Climate Change Issue Profile:
OCEAN ACIDIFICATION

Climate Change and Ocean Acidification
What can people do to lessen impacts and how can marine protected areas help?

What is “ocean acidification” and what causes it?
Ocean acidification (OA) refers to a long term reduction in the pH of the ocean, caused primarily by uptake of CO_2 from the atmosphere and surrounding land and sediments (Figure 1) . The ocean acts as a carbon sink and stores a large percentage of the Earth's total carbon. CO_2 is transferred between the atmosphere and the ocean until the two reach equilibrium. The significant increase in atmospheric CO_2 over time has increased the number of hydrogen (H^+) ions in the water, causing pH to drop, becoming more acidic.

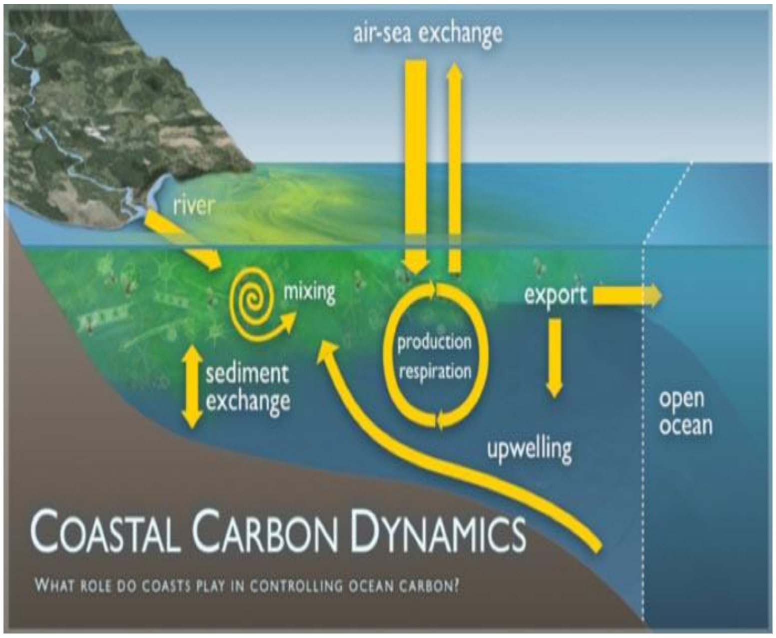

Figure 1. Pathways of the ocean’s carbon cycle leading to changes in the ocean’s acidity. (Source: NOAA PMEL) (http://www.pmel.noaa.gov/co2/story/Coastal+Carbon+Dynamics)

Most of us are familiar with the pH scale from our high school chemistry class, the higher numbers being the most basic (least acidic) and lower numbers being the most acidic (Figure 2). Until recently, oceanographers believed that rivers carried enough dissolved chemicals from rocks and sediments to the ocean to keep the ocean’s pH stable (a term referred to as “buffering”). Today, excess atmospheric CO_2 is dissolving into the ocean so quickly that this natural buffering capacity hasn’t been able to keep up, resulting in rapidly dropping pH in the ocean’s waters. While OA has enormous implications for the health of ocean life, it is less readily observable than other climate related ocean stressors, such as rising sea level or sea surface temperature.

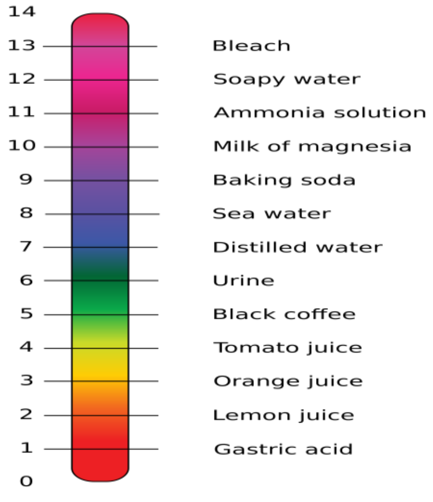

Figure 2. A pH scale identifying some basic and acidic examples. (Credit: Wikimedia Commons)

How is ocean acidification measured?

OA can be detected by measuring various aspects of the ocean carbon chemistry system with high precision and resolution. The NOAA Ocean Acidification Program has made important investments in OA monitoring throughout the country (Figure 3). *In-situ* sensors in the field or laboratory accurately measure these parameters near-continuously as well as taking many discrete measurements.

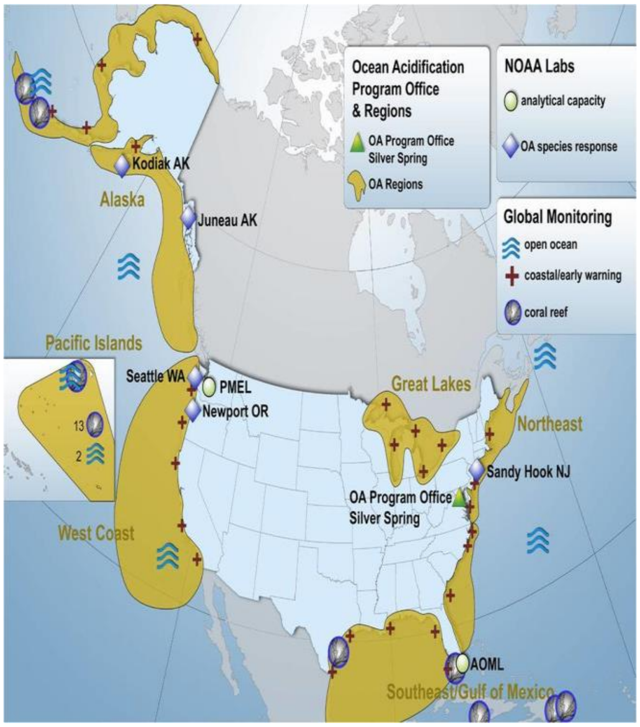

Figure 3. Locations of programs and facilities associated with the NOAA Ocean Acidification (OA) Program. (Source: NOAA)

What changes have we seen in ocean acidity?

Measurements made over the last few decades have demonstrated that ocean CO_2 levels have risen in response to increased CO_2 in the atmosphere, leading to an increase in acidity. Over the past 150 years, the global concentration of atmospheric CO_2 has increased from 290 parts per million (ppm) to 400 ppm, the highest level in recorded history according to data collected from the Mauna Loa Observatory in Hawaii. Scientists estimate that increased CO_2 has made surface oceans about 30% more acidic since the Industrial Revolution.

What are some of the predicted impacts of increasing ocean acidity?

Oceanic uptake of CO_2 lowers pH and carbonate minerals such as calcite and aragonite, materials used to form external skeletons in many major groups of marine organisms containing shells, such as mollusks (e.g., clams, oysters, mussels, scallops), crustaceans (e.g., crabs, lobsters, shrimp) and hard corals. Historical modeling suggests that since the 1880s, increased CO_2 levels made it more difficult for certain organisms to build and maintain their skeletons and shells. Laboratory studies undertaken at the Woods Hole Oceanographic Institution found shells of some larval organisms dissolved in lower pH water. Calcifying (or shelled) organisms such as some zooplankton, mollusks, crustaceans, starfish, urchins and hard corals are all at risk to OA and may have difficulty building their exoskeletons in acidified waters, resulting in a reduction in growth and survival (Figure 4). Recent research undertaken by NOAA, the University of Alaska and the Woods Hole Oceanographic Institution in Alaskan waters predicted that within 15 years the water chemistry will be such that shelled organisms will not be able to build and maintain their shells during certain times of the year. OA is expected to have major impacts on both commercial fisheries and aquaculture industries, with ports in New England – particularly dependent on scallops and lobster – especially at risk to OA impacts in the future.

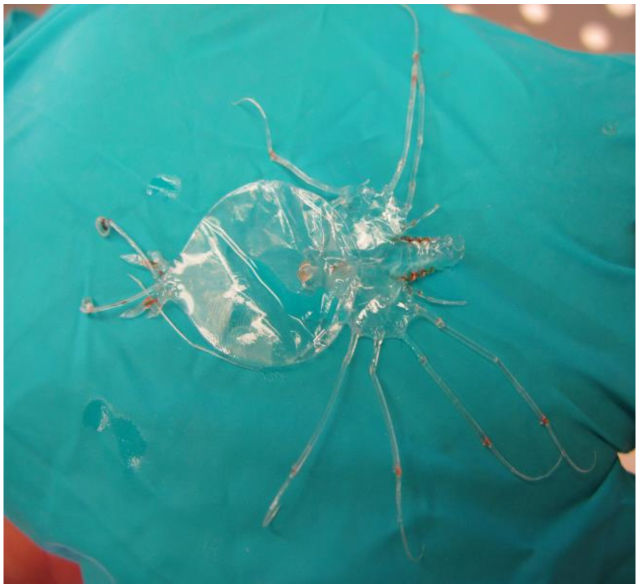

Figure 4. Ecologically and economically important species such as this lobster may have a difficult time surviving their larval stage (Credit: NOAA Ship PICES)

Shellfish hatcheries are at risk, with larval development and overall survival compromised by OA. Due to OA impacts on regional shellfish industries, the Pacific Northwest is developing sensor and monitoring capabilities for impacted industries such as advanced early warning systems. Likewise, oyster and bay scallop growers along the Maine coast measure temperature and acidity of incoming river and bay waters to determine if the water quality is acceptable for larval growth and survival.

Reef-building corals construct their external skeletons from calcium carbonate, forming complex reefs that house the coral animals themselves and provide habitat for many other organisms (Figure 5). Acidification may limit coral growth by corroding pre-existing coral skeletons while simultaneously slowing the growth of new ones; the weaker reefs that result will be more vulnerable to erosion. Many fish and invertebrates are dependent upon healthy coral reefs and their demise can have negative impacts on a wide variety of organisms.

Figure 5. Coral reefs are particularly vulnerable to ocean acidification (Credit: www.coral.noaa.gov)

While impacts are perhaps best studied in shellfish and corals, they extend to many other species. Shell-bearing zooplankton such as crustacean copepods are vital in the ocean's food webs with almost all larger life, from whales to fish, eating zooplankton directly or other animals that eat zooplankton. Larval organisms are directly and indirectly vulnerable to OA impacts (Figure 6). Skeletal growth may be directly impacted by OA and their growth indirectly impacted as the availability of food (crustacean zooplankton) is decreased. Canadian researchers have documented that pink salmon in the Pacific Ocean face a double threat of acidification linked to greenhouse gas emissions, since it both slows their growth in their juvenile life stage in rivers and disrupts the chemistry of seawater they depend on later in adulthood.

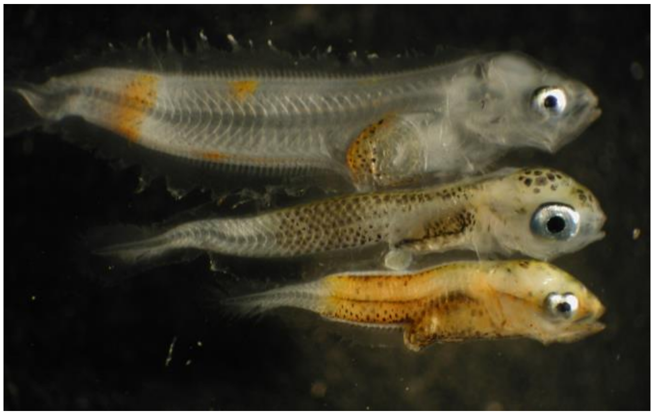

Figure 6. Larval organisms may be directly and indirectly vulnerable to the impacts of ocean acidification (Credit: Matt Wilson/Jay Clark, NOAA NMFS AFSC)

MPAs and Ocean Acidification

OA is already being experienced in parts of the United States, including many marine protected areas (MPAs) along the coast. MPAs can play an important role in addressing the impacts of climate change and building community resilience. As special places with long term protection, many MPAs provide the infrastructure to focus research and monitoring efforts of climate trends, provide protection against non-climate stressors, and effectively engage the community through public education programs, advisory groups, and onsite staff. Familiar examples of MPAs include national parks, national wildlife refuges, national marine sanctuaries, national estuarine research reserves, and state or tribal fish and wildlife areas.

While MPAs have legal authority to provide lasting protection and minimize some local disturbances (e.g., fishing, bottom disturbance, vessel discharge, and development), they remain vulnerable to large scale disturbances originating outside their boundaries, particularly those associated with climate change (e.g., sea level rise, warming sea surface temperature, ocean acidification, magnitude and frequency of storms, storm surge). The acidity of ocean waters is increasing as the amount of atmospheric CO_2 continues to increase. Scientific laboratories around the country are documenting the physiological impacts of OA to a wide variety of organisms under a variety of possible future acidity levels. Understanding the stress of OA combined with other environmental stressors (e.g., water temperature and quality) in the future is very important to our ocean health.

How can MPAs help reduce OA impacts?

Much of the science and planning currently being undertaken on climate change focuses on important questions such as what types of climate changes are predicted by region, how vulnerable are key ecologically and economically important species to these predicted changes, and based on the best available science, what actions can be taken now to reduce and/or minimize these climate change impacts?

While not all impacts can be prevented, they can sometimes be reduced. Local, state and federal agencies have more ability to manage local stressors to the marine environment than to affect global atmospheric CO_2 emissions. Reducing local stressors (e.g., nutrient additions, loss of blue carbon species) on habitats and organisms can help reduce the impacts of OA. In 2012, in response to a Blue Ribbon Panel's recommendations, Washington Governor Christine Gregoire issued Executive Order 12-07, directing the Washington Department of Ecology and other cabinet agencies to implement actions to reduce local stressors in order to mitigate the impacts of OA on state marine resources. The Panel's recommendations included controlling terrestrial runoff, protecting carbon sequestering habitats such as seagrass and intertidal marshes and cultivating seagrass to enhance new growth near shellfish beds to absorb OA (Scigliano 2012).

As many MPAs have the legal authority to establish protective measures to reduce local stressors, MPAs may prove to be important local refuges for habitats and species to predicted climate change stressors, including OA.

What are people doing to reduce OA impacts?

Actions taken at the local level may lessen the impacts of OA in the surrounding area. NOAA's Ocean Acidification Program has noted that high loads of nutrients such as nitrogen and organic carbon can cause acidification. Reducing nutrient loading may offer a short-term solution to the progression of OA in local areas. Protecting "blue carbon" – coastal habitats such as seagrasses, salt marshes and mangroves – can help mitigate CO_2 and OA impacts. Research has found that 83% of the seagrass meadows studied in the tropical Indo-Pacific take up more carbon for photosynthesis then release it through respiration. These seagrass meadows can also raise nearby saturation levels of aragonite – critical to shell-building organisms – by up to 14%. Examples of actions being taken at the local level attempting to lessen impacts of OA include:

- Growing plant communities such as kelp to serve as carbon sinks, thus removing or "sequestering" carbon from the atmosphere and ocean through the photosynthesis process. Actively growing kelp plants and other blue carbon habitats may help reduce OA at local scales. Kelp plants and other marine plants may significantly regrow after sustainable harvesting (Figure 7), absorbing CO_2 in the process. If kelp biomass is left to decompose in the water column and not harvested, this species remineralizes into CO_2, potentially making local OA conditions worse. The Paul G. Allen Family

Figure 7. The sustainable harvest of kelp and other marine plants may help lower acidity in local bays and harbors (Credit: Mandy Lindeberg, NOAA NMFS AFSC Auke Bay Lab)

Foundation awarded the Puget Sound Restoration Fund a grant to investigate seaweed cultivation as a potential strategy for mitigating OA.

- One of the State of Washington's Panel recommendations is to breed OA-resistant strains of oysters. A project being undertaken around Puget Sound, Washington, will breed oysters for resistance to OA using a large number of genetically distinct lines maintained by a commercial grower. The oysters will be conditioned in ambient and elevated dissolved CO_2 levels at two critical larval stages to determine whether, and in which genetic lines, exposure induces changes in gene expression.

Figure 8. Monitoring of food and water quality (including acidity) is important in rearing larval crustaceans and mollusks (Credit: NOAA NMFS AFSC)

- Coastal hatcheries along the Gulf of Maine are closely monitoring the pH of the waters pumped into their tanks. As CO_2 is more easily absorbed in cold water, shellfish hatcheries around Casco Bay and the nearby Damariscotta River estuary adjust the pH balance of the water entering their tanks to increase survival of OA-sensitive shellfish larvae.

Figure 9. Empty oyster shells are dried and recycled, placed in bays and estuaries to aid spat settlement and buffer ocean acidity (Credit: Massachusetts Oyster Project)

- Alaskan Red King Crab cultured in the laboratory depends upon close monitoring of phytoplankton, brine shrimp nauplii, and the correct acidity of the water for development and survival (Figure 8).
- The Massachusetts Oyster Project is dedicated to oyster restoration in Massachusetts estuaries to improve water quality. Dried and recycled oyster shells (Figure 9) are being placed in estuaries and appear to act as a natural buffer to local acidity.
- The Puget Sound Restoration Fund is similarly leading efforts to restore Washington State's native Olympic oyster population with the hope that increased shellfish beds will drawdown local nutrient levels, reducing OA levels in the process.
- The Whiskey Creek Shellfish Hatchery in Oregon is located alongside a bay containing dense seagrass beds. The bay exhibits a spike in daily CO_2 levels due to natural seagrass photosynthesis and respiration. The hatchery times their withdrawal of bay water when CO_2 levels are at their lowest levels (during the day) to reduce OA impacts on shellfish.
- Scientists are assessing the sensitivity of Alaska's iconic king crab species to assess the feasibility of raising the sensitive larvae (Figure 10) in laboratory hatcheries and transporting them out to areas that have seen population declines from a variety of reasons, OA among them.

Suggested Further Reading

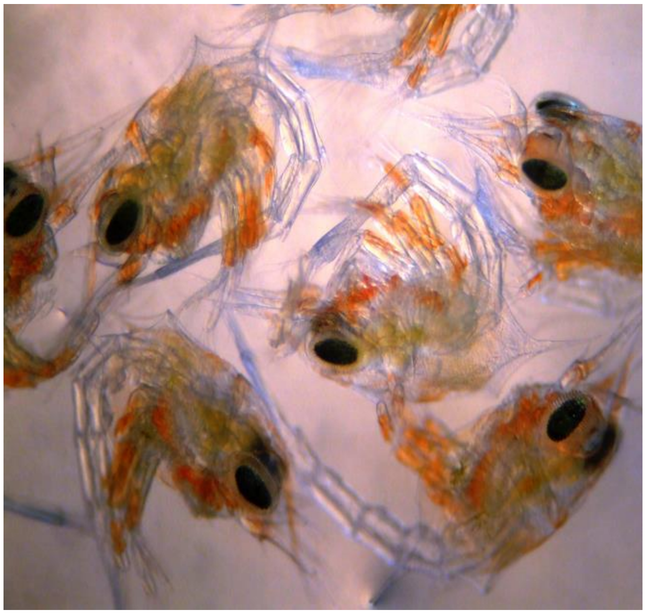

Figure 10. Red king crab larvae molt several times at 1-2 week intervals and are very susceptible to ocean acidification and may benefit from controlled laboratory conditions during this sensitive stage in their life (Credit: Celeste Leroux, Alaska Sea Grant)

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