

# OCEAN "ACIDIFICATION" ALARMISM IN PERSPECTIVE

BY PATRICK MOORE

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### PATRICK MOORE

Dr. Patrick Moore is the Chair of the Energy, Ecology and Prosperity program at the Frontier Centre for Public Policy. He has been a leader in the international environmental field for over 40 years. Dr. Moore is a Co-Founder of Greenpeace and served for nine years as President of Greenpeace Canada and seven years as a Director of Greenpeace International. Following his time with Greenpeace, Dr. Moore joined the Forest Alliance of BC where he worked for ten years to develop the Principles of Sustainable Forestry which have now been adopted by much of the industry. Today, Dr. Moore focuses on the promotion of sustainability and consensus building among competing concerns. In 2013 he published *Confessions of a Greenpeace Dropout – The Making of a Sensible Environmentalist*, which documents his 15 years with Greenpeace and outlines his vision for a sustainable future .

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## EXECUTIVE SUMMARY

1. The concept of ocean acidification is a recent phenomenon that has resulted in an explosion of journal articles, media reports and alarmist publications from environmental organizations.

2. Many papers on ocean acidification, said to be caused by rising man-made CO<sub>2</sub> levels in the atmosphere, predict that it will result in the mass extinction of marine species that employ calcification, including corals, shellfish and many species of plankton, and that this, in turn, will result in the extinction of many other marine species.

3. Assumptions about pre-industrial ocean pH beginning around 1750 and laboratory studies that cannot adequately emulate natural oceanic conditions are the basis for the predictions of the future pH of the oceans.

4. Marine species that calcify have survived through millions of years during which CO<sub>2</sub> was at much higher levels in the atmosphere.

5. All species are capable of adapting to changes in their environments. Over the long term, genetic evolution has made it possible for all species extant today, and their ancestors, to survive radical changes through the millennia. In the short term, phenotypic plasticity and transgenerational plasticity allow species to adapt to environmental change in relatively rapid fashion.

6. Seawater has a very large buffering capacity that prevents large shifts in pH when weak acids such as carbonic acid or weak bases are added to it

7. All species, including marine calcifying species, are capable of controlling their internal chemistry in a wide range of external conditions.

8. If the forecasts of continued global warming are borne out, the oceans will also become warmer and will tend to outgas CO<sub>2</sub>, offsetting to some extent the small increased partial pressure that might otherwise occur.

9. An analysis of research on the effect of lower pH shows a net beneficial impact on the calcification, metabolism, growth, fertility and survival of calcifying marine species when pH is lowered up to 0.3 units, which is beyond what is considered a plausible reduction during this century.

10. There is no evidence to support the claim that most calcifying marine species will become extinct owing to higher levels of CO<sub>2</sub> in the atmosphere and lower pH in the oceans.

## INTRODUCTION

Although there are a few earlier references in the literature, it was not until 2003 that an explosion of journal articles, media reports and glossy publications from environmental groups on the subject of ocean acidification began to appear. This coincided with a paper published in the journal *Nature*, which reported that human emissions of carbon dioxide (CO<sub>2</sub>) “may result in larger pH changes [in the oceans] over the next several centuries than any inferred from the geological record of the past 300 million years.”<sup>1</sup>

The ocean acidification hypothesis proposes that increases in atmospheric levels of CO<sub>2</sub> will inevitably result in the oceans becoming more acidic as they absorb more CO<sub>2</sub>, some of which reacts in the sea to become carbonic acid. In turn, a lowering of pH is predicted to result in a serious, even “catastrophic” impact on shellfish, plankton and corals, species that build protective shells of calcium carbonate from calcium and CO<sub>2</sub> dissolved in seawater. The projected lowering of ocean pH is then going to make it difficult or even impossible for these species to construct their shells, and thus, some people have said they will become extinct.

The term “ocean acidification” is, in itself, rather misleading. The scale of pH runs from 0 to 14 where 7 is neutral, below 7 is acidic and above 7 is basic, or alkaline. The pH of the world’s oceans varies from 7.5 to 8.3, well into the alkaline scale. It is therefore incorrect to state the oceans are acidic or that they will become acidic under any conceivable scenario. The term “acidification” is used to imply that the oceans will actually become acidic. It is perhaps just short of propaganda to use the language in this manner, as it is well known that the terms “acid” and “acidic” have strong negative connotations for most people.

It would certainly be a dire consequence if human emissions of CO<sub>2</sub> were to kill all the clams, oysters, snails, crabs, shrimp, lobsters, coral reefs and the many other calcareous species in the oceans. This paper will examine

this hypothesis in detail and test its assumptions against real-world observations and scientific knowledge.

It is well documented that from 1996 to 2014 there was no statistically significant warming of the global climate.<sup>2</sup> Some years ago, the term “global warming” was largely supplanted by the term “climate change” owing to the assertion that warming would have knock-on effects such as changes in rainfall patterns etc. However, if there has been no recent warming, it follows that there has been no significant change in climate during this period as well. The fact that about 30 per cent of all human CO<sub>2</sub> emissions since the beginning of the industrial era have occurred during this “hiatus” or “pause” has led to questioning of the stated certainty that increased atmospheric CO<sub>2</sub> will inevitably lead to significant warming of the planet. This in turn brings into question the wisdom of spending trillions of dollars on a “problem” that may be inconsequential or may not even exist.

For those campaigning on the issue of climate change, the spectre of ocean acidification neatly solves the problem created by the recent lack of warming. The hypothesis of ocean acidification does not require any warming, any change in climate or any increase in extreme weather events to occur. Its sole basis is the contention that higher levels of CO<sub>2</sub> in the atmosphere will result in a lowering of ocean pH, and this in turn will cause the extinction of shellfish and other calcifying marine species. Ocean acidification has been dubbed “global warming’s evil twin,” thus injecting a degree of false morality into the discussion.<sup>3</sup>

Even scientists one might expect would be more moderate in their tone employ alarmist language. An example from the journal *Trends in Ecology and Evolution*:

*The anthropogenic rise in atmospheric CO<sub>2</sub> is driving fundamental and unprecedented changes in the chemistry of the oceans. ... We argue that ocean*

*conditions are already more extreme than those experienced by marine organisms and ecosystems for millions of years, emphasising the urgent need to adopt policies that drastically reduce CO<sub>2</sub> emissions.<sup>4</sup>*

Yet, the same paper states, "Understanding the implications of these changes in seawater chemistry for marine organisms and ecosystems is in its infancy."<sup>5</sup>

By 2009, the Natural Resources Defense Council (NRDC), an environmental advocacy group, was saying that "by mid-century ... coral reefs will cease to grow and even begin to dissolve" and ocean acidification will "impact commercial fisheries worldwide, threatening a food source for hundreds of millions of people as well as a multi-billion dollar industry."<sup>6</sup> Therefore, not only are calcifying species threatened, but also the entire web of life in the seas.

The NRDC document also contended, "Acidification may already be impacting marine life around the world. For example, Pacific oysters have not successfully reproduced in the wild since 2004." This assertion is quite misleading, as Pacific oyster production has been increasing steadily from 150 thousand tons in 1950 to more than 500 thousand tons in 2013, and is based on the collection of wild seed (spat).<sup>7</sup>

The proponents of ocean acidification think that the oceans are absorbing 30 to 50 per cent of human CO<sub>2</sub> emissions.<sup>8</sup> A 30-year study near Bermuda contains evidence that the oceans are absorbing CO<sub>2</sub> from the atmosphere.<sup>9</sup> Another study based on direct observation in the field indicated that increasingly the CO<sub>2</sub> that was not showing up in the atmosphere was being absorbed by biomass on the land.

*'Increasing trends in carbon uptake over the period 1995–2008 are nearly unanimously placed in the terrestrial biosphere (assuming fossil fuel trends are correct), with a small ocean increase only present in a few inversions. The atmospheric CO<sub>2</sub> network is*

*probably not yet dense enough to confirm or invalidate the increased global ocean carbon uptake, estimated from ocean measurements or ocean models.<sup>10</sup>*

There is direct evidence that trees and plants are taking up a percentage of human CO<sub>2</sub> emissions as CO<sub>2</sub> levels increase.<sup>11</sup> The "CO<sub>2</sub> fertilization effect" is well documented. That greenhouse growers around the world purposely increase the level of CO<sub>2</sub> in their greenhouses in order to increase yield of their crops by up to 50 per cent supports this fact. There is simply no question that terrestrial plants largely benefit from increased levels of CO<sub>2</sub> in the air. Whereas CO<sub>2</sub> is now at about 400 ppm, the optimum growth of most plants occurs at 1,500 to 2,000 ppm, and in some species, it is much higher. The precise division between CO<sub>2</sub> absorbed by the oceans and CO<sub>2</sub> contributing to increased terrestrial biomass is very difficult to determine.

This paper will consider five factors that bring into question the assertion that ocean acidification is a crisis that threatens all or most calcifying species, as well many other species, with extinction. It is important to recognize the role that apocalyptic language plays in this discussion. It can truthfully be said, "Human emission of CO<sub>2</sub> will result in a slight reduction of ocean pH that is well within historical levels during which calcifying species have survived and even flourished." Or, it *could* be stated, "Global warming and ocean acidification will result in the death of all coral reefs by 2050, resulting in the extinction of thousands of species as the marine environment is pushed to the brink of ecological collapse." The latter statement is much more likely to be printed in newspapers and broadcast around the world.<sup>12</sup> It is not objective science but rather a sensationalist prediction that has little basis in fact or logic. Required here is an appeal for critical thinking among the populace in order to distinguish between the factual and the predictive and between sober language and apocalyptic predictions.

## THE HISTORICAL RECORD OF CO<sub>2</sub> AND TEMPERATURE IN THE ATMOSPHERE

All the CO<sub>2</sub> in the atmosphere came from inside the Earth. During the early life of the planet, the Earth was much hotter, and there was much more volcanic activity than there is today. The heat of the core caused carbon and oxygen to combine to form CO<sub>2</sub>, which became a significant part of the Earth's early atmosphere, perhaps the most abundant component until photosynthesis evolved. Most of the CO<sub>2</sub> in the oceans comes from the atmosphere, although some is injected directly from ocean vents.

It is widely accepted that the concentration of CO<sub>2</sub> was higher in the Earth's atmosphere before modern-day life forms evolved during the Cambrian Period, which began 544 million years ago. It was also at that time that a number of marine species evolved the ability to control calcification, an example of the more-general term "biomineralization."<sup>13</sup> This allowed these species to build hard shells of calcium carbonate (CaCO<sub>3</sub>) around their soft bodies, thus providing a type of armour plating. Early shellfish such as clams arose more than 500 million years ago, when atmospheric CO<sub>2</sub> was 10 to 15 times higher than it is today.<sup>14</sup> Clearly, the

pH of the oceans did not cause the extinction of corals or shellfish or they would not be here today. Why, then, are we told that even at today's much lower level, CO<sub>2</sub> is already causing damage to calcifying species?

The most common argument is along the lines of "today's species of corals and shellfish are not adapted to the level of CO<sub>2</sub> that ancient species were familiar with. Acidification is happening so quickly that species will not be able to adapt to higher levels of CO<sub>2</sub>." This is nonsensical in that from a biochemical perspective there is no reason to believe these species have lost their ability to calcify at the higher CO<sub>2</sub> levels that existed for millions of years in the past. The ancestors of every species alive today survived through millennia during which conditions sometimes changed very rapidly, such as when an asteroid caused the extinction of dinosaurs and many other species 65 million years ago. While many more species became extinct than are alive today, it must be said that those species that came through these times have proven the most resilient through time and change.

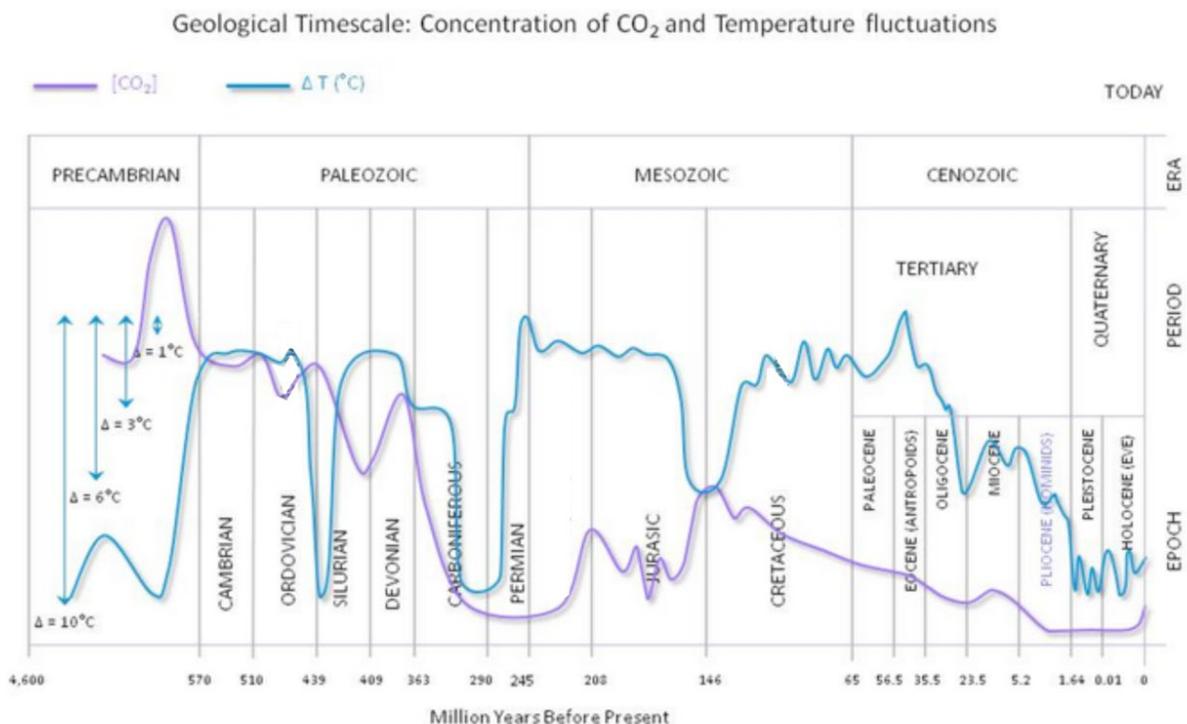


Figure 1. Reconstruction of CO<sub>2</sub> and temperature over the Earth's history. This does not indicate a lockstep cause-and-effect relationship.<sup>15</sup>

As far as is known, there was only one other period in the Earth's history when CO<sub>2</sub> was nearly as low as it has been during the past 2.5 million years of the Pleistocene Ice Age. During the late Carboniferous Period and into the Permian and Triassic Periods, CO<sub>2</sub> was drawn down from about 4,000 ppm to about 400 ppm, probably owing to the advent of vast areas of forest that pulled CO<sub>2</sub> out of the atmosphere and incorporated it into wood and thus into coal (see Figure 1). We know from Antarctic ice cores that CO<sub>2</sub> was drawn down to as low as 180 ppm during the Pleistocene, only 30 ppm above the threshold for the survival of plants, at the peak of glacial advances (see Figure 2). These periods of low atmospheric CO<sub>2</sub>, as is the case at present, are the exception to the much longer periods when CO<sub>2</sub> was more than 1,000 ppm, and often much higher.

For this reason alone, the possibility that present and future atmospheric CO<sub>2</sub> levels will cause significant harm to calcifying marine life should be questioned. However, a number of other factors bring the ocean acidification hypothesis into question.

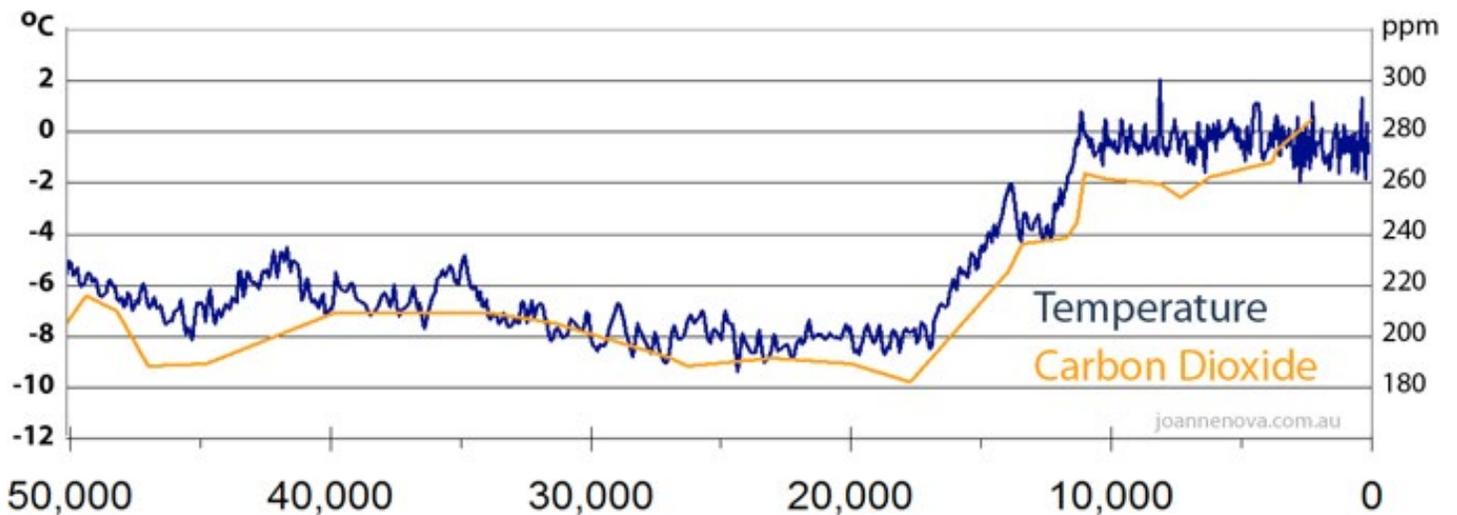


Figure 2. Cryostratigraphic reconstructions of air temperature and CO<sub>2</sub> concentration anomalies from Vostok station, Antarctica, 50-2.5 thousand years BP. CO<sub>2</sub> concentration fell to a little above 180 ppmv 18 ka BP.<sup>16</sup>

## THE ADAPTATION OF SPECIES TO CHANGING ENVIRONMENTAL CONDITIONS

People have a tendency to assume that it takes thousands or millions of years for species to adapt to changes in the environment. This is not the case. Even species with relatively long breeding periods can adapt relatively quickly when challenged by rapidly changing environmental conditions. In fact, it is rapidly changing environmental conditions that foster rapid evolutionary change and adaptation.<sup>17</sup> Stephen Jay Gould explains this well in his classic *Wonderful Life*, which focuses on the Cambrian Explosion and the evolution of vast numbers of species beginning 544 million years ago.<sup>18</sup>

Most of the invertebrates that have developed the ability to produce calcium carbonate armour are capable of relatively rapid adaptation to changes in their environment due to two distinct factors. Firstly, they reproduce at least annually and sometimes more frequently. This means their progeny are tested on an annual basis for suitability to a changing environment. Secondly, these species produce thousands to millions of offspring every time they reproduce. This greatly increases the chance that genetic mutations that are better suited to the changes in environmental conditions will occur in some offspring.

A number of studies have demonstrated that change in an organism's genetic make-up, or genotype, is not the only factor that allows species to adapt to changing environmental conditions. Many marine species inhabit coastal waters for some or all of their lives where they are exposed to much wider ranges of pH, CO<sub>2</sub>, O<sub>2</sub>, temperature and salinity than occur in the open ocean. Two distinct physiological mechanisms exist whereby adaptation to environmental change can occur much more rapidly than by change in the genotype through genetic evolution.

The first of these is phenotypic plasticity, which is the ability of one genotype to produce more than one phenotype when exposed to different environments.<sup>19</sup> In other words, a specific genotype can express itself differently due to an ability to respond in different ways to variations in environmental factors. This helps to explain how individuals of the same species with nearly identical genotypes can successfully inhabit very different environments. Examples of this in humans are the ability to acclimatize to different temperature regimes and different altitudes. There is no change in the genotype, but there are changes in physiology.

The second and more fascinating factor is transgenerational plasticity, which is the ability of parents to pass their adaptations to their offspring.<sup>20</sup> One recent study pointed out that "contemporary coastal organisms already experience a wide range of pH and CO<sub>2</sub> conditions, most of which are not predicted to occur in the open ocean for hundreds of years – if ever."<sup>21</sup> The authors used what they called "a novel experimental approach that combined bi-weekly sampling of a wild, spawning fish population (Atlantic silverside *Menidia menidia*) with standardized offspring CO<sub>2</sub> exposure experiments and parallel pH monitoring of a coastal ecosystem." The parents and offspring were exposed to CO<sub>2</sub> levels of 1,200 ppm and 2,300 ppm compared with today's ambient level of 400 ppm. The scientists report that "early in the season (April), high CO<sub>2</sub> levels significantly ... reduced fish survival by 54% (2012) and 33% (2013) and reduced 1 to 10 day post-hatch growth by 17% relative to ambient conditions." However, they found that "offspring from parents collected later in the season became increasingly CO<sub>2</sub>-tolerant until, by mid-May, offspring survival was equally high at all CO<sub>2</sub> levels." This indicates that a coastal species of fish is capable of

adapting to high levels of CO<sub>2</sub> in a very short time. It also indicates that this same species would not even notice the relatively slow rate at which CO<sub>2</sub> is increasing in the atmosphere today.

The changes that have occurred to the Earth's climate over the past 300 years since the peak of the Little Ice Age around 1700 are in no way unusual or unique in history. During the past 3,000 years, a blink in geological time, there has been a succession of warm periods and cool periods. There is no record of species extinction due to climatic change during these periods.

## THE BUFFERING CAPACITY OF SEAWATER

Over the millennia, the oceans have received minerals dissolved in rainwater from the land. Most of these are in the form of ions such as chloride, sodium, sulphate, magnesium, potassium and calcium. Underwater hydrothermal vents and submarine volcanoes also contribute to the salt content. These elements have come to make up about 3.5 per cent of seawater by mass, thus giving seawater some unique properties compared with fresh water. It is widely believed by oceanographers that the salt content of the sea has been constant for hundreds of millions, even billions of years, as mineralization on the sea floor balances new salts entering the sea.<sup>22</sup>

The salt content of seawater provides it with a powerful buffering capacity, the ability to resist change in pH when an acidic or basic compound is added to the water. For example, one micromole of hydrochloric acid added to one kilo of distilled water at pH 7.0 (neutral) causes the pH to drop to nearly 6.0. If the same amount of hydrochloric acid is added to seawater at pH 7, the resulting pH is 6.997, a change of only 0.003 of a pH unit. Thus, seawater has approximately 330 times the buffering capacity of freshwater.<sup>23</sup> In addition to the buffering capacity, there is another factor, the Revelle factor, named after Roger Revelle, former director of the Scripps Institute of Oceanography. The Revelle factor determines that if atmospheric CO<sub>2</sub> is doubled, the dissolved CO<sub>2</sub> in the ocean will only rise by 10 per cent.<sup>24</sup>

It is widely stated in the literature that the pH of the oceans was 8.2 before industrialization (1750) and that owing to human CO<sub>2</sub> emissions it has since dropped to 8.1.<sup>25</sup> No one measured the pH of ocean water in 1750. The concept of pH was not conceived of until 1909, and an accurate pH meter was not available until 1924. The assertion that more than 250 years ago ocean pH was 8.2 is an estimate rather than an actual measurement. Measuring pH accurately

in the field to 0.1 of a pH unit is not a simple procedure even today. In addition, for two reasons, there is no global-scale monitoring of the pH of the oceans: First, genuine oceanographers know the overwhelming buffering capacity of seawater, so they do not expect the global acid-base balance to change, and secondly, there is no automated instrument available for measuring pH.

The predictions of change in ocean pH owing to CO<sub>2</sub> in the future are based on the same assumptions that resulted in the estimate of pH 8.2 in 1750 when we have no measurement of the pH of the oceans at that time. By simply extrapolating from the claim that pH has dropped from 8.2 to 8.1 during the past 265 years, the models calculate that pH will drop by 0.3 of a pH by 2100.

Many scientists have repeated the claim that the ocean's pH has dropped by 0.1 during the past 265 years. They should be challenged to provide observational data from 1750 that supports their inference. Observations from three eminent oceanographers, including Harald Sverdrup, former director of the Scripps Institute of Oceanography, in a book that covers all aspects of ocean physics, chemistry and biology bring into question these scientists' assertion. The book was written before the subject of climate change and carbon dioxide became politicized.

*Sea water is a very favorable medium for the development of photosynthetic organisms. It not only contains an abundant supply of CO<sub>2</sub> but removal or addition of considerable amounts results in no marked changes of the partial pressure of CO<sub>2</sub> and the pH of the solution, both of which are properties of importance in the biological environment....*

*If a small quantity of a strong acid or base is added to pure water, there are tremendous changes in the*

numbers of  $H^+$  and  $OH^-$  ions present, but the changes are small if the acid or base is added to a solution containing a weak acid and its salts or a weak base and its salts. This repression of the change in pH is known as buffer action, and such solutions are called buffer solutions. Sea water contains carbonic and boric acids and their salts and is, therefore, a buffer solution. Let us consider only the carbonate system. Carbonate and bicarbonate salts of strong bases, such as occur in sea water, tend to hydrolyze, and there are always both  $H^+$  and  $OH^-$  ions in the solution. If an acid is added, carbonate is converted to bicarbonate and the bicarbonate to carbonic acid, but, as the latter is a weak acid (only slightly dissociated), relatively few additional hydrogen ions are set free. Similarly, if a strong base is added, the amount of carbonate increases, but the  $OH^-$  ions formed in the hydrolysis of the carbonate increase only slightly. The buffering effect is greatest when the hydrogen ion concentration is equal to the dissociation constant of the weak acid or base – that is, when the concentration of the acid is equal to that of its salt.<sup>26</sup>

In addition, a study has been published in which the pH of the oceans was reconstructed from 1908 to 1988, based on the boron isotopic composition of a long-lived massive

coral from Flinders Reef in the western Coral Sea of the southwestern Pacific.<sup>27</sup> The report concluded that there was no notable trend toward lower isotopic values over the 300-year period investigated. This indicates that there has been no change in ocean pH over that period at this site. This study, in which actual measurements of a reliable proxy were made, is much more credible than an estimate based on assumptions that have not been tested.

In many ways, the assertions made about the degree of pH change caused by a given level of atmospheric  $CO_2$  are analogous to the claims made about the degree of atmospheric temperature rise that might be caused by a given level of atmospheric  $CO_2$ . This is termed “sensitivity” and the literature becomes very confusing when the subject is researched. Perhaps the assumptions used to estimate future ocean pH are as questionable as those used to estimate the increase in temperature from increases in atmospheric  $CO_2$  (see Figure 3).

The most serious problem with the assertion that pH has dropped from 8.2 to 8.1 since 1750 is that there is no universal pH in the world’s oceans. The pH of the oceans varies far more than 0.1 on a daily, monthly, annual and geographic basis. In the offshore oceans, pH typically varies geographically from 7.5 to 8.4, or 0.9 of a pH unit. A

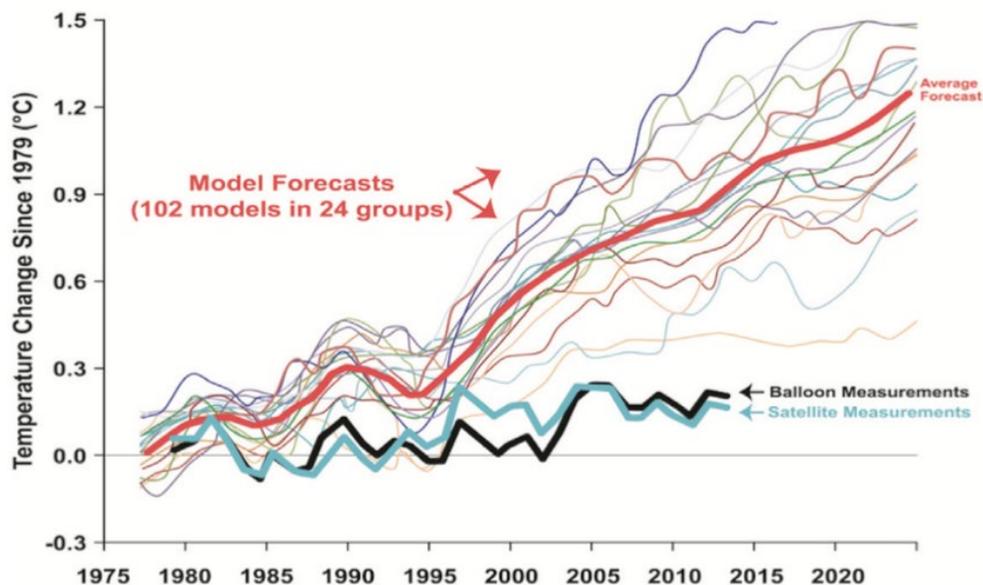


Figure 3. Average of 102 IPCC CMIP-5 climate model predictions compared with real-world observations from four balloon and two satellite datasets.<sup>28</sup>

study in offshore California shows that pH can vary by 1.43 of a pH unit on a monthly basis.<sup>29</sup> This is nearly five times the change in pH that computer models forecast during the next 85 years to 2100. In coastal areas that are influenced by run-off from the land, pH can be as low as 6.0 and as high as 9.0.

The Humboldt Current, a large area of ocean upwelling off the coasts of Chile and Peru, is among the lowest pH found naturally in the oceans. (see Figure 4) The pH of this seawater is 7.7 to 7.8.<sup>30</sup> If the ocean average pH is now 8.1, the water in the Humboldt Current is already at a lower pH than is predicted by 2100. Upwelling waters tend to be lower in pH than other areas of the ocean for two reasons. First, the water has been at a depth where the remains of sea creatures fall down and decompose into nutrients, tending to drive pH down. Second, the water that is upwelling to form the Humboldt Current is water that downwelled (sank) around Antarctica, and being cold, it had a high solubility for CO<sub>2</sub> at the ocean-atmosphere interface. Ocean water that sinks at the poles eventually comes to the surface where it is warmed, thus outgassing some of the CO<sub>2</sub> that was absorbed in the Antarctic and the Arctic.

Despite its low pH, the upwelling waters of the Humboldt Current produce 20 per cent of the world's wild fish catch, which consists largely of anchovies, sardines and mackerel.<sup>31</sup> The basis for the food chain includes large blooms of coccolithophores, a calcifying phytoplankton that produces symmetrical calcium carbonate plates to protect itself from predators. The White Cliffs of Dover are composed of the shells of coccolithophores. To quote from one of the more thoroughly researched papers on the subject, "These biome-specific pH signatures disclose current levels of exposure to both high and low dissolved CO<sub>2</sub>, often demonstrating that resident organisms are already experiencing pH regimes that are not predicted until 2100."<sup>32</sup> The authors remark, "The effect of Ocean Acidification (OA) on marine biota is quasi-predictable at best."<sup>33</sup> It is refreshing to read an opinion that is not so certain about predicting the future of an ecosystem as complex as the world's oceans.

Scientists working at oceanographic institutes in the United Kingdom and Germany published a paper in 2015 that explored the possibility that the asteroid that struck the Earth 65 million years ago caused ocean acidification.

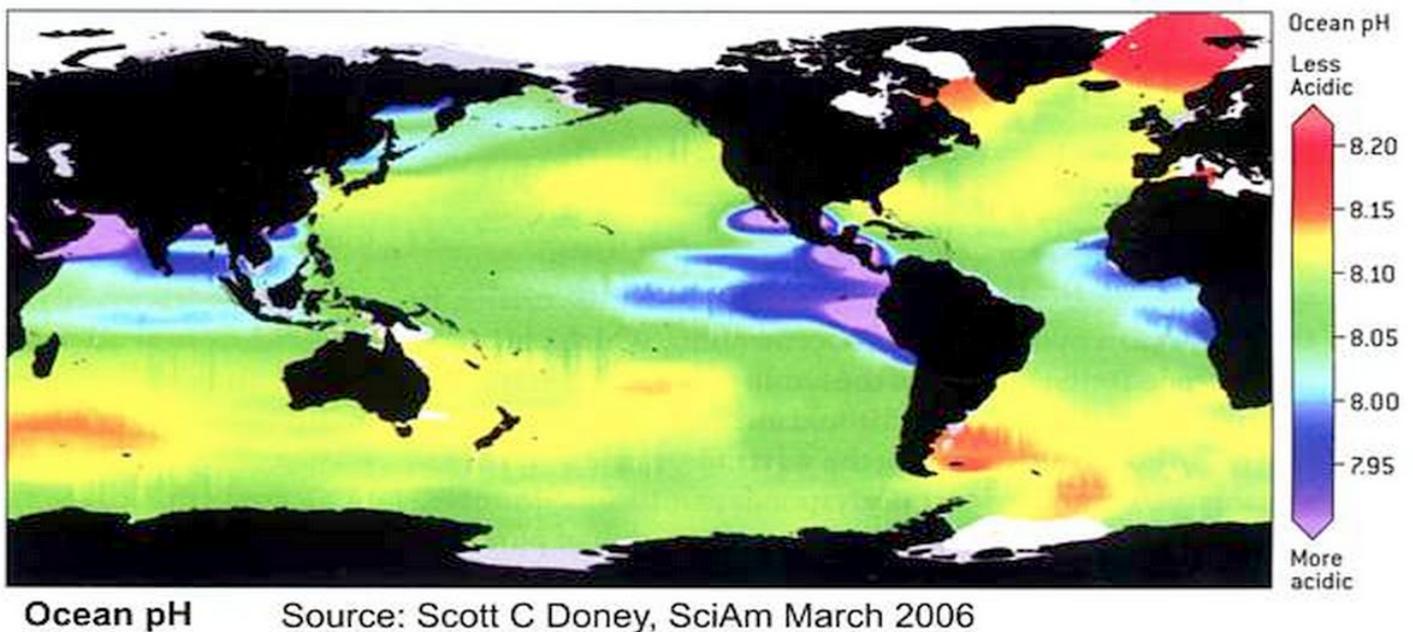


Figure 4. World map depicting the pH of the oceans, including the large area of lower pH seawater off the west coast of South America. To be correct, the scale of ocean pH on the right should read "More Basic" and "Less Basic."<sup>34</sup>

Along with the extinction of terrestrial and marine dinosaurs, 100 per cent of ammonites and 90 per cent of coccolithophores, both calcifying species, became extinct. The study considered the possibility that 6,500 Gt (billion tons) of carbon as CO<sub>2</sub> were produced by the vaporization of carbonaceous rock and wildfires because of the impact. The authors concluded, "Our results suggest that acidification was most probably not the cause of the extinctions."<sup>35</sup>

Six thousand five hundred Gt is the equivalent of 650 years of CO<sub>2</sub> emissions at the current global rate of about 10 Gt carbon as CO<sub>2</sub> per year. Given that atmospheric CO<sub>2</sub> concentration was about 1,000 ppm at the time of the impact, the addition of 6,500 Gt of carbon as CO<sub>2</sub> would have raised the concentration to approximately 4,170, which is about 10 times higher than in 2015 and about five times higher than it may be in 2100.

## THE ABILITY OF CALCIFYING SPECIES TO CONTROL THE BIOCHEMISTRY AT THE SITE OF CALCIFICATION

All organisms are able to control the chemistry of their internal organs and biochemical processes. The term “homeostasis” means that an organism can maintain a desirable state of chemistry, temperature, etc. within itself under a range of external conditions.<sup>36</sup> This is especially necessary in a marine environment because the salinity of the ocean is too high to allow the metabolic processes that take place in an organism. The general term for an important part of homeostasis is “osmoregulation.” There are two biological strategies for accomplishing it. The osmoregulators, which include most fishes, maintain their internal salinity at a different level from their environment. This requires energy to counteract the natural osmotic pressure that tends to equalize an organism’s internal salinity with the salinity of the water it inhabits. The osmoconformers, which include most invertebrate species, maintain their salt content at the same osmotic pressure as their environment, but they alter the make-up of the salts inside themselves compared with their surroundings.<sup>37</sup>

The osmoregulators are best illustrated by the examples of freshwater fish, saltwater fish and fish that are able to live in both fresh water and salt water. Freshwater fish must be able to retain salts in their bodies so are therefore able to repel and expel fresh water and to recover salts from their kidneys before excretion. Saltwater fish are able to retain water while excreting salts through their gills. Fish such as salmon and eels that spend part of their lives in fresh water and part in salt water are able to transform their bodily functions as they move from one environment to the other.<sup>38</sup>

The osmoconformers save energy by maintaining a salt concentration that is the same as their environment, but they, as do the osmoregulators, change the make-up of the salt mixture to allow critical biological functions to occur internally. Some osmoconformers, such as starfish and sea urchins, can only tolerate a narrow range of external salinity

while others, such as mussels and clams, can isolate themselves from the environment by closing their shells and can tolerate a wide range of external salinity.<sup>39</sup>

Osmoregulation is a good example of how species are able to adapt to environments that would otherwise be hostile to life. Controlled calcification is another biological function that depends on species’ ability to alter and control their internal chemistry.

The ocean acidification narrative is based almost entirely on the chemistry of seawater and the chemistry of calcium and carbon dioxide. It is true that the shell of a dead organism will gradually dissolve in water with a lowered pH;<sup>40</sup> however, it cannot be inferred directly from this that the shell, or carapace, or coral structure of a species will dissolve under similar pH while the organism is alive. Even if some dissolution is occurring, as long as the organism builds calcium carbonate faster than it dissolves, the shell will grow. If this were not the case, it would be impossible for the duck mussel, *Anodonta anatina*, to survive in a laboratory experiment at pH 3.0 for 10 days without significant shell loss.<sup>41</sup> This is an extreme example, as it is outside natural conditions. It is, however, well established that calcification growth in freshwater species of mussels and clams occurs at pH 6.0, well into the range of genuine acidity. The Louisiana pearlshell, *Margaritifera hembeli*, is actually restricted to waters with a pH of 6.0 to 6.9. In other words, it requires acidic water to survive.<sup>42</sup> This does not mean that all marine species that calcify will tolerate pH 6.0, only that there are organisms that can calcify at much lower pH than is found in ocean waters today or that are projected even under extreme scenarios.

The coccolithophores account for about 50 per cent of all calcium carbonate production in the open oceans. A laboratory study found that “the coccolithophore

species *Emiliana huxleyi* are significantly increased by high CO<sub>2</sub> partial pressures” and that “over the past 220 years there has been a 40% increase in average coccolith mass” and that “in a scenario where the PCO<sub>2</sub> in the world’s oceans increases to 750 ppmv, coccolithophores will double their rate of calcification and photosynthesis.”<sup>43</sup>

This is good news for the ocean’s primary production and fisheries production up the food chain. It demonstrates that higher levels of CO<sub>2</sub> will not only increase productivity in plants, both terrestrial and aquatic, but will also boost the productivity of one – if not the most important – of the calcifying species in the oceans.

The reason that calcifying marine organisms can calcify under a wider range of pH values than one would expect from a simple chemical calculation is that they can control their internal chemistry at the site of calcification. The proponents of dangerous ocean acidification are not considering this. If the internal biology of organisms were strictly determined by the chemical environment around them, it is unlikely there would be any life on Earth.

As mentioned earlier, it was at the beginning of the Cambrian Period approximately 540 million years ago that marine species of invertebrates evolved the ability to control the crystallization of calcium carbonate as an armour plating to protect themselves from predators. It is hypothesized that this ability stemmed from a long-standing previous ability to prevent spontaneous calcium carbonate crystallization to protect essential metabolic processes. Surprisingly, the common denominator in the anti-calcification–calcification history is mucus, often referred to as “slime.”<sup>44</sup>

The abstract from the paper cited above sums up this hypothesis well:

*The sudden appearance of calcified skeletons among many different invertebrate taxa at the Precambrian-Cambrian transition may have required minor reorganization of pre-existing secretory functions.*

*In particular, features of the skeletal organic matrix responsible for regulating crystal growth by inhibition may be derived from mucus epithelial excretions. The latter would have prevented spontaneous calcium carbonate overcrusting of soft tissues exposed to the highly supersaturated Late Proterozoic ocean ..., a putative function for which we propose the term “anticalcification.” We tested this hypothesis by comparing the serological properties of skeletal water-soluble matrices and mucus excretions of three invertebrates – the scleractinian coral *Galaxea fascicularis* and the bivalve molluscs *Mytilus edulis* and *Mercenaria mercenaria*. Crossreactivities recorded between mucus and skeletal water-soluble matrices suggest that these different secretory products have a high degree of homology. Furthermore, freshly extracted mucus of *Mytilus* were found to inhibit calcium carbonate precipitation in solution.*<sup>45</sup>

The authors found that the mucus produced by a coral, a mussel and a clam were chemically very similar, indicating inheritance from a common ancestor earlier in the Precambrian. The mucus produced by invertebrates has a number of known functions. It assists with mobility, acts as a barrier to disease and predators, helps with feeding, acts as a homing device and prevents desiccation.<sup>46</sup> The authors postulate that the mucus is also central in the calcification process. This explains how the chemistry at the site of calcification can be isolated from the chemistry of the seawater. Calcification can occur in and under the mucus layer where the organism can control the chemistry.

The creation of a shell requires certain biochemical processes. The periostracum, a leathery layer on the outside of the shell, folds around the lip of the shell to form an enclosed pocket called the extrapallial space. Within this space at the lip of the shell, the calcification process occurs, resulting in growth of the shell. The concentration of calcium ions is intensified by ion pumps within the extrapallial space, allowing crystallization to occur. The mucus within the space contains hormones that direct

the pattern of calcium carbonate crystal deposit to result in a smooth layer of new shell. This is a classic case of an organism controlling the biochemistry within itself, despite fluctuations in the external environment that would not permit such sophisticated functions.<sup>47</sup>

These above references make it clear that species that calcify have a high degree of sophistication in controlling the calcification process. The clear implication is that calcification can be successfully achieved despite a varying range of environmental conditions that would interfere with or end the process if it were not controlled. This does not appear to have been considered by most or all authors who propose that ocean acidification will exterminate a large proportion of calcifying species within a few decades.

Much of the concern about ocean acidification in the literature focuses on carbonate chemistry. When the pH of seawater lowers, the bicarbonate ion ( $\text{HCO}_3$ ) becomes more abundant while the carbonate ion ( $\text{CO}_3$ ) becomes less abundant. This is predicted to make it more difficult for calcifying species to obtain the  $\text{CO}_3$  required for calcification. It does not appear to be considered that the calcifying species may be capable of converting  $\text{HCO}_3$  to  $\text{CO}_3$ .

There are very few references to journal articles after 1996 that investigate the biochemical processes involved in calcification. The paper cited above by Marin et al. is the most thorough investigation and discussion of the subject found. Yet, there are hundreds, if not thousands, of articles that predict dire consequences from ocean acidification during this century.

A recent study published in the Proceedings of the National Academy of Sciences highlights how resilient coral reefs are to changes in ocean pH. A five-year study of the Bermuda coral reef shows that during spurts in growth and calcification, the seawater around the reef undergoes a rapid reduction in pH.<sup>48</sup> This reduction in pH is clearly not causing a negative reaction from the reef, as it is associated

with rapid growth. The study found that the reason the pH dropped during growth spurts is due to the  $\text{CO}_2$  emitted by the reef due to increased respiration. It was determined that the growth spurts were the result of offshore blooms of phytoplankton drifting in to the reef and providing an abundant food supply for the reef polyps. The conclusion from the study is that coral growth can increase even though the growth itself results in a reduction in pH in the surrounding seawater. A summary of the study in *New Scientist* concluded, "These corals didn't seem to mind the fluctuations in local acidity that they created, which were much bigger than those we expect to see from climate change. This may mean that corals are well equipped to deal with the lower pH levels."<sup>49</sup> It follows from the discussion above that this is likely due to the fact that the coral polyps can control their own internal pH despite the decrease in pH in their environment.

## A WARMER OCEAN MAY EMIT CO<sub>2</sub> BACK INTO THE ATMOSPHERE

While today's atmosphere contains about 850 Gt of carbon as CO<sub>2</sub>, the oceans contain 38,000 Gt of carbon, nearly 45 times as much as the atmosphere. The ocean either absorbs or emits CO<sub>2</sub> at the ocean-atmosphere interface, depending on the CO<sub>2</sub> concentrations in the atmosphere and the sea below and the salinity and temperature of the sea. At the poles, where seawater is coldest and densest and has the highest solubility for CO<sub>2</sub>, seawater sinks into the abyss, taking CO<sub>2</sub> down with it. In regions of deep seawater upwelling such as off the coasts of Peru, California, West Africa and the northern India Ocean, seawater rich in CO<sub>2</sub> fertilizes plankton blooms that feed great fisheries. The phytoplankton near the surface consumes some of the CO<sub>2</sub>, and some is outgassed to the atmosphere.

As mentioned above, we do not have the ability to determine how much CO<sub>2</sub> is absorbed by the oceans, how much is outgassed back into the atmosphere or the net effect of these phenomena.<sup>50</sup> The Intergovernmental Panel on Climate Change implicitly admits this lack of knowledge when it sets the estimate of the CO<sub>2</sub> feedback on the exceptionally wide interval of 25 to 225 ppmv K<sup>-1</sup>. What we do know is that if the oceans warm as the proponents of human-caused global warming say they will, the oceans will tend to release CO<sub>2</sub> into the atmosphere because warm seawater at 30°C can dissolve only about half as much CO<sub>2</sub> as cold seawater at 0°C does. This will be balanced against the tendency of increased atmospheric CO<sub>2</sub> to result in more absorption of CO<sub>2</sub> by the oceans. It does not appear as though anyone has done the calculation of the net effect of these two competing factors under varying circumstances.

## SUMMARY OF EXPERIMENTAL RESULTS ON EFFECT OF REDUCED PH ON CALCIFIFYING SPECIES

In his thorough and inclusive analysis of peer-reviewed experimental results on the effect of reduced pH on five factors (calcification, metabolism, growth, fertility and survival) among marine calcifying species, Craig Idso of the CO<sub>2</sub> Science Web site provides a surprising insight. Beginning with 1,103 results from a wide range of studies, the results are narrowed down to those within a 0.0 to 0.3 reduction in pH units.<sup>51</sup> A review of these many studies, all of which use direct observation of measured parameters, indicates that the overall predicted effect of increased CO<sub>2</sub> on marine species would be positive rather than negative

(see Figure 5). This further reinforces the fact that CO<sub>2</sub> is essential for life, that CO<sub>2</sub> is at an historical low concentration during this Pleistocene Ice Age and that more CO<sub>2</sub> rather than less would be generally beneficial to life on Earth.

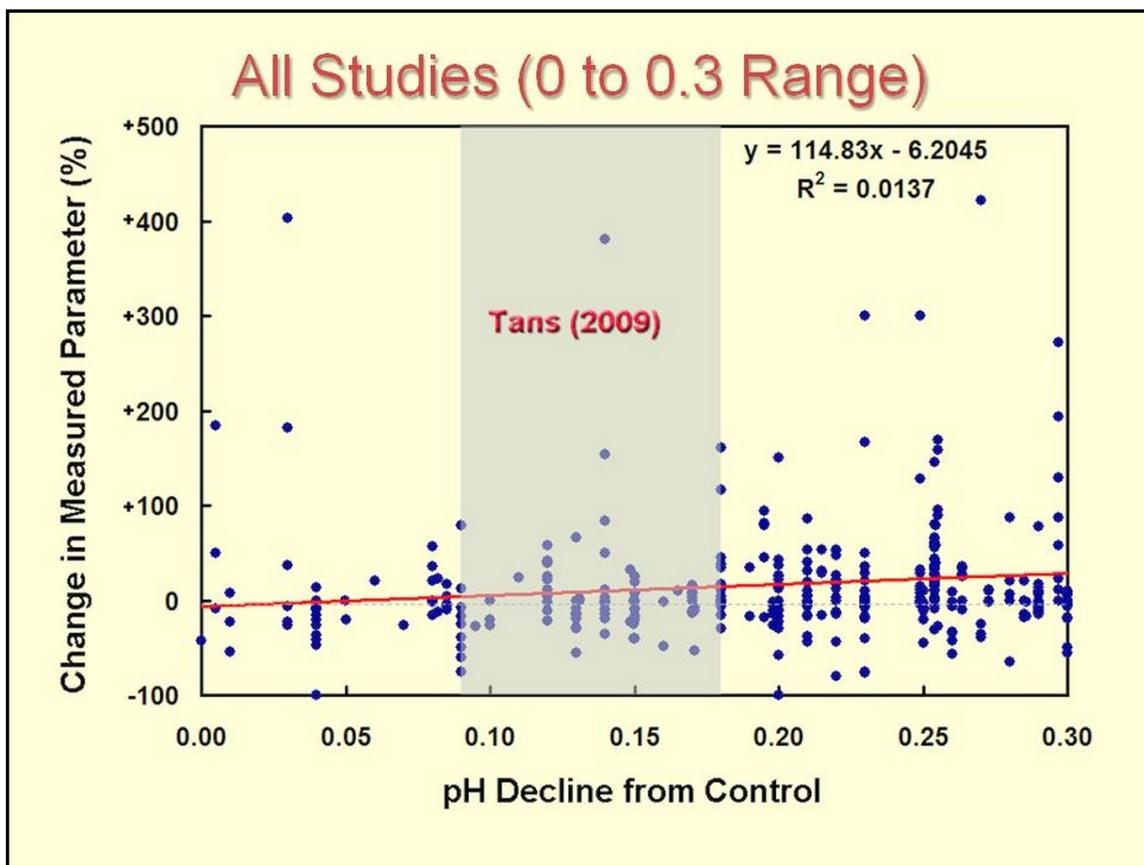


Figure 5. All peer-reviewed experimental results for pH decrease of 0.0 to 0.3 from present value.<sup>52</sup> (Prediction of range of actual expected pH change in grey). Five parameters are included: calcification, metabolism, growth, fertility and survival. Note that the overall trend is positive for all studies up to 0.30 units of pH reduction.

## CONCLUSION

There is no solid evidence that ocean acidification is the dire threat to marine species that many researchers have claimed. The entire premise is based upon an assumption of what the average pH of the oceans was 265 years ago when it was not possible to measure pH at all, never mind over all the world's oceans. Laboratory experiments in which pH was kept within a range that may feasibly occur during this century show a slight positive effect on five critical factors: calcification, metabolism, growth, fertility and survival.

Of most importance is the fact that those raising the alarm about ocean acidification do not take into account the ability of living species to adapt to a range of environmental conditions. This is one of the fundamental characters of life itself.

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