Sea Level Rise and Ocean Acidification

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Projections of Global Sea Level Rise Relative to 20th Century Changes from the A1B (medium emissions) scenario

1870-2003: about +8 inches

Changes relative to the 1980 to 1999 mean

Figure source: IPCC 2007
Drivers of Sea Level Rise (SLR)

Major determinants:

• Global SLR driven by the thermal expansion of the ocean;
• Global SLR driven by the melting of land-based ice;
• Atmospheric dynamics, i.e., wind-driven “pile-up” of waves along the coast; and
• Local tectonic processes (uplift) and subsidence
Relative Sea-Level Changes on U.S. Coastlines

Observed changes in relative sea level from 1958 to 2008 for locations on the U.S. coast.
Rising sea levels will increase the risk of flooding, erosion, and habitat loss along much of Washington’s 2,500 miles of coastline.

- **Global SLR: 7-23” by 2100**
- **Medium estimates of SLR for 2100:**
  - +2” for the NW Olympic Peninsula
  - +11” for the central/southern coast
  - +13” for Puget Sound
- **Higher estimates** (up to 4 feet in Puget Sound) cannot be ruled out at this time.

Risks from SLR

- coastal flooding
- inundation of low-lying areas
- coastal erosion
- salt water intrusion into coastal aquifers
- contamination from coastal landfills/toxic sites
- loss of nearshore habitat
- bluff land sliding

Impacts are highly dependent on location and daily to seasonal fluctuations in sea level, and interactions between these events and other factors, not just changes in mean sea level.
Northwest/Southwest Coastal Areas

- SLR will increase erosion of coasts and cause loss of beaches and significant land area
- South Puget Sound is among the most vulnerable parts of the west coast
- Climate models suggest increased SW winds; combined with SLR will accelerate coastal erosion
- SLR of 50” by 2100 in areas of Puget Sound experiencing subsidence
- Interaction between heavier winter rainfall and SLR will intensify cycle of beach erosion and bluff landslides
  - Factor in NW, less of factor in SW, if drier and storm tracks shift northward
- But in SW evidence of increased variability—more frequent very dry or very wet winters.
Inundation Levels in Olympia from Current and Projected Changes in High Tides

A. Tidal datum elevation 18 feet
B. Tidal datum elevation 19 feet
C. Tidal datum elevation 20 feet
D. Tidal datum elevation 22 feet
• Between 1900 and 2000, sea level increased 7 inches in San Francisco Bay
• Recent analyses indicate sea levels could rise an additional 55 inches in the next 100 years
• Estimated $100 billion worth of public and private development at risk
Figure 3.4 Suisun Marsh Habitats Vulnerable to Sea Level Rise

SOURCE: Baylands (EcoAtlas 2009), Hillshade (USGS NED)
Adapting to Sea Level Rise

• Protecting the shoreline (levees/seawalls)
• Redesign of structures, enhancing wetlands and beaches
• Planned retreat from the coastline
• States/counties and private interests are beginning to take SLR into account (e.g., levees, bridges, sewage treatment plants)
2100 Higher Emissions Scenario
2100 Lower Emissions Scenario
2008 Observed

Lüthi et al.; Tans; IIASA
Ocean Acidification: Global Warming's Evil Twin

- **Average pH of the world’s oceans is about 8.2, which is moderately alkaline, and is buffered by calcium carbonate**

- **Increases in CO₂ concentration in the atmosphere are highly correlated with declining pH of the ocean’s surface waters**
  - About 0.1 pH unit decline since late 1980s – predicted to be ~ -0.3 to -0.5 units by 2100 (wide error bounds)
Ocean Acidification

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}^+ + \text{CO}_3^{2-} + \text{H}_2\text{O} \]

\[ \text{CO}_3^{2-} + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \rightarrow \text{HCO}_3^- \]

Wolf-Gladrow et al., 1999
Ocean Acidification - Impacts to ocean and coastal marine ecosystems

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

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

Value:
- Bivalves: $732M ex-vessel commercial value
- Crustaceans: $1,265M ex-vessel commercial
- Combined: $1,997M ex-vessel commercial value (51% of commercial catch by $)
What we know about ocean \( \text{CO}_2 \) chemistry

...from observed aragonite and calcite saturation depths in the global oceans

- Can calculate the pH at which calcium carbonate precipitates vs. dissolves – called the “saturation state” (generally closer to dissolution with increasing depth). Saturation depth much shallower in the North Pacific vs. North Atlantic

- Because the ocean mixes slowly, \( \frac{1}{2} \) of anthropogenic \( \text{CO}_2 \) is stored in the upper 10% of the world’s oceans

Feely et al. (2004)
What we know about the ocean chemistry of ...

*saturation state*

\[
CO_2 + CO_3^{2-} + H_2O \Leftrightarrow 2HCO_3^{-}
\]

**Saturation State**

\[
\Omega_{phase} = \frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp,phase}}
\]

\[
Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3(s)
\]

- \(\Omega > 1\) = precipitation
- \(\Omega = 1\) = equilibrium
- \(\Omega < 1\) = dissolution
Natural processes that could accelerate the ocean acidification of coastal waters

- Coastal Upwelling
Seasonal Invasion of Corrosive Waters on West Coast North America

Inflow of corrosive waters across shelf and over extensive, productive ecosystems

upwelling of undersaturated waters ($\Omega_{\text{arag}}$ values < 1.0) on to shelf seas

ASH ($\Omega_{\text{arag}}$ values = 1.0) shoaling: 1m/a

Intermediate CO$_2$ rich corrosive waters ($\Omega_{\text{arag}}$ values < 1.0)

Depth of corrosive water along the shelf (m)

Schematic by C. Turley

Feely et al. Science (2008)
Concern for Many Marine Organisms and Ecosystems

- Reduced calcification rates
- Significant shift in key nutrient and trace element speciation
- Shift in phytoplankton diversity
- Reduced growth, production and life span of adults, juveniles & larvae
- Reduced tolerance to other environmental fluctuations
- Changes to fitness and survival
- Changes to species biogeography
- Changes to key biogeochemical cycles
- Changes to food webs
- Changes to ecosystem & their services
- Uncertainties great – research required
Possible fertilization effect of increased \( CO_2 \) (carbon) as phytoplankton nutrient

Studies with some phytoplankton indicate that reductions of 0.3-0.5 pH units have little impact on productivity, but may differentially impact species dominance

Unknown – interaction between Temp and \( CO_2 \)
NMFS Research: Predicting ecological effects of OA

1. Patterns of acidification
   - Average Summer pH 1989 - 2006
     - Depth 0-5 meters
     - Depth 40-60 meters
   - e.g. Puget Sound pH maps

2. Estimating species vulnerability
   - Using treatment experiments
   - e.g. Survey of mineralogy of Puget Sound mollusks

3. Impacts on food webs
   - e.g. Complete and bivalve-centric Puget Sound food webs
NMFS Research
Potential Effects on Open Ocean Food Webs

C coccolithophores
C copepods
P pteropods

Pacific Salmon
Other Examples – Ecosystem Change

Mussels on Tatoosh Island


Mussels generally performed more poorly than barnacles and fleshy algae in years with low pH.
Natural Processes that can Accelerate the Ocean Acidification of Ocean Water Masses

Biological Remineralization of Organic Matter

\[(\text{CH}_2\text{O})_n + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}\]

Can cause hypoxia and pH decrease
Could OA be a factor?

Total crab harvest in Hood Canal has been on the decline since 2003.

“The decline in overall crab abundance in Hood Canal since 2005 appears to be, in part, the result of detrimental environmental conditions that probably impacted juvenile survival” – Randy Hatch
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
CONCLUSIONS--SCIENCE

• **Our footprint** in the oceans is now clearly detectable – It is warmer, more acidic, and less diverse.

• Since the beginning of the industrial age surface ocean pH (~0.1), carbonate ion concentrations (~16%), and aragonite and calcite saturation states (~16%) have been decreasing because of the uptake of anthropogenic CO$_2$ by the oceans, i.e., ocean acidification. *By the end of this century pH could have a further decrease by as much as 0.3-0.4 pH units.*

• Possible responses of ecosystems are speculative but could involve changes in species composition & abundances - could affect marine food webs, commercial shellfish, etc. *More research on impacts and vulnerabilities is needed.*

• An observational network for ocean acidification is under consideration. Modeling studies need to be expanded into coastal regions. Physiological response, mitigation and adaptation studies need to be developed and integrated with the models. *Estuaries should be included in this study.*
Possible Policy and Management Considerations

- **Adaptation:**
  - Observation network
  - Ecosystem model
  - Spatial hazard assessment
  - Infrastructure for authoritative decision support

- **Mitigation:**
  - For migratory resources – any feasibility to buffer a site (e.g., key spawning area)
  - Hatchery/aquaculture facilities – informed siting
  - Shellfish – buffer key enclosed bays
  - Reduce the effect of those stressors on marine ecosystems that we can more directly affect
To Close

• \( \text{CO}_2 \) is changing the ocean – ocean acidification and sea level rise are two of the impacts

• OA can be thought of as a toxicological issue, but the difference is that the input is global not local

• There is uncertainty – who will be the winners and losers, what are the resulting ecosystem consequences, are there interactions with other stressors and what is the rate of change

• The North Pacific appears to be at higher risk for OA and the west coast appears to be lower relative risk to SLR

• Sustained, coordinated research is needed, and mitigation and adaptation needs to be addressed
GLOBAL CLIMATE CHANGE IMPACTS IN THE U.S.

www.globalchange.gov/usimpacts
STATUS OF LEGISLATION
Omnibus Public Land Management Act of 2009

Federal Ocean Acidification Research and Monitoring Act of 2009 (H.R. 146)

- Introduced June and November 2007, respectively
- Senate Bill passed on 20 March 2009
- House Bill passed in 25 March 2009
- Signed by the President 30 March 2009

Goal: To establish an interagency committee to develop an ocean acidification research and monitoring plan and to establish an ocean acidification program within the National Oceanic and Atmospheric Administration.
The purposes of this subtitle are to provide for —

1. Development and coordination of a comprehensive interagency plan to:
   a) monitor and conduct research on the processes and consequences of ocean acidification on marine organisms and ecosystems; and
   b) establish an interagency research and monitoring program on ocean acidification;

2. Establishment of an ocean acidification program within NOAA;

3. Assessment and consideration of regional and national ecosystem and socioeconomic impacts of increased ocean acidification; and

4. Research adaptation strategies and techniques for effectively conserving marine ecosystems as they cope with increased ocean acidification.