Ocean Acidification and Changing Structures of Ocean Ecosystems

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Open Ocean Surface pH Is Decreasing

CO₂ Time Series in the North Pacific Ocean

Iglesias-Rodriguez et al., 2010. Plenary Paper, OceanObs09, ESA Publ. WPP-306
[adapted from Dore et al., 2009, US-PNAS, 106(30)]
High-Frequency Dynamics of Ocean pH: A Multi-Ecosystem Comparison

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**A. Open Ocean**
- Temperate Eastern Pacific (CCE1)
- Tropical Central Pacific (Kingman Reef)

**B. Coral reef**
- Moorea, French Polynesia
- Palmyra Atoll, reef terrace
- Palmyra Atoll, fore reef

**C. Upwelling**
- Pt. Conception, CA (CCE2)
- Pt. Ano Nuevo, CA (M1)

**D. Estuarine/Near shore**
- Elkhorn Slough, CA, tidal estuary (L1)
- Monterey Bay, CA, near shore (L20)
How Do Organisms Adapt to a Changing Climate?

1. **Range Shifts / Drift**
   - 'follow' suitable habitat as it moves poleward

2. **Ecological Adaptation**
   - enabled by existing diversity resulting from a variable environment

3. **Physiological Acclimation / Plasticity?**

4. **Changing Phenology**
   - e.g. changing annual cycle can affect trophic coupling

5. **Evolutionary Adaptation**
   - based on genetic mutations - needs 100s of generations
Range Shifts Following Suitable Habitat

Rapid Range Shifts of Species Associated with High Levels of Climate Warming
I-Ching Chen,1,2 Jane K. Hill,3 Ralf Ohlemüller,3 David B. Roy,4 Chris D. Thomas1*


- Terrestrial organisms are shifting poleward 2-3 times faster than previously reported:
  - 17 km / decade poleward
  - 11 m vertically / decade
- Marine organisms (mostly coastal) are shifting faster:
  - 190 ± 38 (SE) km / decade

Marine range shifts and species introductions: comparative spread rates and community impacts
Cascade J. B. Sorte, Susan L. Williams and James T. Carlton

Are Our Standard Compartment Ecosystem Models Adequate?

• Current planktonic food web models have a 'fixed' structure, and few parameter values vary over time in response to a changing environment (exception – “optimality” or “adaptive” models of Markus Pahlow, S. Lan Smith, A. Merico,...)

• Try a model where adaptation is formulated in terms of the distribution of species or phenotypes as a function of traits (e.g., intrinsic growth rate) which in turn are functions of environmental variables: Temp, pH, O₂, pCO₂, etc.

E.g. maybe a simple ‘Complex Adaptive System’ model
Ecological Adaptation to a Changing Climate

Relative Growth Rate = \( f(\text{environmental variables}: \text{pH, T, O}_2, \text{etc}) \)

Change in Biomass $P(x_i, t)$

of species or phenotype $i$ as a function of environmental variable $x_i$ for a step change in environmental 'fitness', i.e. a regime shift in the environment

\[
\frac{dP(x_i,t)}{dt} = P(x_i,t)[(v(x_i)H(x_i - x_m) - m_i)]
\]

where:
- $v(x_i)$ is the intrinsic growth rate (a 'trait') for phenotype $i$, as a function of the environmental variable $x_i$ (e.g. pH, $O_2$, SST, etc)
- $H(x_i)$, the 'fitness function' is maximum at $x_m$
  \[
  H(x_i) = \frac{1}{2} \left[ 1 + \cos \left( \frac{2\pi(x_i - x_m)}{w} \right) \right]
  \] over $[-\pi, \pi], w =$ width of 'cos' at $H = 0.5$
- $m_i$ is the linear mortality coefficient for phenotype $i$, and
- total biomass $B(t) = \int P(x_i,t) dx_i$ is currently controlled by a 'logistic' equation

So far, ignores diffusion, immigration, emigration, plasticity, genetic adaptation (evolution), etc.
Response to a Shift in pH

Success & rate of adaptation depend on the degree of overlap of the initial distribution $P(x_i, 0)$ of species or phenotypes and the new fitness function $H(x_i, t)$.

$pH_{old}(H_{max}) = 8.05$

$pH_{new}(H_{max}) = 7.90$
Response to Decreasing pH

Smoothly decreasing pH

Fitness function $H(t=0)$

Max $P_i(200) = 1.9$

Total Biomass

$B(10) = 9.4$
$B(200) = 8.1$

Decreasing pH with short term variability

Max $P_i(200) = 1.2$

Total Biomass

$B(10) = 9.4$
$B(200) = 8.5$
Effect of Temporal Variability in pH
(1 generation = 5 timesteps)

Smoothly decreasing pH

Decreasing pH with short term variability

Demonstrates how an extreme in variability imposed on a smooth decrease in pH over several generations could cause local extinction.
Adding Realism? i.e. Complexity

So far we have started to explore only the effect of change in 1 environmental variable pH, on 1 physiological trait (maximum intrinsic growth rate), of 1 group.

Ultimately, we need to:

1. Look at the dependence of various traits (intrinsic growth rate, respiration, mortality, fecundity, etc) on multiple environmental stressors (pH, temperature, $O_2$, $P_{CO2}$, stratification, etc) that are changing with the climate

2. Start to build a foodweb with these adaptive groups

3. Add in- and out-migration (in geographic regions)

4. Add evolutionary adaptation, etc

Is there a simpler approach?
Try Coupling to Higher Trophic Levels Using Hans Pörtner’s Optimum Thermal Window

In addition to the stress of lower pH on calcification, animals will be stressed by lower $O_2$ and higher $CO_2$ because their respiration will “cost” them more energy:

How Will Ecosystems Adapt?

1. When possible, poleward range shift/drift appears to be the dominant mode of survival/adaptation.

2. Need to develop relationships/models linking phenotypic diversity and current environmental variability, with ability to adapt to future conditions.

3. Can we progress from adaptation of individual species or groups to adaptation of a whole ecosystem?

4. Extinctions and major ecosystem damage will probably be caused by extreme climatic events, and/or ‘rapid’ loss of viable habitat (in tropical and high latitude zones).
Thanks

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