

# **Report of the NJDEP-Science Advisory Board**

## **NJ Ocean Acidification Charge Question**

Prepared by the Science Advisory Board Ocean Acidification  
Working Group

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# **Ocean Acidification - Science Advisory Board Report**

OA Work Group: Judith S. Weis, Chair, David A. Vaccari, Jonathan Kennen

## **Charge Question**

*How will ocean acidification affect marine organisms within New Jersey marine waters? What species are at risk (e.g., surf clams, oysters, primary producers, and finfish)? What industries are at risk? Please provide recommendations on mitigation measures.*

## **Executive Summary**

The increasing use of fossil fuels since the start of the Industrial Revolution has increased the carbon dioxide levels in the atmosphere, some of which dissolves in the oceans. Carbon dioxide dissolved in the ocean forms carbonic acid, which releases  $H^+$  ions causing the water to become more acidic. Ocean acidification (OA) is occurring very rapidly. Adverse effects on shell formation are seen in calcifying animals such as corals and shellfish. Harmful effects are also seen in the development and behavior of many species unrelated to effects on shell formation. Since effects on developing oysters have already been seen on the West Coast, commercial shellfisheries in New Jersey and all along the eastern seaboard are at risk. While the long term solution is reducing global emissions of  $CO_2$ , other localized approaches may be possible when we include coastal and estuarine waters within the scope of OA. Since excess nitrogen and phosphorus in coastal waters and estuaries (eutrophication) also contributes to elevated  $CO_2$  levels and acidification, (as well as reduced oxygen) in deeper waters as algal blooms undergo decay, it is possible to mitigate local coastal acidification by reducing effluents and runoff of nutrients from land-based sources.

The OA work group had their first meeting at NJDEP Headquarters on Oct. 22, 2014. Dave Vaccari led off the session by providing an overview of the potential chemical pathways in which ocean acidification can occur. Then Beth Phelan and Allison Candelmo from the National Oceanic and Atmospheric Administration (NOAA) Sandy Hook Laboratory presented ongoing research efforts addressing the effects of ocean acidification on commercially important fin and shellfish fauna in their lab and in other NOAA laboratories. We had one additional face-to-face meeting to discuss recommendations on ocean acidification that are relevant to New Jersey inland and coastal waters and followed by extensive email correspondence.

### **The Cause of Ocean Acidification**

Ocean acidification is a process by which the pH of marine waters decreases. When CO<sub>2</sub> from fossil fuel burning enters the atmosphere, about 1/3 of it dissolves in the ocean (Feeley et al., 2004). Thus, there is a direct correlation between atmospheric CO<sub>2</sub> and the ocean's pH (Feeley et al., 2004) (Figure 1). In the ocean, CO<sub>2</sub> combines with water to form carbonic acid, which becomes bicarbonate ions (HCO<sub>3</sub><sup>-</sup>) and hydrogen ions (H<sup>+</sup>), reducing the pH of the water, making it more acidic (Figure 2). Since the industrial age began, the pH of the oceans has declined by 0.1 pH unit. Although seemingly small, the pH scale is logarithmic and therefore this small decrease is environmentally significant since it represents a 30% increase in acidity.

The extent to which human activities have increased ocean acidity has been difficult to estimate because acidity levels fluctuate naturally between seasons, years, and among regions and locations. Consequently, direct observations of ocean acidity go back only 30 years. Winds and currents that carry warm and cold water around the ocean are known to create localized pathways and acidic patches. If CO<sub>2</sub> emissions continue at the present rate, models project an average worldwide decrease of 0.2-0.3 pH units by 2100 in addition to what has already

happened, doubling the current acidity (National Research Council, 2010). Furthermore, this change in pH also reduces the amount of carbonate ion, also by about 30%. Carbonate ions are needed by many marine organisms to form calcium carbonate for shells and other structures.

In addition to this global source, the decay of algal blooms resulting from increased nutrients then subsequent mortality, is another source of CO<sub>2</sub> that particularly affects coastal waters (Sunda and Cai, 2012). The release of CO<sub>2</sub> from accumulated decaying organic matter is intensifying the acidification of coastal waters and estuaries in particular and making them more acidic than they otherwise would be.

Ocean pH has fluctuated in past geological ages, but the rate of change was much more gradual—over tens of thousands of years. Today's pH change is much faster, over the period of decades rather than millennia. While some marine organisms will be able to tolerate these conditions or adapt to a changing environment, the current changes may be happening too fast for natural adaptation to occur.

### **Chemistry of OA**

The pH of water, whether fresh or saline, is controlled primarily by its total inorganic carbon (TIC) content and the alkalinity. The TIC, in turn, may be controlled by equilibrium with CO<sub>2</sub> in the atmosphere. The equilibrium between atmospheric CO<sub>2</sub> and its amount in the water is described by an equilibrium expression called Henry's law. The TIC is distributed between three forms: carbonic acid, bicarbonate ions, and carbonate ions in equilibrium with each other, providing two additional equilibrium expressions. A fourth equilibrium expression may be written for the dissociation of water. A fifth expression describes the charge balance (the sum of positive ions must equal the sum of negative ions), which includes the alkalinity. These five expressions can be solved simultaneously for the five species involved ([H<sub>2</sub>CO<sub>3</sub>\*], [HCO<sub>3</sub><sup>-</sup>],

[CO<sub>3</sub><sup>2-</sup>], [H<sup>+</sup>], and [OH<sup>-</sup>]), and the pH computed from the resulting [H<sup>+</sup>]. The chemistry is described in more detail in the Appendix.

As pH is decreased, the proportion of carbonate ion decreases. Besides the pH, the carbonate concentration is of interest because many organisms require it to form shells and other structures. Seawater alkalinity is approximately 115 mg/L as CaCO<sub>3</sub>. In equilibrium with the pre-industrial level of CO<sub>2</sub> of 280 ppmv the pH can be computed as described above to be 8.365. Atmospheric CO<sub>2</sub> is expected to reach 560 ppmv (double the pre-industrial level) in the next 50 years or so (IPCC, 2014). At this level the pH is predicted to be lower by 0.293 units, to 8.072. This is an increase of almost 30% in [H<sup>+</sup>]. Although the TIC increases slightly, the fraction that is carbonate ion decreases a significant 30%.

Coastal ocean areas often are eutrophied from nutrient runoff from land. Resulting photosynthetic activity consumes CO<sub>2</sub> from the water, potentially depleting the TIC in the photic zone near the surface. This could leave all the alkalinity in the form of hydroxide. For example, using a typical ocean alkalinity of 115 mg/L as CaCO<sub>3</sub> (0.050 M), the hydroxide concentration will be the same as this value, and the pH will be computed to be 12.7. In actuality, it rarely increases so much, possibly because not all of the TIC is removed and/or additional CO<sub>2</sub> may be absorbed from the atmosphere. However, this shows the potential for eutrophication to offset ocean acidification, at least in the photic zone in areas such as coastal zones that receive significant nutrient input from the land.

However, when the resulting algae biomass settles below the photic zone, it can biodegrade, releasing CO<sub>2</sub> back into the deeper water. Biomass equivalent to 4 mg/L biochemical oxygen demand (BOD: the amount of oxygen consumed in its oxidation) produces

5.5 mg CO<sub>2</sub>/L. The following Tables show the individual and combined effects of doubling atmospheric CO<sub>2</sub> from 280 to 560 ppmv and from adding 5.5 mg CO<sub>2</sub>/L from biodegradation:

BOD	CO <sub>2</sub>		BOD	CO <sub>2</sub>		BOD	CO <sub>2</sub>	
	280 ppmv	560 ppmv		280 ppmv	560 ppmv		280 ppmv	560 ppmv
	pH			[H <sup>+</sup> ] (μM)			[H <sup>+</sup> ] (% change)	
0 mg/L	8.36	8.07	0 mg/L	0.0043	0.0085	0 mg/L	0%	96%
4 mg/L	7.74	7.61	4 mg/L	0.0182	0.0247	4 mg/L	323%	471%

These Tables show that doubling atmospheric CO<sub>2</sub> by itself almost doubles [H<sup>+</sup>] concentration, whereas biodegradation of 4 mg BOD per liter triples it. Together they increase [H<sup>+</sup>] by 471%.

The effect of the same changes on carbonate concentration is shown in the following Tables:

BOD	CO <sub>2</sub>		BOD	CO <sub>2</sub>	
	280 ppmv	560 ppmv		280 ppmv	560 ppmv
	[CO <sub>3</sub> <sup>2-</sup> ] (μM)			[CO <sub>3</sub> <sup>2-</sup> ] (% change)	
0 mg/L	21.9	11.4	0 mg/L	0%	-48%
4 mg/L	5.29	3.9	4 mg/L	-76%	-82%

These Tables show that doubling atmospheric CO<sub>2</sub> by itself cuts carbonate concentration almost in half, whereas biodegradation of 4 mg BOD per liter decreases it by three-quarters. Together they decrease carbonate concentration by 82%.

These changes can directly impact deep ocean organisms, but can also affect coastal zones impacted when upwelling conditions bring the deep water to the surface.

The biological effects of H<sup>+</sup> and CO<sub>3</sub><sup>2-</sup> should be distinguished from each other. For example, pH changes can affect organisms by changing the speciation of toxic substances such as NH<sub>3</sub> or H<sub>2</sub>S, or by direct effect of pH on membranes. Organisms that form calcium minerals,

however, may be adversely affected by the decrease in carbonate concentrations in their environment. Eutrophication, and photosynthesis in general, can offset ocean acidification near the surface and in coastal zones with significant nutrient input. However, eutrophication can also increase the effect of ocean acidification below the photic zone or in areas of coastal upwelling.

### **Biological Effects of reduced pH**

Marine organisms have evolved over millions of years to thrive in slightly alkaline conditions. Thus, when the chemistry shifts and the oceans become more acidic, organisms are directly and indirectly affected. Reduced pH or ocean acidification threatens the ecological health of the oceans and may affect the economic well-being of the people and industries that depend on a healthy marine environment.

The increased acidity of the oceans is expected to harm a wide range of ocean life—particularly those with calcium carbonate shells (Figure 3a and 3b). Many organisms use calcium and carbonate ions from seawater to produce calcium carbonate for shells. Two common mineral forms of calcium carbonate are aragonite and calcite. Those animals that use aragonite - corals, mollusks, including pteropods (a tiny planktonic snail) - are expected to be more severely affected than calcite calcifiers such as coralline algae and sea urchins, because of differences in solubility—aragonite is a more soluble form than calcite. It appears that larval mollusks and some other calcifying organisms are already experiencing harmful effects on shell formation at some locations (Barton et al. 2012).

Calcareous plankton, including some phytoplankton at the base of oceanic food webs (such as coccolithophores) and foraminiferans (McIntyre-Wressnig et al. 2013), are threatened. Among the plankton in the oceans are tiny snails called pteropods that play an important role in

the food web. Because they produce an aragonite shell, they are very susceptible to ocean acidification.

Somewhat lowered pH is natural in some regions. For example, water off the Pacific coast of the United States is already at a low carbonate saturation level due to upwelling. When surface winds blow the top layer of water out from coastal regions, deeper water with higher acidity can well up, and potentially harm shellfish. The acidity of deeper water is due to CO<sub>2</sub> produced by bacterial decomposition, which is concentrated in deeper water. Periodic upwelling of CO<sub>2</sub>-rich water has already happened on the US West Coast, where larval oyster survival has been very low for several years. A few decades ago, such natural upwelling events were not as acidic as they are today and generally were only a minor concern. Now hatcheries in the Pacific Northwest are having difficulty rearing larval oysters because of problems with shell formation. There has been a reduced natural set of juvenile oysters in some Pacific Coast estuaries where the commercial shellfish industry relies on natural reproduction of oysters (Barton et al. 2012). Workers at Oregon's Whiskey Creek Shellfish Hatchery suspected that low pH water may have been killing their oyster larvae by preventing them from making normal shells. Working with Oregon State University and NOAA, they were able to show that that was the case (Barton et al. 2012), and now they monitor the pH of the ocean and time their water intakes to ensure that oysters are exposed to water with lower acidity. A small investment in pH-monitoring equipment has saved Oregon's oyster industry millions of dollars.

Corals show varied responses. Some are particularly sensitive to changes in the ocean's pH, but not all species respond the same way. Some species have a higher degree of tolerance to lower pH, while others experience harmful effects through developmental stages or even generations after short-term exposure (Pandolfi et al. 2011). Bleaching (loss of symbiotic algae

due to increased temperature), acidification, and diseases are expected to exacerbate the effects of OA and reduce survival, growth, reproduction, larval development, settlement, and subsequent growth of many coral species. Interactions with local stresses such as pollution (e.g., increased nutrient levels) and overfishing will likely intensify the effects of climate change. If current trends in OA continue, decreases in coral reefs with declines in associated fishes and invertebrates, which are already taking place due to multiple stresses, will become even more significant.

OA effects are not restricted to shell production. Mussels have been found to reduce their production of byssal threads, which mussels use to attach themselves to surfaces. With reduced thread production their attachment is weaker and they are more likely to be swept away by strong currents (O'Donnell et al. 2013) and are more susceptible to predation. Since mussels are important “ecological engineers” making habitat for other organisms and are cultured on ropes in many parts of the world, reductions in their populations could have serious repercussions both ecologically and economically.

Effects of OA have been seen on behavior and development of a number of marine animals (Briffa et al. 2012). For example, fish use gills to regulate their pH balance, but the early larval stages do not have gills and therefore, cannot regulate pH in this way. Exposure of eggs and larvae of a common estuarine fish (inland silverside, *Menidia beryllina*) to elevated CO<sub>2</sub> severely reduced survival and growth (Bauman et al., 2012). In general, the eggs were more vulnerable to high CO<sub>2</sub>-induced mortality than the larvae. Researchers at the Woods Hole Oceanographic Institution found that Atlantic longfin squid (*Loligo pealeii*) eggs raised in seawater with elevated CO<sub>2</sub> were slower to hatch than those raised in normal seawater (Kaplan et al. 2013). Additionally, mineral structures called statoliths, which help the squid balance and

sense movement, were smaller, oddly-shaped and more porous in acidified waters. Abnormal statoliths could have significant consequences for squid because the statolith is needed for proper swimming and orientation, finding food, and for avoiding predation (Kaplan et al. 2013).

Behavior is also altered in many animals, especially behavior related to the olfactory system. For example, young clownfish normally stay close to the reef in which they live. But elevated CO<sub>2</sub> and reduced seawater pH disrupt olfactory function and cause clownfish (*Amphiprion*) larvae to wander farther and farther from home, where they have a higher probability of being eaten by predators (Munday et al. 2009). Similarly, Dixon et al. (2010) found that orange clownfish (*Amphiprion percula*) in low pH water in the lab or living next to naturally low pH seeps, where carbon dioxide is released by volcanic activity, lose their natural fear of the odor of predators. Living in this acidic environment appears to alter olfactory cues and small reef fish become strongly attracted to the smell of their predators and the ability to distinguish between predators and non-predators was lost. But predatory behavior can also be impaired. The brown dottyback (*Pseudochromis fuscus*), a predatory coral reef fish, under elevated CO<sub>2</sub> levels predicted for 2100, shifted their behavior from preference to avoidance of the smell of injured prey, and decreased their feeding (Cripps et al. 2011). In another example, Devine et al. (2012) found that homing behavior was impaired in the five-lined cardinalfish (*Cheilodipterus quinquelineatus*) under low pH conditions. Additionally, Dixon et al. (2014) found that smooth dogfish (*Mustelus canis*) attraction to the odor of prey decreases in seawater with elevated CO<sub>2</sub> levels. All these modified behaviors can increase mortality.

Since there is great variation in sensitivity to OA, it is expected that some species will thrive while others will diminish, thus causing shifts in marine communities. For example, some large crustaceans such as crabs and lobsters do not seem to be impaired by elevated CO<sub>2</sub>, but

seem to grow larger (Ries, 2009). Under higher CO<sub>2</sub> levels, they tend to molt faster and as they molt, they undergo a growth spurt while in the soft-shell stage. Extra carbon speeds the molt cycle so that they become bigger, potentially less vulnerable to predators. However, even organisms such as crabs and lobsters which show enhanced calcification under elevated CO<sub>2</sub> levels could be negatively affected by the decline of less CO<sub>2</sub>-tolerant organisms in their ecosystems (Ries, 2009).

In acidified conditions mollusks grow more slowly and tend to have weaker shells, making them more vulnerable to predators (Barton et al. 2012), but some recent research indicates that benthic stages of the blue mussel (*Mytilus edulis*) tolerate high ambient CO<sub>2</sub> levels when food supply is abundant (Thomsen et al. 2012). However, sea urchins also seem resistant to OA (Evans et al. 2013), largely because they have genes that appear to provide resistance and can evolve rapidly (Pespeni et al., 2013). Researchers raised *Strongylocentrotus purpuratus* larvae in water with either low or high CO<sub>2</sub>, sampled the larvae, and used DNA-sequencing tools to determine which parts of the genetic makeup changed. By looking at the function of each gene that changed, Pespeni et al. (2013) were able to identify which particular genes were critical for sea urchin survival under acidic conditions. These studies reflect the fact that much work still needs to be done to better understand the effects of OA on a variety of organisms (Dupont and Thorndyke, 2009).

OA can degrade entire ecosystems, resulting in homogenized communities dominated by fewer plants and animals (Cigliano et al. 2012). In the waters by Castello Aragonese, an island off the coast of Italy, volcanic vents naturally release CO<sub>2</sub> (and metals), creating gradients of acidity, which provide a glimpse of what the future communities could look like. Three zones—low (pH 8.09-8.15), high (pH 7.41-7.99), and extremely high acidity (pH down to 7.08) —

representing conditions of the present day, 2100, and estimate for 2500 respectively were selected for sampling. Cigliano et al. (2012) removed animals and vegetation from rocks and examined the rocks periodically for recovery. In more acidic water the number and variety of species was reduced. In both high and extremely high acidic plots, fleshy algae increased and took over, because sea urchins and other grazers were either not present or did not graze on the algae, while they did so in the lower acidity zone. Even though vent systems are not perfect predictors of future ocean ecology and our understanding of the underlying effects of OA on ocean biogeochemistry is still rudimentary, this research indicates that OA can dramatically affect a wide range of benthic organisms, especially grazers, which are important in controlling algal growth and maintaining the balance in marine ecosystems.

Many of the laboratory studies on pH effects have been limited in scope. For example, some studies consist of placing marine animals in laboratory tanks with low pH water for a few days or months to see how they respond. Fish and shellfish larvae often fail to thrive and don't grow as big or live as long as those in more alkaline waters. But some species show substantial resilience. Unlike laboratory tanks, organisms in the ocean live in a community with other environmental factors and with many different species which represent a complex web of interactions. Some species are competitors for space and food; others are potential prey or predators. Limited laboratory studies also cannot indicate the long-term effects of OA or if a species can adapt to acidification. Our present understanding relies mostly on results from short-term studies. Longer-term studies may reveal that some species have a life-history or genetic plasticity to adapt over time. Animals can be impaired when abruptly exposed to elevated CO<sub>2</sub>, but organisms that are gradually acclimated to high CO<sub>2</sub> may be able to adjust to the changing geochemical and osmoregulatory constraints imposed by OA over the long term. For example,

corals (*Lophelia pertusa*) exposed to high CO<sub>2</sub> for 1-week showed a 25-29% decline in calcification for a pH decrease of 0.1 units. In contrast, corals that were able to acclimate to the lower pH conditions over a 6 month period were shown to have a slightly greater calcification rate (Form and Riebesell, 2012). Some molluscan fauna have also been able to increase their tolerance to low pH through acclimation. In one study, elevated CO<sub>2</sub> resulted in reduced growth, rate of development, and survival in larval rock oysters, *Saccostrea glomerata* (Parker et al. 2012). But when the adult oysters were exposed to elevated CO<sub>2</sub> while their gonads were ripening, the larvae they later produced were larger and developed faster in high CO<sub>2</sub> conditions (Parker et al. 2012). In addition, selectively bred larvae were more resistant to elevated CO<sub>2</sub> than wild larvae. Thus, this research appears to indicate that some sensitive marine organisms may have the capacity to acclimate or adapt to elevated CO<sub>2</sub>. Longer-term studies are needed.

Another approach to understanding the effects of OA may be to study wild populations that have already adapted to acidic waters which occur naturally in some parts of the world. For example, along North America's West Coast, the coastal waters off Oregon have low pH due to natural upwelling events. (Upwelling is when cooler, deeper waters move up to the surface. This may be caused by winds blowing the surface water out, or may be due to temperature changes in autumn, when surface water cools and sinks, and deeper water moves up.) While this upwelling has been found to alter growth and survival of juvenile oysters (Barton et al. 2012), it appears that sea urchin larvae found in intertidal areas with naturally low pH are able to tolerate acidic waters and do so better than those from subtidal waters. This study by Moulin et al. (2011) may indicate that sea urchins from tidal pools with naturally high pH may have evolved a resistance to acidification through genetic variation, a variation that may be sufficient enough to allow the offspring of these organisms to tolerate future ocean acidification. There is indication that some

corals may have genes that can provide resistance to acidification. Similar to the genetic selection of agricultural animals and plants, coral could be genetically selected to boost their resilience to environmental stressors such as OA (<http://www.pgafamilyfoundation.org/oceanchallenge/>). Thus, it is important to learn to what extent different organisms could tolerate future acidification; that is, what is their acclimatization capacity (Hoffman et al. 2012).

### **Effects that are already being seen**

In addition to the studies at Castello Aragonese discussed above (Cigliano et al. 2012), effects are being seen in shell formation in several groups of small organisms with thin shells. Calcification rates of shelled phytoplankton, Coccolithophores, are already in decline. Across the entire Southern Ocean there was a 4% reduction in calcification rate during the summer from 1998 to 2014 (Freeman and Lovenduski 2015). They found a 9% reduction in calcification during that period in large regions of the Pacific and Indian sectors of the Southern Ocean. The failure of cultured larval oysters in the Pacific Coast of the U.S. due to upwelled water with low pH was discussed above (Barton et al. 2012). Bednarsek et al (2014) found the frequency of pteropods (tiny planktonic mollusks) with severe shell dissolution damage (Fig. 3B) was related to the percentage of undersaturated water (due to CO<sub>2</sub>) in the top 100 m with respect to aragonite. They found that 53% of onshore individuals and 24% of offshore individuals had severe dissolution damage. They concluded that the extent of undersaturated waters in the top 100 m of the water column has increased over sixfold along the California coast and pteropod shell dissolution due to OA has doubled in near shore habitats since pre-industrial conditions.

## **How Much Acidification in coastal waters can be attributed to eutrophication vs atmospheric CO<sub>2</sub>?**

The percentage of acidification attributable to eutrophication vs atmospheric CO<sub>2</sub> will differ among locations depending on the amounts of nutrient inputs and freshwater inflow. The calculations shown above demonstrate that biodegradation of 4 mg BOD per liter has the potential for a greater effect than the doubling of atmospheric CO<sub>2</sub>. Sunda and Cai (2012) found that the pH change due to eutrophication was greater in systems with low salinity and low temperature (e.g., Baltic Sea, where the pH was lowered by 1.1 unit) than those with high temperature and high salinity (e.g., Gulf of Mexico where the pH was lowered by 0.24 unit). They stated that the 0.24 to 1.1 unit decrease in pH is well within the range that impairs bivalve calcification and fish olfaction. They also commented that deleterious effects on mollusk growth attributed to low DO are more strongly correlated with low pH, which may be more important than low DO in causing deleterious effects. Cai et al. (2011) modeled data from Gulf of Mexico and East China Sea and their findings indicate that eutrophication also reduces the ability of water to further buffer changes in pH. They calculated that pH in the northern Gulf of Mexico has dropped by about 0.45 units since pre-industrial times, of which anthropogenic CO<sub>2</sub> contributed to a pH drop of 0.11 units, respiration of organic matter (eutrophication) contributed 0.29 units, and decreased buffering capacity contributed an additional 0.05 units. Feeley et al. (2011) examined combined effects in Puget Sound and found that the observed pH and aragonite saturation state values in deep waters of Hood Canal sub-basin were substantially lower than would be expected from atmospheric CO<sub>2</sub> alone. They calculated that acidification due to CO<sub>2</sub> accounted for 24% (summer) to 49% (winter) of the pH decrease. Thus, eutrophication accounts for about half of the pH decrease in winter, and three-fourths of the decrease in the summer.

## **The Situation in the mid-Atlantic area**

Although limited, monitoring of pH in New Jersey upstream and estuarine waters has been going on for many years, but only recently has the technology improved to increase accuracy. Monitoring of pH in coastal and oceanic waters has only recently commenced in the last decades, with DO measurement covering a much greater time period. However, correlation between parameters has not been attempted due to inconsistencies in sampling locations, methodology, and simply lack of data prior to the 2000's. Therefore, it is difficult to determine long-term trends with confidence.

In nearby Long Island estuaries, large natural fluctuations in pH, CO<sub>2</sub> and O<sub>2</sub> have been noted on a daily, seasonal, and yearly basis (Baumann et al. 2014). Wallace et al. (2014) examined seasonal trends in hypoxia and pH in nearby estuaries, Narragansett Bay, Long Island Sound (LIS), and Jamaica Bay, and found that DO and pH measurements were highly correlated. Thus, when the DO declined in the summer and fall, so did the pH (Figure 4). The spatial and temporal dynamics of DO, pH, and pCO<sub>2</sub> suggested that they are all ultimately driven by the same processes, namely high rates of microbial respiration fueled by nutrient enriched algal organic matter. The degree of acidification observed in these systems during the summer is within pH ranges that have been shown to adversely impact a wide range of marine life. Furthermore, while hypoxia and acidification co-occurred in these estuaries during the summer, the low pH conditions persisted longer into the fall than low oxygen. For example, during 2011 and 2013 in LIS and during 2012 in Jamaica Bay, waters became normoxic during early fall (October) but maintained pH levels < 7.7.

## **The Situation in NJ**

Monitoring of pH and DO in New Jersey estuarine waters, including Delaware and Raritan Bays has occurred since the mid-1990's, and more extensively since the early 2000's (sourced from the National Coastal Assessment). The monitoring stations included in the Atlantic coast database are those with sensors that are part of the National Estuarine Research Reserve system, data of which does not extend prior to the 2000's. Submersible glider studies were conducted by the NJDEP in the mid-2000's to look at ocean chemistry over an extensive area along the coast. Although NOAA has sampled oceanic (e.g., Mid-Atlantic Bight; MAB) and major bays along the coast since the 1970's, comprehensive sampling that includes ocean pH has only been added since the mid- to late-2000's. The most comprehensive dataset for New Jersey to date is from the Barnegat Bay, with DO and pH data available from the 1970's to present.

Unfortunately, discrepancies in the data as well as large gaps are present. A trend analysis for summer pH in Barnegat Bay for the most recent decade (2003 – 2014) showed yearly variation, however no discernable decadal trend was observed (See Figure 5). New Jersey has at least 13 municipal outfalls that discharge directly to marine waters, however continuous monitoring at the discharge points is not conducted. These would provide a valuable resource for examining how localized hypoxia could affect pH and ultimately what the implications might be. The overall picture of how pH has affected New Jersey waters and natural resources historically, as well as how summer water alkalinity has been influenced by nutrient inputs can not be derived with certainty based on the available data resources.

Periodic summer upwelling events occur off the coast of New Jersey, which can transport deep, acidified water to the surface. To determine if such events can impact shellfish hatcheries, a monitoring study was conducted by Munroe et al. (2014) at the Aquaculture Innovation Center

(AIC) of Rutgers University, a research hatchery that supports oyster aquaculture by producing disease-resistant and triploid seed oysters. In the summer of 2014, the AIC intake pipe in the Cape May Canal was continuously monitored and grab samples were collected at the intake and within the facility. Dissolved inorganic carbon (DIC) and pH were used to calculate the aragonite saturation state of the water. During an upwelling event in July, a decrease in pH was measured at the intake and water of low pH and aragonite saturation was entering the facility. This shows that upwelling may bring in acidified water, which would impair shellfish production in NJ coastal waters. Species at risk include shellfish, (clams, oysters, and mussels), as well as fish populations that are estuarine dependent during parts of their life cycle.

#### **Economic Effects of Ocean Acidification:**

Ocean acidification will directly and indirectly impact tourism and the recreational and commercial fisheries and the jobs and revenue that depend on them. Regions that depend heavily on coral reef tourism or fisheries are likely to see severe economic impacts, which would include decreases in revenue if the quality of reefs or quantity of fish harvests decline. It is also likely that changes in shellfish harvests, coral reef-associated industries, or tourism could affect many other businesses and communities that directly and indirectly depend on revenue from ocean-based industries (Narita et al. 2012). These interdependencies would amplify the overall economic effects resulting from OA. Commercial fisheries, especially the shellfish fisheries in NJ and elsewhere along the eastern seaboard, would be severely affected. Ekstrom et al. (2015) analyzed vulnerability of various states to OA and rated NJ at “high risk of economic harm” because of the value of its shellfisheries and shellfish aquaculture, combined with the level of nutrients and riverine inputs.

**Mitigation possibilities:**

While reduction of CO<sub>2</sub> emissions, or technology for sequestering CO<sub>2</sub> are necessary, they will require national and international action to have a significant effect, local action can help combat acidification because the situation is exacerbated by land-based local pollution including nutrients from farms, sewage systems, and runoff (Sunda and Cai, 2012). These nutrients (primarily nitrogen) stimulate algal blooms which die, sink to the bottom, and undergo decay by bacteria, a process that simultaneously reduces dissolved oxygen and elevates carbon dioxide in bottom waters. These combined effects have been demonstrated by Gobler et al. (2014) to intensify the negative outcomes of OA alone, especially for early life stages of commercially and economically important bivalves such as bay scallops (*Argopecten irradians*) and hard clams (*Mercenaria mercenaria*). Since nutrients contribute to the problem, existing anti-pollution laws such as the Clean Water Act (CWA) can address this aspect of the problem. States have the authority under the CWA to set standards for water quality, and they can use that authority to alter local limits on the nutrient pollution that contributes to acidification in coastal waters and estuaries. As described above (Feeley et al, 2010, Cai et al. 2011, Sunda and Cai, 2012), where the relative contributions of atmospheric CO<sub>2</sub> vs local eutrophication have been compared, eutrophication contributes a substantial amount (sometimes over half) of the acidification in estuaries and coastal waters.

Following reports of severe problems in oyster culture due to OA, Washington State Governor Christine Gregoire convened a Blue Ribbon Commission to review the issue, the known science and solutions, and to determine what could be done at the state and local level. Their report made a number of recommendations (Washington State Blue Ribbon Panel on Ocean Acidification, 2012). The state legislature passed a measure that established monitoring

protocols, defined strategies to mitigate the problem locally, and created a funding mechanism to help fund the initiative. Washington will monitor ocean acidity and create an acidity budget—an assessment of how much acidity is coming from which sources. It will attempt to reduce carbon inputs from land-based sources such as agricultural and urban runoff, develop practical steps to offset carbon, like planting seagrasses, and have an extensive campaign to educate the public, business leaders, and policymakers about OA. Many of the strategies for addressing OA have multiple benefits, e.g. building resilience by replanting seagrass and marshes that take up carbon and filter the water also protects the coastal regions against storm surges. Restoring habitat not only helps the shellfish industry but reestablishes critical nursery and feeding areas for a wide variety of commercially and economically important species, many of which are protein sources for humans and wildlife. Ensuring that additional pollutants such as nitrogen do not further stress already vulnerable coastal areas helps improve water quality for human communities as well.

There are many efforts underway internationally to restore and plant new salt marshes and seagrasses not only as buffers for climate change, but for the habitat they provide for animals and the shore protection they provide to human communities. Restoring oyster reefs has become very popular for a number of reasons. They provide habitat for a wide variety of other animals, serve as a buffer against storm surges, and their calcium carbonate-containing shells can help to buffer effects of decreasing pH. In addition, oysters filter an enormous amount of water and can help to combat eutrophication by consuming phytoplankton. Other local actions include depositing crushed shells in mudflats, for instance, to neutralize the sediment. Such strategies, like pollution control, are worthwhile to help keep shellfish populations as robust as possible.

Other states, including Maine and Maryland, have recently come out with reports and recommendations for state actions on OA. The Maine report (Commission to Study the Effects

of Coastal and Ocean Acidification and its Existing and Potential Effects on Species that are Commercially Harvested and Grown Along the Maine Coast, 2015) discussed freshwater runoff (freshwater has lower pH than seawater) and nutrients as additional drivers of OA and included recommendations to reduce nutrient and carbon inputs among their goals. The Maryland report (Task Force to Study the Impacts of Ocean Acidification in State Waters, 2015) discusses expected impacts on important species, such as oysters, blue crabs, striped bass and forage fish, all of which are also important in NJ. The MD report includes a figure similar to that of Wallace et al. (2014) showing parallel increases and decreases of OA and pH in Chesapeake Bay, in this case on an hourly basis (Fig. 6). The recommendations of that report include reducing emissions of greenhouse gases and nutrients, as well as monitoring waters to quantify the scale, patterns and trends of OA. Following the Maine report, efforts are underway in other New England states. A group of state legislators wants to form a multistate pact to counter increasing ocean acidity along the East Coast, which can endanger multimillion dollar fisheries. They want research to determine the impact that factors such as nutrient loading and fertilizer runoff have on ocean acidification, and advocate for new controls.

(<http://www.providencejournal.com/article/20150330/NEWS/150339977/13942/BUSINESS?tr=y&auid=15365887>).

## **Options**

Kelly and Caldwell (2014) published a detailed description of ways in which states can combat ocean acidification (OA), and why they should. Their recommendations are placed in Appendix 2. We used their recommendations as a basis in developing potential options for DEP to consider.

1. If feasible, pH could be measured and recorded every time DO is measured. In addition, if there are existing data gaps that make OA difficult to assess in NJ coastal and nearshore waters, those gaps could be filled so that there are enough data to support informed decision making. Consistency in how data are collected, as well as spatial and temporal consistency, can enable more accurate analyses and interpretation of these data.
2. To enhance monitoring, DEP should consider steps that would improve coordination of ocean observing monitoring networks, such as NERACOOS (Northeast Regional Association of Coastal Ocean Observing Systems) and MARACOOS (Mid-Atlantic Regional Association of Coastal Ocean Observing Systems). DEP should also consider monitoring the growth and development of shellfish populations at risk by enhanced monitoring networks and broadened support of research programs.
3. Ocean outfalls occur all along the NJ coast, and the science indicates current controls such as NPDES (National Pollution Discharge Elimination System) may not be sufficiently considering the effects of OA. DEP should consider expanding monitoring efforts where practicable to investigate changes in pH that have been shown to be relevant to the health of coastal organisms of economic and ecological concern.
4. DEP may consider developing new criteria for pH-related aspects of carbonate chemistry (Total Alkalinity, Dissolved Inorganic Carbon) to improve monitoring of acidifying waters.
5. We commend the steps DEP has taken to reduce CO<sub>2</sub> emissions in New Jersey and recommend that DEP continues to lead by example in all aspects of CO<sub>2</sub> reduction. DEP should continue to monitor the development of new technologies that capture industrial CO<sub>2</sub> emissions.

6. The NJ CZMA Coastal Nonpoint Pollution Control Program Plan includes Best Management Practices (BMPs) to reduce nonpoint source pollution. DEP should consider providing better incentives to support land use practices that reduce nutrient loads to streams and include outreach to farmers and other land owners emphasizing BMPs for nutrient reduction. Nonpoint source policies that have been developed for the Barnegat Bay could be adopted statewide. NJ has been proactive in improving stormwater regulations; there is a need, however, for data to better understand their effectiveness both for DO and for OA.
7. We recommend that DEP consider the impacts of eutrophication, in terms of releasing CO<sub>2</sub> and lowering pH, as part of any risk assessment where NJ coastal waters may be affected.
8. We recommend that DEP consider developing an outreach program to inform the shellfish industry about the potential risks of OA to their operations, along with ways to mitigate possible problems, should they arise.
9. We are encouraged that DEP continues to reduce or offset the amount of impervious surface by encouraging broader implementation of green infrastructure practices which have been shown to reduce the amount of stormwater runoff. Where possible, the construction of living shorelines will be able to reduce the amount of shoreline erosion and loss of wetlands, which can function to absorb nutrients in runoff. The SAB recommends that research be conducted to better understand the impacts of storm events (e.g., Hurricane Sandy) on resiliency and mobilization of contaminants, in order to mitigate future catastrophic events.

The SAB advises DEP to consider these options for developing actions to mitigate OA in NJ. DEP should consider implementing monitoring as soon as practicable. NJDEP should also

consider evaluating the recommended approaches to reduce nutrient inputs and decide implementation priorities.

Despite decades of ongoing monitoring, the lack of consistency in sampling technology and methods makes it difficult to develop a clear picture of the level of acidification occurring in NJ coastal and marine waters. This emphasizes the importance of monitoring NJ coastal and marine waters in the future, in order to quantify the scale, pattern and trends of OA. Enhancing coastal monitoring programs and analysis of water quality data will advance our understanding of the effectiveness of steps taken to implement these recommendations.

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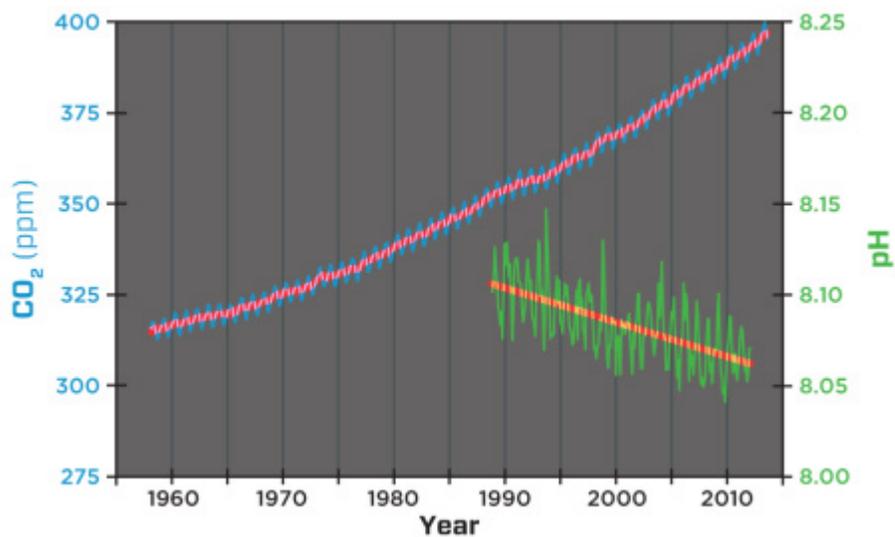
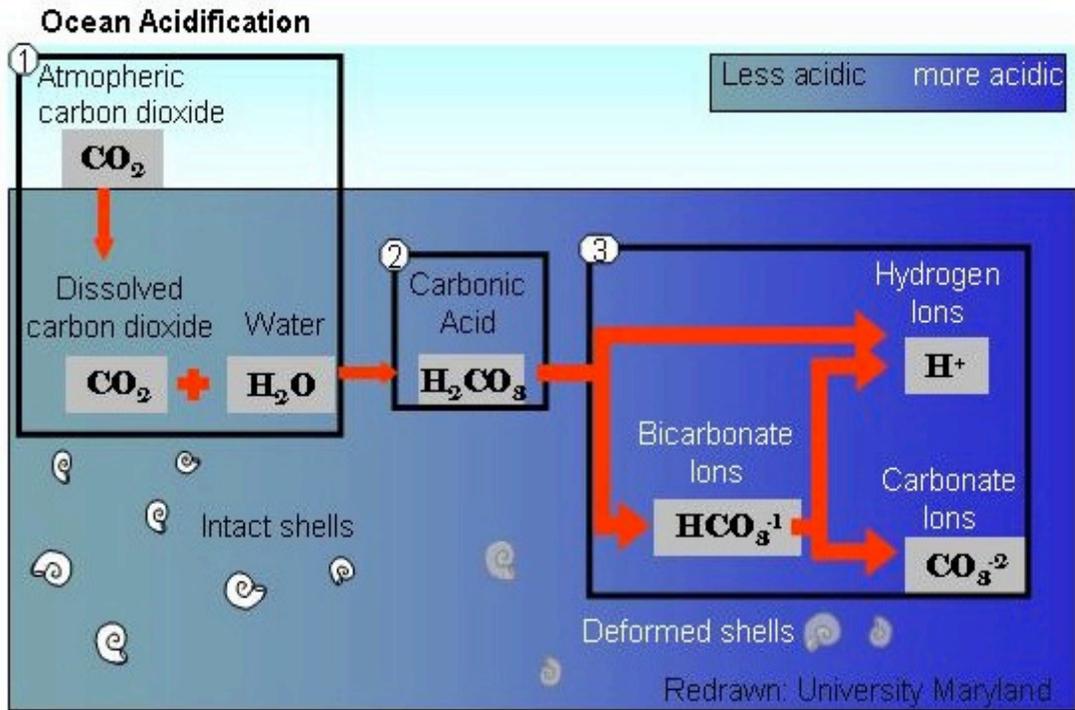


Figure 1

Observations of CO<sub>2</sub> (parts per million) in the atmosphere and pH of surface seawater from Mauna Loa and Hawaii Ocean Time-series (HOT) Station Aloha, Hawaii, North Pacific.

**Credit:** Adapted from Richard Feely (NOAA), Pieter Tans, NOAA/ESRL ([www.esrl.noaa.gov/gmd/ccgg/trends](http://www.esrl.noaa.gov/gmd/ccgg/trends)) and Ralph Keeling, Scripps Institution of Oceanography ([scrippsco2.ucsd.edu](http://scrippsco2.ucsd.edu))

Figure 2



From University of Maryland

Figure 3A

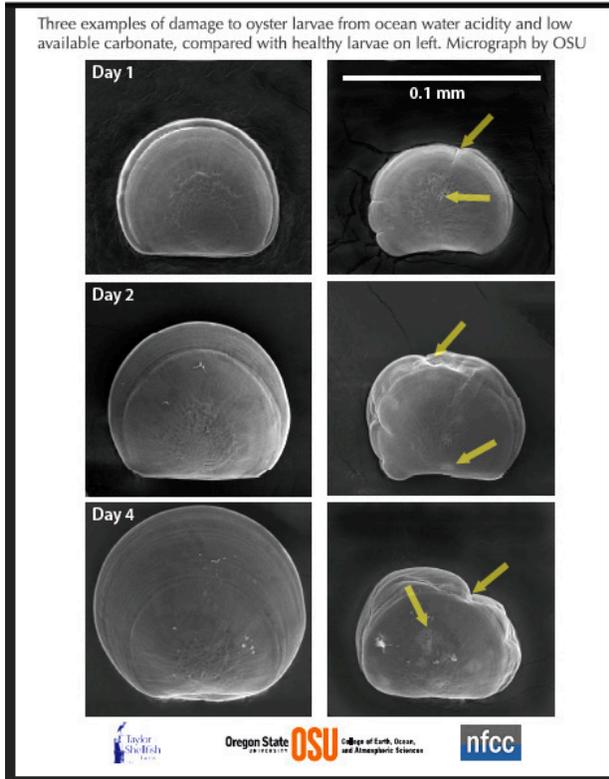
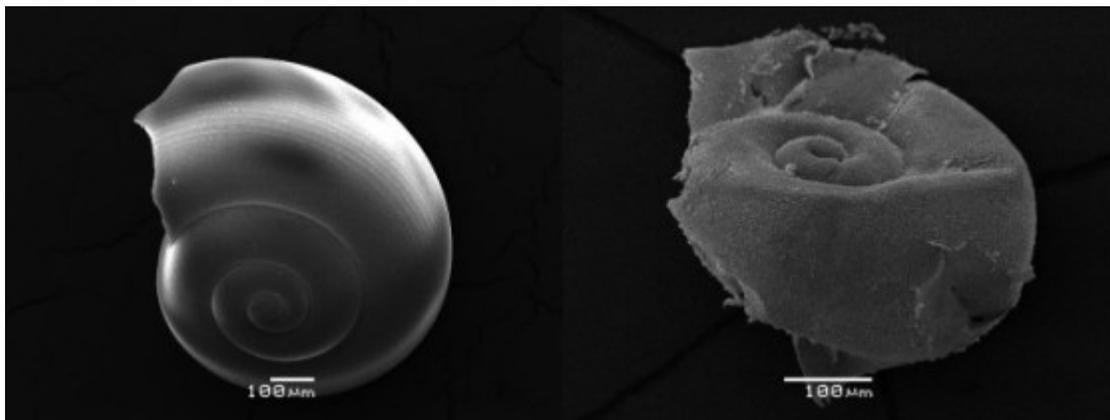


Figure 3 B

Dissolution of pteropod (sea butterfly, planktonic mollusk) shell in area with acidic upwelling water Credit: Nina Bednaršek and Bertrand Lézé



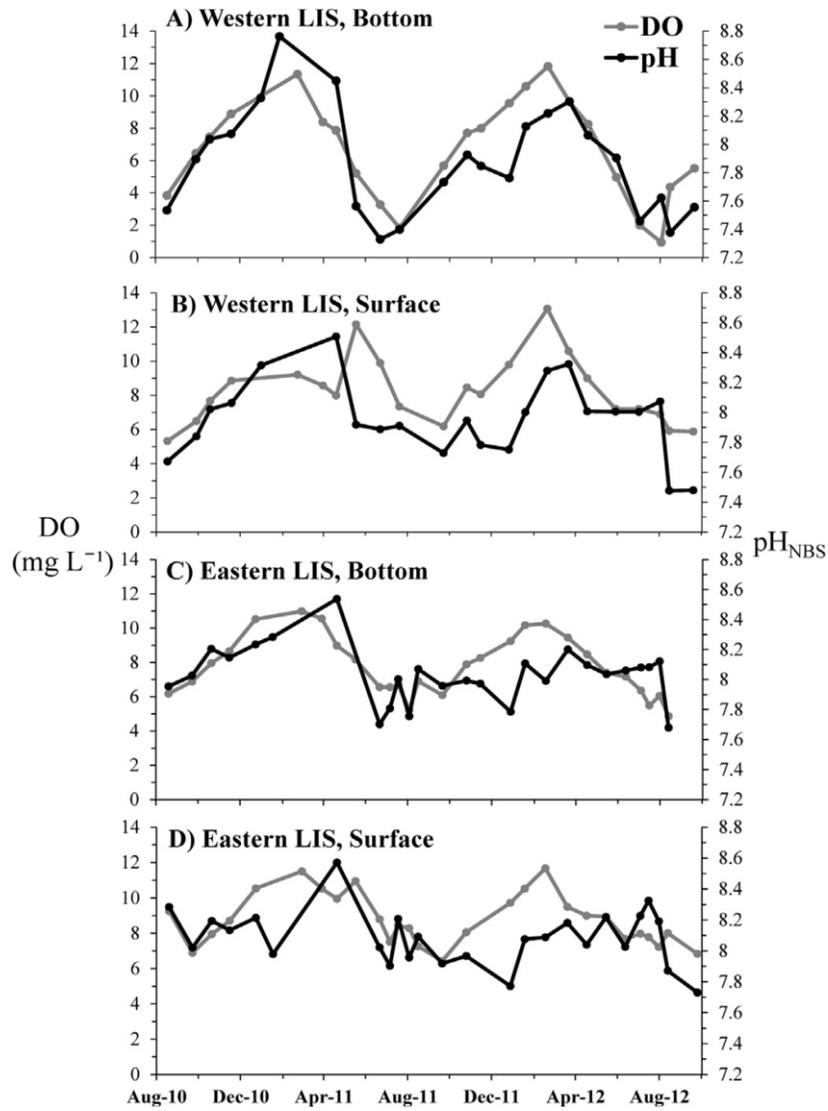


Figure 4 Time series of DO and pH, August, 2010 -October, 2012. A) Western Long Island Sound, bottom & B) surface. C) Eastern Long Island Sound, bottom & D) surface. From Wallace et al. 2014

Figure 5 Average summer pH in Barnegat Bay

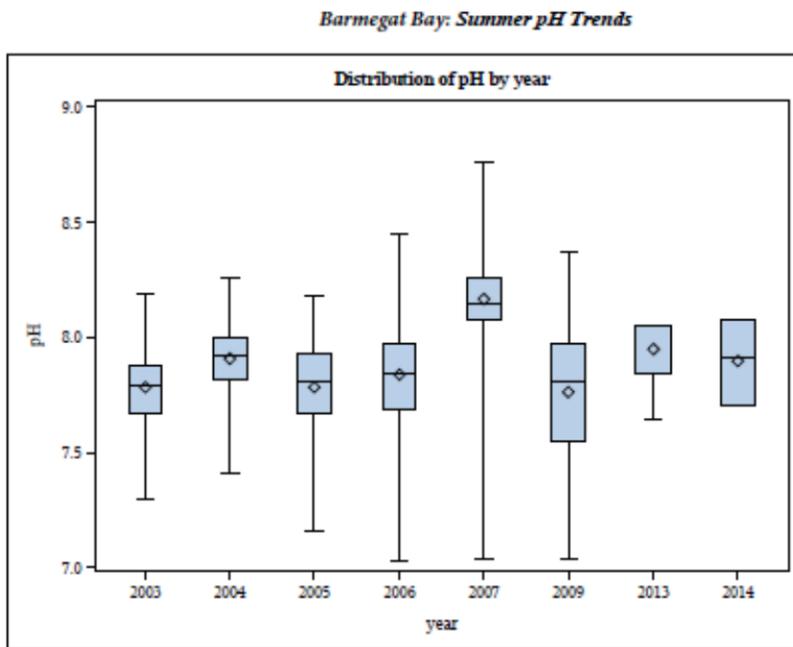
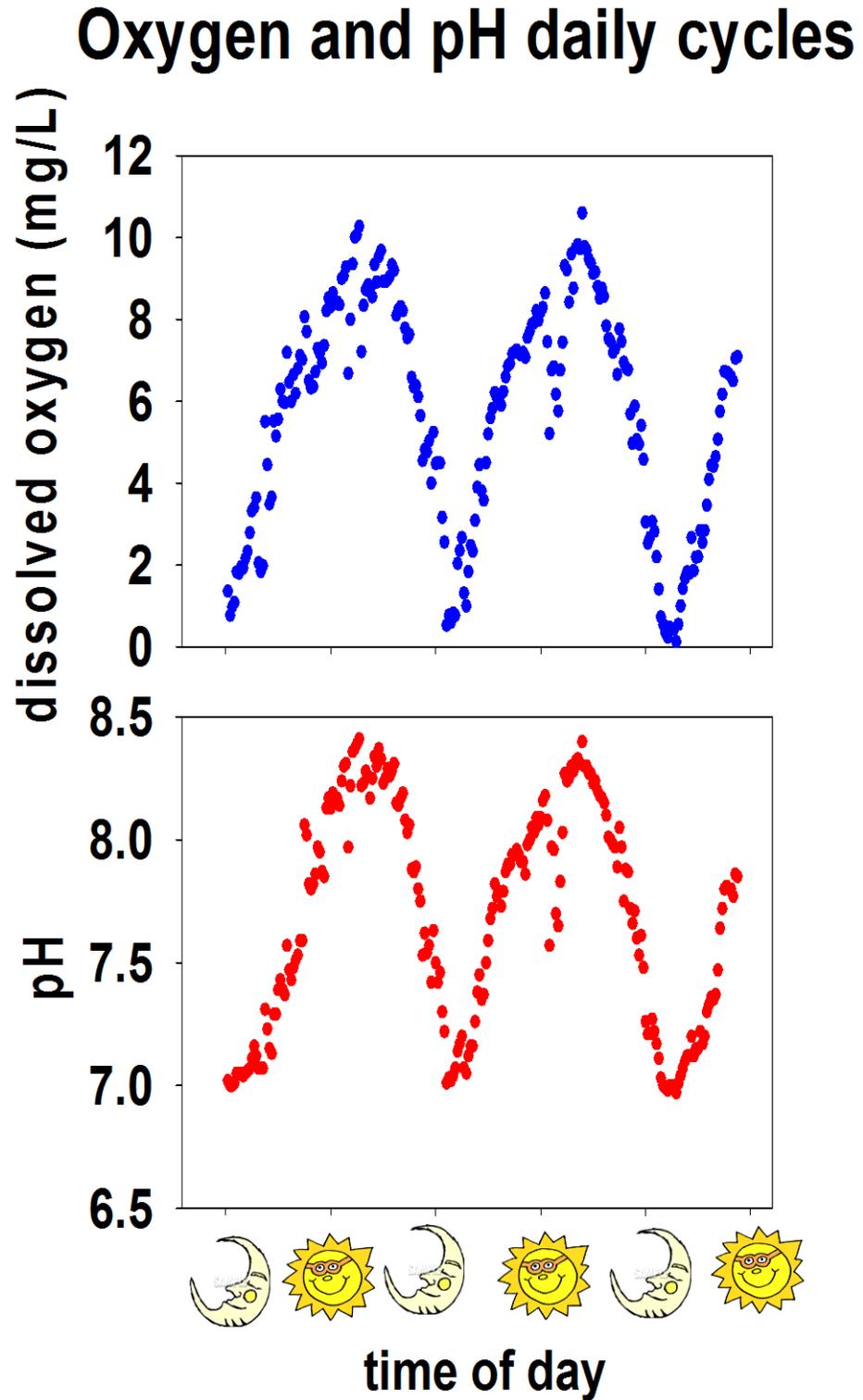


Figure 6 Hourly pH and DO cycles in Chesapeake Bay (From MD-DNR: eyesonthebay.net)

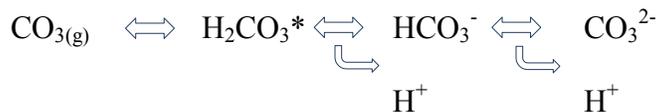


## Appendix – The Chemistry of Ocean Acidification

The pH of water, whether fresh or saline, is controlled primarily by its total inorganic carbon (TIC) content and the alkalinity of the seawater. If the water is in close contact with the atmosphere, and does not contain large amounts of organisms that consume or produce CO<sub>2</sub> in the water, then the water will be in equilibrium with the CO<sub>2</sub> concentration in the air. This is commonly expressed as partial pressure (P<sub>CO2</sub>) or as parts per million by volume (ppmv). In this case, the pH is controlled by the amount of CO<sub>2</sub> in the air and the alkalinity of the water. As second order effects, factors such as ionic strength (e.g. due to salinity), temperature and total pressure can have an influence by affecting the activity constants and equilibrium constants.

### The Carbonate System

The system is determined by four reactions and one additional constraint. The constraint is that of charge balance, the requirement that the total of the positive ions in solution equal the total negative ions. The four reactions include the dissociation of water, plus the following three reactions involving CO<sub>2</sub> and the carbonate species:



The first reaction is for the equilibrium of the CO<sub>2</sub> in the air (CO<sub>2(g)</sub>) with the combined aqueous CO<sub>2</sub> and carbonic acid (H<sub>2</sub>CO<sub>3</sub>). The combination is denoted H<sub>2</sub>CO<sub>3</sub>\*. The ratio of CO<sub>2(g)</sub> to H<sub>2</sub>CO<sub>3</sub>\* is constant. So as atmospheric CO<sub>2</sub> increases, H<sub>2</sub>CO<sub>3</sub>\* increases proportionately. The equilibrium expression is called Henry's law.

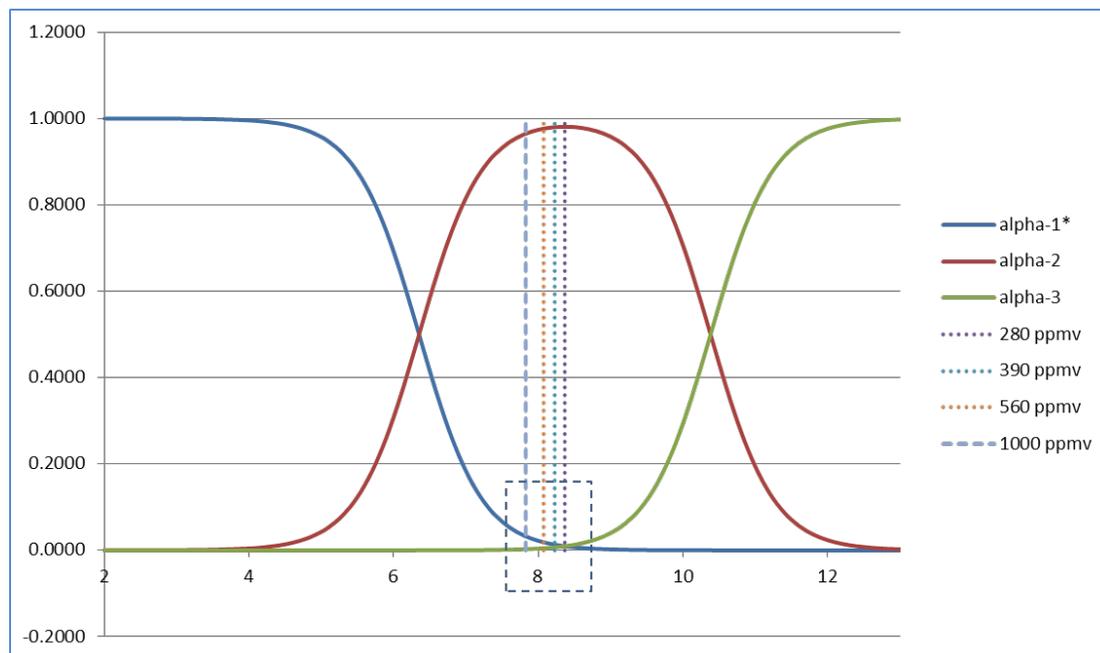
The second reaction is for the first acid dissociation of carbonic acid, producing bicarbonate ions (HCO<sub>3</sub><sup>-</sup>). The equilibrium for this is such that the aqueous forms of CO<sub>2</sub> are approximately evenly divided between carbonic acid and bicarbonate at a pH of 6.35. Once the pH is two or more units above this value, most of the carbonic acid is converted to bicarbonate.

As pH is increased further, the bicarbonate participates in the second acid dissociation, producing carbonate ions ( $\text{CO}_3^{2-}$ ). At pH 10.38, the carbonic acid is mostly gone, and the dissolved aqueous  $\text{CO}_2$  is about evenly distributed between bicarbonate and carbonate.

The charge balance equation can be determined from the alkalinity. The equilibrium expressions for the four reactions, plus the charge balance, constitute five simultaneous equations that can be solved for the concentrations of the five unknown species ( $[\text{H}_2\text{CO}_3^*]$ ,  $[\text{HCO}_3^-]$ ,  $[\text{CO}_3^{2-}]$ ,  $[\text{H}^+]$ , and  $[\text{OH}^-]$ ), assuming  $\text{CO}_{3(\text{g})}$  and alkalinity are known.

As a result, the dissolved carbon dioxide is distributed between three forms – carbonic acid, bicarbonate and carbonate ions. The fraction of the TIC in each form is designated  $\alpha_1$ ,  $\alpha_2$ ,  $\alpha_3$ , respectively. Figure 1 shows how these three fractions distribute themselves as a function of pH.

Figure 1. Fractions of carbonate species and equilibrium pH values in seawater at various levels of atmospheric CO<sub>2</sub>.



The carbonate form of dissolved CO<sub>2</sub> is required by living organisms to form calcium carbonate (CaCO<sub>3</sub>). The lower the concentration of carbonate ions in the water, the more energy required to form calcium carbonate. In some cases, if the carbonate ion concentration (relative to the dissolved calcium ion concentration) is too low, organisms may not be able to form calcium carbonate at all.

The pre-industrial value for atmospheric CO<sub>2</sub> is taken to be 280 ppmv. By 2010, the average annual value had increased to 390 ppmv. Levels are expected to reach 560 ppmv (double the pre-industrial level) in the next 50 years or so (IPCC, 2014).

### **The pH of pure water in equilibrium with the atmosphere**

Pure water (i.e. distilled water, or rain water) has zero alkalinity. The pH of such water in equilibrium with air at 280 ppmv is found by the simultaneous solution of the five equations as

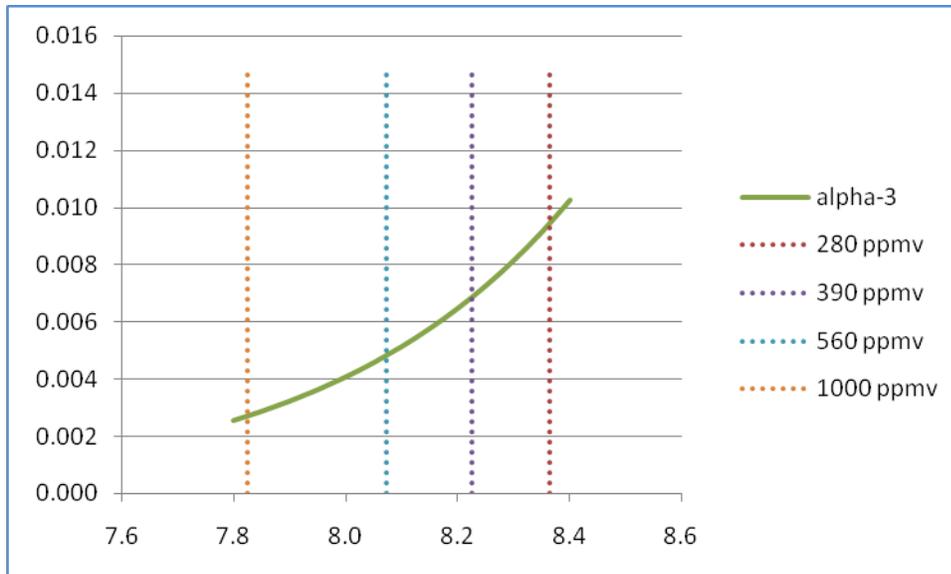
described above to be 5.50. The computed carbonate concentration is  $4.164 \times 10^{-8}$  mM. If the atmospheric  $\text{CO}_2$  doubles to 560 ppmv, the pH drops 0.15 units to 5.35, and the carbonate concentration increases slightly to  $4.166 \times 10^{-8}$  mM. Because pH is a logarithmic scale, the 0.15 decrease in pH is a 41% increase in  $[\text{H}^+]$ . Increasing  $\text{CO}_{3(\text{g})}$  causes a 49% increase in the total of the three dissolved carbonate species (TIC).

### **The pH of water containing alkalinity**

The alkalinity of seawater is about 2.30 mM (115 mg/L as  $\text{CaCO}_3$ ). The computed pH (using the same equilibrium coefficients, and neglecting the effect of ionic strength) is 8.365 at 280 ppmv and 8.072 at 560 ppmv, a decrease in pH by 0.293 units. This corresponds to a 96% increase in  $[\text{H}^+]$  concentration. Thus doubling the atmospheric  $\text{CO}_2$  nearly doubles the  $[\text{H}^+]$ . The pH values at various levels of  $P_{\text{CO}_2}$  are shown by the vertical dotted lines in Figure 1.

The TIC increase caused by doubling the  $\text{CO}_2$  is a scant 0.69%. Although TIC increases, the carbonate concentration actually decreases by 30%. The reason is that the shift in pH shifts the equilibrium between carbonate and bicarbonate, resulting in more carbonate being converted to bicarbonate than would be formed by the increase in TIC. In other words, the  $\alpha_3$  decreases much more than TIC increases. This is shown in Figure 2 by zooming in on the section of Figure 1 denoted by the dotted-line square. The Figure shows that although carbonate is less than 1% of the TIC in this range, its proportion decreases significantly with a fairly small shift in pH.

Figure 2. Effect of  $P_{\text{CO}_2}$  on pH and  $\alpha_3$ .



### Effect of eutrophication in surface zone

Eutrophication is a condition of nutrient enrichment that can result in excessive algae growth. As the algae photosynthesize, they remove dissolved CO<sub>2</sub> from the water. Alkalinity is defined stoichiometrically as:

$$Alk(M) = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] - [H^+]$$

If the TIC were to be completely removed, then  $Alk = [OH^-] - [H^+]$ . In alkaline water, the concentration of  $[H^+]$  is much less than that  $[OH^-]$  of and can be neglected. Thus  $Alk = [OH^-]$ .

Combining this with the definition of pH and the equilibrium expression for the dissociation of water, we have:

$$pH = -\log\left(\frac{K_w}{Alk}\right)$$

For an alkalinity of 125 mg/L as CaCO<sub>3</sub> (0.050 M) =  $[OH^-]$ , the resulting pH would be 12.7. In actuality, it rarely increases so much, possibly because not all of the TIC is removed and/or additional CO<sub>2</sub> may be absorbed from the atmosphere. However, this shows the potential for eutrophication to offset ocean acidification, at least in the photic zone in areas such as coastal zones that receive significant nutrient input from land.

### **Effect of biodegradation below the photic zone**

The photosynthetic activity such as may be caused by eutrophication converts the TIC to organic carbon. The algae may ultimately settle below the photic zone where respiration converts the organic carbon back into TIC. The organic carbon can be expressed as its biochemical oxygen demand (BOD), the amount of oxygen consumed in its oxidation. Each milligram of oxygen consumed adds 1.375 milligrams of CO<sub>2</sub> to the water. This will depress the pH by the mechanism described above.

For example, if the water contains 4 mg BOD/L, degradation can add 5.5 mg CO<sub>2</sub>/L (0.125 mM) to the TIC. For water that was initially equilibrated to air at 280 ppmvCO<sub>2(g)</sub> (pH 8.36), the pH with the added TIC would be decreased to 7.74, and decrease of 0.63 units. The carbonate concentration in this circumstance is decreased by 76%. At 560 ppmvCO<sub>2(g)</sub>, the pH drops 0.46 units from 8.07 to 7.61, and carbonate decreases 66%.

Some coastal zones experience upwelling of deep ocean waters either regularly due to prevailing winds, or episodically due to weather. Thus this can cause significant pH depression in these areas.

Of interest is the effect of increased CO<sub>2(g)</sub> on pH and carbonate superimposed on the effect of organic decay. In this example, the pH is decreased by 0.13 units. This results in a 28% additional decrease in carbonate.

### **Discussion and Conclusions**

The biological effects of H<sup>+</sup> and CO<sub>3</sub><sup>2-</sup> should be distinguished from each other. For example, pH changes can affect organisms by changing the speciation of toxic substances such as ammonia and hydrogen sulfide, or by direct effect of pH on membranes.

On the other hand, organisms that form calcium minerals (shells, otoliths, etc.) may be adversely affected by the decrease in carbonate concentrations in their environment.

Eutrophication, and photosynthesis in general, can offset ocean acidification near the surface and in coastal zones with significant nutrient input.

However, the eutrophication can also increase the effect of ocean acidification below the photic zone or in areas of coastal upwelling.

**References:**

IPPC (2014) “Carbon Dioxide: Projected emissions and concentrations”, [http://www.ipcc-data.org/observ/ddc\\_co2.html](http://www.ipcc-data.org/observ/ddc_co2.html) (Content last modified April 4, 2014, accessed October 29, 2014)

Appendix 2 Kelly and Caldwell Recommendations:

- 1. Create more stringent technology-based clean water standards for point sources. States can redefine existing technology-based standards for point sources that most strongly contribute to OA (e.g., sewage outfalls).*
- 2. Change Water Quality Criteria for marine pH – criteria and Total Maximum Daily Loads for both atmospheric and non-atmospheric drivers of acidification. More stringent criteria would protect coastal ecosystems and be implemented under NPDES (National Pollution Discharge Elimination System) and TMDL (Total Maximum Daily Load) programs where technology-based standards are insufficient to protect receiving waters.*
- 3. Create new Water Quality criteria for carbonate chemistry and new designated uses for coastal waters. New criteria for pH-related aspects of carbonate chemistry (Total Alkalinity, Dissolved Inorganic Carbon) would help monitor acidifying waters more accurately and are easier to measure accurately and consistently. New designated uses could include “to maintain buffering capacity against chemical change” or “to preserve the structure and function of the nearshore ecosystem.” Such uses would set a higher bar for water quality in coastal areas.*
- 4. Use Clean Air Act (CAA) to decrease SO<sub>x</sub> and NO<sub>x</sub> deposition near coasts. CAA already regulates these gases, and states could lower their overall cap on acid gas emissions.*
- 5. Enhance wastewater treatment at Publicly Owned Treatment Works (POTWs). More stringent controls through NPDES permits would reduce nutrient loading in the coastal ocean and thus reduce acidification as well as harmful algal blooms and hypoxia. A state can require POTWs to minimize discharges by altering the prevailing water quality standards. They can require tertiary treatment including nitrification/denitrification (the process by which bacteria remove*

*biologically available nitrogen). Nitrification-Denitrification (N-DN) can be added to improve the quality of treated effluent.*

*6. Leverage Clean Water Act money to implement Best Management Practices (BMPs) and permanent nutrient-management improvements that include processes to reduce non-point source runoff. State agencies can use funds under CZARA (Coastal Zone Act Reauthorization Amendments) of 1990) as incentives for best management practices and permanent nutrient-management improvements.*

*7. Participate in the National Estuary Program (NEP) and National Estuarine Research Reserve (NERR) systems.*

*8. Incorporate OA impacts into environmental review under state National Environmental Policy Act (NEPA) equivalents. At least 19 states have followed the federal National Environmental Policy Act with some form of state level environmental policy act or environmental quality act, including New York, Maryland, California and others. The basis of the concept is that before the state take any action or issues any permit the proponent of the project has to study the environmental effects of the project.*

*9. Act to enforce public nuisance and criminal statutes. The state has the power to sue polluters as public nuisances. There have been a number of successful actions taken by harmed individuals for marine pollution, for example commercial fishermen have sued for damages from land-based and ocean-based pollution.*

*10. Practice smart growth and smart land use changes. The state and local governments are beginning to modify land use planning, particularly after the devastating effects of Hurricane Sandy, because these approaches will also reduce storm surge and flooding in the future.*

