

The effects of ocean acidification



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As carbon dioxide (CO₂) emissions continue to rise, ocean acidification will continue to change our oceans ecosystems. There has been a recent tumult of research identifying the impacts of ocean acidification on marine organisms with more than 62% of the papers published since 2004 (UNESCO, 2008). A clear focus has been on coral ecosystem SO I'M NOT GOING TO. This paper lays out the fundamental oceanic processes that are affected by ocean acidification and then critically evaluates research methodologies and conclusions compiled for two, a coccolithophore, *Emiliana huxleyi* and the bivalve, *Mytilus edulis*, to determine if any clear correlations exist among research projects and what further research is needed. The conclusion is twofold: ocean acidification is species specific with adaptation taking center stage and past research is not indicative to true environmental conditions. (problem is that research isn't done over 100's of years but w/in 2-3 years ... CO₂ is changed dramatically). TOTALLY NEEDS WORK

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INTRODUCTION TO OCEAN ACIDIFICATION

In 2003, Ken Caldeira coined the term Ocean Acidification in hopes of drawing attention to a critical issue to our future. He defined it as the decrease in pH levels, and corresponding rise in acidity due to increased uptake of atmospheric carbon dioxide (CO₂) into the oceans (Caldeira and Wicket, 2003). Through modeling, Caldeira discovered that in the coming centuries the world would see more ocean acidification than in the past 300 million years. Six years later, 15, 000 (Indian Express, 2010) scientists and legislators gathered in Copenhagen, Denmark to determine what can be <https://assignbuster.com/the-effects-of-ocean-acidification/>

done to slow the inevitable process of rising CO₂ levels. Most of the attendees will not have a clear understanding of what ocean acidification is but will walk away with the knowledge that CO₂ emissions lead to much more than an increase in global temperatures. In fact, extensive research has been done to determine how marine organisms will adapt to this environmental shift. Each organism's ability to adapt will influence tropic levels and the corresponding ecosystems.

CO₂ Reservoirs

Atmospheric

The Industrial Age led to an undeniable rise in mass production and some would argue, a higher quality of life. However, this increase engendered a significant dependence on the combustion of fossil fuels which has led to a dramatic increase in atmospheric CO₂. This prodigious CO₂ release has been exacerbated by deforestation and urban development, which is eliminating an important CO₂ sink (Miller et al, 2009). Carbon is found not only in the atmosphere but also in the oceans and vegetation with carbon levels at 605 GT in the atmosphere, 433 GT in the oceans and 143 GT in plants (Dickson, 2009). The average concentration of atmospheric CO₂ (as of 12/12/09) is 385 parts per million (ppm), which is 38% higher than the pre-industrial level of 280 ppm only 200 years ago (IPCC, 2007). In comparison, CO₂ levels prior to the industrial revolution appear to have been fairly constant for the past XXXX years (Calderia and Wicket, 2003). Most alarming, is that 50% of this increase has taken place in the last 30 years (CITE).

Oceanic

Studies by the Royal Society (2005) indicate that the Earth's oceans act as a carbon sink, having absorbed 1/3 of all anthropogenic CO₂. This is approximately 2 billion metric tons of carbon per year. Chillingly, many do not realize that atmospheric CO₂ concentrations would be 48% higher if the oceans had not been diffusing CO₂ proportionately to atmospheric CO₂ (Sabine et al, 2004). This accounts for at least half of anthropogenic CO₂ emissions that has occurred since 1750 (Sabine et al, 2004). Another way to look at the atmospheric versus oceanic CO₂ volumes is to compare the total CO₂ concentrations. The ocean holds roughly 50 times greater concentration per unit volume than the atmosphere (World Resources Institute, 2009). Even if the atmospheric CO₂ began to decrease, the ocean's CO₂ saturation rate will continue to rise as the residence time of carbon in seawater is thousands of years (Nybakken and Bertness, 2005).

[Need to tie in / transition to this diagram. The following carbon flow diagram shows how carbon is cycled through the deep ocean and atmosphere. ?? Tie in to lag time??,]

Global Carbon Flows Fig. X

(Diagram courtesy of NASAscience. com, 2009)

OCEANIC PROCESSES AND CHEMISTRY

To understand the oceanic effects of rising atmospheric CO₂ levels it is imperative to review some fundamental oceanography concepts. Carbon is a natural and necessary part of seawater chemistry and without carbon in seawater, marine life would cease to exist. Just as there are several

biochemical cycles that are responsible for the movement of chemicals through the biosphere, there are two major pumps in the ocean. The biological pump which involves productivity and particle sinking and the solubility pump which is responsible for ocean circulation and mixing.

Ocean Processes

Oceanic Solubility Pump Fig. X

The solubility pump is responsible for moving carbon (DIC - Dissolved Inorganic Carbon) through the water column.

(Photo courtesy of Wikkipedia, 2009)

Atmospheric gases get absorbed, dissolved and released from the ocean via the solubility pump. Two ocean properties drive this pump: the thermohaline circulation and CO₂ solubility in water. The ocean's thermohaline circulation pattern connects surface waters with deeper waters via vertical and horizontal ocean currents (Nybakken and Bertness, 2005). The pattern is driven by water temperature, salinity and depth (Piney 2009). Colder, more saline water at higher latitudes is denser and therefore sinks (Press et al, 2004). For example, a major downwelling exists between Greenland and Iceland (CITE). This denser water eventually moves towards the equatorial latitudes with upwellings circulating the water towards the surface. When this water breaks the surface, CO₂ is out gassed to the atmosphere. This example is part of the ocean conveyor belt. The second property of the solubility pump consists of the solubility of CO₂ in seawater which is inversely related to the water temperature. As the water temperature decreases, the solubility of gases increases. Therefore, colder water in higher

latitudes carries more CO₂ than water at the equator (Pinet, 2009). As the colder water upwells, CO₂ is released because of warmer waters lower CO₂ capacity.

Oceanic Thermohaline Circulation

(Diagram courtesy of NASA, 2009)

There are two different sources of dissolved CO₂ in oceanic waters. The first is from atmospheric CO₂ that transfers across the water surfaces. The second is organic matter obtained from dissolved organic carbon (DOC) decomposition. As food is broken down, CO₂ is released and plants take up CO₂ when photosynthesizing. In a natural system, without excessive anthropogenic CO₂, the CO₂ values for the ocean and atmosphere are in equilibrium as the ocean is able to buffer small fluctuations. But as more and more atmospheric CO₂ enters the oceans, the equilibrium is disturbed. Similar to a production line, as more raw materials are added to the line, the rate of production needs to increase in order to maintain equilibrium. The ocean however can not “speed up” as it functions at a fixed rate. When CO₂ levels change over a period of more than 105 years, carbonate minerals buffer the CO₂ inputs and negligible pH changes occur (Calderia et al, 1999). However, when a CO₂ change occurs over a shorter time interval, less than 105 years, ocean pH is affected as the ocean’s natural buffering system can not cope with the higher input of CO₂ over the shorter time period (Calderia et al, 1999). As more CO₂ dissolves into the ocean, the higher oceanic CO₂ level persists without dispersing directly back into the atmosphere.

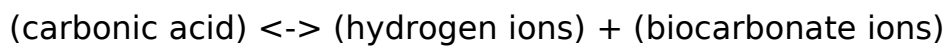
Oceanic Carbon Chemistry

When CO₂ dissolves in seawater, carbonic acid is produced via the following reaction:



The carbonic acid is not stable in seawater and immediately disassociates.

This causes a release of hydrogen (H⁺) ions and forms a bicarbonate ion:



An increase in hydrogen ion concentration increases the acidity of the seawater. When the hydrogen ions are released, they are able to combine with any carbonate ions in the water to form bicarbonate. Therefore the CO₃²⁻ is reduced by the number of hydrogen ions (Baird and Cann, 2008).



Calcifying organisms form calcium carbonate CaCO₃ from CO₃²⁻ (Miller et al, 2009). Therefore the calcification rate declines proportionately with the decline of CO₃²⁻ availability. The decrease of CO₃²⁻ (carbonate ions) is inversely proportional to the increasing anthropogenic CO₂ concentration (Orr et al, 2005). This process is referred to as lowering the water's saturation state with respect to calcium carbonate per (Sabine et al, 2004). Simply stated, more atmospheric CO₂ leads to more oceanic CO₂ which increases the hydrogen ion [H⁺] concentration and lowers the pH. Hence the term ocean acidification, the lowering of the ocean's pH.

Understanding Biomineralization and Calcification

Biomineralization is defined by Simkiss and Wilber as the process that produces the skeletons, shells, and teeth of most animals (1989). There are two different mineralization processes utilized by marine invertebrates: extracellular and intracellular mineralization (Weiner and Dove, 2003). Mollusks, scleratinian corals, bryozoans and some foraminifera use extracellular mineralization which involves secretion or active pumping of ions with active transport of vesicles across cell membranes (Weiner and Dove, 2003). Coccolithophores, echinoderms and other foraminifera utilize intracellular mineralization where specialized vesicles nucleate biominerals within the cell (Weiner and Dove, 2003). Calcification is a division in the field of biomineralization.

Marine calcifiers create shells or skeletons out of calcium carbonate. They employ carbonate ions as fundamental building blocks. This formation of structures utilizing calcium carbonate (CaCO_3) is called calcification (Baird and Cann, 2008). This definition may lead the reader to assume that CaCO_3 is a unique compound however calcium carbonate is predominate in marine environments as two common polymorphs, aragonite and calcite are the most commonly biomineralized forms of CaCO_3 (Miller et al, 2009). The difference is not the chemical makeup but rather their crystalline structure. For example pteropods have shells made of aragonite (Fabry, 2008) whereas, echinoderms and coccolithophores have shells made from calcite (Royal Society, 2005). Regardless of the polymorph, both aragonite and calcite dissolve as partial pressures of CO_2 increases (Miller et al, 2009). Calcification rates are sensitive not only to carbonate saturation state but

also to temperature, nutrients and light as well (Tuley et al, 2005). Once the solid CaCO_3 structure has formed, it then is constantly vulnerable to dissolution [HYPERLINK " http://en. wikipedia. org/wiki/Dissolution_\(chemistry\)"](http://en.wikipedia.org/wiki/Dissolution_(chemistry)) as the surrounding seawater must be saturated with carbonate ions (CO_3^{2-}) to maintain equilibrium. This is analogous to osmosis when the cell has an equivalent concentration to the surrounding liquid, it is in equilibrium and no exchange takes place. If the surrounding liquid has a lower concentration, then the cell donates ions to the water to reach equilibrium. This is true of the calcium carbonate, when the surrounding seawater becomes CO_3^{2-} poor the shell donates CO_3^{2-} to the surrounding seawater, leading to shell dissolution. As aragonite becomes less saturated in the surrounding seawater, the organism's metabolic costs for biomineralization increase (Weiner and Dove, 2003) leading to a trade off for energy usage. Note that an organism can use different polymorphs at different life cycle stages. For example, larvae will biomineralize aragonite, the metastable form of calcium carbonate and the more soluble form of CaCO_3 , as it requires less energy to utilize (Orr et al, 2005). In contrast, calcite is the predominant material used in adult shells (Miller et al, 2009) and is the more stable form of CaCO_3 (Orr et al, 2005). The higher the saturation state of aragonite, the greater the relative availability of both Ca^{2+} and CO_3^{2-} ions, which lowers the energy required for biochemical pumping needed to generate local supersaturation. Note that local supersaturation is required to produce shell material (Miller et al, 2009).

Saturation State

Any mineral in seawater has a saturation state (known as Ω). This is the measure of the energy of a system that allows the mineral to form or to dissolve.

Ω equals the multiple of the concentrations of calcium and bicarbonate ions when the mineral is at equilibrium (K_{sp}) divided by K_{sp} when the mineral is neither being created nor dissolved (Atkinson and Cuet, 2008).

The saturation state for CO_2 occurs in seawater when the maximum amount of dissolved CO_2 is held (Pinet, 2009). The amount is dependent on water temperature, pressure and salinity. If the water is colder, then more carbonate ions are being used to create bicarbonate ions and therefore not available to calcifiers to create calcium carbonate. At equilibrium, the carbonate ion is supersaturated and the calcite and aragonite are stable. But as ocean pH falls, the carbonate ion concentration also falls at the same rate, and when seawater becomes undersaturated, structures made of calcium carbonate dissolve. Today, most surface waters are supersaturated and therefore, calcium carbonate is insoluble. Descending through the water column, water chemistry changes due to temperature and depth which facilitates calcium carbonate solubility. The natural saturation horizon delineates where the solubility of $CaCO_3$ increases dramatically becoming undersaturated (UNESCO, 2009). Of the two polymorph structures, aragonite is 50% more soluble than calcite in seawater (Mucci and Morse, 1984) inferring that the aragonite saturation horizon is always above the calcite saturation horizon (Royal Society, 2005). This implies that organisms producing aragonite structures are more susceptible to increased acidity

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levels than those which produce calcite as the undersaturated levels for aragonite are closer to the ocean's surface (Orr et al, 2005).

Above the saturation horizon ($\Omega > 1$) calcite and aragonite do not dissolve. This is why most calcifying organisms are found in this habitat (Royal Society, 2005). This seawater zone is referred to as being supersaturated and is where CaCO_3 can form (Corliss and Honjo, 1981).

Below the saturation horizon ($\Omega < 1$) the rate of CaCO_3 dissolution, increases dramatically. As the CaCO_3 saturation decreases, shells start to dissolve.

Carbonate Compensation Depth (CCD)

The carbonate compensation depth (CCD) is located below the saturation horizon. At this depth, the rate of CaCO_3 supplied is equal to the rate of dissolution which means all CaCO_3 has dissolved (Pinet, 2009). Since the dissolution rate exceeds the production rate no calcareous plankton or sediment particles are found in the water column below the CCD.

(Calcium carbonate) + (Carbon dioxide) + water \leftrightarrow (calcium) + (bicarbonate ions)

This concept is critical to understanding where calcifying organisms are found in the ocean. If the sea floor is above the CCD, then when calcareous organisms die, the organism will fall to the bottom without dissolving. Otherwise, if the sea floor is below the CCD, all calcareous material will dissolve before reaching the sea floor. Therefore, shallow waters are usually full of shells as the waters are supersaturated in calcite and shells will not

dissolve in that environment. The crux is that the CCD is not a fixed point but is rather determined by temperature, pressure and chemical composition of the water. The shallowest CCD has been recorded in Guatemala at 3400 meters, and the deepest at 6000 meters, off the coast of North America. Generally, the CCD is shallow in high latitudes where downwelling conveys young, surface water with relatively low concentrations of carbon dioxide into the deep ocean, depressing the CCD. The various CCD depths depend on the length of time since the bottom water has been exposed to the surface; the concept is expressed as the age of the water. These 'water ages' are based on temporal variations regarding where the water is located on the global conveyor belt. The oldest water masses have the highest concentrations of CO₂ which also correlate to the shallowest CCD. The following diagram shows how the calcite dissolution level affects the formation of sediments as carbon is cycled through the water column.

Carbon Transformation Through Water Column Fig X

(Courtesy of Uriarte, 2009)

Ocean pH levels

Oceanic waters are naturally alkaline. The pH level defines how many free hydrogen (H⁺) ions are available in a sample of water or conversely, how many hydroxyl (OH⁻) ions are available (Baird and Cann, 2008). All living organisms have a pH tolerance range which is the organism's acidity tolerance. If the pH levels drop or rise beyond the organism's tolerance, then it will cease to inhabit that location. The free hydrogen ions control the acidity of the water (Pinet, 2009). For example, deep, cold waters are naturally too acidic for marine calcifiers to survive (World Resource Institute, <https://assignbuster.com/the-effects-of-ocean-acidification/>)

2009). A pH scale ($\text{pH} = -\log_{10}[\text{H}^+]$) represents the acidity of a liquid ranging from 1 to 14 with 1 being extremely acidic, 7 is neutral and 14 is extremely alkaline or basic. The H^+ ions react with other compounds in the water and therefore, the more free H^+ ions there are, the more acidic the water is (Baird and Cann, 2008). As hydrogen ions increase, pH decreases. Since acidity is measured on a logarithmic scale, for every unit decrease on the pH scale, the hydrogen ion concentration increases 10-fold. For example if the pH drops from 8 to 7, the hydrogen ion concentration has increased 10 fold. If the pH dropped 0.4 units that would represent more than a doubling, an almost 150% increase, in acidity. The oceans regularly have slight fluctuations in pH as water temperature, water pressure and salinity all impact the amount of dissolved CO_2 that the water can hold and thus hydrogen ions. These small changes in pH are mitigated by buffering capabilities of the natural oceanic system. The pH of pristine seawater ranges between 7.5 and 8.4 depending on the source (World Resource Institute, 2009) (Nybakken and Bertness, 2005) (Pinet, 2009). Since 1760, a 0.1 decrease in pH has been observed which equates to a 30% change in hydrogen ion concentration in the upper 200 meters of the water column (Miller et al, 2009) (Orr et al, 2005).

RESEARCH: HISTORICAL AND PREDICTIONS

Ocean Research and Predictions

A global ocean survey was conducted in 1994, analyzing the water chemistry from 17,000 locations at 37 depths (Dickson, 2009). These readings help provide a picture of the oceanic status throughout the world. One of the major findings highlighted that the ocean is being contaminated with CO_2

from the surface waters. Where the highest CO₂ concentration was found correlated with a reduced CCD (Dickson, 2009). The North Atlantic Ocean results differed from global findings as dense cooling waters sank to the seafloor bringing CO₂ along with it (Dickson, 2009). The importance of this distinction is that when this water hits an upwelling, those higher CO₂ are brought closer to the surface. Research has shown that the saturation horizons for calcium carbonate have shifted towards the surface by 50-200 meters since prior to the industrial revolution (Doney, 2006). Also noted from the global data was that continental shelves play a critical role as spawning and nursery habitats (Feely et al, 2008). The global research indicated that temperate coastal locations had a faster rate of acidification than previously predicted (Science Daily, 2009).

In 2004, world renowned marine biologists predicted in *Nature* that by 2050, 15% to 37% of species and taxa will become extinct (Thomas et al, 2004). More recently, in 2007, the Intergovernmental Panel on Climate Change (IPCC) predicted ocean acidity could increase 150% by 2100 based on current usage predictions for 2007 (IPCC). Many general predictions have been made regarding the oceans fate, in particular the calcifying organisms. At the Ocean Acidification Second Symposium in 2008, it was announced that even if CO₂ levels were maintained at 450 ppm the polar oceans may still become corrosive and coral habitats would be lost. Additionally, it was suggested that further research be focused on coastal zones influenced by river inputs or upwellings as these habitats would be indicative of future ecosystems (UNESCO, 2008). The reasoning is that coastal zones have low biodiversity and high counts of invasive species, which could be a similar

result with acidification as few organisms can tolerate higher acidities. Also anthropogenic ocean acidification greatly influences coastal regions due to its close proximity of emission sources (Doney et al, 2007). Lastly, based on the 'age of water' concept regarding the oceanic global conveyor belt, it could take thousands of years for water chemistry to return to pre-industrial levels. The following diagram illustrates the correspondence between increasing CO₂ levels and decreasing pH Levels.

Global Ocean Acidification (How CO₂ Impacts pH Levels) Fig. X(Courtesy of IPCC, 2007)

Calderia and Wickett (2003), Sabine et al (2004) and The Royal Society (2005) all predict a decrease in pH of 0.1 to 0.5 by the end of the century utilizing the IPCC IS92a scenario which correlates with a 100 to 150% increase of hydrogen ion concentration. As the atmospheric CO₂ rises, so too will the saturation horizon and the CCD. The saturation horizon has been predicted to rise 50-200 meters relative to its position in pre-industrial times (Doney et al, 2007) with downwelling zones first being affected (Orr et al, 2005) which was proven by the global ocean survey. Currently the National Oceanic and Atmospheric Administration (NOAA) is investigating large bodies of water that are already undersaturated in aragonite in upwellings off the Pacific continental shelf (Feely et al, 2008).

Projections

In 1992 the IPCC released projected emission scenarios levels ranging from best case to worst case. These levels were used throughout the scientific community as standard predictions for research. Alarming, current CO₂

emission levels are now greater than what was projected as the worst case scenario 17 years ago (UNESCO, 2008).

The reason why pH is important is that CO₂ regulates the acidity of seawater (Pinet, 2009).

Given the input Co₂ levels, the projected Oceanic pH levels are shown.

pH Predictions Fig. X

(Courtesy of World Resources, 2009)

Past levels (Pearson and Palmer, 2000)

Future predictions based on IPCC mean scenarios.

Historical Carbon

Critics to the severity of ocean acidification fall back on the argument that large atmospheric CO₂ releases have taken place, due to significant volcanic activity without significant implications. This refers to the Paleocene-Eocene Thermal Maximum (PETM) that occurred 55 million years ago at the end of the Paleocene epoch (Gibbs, 2006). Analyzing geologic sediments for fossil foraminifera remains, an oceanic pH history can be recreated demonstrating a much shallower CCD (Orr et al, 2005). The higher CO₂ levels were mitigated by corresponding elevated ocean temperatures and the natural oceanic buffering system (Orr et al, 2005). Researchers have estimated over 50 species of foraminifera disappeared with previously rare organisms becoming prominent (CITE). However, the current day CO₂ atmospheric rise and PETM comparison is equivalent to comparing a pteropod to a Humpback whale. Yes, both today's CO₂ rise and PETM were dramatic increases in CO₂ but that is where the similarities end. The PETM duration is estimated to be

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1, 000 to 10, 000 years in length. During this time, the natural buffering process of discarded shells can alleviate the increased CO₂ impact. Today's rate of CO₂ release is comparable to a 3 times to 30 times quicker release, respectively (Gibbs et al, 2006). The current release levels of CO₂ are too high to be absorbed by the ocean's natural buffer capacity .

ORGANISMS IMPACTED

All organisms, whether referring to bacteria, phytoplankton or multi-celled organism, the goal is the same, to survive and reproduce. Organisms have water chemistry tolerances and differ in their ability to adapt to change. For calcifying organisms changes in water chemistry, including pH levels can alter metabolic efficiencies and demand energy trade-offs between physiological needs and calcification requirements (Miller et al, 2009). There are two major concerns with acidity levels, the length of exposure to higher acidity levels and the tolerance to under saturation of aragonite or calcite (Miller et al, 2009). In most of the calcifying organisms researched in more acidic waters, ranging from single-celled foraminifera, to crustacea, there was a notable decrease in the organism's ability to produce calcium carbonate (Feely et al, 2004) (Gazeau et al, 2007) (Bibby et al, 2008) (Findlay et al, 2009) (Berge et al, 2009).

The effects of ocean acidification can vary dependent on existing environmental conditions, (including water chemistry), as well as, organism-specific dependencies such as stage of life cycle and habitat preferences.

Environmental Dependencies Table X

Physical Characteristic

Impact

Water temperature

Influences solubility rate

Salinity range

Influences solubility rate

Depth (pressure)

Influences solubility rate

Water currents

Upwelling & downwelling

Latitude

Impacts solar radiation

Whereas, organism specific dependencies range from life cycle stage to habitat preferences that can influence the effects of raised CO₂.

Organism Dependencies Table X

Characteristic

Impact

Species

Species specific impacts

Life Cycle

Larvae, juvenile, adult

Adults have ability to redirect energy reserves (McDougall, 2009)

Juveniles uses aragonite versus adults use more calcite (,)

Habitat Location

Latitude & depth

Water chemistry

Tolerance ranges

Biomineralization

Dependent on use of aragonite versus calcite

During testing for susceptibility to higher CO₂ (lower pH) , effects covers an immense range of morphological and physiological deformities from reduced growth to respiratory distress and mortality (Royal Society, 2005).

Organism Impacts for Rising CO₂ Levels Table X

System

Implications

Result

Source

Morphology

Ability to construct calcareous structure/shell

Diminished or eliminated growth progress

(Kurihara, 2008) (Riebesell et al, 2000)

Physiology

Acidosis, build up of carbonic acid in body fluids

Disrupt growth, respiration and reproduction

(World Resource Institute, 2009)

Physiology

Energy transference

Growth energy diverted to increase calcification and/or energy reserves depleted

(Miller et al, 2009)

Physiology

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Hypercapnia – acidification of body tissues and fluids

Reproductive and physiological effects

(Miller et al, 2009) (Turley et al, 2005)

Physiology

Respiration affected

Decreased rate, ineffective energy use

(Kurihara, 2008)

Physiology

Food resource limitations

Mortality

(Royal Society, 2005)

Physiology

Reallocation of resources from feeding and reproduction to maintain consistent internal pH levels

Reduction in recruitment and growth

All things considered 34 = wiki

Physiology

Less effective sperm

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Decreased fertilization success, mortality

(Scripts Insitute, 2009)

Behavioral

Echolocation distance increases

Communication and predatory consequences

All things considered

34 = wiki

Behavior

Vulnerable larval development stage

Increased pre-settlement time increases mortality

(McDougall, 2009)

Behavior

Impacts habitat, settlement preferences ,

Increased larval stage in water column increases predation leads to mortality

(Kurihara, 2008)

Ocean Acidification Possible Impacts Fig. X

(Courtesy of Kurihara, 2008)

RESEARCH

pH Tolerant Organisms

It should be noted that some calcifying species were tolerant to increased CO₂ levels. For example, nitrogen-fixing cyanobacteria may benefit from elevated CO₂ levels as reported by the Ocean Acidification Symposium in 2008. Increased carbon fixation rates in some calcifying and noncalcifying photosynthetic organisms due to rising CO₂ was also noted by Doney (2009). There is also the potential for marine organisms to adapt to increasing CO₂ over a period of time. These adaptations could occur over generations and not be observable during a month or two research project.

pH Intolerant Organisms

There is an enormous breadth of species that ocean acidification affects ranging from benthic invertebrates with skeletal elements including crustaceans (barnacles, lobsters, cnidarians, sponges, bryozoans, annelids, brachiopods and tunicates to echinoderms such as the starfish, mollusks (oysters, clams, scallops) (Fabry et al, 2008) . Some of these organisms may be able to adapt relatively quickly to changes in water chemistry, however echinoderms and bivalves have long generation times which means that any adaptations will occur over a period of time (Kurihara, 2008). The remainder of this paper will focus on two different organisms where extensive acidification research has been conducted. The coccolithophore, *Emiliana Huxley* and the bivalve, *Mytilus edulis*. The purpose of the review is to determine if the research has any commonalities, if the methodologies correlate and were appropriate and determine if the analysis are predictive of future research results.

Coccolithophores – *Emiliana huxleyi* (Table X)