ESF Ocean Acidification Strategic Workshop

Response of Natural Ecosystems to Ocean Acidification

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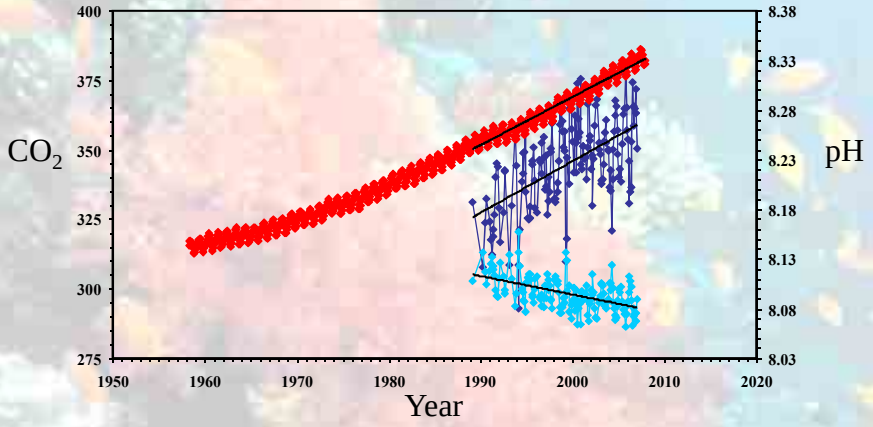
January 28, 2008



What we know about ocean CO_2 chemistry

…from cumulative carbon sources and sinks over the last two centuries

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Sources	Sinks
Land-use change *200* Pg C (42%)	Atmospheric accumulation *190* Pg C (40%)
Fossil emission *280* Pg C (58%)	Terrestrial sink *166* Pg C (35%)
	Ocean sink *124* Pg C (26%)

House et al. (2002) GCB

Ocean Acidification

Since the beginning of the industrial age, the pH and CO_2 chemistry of the oceans (ocean acidification) have been changing because of the uptake of anthropogenic CO_2 by the oceans.

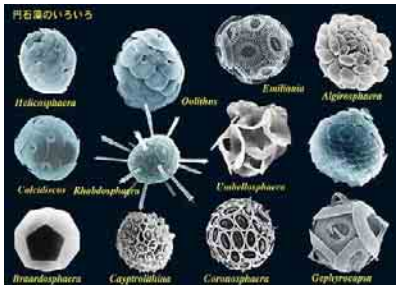
- Decrease in pH 0.1 over the last two centuries
- 30% increase in acidity; decrease in carbonate ion of about 16%

Ocean Acidification

These changes in pH and carbonate chemistry may have serious impacts on open ocean and coastal marine ecosystems.

Photo: Missouri Botanical Gardens

Corals

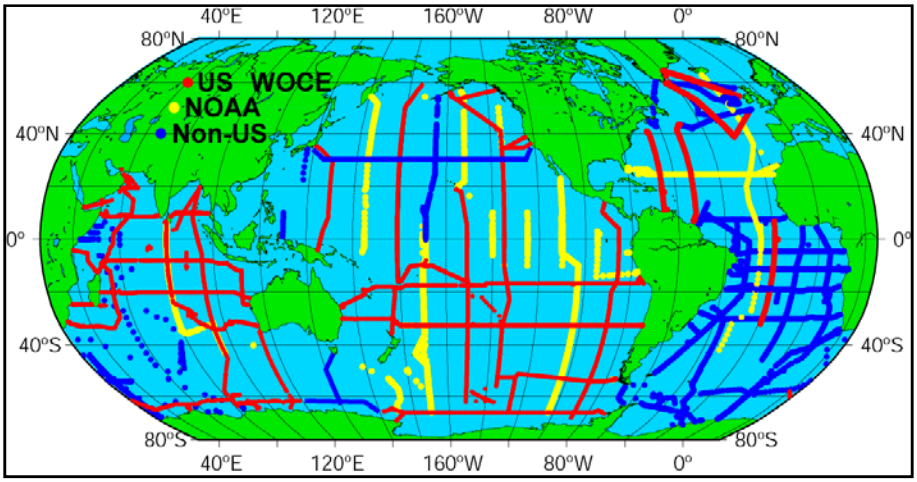


Calcareous Plankton

http://www.biol.tsukuba.ac.jp/~inouye

What we know about ocean CO_2 chemistry

…from field observations



WOCE/JGOFS/OACES Global CO_2 Survey

~72,000 sample locations collected in the 1990s

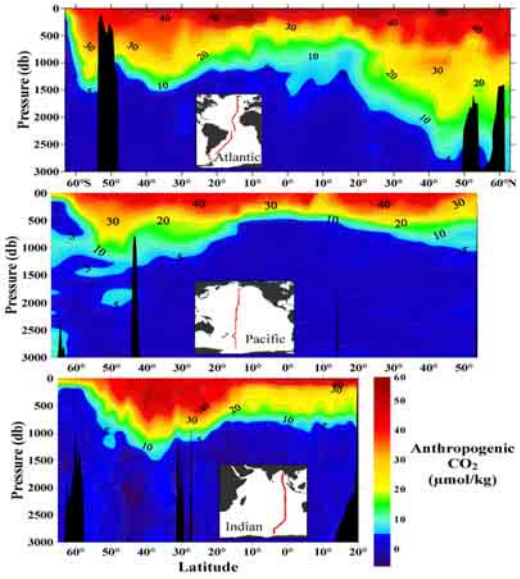
DIC ± 2 µmol kg^{-1}

TA ± 4 µmol kg^{-1}

Sabine et al (2004)

What we know about ocean CO_2 chemistry

…about human impacts on ocean CO_2 chemistry



- From the WOCE/JGOFS global CO_2 survey, the observed anthropogenic CO_2 inventory through 1994 is calculated to be 118±19 Pg C.
- Because the ocean mixes slowly, half of the anthropogenic CO_2 stored in the oceans is found in the upper 10% of the ocean
- What are the impacts of increased CO_2 on marine ecosystems?

Sabine et al. Science (2004)

What we know
about ocean CO_2 chemistry
…from observed aragonite and calcite saturation depths in the global oceans

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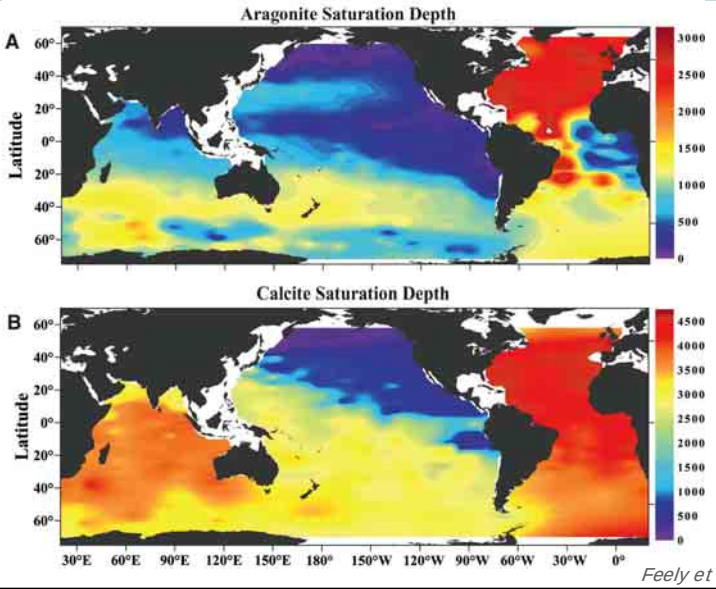

Feely et al. (2004)

What we know
about ocean CO_2 chemistry
…from observed shoaling saturation horizons

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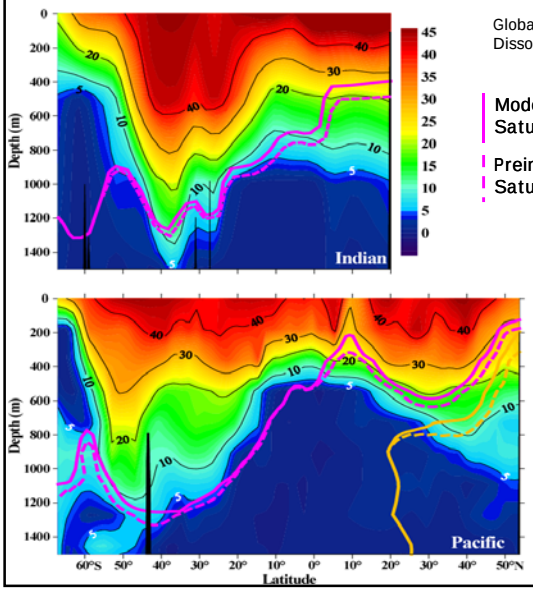


Global Water-column
Dissolution = 0.5 Pg C yr^{-1}

Modern Aragonite Saturation Horizon

Modern Calcite Saturation Horizon

Preindustrial Aragonite Saturation Horizon

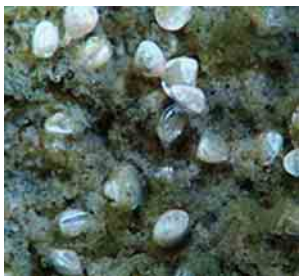
Preindustrial Calcite Saturation Horizon

The aragonite and calcite saturation horizons have shoaled towards the surface of the oceans due to the penetration of anthropogenic CO_2 into the oceans.

Feely et al. (2004)

Bivalve juvenile stages can also be sensitive to carbonate chemistry

Control
$\Omega_A = 1.5$



$\Omega_A = 0.3$

Hard shell clam *Mercenaria*

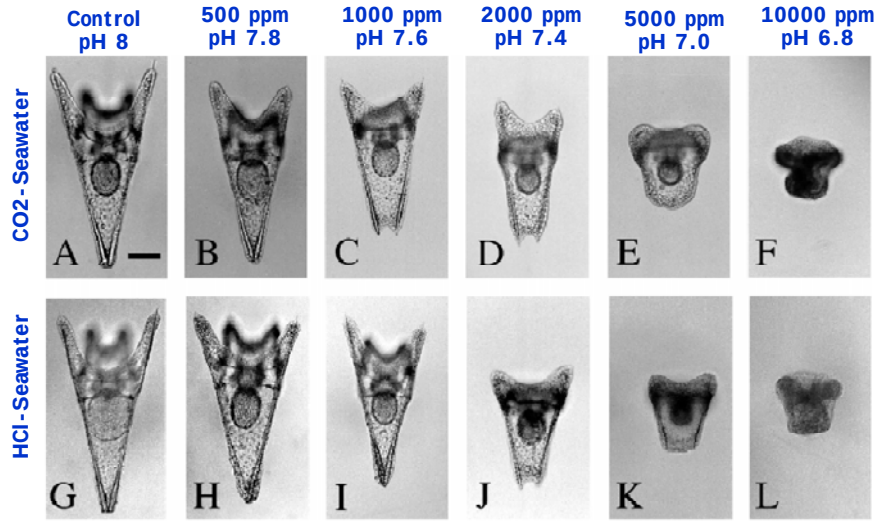
- Common in soft bottom habitats

Used newly settled clams

- Size 0.3 mm
- Massive dissolution within 24 h in undersaturated water; shell gone w/in 2 wks
- Dissolution is source of mortality in estuaries & coastal habitats

Green et al., 2004

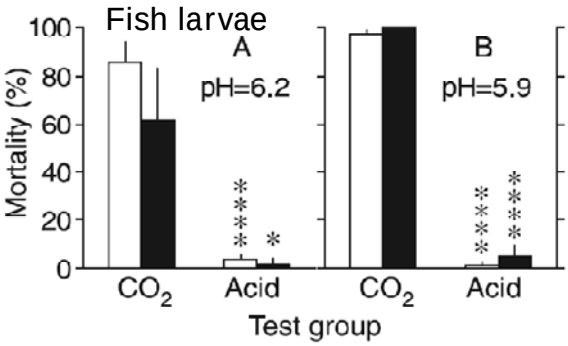
Sea urchins: Increased CO_2 results in malformation of larval stages



Kurihara & Shirayama., 2004

Potential impacts of high CO_2 on marine fauna

- Adverse effects on reproductive success
  - Decreased fertilization rates (sea urchins, bivalves)
  - Increased juvenile mortality (bivalves, sea urchins, copepods, fish larvae)



Ishimatsu et al. (2004)

Potential impacts of high CO_2 on marine fauna

- Adverse effects on reproductive success
  - Decreased fertilization rates (sea urchins, bivalves)
  - Increased juvenile mortality (bivalves, sea urchins, copepods, fish larvae)
- Reduced growth in adults (sea urchins, bivalves)
- Impaired oxygen transport (squid)
- Reduced metabolism/scope for activity (squid)

Potential Ecosystem Responses

Changes in relative abundance & distribution of calcifying species

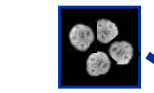
- Non-calcifying species may outcompete calcifiers
- Geographical ranges of calcifying species may shift
- Vertical depth distributions of calcifying species may shoal with decreasing $CaCO_3$ saturation state

Changes in food webs and other species interactions

Impacts on biogeochemical cycles

- Speciation of nutrients and trace metals
- Changes in cycling of carbon and $CaCO_3$ within oceans
- Feedbacks to climate

Potential Effects on Open Ocean Food Webs



Coccolithophores

ARCOD@imsuaf.edu

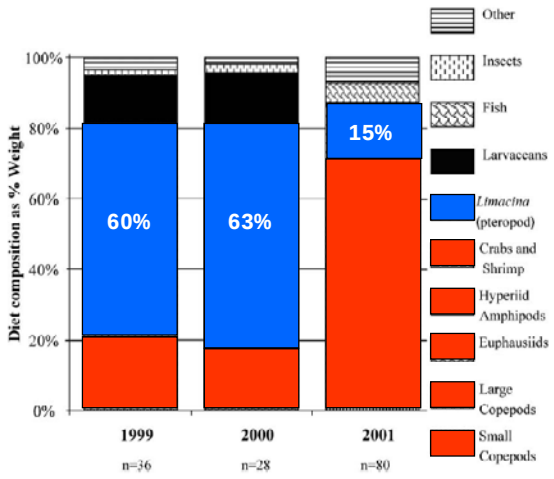
Copepods

Vicki Fabry

Barrie Kovach

Pacific Salmon

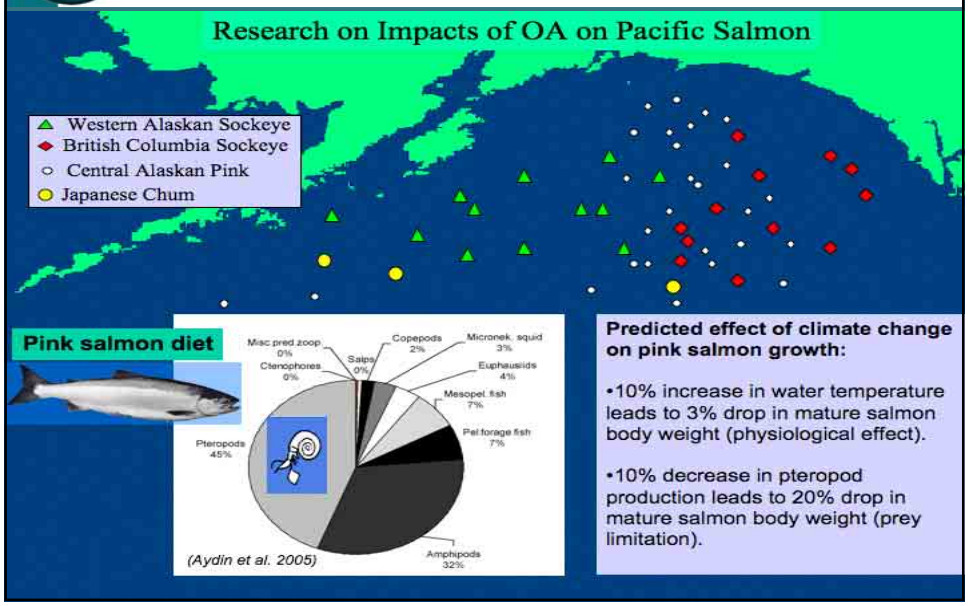
Food Web Impacts: Diet of Juvenile Pink Salmon



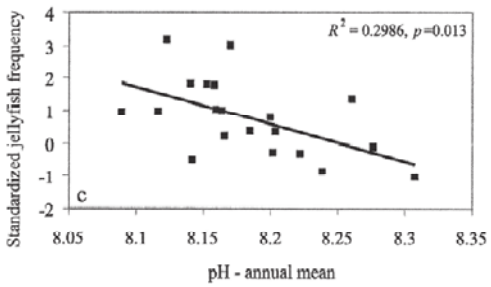
Impacts of increasing pCO_2 on nearly 100% of prey types are unknown

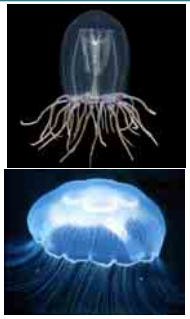
Armstrong et al., 2005

What we know about the biological impacts of ocean acidification *…on marine fish*



Increasing occurrence of jellyfish correlated with pH decrease





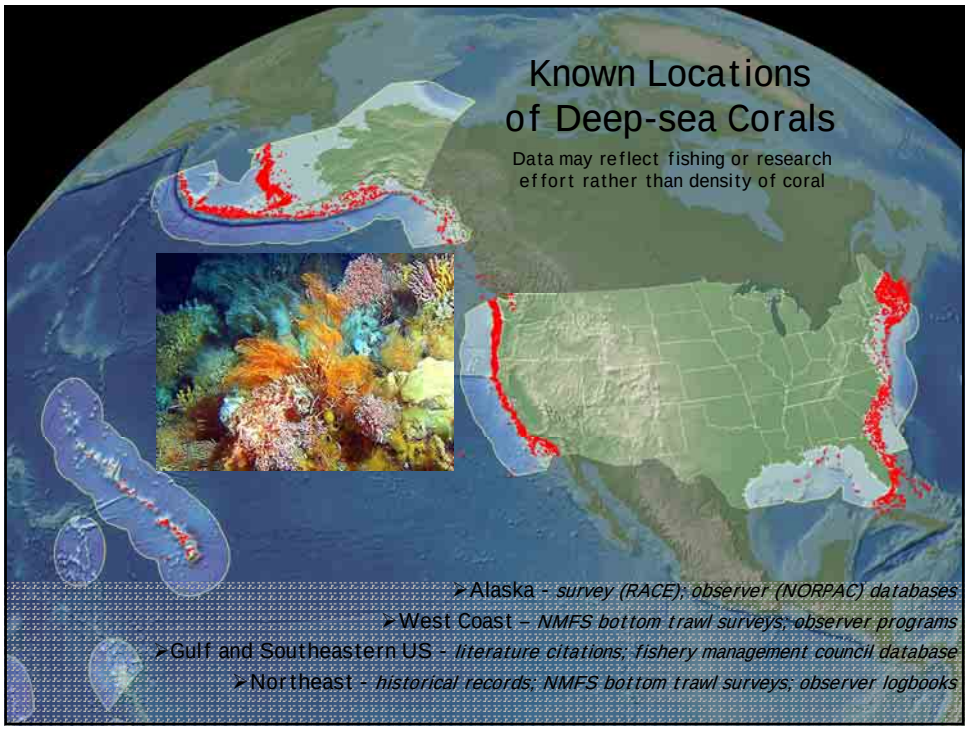
- Frequency (presence/absence) of nematocysts in Continuous Plankton Recorder samples from 1958-2000
- Significant correlation between reduced pH and increased jellyfish occurrence
- Mechanism unknown – may be associated with 1980's regime shift in North Sea
- Suggest that jellyfish occurrence will increase over the next century as pH values decrease
- Major adverse implications for marine ecosystems & fisheries

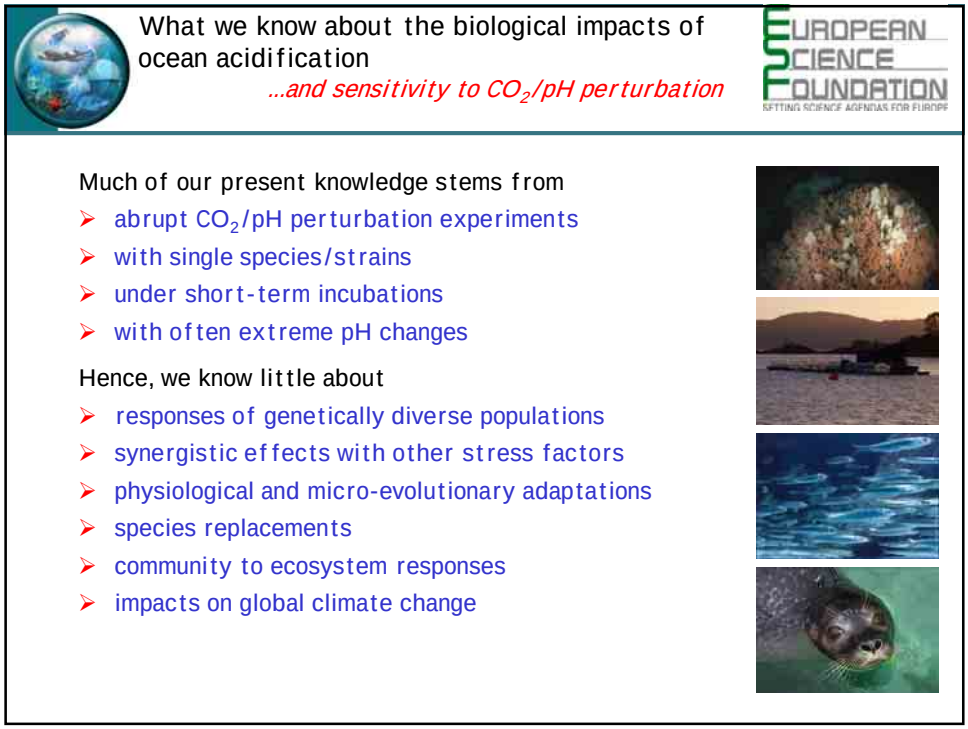
Attrill et al. (2007)

Potential Ocean Acidification Impacts on Crustaceans

- Larval blue king crab, Kodiak Alaska, pilot experiment, 2006
- Tested range of projected global ocean pH change over the current century
- ~15% reduction in growth and ~67% reduction in survival when pH was reduced 0.5 units
- Expansion to red, brown and blue king crab planned for 2007

M. Litzow and J. Short, NOAA Alaska Fisheries Science Center


Known Locations
of Deep-sea Corals
Data may reflect fishing or research effort rather than density of coral
➢ Alaska - survey (RACE); observer (NORPAC) databases
➢ West Coast – NMFS bottom trawl surveys; observer programs
➢ Gulf and Southeastern US - literature citations; fishery management council database
➢ Northeast - historical records; NMFS bottom trawl surveys; observer logbooks


What we know about the biological impacts of ocean acidification
...and sensitivity to CO_2/pH perturbation
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Much of our present knowledge stems from
➢ abrupt CO_2/pH perturbation experiments
➢ with single species/strains
➢ under short-term incubations
➢ with often extreme pH changes
Hence, we know little about
➢ responses of genetically diverse populations
➢ synergistic effects with other stress factors
➢ physiological and micro-evolutionary adaptations
➢ species replacements
➢ community to ecosystem responses
➢ impacts on global climate change

Future Research Challenges

- Can we develop methods to investigate *in situ* response of calcifiers that are difficult to maintain in the lab (e.g., forams, pteropods, squid)?
- How can we identify sub-lethal effects of chronic exposure to elevated pCO_2?
- How can we address questions of adaptation over timescales of decades?
- Can we develop a predictive capacity of probable impacts to key organisms & communities so that mitigation measures may be developed?

Conclusions

- Impacts of ocean acidification on ecosystems are largely unknown.
- Calcification in many planktonic organisms is reduced at elevated CO_2, but the response is not uniform.
- Possible responses of ecosystems are speculative but could involve changes in species composition & abundances - could affect food webs, biogeochemical cycles
- Baseline data with sufficient resolution are lacking in regions where $CaCO_3$ saturation states are expected to decrease <1 over in next 50-100 years.