Large-scale natural variability and anthropogenic trends in multiple ocean ecosystem stressors

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Ocean moderates climate change, but ..
The global-scale evolution of stressors in the 21\textsuperscript{st} century

Warming up, turning sour, losing breath (and food)

The quadruple whammy for ocean life

Frölicher et al. (2016, Global Biogeochem. Cycles)
see also Bopp et al. (2013)
Reduction in global fisheries catch potential

NEWS & VIEWS

FISHERIES

Climate change at the dinner table

An innovative use of catch statistics shows that climate change has already influenced the composition of species in fisheries around the world, and thereby the fish that we eat. See Letter p.365

MARK R. PAYNE

Fisheries scientists tend to view climate change as a dark cloud on the horizon: potentially problematic in the future, but not of immediate concern. Over the multi-decadal to centennial scale, warming, acidification and deoxygenation of the oceans are expected to have significant impacts on marine ecosystems and fisheries. By contrast, other problems, such as the global overfishing crisis, are immediate and pressing and have rightly garnered the field’s attention for the past decade. However, on page 365 of this issue, Cheung et al. present startling evidence that global fisheries catches have already changed in a manner associated with the warming trend — climate change is suddenly an unexpected guest at dinner.

Changes in the spatial distribution of species are one of the major predicted impacts of climate change on marine ecosystems. Marine species tend to occupy the full range of temperatures that they can physiologically tolerate and therefore, on a broad scale, their distributions closely track temperature boundaries.
Risk for marine organisms and ecosystems

Modified from IPCC AR5 Synthesis Report (2014)
1. The ocean at risk
   or how ocean ecosystem services cause troubles

2. Sources of uncertainties in projections of multiple stressors
   or how important is natural variability on global and regional scale?

3. Impacts on marine organisms and ecosystem services
   or what are the benefits to marine fisheries of meeting the 1.5°C target?

4. Ocean extreme events
   or have we overlooked a potential serious problem?

5. Conclusions
The global-scale evolution of stressors in the 21st century

Climate model projections have large uncertainties.

Changes occur on top of regional and natural variability.

Frölicher et al. (2016, Global Biogeochem. Cycles)
Decision makers and regional impact assessment modelers would like quantitative projections of future changes in ocean ecosystem stressors on regional scale, especially for the next few decade.

Frölicher et al. (2016, Global Biogeochem. Cycles)
Questions

- What are the sources of uncertainties on global and regional scales?

- Does the source of uncertainty vary with region, time horizon and ocean ecosystem driver variable?
Sources of projection uncertainty

Internal variability uncertainty

Scenario uncertainty

Model structural uncertainty

Attribution framework developed by Hawkins and Sutton (2009, 2011)
see also Lovenduski et al. (2016, 2017)
Sources of projection uncertainty

**Model structural uncertainty**

- **TOPAZ**
  - Diatoms
  - Diazotrophs
  - Nano (Fe, NH4, PO4)

- **REcoM2**
  - Diatoms
  - Nano (Fe, NH4, PO4)

- **PISCES**
  - Diatoms
  - Nano (Fe, NH4, PO4)

- **PlankTOM**
  - Diatoms
  - Nano
  - Cocco

**Scenario uncertainty**

- RCP8.5: 3.2–5.4°C
- RCP6: 2.0–3.7°C
- RCP4.5: 1.7–3.2°C
- RCP2.6: 0.9–2.3°C

**Internal variability uncertainty**

- Attribution framework developed by Hawkins and Sutton (2009, 2011)
- See also Lovenduski et al. (2016, 2017)

**Attribution framework for 2015 estimate**

- Rodgers, Lin, Frölicher (2015, Biogeosciences)
- Von Känel, Frölicher, Gruber (2017, GRL in press)

**GFDL ESM2M large ensemble**

- ΔGlobal mean surface temperature (°C)
- 1860 control: >1000 yrs
- Ensemble mean: Ensemble members 1-30

- See also Laufkötter (2015, PhD thesis)
Projected SST changes in the Humboldt Current System with the large GFDL ensemble
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Global-scale fractional uncertainty

Frölicher et al. (2016, Global Biogeochem. Cycles)
Global vs. local-scale fractional uncertainty

Frölicher et al. (2016, Global Biogeochem. Cycles)
Question

When does the signal move outside of the internal variability range?
Changes in the combined stressors emerge from the noise in 54% of ocean

**Time of emergence**: $S/N > 1$

**Signal $S$**: Amplitude of forced changes for RCP8.5 relative to 1986-2005

**Noise $N$**: Internal variability + model uncertainty

Frölicher et al. (2016, Global Biogeochem. Cycles)
High risk of impacts in low latitudes

Frölicher et al. (2016, Global Biogeochem. Cycles)
Outline

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5. Conclusions
The Paris Agreement

- Holding the increase global mean temperature to well below 2°C above preindustrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C

- 147 of 197 parties have ratified the convention
The Paris Agreement

Translating the Paris Agreement into impact-related targets facilitates communication of the benefits of mitigating climate change to policymakers and stakeholders.

• Holding the increase global mean temperature to well below 2°C above preindustrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C

• 147 of 197 parties have ratified the convention
Climate change impact on fisheries

Large benefits to marine fisheries of meeting the 1.5°C global warming target

William W. L. Cheung, Gabriel Reygondeau, Thomas L. Frölicher

Translating the Paris Agreement to limit global warming to 1.5°C above preindustrial level into impact-related targets facilitates communication of the benefits of mitigating climate change to policymakers and stakeholders. Developing ecologically relevant impact-related targets for marine ecosystem services, such as fisheries, is an important step. Here, we use maximum catch potential and species turnover as climate-risk indicators for fisheries. We project that potential catches will decrease by more than 3 million metric tons per degree Celsius of warming. Species turnover is more than halved when warming is lowered from 3.5° to 1.5°C above the preindustrial level. Regionally, changes in maximum catch potential and species turnover vary across ecosystems, with the biggest risk reduction in the Indo-Pacific and Arctic regions when the Paris Agreement target is achieved.

Cheung, Reygondeau, Frölicher (Science, 2016)
Modeling framework

- 19 (3) Earth System Models

- 2 future scenarios:
  - RCP8.5: about 4-5°C
  - RCP2.6: about 2°C
Modeling framework

- 19 (3) Earth System Models
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- Marine species distribution model that simulates interactions between changes in ocean conditions, ecophysiology, population dynamics, dispersal, habitat productivity
- > 890 exploited fish and invertebrates
Changes in fisheries maximum catch potential in LMEs

- Maximum catch potential is a proxy for maximum sustainable yield
- Changes in maximum catch potential scales negatively and nearly linearly with atmospheric warming
  - $-3\%$ per $\degree C$ warming
  - $-3.4 \times 10^6$ t per $\degree C$ warming

![Graph showing changes in maximum catch potential with atmospheric temperature rise]

- Current nationally determined contributions
- 1.5$\degree$ C Paris target
- 3.5$\degree$ C
Regional changes in maximum catch potential in LMEs

**Tropics:**
Indo-Pacific LMEs

- 1.5°C: -10%
- 3.5°C: -50%

**High latitudes:**
Arctic LMEs

- 1.5°C: +30%
- 3.5°C: +55%

**Norwegian Sea**

- 1.5°C: +10%
- 3.5°C: -35%

Cheung, Reygondeau, Frölicher (Science, 2016)
Impact of one tonne of CO$_2$ emissions on fishing catch

Cheung, Reygondeau, Frölicher (Science, 2016)

Frölicher (Nature Climate Change 2016)
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I am happy to provide more information by email if you are interested: thomas.froelicher@usys.ethz.ch
Conclusions

1. Future projections of potential ocean ecosystem stressors are fraught to large uncertainty

2. Internal variability is the dominant source of uncertainty in middle-to-low latitudes and in most coastal large marine ecosystems over the next few decades, suggesting irreducible uncertainty inherent these short projections

3. Operating within the Paris Agreement substantially reduces risk of impacts on fisheries

4. Global warming has significantly increased the odds of marine heat waves to occur