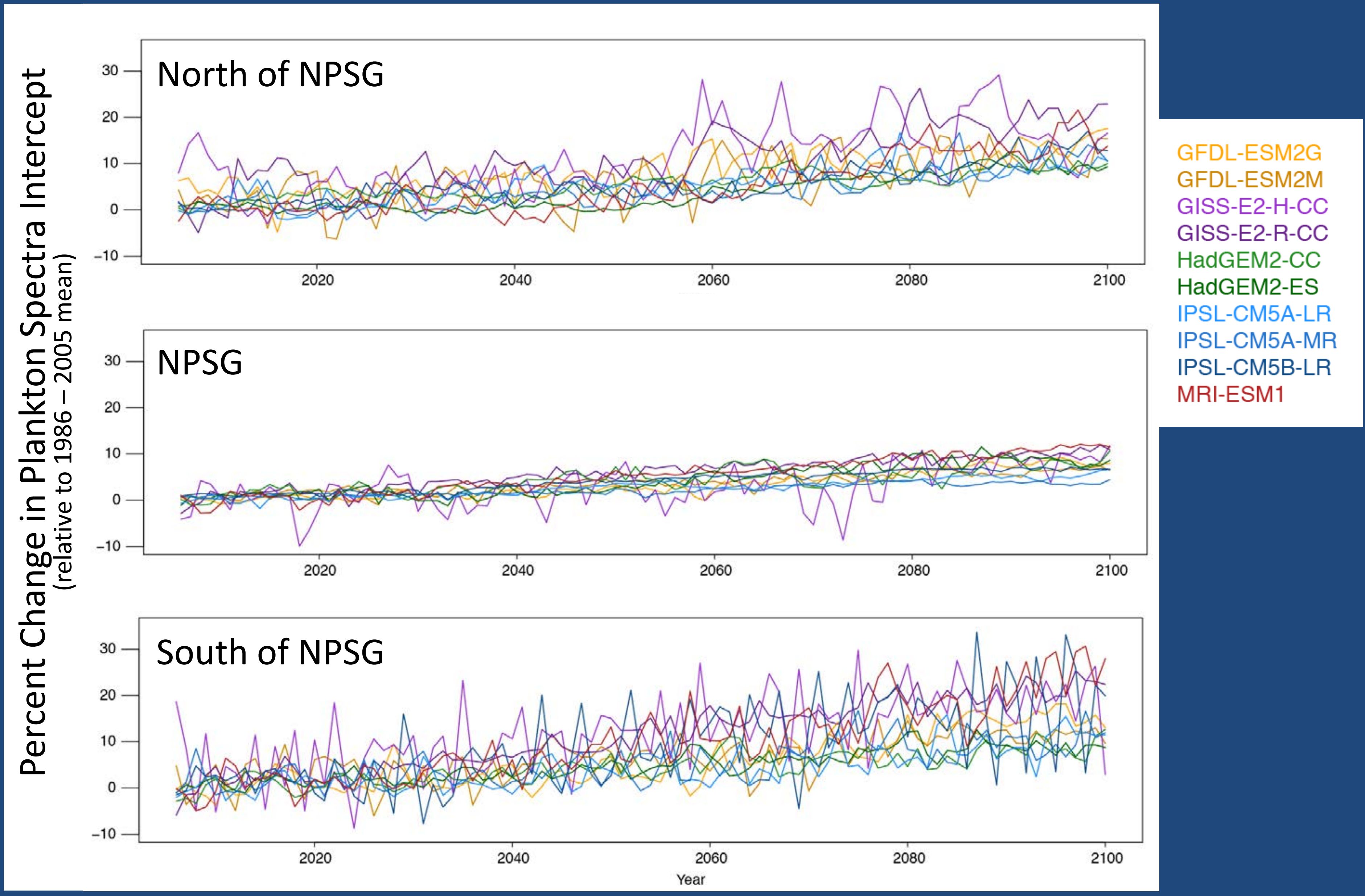
Plankton Spectra - NPSG



Change in Plankton Spectra Slopes



Change in Plankton Spectra Intercepts

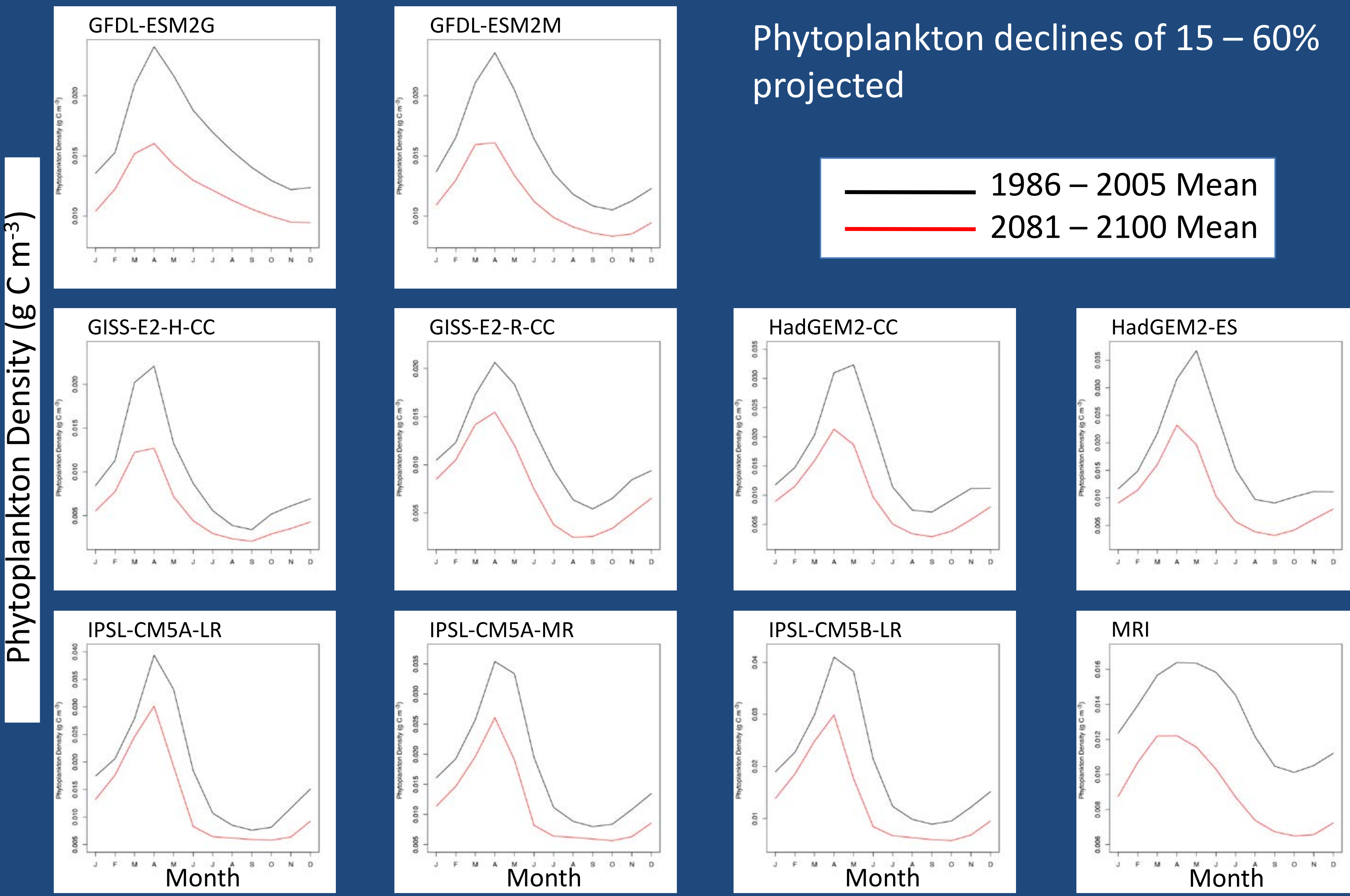


Changes to Plankton Spectra

- Declines in both slope and intercept
  - Slope: declines 0 – 6%
  - Intercept: declines 0 – 30%
- Greater declines in intercept than slope
  - Decline in abundance > change in size structure
  - Reduced biomass available to higher trophic levels

Annual Phytoplankton Biomass North of the NPSG

Phytoplankton declines of 15 – 60% projected

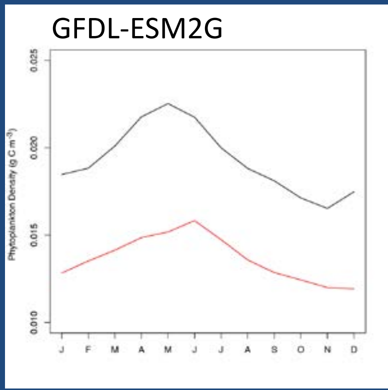


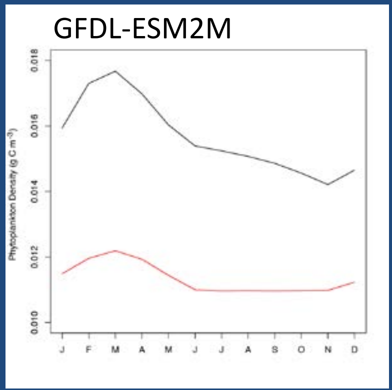
Annual Phytoplankton Biomass South of the NPSG

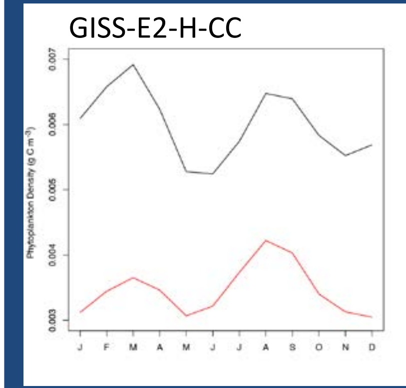
Phytoplankton declines of 24 – 48% projected

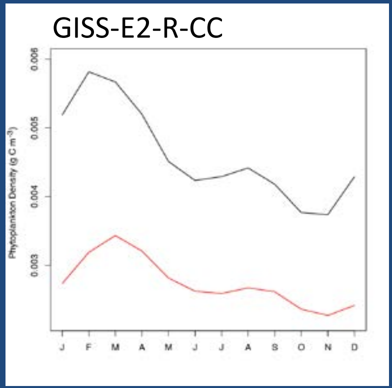
1986 – 2005 Mean
2081 – 2100 Mean

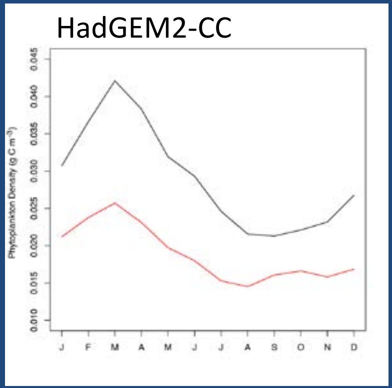
Phytoplankton Density (g C m^{-3})

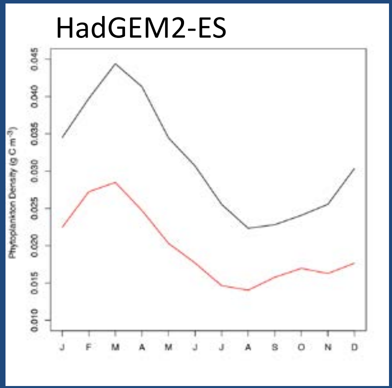


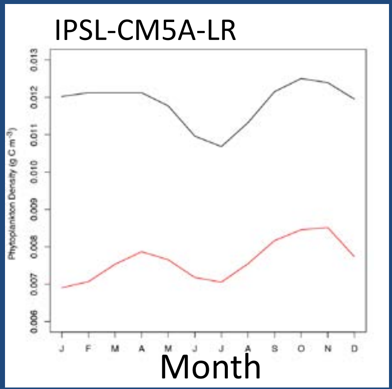


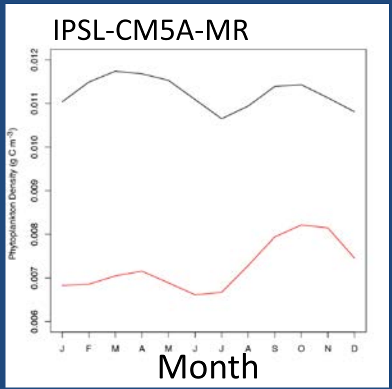


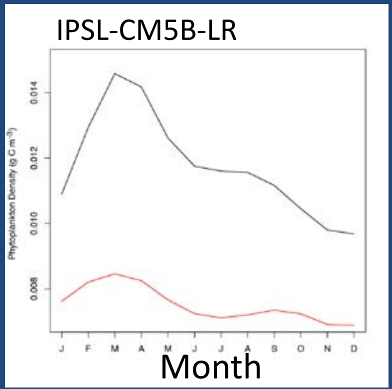


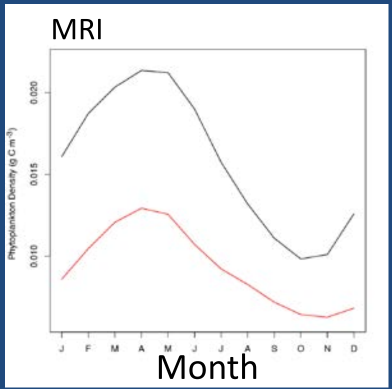




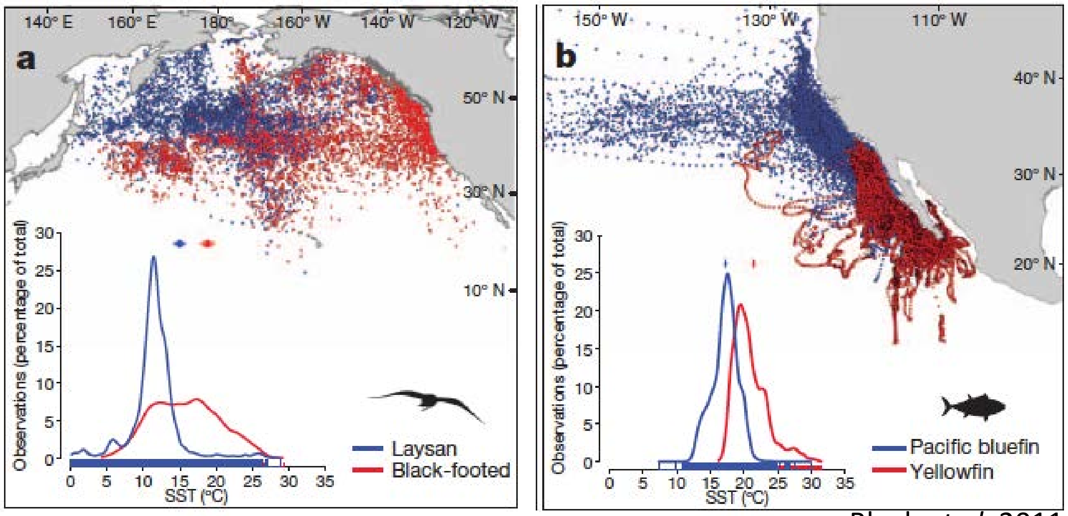




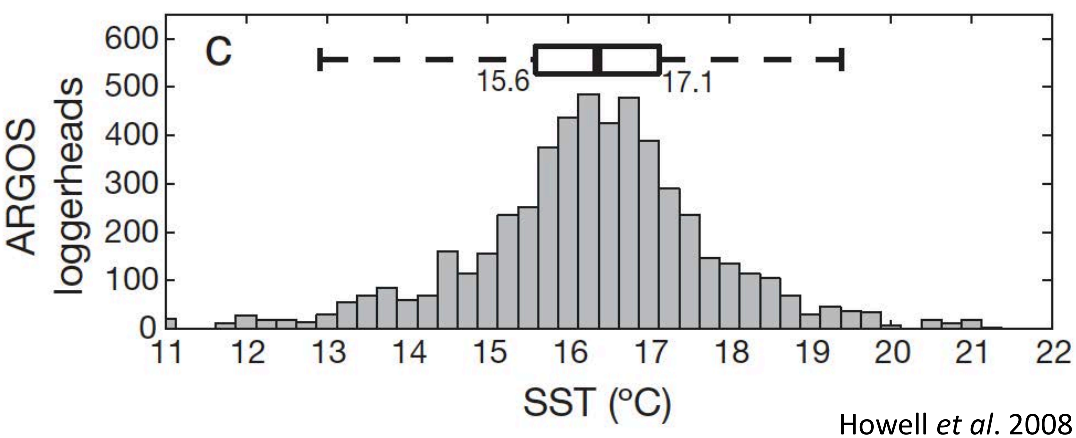




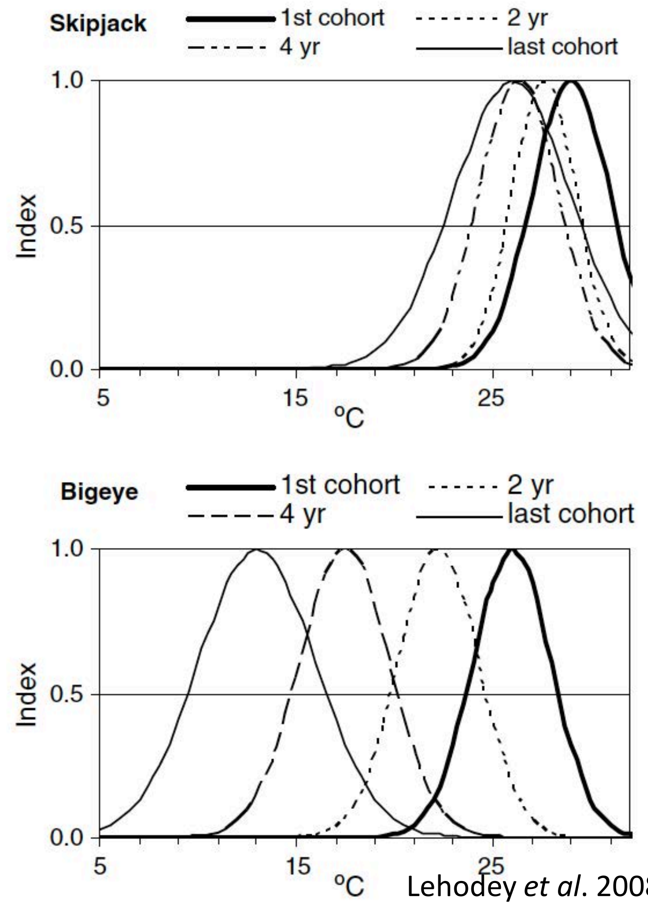
Impacts of Projected Temperature Change



Block *et al.* 2011



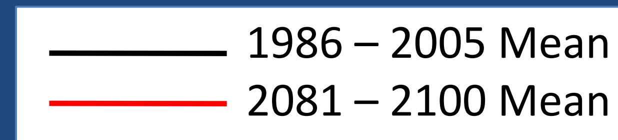
Howell *et al*. 2008



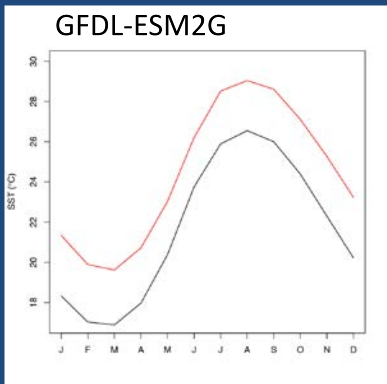
Lehodey *et al*. 2008

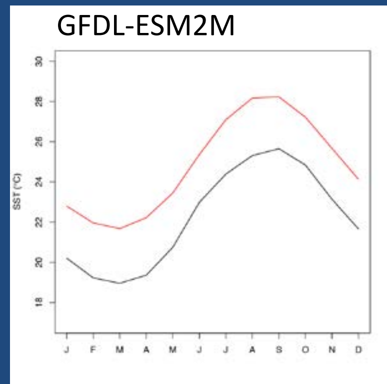
Annual SST North of the NPSG

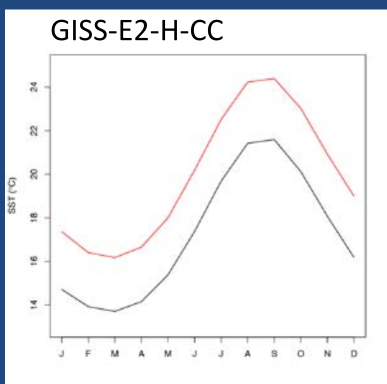
SST increases of 1.6 – 5.0°C projected

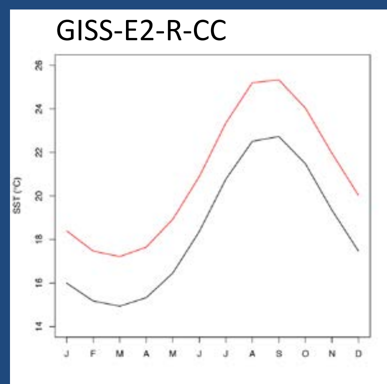


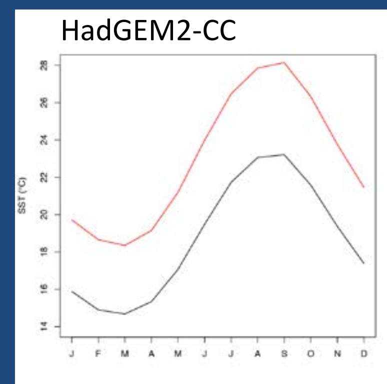
SST (°C)

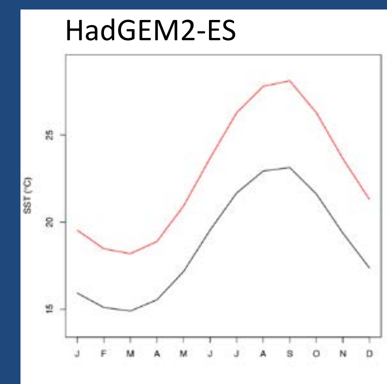


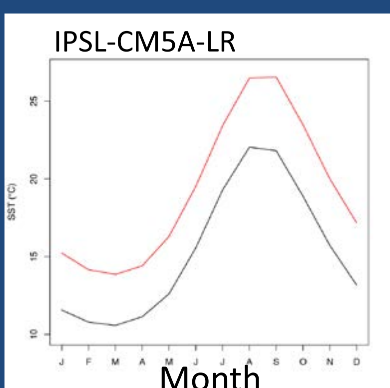


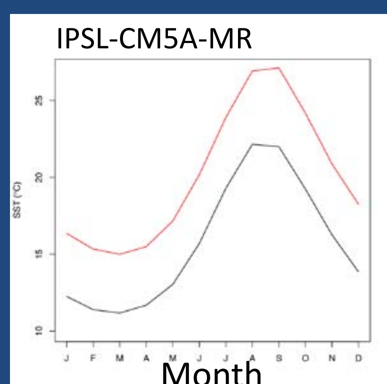


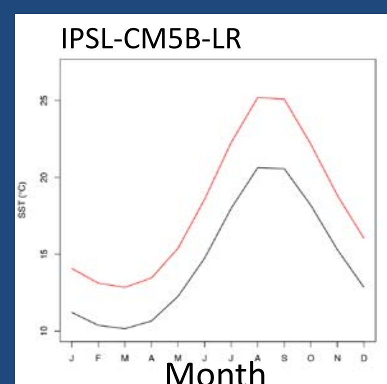


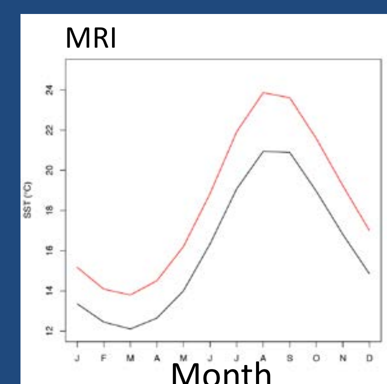










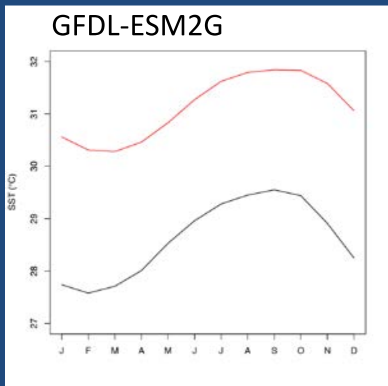


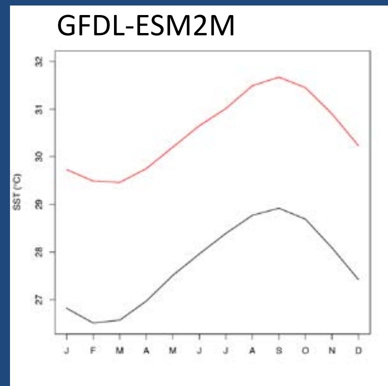
Annual SST South of the NPSG

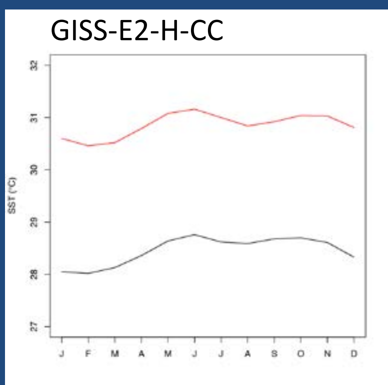
SST increases of 2.1 – 4.3°C projected

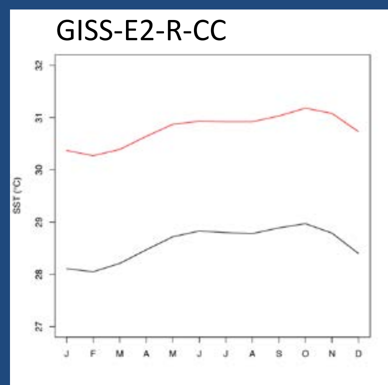
1986 – 2005 Mean
2081 – 2100 Mean

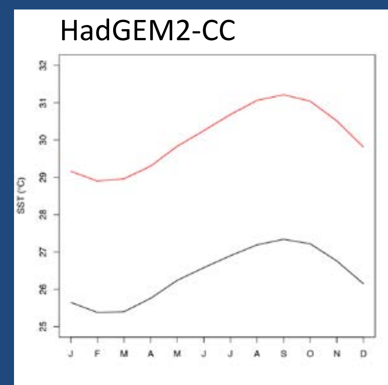
SST (°C)

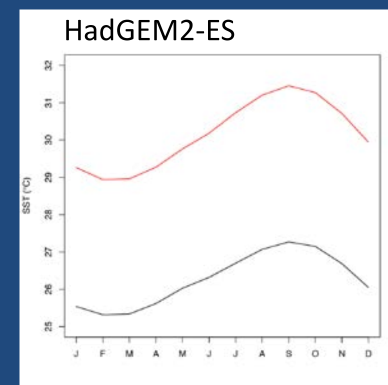


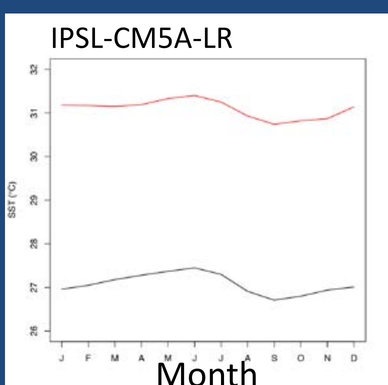


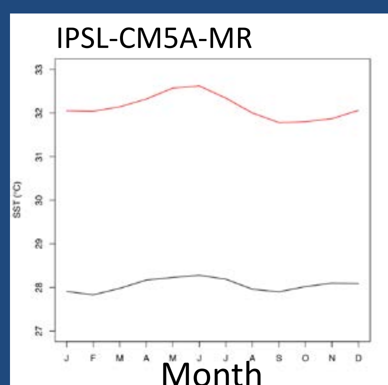


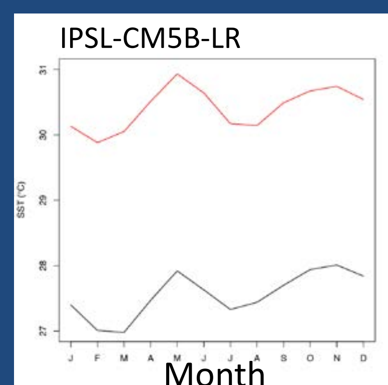


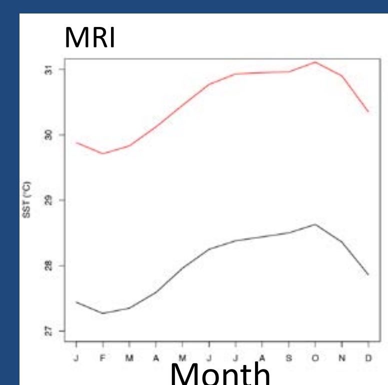












Conclusions and Next Steps

- Conclusions
  - Projected declines in phytoplankton biomass greatest in association with the boundaries of the North Pacific subtropical gyre
  - Change in plankton spectra suggest overall plankton biomass declines are greater than relative changes in size structure
  - Areas of greatest phytoplankton declines are of ecological significance for top predators
  - Declines in phytoplankton biomass are accompanied by increasing SST, potentially exacerbating ecosystem impacts
  - **Areas to focus climate and ecosystem monitoring efforts**
- Next steps
  - Closer examination of changes in size structure
  - Examine mechanisms behind model disparities
  - Incorporation into ecosystem and food web models