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**Critical Literature Review**
**(ANTA602)**

# To What Extent Can Acidification in the Southern Ocean Impact on Marine Biodiversity?

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**Abstract**

Ocean acidification is regarded as one of the most recent threats to the global environment resulting from unprecedented absorption of elevated anthropogenic carbon dioxide emissions. The emerging research on the effect of acidifying oceans on marine organisms collectively indicates a potential detrimental effect on biodiversity, particularly for aragonite-derived organisms. This in turn affects marine food webs that can impact on the livelihood of humans. An urgent need for multidisciplinary research is highlighted which, ideally, needs to be internationally coordinated. This will enable a better understanding of the predictability and effects of ocean acidification on marine biodiversity and can be implemented in mitigation and policy-making.

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## 1. <u>Introduction</u>

The ever-increasing concern about carbon dioxide emissions contributing to ocean acidification is well documented (IGBP; Stocker et al., 2013) and there is now wider recognition of it as a developing threat (Abbasi & Abbasi, 2011; Halpern et al., 2008; Orr et al., 2005). The aim of this review is to critically evaluate the current knowledge base to identify predicaments and ways forward. It will define ocean acidification and explore areas including case studies, socio-economic effects, mitigation and policy-making. The lowering of the pH is just one of many stress factors that can influence marine ecosystems (Bopp et al., 2013; Gruber, 2011; Pörtner, 2008). These will be evaluated to establish whether or not Southern Ocean acidification is indeed a problem for biodiversity.

## 2. <u>What is Ocean Acidification?</u>

Ocean acidification is measured as the pH of the ocean and whether it is decreasing, becoming more acidic. In chemistry, pH is a measure of the acid-base level of aqueous solutions such as seawater, where pH 7 is neutral; anything below this is acidic and above, alkaline or basic. Since the Industrial Revolution of the late 18$^{th}$ century, the average pH of the oceans has decreased by at least 0.1 to approximately pH 8.1; note pH is a logarithmic scale so 0.1 increase is a factor of 10 (Caldeira, 2005; Caldeira & Wickett, 2003; Halpern et al., 2008; Stocker et al., 2013). Although at first this might not seem significant, there is emerging evidence linking this change to unforeseen effects on a variety of marine organisms and ecosystems.

The main cause of recent ocean acidification is attributed to the increased anthropogenic emissions of carbon dioxide from the burning of fossil fuels (Gattuso & Hansson, 2011; IGBP; Raven et al., 2005; Stocker et al., 2013). Gaseous carbon dioxide is dissolved in marine surface waters and elevated levels interfere with the natural buffering systems of oceans (Feely, Doney, & Cooley, 2009; Sabine et al., 2004). According to the latest report by the Intergovernmental Panel on Climate Change (IPCC) (Stocker et al., 2013), approximately 30% of all human-derived carbon dioxide emissions are absorbed into the oceans. This accounts for a 26% rise in the acidity of the oceans since pre-industrialized times. Current atmospheric $CO_2$ concentrations are about 395 ppm compared to 280 ppm from before the Industrial Revolution; this trend is predicted to rise significantly.

The correlation between atmospheric and surface water pH is well documented (Bopp et al., 2013) and projections (Figure 1) indicate that, even if man-made $CO_2$ did cease immediately, it would still take centuries for the ocean's pH to return to pre-industrial levels (Joos, Frölicher, Steinacher, & Plattner, 2011).

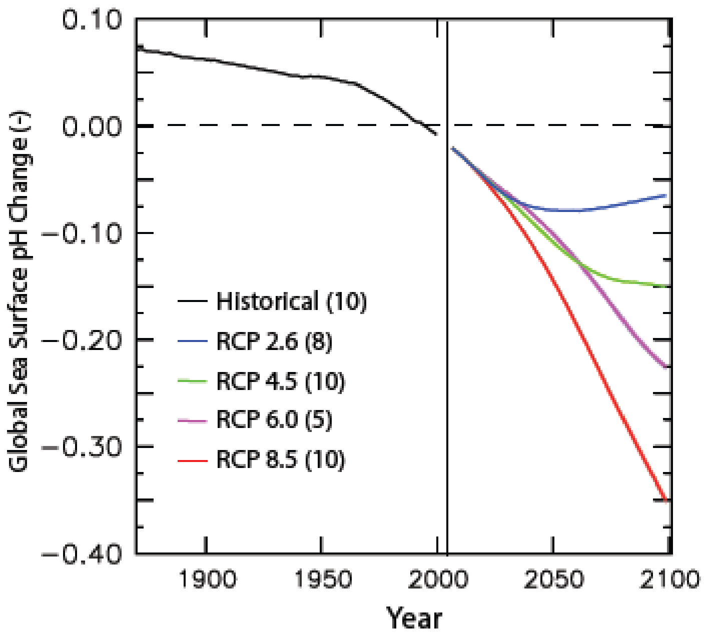


*Figure 1. Global Sea Surface pH change for different projected scenarios (Representative concentration Pathways RCPs)* (from Bopp et al., 2013)

The latest Symposium on ocean acidification report (IGBP) highlighted statistics on ocean acidification, which inevitably has provoked discussion and proactiveness amongst research groups and policy-makers; data included:

- 24 million tonnes of carbon dioxide is absorbed by oceans every day
- 170% is the projected increase in ocean acidity by 2100 if current carbon dioxide emissions continue
- the current ocean acidification rate is more than 10 times fastest than rates recorded for the last 55 million years

- atmospheric carbon dioxide concentrations have increased by 40% since the invention of the internal combustion engine.

The IPCC working group report (Stocker et al., 2013), looked at future $CO_2$ emissions and came up with several scenarios. The 'business-as-usual' scenario refers to what is likely to happen if current emissions continue unadjusted, in other words, remain high. It was termed the Representative Concentration Pathway (RCP 8.5) and was the projection for 2100 (8.5 refers to $Wm^{-2}$ radiative forcing). It predicted that by 2100, on average 60% of the Southern Ocean would be so acidic that it would be too corrosive for many calcified marine organisms such as Pteropods. On the other hand, they predicted that if effective mitigation was implemented (RCP 2.6), then there is a chance of avoiding the worst case scenario (Steinacher, Joos, & Stocker, 2013) (Figure 2).

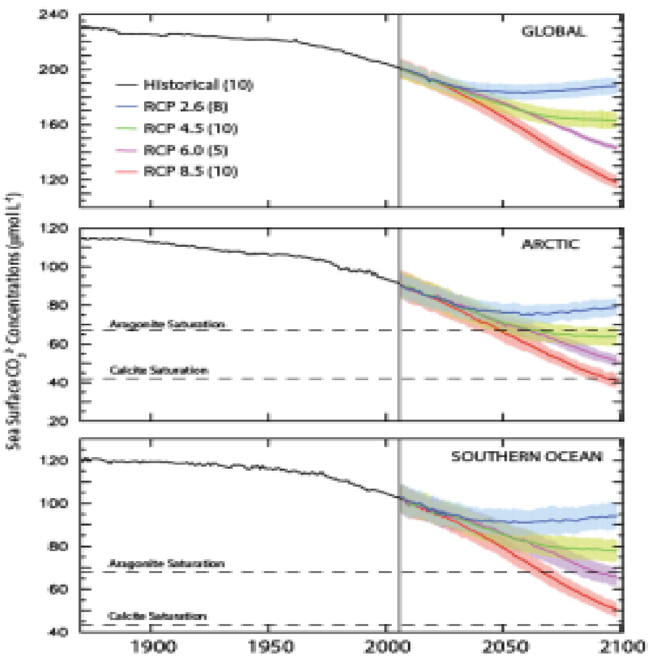


*Figure 2. Surface carbonate ion concentrations for the global ocean, the Arctic Ocean (north of 70º N), and the Southern Ocean (south of 60º S) over 1870–2100 using historical simulations as well as all RCP simulations* (from Bopp et al., 2013)

## 2.1 Carbonate chemistry

When atmospheric carbon dioxide ($CO_2$) dissolves in seawater it interacts with water molecules to form a weak acid called carbonic acid ($H_2CO_3$). This dissociates to form hydrogen ions ($H^+$), bicarbonate ions ($HCO_3^-$) and carbonate ions ($CO_3^{2-}$). Saturation state is a measure of the concentration of calcium carbonate ($CaCO_3$) in seawater. It has the symbol Ω (Omega). High $CO_2$ concentrations reduce levels of carbonate ions causing undersaturation. In marine habitats, calcium carbonate exists in two main forms: calcite and, the more soluble aragonite. Both constitute structural parts of many marine shell fish and skeletal animals. Undersaturation (when $\Omega < 1$) can pose a problem for aragonite-based creatures, as the seawater becomes corrosive and starts to dissolve shells (S. Comeau, Gattuso, Nisumaa, & Orr, 2012; Steeve Comeau, Jeffree, Teyssié, & Gattuso, 2010; Orr et al., 2005). On the other hand when Ω is > 1, most calcifying organisms thrive. However, in some cases, as with many corals, the threshold needs to be a lot higher around $\Omega \geq 3$ for good growth. Corals are therefore more at risk from ocean acidification, especially with the RCP 8.5 projection (Kleypas, 1999; Ricke, Orr, Schneider, & Caldeira, 2013).

## 2.2 Ocean Acidification and Polar Regions

What happens in polar waters is often regarded as a 'bellwether' or early warning system (Fabry, McClintock, Mathis, & Grebmeier, 2009). Such waters are more at risk due to augmented solubility properties of carbon dioxide at colder temperatures. The findings of Fabry et al. predict a significant seasonal undersaturation of the aragonite form of calcium carbonate by 2050 in high latitude surface waters. Calcified organisms most at risk include thecosomatous pteropods, cold water corals, foraminifers, sea urchins, molluscs and coralline algae. The authors point out that research and monitoring needs to be on-going and extensive for Arctic and Antarctic waters so more meaningful interpretation of data can be made.

A large scale observational survey was carried out by McNeil and Matear (McNeil & Matear, 2008) in the Southern Ocean. This study looked at seasonal variability of carbonate concentration and pH and found a prominent reduction in $CO_3^{2-}$ levels during the winter south of the Antarctic polar front. This, combined with absorption of elevated atmospheric $CO_2$ (~450ppm), does not forebode well for marine ecosystems. At this level of acidification they predicted a tipping-point for a harmful impact on aragonite-based plankton such as the pteropod species *Limacina helicina*, particularly the larval stages which typically occur in winter. These findings are further supported by those of Comeau et al. (Steeve Comeau, Gattuso, Nisumaa, & Orr, 2011) who concluded that migratory pteropods, such as *L. helicina* would not be able to synthesise their own shells at high latitudes. This in turn would have a huge negative effect on pelagic ecosystems. Ocean acidification studies in Arctic waters have been extensively reported, see for example Riebesell (Riebesell & Tortell, 2011) and Bellerby (2009), and appears to support comparable work in the Southern Ocean.

## 3. <u>Impacts and Predicaments for Marine Life</u>

In addition to studies reported in the previous section, other researchers have reported similar fates for calcium carbonate dependent marine species. McClintock et al. (McClintock et al., 2009), for example, have shown in their study that Antarctic benthic macro organisms are particularly vulnerable to shell dissolution from ocean acidification. These included two species of bivalves, a limpet, a brachiopod and a coralline alga found on limpet shells.

More specific studies have included that by Cummings et al. (Cummings et al., 2011) looking at functioning of the Antarctic bivalve *Laternula elliptica*. Here, controlled laboratory experiments indicated negative physiological and metabolic responses at low pH levels (pH 7.78) which, worryingly, occurred over a relatively short period of time (weeks to months). Conversely, Godbold and Solan (Godbold & Solan, 2013), boast the longest study to date (542 days) of the inter-tidal polychaete, *Alitta virens*, a non-calcifier. They looked at warming and pH and concluded that no short-term effects were noted but problems manifested over time; their experiment involved temperate rather than cold-water species. These authors also emphasised the necessity for more research into seasonal variation and ecosystem response to marine environment stress factors.

A major knowledge gap has also been identified by Gibson et al. (Gibson, Atkinson, Gordon, Smith, & Hughes, 2011) where data on the effect of climate change stressors, including temperature and pH, is lacking. These researchers were investigating how skeletogensis was affected by hypercapnia (high $CO_2$) and hence an increase in ocean pH. Although they reported similar results to other scientists, they acknowledged that other stress factors like temperature rise, needs to be considered. Interestingly, a study of brittle star fish indicated that calcification increased in response to high pH levels. This, however, was at the expense of muscle deterioration and deemed unsustainable (Wood, Spicer, & Widdicombe, 2008).

Using pteropods like *Limacina helicina* as bio-indicators of ocean acidification has been suggested by Bednarsek et al. (2012) who also emphasise the need for accurate and sensitive methodology. The idea of bio-indicators, but using benthic organisms, has also been reported by Ruddiman and Heezen (Ruddiman & Heezen, 1967) and Almogi-Labin et al. (Almogi-Labin, Luz, & Duplessy, 1986).

The need for further work on physiological responses of marine animals in conditions of high $CO_2$ levels has been highlighted by Maas et al. (Maas, Wishner, & Seibel, 2012) who suggested that organism's natural chemical environment may influence their resilience to increased acid conditions. Similarly, Widdicombe and Spicer (Widdicombe & Spicer, 2008) have pointed out a significant knowledge gap on the effects of increasing ocean acidity on marine organisms. They stress the need for priority research focussing on:

- adaptation or acclimation studies on long term effects of acidification
- more accurate predictions in changes in biodiversity
- a more holistic understanding using multidisciplinary research
- better understanding of ecological mechanisms and interactions between marine communities
- the ability to quantify the capacity of marine animals to adapt and survive/ evolve changes in ocean acidity.

This approach is intended to enable the development of robust predictions and meaningful data on the effects of ocean acidification faced by marine ecosystems.

Other studies include work on the mortality rates of the purple-tipped sea urchin, *Psammechinus miliaris* where 100% death tolls was observed at acid pHs (Miles, Widdicombe, Spicer, & Hall-Spencer, 2007); Corals were found to be particularly vulnerable to ocean acidification (Cohen & Holcomb, 2009). Additionally, Seibel and

Fabry provide a overview of the response of marine biota to elevated $CO_2$ levels (Seibel & Fabry, 2003).

## 4. Socio-Economic Effects

The sea has been the livelihood of many people since ancient times. Damage to this resource due to ocean acidification will inevitably impact on marine food webs and hence societies and economics. The IGBP report of 2013, details some of the socio-economic effects that can or have already impacted on humans (Broadgate et al., 2013). These include resources such as molluscs, echinoderms, crustaceans, fin fish and corals.

## 5. Mitigation and Policy-Making

The most obvious way to solve the problem of ocean acidification is to reduce anthropogenic $CO_2$ emissions. This will involve large scale international collaboration: akin to the ozone problem of the late 1970s (Parson, 2003; Penner, 1999); NASA (n.d.) has a dedicated Ozone Hole Watch website.

Seibel & Walsh, 2002 have assessed the suggestion that carbon dioxide from man-made sources is stored in the deep ocean. They argued that the relatively low-metabolic rates of many deep-sea dwellers would not cope with subsequent increases in $CO_2$ levels and would be detrimental. In addition to attempts to reduce atmospheric $CO_2$ levels, a more aggressive approach to research on biological impacts is needed.

The 2013 Symposium on Ocean Acidification (IGBP) has considered many aspects and put forward considerations for policy-makers. These include:

- limiting future atmospheric $CO_2$ emissions
- restoring wetlands and forests
- treating small-scale coastal areas with alkaline minerals
- impacts of other stressor such as temperature and deoxygenating
- relocation of shell-fish hatcheries
- developing sustainable fisheries management
- Marine Protection Areas (MPAs)

- monitoring and regulating runoffs and
- reducing sulphur dioxide and nitrous oxide production from fossil-fuelled power stations and ships

There also has to be meaningful international coordination of research bodies. Engaging stake holders is also important whereby effective dialogue between, scientists, industries and policy-makers is essential.

## 6. <u>Conclusion</u>

From the literature reviewed here, it is evident that ocean acidification is a genuine problem and does have the capacity to impact negatively on marine biodiversity. As $CO_2$ is more soluble in cold waters, this is more of a concern in polar waters such as the Southern Ocean. Most at risk are the aragonite-based organisms which suffer from dissolution of shells and skeletons along with irrecoverable physiological changes. A range of other marine biota, including corals, starfish and benthic communities, are also implicated.

An urgent need for multidisciplinary research is highlighted which, ideally, needs to be internationally coordinated. This will enable a better understanding of the predictability and effects of ocean acidification on marine biodiversity and can be implemented in mitigation and policy-making.

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