Confronting the complexities of ecological responses to ocean acidification

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Why should we be concerned about climate change?

Maine Atlantic Salmon Commission

“How will OA affect my favorite species?”
Predicting biological responses to ocean acidification
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modified from Harley et al. 2006, Ecol Let
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Predicting biological responses to ocean acidification

OA

Warming, etc.

Larvae

Adults

Other species

modified from Harley et al. 2006, Ecol Let
Predicting biological responses to ocean acidification

modified from Harley et al. 2006, Ecol Let
Multiple stressor and cumulative effects

Larvae

Adults

OA

Warming, etc.

Other species
3 fundamental cumulative effects

- Control
- Stress A
- Stress B
- Additive
- Sub-additive
- Super-additive

Con – A - B

Synergism
Antagonism

Response (e.g., growth)
Cumulative effects of near-future warming + OA

- 33% Warming offset OA effects
- 31% No interaction
- 36% Warming exacerbated OA effects

"Synergistic"

N = 125

Kroeker et al. in prep
OA and temperature interaction may be predictable using existing physiological theory, e.g., the oxygen and capacity limited thermal tolerance hypothesis.
Note that patterns at one level of biological organization don’t necessarily translate to similar patterns at other levels.
Kroeker et al. 2017 Biology Letters
Increased competition or consumer pressure

Increased food supply or facilitation

Community population size vs time

Population size vs time

\[ \lambda \]

Performance vs temperature

high O$_2$ or low CO$_2$

low O$_2$ or high CO$_2$
Ontogenetic and inter-generational effects

OA
Warming, etc.

Larvae
Adults

Other species
Manon Picard’s MSc research

Oyster life cycle

- Adult
- Gametes
  - Fewer embryos produced
  - Trisacophore larva
  - Prodissoconch I larva
  - Prodissococonch II larva
  - Late prodissococonch II larva (pedioconch larva)
  - Settlement
  - Poorer condition
  - Reduced growth
  - Delayed mortality
  - Dissoconch (juvenile)

Delayed development

Reduced growth

Poorer condition

Delayed mortality

Dissoconch (juvenile)
(Natural) selection to the rescue?

Blue mussel
- fast generation time

Red urchin
- slow generation time
(Natural) selection to the rescue?

Blue mussel
- fast generation time
- no relevant heritable variation
- predicted not to adapt with OA

Red urchin
- slow generation time
- much relevant variation
- predicted to adapt with OA

Sunday et al. 2011 PLOS ONE
Food web and biogenic habitat effects

OA

Warming, etc.

Larvae

Adults

Other species
If OA is fundamentally an energetics problem...

...could increasing food supply solve the problem?
OA effects vs. food supply – possible outcomes of a factorial meta-analysis
OA effects vs. food supply – possible outcomes of a factorial meta-analysis
Observed influence of food on OA effects (factorial meta-analysis)
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Observed influence of food on OA effects (factorial meta-analysis)
Bottom-up effects matter. What about top-down effects?
growth of *Pisaster ochraceus*

% wet weight change vs Day

- 12 C, 380 ppm CO2
- 12 C, 780 ppm
- 15 C, 380 ppm
- 15 C, 780 ppm

Gooding et al. 2009 PNAS
Take-homes: key vulnerabilities and research priorities

“surprises” (thresholds and synergistic effects)  ontogenetic bottlenecks, lack of genetic diversity  habitat and food web effects, microbes

Integrating across levels of organization will be required to fully understand the ecological implications of ocean acidification

OA
Warming, etc.

Other species
Special thanks to:

Students and postdocs: Norah Brown, Ryan Crim, Kelsey Flynn, Becca Gooding, Manon Picard, Jenn Sunday, and the rest of the lab

Collaborators: Joey Berhardt, Becca Kordas, Kristy Kroeker, PWIAS Roundtable participants

Funding: NSERC, Hakai Institute, Peter Wall Institute for Advanced Studies

Intertidal adventurers: Sam, Zoe, Christina, and the dog