

Effects of Ocean Acidification on the Marine Organisms

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Abstract. Climate change is a severe environmental issue which can mainly be caused by anthropogenic activities like deforestation. It can cause another severe environmental issue called ocean acidification. It is worth seeking how ocean acidification occurs and how ocean acidification affects marine organisms including marine animals, marine plants and marine microorganisms. The increase of atmospheric carbon dioxide can be a dominant driver of ocean acidification. Ocean acidification can adversely influence marine animals like oysters. It can also either cause positive or negative impacts on marine plants. Marine microorganisms and marine biodiversity can also be sensitive to ocean acidification. Multiple strategies can be implemented to mitigate ocean acidification such as atmospheric carbon dioxide removal, growing of coastal seagrass, educational activities, and cultivation of marine submerged aquatic vegetation. However, the effectiveness and efficiency of mitigation strategies still need to be tracked in the long term. The quality of data collection for implementing the mitigation strategies is essential to determine and predict the response of the ocean towards to mitigation of ocean acidification.

Keywords: Climate change; ocean acidification; carbon dioxide; marine microorganism; marine organisms.

1. Introduction

Climate change can be caused by the increase in burning fossil fuels, production of cement and land use changes, which can cause higher emissions of atmospheric carbon dioxide [1]. In this situation, climate change has gradually become one of the most severe environmental issues occurring nowadays. An adverse impact on the ocean can be resulted by climate change and can cause ocean acidification because the ocean can be a large carbon sink to absorb atmospheric carbon dioxide and react with the atmospheric carbon dioxide (CO₂) to form the weak acid [2]. Therefore, ocean acidification can occur more severely following climate change. Ocean acidification can adversely influence marine life inducing both marine organisms and marine microorganisms can show different responses to the ocean acidification [3]. Ocean acidification can adversely influence the coral reefs, shrimps and cyanobacteria and other marine organisms [3].

Tracking and alleviating ocean acidification are essential due to ocean acidification can lead to phenotypic plasticity, loss of biodiversity and other biological issues, indicating marine organisms can be susceptible to ocean acidification [3]. Recent studies can mainly focus on how ocean acidification mainly influences around one or two organisms in each study. Some studies can illustrate the reason and mechanisms of ocean acidification in general. However, the broader scale of illustrating ocean acidification can be discussed in this paper. It is because some research papers do not include a discussion of how ocean acidification arise in detail and the discussion of how effects of ocean acidification influence organisms living in the ocean and marine microorganism in one paper simultaneously.

This paper illustrates briefly how ocean acidification occurs and influences marine life including marine organisms and marine microorganisms in detail. Also, the specific mitigation strategies for alleviating ocean acidification are demonstrated in the paper.

2. Mechanism of Ocean Acidification

Ocean acidification can happen due to the increase of carbon dioxide emissions having a dominant contribution to greenhouse gas emissions [1]. RCP 8.5 can have the highest carbon dioxide emission

resulting in a more severe state of ocean acidification. Multiple distinct chemical reactions can consist of ocean acidification. Firstly, atmospheric carbon dioxide can dissolve in the surface water of the ocean and become aqueous carbon dioxide [4]. It is because atmospheric carbon dioxide can be soluble in water [5]. Secondly, aqueous carbon dioxide can react with water molecules to produce many ions through the sequence of reversible chemical reactions [4]. 90% of the product can be bicarbonate ions (HCO_3^-) 9% of the product can be carbonate ions (CO_3^{2-}) and 1% of the product can be remained as carbon dioxide (CO_2) or carbonic acid (H_2CO_3) [4]. The chemical reactions of ocean acidification can also indicate that the net effect can be the increase of hydrogen-ions (H^+) and the decrease of carbonate ions with the addition of carbon dioxide to the ocean water [4]. The RCP is termed Representative Concentration Pathways which can describe the range of greenhouse gas (GHG) emissions and can be used to simulate the consequence of a specific climate system [6]. The RCP 2.6 suggests a stringent mitigation scenario which regulates greenhouse gas emissions stringently and can show a slight and gradual increase in greenhouse gas emissions [6]. RCP 8.5 suggests the loose mitigation scenario which shows very high greenhouse gas emissions without regulation [6]. Ocean pH can drop around 0.4 and 0.77 by 2100 and 2300 respectively [1]. The decrease in pH can cause specific biological impacts on marine life due to pH value is essential to influence chemical properties including chemical reactions, and toxicity [7]. One of the most apparent outcomes of ocean acidification can be the decrease of ocean pH under scenarios which does not have any mitigation or regulation strategies for carbon dioxide emission as shown in Fig. 1 [8]. It is due to the higher hydrogen ions that can occur to lower the pH of the ocean [4].

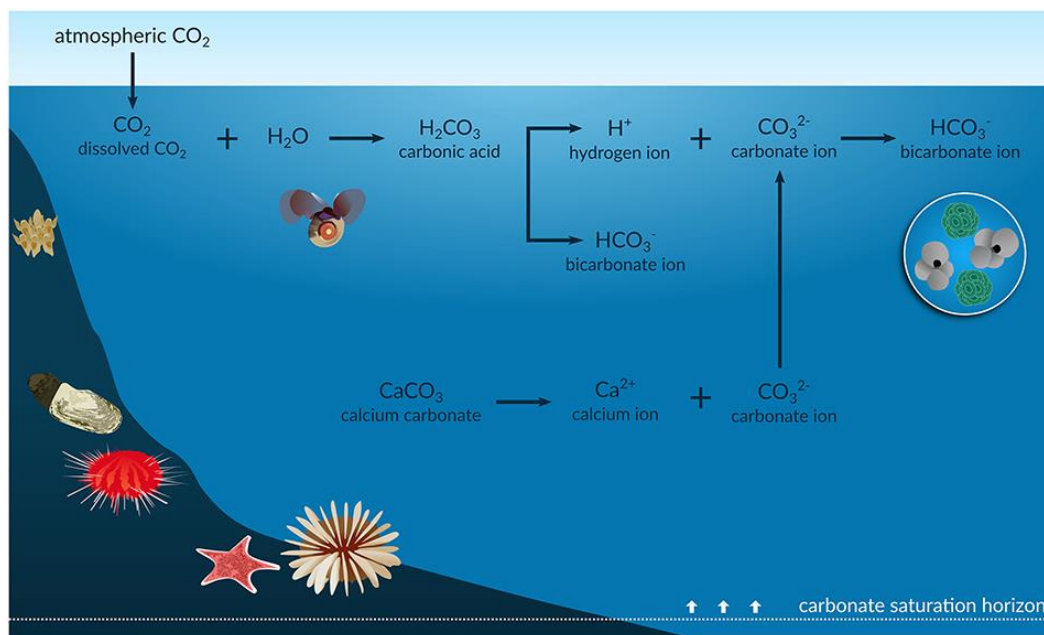


Fig 1. Chemical reactions of ocean acidification with showing distinct stages and products.
<https://reaktoro.org/applications/solubility/solubility-calcite-on-acidity-and-temperature.html>

3. Impact of Ocean Acidification

3.1. Impact on Marine Organisms

3.1.1 Marine animals

It has been mentioned the decreasing pH of ocean water can be a primary outcome of the environmental issue, ocean acidification. Therefore, it can negatively affect the organisms living in the ocean including fish or invertebrates [4]. Some marine life can be very sensitive to ocean acidification. It is because ocean acidification occurs with the rising of carbon dioxide partial pressure and the declining of carbonate ions in seawater, altering the saturation state of aragonite (the mineral form of calcium carbonate) in the seawater at different temperatures [2]. Normally, scleractinian

corals can build reefs by using aragonite used for forming skeletons of the algae [2]. Moreover, some coral reefs living in warm seawater favor growing as the saturation state of aragonite is more than 3.3 and some coralline algae favor growing as the saturation stage of aragonite is more than 2 [2]. Under ocean acidification, the rising carbon dioxide partial pressure in ocean can cause the saturation state of aragonite to fall below the suitable level for marine life to grow [2].

As mentioned above, the coral reef can be vulnerable to ocean acidification. It is also because coral reef building can rely on the scleractinian corals and calcified algae. Also, ocean acidification can negatively influence organisms producing calcareous shells and skeletons. Both calcified algae and scleractinian corals can be negatively affected by ocean acidification, making the coral reefs can be vulnerable to more severe ocean acidification [9].

The macro-fauna can be susceptible to ocean acidification at the larval stage and even can cause about 30% of marine animal biodiversity when the ocean acidification allows the pH to drop [2]. It can be due to the ocean acidification enables the pH to decline which can increase the metabolic cost of some marine organisms for dealing with the hypercapnia [2]. Also, ocean acidification can interfere with the ecosystem services offered by marine organisms like oysters [10]. For example, the oyster can form biogenic reefs to improve the water quality [10]. However, the reef structures formed by oyster has declined worldwide in the last century [10]. It is mainly because ocean acidification can cause the decline of calcium carbonate availability for oysters to form biogenic reefs which provide multiple ecosystem services [10]. The mussels like California mussels can develop weaker and thinner shells (skeleton) under the elevated carbon dioxide level in the seawater [4]. It makes sense due to ocean acidification can occur under elevated carbon dioxide and can cause the reduction of available carbonate ions for reacting with calcium, forming calcium carbonate (CaCO_3) [4]. The reduction of calcium carbonate can result in a thinner skeleton or shells due to calcium carbonate is the essential compound to form a skeleton in seawater [4].

3.1.2 Marine plants

Although ocean acidification can cause a negative impact on marine organisms including marine plants and marine animals, some marine plants can be less vulnerable to ocean acidification. The coastal seaweed farm can buffer the ocean acidification effect [10]. It is because *Laminaria japonica* (a species of seaweed) can have a higher capacity to increase about 0.10 pH [11]. It also can act as refugia for marine life due to the research suggesting the deficit of carbon dioxide is detected in ocean water within the seaweed farm, which allows a lower amount of hydrogen ions to occur in the seawater [11]. Furthermore, some marine life can benefit from ocean acidification such as phytoplankton, macro-algae and seagrass [2]. Another research suggests around the abundance of five macro-algal species can increase under elevated carbon dioxide in the seawater [12]. However, the toxic phytoplankton can also grow with increasing abundance under high carbon dioxide in seawater triggering ocean acidification to threaten aquaculture and fisheries due to some marine organisms can eat toxic phytoplankton [2]. Moreover, the macroalgae can have an enhanced growth rate under the ocean acidification scenarios which cause higher levels of dissolved carbon dioxide in seawater. Although the pH is lowered by ocean acidification, higher tolerances of macroalgae can be developed through research [13]. Also, coralline algae can be susceptible to ocean acidification due to there is research suggests the growth rate, abundance and calcification rate of coralline algae can decline. It can indicate that some marine plants can be sensitive to ocean acidification [14].

3.2. Impact on Marine Microorganisms

Marine microorganisms are crucial in the global process including the nitrogen cycle, carbon cycle and sulfur cycle [15]. The ocean has a nitrogen cycle as shown in Fig. 2, involving the specific marine microbes [15]. These processes can have a vital effect on the climate [15]. The abundance, diversity and metabolic activities of marine microbes like bacteria can determine whether the half of global primary production process producing chemical energy from organic compounds by living organisms occurs in a normal state. Therefore, the negative impact of ocean acidification can occur more severely at a larger scale as ocean acidification can threaten the majority of marine microbes doing

primary production in the ocean. Some marine microorganisms can be affected by ocean acidification. It is because ocean acidification can alter the pH of the seawater and alter the nitrification reaction in the nitrogen cycle and can allow oxidation of ammonium (NH_4^+) to Nitrate (NO_3^-) to occur [16]. Nitrification can be the most sensitive chemical process to the pH change resulting from ocean acidification [16]. The nitrifying marine microorganisms can have less available ammonia under the change of pH which is caused by ocean acidification [11]. The ocean acidification experiment can suggest some planktonic microbes can show slower or reduced nitrification rates [16]. Ocean acidification can also allow bacterial production to decrease [17]. It is mainly because the abundance of some oligotrophic bacteria with high nucleic acid can be repressed by ocean acidification due to they cannot fully survive under elevated carbon dioxide levels [17].

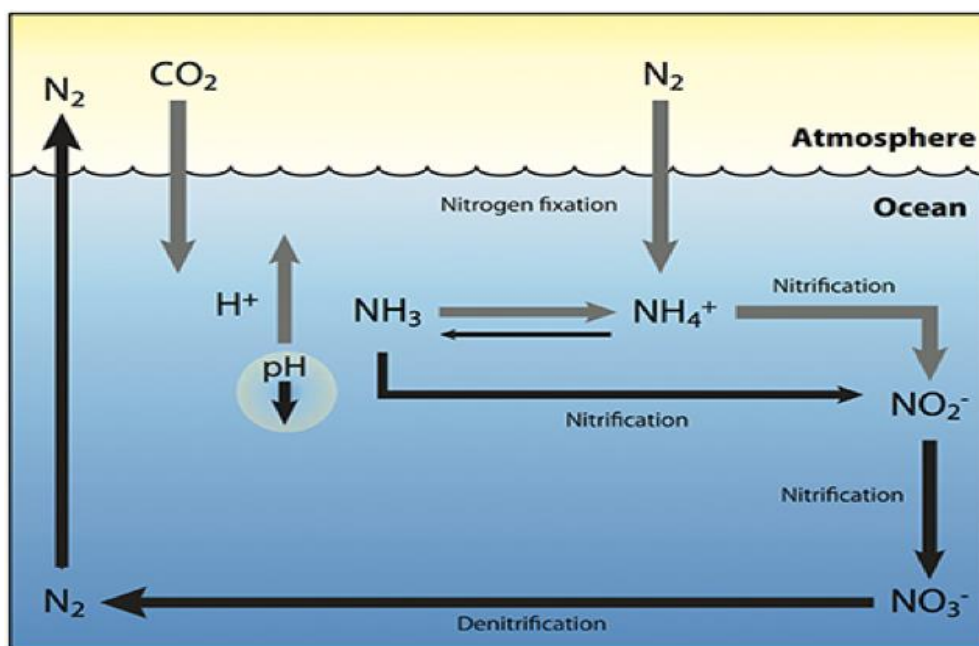


Fig 2. The nitrogen cycle involving processes like nitrogen fixation, nitrification, and denitrification in the ocean. <https://www.frontiersin.org/articles/10.3389/fmars.2016.00047/full>

3.3. Impact on Marine Biodiversity

Ocean acidification can influence marine biodiversity. However, the impact of ocean acidification cannot be fully negative. Some researchers propose that ocean acidification can drive the biodiversity loss of marine life. It is because the results suggest that some habitats like coral reefs can decline, which can decrease the number of the species that are supported by the habitats. This concept is supported by the research which analyzes the real-world data of the site with the growing coral reef near the location called Papua New Guinea. The result of the research indicates the biodiversity of the marine organism living in coral reef decline as ocean acidification be more severe [18].

However, ocean acidification also can increase the biodiversity of the species living in the seagrass bed because the results of the research suggest there is an increase of macroalgae biomass and seagrass biomass under the decreasing pH condition. This finding is supported by the positive relationship between density and species of seagrass and macroalgae.

4. Mitigation Strategies for Ocean Acidification

Ocean acidification can also cause adversely affect the coastal ecosystem [19]. However, the researcher has suggested that restoration of the coastal seagrass bed can protect the coastal area from ocean acidification [19]. It is because seagrass can be very productive to uptake the organic carbon from the sediments, export the carbon to deep seawater and reduce the water flow velocity [19]. The seagrass involving eelgrass can have photosynthesis triggered by elevated levels of carbon dioxide,

which potentially improves the removal of carbon dioxide via the specific seagrass species in seawater [19]. Although the concept can make sense, the actual research cannot show significant results to indicate the coastal seagrass bed can fully be considered as the effective mitigation strategy for ocean acidification through modifying the pH in the long term. However, some findings of the research can suggest in the short term, the coastal seagrass bed can adjust the seawater pH value (around 0.02 units) through the metabolism, showing ocean acidification can be retarded. Also, the framework offered by the research can allow future studies to take more parameters and limitations mentioned in this research into account for conducting and monitoring whether the coastal seagrass bed can mitigate ocean acidification in-depth and in the long term. Furthermore, macrophytes also can mitigate ocean acidification. It is because the results analyzed from the research involving lab works, mesocosms and field studies suggest macrophytes can increase the overall pH by around 0.3 units in the habitat, which can improve the calcification process carried by the blue mussel in the habitats. Therefore, the alleviated state of ocean acidification can be achieved.

Moreover, the increasing amount of atmospheric carbon dioxide can be the dominant driver leading to more severe ocean acidification [1]. Some calcifying organisms, tropical corals and other marine organisms playing key in the marine ecosystem can only be maintained in their favourable conditions if the carbon dioxide emission decline from 2025 to 2050 [20]. For example, the corals can cost more energy for the calcification process, which can cause the corals to have slower growth and become more vulnerable to disease [21]. However, atmospheric carbon dioxide removal has been argued to resolve ocean acidification and it is encouraged to be implemented as early as possible [21]. It is because extreme atmospheric carbon dioxide removal can fail to restore ocean acidification when the atmospheric carbon dioxide removal intervention is carried out too late [21]. There are multiple strategies to remove atmospheric carbon dioxide. Forest restoration can be an effective solution to remove a large amount of atmospheric carbon dioxide. It is because the forest can be able to sequester carbon dioxide for sustaining the growth of the forest. The current progress of forest restoration has shown that about 300 million hectares (Mha) of degraded land have been restored globally for forest growth, which can almost reach the target (350 Mha) for removing carbon dioxide and repressing the increasing temperature to 1.5 °C [21]. Moreover, direct air capture can also remove atmospheric carbon dioxide. One of the work mechanisms of direct air capture can consist of 2 distinct phases. In the first phase, the air can be captured by the machine. Then the carbon dioxide in the air can bind to the filter inside the machine and the air now become carbon dioxide-free air. This process is repeated until the filter can be saturated which means the filter is full of carbon dioxide. Then phase 1 ends and phase 2 starts to allow the filter to be heated for carbon dioxide collection.

Educational activities can also play an important role in mitigating ocean acidification. It is worth encouraging more people to understand how ocean acidification occurs and how ocean acidification can be a crucial environmental issue. When people can understand the importance of ocean acidification mitigation, more people can have a chance to participate into deal with ocean acidification in future.

The cultivation of marine submerged aquatic vegetation like sea grass and kelp can mitigate ocean acidification due to the habitats of submerged aquatic vegetation can provide suitable living conditions to marine life that are sensitive to ocean acidification [22]. The advantage of using submerged aquatic vegetation to alleviate ocean acidification locally is that it can utilize the dissolved inorganic carbon for photosynthesis, influencing the marine ecosystem directly. Also, the submerged aquatic vegetation can be widespread and persistent regionally. The submerged aquatic vegetation can absorb the dissolved carbon dioxide in the ocean into the tissue through photosynthesis. In this case, the more photosynthesis occurs can trigger the more removal of carbon dioxide in the ocean. The less carbon dioxide undergoes chemical reactions in the ocean, the pH can be less likely to drop. Therefore, ocean acidification can be ameliorated. However, growing a large number of submerged aquatic vegetation cannot be fully efficient for ameliorating ocean acidification. It is because photosynthesis can be the key process for removing the carbon dioxide in ocean acidification amelioration. However, photosynthesis can only operate efficiently in day time. In the night time, the

removal of carbon dioxide in seawater can decline. Currently, kelp and sea grass can be cultivated for ameliorating ocean acidification, while they can mainly alleviate ocean acidification locally. In the extreme area of the ocean, the suitability of growing submerged aquatic vegetation still can be uncertain, which can be difficult to monitor whether the effective removal of carbon dioxide in the ocean can occur.

5. Conclusion

Climate change can be derived from increasing atmospheric carbon dioxide emission dominantly attributed to anthropogenic actions like deforestation and so on. Ocean acidification can occur under climate change due to ocean can act as one of the largest carbon sinks to absorb atmospheric carbon dioxide. The key outcome of the mechanism illustrating ocean acidification is that the level of dissolved carbon dioxide increase to cause further chemical reactions for producing more hydrogen ions in seawater to lower the seawater pH value. Also, ocean acidification can cause negative impacts on marine organisms like corals, oysters and mussels by affecting the calcification rate which is essential to sustain their life. Differently, the majority of marine plants like macroalgae, phytoplankton, seaweed and so on can be benefited from ocean acidification. It is because the more available aqueous carbon dioxide can be used for their photosynthesis, which can cause the increase of tolerance and abundance of some marine plants. Moreover, ocean acidification can influence the biodiversity of organisms by affecting the habitats of the marine organism normally breeding. Ocean acidification can either cause a positive or negative impact on the biodiversity of marine life depending on the specific types of habitats. To mitigate ocean acidification, the restoration of coastal sea grass beds, forest restoration, atmospheric carbon dioxide capture, the cultivation of submerged aquatic vegetation (kelp etc.), and educational activities can be implemented for mitigating ocean acidification. Although the thesis statements mentioned above can be supported by numerous research findings, the results contributing to the findings can be improved. It can be due to the some research findings are only created by simulation, which can be biased as the simulated results lack comprehensive and up-to-date real data collected from the field.

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