MOOK SEA FARM
OUR WORLD IS YOUR OYSTER
DAMARISCOTTA, ME
43° 58' 35.6412", -69° 33' 30.7512"

Testimony of Bill Mook, President of Mook Sea Farm
Before the Senate Subcommittee on Clean Air and Nuclear Safety
Examining the Threats Posed by Climate Change
July 29, 2014

Senator Whitehouse, Senator Sessions, and members of the committee, I am President and owner of Mook Sea Farm, located on the Damariscotta River in mid-coast Maine. In our hatchery, we produce up to 100 million juvenile oysters each year, most of which are sold as "seed" to other oyster farmers from Virginia to Maine. The seed oysters we do not sell, we grow on our 40 acres of leases and sell to the domestic half-shell market as "Wiley Point" and "Pemaquid Point" oysters.

The testimony below provides background and detail about ocean acidification and the threat it poses to marine resources, ecosystems, and those individuals and communities who depend on them. I've been in business for 30 years and, depending on the time of year, my company employs 10 to 14 people including myself. So, because "our world is your oyster," at Mook Sea Farm, ocean acidification has my company's riveted attention.

Shellfish hatcheries are "canaries in the coal mine" for water quality problems because the early life stages we rear are so sensitive to changes in water chemistry. When larval production in our hatchery began to falter about 5 years ago, we started a journey to figure out and solve the problem, which (for now) we have done. We suspected ocean acidification was the root of our problem, and this assumption drove our efforts to change hatchery practices. After seeing the results of our remedies this year, we believe that our hunch was correct.

Our experience, taken together with recent research, leads me to conclude that ocean acidification poses a serious threat to Maine's marine economy. Because the study of ocean acidification is so new, we do not have the information needed to fully "examine the threats" it poses. There are two critical research priorities:

- Water chemistry monitoring; and,
- Understanding species and ecosystem responses to present and future levels of carbon dioxide.

If, and only if, these are addressed, can we plan for the challenges and opportunities posed by ocean acidification.

Ocean Acidification Basics.

The carbon dioxide (CO_2) released from burning fossil fuels doesn't just stay in the atmosphere. About 25% of it dissolves in the world's oceans where it forms carbonic acid. This has resulted in a 30% increase in the average acidity of ocean surface waters since the start of the industrial revolution. The rate of change in ocean pH is accelerating as carbon dioxide emissions increase. By the year 2100, ocean acidity is projected to have doubled. This process is called ocean acidification (OA), and it is occurring at a rate that may be unprecedented in the Earth's history.

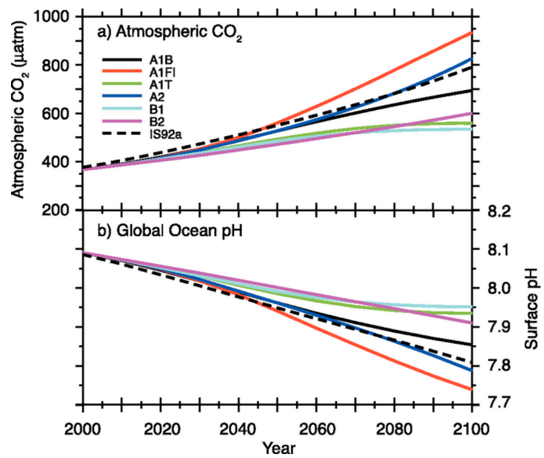

Figure 1. Changes in global average surface pH and under various carbon dioxide emission scenarios. Time series of (a) atmospheric $CO_2$and (b) projected global average surface pH for the six illustrative carbon dioxide emission scenarios Modified from Orr et al. (2005) and obtained from the IPCC Climate Change 2007: Working Group I .

Ocean acidification past, present and future. The top panel in Figure 1 shows how scenarios of projected carbon dioxide emissions will change the concentration of CO_2 in the atmosphere. The lower panel shows the resulting increase in ocean acidity for the various emissions scenarios, which is measured as a decrease in pH.

Acidity is defined as the concentration of hydrogen ions (H^+) in a solution, and is measured using the pH scale, which spans from 0 to 14 with 0 being most acidic, 7 neutral and 14 most basic. The 30% increase in ocean acidity since the industrial revolution referred to above represents a change of 0.1 pH units or a drop from 8.2 to 8.1. The small change in pH is deceiving because the scale is logarithmic (counting on this scale is done as follows: 1, 10, 100, 1000).

Ocean acidification is a new topic for scientific inquiry. Since the first publications in the early part of the last decade, concern about and funding for OA have grown. After only 14 years of study, we have more questions than answers about local acidification processes, how marine ecosystems will be impacted, and what those impacts will mean for individuals and communities whose livelihoods depend on marine resources.

Complicating factors. The problem is more complicated than the simple dissolution of CO_2 from the atmosphere into the oceans. There are several climatic and oceanographic factors that can exacerbate acidification of coastal oceans:

- Freshwater from ice melt, precipitation, and runoff has low pH and poor buffering capacity (e.g., makes ocean water more likely to change pH in response to CO_2 addition);
- Lower water temperatures mean that more CO_2 can dissolve in the water;
- Wind patterns and submarine topography can create natural upwelling of colder, more acidic, deep water into shallow areas.

In the Gulf of Maine, where my business is located, the exacerbating factor is fresh water. Figure 2 shows the percentage change in very heavy precipitation since the 1950's.

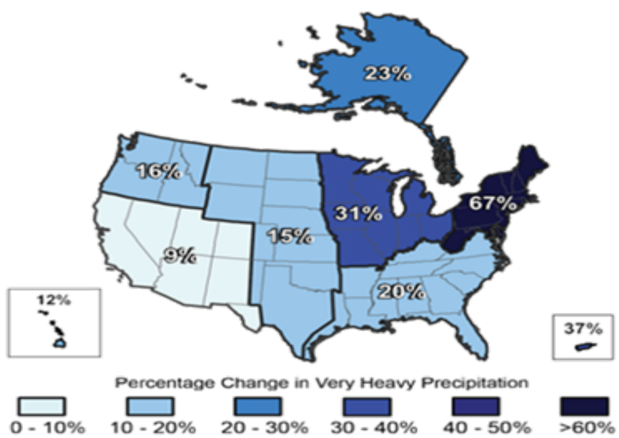

Figure 2. Fresh water from increasing runoff. (Updated from Groisman et al. 2004)

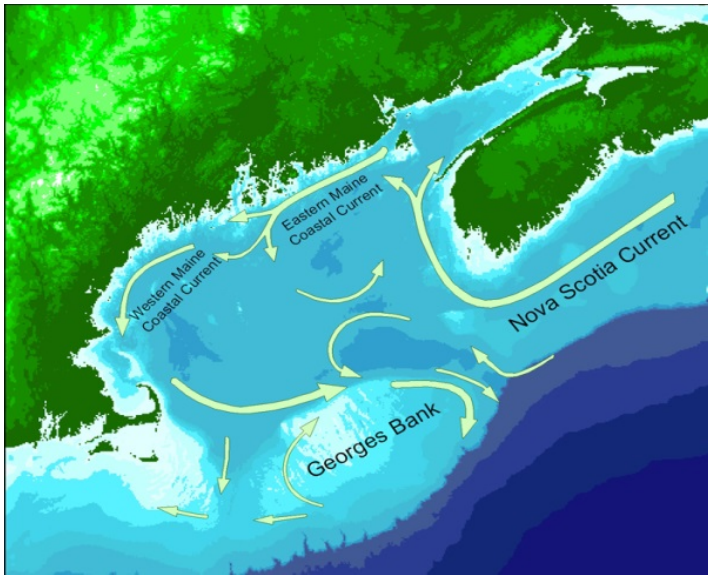

Figure 3. More fresh water from the Scotian Shelf.

To make matters worse, not only is fresh water runoff from the land surrounding the Gulf of Maine increasing, but the Nova Scotia Current is bringing colder, less salty water into the Gulf around the southern tip of Nova Scotia.

How does OA affect marine resources and ecosystems?

With the realization that ocean acidity is increasing, concern in the scientific community initially was focused on shellfish. This is because shellfish, like clams, oysters, scallops, and lobsters, use calcium carbonate ($CaCO_3$) to make their shells. As shown in Figure 4, hydrogen ions increase when CO_2 dissolves in water, and this causes a reduction in the availability of carbonate ions (CO_3), potentially making shell formation problematic.

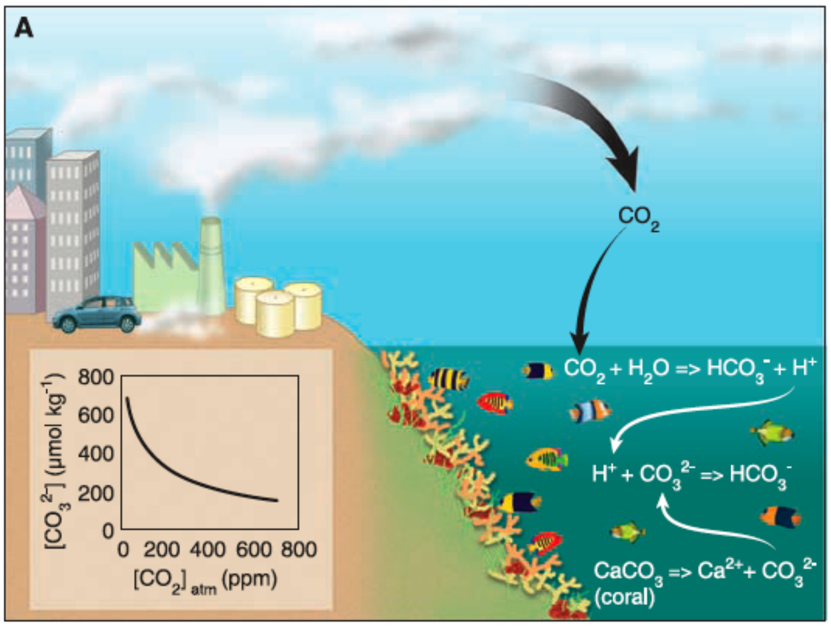

Figure 4. CO_3 availability decreases with increasing acidity.

If populations of harvested bivalves (e.g., scallops, clams, mussels, and oysters) are diminished or eliminated by acidification of their habitats, the losses will not be only financial. In many coastal areas, bivalves perform a vital ecosystem service. They are filter feeders and they keep phytoplankton levels in the water low. This has a cascading effect. Greater water clarity means more light penetrates to the bottom, allowing plants like sea grasses or kelp to flourish. Flora like sea grasses and kelp remove excess nutrients from the water, serve as refuges from predation for smaller prey animals including young fish, and increase ecosystem health and diversity.

From numerous studies conducted over the past 5 years, we now know that acidification of the marine environment will hurt many bivalves. As shown in Figure 5, survival of the freeswimming, larval phases of bay scallops and hard clams declines as CO_2 in the water increases from pre-industrial atmospheric levels to atmospheric levels seen today (390 ppm) and those expected at mid-century and by 2100.

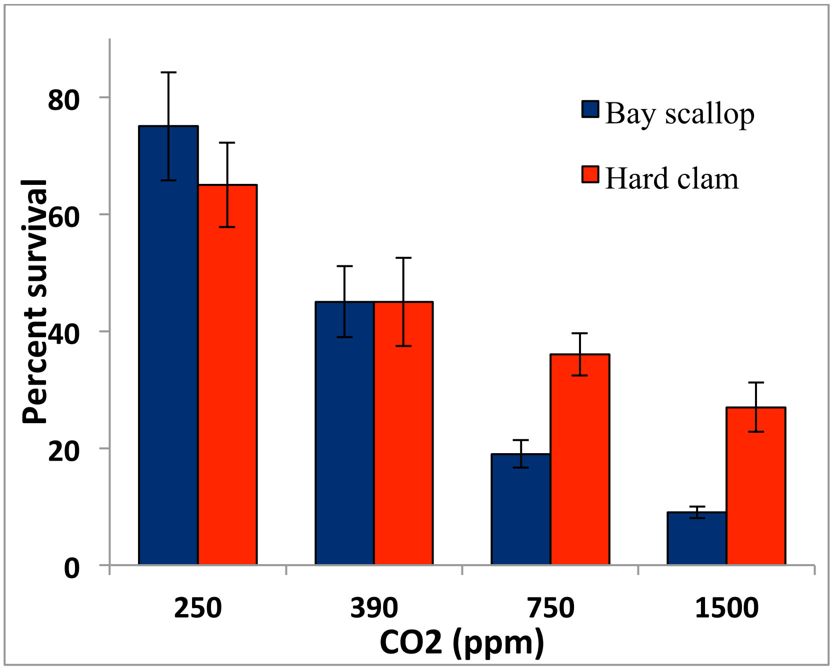

Figure 5. Effects of past, present, and future ocean carbon dioxide concentrations on the growth and survival of larval shellfish (Stephanie Talmage and Christopher J. Gobler. Proceedings of the National Academy of Sciences, volume 107, 2010).

Although larval stages are most vulnerable to high CO_2 concentrations, slower growth rates with increasing acidity have also been documented for juveniles. For both larvae and juveniles, the negative effects of acidification when combined with other climate change parameters, like higher temperatures and low oxygen, can be additive and sometimes synergistic. Recently, researchers have found that some fish species are sensitive to the changes in CO_2. The survival, health, and behavior of species like the Atlantic cod, summer flounder, Atlantic silverside, and even clownfish are compromised in high CO_2 conditions.

While many of these studies were ongoing, at Mook Sea Farm, we were trying to figure out why our oyster larvae were having problems. Fertilized eggs would periodically show poor survival and many of the survivors were severely deformed. More often, larval populations would stall. They would stop feeding and growing and the larval period, which normally lasts 14 to 16 days, would drag on for an additional week or more. These larvae would typically take longer to metamorphose from larvae to juveniles, and exhibit lower survival rates than normal populations. Large storm events seemed to be the common denominator.

The 2009 hatchery season was especially wet and stormy, and we had lots of problems raising larvae. Carbonate chemistry was not on our “radar screen.” Late in that year, the first blip showed up. At a meeting with hatchery operators from the West Coast, we learned of their problems (which were similar but more severe) and how they had linked them to the acidified waters pumped into their hatcheries.

Over the next several years we developed a suite of management/mitigation strategies all of which assumed that low pH water was the culprit affecting our larval populations. This season, for the first time, these efforts were all consistently applied to every group of larvae we produced. Since our first spawn in late December we have reared 16 cohorts of oyster larvae. For the first time in my 30+ year career, we were 16 for 16. Every group passed through the larval phase in 14-16 days.

Figure 6. Healthy, swimming American oyster larvae. They are less than 0.2 mm in length at this stage of life.

Through observation, trial, and error, we reached the same conclusion made by researchers using controlled, replicated, experimentation. Acidification is not a future problem. It is a problem ***now*,** and it will only get worse. Further support for this conclusion and cause for concern come from monitoring data we have collected from the incoming water at our hatchery.

For the past several years, we have measured the salinity, temperature, and pH of our intake water on a fairly regular basis. In April of this year, with the help of researchers from the University of New Hampshire, we installed more sophisticated equipment that continuously monitors and records temperature, salinity, dissolved oxygen, and pCO_2.

Other parameters related to ocean chemistry are calculated from the measured values, including the saturation level of calcium carbonate which is represented by the Greek letter omega (Ω). Ω is important because it tells us how easy or hard it is for shellfish to make their calcium carbonate shells. An Ω value of <1.0 means that the water is under saturated with calcium carbonate; 1.0 means it is saturated; and >1.0 means that it is super saturated. The forms of calcium carbonate commonly used by shellfish to build their shells are aragonite and calcite. They differ in how easily they can dissolve, with aragonite being more prone to dissolution than calcite. One reason oyster larvae are more vulnerable to ocean acidification than juveniles is that their shells are made of aragonite, which is more soluble than the calcite found in juvenile and adult shells.

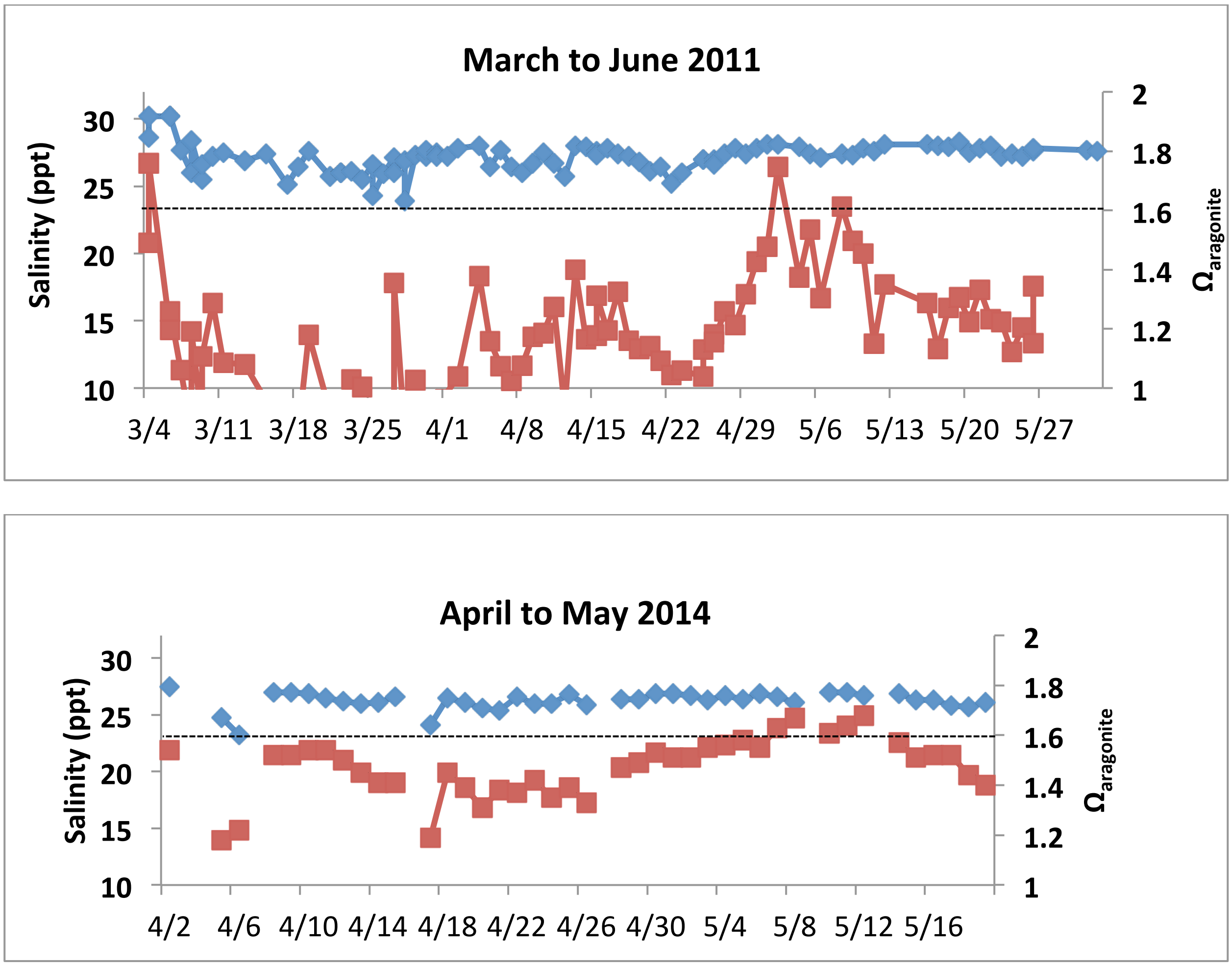

Figure 7. Salinity (blue) and $\Omega_{aragonite}$ (red) of the seawater pumped into our hatchery. $\Omega_{aragonite}$ at 1.6 is indicated by a black dashed line.

Figure 6 shows salinity and $\Omega_{aragonite}$ for spring 2011 and 2014. The $\Omega_{aragonite}$ data shown for 2011 were calculated from temperature and salinity measurements made with hand-held, relatively inexpensive equipment. The data from 2014 were collected with the pCO_2 monitoring equipment. West Coast hatchery operators consider $\Omega_{aragonite}$ values less than 1.6 to be sub-optimal for growing oyster larvae. The studies discussed above found reductions in survival and growth at $\Omega_{aragonite}$ levels even higher than 1.6. What is concerning about the data we have collected is that we rarely see $\Omega_{aragonite}$ exceed 1.6.

While we can manipulate conditions in our hatchery, what is the fate of wild populations subjected to the steady movement of CO_2 into seawater from the atmosphere, exacerbated by extreme variability caused by the increasing number of intense storms dumping more and more freshwater into the Gulf of Maine?

My prediction is: the success of bivalve larvae in coastal waters will become more and more sporadic as acidification progresses, reaching a point where some natural bivalve populations won't occur. There are indications that this process may be under way. At a mussel farm not far from our hatchery, the once predictable appearance of natural mussel seed is now unreliable. Soft-shell clam larvae no longer settle and grow on acidified mudflats in Casco Bay, Maine. Oyster farmers from New Brunswick, who have always relied on collecting larvae from natural populations, are building a hatchery to insure a steady supply of seed.

Figure 8. Mussel seed.

The stakes.

The shellfish industry extends far beyond the farmers and harvesters. As shellfish move through the supply chain, its value increases substantially. Every day enormous quantities of calcium carbonate are trucked around the country by wholesalers who buy from producers and transport shellfish to distributors, who sell to supermarkets, fish markets, and restaurants.

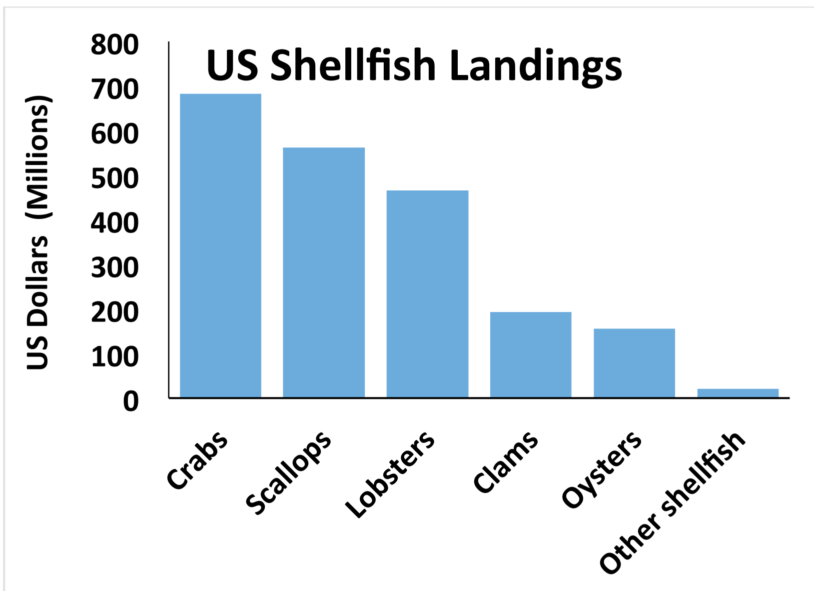

Figure 9. U.S. Shellfish Landings generated over $2 Billion in 2012.

Ironically, even though lobsters and crabs represent over half of the annual landed value of shellfish, we know little about their responses to changes in ocean acidity. This is of special concern to us in Maine, where lobsters are king of marine resources, sustain thousands of people, and are the life blood of communities from Kittery to Eastport.

How do we lessen the negative impacts and take advantage of the economic opportunities afforded by acidification?

We know that negative effects of changing seawater chemistry are a certainty. As with any major change, there will also be opportunities for businesses with knowledge and foresight.

Figure 10. A kelp farm in China. A carbon sink? (Photo credit: George Steinmetz)

Our immediate problem is that we need more information to adequately plan for both the challenges and the opportunities. We need the ability to accurately forecast (at multiple time scales) local changes in key carbonate parameters important to marine organisms and ecosystems. This will require an in depth understanding of the factors that determine these key parameters and how they vary in time and space. In order to develop forecast models, chemical oceanographers need better monitoring at strategic locations.

We know much about the transfer of CO_2 from the atmosphere to the sea, and how temperatures are changing with the accumulation of greenhouse gases. The chemistry (and its variability) for the freshwater inputs are not well understood. Currently, we do not understand quantitatively how changes in the factors which exacerbate acidification will control biological processes that also have profound effects on carbonate chemistry. Photosynthesis by marine plants takes CO_2 out of the water and releases oxygen, but the rate at which this happens may change with acidification. Animals and plants, through respiration, consume oxygen and release CO_2 into their environment. How all of the members of marine ecosystems will respond to ocean acidification is largely unknown. Scientists expect from their knowledge of plant and animal physiology that, at all levels of the food web, some species will be harmed by acidification, some will benefit, and the structure and function of the communities will change.

Forecasting the pH or Ω of coastal oceans two days, two weeks, or two months into the future is only useful if we understand how species and ecosystems will respond to those conditions. More studies of biological responses to current and future conditions are crucial to providing us with the capacity to plan for the future.

If we make the investment in monitoring and research we can forecast, mitigate, adapt, and re-focus endangered local economies. But this will only buy us time. By taking no action to reduce carbon emissions, we take a huge, uncalculated risk with our future. To those who predict doom and gloom for our economy from curbing greenhouse gases, I would suggest they consider some recent history. Many predicted that the Clean Water Act would cost jobs and stall economic growth. It didn't happen. The same is true for the Montreal Protocol. We switched from underarm spray to deodorant sticks with barely an eye blink. I view the solution to the greenhouse gas as a word problem like the ones we all solved in our school days:

$$\mathbf{L_{Wisdom} + L_{Skill} + BSR + SME + A_{ii} = (G + UB)^{X}}$$

Where **L** = leadership; **BSR** = basic scientific research; **SME** = science and math education; $\mathbf{A_{ii}}$ = American innovation, and ingenuity; **G** = the goal; and, **UB** = unexpected benefits.

The exponent is **X** because when America unites with purpose, the results tend to exceed what can easily be imagined.