

**Statement of**  
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HEARING ON

The Environmental and Economic Impacts of Ocean Acidification

BEFORE THE

Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard of the  
Committee on Commerce, Science, and Transportation

United States Senate  
April 22, 2010

Mr. Chairman and Members of the Committee, thank you for inviting me to appear before you today. I am John Everett. I am not here to represent any particular organization, company, nor special-interest group. I have never received any funding to support my climate change work other than my NOAA salary, from which I retired after a 31 – year career in various positions. I was a Member of the Board of Directors of the NOAA Climate Change Program from its inception until I left NOAA. I led several impact analyses for the Intergovernmental Panel on Climate Change from 1988 to 2000, while an employee of NOAA. The reports were reviewed by hundreds of government and academic scientists as part of the IPCC process. My work included five impact analyses: Fisheries (Convening Lead Author), Polar Regions (Co-Chair), Oceans (Lead Author), and Oceans and Coastal Zones (Co-Chair/2 reports). Since leaving NOAA I have kept abreast of the literature, have continued as an IPCC Expert Reviewer, have talked to many individuals and groups and have maintained these subjects in the UN Atlas of the Oceans, where I am the Chief Editor and Project Manager. I own a fisheries and oceans consulting business called Ocean Associates, Inc. and a website ClimateChangeFacts.Info<sup>1</sup> that I try to keep unbiased in its treatment of conflicting science. This site is the number 1 Google-ranked site of many million for certain search terms. My approach to impact analysis is a product of my education and work experiences at NOAA and the work I led for IPCC. This statement provides my analysis of the effects of ocean acidification on our living resources and our economy.

All opinions are mine alone.

**Background.**

I was assigned the climate change duties when I was the NOAA National Marine Fisheries Service Division Chief for Fisheries Development in the 1970s. The agency was very concerned about the impact of climate change on the United States fisheries and fishing industry. **Global cooling** would be devastating to our fisheries and aquaculture. About 1987, the momentum shifted to fears of **global warming** and with my background, and as Director of Policy and Planning for NOAA Fisheries, I was tasked to lead our efforts dealing with it. In 1996 I received the NOAA Administrator’s Award for “accomplishments in assessing the impacts of climate change on global oceans and fisheries.” In 2008, I received recognition from the IPCC for having “contributed to the work of the IPCC over the years since inception of the organization”, leading to its Nobel Peace Prize.

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<sup>1</sup> <http://www.ClimateChangeFacts.Info>

## **I. THE CONCERNS**

There are several concerns about CO<sub>2</sub> entering the oceans and causing its pH to become lower. Their discussion in the press and among policy officials is at the foundation of this hearing. These concerns are:

1. Animals with calcium carbonate shells will lose the ability to make shells
2. Existing shells will become weaker
3. Loss of shell-forming animals will reduce food for those higher in the food chain
4. Many species will be gone in 30 years
5. Oysters and clams are dying
6. Jellyfish are increasing
7. Seagrasses will be injured.

The concerns are based on the work of respected scientists who have shared the above beliefs or authored papers that argue the above points. They believe increased atmospheric CO<sub>2</sub> will increase the acidification of the oceans. The basis is largely a set of emission scenarios developed by IPCC in the early 1990s in an attempt to reign in the mass confusion about the future trajectory of CO<sub>2</sub> emissions. With this standard set of scenarios, climate modelers could then have a standard set of inputs in terms of what was broadly considered a primary determinant of climate – the proportion of CO<sub>2</sub> in the atmosphere. This proportion is based on new contributions after deducting removals by the Earth system and assumes a decreasing removal ability as CO<sub>2</sub> increases. For the first time, modelers around the world could compare results while impact assessment scientists and policy makers could look at points on which most models agreed. Standardization of scenarios allowed modelers to identify errors or alternative ways to predict or handle parameters, such as cloud cover. One of the scenarios became heavily used and is identified as IS92 – Business as Usual. Nearly 20 years ago, it was a reasonable approach and pretty much in the middle range of alternative scenarios. It underpins much of the research findings I will present today.

There are other respected scientists who believe that the Business as Usual scenario has been overtaken by events. The cost of fossil fuels is rising, reflecting increasing scarcity and contributing to a slower CO<sub>2</sub> growth in the atmosphere and a lack of acceleration. New science shows the Earth's ability to absorb the same proportion of new CO<sub>2</sub> each year has not been diminished, removing a key underlying assumption. Importantly, oceans are alkaline - not acidic (much more so than rain-water), so use of the term "acidification" promotes fear. If all the CO<sub>2</sub> in the air were put into the ocean, the oceans would still be alkaline. With all this talk of acidification, we need to reassure bathers that their feet will not dissolve when they step into the ocean. Ocean water at the surface generally has a pH over 8 and neutral is 7.0 (pure water) while a puddle of rain water is far more acidic after having picked up CO<sub>2</sub> in its fall. Technically, we should say the oceans could become less alkaline, a term not so endearing to those trying to get attention.

## **II. THE PHYSICS**

At the bottom of our inverted pyramid of climate science are a few good scientists working to improve our knowledge of how the Earth system operates, and then to project future possibilities. The physics are daunting. Similarly, the modelers must get observational input data from the physical world and from prognosticators about how many people will be born in future years and how they will get and use their energy. The number of scientists doing this work is small

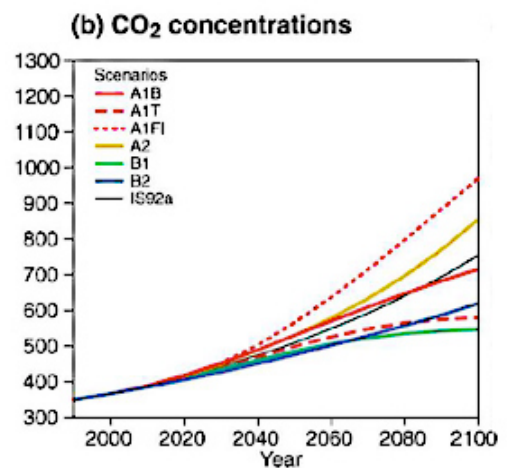
compared to the number who will use their information to analyze impacts and make policy recommendations to governments and industry.

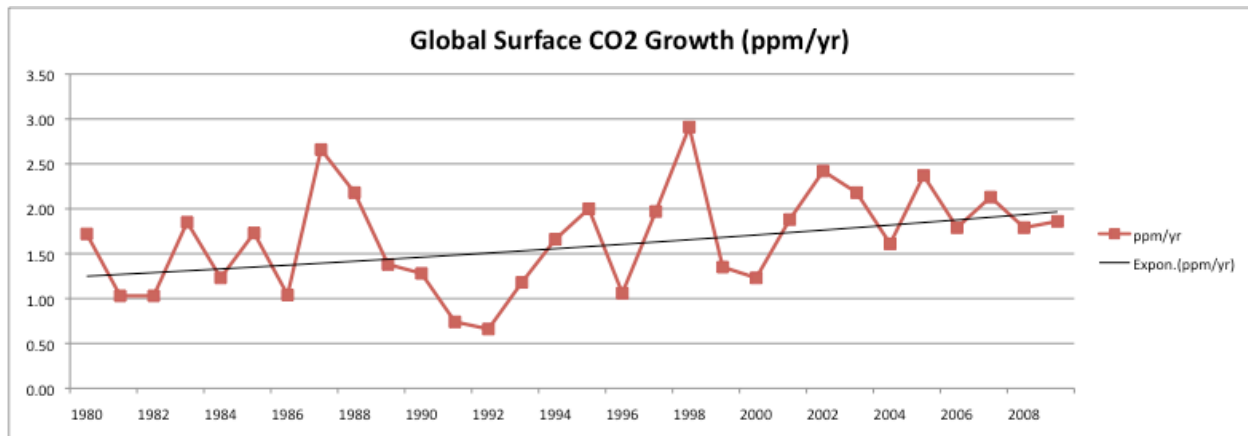
As a research manager much of my life, I have a healthy skepticism of things that underpin important decisions. Whether it is a column of numbers that will tie up a fishing fleet because of an addition error or a wiring harness on a manned lunar rocket that doesn't quite fit, I have learned to pause and check it out. There are some things at the bottom of the CO<sub>2</sub> pyramid that make it seem wobbly and in need of a check.

Physics tells us that increasing atmospheric CO<sub>2</sub> lowers oceanic pH and carbonate ion concentrations, thereby decreasing calcium carbonate. Surface ocean pH (a logarithmic measure of hydrogen ions) today is believed to be 0.1 unit lower than pre-industrial values. The median value of ocean model runs projects that pH will decrease by another 0.3 to 0.4 units by 2100. This translates into a 100 to 150% increase in the concentration of H<sup>+</sup> ions while carbonate ion concentrations will decrease. When water is undersaturated with respect to calcium carbonate, marine organisms can no longer form calcium carbonate shells. The model simulations project that undersaturation will be reached in a few decades<sup>1</sup>. The conventional wisdom also says that as CO<sub>2</sub> concentration becomes higher, saturation will mean that more of it will remain in the atmosphere each year, accelerating its accumulation.

However there are some major problems with the science. The wisdom at the time of the IPCC 2007 report was that half of CO<sub>2</sub> emissions would remain in the atmosphere and that we would have 712 ppm (IS92a) by 2100<sup>2</sup>. This would require the atmosphere to more than double the present rate of growth of CO<sub>2</sub> to 3.05 ppm, yet the growth rate seems to be leveling off. The meaning of this information (and the future of all climate models based on it) became VERY cloudy on 31 December 2009 with the ScienceDaily acknowledgment of a paper published by American Geophysical Union and authored by Wolfgang Knorr that shows "No Rise of Atmospheric Carbon Dioxide Fraction in Past 160 Years", despite the predictions of carbon cycle/climate models<sup>3</sup>. The implications of this have yet to be assimilated by the modeling community. This does not mean that CO<sub>2</sub> proportion is not rising but rather that the proportion not being assimilated has not changed since 1850. Importantly, it means that the rate of CO<sub>2</sub> cycling increases as it becomes more concentrated, and does not decrease as assumed in climate models. The rate of projected growth in CO<sub>2</sub> appears to be greatly exaggerated.

The CO<sub>2</sub> scenarios are literally falling flat and need revision. The observational trend line shows monotonic growth – pretty much a straight line as in the chart below of global marine CO<sub>2</sub> measurements (NOAA data)<sup>4</sup>, while the IPCC scenarios used in most research rely on an accelerating growth. Certainly the predicted rapid acceleration of the IS92a model (see solid black line in middle of figure) is missing from the NOAA data plotted below. In fact, if we wonder if the last 8 or 12 years are representative of the future, we might imagine a downward slope in the growth rate. This could be real as rising prices cut usage and lead to economic distress. It could also mean that the ocean is absorbing more CO<sub>2</sub>, which might not bode well in light of concerns over acidification. However, it may be that the ocean is converting and storing the CO<sub>2</sub> as calcium carbonate in the form of shells of oyster, clams and planktonic organisms. It is a complicated environment and there is much we do not know.





Using the average rate of increase for the past 10 years (1.87/year), and assuming a straight-line growth, my projection for 2100 is 560 ppm. I have great reservations about our ability to find the necessary amount of fuel even this would require, never mind enough to reach 712 ppm (IS92a) or higher.

Thus, if the projections we are concerned with today are based on the IPCC IS92a model, or one of its cohorts, and the concept of CO2 sink saturation, we should give the information on its impacts a second look.

Further, if a model can't replicate the past by relying on principles of physics and mathematics, without "tuning" its parameters to reflect past variations, we must not trust that it properly represents the real world. Some important physics may be missing or misrepresented. This is particularly true of any model that failed to predict the present leveling of temperatures in the face of rising CO2. I know of none that got it right.

Something is very wrong at the bottom of our inverted pyramid!

### III. THE BIOLOGY

#### The Concerns

Much of the concern flows from the latest IPCC report. The text from the Summary for Policy Makers states: "The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units. Increasing atmospheric CO2 concentrations lead to further acidification. Projections based on SRES scenarios give a reduction in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century. While the effects of observed ocean acidification on the marine biosphere are as yet undocumented, the progressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species"<sup>5</sup>

1. **Animals with calcium carbonate shells will lose the ability to make shells.** These animals include corals, coralline algae (e.g., encrusting algae), and foraminifera, pteropods (swimming planktonic snails with aragonite shells), and mollusks (e.g., clams and oysters).
2. **Existing shells will become weaker and even dissolve.** Dissolution of shells after death is the norm. Calcium carbonate flows back into the water wherever it is not saturated. In the deep ocean, this can happen rapidly to exposed shells.

3. **Loss of shell-forming animals will reduce food for those higher in the food chain.** Dissolved calcium and carbonate ions are used by ocean animals to produce their shells and skeleton. A lower pH can slow shell production by disrupting the supply of carbonate ions, thus slowing shell production and increasing the susceptibility to dissolution, early death and predation.
4. **Many species will be gone in 30 years.** This is founded in a belief in the IS92a emission scenarios and some research results.
5. **Oysters and clams are dying.** In the Pacific Northwest there are charges that an acidic ocean is to blame for extensive mortalities of young oysters and clams. Fears include the possibility that acidic upwelling waters will get even more so when exposed to high CO<sub>2</sub> air.
6. **Jellyfish are increasing.** Some have postulated that ocean acidification could open ecological space for noncalcifying species.
7. **Seagrasses will be injured.** Acid waters will disrupt life processes and slow growth.

### Biological considerations

There is limited research. I have reviewed the major papers and the critiques about the papers. Below are a few that I think merit bringing before the committee. It is only a few that show no obvious bias. For example, it is quite common among researchers vying for scarce funding dollars to hype their findings or the importance of the problem. Whether it is the use of hydrochloric (HCl) acid to mimic CO<sub>2</sub> but which introduces other issues such as shell decay, or presenting the findings of grave consequences at high acidity while not mentioning the lack of change at lower levels, or not investigating whether low pH was due to degraded water quality from runoff and sewage, the real cause of reduced growth or mortality. In some cases a lower base year is chosen that exaggerates the percentage change, such as “pH levels will drop 30% from pre-industrial levels – when current levels are far less disputed, but the % change is less.

Each study must be scoured for hints of inappropriate procedures and unfounded statements. None can be accepted at face value. The peer review process has warts. A good example is the dispute over whether acidification is good or bad for shell-forming plankton, a vital part of the ocean’s biology and the ability to sequester vast amounts of CO<sub>2</sub>. The first paper says more CO<sub>2</sub> is good, the second bad, and then the first successfully refutes the criticism and gets the last word, sustaining the positive assessment in great detail. All published in Science.

“Ocean acidification in response to rising atmospheric CO<sub>2</sub> partial pressures is widely expected to reduce calcification by marine organisms. From the mid-Mesozoic, coccolithophores have been major calcium carbonate producers in the world’s oceans, today accounting for about a third of the total marine CaCO<sub>3</sub> production. Here, we present laboratory evidence that calcification and net primary production in the coccolithophore species *Emiliana huxleyi* **are significantly increased by high CO<sub>2</sub>** partial pressures. Field evidence from the deep ocean is consistent with these laboratory conclusions, indicating that **over the past 220 years there has been a 40% increase in average coccolith mass.** Our findings show that coccolithophores are already responding and will probably continue to respond to rising atmospheric CO<sub>2</sub> partial pressures, which has important implications for biogeochemical modeling of future oceans and climate.<sup>6</sup>” However, Riebesell et al. vigorously attacked the paper, claiming that “shortcomings in their experimental protocol compromise the interpretation of their data and the resulting conclusions.”<sup>7</sup> In rebuttal, also in Science, Iglesias-Rodriguez et al. successfully

demonstrate that the logic and methods of Riebesall et al. are the ones that are flawed and the original findings of increased calcification are valid<sup>8</sup>.

Perhaps the most thorough review of the literature on acidification impacts is by Fabry et al.<sup>9</sup> They found that little research was done on CO<sub>2</sub> concentrations that were relevant to answer today's questions. They express much concern that acidification will retard development of shells. They as do several other authors, note that studies have not been long-term enough to discover adaptations over multiple generations. I believe this is key because these genera have genetic information about past events and this may well take several generations for stabilization. In any scenario, there will be ample time for this to happen. In a laboratory it happens with the throw of a switch. If my family or its descendants needs to hold its head underwater for 5 minutes and they have a couple generations to adapt, it can be done. However, I can't do it very well today.

With respect to corals, Atkinson reviewed recent literature on ...“how ocean acidification may influence coral reef organisms and coral reef communities. We argue that it is unclear as to how, and to what extent, ocean acidification will influence calcium carbonate calcification and dissolution, and affect changes in community structure of present-day coral reefs<sup>10</sup>”. Also, the latest IPCC report (summary above) found no empirical evidence supporting effects of acidification on marine biological systems<sup>11</sup>.

Kurihara et al investigated the “effects of seawater equilibrated with CO<sub>2</sub>-enriched air (2000 ppm, pH 7.4) on the early development of the mussel” and found that the mussels, as clams studied by them earlier, were significantly impaired when exposed to CO<sub>2</sub> over 5X! that of today<sup>12</sup>.

Marubini et al. found that seawater acidification may lead to a decrease of tropical coral growth calcification. This effect is either mediated by a decrease in carbonate, in pH, or by an alteration of the internal buffering system leading to a disruption of carbon supply to calcification rather than by a direct effect of CO<sub>2</sub> or a change of HCO<sub>3</sub><sup>-</sup> concentration. Results showed that the negative effect of acidification may be counteracted by increasing the bicarbonate concentration of seawater, resulting in an increase in the carbonate concentration.<sup>13</sup>

Research in laboratories shows that shell growth is slowed in some animals and enhanced in others. Woods Hole Oceanographic Institution (WHOI) researchers found that 7 of 18 species of animals “such as crabs, shrimp and lobsters—unexpectedly build more shell when exposed to ocean acidification caused by elevated levels of atmospheric carbon dioxide (CO<sub>2</sub>)”<sup>14</sup>. They tested as high as 7 times present levels. They found that hard clams and corals slowed formation of shells but only above 1,000 ppm, while soft clams and oyster slowed formation at lower levels. Note that the shells did not dissolve, but only grew somewhat slower at 7X present CO<sub>2</sub> concentrations.

There is no basis to predict the demise of shelled animals living in the sea or the animals above them in the food chain at any likely level of CO<sub>2</sub> that might be put in the air by humans.

A study at the University of Hawaii found the olfactory-based homing ability of clownfish was disrupted at 1,000 ppm and non-existent at 2,000 ppm. The values of CO<sub>2</sub> acidification were high: “These values are consistent with climate change models that predict atmospheric CO<sub>2</sub> levels could exceed 1,000 ppm by 2100 and approach 2,000 ppm by the end of next century under a business as usual scenario”<sup>15</sup> This has implication for all fish that need to find their way back to natal streams, if we were ever to get to 1,000 ppm.

**With respect to clam and oyster mortalities** being caused by acidified water, it is unlikely that CO<sub>2</sub> deposition from the air is the culprit. Upwelling brings water from the depths to the surface. This water has been out of sunlight perhaps for centuries. There has been no photosynthesis for plants to turn the CO<sub>2</sub> into oxygen, and whatever oxygen there was, has been converted into CO<sub>2</sub> by animals. When this cold water reaches the surface, it is saturated with CO<sub>2</sub> and is acidic, plus it has little oxygen. This warming water will be outgassing CO<sub>2</sub>, rather than picking it up as claimed by some. Acidic water is also symptomatic of coastal eutrophication, whether caused by runoff or sewage. The WHOI work cited above shows that the growth of clams and oysters can be slowed by CO<sub>2</sub>-induced acidification. In their studies, the animals did not die even at rates several multiples of today’s CO<sub>2</sub> levels and for clams, growth slowed only at the highest levels of CO<sub>2</sub>.

**With respect to being overrun with jellyfish,** because ocean acidification could open ecological space for noncalcifying species. Richardson and Gibson studied the possibility that there were more noncalcifying jellyfish when conditions were more acidic (lower pH) in the Northeast Atlantic using coelenterate records from the Continuous Plankton Recorder and pH data from the International Council for the Exploration of the Sea for the period 1946–2003. They could find no significant relationships between jellyfish abundance and acidic conditions in any of the regions investigated<sup>16</sup>.

**With respect to sea grasses,** Zimmerman studied sea-grasses that form the bases of highly productive ecosystems ranging from tropical to polar seas. Despite clear evidence for carbon limitation of photosynthesis, seagrasses thrive in high light environments, and show little

Example of shell formation at 7X current CO<sub>2</sub>. Source: WHOI 2009



[Enlarge Image](#)

The conch shell at left was exposed to current CO<sub>2</sub> levels; the shell at right was exposed to the highest levels in the study. (Tom Kleindinst, Woods Hole Oceanographic Institution)



[Enlarge Image](#)

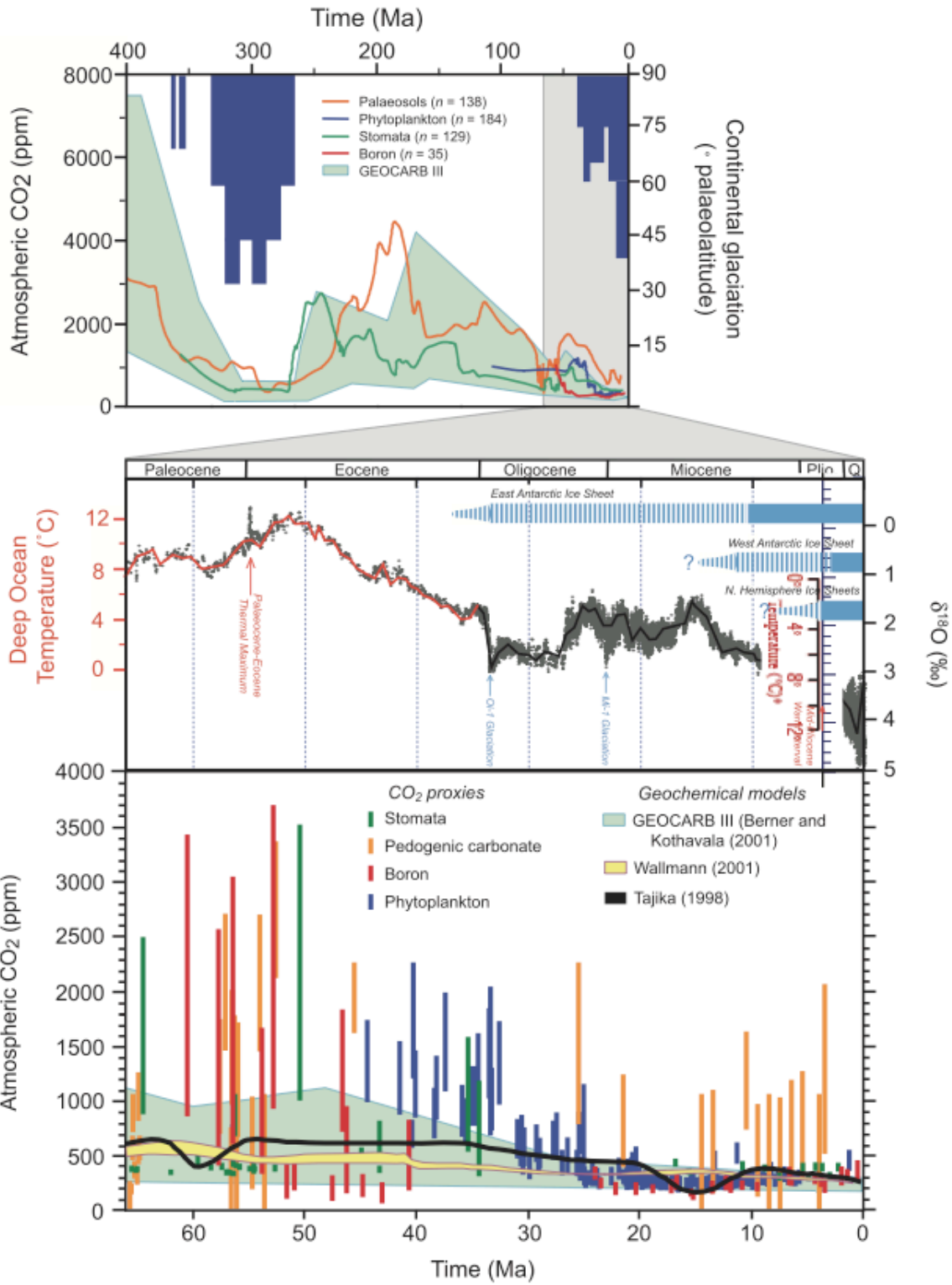
The larger of these two pencil urchins was exposed to current CO<sub>2</sub> levels; the smaller was exposed to the highest CO<sub>2</sub> levels in the study. (Tom Kleindinst, Woods Hole Oceanographic Institution)

evidence of light-induced photoinhibition. Increasing the availability of dissolved aqueous CO<sub>2</sub> can increase instantaneous rates of light saturated photosynthesis by up to 4 fold. Prolonged exposure to elevated CO<sub>2</sub> concentrations increases the concentrations of non-structural carbohydrates (sucrose and starch), rates of vegetative shoot proliferation, and flowering, and reduces light requirements for plant survival. Consequently, seagrass populations are likely to respond positively to CO<sub>2</sub>-induced acidification of the coastal ocean, which may have significant implications for carbon dynamics in shallow water habitats and for the restoration/preservation of seagrass populations.<sup>17</sup>

#### **IV. HAS THIS HAPPENED BEFORE?**

From 50-600 million years ago, CO<sub>2</sub> levels in the atmosphere were usually 2-20 times higher than at present. All the animals of concern evolved during this period. This included the age of the dinosaurs, when life was so prolific on land and in the oceans that we are still using the carbon (and chalk) deposited during those periods. The animals of concern all should have the innate genetic plasticity to quickly respond to the relatively modest changes of even the unlikely worst-case scenarios, none of which move our atmosphere's present concentration of CO<sub>2</sub> into the earlier range. The CO<sub>2</sub> we are putting into the atmosphere, originally came from it during the epochs when the species of concern flourished. The chart below compiles the work of several authors and methods. It is from the latest IPCC report, showing time in Ma (millions of years) before present. For comparison, the present CO<sub>2</sub> level is 388 ppm.





## **V. IS THIS BAD OR GOOD OR JUST DIFFERENT?**

We and all other animals use oxygen and expel CO<sub>2</sub>. Plants do the opposite. CO<sub>2</sub>, combined with light and nutrients is their food. We must not lose sight of the fact that plants have consumed once-abundant CO<sub>2</sub> to the point that it is 0.000388 of the atmosphere. Many greenhouse operators pump CO<sub>2</sub> into their buildings to enhance growth, indicating plants evolved during higher concentrations of CO<sub>2</sub>. Plants in the ocean also rely on CO<sub>2</sub>. There is a high ability to move the excess out of circulation, turning it into oxygen (by plants) or calcium carbonate (by animals-mostly). A view of the CO<sub>2</sub> growth chart and analyses such as that of Wolfgang Knorr cited above show this has not been adequately taken into account by climate modelers or those who provided their inputs.

We know that the Earth has seen these conditions before, and that all the same types of animals and plants of the oceans successfully made it through far more extreme conditions. Virtually all the ecological niches were filled at all times. If someone could demonstrate that there were no corals, clams, oysters, or shelled plankton when the Earth had double or triple the amount of CO<sub>2</sub> in the air, we would have reason for concern. Just as IPCC has concluded, there is no observational evidence that things would be better or worse, or even different. Similarly, there is nothing conclusive in the very recent scientific literature to indicate any reason for concern. If anything, the science indicates plants will be more successful, and since they are the bottom of the food chain, this cannot be totally bad.

## **VI. WHAT CAN BE DONE ABOUT IT?**

Oceans are actually alkaline with a surface pH of around 8.1. But it can vary from higher levels in shallow areas, where CO<sub>2</sub> and hydrogen ions are consumed by plants, to relatively acidic areas in eutrophic estuaries. Upwelling areas are also less alkaline, as cold bottom waters are brought into sunlight near the surface where algae use the deep-water CO<sub>2</sub> and nutrients to create a productivity boom that sustains fisheries production in several areas of the world. There are no long-term data, using similar instruments that provide a real clue as to global trends in alkalinity. There are only a few data sets of over a decade, such as that of the Monterrey Bay Aquarium. The variability, because of nearby ocean currents and upwelling shows the difficulty in portraying a global average value.

Some pundits have argued that we could add limestone to the oceans to make them more alkaline, but this has little merit due to costs and the fact that the oceans already contain immense buffering capability. We should bear in mind that this limestone and chalk for the most part came from the shells of plankton as they fed on the CO<sub>2</sub>-laden ancient seas.

## **VII. RESEARCH SUGGESTIONS**

There are some items that would go a long way toward establishing the likely effects of an increased CO<sub>2</sub> world.

1. Develop a CO<sub>2</sub>/temperature timeline based on extant research on past climates, at least back to about 600 million years before the present. This effort would provide a critical review of candidate papers and unpublished work that goes well beyond a typical peer-reviewed journal publication, or prior summary reports of the IPCC.
2. The acidification debate has showed us we lack a sufficient understanding of some fundamental chemical and biological processes. The research to resolve these questions should continue and perhaps centrally coordinated so that scarce dollars are targeted at real and important knowledge gaps.

3. Examine the growth rates, densities, and shell thicknesses of clams, oysters, or other mollusks from Indian middens and sediments to determine if any changes can be detected and if they correlate to any known changes in the oceans or atmosphere, including pH and CO<sub>2</sub> levels.
4. Before the next IPCC assessment begins, assemble a USA review team and nominees for the IPCC writing and Chair assignments that make up a cross-section of scientific viewpoints. There are qualified scientists in agencies, industry, and among the citizenry who can contribute. Just as we shouldn't have too many from the energy industry, the same goes for the agencies, universities, and NGOs. We all have biases, even if we think it is the other person who is the one with an agenda. We cannot afford to have only people with the same agenda, no matter how righteous they might think it to be.

## VIII. CONCLUDING REMARKS

There is no reliable observational evidence of negative trends that can be traced definitively to lowered pH of the water. If there were, it would be suspect because there is insignificant change relative to past climates of the Earth. Scientific studies, and papers reviewing science papers, have similar messages. Papers that herald findings that show negative impacts need to be dismissed if they used acids rather than CO<sub>2</sub> to reduce alkalinity, if they simulated CO<sub>2</sub> values beyond triple those of today, while not reporting results at concentrations of half, present, double and triple, or as pointed out in several studies, they did not investigate adaptations over many generations.

The oceans and coastal zones have been far warmer and colder and much more acidic than is projected by climate models. Marine life has been in the oceans nearly since when they were formed. During the millennia life endured and responded to CO<sub>2</sub> levels well beyond anything projected, and temperature changes that put tropical plants at the poles or had much of our land covered by ice more than a mile thick. The memory of these events is built into the genetic plasticity of the species on this planet. IPCC forecasts are for changes to occur faster than evolution is considered to occur, so impacts will be determined by this plasticity from past experiences and the resiliency of affected organisms to find suitable habitats.

In the oceans, major climate warming and cooling and pH changes are a fact of life, whether it is over a few years as in an El Niño, over decades as in the Pacific Decadal Oscillation or the North Atlantic Oscillation, or in a few hours as a burst of upwelling moves into an area or a storm brings rainwater into an estuary. Upwelling and rainwater each have pH values that are dozens or orders of magnitude lower than in any scenario.

Currents, temperatures, salinity, pH, and biology change rapidly to the new state in months or a couple years. These changes far exceed the changes expected with human-induced climate change and occur much faster. The estimated 0.1 change in alkalinity since 1750 and the one degree F. temperature rise since 1860 are but noise in this rapidly changing system. Sea level has been inexorably rising since the last glaciation lost its grip a mere 10,000 years ago. It is only some few thousand years since trees grew on Georges Bank and oysters flourished on its shores. Their remains still come up in dredges and trawls in now deep water, with the oysters looking like they were shucked yesterday. In the face of all these natural changes, and those we are here to consider, some species flourish while others diminish.

I do not know whether the earth is going to continue to warm, or that having reached a peak several years ago, we are at the start of a cooling cycle that will last several decades or more. I think carbon-based fuels will continue to increase in price and become scarcer as reserves are depleted even though I am an optimist about our technological advances in helping us find and

exploit additional reserves. Nevertheless, our consumption is more likely to fall than to rise. In any case, I am optimistic about our ability to deal with the consequences.

The most important approach in determining the impact of CO<sub>2</sub> on the oceans is to examine what happened during past times. The world has been down this path before and all the existing genera, and many species, endured. It has often been a difficult journey, with volcanism, meteoroid collisions, severe ice ages, and great heat, with many of these events causing mass extinctions. The ancestors of these animals were on Earth long before humans. They are the survivors of great disasters. The memory of these difficult times is in their genetic makeup. Adaptation will be swift, if needed.

Whichever response the US takes, our actions should be prudent. Our fishing industry, maritime industry and other users of the ocean environment compete in a world market and are vulnerable in many ways to possible governmental actions to reduce CO<sub>2</sub> emissions. We already import most of our seafood and many of the nations with which we compete do not need further advantages. Our research should focus on those ecosystem linkages we need to understand in order to wisely manage our fisheries, and conserve our protected species.

I think it is important to do the necessary research to see whether my views or those who see impending doom are correct. The research is important, but actions that would decrease our Nation's ability to afford the research should not be taken on the basis of what I believe is unfounded fear.

## References:

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<sup>1</sup> IPCC Fourth Assessment Report: Climate Change 2007: Working Group I: The Physical Science Basis. 10.4.2 Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide. Available: [http://www.ipcc.ch/publications\\_and\\_data/ar4/wg1/en/ch10s10-4-2.html](http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-4-2.html)

<sup>2</sup> IPCC Working Group I: The Scientific Basis, 3.7.3.2 Concentration projections based on IS92a, for comparison with previous studies available: <http://www.ipcc.ch/ipccreports/tar/wg1/122.htm>

<sup>3</sup> Knorr, Wolf. "No Rise of Atmospheric Carbon Dioxide Fraction in Past 160 Years" *Geophysical Research Letters*, Vol. 36, L21710, 5 PP., 2009. Available: <http://www.agu.org/pubs/crossref/2009/2009GL040613.shtml>

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