The Response of Fisheries Production to Natural and Anthropogenic Forcing: Past, Present, and Future

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PICES Annual Meeting San Diego
10 Nov 2016
Expected changes to fish

Graph showing climate-dependent distribution, invasion, reduction in body size, local extinctions, and change in maximum catch potential.
Global size-based fish model

GFDL ESM COBALT

Stock et al. 2014; Watson et al. 2014
Global size-based fish model

- Pelagic
- Adults
Global size- and type-based fish model

Structured by:

- Feeding & habitat “functional type”
  - forage fishes
  - large migratory pelagics
  - demersals

- Maturity stage
  - larvae
  - juveniles
  - adults

- Size
  - small
  - medium
  - large
Forage fishes
Large pelagics
Demersals
Benthic material

Functional types and sizes

<table>
<thead>
<tr>
<th>Meso</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
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<tbody>
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<td>0.2 mm</td>
<td>2 mm</td>
<td>20 mm</td>
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- Zooplankton
- Forage fishes
- Large pelagics
- Demersals
- Benthic material
Life cycle dynamics - reproduction

- Forage fishes
- Large pelagics
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Zooplankton

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- Zooplankton
- Forage fishes
- Large pelagics
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Life cycle dynamics - recruitment

- Zooplankton
- Forage fishes
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- Benthic material
Size-based trophic interactions

- **Zooplankton**
- **Forage fishes**
- **Large pelagics**
- **Demersals**
- **Benthic material**

Size categories: 0.2 mm, 2 mm, 20 mm, 200 mm, 2000 mm
Small eats medium zooplankton

Forage fishes

Large pelagics

Demersals

Benthic material
Medium eats small animals
Large eats medium animals

Forage fishes

Large pelagics

Demersals

Benthic material

Zooplankton

0.2 mm 2 mm 20 mm 200 mm 2000 mm
Type-based trophic interactions

- Forage fishes
- Zooplankton
- Large pelagics
- Demersals
- Benthic material

Size categories:
- Meso: 0.2 mm
- Small: 2 mm
- Medium: 20 mm
- Large: 200 mm
- Extra Large: 2000 mm
Forage fishes eat plankton

- **Zooplankton**
  - Small
  - Medium
  - Large

- **Forage fishes**
  - Meso
  - Small
  - Medium
  - Large

- **Large pelagics**
  - Meso
  - Small
  - Medium
  - Large

- **Demersals**
  - Meso
  - Small
  - Medium
  - Large

- **Benthic material**
  - Meso
  - Small
  - Medium
  - Large
Large pelagics eat pelagic animals

- Forage fishes
- Large pelagics
- Demersals
- Benthic material

Zooplankton

0.2 mm 2 mm 20 mm 200 mm 2000 mm
Demersals eat ... it depends

Forage fishes

Zooplankton

Large pelagics

Demersals

Benthic material

Size categories:
- Meso: 0.2 mm
- Small: 2 mm
- Medium: 20 mm
- Large: 200 mm, 2000 mm
Unfished historic global fish distribution

1951-2000 log10 mean biomass All F (g m⁻²)

1951-2000 log10 mean biomass All P (g m⁻²)

Forage fishes

Large pelagics

Demersals
Comparisons to other estimates

All consumers

Size-based model

weight = $10^2 - 10^4$ g

0.09 – 8.89 $10^9$ MT

Size- and type-based model

Jennings & Collingridge 2015

0.35 $10^9$ MT
Comparisons to other estimates

Benthic invertebrates > 1mm

Statistical model

Mechanistic model

Wei et al. 2011
Comparisons to other estimates

Commercial fish catch

1951-2000 mean catch without Australia and polar regions

\[ r = 0.56 \]

Modeled fish catch (MT)

SAUP estimated fish catch (MT)

F = 0.3

~ MSY
4 comparisons to highlight drivers

- Historic unfished vs. Pre-industrial
  - Industrial CO₂

- Historic fished vs. Historic unfished
  - Contemporary Fishing

- Future unfished vs. Historic unfished
  - Climate change (RCP 8.5)

- Future fished vs. Historic fished
  - Climate change + Future Fishing
Nominal changes from climate change to date

![Graph showing mean biomass (g/m²) for unfished and fished all fishes over the years from 1860 to 2100. The graph indicates a decline in mean biomass due to climate change and fishing.]
Future climate change similar magnitude as fishing

Mean biomass (g/m²)

unfished

fished

Fishing

Climate change

Climate change +

Fishing

Year

1860
1900
1950
2000
2050
2100

Mean biomass

7.4 × 10^4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
Future climate change similar magnitude as fishing

Mean biomass (g/m²)

- Unfished: -9.0% to -8.5%
- Fished: -9.1% to -16.7%
Future climate change similar magnitude as fishing

Mean biomass

Mean biomass (g/m²)

all fishes

unfished

fished

Climate change + Fishing

- 9.1%
Trophic amplification

Global change in productivity

% change

NPP  Mesozoo  Fish
Huge regional variations in % change
N Pac regional variations % change

2051-2100 % difference from 1951-2000 mean biomass of all fishes
N Pacific changes in biomes

1951-2000

2051-2100

LC – Low Chl +0.23
ECCS – Elevated Chl, Cont Strat +0.03
ECSS – Elevated Chl, Seas Strat −0.25

c.f. Polovina et al. 2011; Stock et al. 2014
N Pacific % change in fish by biome

1951-2000

2051-2100

% change

% change area integrated biomass (g)

Climate Change + Fishing

Legend:
- All
- LC
- ECCS
- ECSS
N Pacific % change by biome

% change area integrated biomass (g)
N Pacific % change by biome

% change area (m)

% change area integrated biomass (g)

% change biomass (g/m²)
Conclusions

- Amplifying effects from anthropogenic forcing
  - $\Delta$ area + $\Delta$ abundance $\neq$ $\Delta$ biomass
  - $\Delta$ fished $>$ $\Delta$ unfished
  - trophic amplification of $\Delta$ productivity
Future directions

- Effect of movement
- Recruitment dynamics
  - Spawning phenology (Rebecca Asch)
  - Predation by zooplankton
- Jellyfish as competitors and predators (Natasha Henschke)
- Fisheries management scenarios
Acknowledgments

- Ken Andersen, Charlie Stock, Jorge Sarmiento, James Watson
- Nereus Program (Nippon Foundation)
- NOAA Geophysical Fluid Dynamics Laboratory
- Princeton University
- Sea Around Us Project

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