The Impact of Ocean Acidification on Aquatic Organisms

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Abstract

When carbon dioxide dissolves in oceans it forms carbonic acid which triggers chemical reactions that reduce the pH (increasing the acidity) while reducing the availability of buffers such as carbonates. Most water dwelling organisms particularly fish depend on their chemoreceptors to detect the odor of food, finding mates for reproduction, predators/ prey recognition, homing clues etc. When chemoreceptors are compromised due to ocean acidification the life of fish is disoriented and in chaos. The carbonates are not only acting as buffers in oceans, seas or rivers but are crucial in that many shellfish and corals need it to build their skeletons and shells. When the carbonate is less, organisms spend more time on shell building and less on eating and basic survival skills. This harm the organism and eventually reduces the entire population. The world’s oceans are warming up and becoming more acidic. Both stressors (ocean warming up and acidification), singly or in combination, impact marine species, in diverse ways and the effects might be particularly serious for early life stages of aquatic organisms. The paper reviews and addresses six spheres of ecological and ecosystem consequences of ocean acidification. The spheres are effects of acidification on i) Chemoreception, ii) Shells of organisms, iii) On coral reefs, iv) On algae, v) Invasive species and vi) Minute (unknown and may be less known) organisms.

Keywords: Acidification; Ocean; pH; Fish; Acidic; CO₂; Larvae; Organisms

Introduction

The acid in rivers and lakes are as a result of acid rain or snow or/and carbon dioxide deposition. The release of sulfur dioxide and nitrogen oxide following fossil fuel combustion and consequently these gases combining with water vapor to form sulfuric and nitric acids reduce the water pH. When precipitation fall into rivers or lakes the pH value of water becomes as low as 5.50 or even lower than this. In the Northeastern part of the United States and Eastern Europe, decades of acid precipitations have depleted the soil buffering capabilities such that any further acidic depositions may have rapid long lasting effects on ambient water pH [1]. While it is clear now that in these parts of the world emissions have generally decreased [2], globally they remain at relatively constant levels from other countries still emitting high amounts of sulfur dioxide [3,4], and as such the problem of acid rain is likely to reach areas previously not affected by acid rain. Since the beginning of the Industrial Revolution, the burning of fossil fuels, the production of cement and other anthropogenic activities have increased atmospheric carbon dioxide concentrations and the amount of carbon dioxide dissolved in the oceans [5] (Figure 1).

Acidification of oceans which occurs through addition of carbon dioxide from the atmosphere compounds the already existing problem decreasing the pH to lower levels. Oceans face a serious change to their natural biochemical cycle due to the rapid absorption of carbon dioxide generated by human activities. The world's oceans are becoming more and more acidic.

Other Research Done on the Impact of Acidification

A great deal of laboratory research has been done over the past 15 - 25 years on how increasing ocean acidity may be affecting fish, cray fish, salmon etc, how the small fry struggle to grow, how both young and adult fish lose the ability to detect the odor of their predators and food, how they fail to select their mate for reproduction and consequently how their whole life is impacted by acidification. Tembo [6], explained how Acidification significantly affected the chemosensory behavior of gold mollies (Poecilia sphenops). Not only were the fish affected in their chemoreceptors but failed to locate the food odor source presented to them. A dangerous scenario because chemoreception plays a major role in the lives of fish which include feeding, prey detection, predator avoidance, species and sex recognition, sexual behavior-mate selection, homing, microhabitat choice, kin recognition and migration are all dependent upon the use of their chemoreceptors, at least to some extent. Anything that damages the chemoreceptors in fish decreases the chance to see the basic environmental stimuli critical for long term survival. Mature fish ready for reproduction become insensitive to sexual pheromones. A loss in chemoreceptors means the fish is hopelessly vulnerable to all ills. Other researchers have investigated and

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found that the time necessary for recovery of the olfactory sampling and orientation abilities mirrors that which is needed for the regeneration of the damaged olfactory tissues and complete neurogenesis [7,8]. This may indicate that impairment to olfactory mediated behavior might require a longer recovery period, particularly if no time is provided between exposure events allowing for regeneration of necessary tissues and neurons Azzizirizra et al. [9] - that is laboratory experiments, imagine the impact that is there when the fish is continuously living in acidified ocean environment. Ocean acidification has significant behavioral and sensory impacts attributed to impacts on the nervous system of several species of fish [10, Dixson et al. [11] found that settlement stage larvae could not discriminate between predator and non-predator chemical cues at pH 7.8 and studies at carbon dioxide seeps demonstrate altered predator cue responses in juvenile fish [12,13] increasing vulnerability to predation. Visual and auditory predator cue responses can also be compromised by near-future ocean acidification [12,14,15]. Baumann et al. showed that exposure of early life stages of a common estuarine fish (Menidia beryllina) to elevated carbon dioxide concentrations caused severely reduced survival and growth rates. The egg stage was found significantly more vulnerable to high carbon dioxide induced mortality than the post hatch larval stage. In another experiment with high commercially important mass spawning fish, Atlantic cod larvae (Gadus morhua) Frommel et al. [16] showed detrimental effects of ocean acidification on the developmental stages of cod. Exposure to carbon dioxide resulted in severe to lethal tissue damage in many internal organs in larval cod, degree of damage increased with increase in carbon dioxide concentrations. As larval survival is the bottleneck to recruitment, ocean acidification has the potential to act as additional source of natural mortality, affecting populations of already exploited fish stocks and small change in early life survival can generate large fluctuations in adult fish abundance.

A rapidly growing body of research indicates that ocean acidification will severely disrupts marine ecosystems, since it alters the balance of success between competing organisms. Ocean acidification is projected to impact all areas of the oceans, from the deep sea to the coastal estuaries [17] with potentially wide-ranging impacts on Marine life [18]. This will affect a wide range of processes across marine taxa, including photosynthesis, acid-base homeostasis, calcification and behavior [19]. There is no definitive pH range within which all freshwater aquatic life is unharmed and outside which adverse impacts occur. Rather, there is a gradual deterioration in acceptability as pH values become further removed from the normal range. The acceptable range of pH to aquatic life, particularly fish, depends on numerous other factors, including prior pH acclimatization, water temperature, dissolved oxygen concentration and the concentrations and ratios of various cations and anions [20]. In 1980 Alabaster and Lloyd identified the pH range that is not directly lethal to freshwater fish as between 5.0 – 9.0. Some aquatic organisms (e.g., certain species of algae) have been found to live at pH 2 and lower and others at pH 10 and higher [21]. However, there are few such organisms and their extreme tolerance are not reflective of the pH tolerated by the majority of organisms occurring in a given aquatic ecosystem.

Impact on Organisms with Shells

Fabry et al. [22], said the ocean carbonate chemistry is extremely important for the mineral formation of calcium carbonate (CaCO$_3$) which is a crucial structural element of shells and skeletons of marine calcifying organisms. If ocean acidification continues to evolve at the present rate of approximately 0.5% year$^{-1}$ from 180-300 ppmv (prior to Industrial revolution, Siegenthaler et al. [23] to 380 ppmv (Fabry et al. [22]), the surface of the arctic ocean will be under saturated with respect to aragonite (the more soluble form of CaCO$_3$) by the year 2050, with atmospheric carbon dioxide of over 500 ppmv and undersaturated with respect to calcite by the year 2100, with atmospheric carbon dioxide of over 800 ppm [24]. Despite the fact that shells protect mollusks from physical stresses such as heat, desiccation and wave forces, they function primarily as a defense against predators. Co-evolution between predatory crabs and their gastropod prey has led to increased shell thickness and sculpturing in marine gastropods and bivalves for defense [25]. Some mollusks exposed to cues from their predators increase shell thickness as an inducible defense [26]. While many mollusks species also use habitat or density refugia to avoid encounters with predators, sessile species that cannot move to escape predators such as oysters and mussels rely for defense primarily on their shell thickness. Calcified prey allocate a large amount of energy to shell growth as a defense against predators. As ocean acidification increases the shells of these organisms become thinner or weaker shells for some species. Mollusk larvae and juveniles are sensitive to acidity, exposure of early life stages of mollusks to acidification may result in bottleneck for their populations [27,28]. The slow development of mollusk larvae and recent studies suggest that carry over effects between life history stages of mollusks can influence the response at later life stages. Larvae abnormalities have been reported in mollusks and echinoderms exposed to sea water acidification by carbon dioxide [29]. The morphological abnormalities could be due to two possibilities: (a) damage to the embryonic ectodermic cells rendering them unable to produce sufficient amorphous calcium carbonate, which is crucial in the development of a strong shell and (b) dissolution of the shell due to corrosion by acidified sea water. Most species will not be able to make their shells and will not be able to grow.

The Impact on Coral Reefs

The effect of ocean acidification decreases the carbonate ion concentration which leads to reducing the rate of calcification of marine organisms such as reef building corals, favoring erosion at 200 mol. kg$^{-1}$ sea water [30]. Reef-building corals may exhibit several responses to reduced calcification, all of which have deleterious consequences for reef ecosystems:

1. Decreased linear extension rate and skeletal density of coral colonies as the one shown on the massive coral Porites on the Great Barrier Reef with a reductions in linear extension rate of 1.02% year$^{-1}$ and in skeletal density of 0.36% year$^{-1}$ during the past 16 years. Truly this is equivalent to reduction of 1.29% year$^{-1}$ or 20.6% drop in growth rate over the 16-year period.

2. Corals may maintain their physical extension or growth rate by reducing skeletal density. However, erosion could be promoted by the activities of grazing animals such as parrotfish, which prefer to remove carbonates from lower density substrates. Increasingly brittle coral skeletons are also at greater risk of storm damage [31], if the rates of erosion outstrip calcification, then the structural complexity of coral reefs will diminish, reducing habitat quality and diversity. A loss of structural complexity will also affect the ability of reefs to absorb wave energy and thereby impairs coastal protection.

3. Corals may maintain both skeletal growth and density under reduced carbonate saturation by investing great energy in calcification. The side effect of this strategy is the diversion of resources from other essential processes such as reproduction as seen in chronic stress [31], which could ultimately reduce the larval output from reefs and impair the potential for recolonization following disturbance. Corals in deep waters are excellent nursery habitats for many species of fish and other
micro-organisms and also food for many predators, natural defenses for storms and erosion (Figure 2).

What happens when corals are left for a number of hours in acetic acid (vinegar)? What would happen then if these corals are in acidic environment forever? (Figure 3).

The Impact on the Algae

Algae species will greatly benefit from ocean acidification since increased availability of Carbon dioxide and bicarbonate ions (HCO$_3^-$) can stimulate photosynthesis [32]. Uncalcified algal taxa have been considered unresponsive to CO$_2$ enrichment due to the presence of efficient carbon concentrating mechanisms (CCMs) and carbon saturated photosynthetic rates [33]. However, not all algal groups contain and utilize CCMs, as some rely upon the diffusive flux of CO$_2$ to support photosynthetic rates [34-36]. Thus, these taxa may benefit from acidification and increases in CO$_2$ [37]. Prior work has demonstrated increases in the biomass of temperate turfs under CO$_2$ enrichment [38,39]. These responses were linked to increases in effective quantum yield, suggesting that CO$_2$ enrichment may have improved photosynthetic efficiency. Some primary producers are better able to capitalize on increasing carbondioxide availability than others, and this will definitely alter marine communities. Invasive algae will be expected to benefit in competitive interactions under acidified conditions since they tend to be non-calcarous, have wide thermal and salinity tolerances, are highly fecund, grow rapidly and are often parthenogenic. This carbon boost to invasive algae may be coupled with temperature-driven range extensions of warm water herbivorous fish that can remove temperate macroalgae, facilitating the spread of warm water invasive species such as *Neosiphonia harveyi* [40]. Ocean acidification will help certain invasive species of algae like, jelly fish, crabs and shellfish which are more tolerant of the rising Carbon dioxide levels than native species in many areas to spread and take over new habitats. Results from research done by other researchers show that different species of algae (phytoplankton) reacted differently according to the acidity (Figures 4 and 5).

Subtle Impacts on Known and Unknown Organisms

But there are many other, more subtle effects of increased sea water acidity on microorganisms which will not be known because scientists tend to concentrate researching on relative well defined sized organisms. The nutritional chemistry of the food chain producers at the bottom of the sea or ocean, the ciliates, flagellates what of the growth and health of the many marine microorganisms (zooplankton) that feed on phytoplankton (the producers). How is the whole dynamic of

*Figure 2: Corals impacted by acidic oceans.*

*Figure 4: Killer algae thriving well in ocean acidified water.*

*Figure 3: Ocean acidification risking marine life.*

*Figure 5: Photosynthetic seagrass benefiting from higher CO$_2$.***
intraspécifique et interspécifique interactions among the many organisms in the food chain and entire ecosystem affected by this acidification? There is also an increased energetic demands of predators due to the physiological effects of ocean acidification which could also increase predation rates in some species [41]. How do all these minutest microorganisms respond to acidified water of our seas and lakes? What of their eggs/gametes, hatchlings and young adults? Can it be that pH tolerance is related to local pH variability regimes (defined here as sites with high variance in pH time series observations and frequent exposure to low pH). As the pH variability range increases, the pH range within which organismal physiology must operate widens, creating the environmental regime that would select for fertilization kinetics that are resistant to low pH (Figure 6). Observing this effect in natural populations is extremely valuable as it infers transgenerational plasticity (via maternal provisioning or epigenetic modification Ross, Hofmann et al. [42,43] or local adaptation and a potential means for genetic adaptation to future ocean acidification [44-47]. Species that can adapt to spatial environmental differences may be better equipped to adapt to temporal changes, such as ocean acidification.

In the context of ocean acidification, the environmental parameter on the Y axis is pH. As low pH exposures increase in frequency and the pH variability envelope widens (Site 2), the pH range within which organismal physiology must operate also widens. Through local environmental conditioning or natural selection, this may cause spatial differences in a species' tolerance window across its biogeographic range (dashed lines). Invasive species are by nature adaptable and this will play an important role in determining their success as the chemistry of the oceans continue to change. The role of adaptation has not been explored extensively with regard to ecologically harmful marine species, however, the increasing rate of ocean acidification is narrowing the time window available for marine organisms to adapt, thus organisms with resilient genotypes present in current populations have an advantage. Some invasive species have strains that are particularly resilient ocean acidification, for example the invasive C. gigas may adapt more readily to ocean acidification than its native competitor S. glomerata in Southern Australia [48].

Conclusion

Is there a possibility that nations of the world can stop/reduce the emission of sulfur dioxide, nitrogen oxides and carbon dioxide into the atmosphere? Maybe it is more political than moral will. The major concern is that atmospheric carbon dioxide levels are relentlessly going up and are expected to reach and exceed 500 ppm by 2050 [49]. More research is required on species-specific response to acidification to accurately predict which species might be at greatest risks. The short term technique of liming has been used in the past by Scandinavia to partially neutralize the acidic waters and was very successful [50]. To avoid substantial damage to ocean ecosystems and marine life, deep and rapid reductions of global Carbon dioxide emissions are needed from human activities. Can Presidents of the world do something like this to mitigate the ocean acidification and the impact on marine life caused by their nations? The saying ‘reduce, re-use, recycle’ also applies to the ocean acidification crisis. Using less products will lead to a decreased demand to create new product out of new materials. Everyone should be able to think of a way they can consume less in their daily lives. Transportation is a huge concern, and is one that is difficult for people to make adjustments to. Driving less and using public transportation may not be a realistic option for everyone, but people can make sure their automobiles run efficiently by keeping the tires properly inflated, getting their cars serviced regularly, and by choosing fuel efficient vehicles. Automobile manufacturers must quickly start making cars that are hybrid or more efficient so that no much CO₂ should be emitted out in the environment. But definitely if we humans don't do anything to ameliorate the acidification impacts on marine life, salvation of these organisms may come through other way but only after many have died. In marine habitants, adaptation through natural selection on individual variation in carbon dioxide sensitivity could occur with or without mitigation to acidified seas water. Variation in the level of behavioral impairment has been shown by individuals of fish exposed to elevated carbon dioxide with some individuals apparently showing more resistant to the effects of elevated carbon dioxide than others [51]. There is clearly the potential for natural variation in sensitivity among individuals to lead to genetic adaptation in marine organisms. Thus organisms with resilient genotypes present in current populations have an advantage. But really as human beings should we leave the survival of marine organisms to the fate of natural selection? Knowing the adaptive potential of marine fishes and other aquatic organisms to elevated CO₂ and the speed at which adaptation might occur will be critical in predicting the impacts of acidification on marine ecosystems. A lot of research work on ocean acidification done so far has been on the laboratory level. It will be important to consider the limitations in applying organisms' responses from laboratory experiments to predictive modeling of natural habitats, as laboratory responses will not necessarily translate to the wild.

A deadly recipe is brewing that threatens the survival of countless creatures throughout the earth's oceans. For years we have known that the oceans absorb about 25% of the atmospheric carbon dioxide, but with a higher carbon dioxide emissions worldwide, this silent killer is entering into our seas at a staggering rate, raising the ocean's acidity and lowering the pH. The combining effect of global warming and ocean acidification has unspeakable detrimental effects on coral reefs plus millions of organisms that live under acidified water. There is no doubt on my mind that sea water acidification affects the intracellular pH of the egg and sperm and alters sperm motility, fertilization and embryo development of many aquatic micro-organisms.

References


