Fishy tales from Antarctica

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Today’s topics

- Why is Antarctica important?
- Southern Ocean features
- Fascinating Antarctic fish
- Ecology of Antarctic fish & global warming
- What’s life like as a scientist on the ice?
- Fishy issues- commercial fishing in the ice
We think about Antarctica because.....

- IPY brings international focus to Antarctica
- of Global climate change

BUT we still don’t know understand much about Antarctica
A pivotal continent

- Maintains the health of our planet
- Linked to Antarctica:
  - Weather
  - Ocean currents
  - Sea level
  - Ecosystems

JEEPERS! IT'S GETTING PRETTY THIN... MAYBE IF I COMB SOME OZONE FROM HERE...
Why study Antarctica

“However, while it is true that the geophysical and meteorological situations which it presents are unparalleled anywhere else and that its living organisms are remarkable in their successful adaptation to some of the most extreme conditions found on the planet, the same scientific laws appear to operate in Antarctica as anywhere else.”

A natural laboratory

- Polar organisms = ‘canaries in a goldmine’
- How have organisms adapted to their environment?
- What is their capacity to adapt to future change? (‘Health’)
- Stenothermal = ideal model system
  - e.g. ability to cope with thermal change
Antarctica – an introduction

- Characteristics:
  - 2x Australia
  - Driest place on earth
  - Covered in 2160 m ice
  - 2.4% exposed rock
  - Frozen seas, ice shelves
  - Cold temperatures
  - Unique flora & fauna
Antarctica
Land environments
Southern Ocean – an introduction

- Southern part of Pacific, Indian and Atlantic oceans, 10% of world ocean
Southern Ocean

- Characteristics:
  - 3000-5000m deep
  - Temperature < 0ºC (continental shelf -1.87 ºC)
  - Thermally stable (McMurdo varies from -1.9 - 1.4)
    - 2-3 m sea ice for most of the year
    - 1-2 m platelet ice
    - Anchor ice to 30 m depth
Southern Ocean currents

- Antarctic Circumpolar Current (WWD) ~ APF (Convergence) extends to seafloor
- Limits latitudinal dispersion; physical barrier
- EWD next to continent

Gon and Heemstra, Fishes of the Southern Ocean, 1990
Why it’s harder to swim in Antarctica
Why it’s harder to swim in Antarctica

- **Viscosity**
  - Viscosity of pure water is 1.92 X more viscous at -2 vs 20°C
  - Viscosity of seawater is 7-8% greater than fresh water

- The energy required for locomotion is increased
But there is a richness of life

- Oxygen solubility nearly doubles from 20-0°C

Paradox: Freezing water requires adaptation but increased oxygen solubility supports richness of life
Changes over time on land

- But it hasn’t always been like this

Land:
and in the sea

- But it hasn’t always been like this

Sea:

- Antarctica above and below water has changed significantly over time
## Antarctica – geological evolution

<table>
<thead>
<tr>
<th>Era</th>
<th>Epoch</th>
<th>Ma</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palaeozoic</td>
<td></td>
<td>590</td>
<td>Antarctica- central to Gondwana</td>
</tr>
<tr>
<td>Mesozoic</td>
<td>Jurassic</td>
<td></td>
<td>Mainly near South Pole</td>
</tr>
<tr>
<td></td>
<td>Cretaceous</td>
<td>144</td>
<td>Fragmentation</td>
</tr>
<tr>
<td>Cenozoic</td>
<td>Palaeocene</td>
<td>65</td>
<td>Continental drift to current position</td>
</tr>
<tr>
<td></td>
<td>Eocene</td>
<td>55</td>
<td>First notothenoid by 40 Ma; sea ice?</td>
</tr>
<tr>
<td></td>
<td>Oligocene</td>
<td>38</td>
<td>Final separation</td>
</tr>
<tr>
<td></td>
<td>Miocene</td>
<td>25</td>
<td>25 Ma- Drake Passage, ACC, APF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14 Ma- extensive ice sheets, 1-3 Ma</td>
</tr>
<tr>
<td></td>
<td>Pliocene</td>
<td>5</td>
<td>2.5 Ma- latest ice sheet expansion</td>
</tr>
</tbody>
</table>
What’s cool about Antarctic fish?

- 1% of fish in Antarctic waters BUT large diversity
- 3 main groups of species
  - Eelpouts
  - Snailfishes
  - Notothenioids

Gon and Heemstra, Fishes of the Southern Ocean, 1990

- All avoid freezing which is why they are successful
Antarctic fish

- **Notothenioids**
- **Single superorder of the Perciformes Order (perch-like)**
- **Dominant Antarctic fish fauna (45%; 92% biomass).**
- **Largely endemic group; vicariance origin**
- **96 sp. in Antarctic waters, 5 families**
- **25 non-Antarctic sp.**

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Eastman, Antarctic Fish Biology 1993
- **Bovichtidae** = basal family (non-Antarctic) of bottom dwellers
- **9/10** = non-Antarctic bottom dwellers
- **Formation of ACC** = agent of vicariance that separated Bovichtidae and some sp. of other families from their Antarctic sister sp. and from 3 exclusively Antarctic families.

*Near et al 2004*
Remaining Antarctic sp. diversified (less competition) and speciation largely occurred 7-15 Ma, partly as result of current that circles the continent (EWD)
Notothenioid key adaptations

- Anti-freeze: the key innovation but creates problems
- Blood modifications – (fluid viscosity and O₂ issues)
- Lipid (fuel, buoyancy, store, membranes)
- Demineralisation/decalcification
- Cutaneous respiration
- Small body size
- Large eyes
- Pelagicism through buoyancy
- Species flock (adaptive radiation)
Controversy over cold adaptation

- Metabolic cold adaptation first proposed by Wohlschlag
- Increase in the resting metabolic rate of ectotherms
- Metabolic rate of polar species has undergone an upwards adjustment to offset the effects of low temperature

BUT IS IT REAL?
- Polar fish have elevated resting oxygen consumption
- Steffensen argues that this doesn’t exist in the whole organism sense
- Kawall et al- brain enzyme activities elevated

- Needs a fresh experimental approach

Gon and Heemstra, Fishes of the Southern Ocean, 1990
Habitat zonation

Pelagic  Widely distributed in the water column
Epipelagic  Living in the upper 200m
Mesopelagic  Living between 200-1000m
Bathypelagic  Living between 1000-4000m
Abyssopelagic  Living below 4000m
Benthopelagic  Living in the lower few 100 m
Epibenthic  Living within a few m of the ocean floor
Benthic  Living on the ocean floor
Extreme ecology

- Notothenioids have evolved from being bottom dwellers to species filling a variety of ecological niches
# Distribution of Antarctic species

<table>
<thead>
<tr>
<th>Habitat</th>
<th># Species</th>
<th>% fauna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epipelagic/Pelagic</td>
<td>6</td>
<td>2.2</td>
</tr>
<tr>
<td>Mesopelagic</td>
<td>71</td>
<td>26.1</td>
</tr>
<tr>
<td>Bathypelagic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Abyssopelagic</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>Benthopelagic</td>
<td>16</td>
<td>5.9</td>
</tr>
<tr>
<td>Epibenthic</td>
<td>6</td>
<td>2.2</td>
</tr>
<tr>
<td>Benthic</td>
<td>174</td>
<td>63.2</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>274</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

Eastman, Antarctic Fish Biology, 1993
Adaptive radiation

- A single or small group of ancestral species rapidly diversifies into a large number of descendent species that occupy a wide variety of ecological niches

- Notothenioids = adaptive radiation
  - Nototheniids in particular

- Ecological opportunity = extensive ice formation
  - Notothenioids prepared? (AFGP)
  - Widespread extinction
  - Cf. mammals, dinosaurs and K-T boundary

- Morphological innovation = buoyancy capability

- Unusual to have both substantial ecological and morphological diversification

Near et al 2004
Ross Sea marine ecosystem

La Mesa et al 2004
Reproduction in Antarctic fish

- Basic biological knowledge lacking, room for young scientists!
- Important for managing fisheries
- Nest guarding in some species
- Slow to mature, don’t all spawn every year
- Latitudinal trend in spawning?
- Autumn/winter vs spring/summer spawners; Ross Sea understudied

*P. borchgrevinki* female, mid-vitellogenesis (large oocytes show yolk development), Nov

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Reproduction in Antarctic fish

- *P. borchgrevinki* in McMurdo Sound is probably a summer spawner
- Contrary to the published literature

*P. Borchgrevinki* male, spermatogenesis stages, Nov
V Metcalf

- Time to mature for males is probably shorter
- *sp*, mix of primary + secondary spermatogonia
- *sp-sc*, spermatocytes being created from spermatogonia through mitosis/meiosis
Reproduction in Antarctic fish

- Variation between species in same area in timing of spawning
- Variation between species in structure of testes and oocytes
- Icefish, *C. hamatus*, has most unusual oocytes
  - extra membranes?

*P. borchgrevinki* oocytes
V Metcalf

*C. hamatus* oocytes
V Metcalf
Fieldwork in Antarctica

- Flying is the major way that people are transported.
Fieldwork in Antarctica

- Ship based
- Can be long voyages
- Limited experiments on board; mainly sample collection
- SEASICKNESS!!
Fieldwork in Antarctica

- Ship based
Fieldwork in Antarctica

- Shore based
  - Deep field
Fieldwork in Antarctica

- Shore based
  - Station
Base physiological experiments

- My nutritional experiment
  - Differences between fed and starved animals in metabolism and fat transport
- Bill Davison’s research
- Acclimation @ different temp.
- P.b. can cope with increased temps. (aerobic swimming)
  a) 4°C acclimated fish shift maximal critical swimming speed ($U_{crit}$) higher to more than 5°C, while fish acclimated to -1°C reach their maximum at 2°C.
  b) Heart function of warm acclimated fish increases with increasing temperature, -1°C acclimated fish show the reverse trend.

P. borchgrevinki, Seebacher et al 2005
Environmental change

- *P. borchgrevinki* has not lost its ability to cope with increasing temperatures
- Falsifies predictions for stenothermal (narrow thermal tolerance) organisms
- Other relatives of this fish appear to not be able to adapt, spelling bad news for them with global warming
Fishing on ice
Fishing on ice
Processing fish
Getting into icy water

- Commercial fishing in Antarctica
  - Since 1900’s, heaviest since 1970
  - 2 x toothfish species
  - Mackerel icefish
  - Antarctic krill
  - Illegal Unregulated Unreported fishing a problem
  - Food web roles largely unknown
Getting into icy water

- Trawling in spawning areas (parental care)
- Seabird bycatch
- Quota exceeding
- Congregation areas where fishing occurs lead to stock overestimates
- Value-added products - the role of biotech in getting more out of fishing
Conclusions

- Understanding Antarctica and the Southern Ocean is pivotal to understanding our planet
- Antarctic fish have many special adaptations
- Yet there is much we don’t understand
- Antarctica provides a natural laboratory
- At least one Antarctic fish species may adapt
- Commercial fishing is already threatening Antarctica
Acknowledgements

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- Sanford
Any questions?