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Impact of Global Change on Oceanic Dissolved Carbon Chemistry and Acidification: A Review

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ABSTRACT: Increasing atmospheric carbon dioxide and temperature, decrease marine pH and rising dissolved organic carbon (DOC), causing extensive shifts in ocean water carbon chemistry with forecasts of long-term ecosystem impacts. This study aimed to carry out a systematic review and try to find out the actual chemistry, spatial variation at a global scale, future prediction of these natural and human-induced changes, and how this situation impacts the marine ecosystem and green economy. Literature proved that Antarctica and southern shallow polar ocean and any seaside area are particularly vulnerable to marine acidification and disturbed DOC cycle. Based on over a hundred investigations, the study observed that (a) marine acidification and DOC cycle are basically difficult-to-understand phenomena, (b) these two realities are consistent with each other and with climate change, (c) the potency of these threats is very altitudinal, periodic, and stratified (d) the mood of global change stressors on these two facts in the future ocean is unpredictable. It was found that over the past half-century, the acidity of the surface ocean has even now increased by almost 30%, and by 2100 it will increase to 150. Such a major change in ocean chemistry will have and is already having widespread consequences for marine organisms.

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The global climate has continuously changed for centuries. Our continual burning of fossil fuels is rising a load of carbon dioxide (CO_2) in the atmospheric air. As a result, the oceans have been receiving big volumes of CO_2 since the global industrial revolution (before the 1750s). This rising amount of dissolved CO_2 in the oceans is producing ocean acidification. At what time CO_2 arrives in the ocean, it mixes with marine water to form carbonic acid (H_2CO_3), which rises the acidity of the water systems, dropping its pH value. While the beginning of 1750, around one-third to one-half of the CO_2 released into the air by anthropogenic actions has been absorbed by the sea (Hall-Spencer et al., 2008). Throughout that period, investigators have projected, the mean pH of marine water deteriorated from 8.19 to 8.05, which resembles a 30% rise in acidity (Jewett et al., 2020). Several scientists guess that the pace of marine acidification since the beginning of the eighteen century has been roughly 100 times more quickly than at any other time throughout the near past 650,000 years (Feely et al., 2020). In addition, they showed that levels of air CO_2 between 1000 and 1900 current era (CE) ranged between 275 and 290 ppm(V) (Jewett et al. 2020). In 2010 the average level was 390 ppm(V), and scientist expects the concentration to increase to between 413 and 750 ppm(V) by 2100, dependent on the concentration of greenhouse gas emissions (Friedlingstein et al., 2020). With extra CO_2 entered to the seas, the pH would decline further and marine water pH would drop to 7.8 from 7.9 by 2100 (Jacobson, 2005). Generally, 23 to 30% of the total

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atmospheric CO_2 dissolves into oceans, rivers, and lakes (Friedlingstein et al., 2020). Not only the absorbed CO_2 by the oceans, but other chemical phenomena in the ocean can also cause acidification (Field et al., 2022) as the sea absorbs CO_2, marine water chemistry changes, which changes the living conditions of oceanic organisms. Several different biotas are affected, particularly species that depend on calcium carbonate ($CaCO_3$) skeletons and shells (Robert, 2012). Increasing acidity is affecting the ecosystem of the marine environment that delivers food, livelihoods, and other ecological services for a great proportion of human residents. As a whole, the changed marine chemistry highly impacted the food chain of marine biota and the global green economy. Marine saturated CO_2 impacts the dissolved organic carbon (DOC) cycle in the ocean and creates a complex chemical environment in the sea system. DOC is on the interface between chemical and biological functioning, it controls marine food chains, and is a key part of the earth's carbon cycle and chemistry. Changes in DOC cycling owing to global change can result in alterations in the atmosphere-ocean exchange of CO_2 and have the potential to make significant feedback on climate change itself. This manuscript will focus on the impact of increasing CO_2 and acidity on DOC pools in the future ocean on a big scale. Particularly, this study describes the impacts of climate change stressors on the marine DOC cycle in the upcoming ocean. These stressors comprise deoxygenation, ocean warming and stratification, marine acidification, changed inflow from rivers, glacial and marine ice-derived substantial, wet and dry deposition, and ocean upwelling (Zark et al., 2017). On the other hand, the less pH or acidic medium hampered the many phases of the DOC cycle and changes the mood of involving reductions in the functioning of DOC in marine systems. In this study, we report findings from the systematic review of literature because of the potential economic and marine ecological impacts of marine acidification. We recognize that though this is a rising field of research, comparatively insufficient assessments have been directed to date, with those that have been done vastly focused on scope only. Therefore, this review highlights the major gaps in understanding, the present state of knowledge, and directions that may be used in future research.

Background - carbon budget scenarios: Primarily CO_2 is the main culprit to acidify marine water. While atmospheric temperature rises are the secondary influencing factor for this phenomenon. Since 1958, the global CO_2 level has been monitored in the mid of the Pacific Ocean on Mauna Loa, Hawaii at the National Centre for Environmental Prediction (NCEP) as well as other stations are Barrow Alaska, American Samoa, and South Pole (Keeling et al., 2009). Both CO_2 level and their rate of change have increased continuously over most of our lifetimes. In 2018, the concentration of CO_2 gas had increased by about 160% since pre-industrial times (WMO, 2020), and in 2013, CO_2 concentrations taken at the world's primary standard site in Mauna Loa exceeded 400 ppm for the first time (Schiermeier, 2015). The present (September 2022) level of this gas is 415.95 ppm(V) which this value is 2.65 ppm(V) greater than September 2021's concentration (NOAA, 2022). The increasing CO_2 concentration in the atmosphere (Fig. 1) as well as the rising temperature impacted the marine pH, which regulates the total ecosystems of oceanic systems.

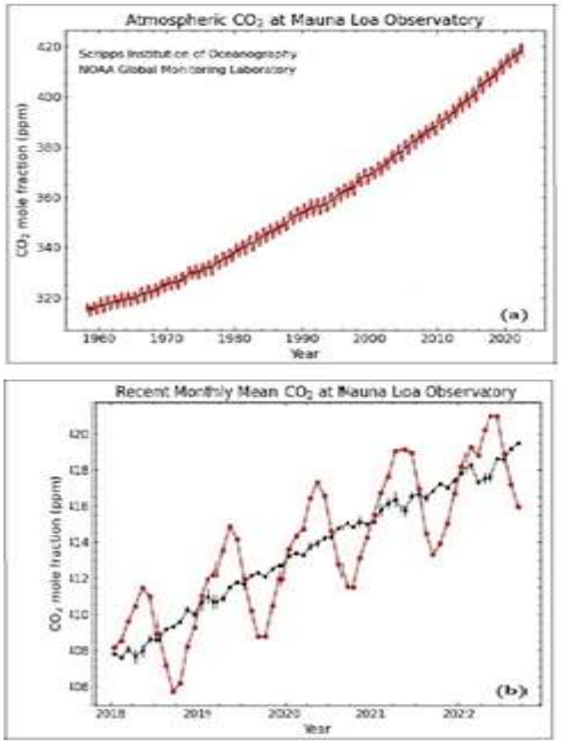

Fig. 1. The historical concentration of CO_2 gases in the atmosphere (**a**: 1960-2020; **b**: 2018-2022)

Changes in Seawater Chemistry - mechanism of acidification: Anthropogenic activities such as the excess combustion of fossil fuels and agricultural diversity have led to new unrest of the CO_2 budget into the air. Among the total CO_2, about 45% remains in the atmosphere; about 23% is absorbed by the oceans, and 32% is taken up by upland plants (Friedlingstein et al., 2022). More atmospheric CO_2 means absorbed more and more by an ocean that makes acidify the ocean water. The acidity of an aqueous solution is determined by the corresponding level of hydrogen ion (H^+). A higher level of H^+ ions in an aqueous medium corresponds to elevated acidity, which is measured as a less pH. When CO_2 intake by marine water, it generates carbonic acid (H_2CO_3) and releases H^+, which consequently combines with carbonate ions (CO_3^{2-}) and calcite (the common mineral of carbonate) to form bicarbonate (HCO_3^-) ion (Eqns. 1 to 3). At present marine water is enormously rich in dissolved carbonate minerals. Nonetheless, as marine acidity increases CO_3^{2-} ion levels fall. The absorption of CO_2 in seawater largely results from the dissolution of the gas into the top layers of the ocean, but CO_2 is also brought into the ocean's water through the photosynthesis and respiration of marine plants and microbes. Algae and other oceanic photosynthesizes take in CO_2 and store it in their tissues as carbon. Then carbon is passed to plankton and other microorganisms through the food wave, and these organisms can liberate CO_2 to the ocean through the respiration process. Besides, when marine biotas die and accumulate in the ocean bed, CO_2 is produced through the process of decomposition. So, the CO_2 budget in the oceanic system is not only depending on the concentration of it in the air. All types of incoming CO_2 may take part in the process of acidification in seawater. The oceanic pH will vary in the coming years as a result of emission the of CO_2 by human activities; changes in ocean chemistry are undeniable (Doney et al., 2009). This chemistry is clear-cut, but not simple; as manmade CO_2 rises in the atmosphere, it dissolves in the surface ocean and forms carbonic acid (H_2CO_3) - a very weak acid which shows by the following reactions. These reactions are equilibrium reactions that are highly impacted by the ambient temperature and pH of the medium.

$$[CO_2]_{aq} + [H_2O] = [H_2CO_3] \qquad (1)$$
$$[H_2CO_3] = [HCO_3^-]_{aq} + [H^+]_{aq} \qquad (2)$$
$$[H^+] + [CO_3^{2-}] = [HCO_3^-]_{aq} \qquad (3)$$

The above-mentioned mechanism may be impacted by the potentiality of Surface Ocean warming because warm waters will not absorb as much CO_2. Thus, larger ocean water warming could limit CO_2 absorptions and lead to a small variation in water pH for a given rise in CO_2. The change in temperature between basins is one of the main causes of the variance in acidification potentiality in different locations. Currently, the surface ocean is acidifying at a degree of 0.003 - 0.026 units (pH value) per decade. Though, this tendency is quicker in the polar areas (-0.002 to -0.026 per decade) than in the tropical areas (-0.016 to -0.020 per decade) (Bialik et al., 2016). On the other hand, the rate of changes in ocean pH can vary dependent on the depth and location of the ocean. Generally, higher latitudes and more cold waters have more capacity to absorb more CO_2. Other factors such as ice coverage, marine currents, nearness to the big continental river, and exchange between air-sea of nitrogen and sulfur generated from the burning of fossil fuel and agriculture impact the air-ocean CO_2 exchange, and thus influence local ocean acidification. (Anthony et al., 2008).

Trends of Marine Acidification - past and present rate: Marine acidification and decreasing DOC are interconnected with each other and with global change. The mood of climate change stressors on these two facts in the future ocean is unpredictable. Caldeira and Wickett (2003) showed that if the present rate is continued, the probable future variations in pH in the ocean and upper marine water pH would decrease by 0.77 units by the year 2300. Also, they showed that, if CO_2 emission continues at the current rate, marine pH would show bigger changes, and quicker rates of change, than are noticed in the geological record with the probable exception of a few past terrible events. Pearson and Palmer (2000) recommended that the pH of ocean water was changed by less than 0.1 units in the former 25 million years. According to these and other investigations, there has been rising concern that ocean acidification could have severe impacts on marine organisms. On the other hand, UK Ocean Acidification Research Program, 2015 showed that if it continues releasing CO_2 at the present rate, by 2100 acidity of marines will rise by around 150%, a rate that has not been known for at least 400,000 years (Humphreys, 2016). Table 1 showed the rate of Marine pH changes with time-varying (18^{th} to 21^{st} centuries). The output of various studies is included in this Table 1 and the result illustrated that from the pre-industrial period to 2100, the marine pH will be decreased by –0.355, and the concentration of H^+ increases to 126.5%. These findings are almost similar to other studies.

Table 1. Ocean pH changes with time-varying

Time	Ocean pH	pH changes with pre-industrial	H^+ level change comparative to pre-industrial	Source	Reference
Pre-industrial age (18th century)	8.179	–	–	Field study	AAD, 2007
Near past (the 1990s)	8.105	−0.074	+ 18.9%	Field study	AAD, 2007
Present levels (2020)	8.068	−0.111	+ 28.8%	Field study	Gulev et al., 2021
2050 ($2\times CO_2$ = 560 ppm) (projected)	7.949	−0.230	+ 69.8%	Model	Key et al., 2004
2100 (projected)	7.824	−0.355	+ 126.5%	Model	Key et al., 2004

Present rates of ocean acidification have been related to the greenhouse incident at the Paleocene–Eocene age limit (around 56 million years back) when top-layer ocean temperature rises by 5–6 ºC (Zeebe et al., 2012). The degree of carbon addition to the air-sea system at the current time is about 10 times the rate of carbon adding than in the above age boundary. Another study in 2013 demanded acidity be rising at a rate 10 times quicker than in any of the evolutionary calamities in Earth's history (Humphreys, 2016). In a study report published in Science Journal in 2015, 22 foremost ocean scientists demonstrated that CO_2 from burning fossil fuels is altering the oceans' chemistry more rapidly than at any time subsequently 100 years ago (Gulev et al., 2021). Though the present marine acidification is on a path to reach lesser pH values than any other level documented in the last 300 million years, the degree of carbon addition is incomparable, so the present and projected acidification have been designated as unparalleled in the geological record (Henehan et al., 2019). A National Research Council investigation published in April 2010 similarly concluded that the value of acidity in the ocean’s water is increasing at an unparalleled rate. In the 15 years dated 1995–2010 alone, acidity has raised 6% in the surface 100 meters of the Pacific Ocean from Hawaii to Alaska (Fiona, 2013). As said by an announcement in July 2012 by U.S. National Oceanic and Atmospheric Administration (NOAA), the surface waters of marines are changing much more quickly than preliminary calculations have suggested. This U.S. organization makes a graph (Fig. 2, above) in which they showed the relation between atmospheric CO_2 and marine pH from 1958 to 2018 (station: Mauna Loa). It illustrated that marine acidification steadily increases with the increase of partial pressure on marine CO_2 (station Aloha). Also, Fig. 2 (below) demonstrated the relative picture of marine acidification from the late 1800s to 2100. On the other hand, the decreasing rate of ocean acidification from 1988 to 2019 is shown in Fig. 2 (right).

Projected future rate - Earth System Models (ESM) scheme that, by 2008, marine acidity exceeds historical similarities and, in amalgamation with other changes in ocean biogeochemical, could damage the operative of marine ecosystems and interrupt the provision of many goods and services related to the sea beginning as early as 2100 (Mora et al., 2013). If the ‘dealing as usual' model for human activity persists, model projections estimate that top ocean pH could decline by 0.16 to 0.44 units compared to the current time by the end of the next 100 years (McNeil and Matear, 2008). The ocean has not been knowledgeable about this value of pH (acidity) for 300 million years (Fiona, 2013). In addition, the biodiversity advisory board of the World Bank has recommended that ocean acidity will more than double in the following 40 years. They say this rate is 100 times quicker than any variations in ocean acidity in the last 20 million years, making it unlikely that marine life can someway adapt to the changes (Gattuso et al., 2013). It is expected that, by the year 2100, if cooccurring biogeochemical changes impact the delivery of marine goods and services, then they could also have a substantial impact on human well-being for those who depend seriously on the marine for food, jobs, recreation, and revenues (Henehan *et al.*, 2019).

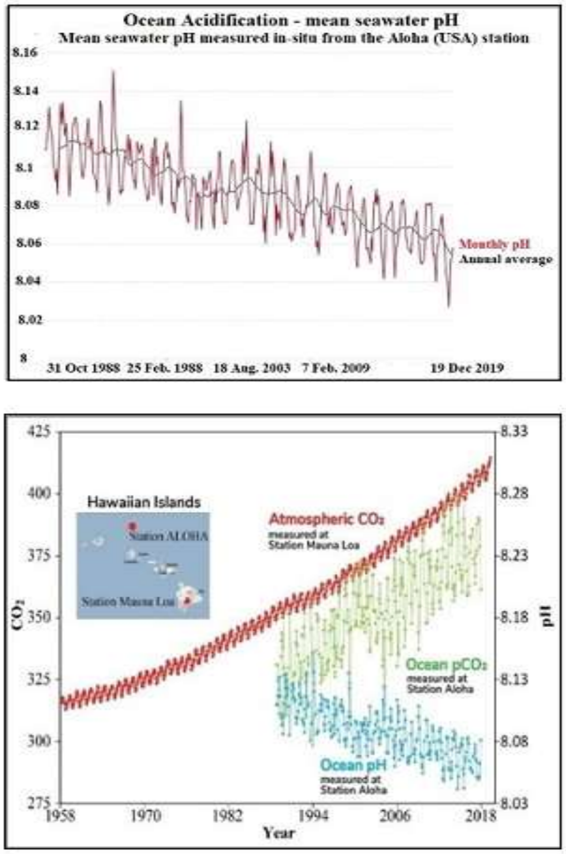

Fig. 2. Marine pH changes with atmospheric CO_2 by 1958 to 2018 (above) and simple decreasing rate of ocean acidification by 1988 to 2019 (below)

Marine DOC and Acidification: Usually, organic matter (OM) in the marine system is distinguished by its filtration performance, with the material retained on a filter (pore size: 0.2 to 0.7 µm) denoted as particulate organic matter (POM), while OM that passes the filter is term dissolved organic matter (DOM) (Verdugo, 2012). Maximum studies of DOM have mainly focused on the DOC pool because from a climate change viewpoint, DOC is very sensitive because the ocean DOC pool contains analogous amounts of carbon to air CO_2 (Hedges, 2002). Thus, little variations in DOC cycling can have huge implications for atmospheric CO_2 concentrations and consequences for the warming and cooling of the Earth's surface over millions of years (Sexton et al., 2011). At shorter times (years) the amount of DOC injected into the deep ocean (~2000 mMT/y) is equivalent to the levels of CO_2 incoming the ocean from the atmosphere each year; as a result, variations in ocean DOC cycling could influence ocean and air CO_2 levels (Gruber et al., 2019). Inversely, the changes in marine acidity mostly influence the DOC to release the oceanic system. Present air CO_2 concentrations are about 40% higher than before the industrial revolution period (Gattuso et al., 2013). Around 30-35% of human-made CO_2 has been dissolved in the ocean (Gruber et al., 2019). Generally, marine DOC comes from seaweeds and organisms and it sinks through various microbial actions. Atmospheric CO_2 levels as well as marine pH directly impacted the DOC pool oceanic system. As human-made CO_2 pass in the ocean mostly through its top layer, it is expected that acidification will primarily impact the DOC cycling in sea surface waters (Monica et al., 2021). Though, the observed influences of ocean acidification on the DOC pool are changeable. Some researchers illustrate increased carbon fixation by planktons with boosted production and DOC accumulation whereas others have found no effect, but instead propose more production of transparent exopolymeric particles (TEP) (Piontek et al., 2013). Another investigation where the composition of plankton produced DOC was followed in mesocosm studies exposed to a range of CO_2 concentrations, presented that increases in DOC level and changes in the chemical composition were free of CO_2. These types of differences between investigations may explain by (a) changeable organic carbon partition between the particulate and dissolved phase, which depends on community diversity and food chain systems; (b) rapid microbial degradation of the extra DOC released; (c) loss of extra organic carbon as TEP to the bottom sea sediment; and/or (d) different organisms creating different responses and rates of flexibility to changes in pH. Though, usually in most environments, DOC levels seem to increase with higher CO_2 concentrations without clear impacts on the molecular composition (Zark et al., 2017). A supplementary factor may be that the bioavailability and concentration of possibly limiting micronutrients (e.g., iron) have been revealed to increase with marine acidification and this may result in a change in both primary production and species composition which in turn could affect oceanic DOC pool.

Impact of Acidification on Marine Environment: The rising acidity of seawater directly impacted the community of calcifying species, coral reefs, and the world's green economy. Both direct and indirect influences of CO_2 and marine acidification on the oceanic environment are identified. Along with economic losses, several influences on marine ecosystems and chemical processes hampered the total food chain of marine biota.

Physiological and ecological effects of marine acidification: Physiological deviations carried on by rising acidity in the oceans have the potential to change prey-predator relations. Seawater pH dropped to between 7.8 and 7.9 in the last 100 years, resulting in CO_3^{2-} ion concentrations would decline by at least 50% (Eqns 1 to 3). The global coral reefs, which deliver habitat for many classes of biotics, could decrease and even vanish if ocean acidification intensifies and CO_3^{2-} concentration continues to decrease. The oceanic calcifiers are large and small organism that uses CO_3^{2-} and Ca^{2+} ions dissolved in ocean water to build up their hard shells and skeletons. Due to less concentration of carbonate, oceanic calcifiers would have significantly less material to maintain their shells and skeletons (Fig. 3). Field experimentations in which the pH of marine water has been dropped by 7.8 have revealed that such organisms placed in this environment do not grow as well as those placed in an environment considered by early 21st-century levels of oceanic acidity (pH = 8.05). For this reason, their small size places them at higher risk of being eaten by predators (Hansell and Carlson, 2020). In addition, the shells of some organisms (e.g., pteropods - sea snails) which serve as food for krill and whales, dissolve significantly after only 40 days in such highly acidic environments (Lønborg et al., 2020).

Bigger animals such as squid and fish may also feel the effects of increasing acidity as H_2CO_3 levels rise in their body fluids (Gruber et al., 2019). This situation is called acidosis which may cause problems with the respiration of animals as well as with growth and reproduction. Besides, numerous marine experts believe the significant decline in oyster reefs along the West Coast of the USA since 2005 is produced by the increased ocean acidification placed on oyster larvae (Jewett et al., 2020). Some study has illustrated that the carbonate skeletons of marine urchin larvae are smaller under the situation of increased acidity; such a weakening in overall size could make them more edible to predators who would avoid them under normal situation (Fig. 3) (Van de Waal et al., 2013). Consecutively, decreases in the abundance of pteropods (sea snails), foraminiferans (a technical term for internal shells), and coccoliths (individual plates of calcium carbonate) would force those animals that eat them to switch to other prey.

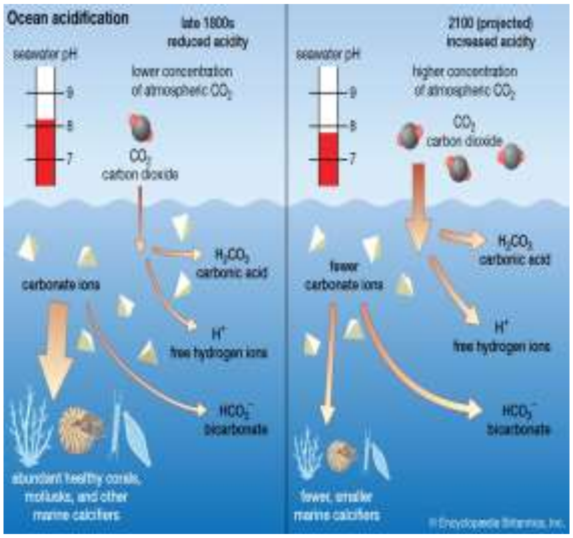

Fig. 3. Relative picture of marine acidification history and their impact on oceanic calcifiers

The physiological impact of marine acidity is not uniform in an ocean. The deeper waters of the sea are generally more acidic than the sea surface since CO_2 that dissolves on the surface moves down with dense through the thermo-haline circulation (Feely et al., 2020). The more acidic lower layers of the sea are separated from the less acidic upper layers by a boundary called the 'saturation horizon' or esterification. Above this horizon, there is enough carbonate present in the water to sustain coral communities. In waters closer to the poles, many cold-water coral communities are found at depths that range from 40 to 1,000 meters, but tropical coral reefs are rarely found below 100 meters (Jewett et al., 2020). By the year 1800, the investigation has shown, increased acidity has raised the length of the saturation horizon by about 50 to 200 meters in semi-polar and midlatitude areas (Gao et al., 2019). This change is sufficient to threaten cold-water coral communities, and some investigators fear that additional communities will be placed at risk if the horizon boundary approaches the surface of the sea. Furthermore, marine researchers guess that the decreasing of marine phytoplankton communities owing to rising acidic levels in the sea will produce a positive response that increases global warming (Feely et al., 2020). Oceanic planktons produce dimethyl sulfide, $(CH_3)_2S$ which is the most important source of sulfur in the earth's atmosphere. Sulfur (S) in the upper atmosphere region reflects some of the incoming solar radiation from the sun into space and therefore keeps it from warming the earth's surface. Several models projected that $(CH_3)_2S$ production will diminution by about 18% by 2100 from 1750, which will result in additional radiative forcing equivalent to an atmospheric temperature rise of 0.25 °C (Middelburg, 2019; Jewett et al., 2020). The above-mentioned consequence of acidification on marine physiology is doubtful, says several investigators. Numerous experimental works have investigated the effect of ocean acidification, but these have typically focused on single-species experiments over short periods (Alvarez-Fernandez et al., 2018). These investigations have recommended positive, negative, and neutral impacts of marine acidification on ecology, species physiology, and demography (Kroeker et al., 2013). Studies investigating the influences of declining pH on marine microbial groups show variations in phytoplankton and bacterial community composition, growth, and cell size (Orr et al., 2005). Though, the effects on the plankton group are not uniform. For instance, some phytoplanktons, such as those creating $CaCO_3$ shells, could have lesser growth rates, while phytoplankton primary production, in general, might not be affected as they are not limited by current CO_2 concentrations (Beardall and Raven, 2004). In addition, natural pH in marine ecosystems, higher than the projected pH increases, already occurs naturally (Joint et al., 2010). So overall as responses to rising CO_2 vary between species communities and the environment, general influence statements are difficult to make.

Calcification: Fig. 3 showed clearly how the marine calcifiers change (healthy to smaller) with the changes in carbonate chemistry in the ocean. Previously discussed that the reaction of CO_2 with seawater (Eqs. 1 to 3) reduces the accessibility of CO_3^{2-} ions that are essential for oceanic calcifying organisms, such as corals, echinoderms, crustaceans, and mollusks, to produce their calcite ($CaCO_3$) shells and skeletons (Kump et al., 2009). Such organisms are influenced mostly by the $CaCO_3$ saturation index (Ω), which is the product of the concentrations (mg/L) of Ca^{2+} and CO_3^{2-}, divided by the solubility product (K_{sp}) for calcite or aragonite (two types of $CaCO_3$ generally secreted by marine organisms):

$$\Omega = \frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp}} \qquad (4)$$

where the $[Ca^{2+}]$ is determined from the water salinity, and $[CO_3^{2-}]$ is computed from dissolved inorganic carbon (DIC) and total alkalinity (TA) of marine water (Feely et al., 2004). In areas where $\Omega_{aragonite}$ or $\Omega_{calcite}$ is >1, the formation of shells and skeletons in calcified organisms is favored. For values <1, marine water is corrosive to $CaCO_3$ and, in the absence of protective mechanisms, dissolution will begin (Fabry et al., 2008). Saturation states are usually lowest in the high latitude and high in the tropic areas because the solubility of $CaCO_3$ rises with falling temperature (inverse solubility) and cumulative air pressure. As a result, there are significant shoaling of the calcite ($CaCO_3$) saturation horizons in the Pacific Ocean, north of 40°N (in the equator), because of the higher DIC levels relative to TA at shallower sea depths (Keeling *et al.* 2010). Fabry et al., (2008) showed that these result from enhanced upwelling that brings nutrients and DIC-rich deeper waters to the upper portion of the ocean and supports high animal biomass. If moves to the north, the calcite saturation depth shoals from 1000 m nearby 30°S to 300 m at the equator. In the North Pacific area, the rising migration of the calcite saturation horizon from manmade CO_2 uptake is presently 1–2 m/y (Feely et al., 2008).

Table 2. Present and predicted pH, dissolved inorganic carbon (DIC), and $CaCO_3$ saturation state (Ω) values (adapted from Feely et al., 2004 and Kleypas et al., 2006)

Factor	Glacial age	Pre-industrial age	Present day	Projected: $2\times CO_2$	Projected: $3\times CO_2$	Changed from pre-industrial to $3\times CO_2$
DIC (μmol/kg)	1952	1970	2026	2090	2144	8.8%
pH	8.32	8.16	8.05	7.91	7.76	-0.4%
$\Omega_{cal.}$	6.63	5.32	4.46	3.52	2.77	-48%
$\Omega_{arag.}$	4.26	3.44	2.90	2.29	1.81	-47%

Table 2 showed that concentrations of DIC (μmol/kg), pH values, and calcite and aragonite saturation states (Ω) of average surface marine water pCO_2 levels (ppm) during glacial age, preindustrial age, present day, two times pre-industrial CO_2, and three times pre-industrial CO_2 concentration. The last column displays the changes from the pre-industrial levels to three times atmospheric CO_2. In this Table 2, it is clear that the saturation index values for oceanic carbonate minerals are gradually decreasing with glacial age to date. Some studies stated that numerous other biotic and abiotic aspects have perhaps donated to the construction of the hard parts of $CaCO_3$ in different groups of fauna at different times in evolutionary history (Langdon et al., 2000). Maximum calcifying organisms explored to date demonstrate reduced calcification in response to the increased partial pressure of CO_2 in seawater and decreased CO_3^{2-}, $CaCO_3$ saturation index (Ω), and marine pH (Kleypas et al., 2006). The literature review observed that most of the study has been carried out in the case of warm-water corals and coccolithophorid (unicellular) algae.

Effect on green economy: The possible economic effects of ocean acidification are a comparatively new field of research. This subject was first documented in published academic literature in 2007 and by 2021, this study identified over 100 published papers on this topic. In most of these studies, the connection between ocean acidification and saturated sea CO_2 economic effects was discussed. Though, several challenges were observed when assessing these effects due to the involvement of numerous disciplines. In the majority of studies, the forecasted impact of ocean acidification is negative, and only one assessment of this review recognizes positive economic effects. These negative influences are likely observed as most investigations focus on the calcifying organism and the habitats they form (e.g. mollusks, crabs, corals, and other invertebrates) which are predictable to respond negatively to marine acidification rather than non-calcifying organisms that may reply positively (e.g., sea grasses and algae). Oceanic organisms and habitats offer a range of ecosystem services to human societies, and while this review identified that many of these services may be influenced by ocean acidification (Fig. 3). The mass of studies has measured the ecosystem services of sea animals and their outputs providing by mollusks, crustaceans, fish, or coral reefs. Marine acidification may have economic impacts on a range of geographical scales, which is reflected in the assessment directed that has considered global, national, sub-national, and regional scales.

Conclusion: The scientific and field investigation of marine water chemistry changes owing to increasing atmospheric CO_2 and the sensitivity of oceanic life to elevated CO_2 as well as acidity has advanced dramatically in the past three decades. Key challenges remain, though, in understanding the implication of the ongoing long-term, press perturbation of marine acidification for ocean organisms, marine biological communities, and ecosystems, and the risks to the human community that depend on oceanic resources and ecosystem services. With extra CO_2 entering the oceans, the pH would decline and marine water pH would drop to 7.8 from 7.9 by 2100 and altering the total marine carbon chemistry.

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