Pteropods and Ocean Acidification: Combining Observation, Experiments and Modelling

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Surface water $pCO_2$ is increasing at about the same rate as atmosphere $CO_2$ emissions.

We see a commensurate decrease in pH with the rise in surface water $pCO_2$.

*Doney, Science 2010*

*Dore et al., PNAS 2009*
Natural processes that could accelerate ocean acidification in coastal waters

Coastal Upwelling brings high $CO_2$, low pH, low $O_2$, low $\Omega$, water to surface

Exposure of coastal ecosystems to corrosive upwelled water
Saturation State

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

\( \text{Ca}^{2+} \) calcium \hspace{2cm} \text{CO}_3^{2-} \) carbonate
\( \text{CaCO}_3 \) calcium carbonate

\[ \text{phase} = \frac{[\text{Ca}^{2+}][\text{CO}_3^{2-}]}{K^*_{\text{sp,phase}}} \]

\( \Omega > 1 \) CaCO\(_3\) precipitates
\( \Omega = 1 \) equilibrium
\( \Omega < 1 \) CaCO\(_3\) dissolves
Percent of upper 100 m in CCE water column estimated to be undersaturated during the (a) pre-industrial, (b) 2011 and (c) predicted for 2050.

Bednaršek et al., in review.
Ocean Acidification from a perspective of:

a) carbonate chemist  
b) bio experimentalist  
c) modeler

- Basic biological processes (calcification, growth, survival, biogeography) → changes in food webs, ecosystem goods & services
- Understanding impacts → correlation to carbonate chemistry and interactive effect of multiple stressors
- Experimental design
- Biologically relevant index (Magnitude/Duration/Severity Index)
- Pteropods as a case study

Teasing out each process at space/time scale, observations to validate models
Pteropods are ubiquitous shelled pelagic snails and belong to zooplankton group (2 classes: Thecosomata and Gymnosomata).

- Vertical migrators
- Compose ~10% of total number of organisms of the CCS in the upper 40 m and important component of NP community
- With their high grazing rates they play a vital role within the zooplankton community
Pteropods as food source for ...
Pteropods – biogeochemical implications

- As a microphagous zooplankton important producer of faecal pellets → biogenic matter export
- The only pelagic aragonite producers → maintaining alkalinity flux
- 20-42% to the global carbon export production → fuelling long-lived carbon pool and carbon sequestration
Space-for-time approach

pteropod response at various carbonate gradients in the natural environment

What ‘stress’ are pteropods exposed to due to OA? What is the status of ‘healthy’ pteropod?
Pteropod shell dissolution in the California Current Ecosystem

Shell dissolution not the case of future scenarios (North, Coastal regions of CCS)
Onshore vs offshore shell as observed under the scanning electron microscope
Pteropod Shell Dissolution in the Natural Environment

- Strong positive relationship between % of undersaturated waters and proportion of dissolved individuals

- ↑ % of undersaturation → reduction in suitable habitat availability

Bednaršek et al., Proceedings to the Royal Society, 2014
Dissolution of indicator of past, present and future

Pre-industrial level of dissolution only due to upwelling: naturally occurring dissolution (18%)

Currently, significant increase in dissolution $\rightarrow$ 53% in the coastal regions.

By 2050: ~70% of water column will be undersaturated $\rightarrow$ 70% of pteropods affected by severe dissolution in the coastal regions.
Vertical migration responses

- Eddy-associated front (off- and on-shore of the front)
- Difference in the aragonite saturation depth: Cycle 4 vs Cycle 3

- Space-for-time exchange approach to examine pteropod vertical distribution and species richness
Changes in vertical migration and species richness

- Changes in biodiversity with reduced habitat
- Potential food web implications

Bednarsek and Ohman, in review, MEPS
Dissolution vs Calcification?

Dissolution becomes the dominating process even at $\Omega_{ar} \sim 1$

Calcification cannot offset dissolution $\Omega_{ar} < 1$

$\rightarrow$ 1.4% of shell mass per day ($\Omega_{ar} = 0.8$) and slower sinking velocities ($2X$) and decreased carbonate fluxes to the deep

Bednarsek et al., PLOS One, 2014
Model predictability

J-SCOPE: Combination of NOAA's Climate Forecast System and Regional Ocean Modeling System

Model Output, forecasting average undersaturation July 2013

Model largely agrees with chemical observations \(\rightarrow\) forecasting of biological responses \(\rightarrow\) Magnitude index
Next steps

- Various pteropod responses strongly correlated with $\Omega_{ar}$, OA monitoring: hypoxia next $\rightarrow$ multicollinearity!
- First steps towards the development of an index for forecasting OA for pteropods (other calcifiers?)
- Determination of exposure regimes for bioassays
- Pteropods as ecosystem indicators in the integrated ecosystem assessment
- Translation into policy (communication and information sharing) for stakeholders along the West Coast $\rightarrow$ Mitigation/Adaptation Strategies
Future of Pteropods?

Will pteropods survive ocean acidification?

At 600-700 ppm stabilization scenario, dissolution and mortality increased, calcification decreased.

Important to keep pCO$_2$ as low as possible.