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OCB-OA: Individuals and Ecosystems

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Why is the long-term change in average seawater pH of concern, when short-term fluctuations regularly exceed these limits?

Basic: The daily and seasonal changes in coastal water pH are much greater than in ocean water located offshore from the coast. Marine species that live in coastal waters are thought to have evolved strategies to deal to fluctuating pH, continued decreases in ocean water pH are also expected to affect pH fluctuations in coastal water. The time that organisms are exposed to unfavorable pH conditions could increase and exceed their tolerance limits.

Intermediate: The fluctuation of pH in coastal waters can be caused by a number of different factors including the influence of freshwater from land, interaction of seawater with fringing coastal habitats, and from changes in seawater chemistry caused by the metabolism of seafloor flora and fauna. Diurnal and seasonal variations in coastal seawater chemistry such as pH typically increase and decrease relative to the chemical signature of offshore oceanic seawater that is generally stable and responds primarily to ocean scale changes in seawater chemistry such as those driven by climate change. Organisms that live in areas with highly variable pH values have developed physiological strategies that allow them to tolerate the fluctuations that are characteristic of coastal environments. The problem is that, as ocean acidification continues to lower ocean pH, the diurnal and seasonal variation will also shift, and the time that the organisms are exposed to unfavorable pH conditions will increase and can exceed their tolerance limits.—H. Findlay, J. Kleypas, M. Holcomb, K. Yates

Advanced: The fluctuation of pH in coastal waters can be caused by a number of different factors including the influence of freshwater from land, interaction of seawater with fringing coastal habitats, and from changes in seawater chemistry caused by the metabolism of seafloor flora and fauna. In some areas, these fluctuations can be extreme and far exceed the changes predicted for seawater pH in the future (Kleypas and Langdon 2006). Organisms that live in areas with highly variable pH values have developed physiological strategies that allow them to tolerate the fluctuations that are characteristic of coastal environments. This does not mean that they are not affected by lower pH, but they have developed ways of dealing with or responding to these conditions.

Diurnal and seasonal variations in coastal seawater chemistry typically increase and decrease relative to the chemical signature of offshore/oceanic seawater that is generally more stable and responds more slowly to the impacts of climate change (Feely et al. 2009). As pH continues to decrease in offshore source waters that are supplied to the coast, the coastal fluctuations will shift relative to the decrease in pH. Additionally, decreasing pH causes a reduction in the ability of seawater to buffer changes in carbon dioxide and pH that can result in an increase in the amplitude of diurnal and seasonal fluctuations (Egleston et al. 2010). Most organisms living in coastal waters are thought to have adapted to the daily and regional variability associated with the habitat in which they live. However, as pH continues to decrease, and the range of variation both shifts along that sliding baseline and increases in amplitude, organisms may be exposed to conditions outside of their tolerance limits for longer periods of time.

Original contributors: H. Findlay, J. Kleypas, M. Holcomb, K. Yates

If ocean acidification varies regionally, can organisms just move to areas where conditions are more favorable?

Basic: In most cases, no. Oceans are populated by many species of organisms that have a limited ability to move. Some adult organisms, like corals, cannot move to better conditions because they are attached to the ocean floor or rocks on the shoreline, but juvenile forms of these unmovable organisms can move to new locations. Therefore, organisms may be able to reach new areas with favorable water chemistry, but in those places these organisms also need many other factors, like relevant habitat, enough food, and proper temperature, for the organisms to survive.

Intermediate: Oceans are populated by many species, especially invertebrates, that have a limited ability to move and are very long-lived. Whether or not a species can move to new areas is dependent on many factors. One of the main factors relates to the question of mobility and dispersal: does a particular organism have the ability to physically get to new locations either as an adult or through its offspring? Furthermore, ocean acidification is only one aspect of the physical environment that defines where conditions are favorable for organisms to live. Certain sites may be relatively unaffected by ocean acidification, but also lack in necessary food sources, have different predators or parasites, be a different temperature, or otherwise be unfavorable for colonization. —M.J. O'Donnell, S. Sundby, K. Y. Børsheim

Why can't organisms adapt to the new conditions?

Basic: Organisms can adapt to new conditions by evolving, but generally this takes many generations. It does not happen within the lifetime of one individual. Organisms with short reproduction times and large population sizes, such as many microorganisms, may therefore be able to adapt. Long-lived organisms with reproduction times of months to years, such as most animals, are less likely to adapt to ocean acidification. But, at the same time, some organisms that can tolerate more changeable conditions will probably do better in the future.

Intermediate: It is true that organisms have demonstrated an incredible ability to adapt to a wide range of environmental conditions, including reduced pH. However, evolutionary adaptation is a slow process, requiring many generations, and ocean acidification is occurring at a rapid pace compared to the life history of some organisms. Evolution is also facilitated by very large population sizes that include a great deal of genetic diversity, and by the ability to exchange genetic material between individuals freely. For these reasons, microorganisms like bacteria and phytoplankton are much more likely to exhibit adaptive evolution in response to rapid ocean acidification compared to larger, rarer, and more slowly reproducing organisms like fish or marine mammals. The many years that elapse for larger organisms to reach adulthood and produce offspring of their own could mean it would take tens to hundreds of years before a species can alter its physiology at the genetic level to better cope with these new conditions. Even species that reproduce more quickly may not be able to adapt; for example, at the edges of regions with favorable temperatures and water chemistry, corals have been trying to adapt to lower carbonate ion concentrations for many millions of years, but they have not been able to succeed in outcompeting algae and other non-calcifying species there. It seems unlikely, therefore, that corals could succeed in adapting to new temperatures and water chemistry in a few decades to respond to OA. Thus, species will be affected differently by changing ocean chemistry, depending upon their existing tolerance for environmental change versus their potential for evolutionary change. We expect that those species with shorter generation times and broad genetic variation for coping with change will be able to adapt to these rapid environmental changes. Those organisms that are more tolerant of the new conditions are likely to increase in importance in their communities as they don't have to spend as much energy coping with the CO_2 acidified water and can spend more energy on important processes like growth and reproduction. This could lead to large shifts in the composition of the groups that live in a habitat. For instance, coral reefs might increase in algal cover as corals decline. —M.J. O'Donnell, D. Hutchins, A. Todgham, K. Caldeira, C. Pfister

Won't ecosystems adjust if a few calcifying species leave an area?

Basic: Yes, ecosystems may adapt to loss of some species, but the new ecosystems may look and function very differently. Ecosystems are complex networks of interactions among biological organisms and the environment, and it is difficult to predict the full ecological impacts of changing any of those links. For instance, a coral reef ecosystem without living coral may still support organisms, but not necessarily the same ones as a healthy reef.

Intermediate: During profound rapid changes in ocean chemistry like present-day ocean acidification, organisms respond in one of 3 ways: acclimation, adaptation, or extinction. If most species acclimate rapidly, the biodiversity and function of marine ecosystems may be relatively unchanged. Evolutionary adaptation, however, is linked to generation time, meaning that long-lived species that mature slowly will have fewer opportunities to produce offspring more resistant to the rapidly changing environmental conditions. If OA drives large shifts in the abundance of key organisms in food webs, or significant rates of extinction, we can expect important changes in the function of ecosystems--- how energy and material flow from primary producers like plankton to top predators like fish and mammals.

Ecosystems are complex networks of interactions among biological organisms and the environment, and it is difficult to predict the full ecological impacts of changing any of those links. We know from CO_2 vent studies that OA affects biological species differently and the mix of marine species shifts, leading to lowered biodiversity and a change in the overall functioning of ecosystems. We depend on a whole range of marine ecosystem services, including food from fisheries, income from tourism and recreation, and oxygen and nutrient recycling from biogeochemical processes; all of these services could be altered, and in many cases degraded, by ocean acidification. Imagine, for example, the economic effects of the disappearance of sea urchins from Japanese fisheries or the decline in fish larvae of commercially important species. Furthermore, decreasing or disappearing calcifying organisms will affect (1) the chemical environment, (2) other calcifying and non-calcifying organisms that may depend on them (e.g., many organisms and hundreds of millions of people depend on coral reefs), and (3) the reservoir of carbon on Earth (the "rock" produced by calcifying organisms falls on the ocean floor to form massive "chalky" deposits that lock away some carbon into geological structures). Just like a neglected aquarium that gives way from fish and shellfish to algae, marine ecosystems may adjust, but they might then be populated by species that are less useful or desirable to humans, making the traditional resources and services provided by the changed ecosystems unavailable, different from before, or unpredictable.— D. Iglesias-Rodriguez, S. Doney, S. Widdicombe, J. Barry, K. Caldeira, J. Hall-Spencer

Will ocean acidification kill all ocean life?

Basic: No, ocean acidification will not kill all ocean life. But many scientists think we will see changes in the number and abundance of marine organisms living in certain ecosystems. Many marine ecosystems may be populated by different, and potentially fewer, species in the future. This could have consequences for the whole ecosystems. For instance, removing sea urchins from a kelp forest ecosystem has been shown to cause major shifts in the algae that grow there, while depriving predators, such as sea otters, of an important food source.

Intermediate: No. However, many scientists think that ocean acidification will lead to important changes in marine ecosystems. This

prediction is largely based on geologic history: millions of years ago, marine ecosystems experienced rapid changes during ocean acidification events, including some species extinctions (see “Geologic History” below). Today, some species and the ecosystems they sustain are threatened by ocean acidification, particularly in combination with other climate changes such as ocean warming. Examples include tropical corals, deep-sea corals, bivalves, and swimming snails. These species play key roles in the oceans either because they build three-dimensional structures, which host a considerable biodiversity, or because they are key components of the food chain. Some species that build calcium carbonate structures, such as coral reefs, also provide key services to humans by providing food, protecting shorelines, and supporting tourism. Evidence for the ecological effects of ocean acidification today can be found at “champagne sites,” locations where volcanic CO_2 vents naturally acidify the water and small CO_2 bubbles rise through the water column. At one of these sites around the Island of Ischia (Italy), for example, biodiversity is reduced by 30% at the acidity level that matches the level expected globally in 2100. However, these sites aren’t perfect analogs for future conditions since selection pressures are much lower at vents compared to in future oceans. — J.-P. Gattuso, J. Hall-Spencer

Will warming and acidification balance out responses from organisms?

Basic: This is very unlikely. In theory, it is possible that some negative effects of reduced pH may be countered by increased temperature. However, both pH and temperature shifts act on many biological processes in many different organisms. It is impossible that they will all balance out. Many experiments show that decreased pH may actually enhance the detrimental effects of warming.

Intermediate: In principle, there may be some benefit from warming for the calcification process, because precipitation of calcium carbonate is enhanced by temperature up to a certain threshold. However, organisms are accustomed to living in a limited thermal range and are performing less well in temperatures outside of this range. In many marine areas, organisms (calcifiers and non-calcifiers alike) are already exposed to temperatures reaching the upper end of their thermal windows. Pilot studies on crab and fish have demonstrated that exposure to CO_2 levels expected if CO_2 emissions continue to increase reduces the animals’ capacity to tolerate extreme temperatures. Studies on corals have also shown that CO_2 enhances thermal sensitivity. In this case it encourages the likelihood of bleaching events triggered by warming. Overall, it appears that ocean acidification may enhance the sensitivity of organisms to climate warming. — H.-O. Pörtner, U. Riebesell

Will adult organisms be safe if survive the effects of OA when they are young?

Basic: Some experiments show that negative effects on juvenile organisms can last through their lives even if CO_2 is reduced later. Other experiments show that effects can occur at any life stage, including during reproduction and growth.

Intermediate: For common marine organisms, the gametes, eggs, various larval stages, juveniles, and adults may be affected differently by ocean acidification because they have different tolerances and coping strategies to environmental stress. In some cases, the early life stages may be more susceptible to stress, while in other cases, the adults may be. Experiments are necessary on all life stages to understand the full effects on an organism and to highlight stages that represent weak links. It is also important to consider ocean acidification's lifelong impacts on survival and reproduction. In general, early life history phases (gametes, larvae, juveniles) are expected to be more sensitive to ocean acidification than adults. Sometimes, early exposure carries over to cause later effects; for example, exposure of adults can decrease reproduction, and exposure of larvae can impact them as juveniles. Furthermore, acclimation may offset these effects after long-term exposure. If fewer young organisms survive to adulthood, population size will clearly be reduced. Ongoing stress usually limits the success of organisms – for example, stressed organisms grow slower and smaller, stressed predators will be less effective, and stressed prey may be less able to avoid capture – and ultimately this stress will decrease survival, causing population size to suffer. For adults, stress caused by ocean acidification may not affect everyday activities, but it will ultimately reduce organisms' growth and reproduction rates. Decreased reproduction can also alter the entire population's size. Impacts at any life stage can reduce the potential for a population to grow or to recover from losses due to disturbance or stress. —J. Barry, H. Findlay, S. Dupont

How can CO_2, a normal product of respiration, be toxic?

Basic: Virtually any chemical can be toxic at some concentration. Organisms have evolved precisely tuned mechanisms to remove waste products like CO_2 from their cells to maintain proper cellular function. Even slight changes in internal pH caused by too much CO_2 trigger responses in organisms to reset their internal chemistry. As an example, when humans hold their breath, the trigger that makes a person feel the need to breathe is excess CO_2 changing the pH of the fluid in the brain before conditions in the cells become toxic.

Intermediate: Just as in seawater, respiratory CO_2 reduces the pH within cells. Organisms have evolved mechanisms to buffer, transport, and remove CO_2 from their cells at the rate at which it is produced. Ocean acidification reduces the CO_2 difference between the inside and outside of an animal's body, thereby hindering CO_2 removal and causing “respiratory acidosis.” (This term is analogous to “ocean acidification” because normal bodily fluids are slightly basic.) Respiratory acidosis may lead to, among other things, reduced metabolism

and reduced organism activity. Additionally, many cellular functions are pH sensitive and may respond negatively to respiratory acidosis. For example, respiratory proteins (e.g. hemoglobin) in the blood bind oxygen at high pH and release it at low pH, allowing oxygen uptake at the gills and release at the cells, where metabolically produced CO_2 has decreased local pH. Many organisms can compensate for respiratory acidosis by shifting the balance of ions in the body. However, it is unknown whether they can maintain such an ionic imbalance in the long term. — B. Seibel

Has ocean acidification caused any impacts on marine life so far?

Basic: Yes, scientists are just beginning to observe the impacts of ocean acidification on marine life in the field and several studies and events have already shown impacts. Since 1990, some corals on the Great Barrier Reef are growing slower than anytime in the last 400 years, most likely caused by a lower pH. Oyster farms on the U.S. west coast have had massive die-offs of oyster larvae when upwelling of carbon rich waters were pumped into their hatcheries, and these die offs were connected to high carbon dioxide levels. Plankton species in the Antarctic Ocean called foraminifera cannot build shells as large as the ones their ancestors formed as recently as a century ago. The modern shells are 35 percent smaller than in the recent past.

Intermediate: Yes. Chemical changes in the ocean have been part of the environmental template in which marine biota have evolved, and in the present changes are also modulating ecological processes of marine populations and ecosystems. Recent evidence demonstrates that several coastal ecosystems are characterized by naturally low pH levels due to increased levels of pCO_2. The evidence collected in these ecosystems demonstrates how low pH levels (accompanied by high pCO_2 and low ?) may impact organisms, populations, and community structure and function. Three examples of these ecosystems are explored below. 1) Cold CO_2 vents off Ischia (Italy): Volcanic gas vents emit CO_2 from the sea floor at ambient seawater temperatures, which leads to a natural pH gradient that impacts the distribution and abundance of benthic calcifier invertebrates. A 30% reduction in species diversity in the areas near the CO_2 vents has been reported. 2) Eastern Boundary Upwelling Systems (EBUEs): These regions have naturally lower pH and saturation state because upwelled waters are enriched with CO_2 from remineralization of organic matter in the deeper ocean. The impact of low pH levels and ? of the upwelled waters has been recently reported as a primary cause of the oyster larvae die-offs in hatchery on the United States' Oregon coast. 3) Coastal environments functioning as sinks for atmospheric CO_2: Adverse carbonate system conditions also occur naturally in these regions. For instance, the cold water of the Chilean Patagonia is a net sink for CO_2, and contrary to the previous examples, where increased pCO_2 (and corresponding decrease in pH and ?) is due to a natural process, the chemical changes occurring in CO_2-sink areas represent an example of anthropogenic OA. However, natural processes may also react synergistically with anthropogenic OA, exacerbating the biological impacts reported for those habitats.—N.A. Lagos, P. Manríquez

Last updated: September 19, 2012

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Mail: Woods Hole Oceanographic Institution, 266 Woods Hole Road, Woods Hole, MA 02543, USA.
E-Contact: info@whoi.edu; press relations: media@whoi.edu, tel. (508) 457-2000
Problems or questions about the site, please contact webdev@whoi.edu