Modeling capabilities and challenges:

Empirical and mechanistic modeling of marine ecosystems/fisheries

Colleen Petrik

Scripps Institution of Oceanography

13 April 2022

cpetrik@ucsd.edu

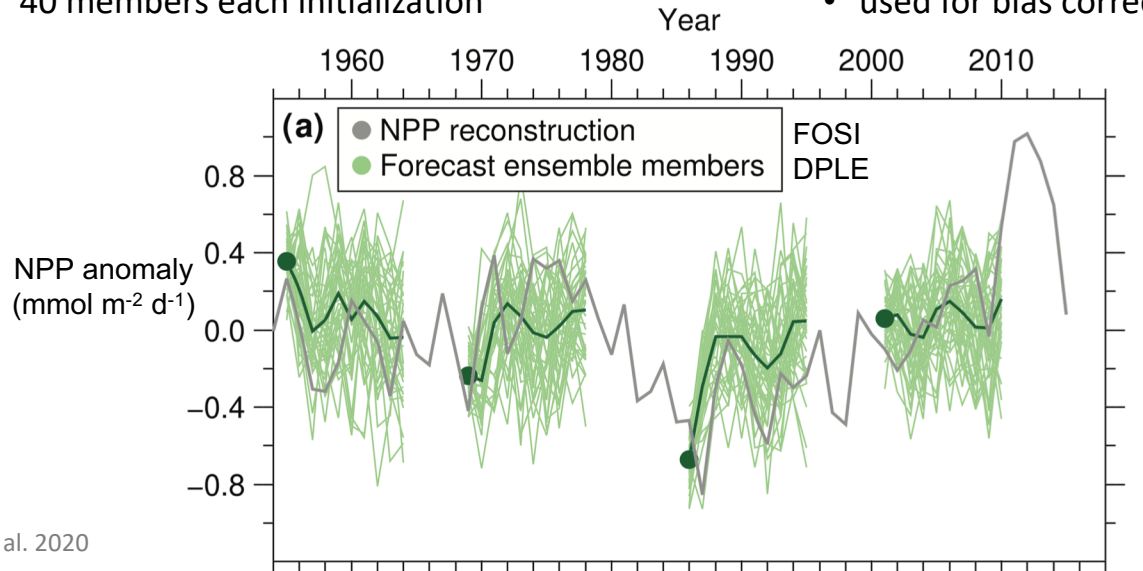
Major accomplishment: Ocean Predictions

CESM DPLE

- Decadal Prediction Large Ensemble
- 1954-2015
- initialized every Nov, run for 10 yr
- 40 members each initialization

CESM FOSI

- Forced Ocean-Sea Ice
- 1948-2015
- forced by reanalysis products
- used for bias correction and potential predictability



Krumhardt et al. 2020

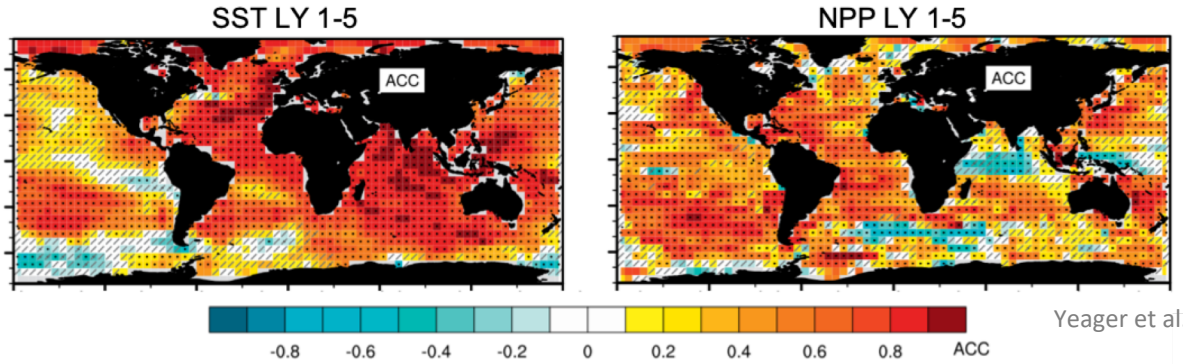
Major accomplishment: Ocean Predictions

Mechanistic ocean

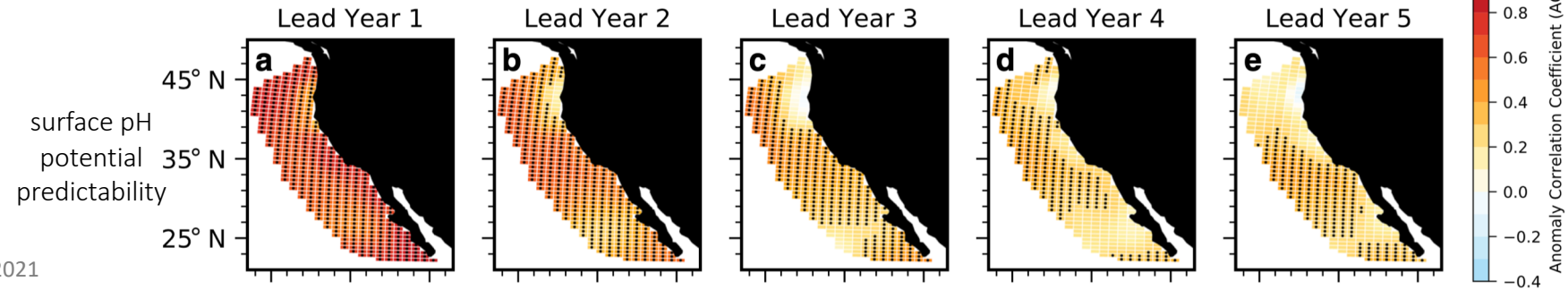
Potential predictability of

- SST
- NPP
- pH

ACC = Correlation of Retrospective forecasts with FOSI



Yeager et al. 2018

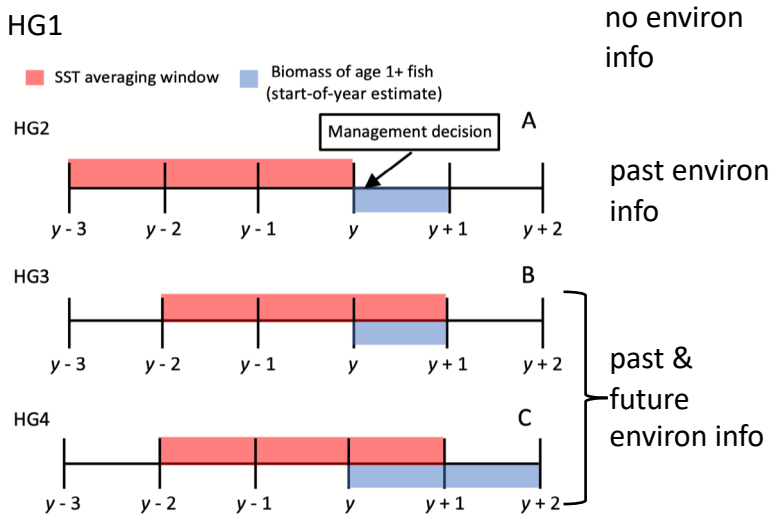


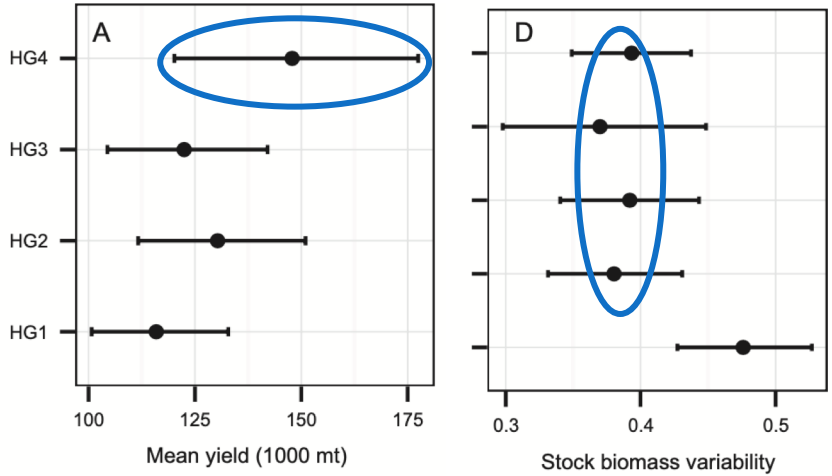
Brady et al. 2021

Major accomplishment: Fish predictions

Mechanistic ocean, empirical fish

- GFDL seasonal-to-multiannual prediction experiments
- Predictive skill of SST
- SST-sardine biomass relationship
- Use of SST predictions improved harvest guidelines for Pacific sardine
  - ↑ yield (catch)
  - ↓ stock biomass variability





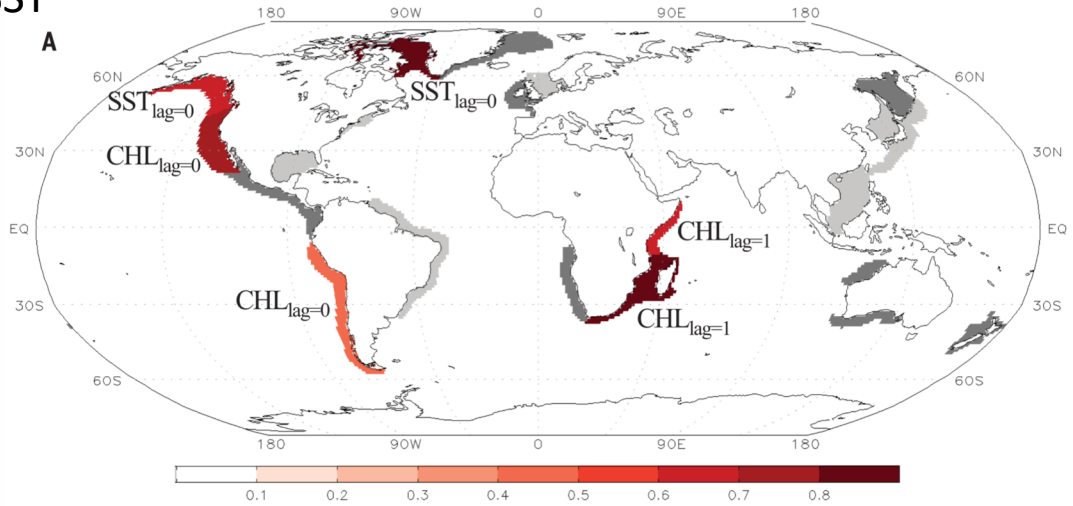
Tomassi et al. 2016

Major accomplishment: Fish predictions

Mechanistic ocean, empirical fish

- GFDL seasonal-to-multiannual prediction experiments
- Predictive skill of SST and/or chlorophyll
- Significant relationship between SST or chlorophyll with catch
- Predictive skill of fish catch

Correlation of Fish catch model forced by retrospective forecasts with Observations

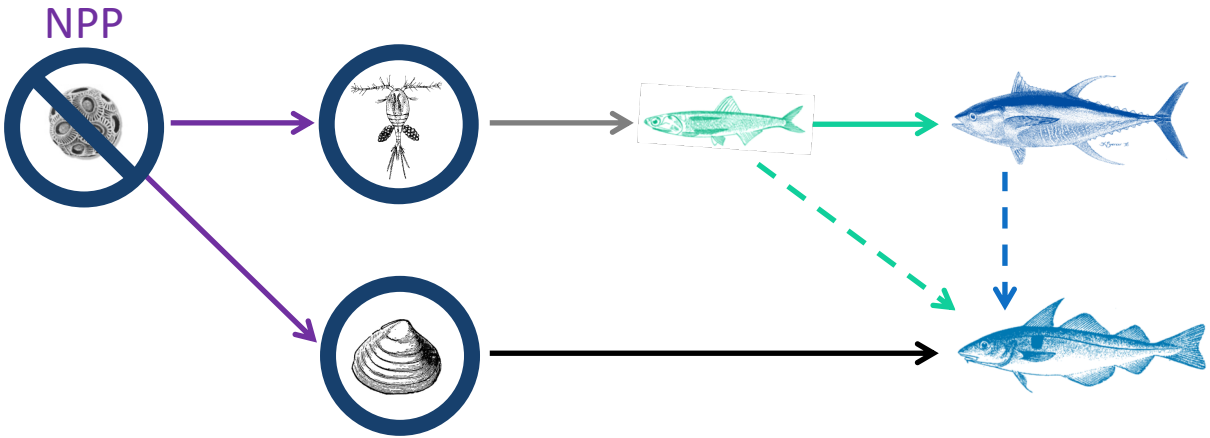


Park et al. 2019

Potential challenges

Empirical fish relationships

- Other drivers beyond SST, NPP/chl



- Friedland et al. (2012): *pe*-ratio, *z*-ratio
- Stock et al. (2017): bottom detritus flux, mesozooplankton production
- van Denderen (2018): fraction NPP photic to fraction NPP benthic

Total fish catch

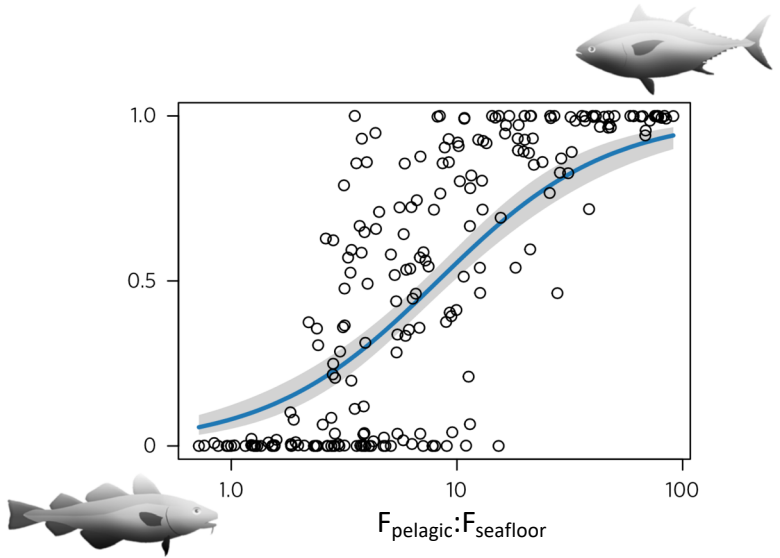
Large pelagic vs. Demersal

Potential challenges

Empirical fish relationships

- Other drivers beyond SST, NPP/chl
  - 2º production
  - Export production

SAU catch reconstruction



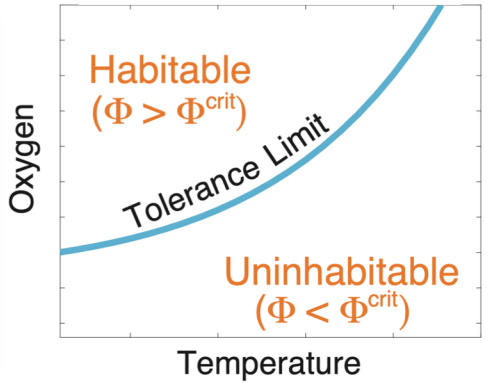
F= fraction NPP

van Denderen et al. 2018

Potential challenges

$$\text{Metabolic Index} = \frac{\text{Oxygen supply}}{\text{Oxygen demand}}$$

$$\Phi = A_o B^{\varepsilon} pO_2 \exp(E_o / k_B T)$$



Empirical fish relationships

- Other drivers beyond SST, NPP/chl
  - 2^{o} production
  - Export production
  - Oxygen, MI (Zhuomin Chen poster)
  - Bottom temperature
  - pH

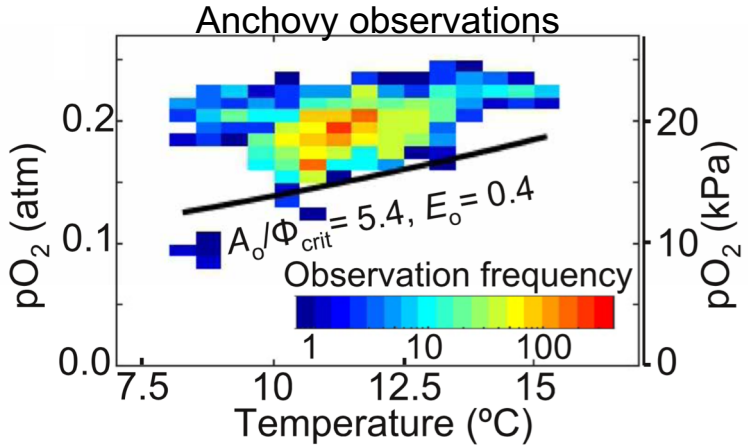
Deutsch et al. 2015, 2020

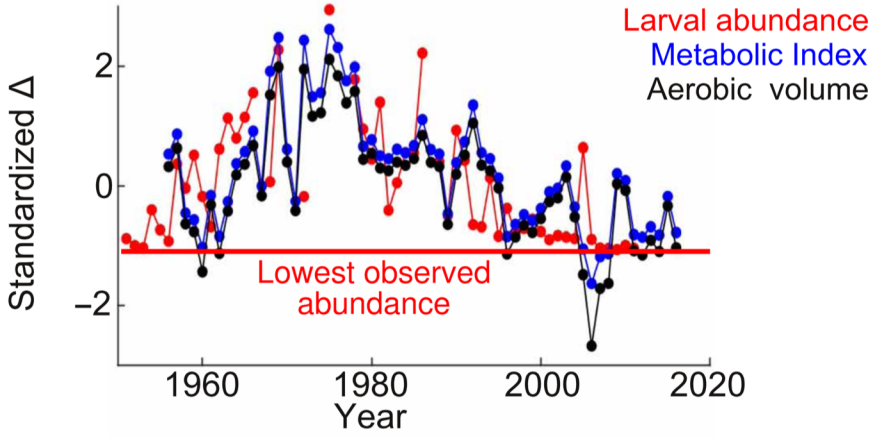
Potential challenges

Empirical fish relationships

- Other drivers beyond SST, NPP/chl
  - 2º production
  - Export production
  - Oxygen, MI (Zhuomin Chen poster)
  - Bottom temperature
  - pH

$$\text{Metabolic Index} = \frac{\text{Oxygen supply}}{\text{Oxygen demand}}$$





Deutsch et al. 2015, 2020; Howard et al. 2020

Potential challenges

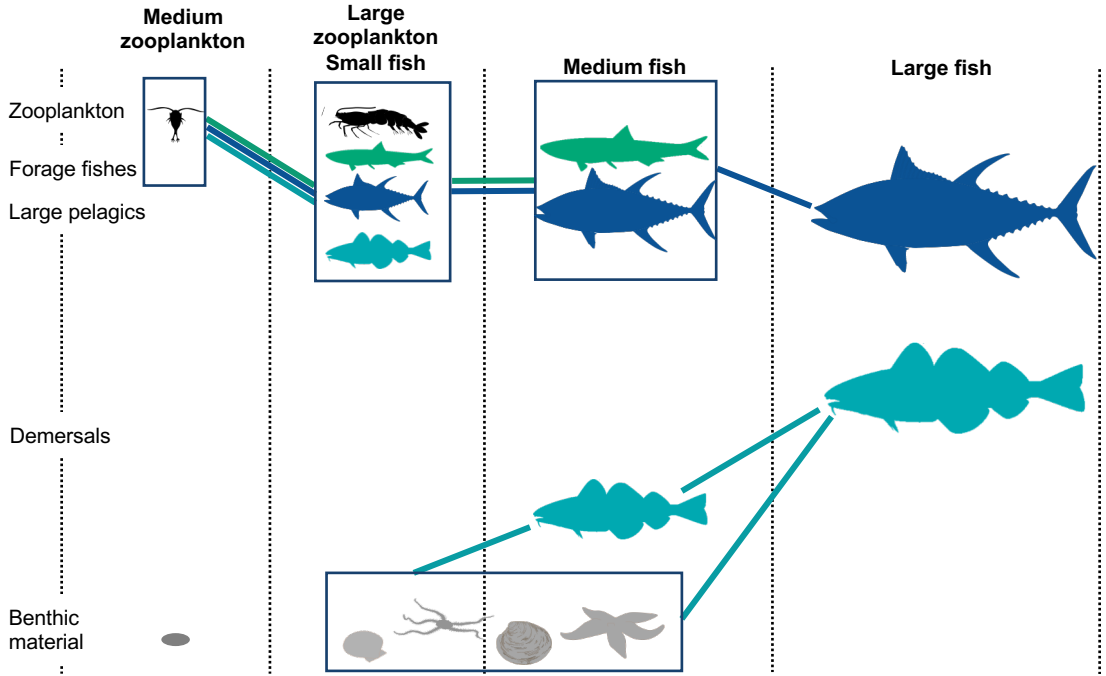
Empirical fish relationships

- Other drivers beyond SST, NPP/chl
  - 2^o production
  - Export production
  - Oxygen, MI (Zhuomin Chen poster)
  - Bottom temperature
  - pH
- Static relationships estimated during historic period
  - Climate change conditions extrapolate outside of range experienced
  - Need to continuously reevaluate relationships with new observations

Major accomplishment – ecosystem climatology

Mechanistic ocean, mechanistic fish

FEISTY – Fisheries Size and Type Model

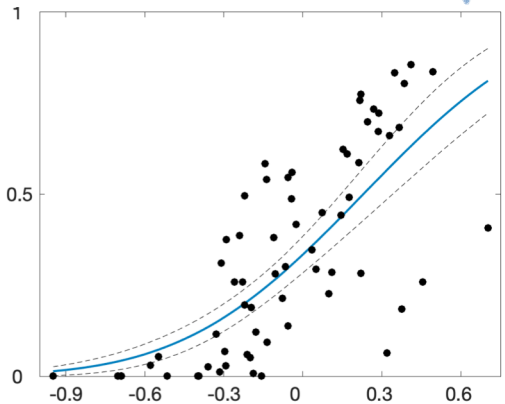


Petrik et al. 2019

Major accomplishment – ecosystem climatology

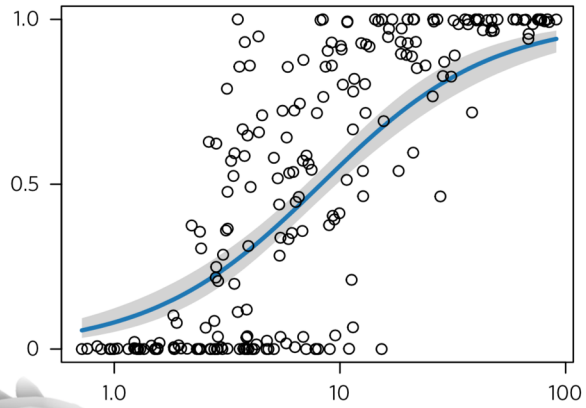
Mechanistic ocean, mechanistic fish

FEISTY



log10 Zoop:Bent

SAU catch reconstruction



$F_{pelagic}$:$F_{seafloor}$

F= fraction NPP

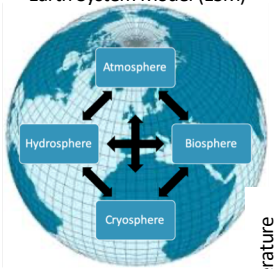
Petrik et al. 2019

van Denderen et al. 2018

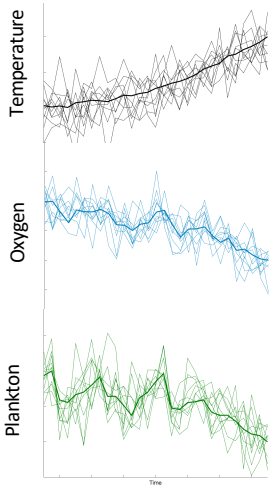
Modeling Climate Impacts on Predictability of Fisheries

M. Long, C. Petrik, S. Siedlecki

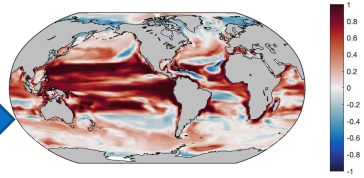
Earth System Model (ESM)



Earth System Model predictions



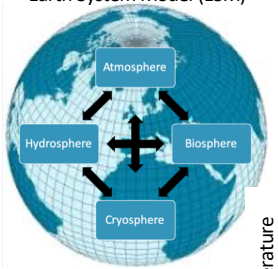
ESM Plankton skill



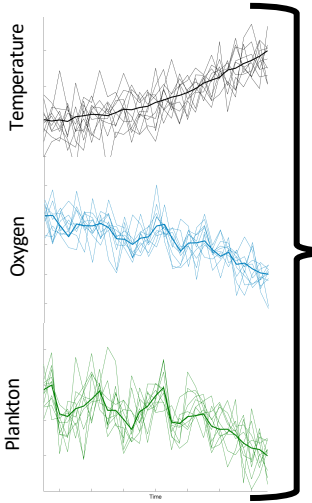
Modeling Climate Impacts on Predictability of Fisheries

M. Long, C. Petrik, S. Siedlecki

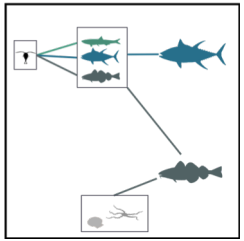
Earth System Model (ESM)



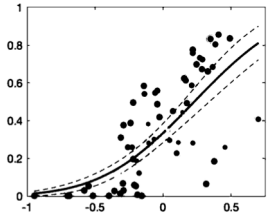
Earth System Model predictions



Ability of physics and biogeochemistry to explain fish variations



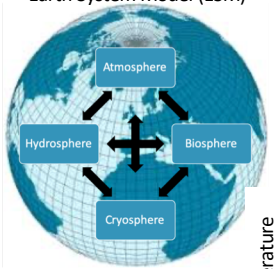
Plankton and Fish correlation



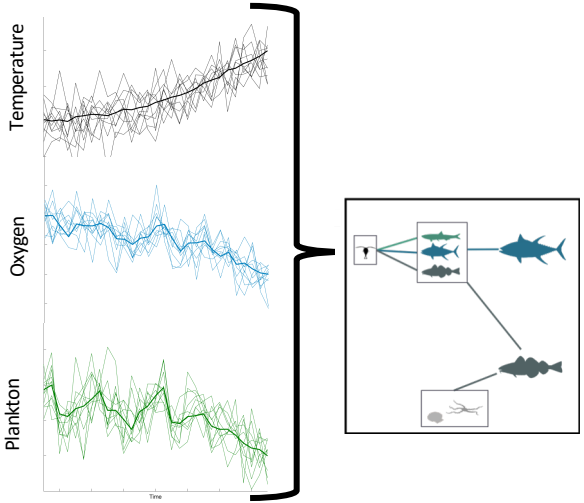
Modeling Climate Impacts on Predictability of Fisheries

M. Long, C. Petrik, S. Siedlecki

Earth System Model (ESM)

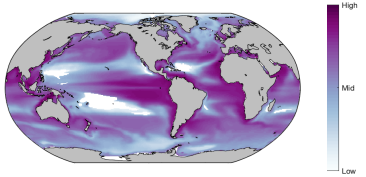


Earth System Model predictions



Fish model predictions

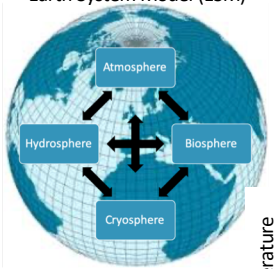
Fish model prediction



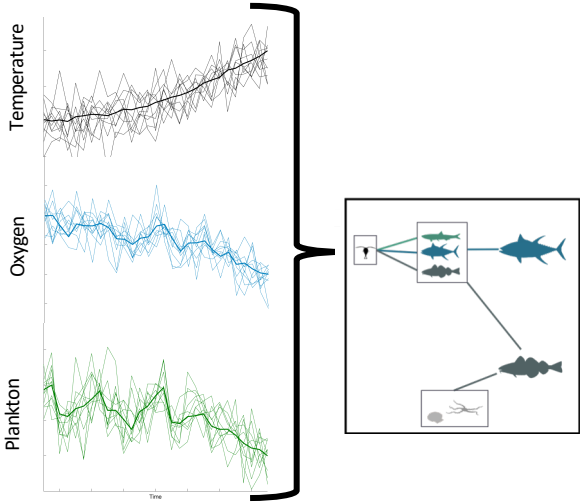
Modeling Climate Impacts on Predictability of Fisheries

M. Long, C. Petrik, S. Siedlecki

Earth System Model (ESM)

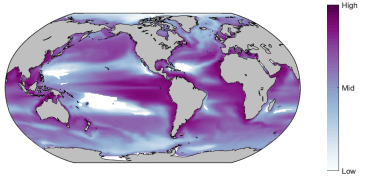


Earth System Model predictions

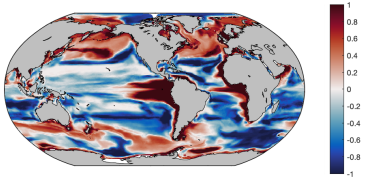


Fish model predictions

Fish model prediction



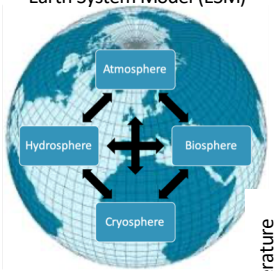
Fish model skill



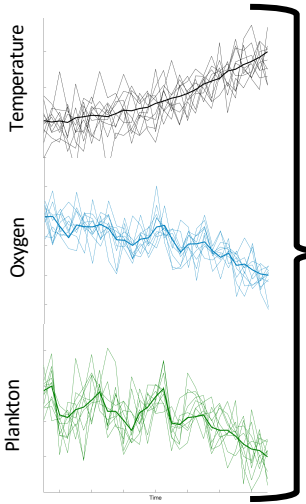
Modeling Climate Impacts on Predictability of Fisheries

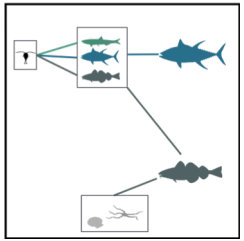
M. Long, C. Petrik, S. Siedlecki

Earth System Model (ESM)



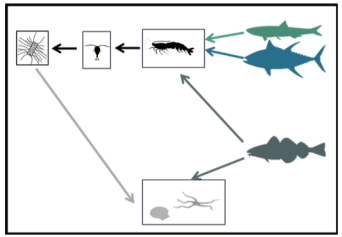
Earth System Model predictions



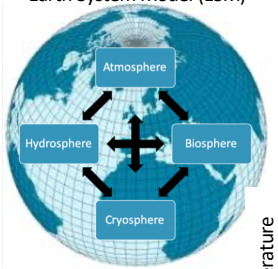


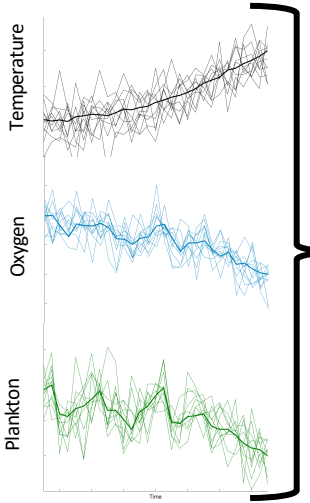
Fish food webs

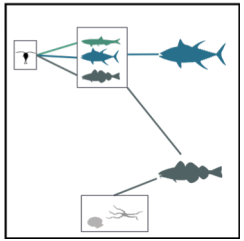
Effects of fish on biogeochemistry



Earth System Model (ESM)

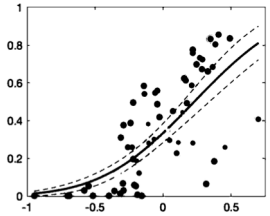






Ability of physics and biogeochemistry to explain fish variations

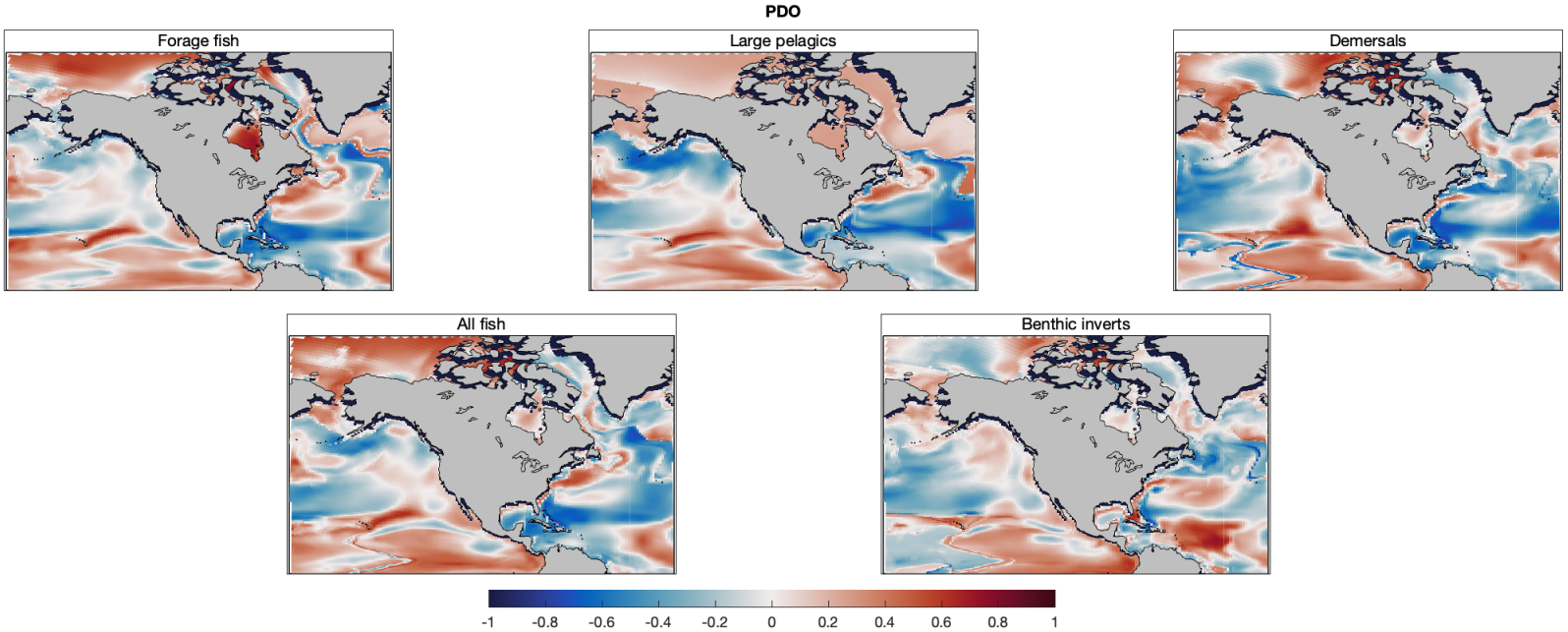
Plankton and Fish correlation



Potential accomplishment – ecosystem hindcasts

Mechanistic ocean (FOSI), mechanistic fish

- Correlations with climate indices: PDO & N America

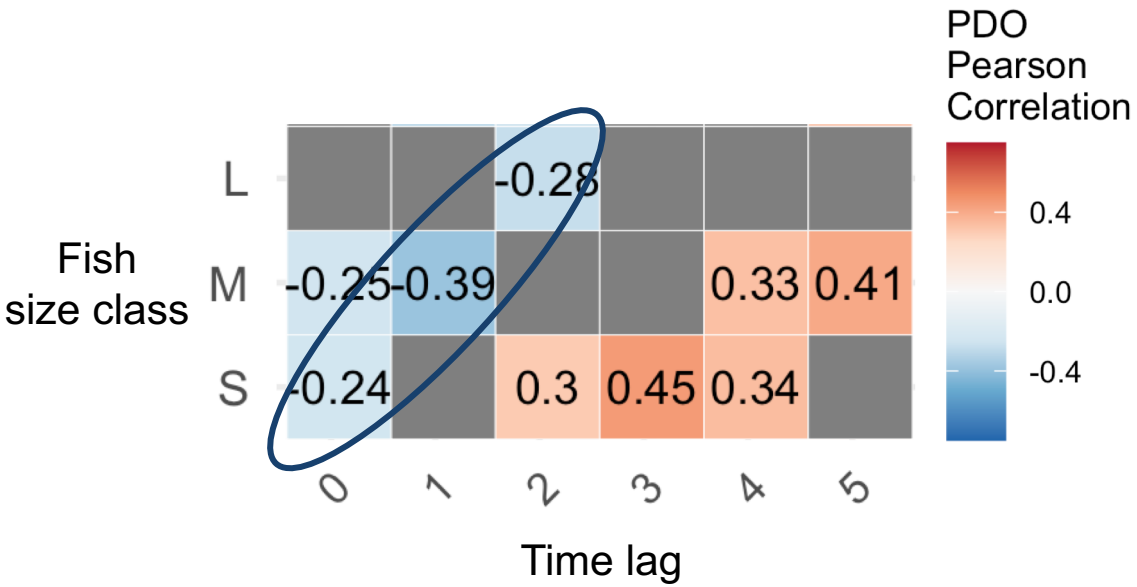


Petrik et al. in prep

Potential accomplishment – ecosystem hindcasts

Mechanistic ocean (FOSI), mechanistic fish

- Correlations with climate indices: PDO & California Current LME
  - Lagged in time as fish size increases

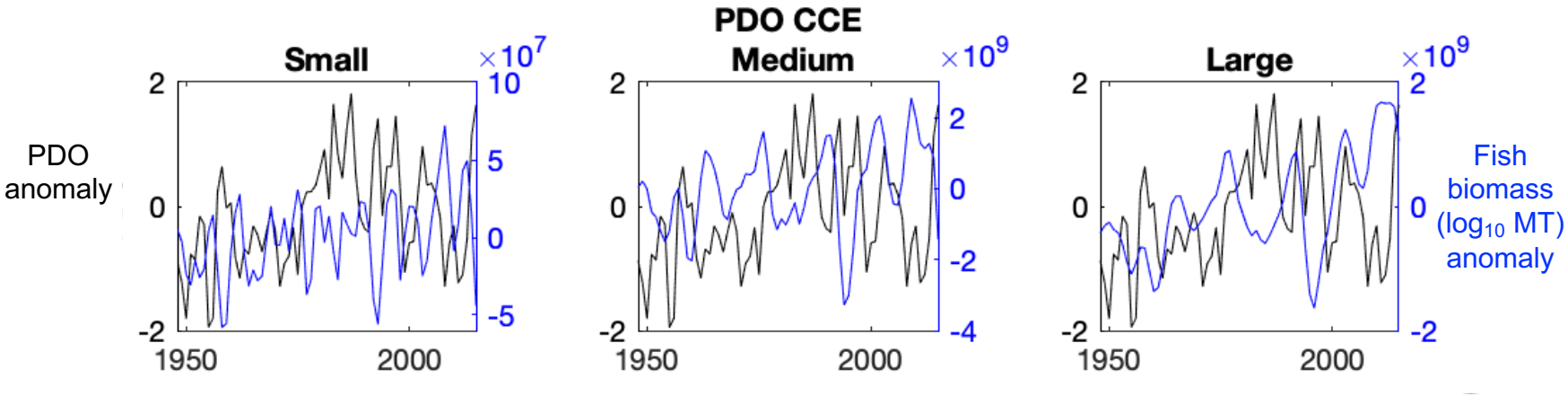


Petrik et al. in prep

Potential accomplishment – ecosystem hindcasts

Mechanistic ocean (FOSI), mechanistic fish

- Correlations with climate indices: PDO & California Current LME
  - Smoothing of variability as fish size increases



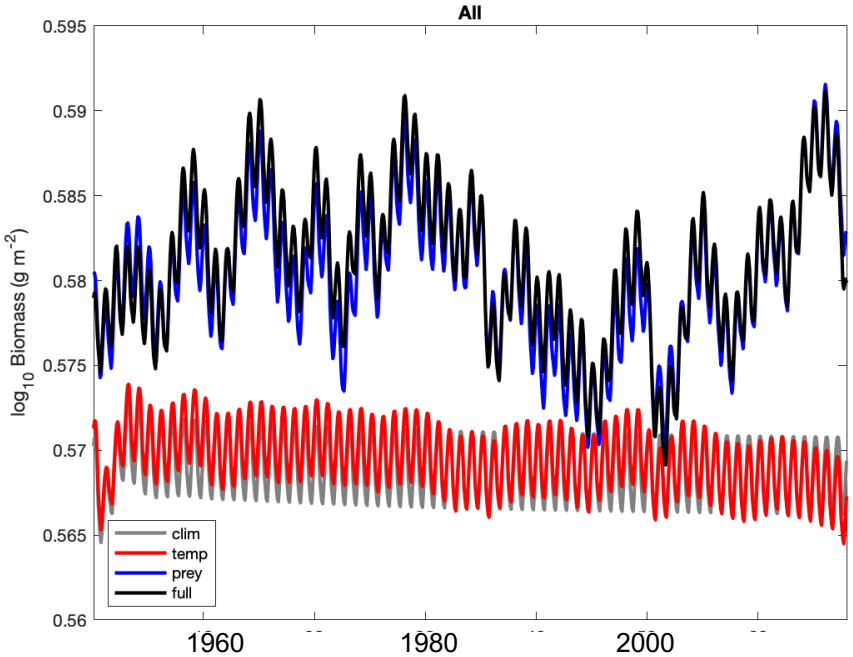
Petrik et al. in prep

Potential accomplishment – ecosystem hindcasts

Mechanistic ocean (FOSI), mechanistic fish

- Ability of physics and biogeochemistry to explain fish variability

Total fish biomass ($\log_{10}$ MT)

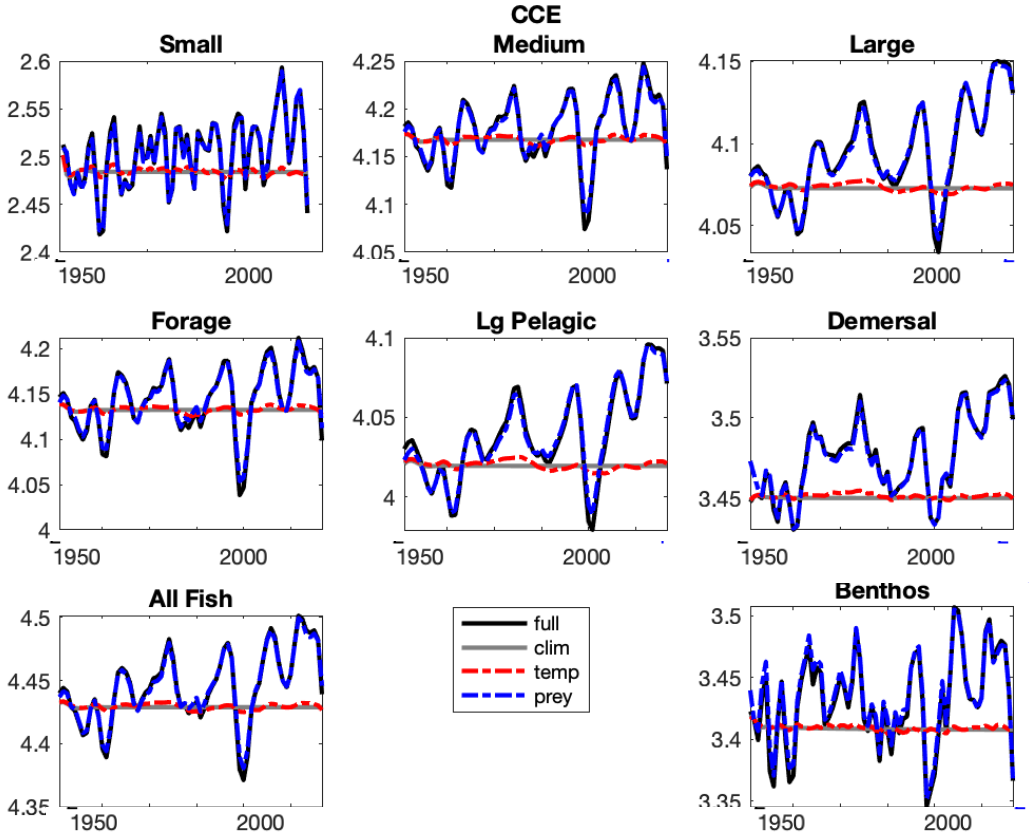


"Reynolds decomposition" of FOSI

- Full $= \overline{(T} + T') + (\bar{Z} + Z')$
- Climatology $= \overline{(T)} + (\bar{Z})$
- var Temp $= \overline{(T} + T') + (\bar{Z})$
- var Prey $= \overline{(T)} + (\bar{Z} + Z')$

Petrik et al. in prep

Potential accomplishment – ecosystem hindcasts



Mean biomass (log_{10} MT)

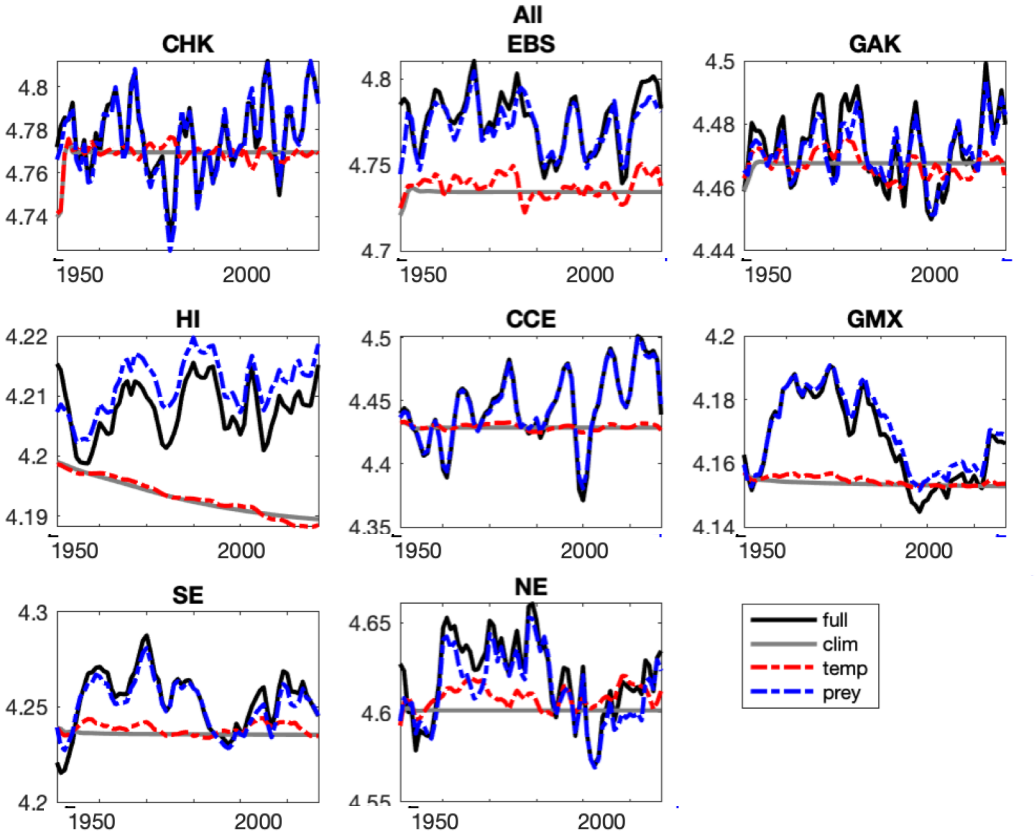
Varying the prey alone captures the full dynamics

*prey were influenced by varying temperature in the ESM

Petrik et al. in prep

Potential accomplishment – ecosystem hindcasts

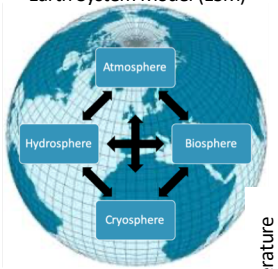
Mean biomass of all fish (log_{10} MT)



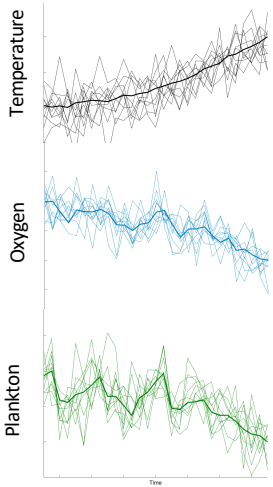
Temperature effects on physiology greater influence in cold and hot LMEs

Petrik et al. in prep

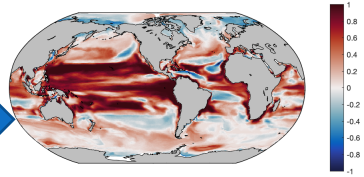
Earth System Model (ESM)



Earth System Model predictions



ESM Plankton skill

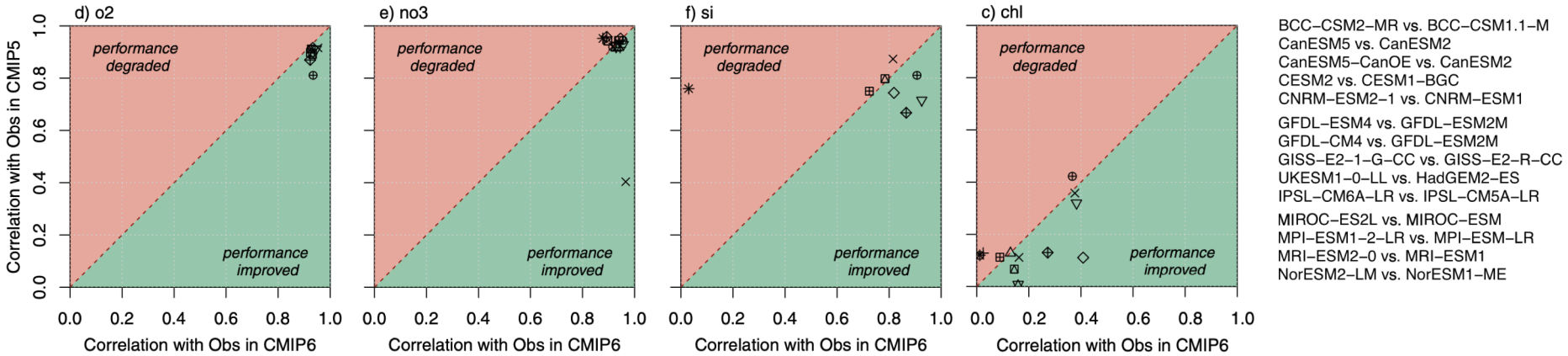


Potential challenges – mechanistic

Predictability of secondary production

- ESM skill assessment of historical simulations
- SST – heavily validated by model developers and CMIP

BCG – mostly nutrients and Chl and/or NPP



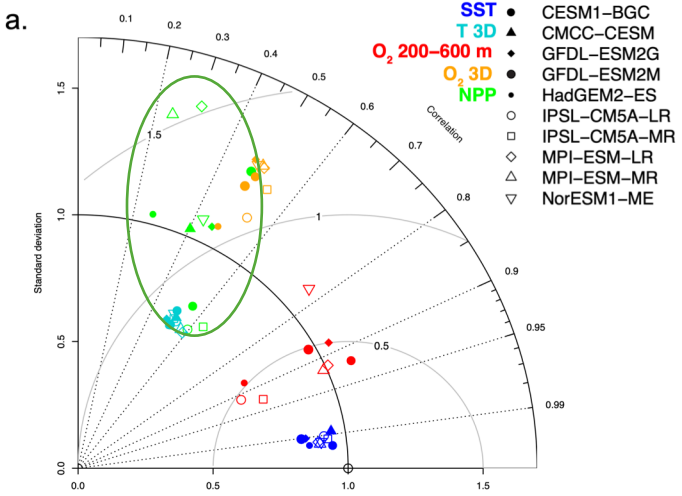
Séférian et al. 2020

Potential challenges – mechanistic

Predictability of secondary production

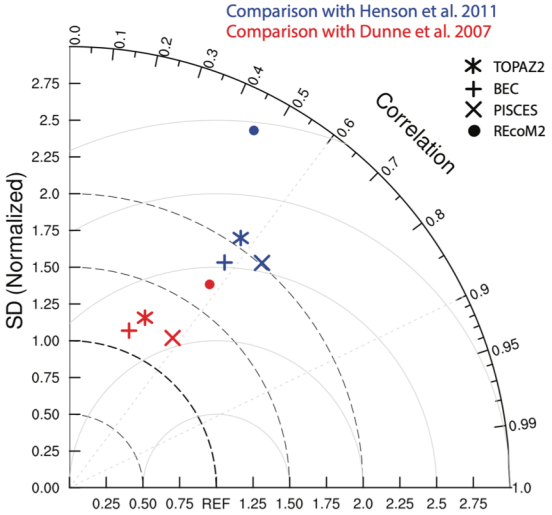
- Comparisons of modeled plankton and export with observations are not strong

CMIP5 NPP



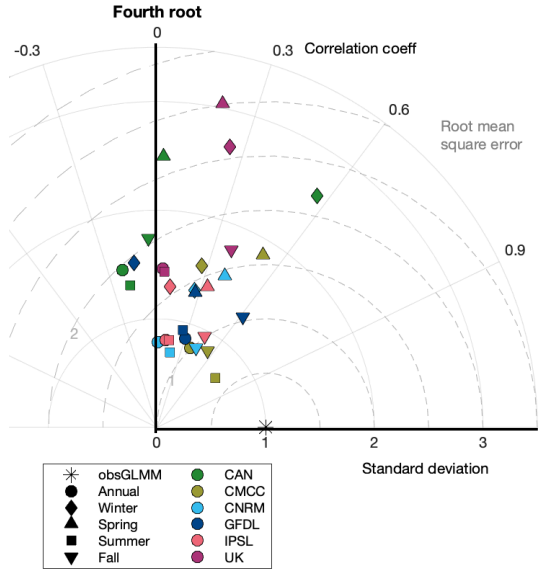
Bopp et al. 2013

CMIP5 Export production



Laufkötter et al. 2016

CMIP6 Mesozooplankton

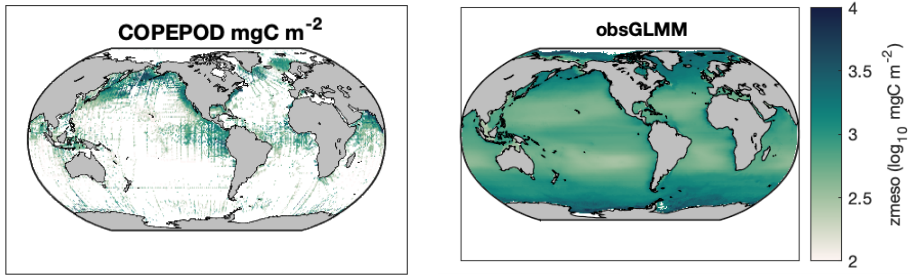


Petrik et al. submitted GBC

Potential challenges – mechanistic

Predictability of secondary production

- Lacking observations globally, over time
  - Chlorophyll, NPP, Export production skill assessments all cover multiple decades
  - Zooplankton only has a climatology from all data collected before 2015
  - Can create a global product using GLMMs

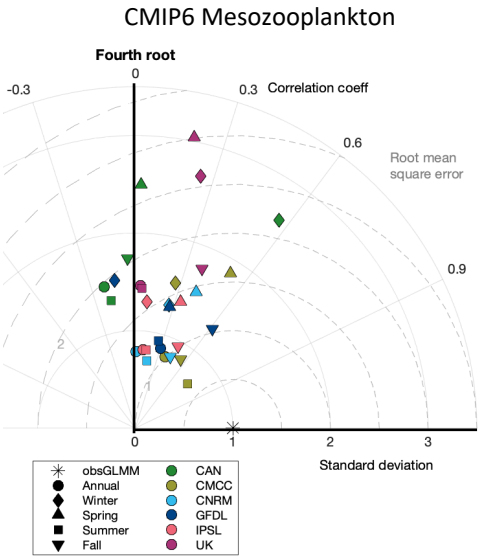


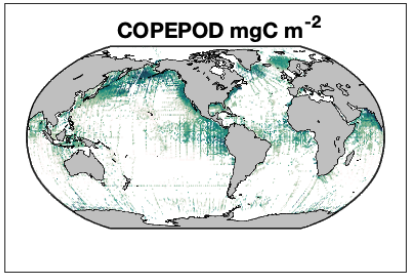
Moriarty & O'Brien 2013; Heneghan et al. 2020

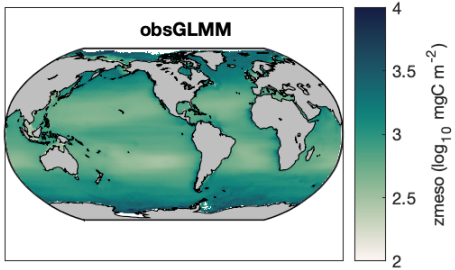
Potential challenges – mechanistic

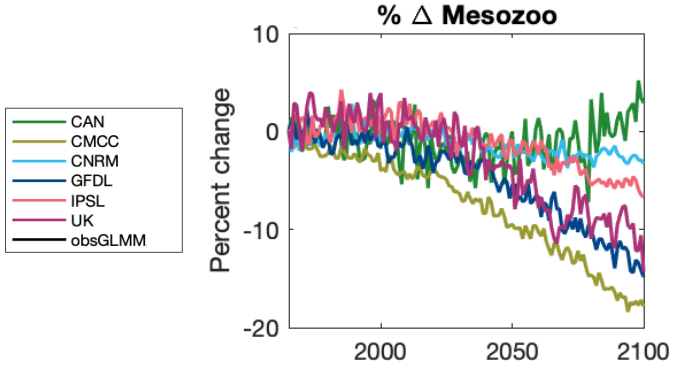
Predictability of secondary production

- Lacking observations globally, over time
  - Can create a global product using GLMMs
  - Used for skill assessment
  - Spatial patterns and Seasonal trends







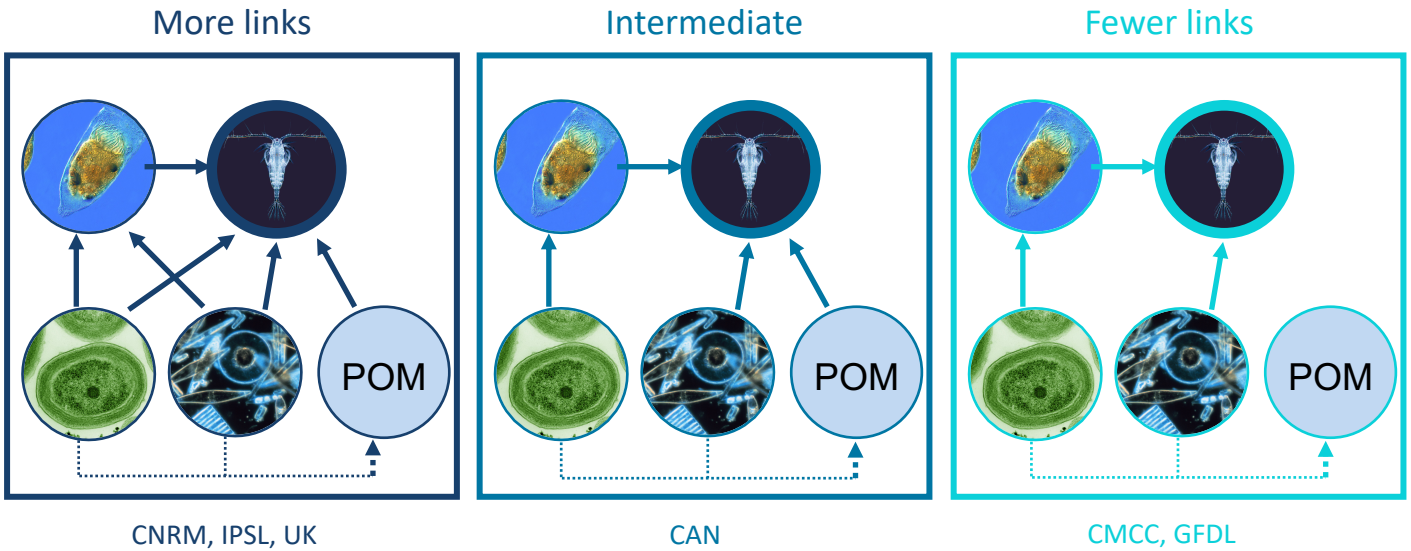


Moriarty & O'Brien 2013; Heneghan et al. 2020; Petrik et al. submitted GBC

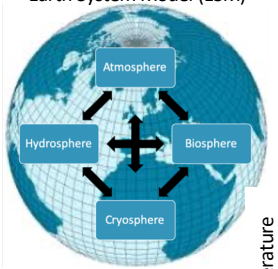
Potential challenges – mechanistic

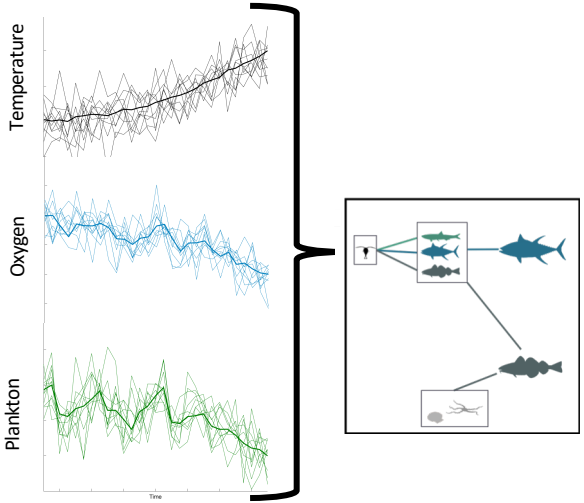
Predictability of secondary production

- Lacking zooplankton rates – could constrain & lend mechanistic insights
  - Structural and parameter uncertainty of biogeochemical models (see Kearney et al. 2021)



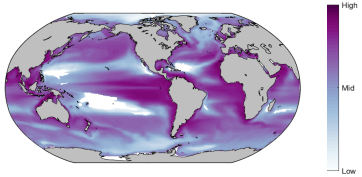
Earth System Model (ESM)



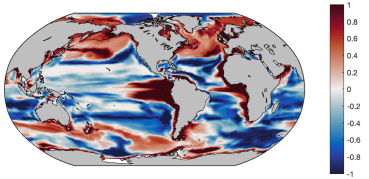


Fish model predictions

Fish model prediction



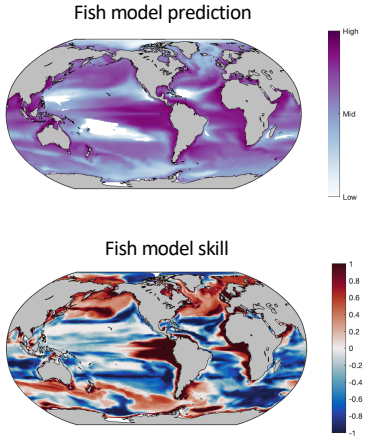
Fish model skill



Potential challenges – mechanistic

Predictability of fish

- Lacking observations globally, over time
  - Fisheries-independent fish biomass
  - Scattered throughout institutions, not centrally located
  - No processing that facilitates comparing places and times (standardization of units, etc.)



Perspectives



- More predictive skill assessment of non-temp, non-NPP variables
  - Mechanistic understanding still needed
  - Temperature and oxygen affects on physiology
  - Resource availability

- Use of ensembles that span structural and parameter uncertainty instead of ensemble of initial condition perturbations?

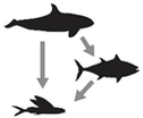
- Top-down effects
  - How important is fishing mortality for ecosystem predictions?

Acknowledgments

- Collaborators:
  - Matt Long, Sam Siedlecki, Charlie Stock, Curtis Deutsch, Zhuomin Chen
  - Jason Everett, Cheryl Harrison, Ryan Heneghan, Jessica Luo, Anthony Richardson
  - Daniel van Denderen, Ken Andersen, Remy Denechere

FISHERIES & MARINE ECOSYSTEM FISH-MIP MODEL INTERCOMPARISON PROJECT

Ecosystem models
Fisheries Ecosystem Model Inter-comparison Project
FISHMIP



Earth system models
Coupled Model Inter-comparison Project
CMIP

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION U.S. DEPARTMENT OF COMMERCE

MAPP
Modeling, Analysis, Predictions, and Projections

cpetrik@ucsd.edu