Field Notes from a Physiologist: Costs & Consequences of Growing up in a Changing World

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OUR CHANGING OCEANS & ESTUARIES WORKSHOP
Comparative Environmental Physiology

How animals do the unusual things that they do, in the unusual environments in which they live

Emphasis is on mechanism
The Plan

1. Global Climate Change: the challenges and options available to marine organisms
2. Identifying vulnerable organisms
3. Costs and consequences of living in a changing world
   - Temperature tolerance of interidal limpets
   - Multiple stressors in SF Estuary, an important nursery ground for juvenile Dungeness crabs
   - Cold and stable no more: Antarctic fishes
Environment

PHYSIOLOGY

- genome
- cell
- tissue
- organ
- whole organism

- integration of environmental signal

ECOLOGY

- distribution and abundance
- population biology
- community & ecosystem processes

Differential Performance
“It is very likely that [man-made] greenhouse gas increases caused most of the average temperature increase since the mid-20 century”
- IPPC 4th Assessment Report

Data from the Vostok Ice Core

We are in a committed period of Global Warming

Ocean Warming
+2°C → +6°C

Global warming has resulted in shifts in marine ecosystem composition and function (Parmesan, 2006).
Ocean Acidification: The “Other” CO$_2$ Problem

Dr. Pieter Tans, NOAA/ESRL
The Ocean is a sink for atmospheric CO$_2$

Pre-Industrial [CO$_2$] = 280 ppm

Atmospheric

CO$_2$

Present [CO$_2$] = 387 ppm

$\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{HCO}_3^- + \text{H}^+$

$\text{H}^+ + \text{CO}_3^{2-} \rightarrow \text{HCO}_3^-$

$\text{CaCO}_3 \rightarrow \text{Ca}^{2+} + \text{CO}_3^{2-}$

<table>
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<tr>
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<th>1XCO$_2$</th>
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<th>3XCO$_2$</th>
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<td>[CO$_2$]</td>
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<td>[CO$_3^{2-}$]</td>
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<td>pH</td>
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Ocean Acidification: -0.2 $\rightarrow$ -0.4 pH units

Ocean Carbonation: Reduction in Carbonate Ion
Changes in temperature, sea level and Northern Hemisphere snow cover

Sea level rise is due to two processes: thermal expansion of seawater & increased freshwater input from melting glaciers, ice caps & ice sheets.

Global average sea level has risen since 1961 at an average rate of 1.8 mm/yr and since 1993 at 3.1 mm/yr.

Increased intrusion of salt water into freshwater systems.
Intergovernmental Panel on Climate Change (IPCC)

Awarded the Nobel Peace Prize "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change".

As a group of scientists, the IPCC has come up with predictions of what our global climate will look like in 2100.


Next assessment in 2014

www.ipcc.ch/index.htm
Two problems

Novelty of environmental change

Rate of environmental change

Can Biology keep up?
Physiology in a Changing Climate

From a broad perspective there are three main response options for organisms faced with environmental change:

1. Species may disperse to a more hospitable habitat
2. Phenotypic and physiological plasticity may allow species to tolerate the new conditions
3. Species may adapt through genetic change through the process of evolution
Physiology in a Changing Climate

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Can contemporary animals “flex” their physiology to buffer the effects of climate change?

What is their potential to acclimate to future environmental conditions?
Surviving a Changing Environment

A. Single Threshold

B. Multiple Thresholds
   – Organisms will differ in their tolerance to environmental change

C. Acclimatization/Adaptation
   – Tolerance will change over time through acclimatization or adaptation

Hughes et al. (2003) Science
Assessing Vulnerability to Change: Who will be the winners & losers?

Future Environments

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- genome
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- tissue
- organ
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**ECOLOGY**
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Differential Performance
Where do we look to find vulnerable populations?

• Organisms already living on the edge
  ➤ Intertidal limpets

• Organisms living in ecosystems where large fluctuations in many environmental conditions
  ➤ Dungeness Crabs

• Organisms adapted to extremely stable conditions that are intolerant of change
  ➤ Antarctic Fishes
How do we assess vulnerability?

- Linking stress tolerance to current environmental conditions and projected change

- Understanding changes in energy allocation and trade-offs in performance. Animals must do more than just survive!
Vulnerability of Intertidal Organisms

• Organisms already living on the edge
  ➔ Intertidal limpets

• Linking current stress tolerance to current environmental conditions and projected change
What are the limits of an animal’s ability to tolerate change? Where does the animal live today within this performance curve? Where will the animal live in the future?
Rocky Intertidal

Hopewell Flower Pots, Bay of Fundy (Photo credit: Jim Loftus)
• Intertidal species, like limpets, live in a highly variable environment
• Predicted to be vulnerable because they have already stretched their physiology to live in such a stressful environment
• How much more environmental change can they tolerate?
• Increases in mean temperature and extreme heat waves
Cardiac Performance: Measuring Break Point Temperatures
Limpet hearts fail around 38°C under emersion conditions

The fingered limpet, *Lottia digitalis*
How close are limpets living to their thermal limits?

![Graph showing temperature (°C) over time (months) for different logger sites, with a dashed line indicating the mean break in heart rate.]
Multiple stressors & life stages

• Organisms living in ecosystems where large fluctuations in many environmental conditions ➞ Dungeness Crabs

• Understanding changes in energy allocation and trade-offs in performance. Animals must do more than just survive!
Metabolic cost of living in a changing world

Assessing energy allocation to different processes and associated tradeoffs

Scenario 1 = Change in energy allocation to different pathways

Scenario 2 = Energy budget decreases but energy allocation stays the same
Sensitivities to environmental change can lie at a number of developmental stages

- Many marine animals have a bipartite life cycle
- Benthic adults spawn free-swimming pelagic larvae
- These larvae eventually metamorphose and settle as benthic juveniles
- What is the most vulnerable stage?

Kurihara 2008 – Effects of CO$_2$-driven ocean acidification on early developmental stages of invertebrates
Habitat Restoration & Climate Change Impacts on Dungeness Crabs

- Estuaries are important nursery habitats for ecologically and economically important species
- Juvenile Dungeness crab spend ~1 yr in SF Estuary
- Destruction of Bay habitat
- Estuaries are vulnerable to climate change (FW & SW)
- Do particular habitats in the SFE provide more nutrient availability?
- How do changes in food availability affect stress tolerance of crabs
Variability in salinity (and temperature) projected for SF Estuary
Food availability and temperature tolerance of Dungeness crabs

- Two feeding regimes (high & low) for 4 weeks
- Assessed upper temperature tolerance during summer
- Significant decrease in growth & shell strength
- Not effect on cardiac performance at high temperature
Cost of living in a resource poor environment

High Food Group

- Maintenance
- Growth
- Calcification
- Stress Response

Low Food Group

- Maintenance
- Growth
- Calcification
- Stress Response

Will crabs catch up in size?
Will they reach adulthood later?
Will they be able to produce as many offspring?

Scenario 1 = Change in energy allocation to different pathways
Impacts of Climate Change on Larval Fish Development

- Antarctic Fishes
- We presently know little about the impact of ocean acidification on fishes
- Polar species are projected to be particularly vulnerable to climate change
- Evolved under stable, sub-zero conditions for last 11-14 million years
- How is larval development affected by elevated CO$_2$?
- Is this exacerbated by increases in environmental temperature?

Erin Flynn, MS student
• Taking a comparative approach across different environments allows physiologists to assess variability in stress tolerance

• Understanding the consequences of trade-offs in energy allocation is critical to our ability to predict the resilience of marine organisms to climate change

• Identifying the vulnerable organisms and ecosystems will provide critical information to managers