Modeling capabilities and challenges:
Empirical and mechanistic modeling of marine ecosystems/fisheries

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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
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
  • $2^{\circ}$ production
  • Export production

van Denderen et al. 2018
Potential challenges

Empirical fish relationships

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

\[ \Phi = A_o B^e pO_2 \exp \left( \frac{E_o}{k_B T} \right) \]

Deutsch et al. 2015, 2020
Potential challenges

Empirical fish relationships

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

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

**Empirical fish relationships**

• Other drivers beyond SST, NPP/chl
  • 2º 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

$F_{\text{pelagic}}:F_{\text{seafloor}}$

$F = \text{fraction NPP}$

Petrik et al. 2019

van Denderen et al. 2018
Effects of fish on biogeochemistry

Temperature

Oxygen

Plankton

Earth System Model (ESM)

Earth System Model predictions

ESM Plankton skill

Modeling Climate Impacts on Predictability of Fisheries

M. Long, C. Petrik, S. Siedlecki
Modeling Climate Impacts on Predictability of Fisheries
M. Long, C. Petrik, S. Siedlecki

- Effects of fish on biogeochemistry
  - Oxygen
  - Plankton

Earth System Model (ESM)
- Earth System Model predictions
- Ability of physics and biogeochemistry to explain fish variations

- Temperature
- Oxygen
- Plankton

Plankton and Fish correlation
Modeling Climate Impacts on Predictability of Fisheries
M. Long, C. Petrik, S. Siedlecki

- Effects of fish on biogeochemistry
- Oxygen
- Plankton
- Temperature

Earth System Model (ESM)
Earth System Model predictions

Fish model predictions
Fish model prediction
Modeling Climate Impacts on Predictability of Fisheries

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Effects of fish on biogeochemistry

Fish model prediction

Earth System Model (ESM)

Earth System Model predictions

Temperature

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Fish model predictions

Fish model prediction

Fish model skill
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Effects of fish on biogeochemistry

Earth System Model predictions

Earth System Model (ESM)

Temperature

Oxygen

Plankton

Fish food webs

Ability of physics and biogeochemistry to explain fish variations

Earth System Model predictions
Effects of fish on biogeochemistry

Oxygen

Plankton

Earth System Model predictions

Ability of physics and biogeochemistry to explain fish variations

Temperature

Oxygen

Plankton

Earth System Model (ESM)
Potential accomplishment – ecosystem hindcasts

Mechanistic ocean (FOSI), mechanistic fish

• Correlations with climate indices: PDO & N America
Potential accomplishment – ecosystem hindcasts

Mechanistic ocean (FOSI), mechanistic fish

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

![Heatmap diagram showing correlations between fish size classes and time lags with PDO Pearson correlation values.](image)
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

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

"Reynolds decomposition" of FOSI
- Full = $\bar{T} + T' + \bar{Z} + Z'$
- Climatology = $\bar{T} + \bar{Z}$
- var Temp = $\bar{T} + T' + \bar{Z}$
- var Prey = $\bar{T} + (\bar{Z} + Z')$
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Potential accomplishment – ecosystem hindcasts

Varying the prey alone captures the full dynamics

*prey were influenced by varying temperature in the ESM
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
Effects of fish on biogeochemistry

- Temperature
- Oxygen
- Plankton

Earth System Model (ESM) predictions

Earth System Model (ESM) 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

Bopp et al. 2013
Laufkötter et al. 2016
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)
Effects of fish on biogeochemistry

Oxygen

Plankton

Temperature

Fish model predictions

Fish model skill

Earth System Model (ESM)

Ability of physics and biogeochemistry to explain fish variations

Fish model predictions

Earth System Model predictions
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?
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