Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

An Orphan Problem Looking for Adoption

Responding to Ocean Acidification Utilising Existing International Institutions

Ellycia R. Harrould-Kolieb[1]

[1]Australian-German Climate and Energy College, University of Melbourne, Melbourne, 3000, Australia

Correspondence to: Ellycia R. Harrould-Kolieb (ellycia.harrould@unimelb.edu.au)

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

Abstract

Ocean acidification poses a substantial threat to the ocean, marine wildlife and the goods and services they provide. As a result it presents a substantial regulatory challenge at the international, regional, national and sub-national levels. In the international realms, ocean acidification is not currently addressed by any international instrument or stand-alone agreement, nor does there appear to be any coherent framework for responding to the issue. Despite this, there are a number of international institutions, including treaty bodies and specialised UN agencies that have expressed an interest in ocean acidification and have begun to initiate an array of relevant activities – a small number of which may be considered substantive activities, including rule-making and implementation.

This paper is an effort to explore the existing international frameworks that are applicable to forming a response to ocean acidification in an attempt to prevent worsening acidification and respond to impacts now and into the future. Six policy domains are outlined that together comprise a comprehensive response to ocean acidification. Each of these are then addressed with respect to what institutions are currently doing to respond to acidification and what could be done in the future.

This paper finds that only three international institutions have initiated substantive policy-making in response to ocean acidification with respect to the regulation of carbon capture and storage and the protection of species. While these are important policy interventions, they are simply not enough to prevent worsening ocean acidification or respond to the impacts resulting from increased acidity, even when coupled with policies, such as regulation of carbon dioxide under the UNFCCC that have been implemented without reference to ocean acidification. In order to fill the existing gaps, this paper proposes a series of, as yet unutilised mechanisms that could be employed to enhance a response to ocean acidification.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

1. Introduction

The problem of ocean acidification is a complex global issue, resulting primarily from the emission of anthropogenic carbon dioxide (CO_2) (Doney et al., 2009) and yet, is exacerbated by a myriad of local stressors (Cai et al., 2011;Hassellöv et al., 2013). Its impacts are present across many scales, from the microscopic, through to ecosystems and on to the global (Gattuso and Hansson, 2011). Its consequences are not limited by geography and are felt in and across national boundaries and in areas of the global commons. However, consequences are not experienced evenly, sometimes with those least responsible the most vulnerable. Further, ocean acidification has implications for biodiversity (Sutherland et al., 2009), economic stability (Narita et al., 2012) and sustainable development (Rockström et al., 2009) and its solutions are intimately tied with other complex global problems, such as climate change. Ocean acidification and its consequences are, therefore, pertinent to and present challenges for the work of a number of international institutions and yet, a response does not appear to fall neatly with the mandate of any. Thus, causing it to sit "within a very complex institutional landscape, at a rather cracked interface between the climate, biodiversity and oceans regimes" (Kim, 2012 p.257).

With no treaty or international instrument designed deliberately to address ocean acidification the issue is somewhat relegated to the 'twilight zone' with no single institution responsible for guiding a response. Despite this, there are a number of international institutions, including treaty bodies and specialised UN agencies that have expressed an interest in ocean acidification (UNGA, 2006;CCAMLR, 2009;UNFCCC, 2015b). However, much of this interest appears to be limited to calls of concern and knowledge production activities, with limited efforts to change legal frameworks or initiate implementation policies to integrate ocean acidification into existing structures (Billé et al., 2013).

Given this lack of substantive policy making, one is left asking what can be done to enhance the global governance of ocean acidification. One avenue that has been proposed is the creation of a comprehensive ocean acidification treaty, that would tackle all aspects of a response in one forum (Lamirande, 2011;Kim, 2012). However, such an effort seems unlikely at this time, with seemingly little support in the wider policy or academic communities. Thus, we are left attempting to fill the gaps by utilising existing international mechanisms to respond to ocean acidification.

This paper is, therefore, an effort to explore in more depth the existing international frameworks that are applicable to ocean acidification and can be utilised to take action. This paper proceeds by first exploring the problem of ocean acidification and its solutions. Six policy domains are proposed that need to be filled in order to prevent worsening acidification and address its impacts now and into the future. The discussion then turns to a review of activities initiated by the United Nations (UN) and UN affiliated bodies as well as international treaties deposited with the UN that have been implemented, at least in part, as a response to ocean acidification. This review reflects upon their capacity to fill all six policy domains. Substantial gaps are found, hence, non-acidification directed policies are accessed to see if it is possible that ocean acidification is being addressed without explicit intent to do so. Again the responses are found lacking. Thus, this paper turns to an exploration of existing mechanisms and institutions, which are not yet being applied to ocean acidification, to investigate how they can be utilised to further contribute to a response.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

2. Responding to Ocean Acidification

An ocean acidification response has two main objectives: preventing acidification from worsening, while simultaneously addressing the impacts that have already occurred (or those that are yet to occur due to already released emissions). Billé et al. (2013) identified the main way to achieve these two goals. First and foremost is the need to limit carbon dioxide concentrations in the atmosphere. This can be achieved by the direct reduction of carbon dioxide emissions or the removal of carbon dioxide from the atmosphere. Reducing the local factors that cause acidification, including nutrient inputs, can also help to prevent worsening acidification. Strengthening ecosystem resilience to ocean acidification, adapting human activities in anticipation of, or reaction to, ocean acidification, and repairing damages when the ocean has already acidified by restoring degraded systems or reducing acidity using additives other than iron are all measures that can be used to address the impacts of rising ocean acidity.

This range of available responses can be grouped under six types of policy domains (as summarised in Table 2). *Mitigation* policies are those intended to lead to reductions in carbon dioxide emissions, while *non-*CO_2 *mitigation* policies are those aimed at reducing non-CO_2 emissions that contribute to OA as well as efforts to reduce or remove other local exacerbating factors, such as run-off. *Adaptation and Protection* measures are policies aimed at enhancing resilience in human and ecological communities to enable them to better withstand the impacts of ocean acidification. These are grouped together as the terms adaptation and protection appear to be used interchangeably within a number of policy settings and can refer to either human or ecological communities. *Restoration* policies are those intended to facilitate the repairing and rebuilding of ecological communities harmed by ocean acidification, while *reparation* policies are those implemented to assist human communities that have suffered damage or loss. Finally, those policies aimed at manipulating oceanic or atmospheric properties to address ocean acidification, whether they be mitigation, restoration or other type policies, are termed *geoengineering*, such as addition of additives to increase alkalinity.

Table 1: Interventions for Preventing Worsening OA

POLICY DOMAIN	OBJECTIVE	EXAMPLES
CO_2 Mitigation	Reducing the primary global driver of ocean acidification	Introduce renewables Increase efficiency Land use changes
Non-CO_2 Mitigation	Reducing the local factors that exacerbate ocean acidification	Reduce runoff Reduce Non-CO_2 emissions
Adaptation and Protection	Building or maintaining resilience in order to assist human communities and ecological systems to overcome, absorb, return from or adjust to change	Establish marine protected areas Reduce non-OA stressors Alter species distribution Protect ecosystem services Identify alternative sources of income Alter commercial/industrial practices
Restoration	Repairing ecological communities after damage has occurred	Replant vegetation Reseed coral reefs Reintroduce species
Reparations	Ameliorating damage that has occurred within human communities	Establish reparation funds
Geoengineering	Altering the physical properties of the ocean or atmosphere to prevent further acidification or reduce acidity	Sequester CO_2 Remove CO_2 from atmosphere Increase alkalinity of water

This suite of options for tackling ocean acidification begins with the reduction of carbon dioxide in the atmosphere. It is the primary solution to halting further increases in acidity as it is largely these emissions that

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

will determine the trajectory of the acidity of the global ocean in the near future (Caldeira and Wickett, 2003). This can be achieved, for example, via the introduction of renewable energy and the removal of fossil fuels, increases in efficiency of energy production, changes in land use and the capture and storage of carbon dioxide. In addition to carbon dioxide, local factors can exacerbate or alleviate this global trend and therefore for some locations the removal or reduction of these factors can be an important way of protecting discreet geographic areas, for example, limiting run-off (Cai et al., 2011) and reducing emissions, such as sulphur and nitrogen emissions from shipping (Doney et al., 2007).

While mitigation is the only way to prevent long term increases in acidity, negative effects are already occurring (De'ath et al., 2009;Bednaršek et al., 2014) and will continue to occur due to the locked in impacts from already released emissions (Joos et al., 2011). Thus, efforts to build and maintain resilience in order to assist human communities and ecological systems withstand, absorb, or adjust to these changes are also required. These types of policies can be targeted at protecting ecological communities, for example by establishing marine protected areas, clearance of invasive species and the removal of other anthropogenic stressors, such as pollution (Billé et al., 2013). Alternatively, policies can be targeted at ensuring human communities have the potential to adapt to changes, for example, by switching fisheries targets to less vulnerable species (Ekstrom et al., 2015) or establishing monitoring systems to allow commercial enterprises to respond appropriately to changing pH levels, as has occurred in Washington State oyster hatcheries (Barton et al., 2015).

It is also possible that efforts to reduce emissions, protect ecological systems and enhance the adaptive capacity of human communities may simply not be enough in some cases. As a result it is also important to consider whether human communities may be entitled to reparations for damages and loss experienced due to the impacts of ocean acidification. In addition, efforts will be needed to determine whether degraded ecosystems can and should be restored, and if so, via what methods. For example, the reintroduction of species, reseeding coral reefs, or increasing ocean pH via introduction of various additives (Rau et al., 2012).

3. Current Responses to Ocean Acidification

These six domains offer a typology for examining how the international community, via the UN and its affiliated institutions, is either preventing ocean acidification from worsening or responding to impacts that have already occurred. This research revealed that only three institutions, the London Convention and Protocol (LC&P), the OSPAR Convention, and the Convention on Biological Diversity (CBD), have implemented any of these types of policies with explicit consideration of ocean acidification.[1]

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (LC, 1972), known as 'The London Convention' or the 'dumping Convention' was designed to prevent pollution of the ocean from the dumping of waste from vessels, aircrafts and platforms. The Convention functions by providing a banned list of substances that cannot be disposed of in the marine environment. The London Protocol (1996), designed to replace the Convention is more precautionary and provides a 'reverse list' naming substances that may be considered for dumping, while prohibiting all others (Annex 1). The Convention on Biological Diversity

[1] A number of other activities were found to have been initiated in response to ocean acidification, including calls of concern, calls for action and knowledge production, all of which are important and contribute to the larger discourse around ocean acidification and will (hopefully) lead to further policy making. However, these activities are beyond the scope of this particular discussion as they are not classified as policies designed to directly prevent further acidification or address the impacts that have already occurred.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

Biogeosciences Discussions Open Access EGU

(1992a) was designed to conserve biological diversity, as well as its sustainable and equitable use. The Convention provides a framework for national action via agreed upon goals and guidelines, without putting in place many binding obligations, beyond the obligation to address the issues covered by the Convention (Secretariat, 2001).Both the LC&P and the CBD are conventions with global scope and both enjoy fairly high participation rates (with 87, 48 and 196 members respectively). The Convention for the Protection of the Marine Environment of the North-East Atlantic, or the "OSPAR Convention" (1992) is a regional convention focused on the protection of the North-East Atlantic and has 18 contracting parties. The objectives of the OSPAR Convention are implemented via the adoption of decisions (which are legally binding) and recommendations and other agreements that guide the activities of its members.

3.1 Geoengineering

As early as 2004, ocean acidification began to appear in discussions around the possible placement of carbon dioxide in the OSPAR maritime area as a way of addressing climate change. The potential detrimental effects of ocean acidification due to increasing anthropogenic carbon dioxide were highlighted and a review of existing knowledge was commissioned (OSPAR, 2005). This resulted in the publication of a technical report, *Effects on the marine environment of ocean acidification resulting from elevated levels of* CO_2 *in the atmosphere*, which provided an overview of ecosystem sensitivity to carbon dioxide exposure (Haugan et al., 2006).

In 2007, the OSPAR Commission (the decision-making body of the Convention) formally expressed concern over the 'implications for the marine environment of climate change and ocean acidification due to elevated concentrations of carbon dioxide in the atmosphere' (OSPAR, 2007b, p. 1). The Commission further recognised that the storage of carbon dioxide in geological formations could act as part of a portfolio of measures for mitigating these impacts (OSPAR, 2007a). OSPAR adopted a *Decision* to ensure environmentally safe storage of carbon dioxide streams in geological formations, while legally ruling prohibiting the placement of carbon dioxide streams in the water column or on the seabed, due to the likelihood of resulting harm to living resources and marine ecosystems (OSPAR, 2007b).

Echoing the discussions taking place within the OSPAR regime, the Consultative Meeting of Contracting Parties to the London Convention acknowledged, in 2005, that carbon dioxide posed a direct threat to the marine environment and was responsible for causing ocean acidification. It was also acknowledged that carbon dioxide sequestration and storage, which had effectively been banned until this point, could bring about benefits to the oceans in terms of reducing ocean acidification and climate change. Furthermore, it was agreed that the act of carbon sequestration and its implications for the marine environment came under the purview of the LC&P (IMO, 2005). As a result, in 2006 an amendment was made to Annex 1of the Protocol (the 'reverse list') that allowed for the consideration of dumping of 'carbon dioxide streams from carbon dioxide capture processes for sequestration' (IMO, 2006, p.3). It was decided that carbon dioxide may only be considered for dumping if 'disposal is into a sub-seabed geological formation'(IMO, 2006, p.3), thereby effectively maintaining a prohibition on its disposal in the water column or on the sea floor.

3.2 Protection and Adaptation

In 2010, the OSPAR Commission *agreed* to 'monitor and assess the nature, rate and extent of the effects of climate change and ocean acidification on the marine environment and consider appropriate ways of responding to those developments' and that '[c]onsiderations of the impacts of climate change and ocean acidification, as

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

well as the need for adaptation and mitigation, will be integrated in all aspects of the work'(OSPAR, 2010, p.3). Significantly, the Commission also *agreed* that it would strengthen the OSPAR network of marine protected areas in recognition of their role in 'maintenance of ecosystem integrity and resilience against human activities and impacts of climate change and ocean acidification' (OSPAR, 2010, p.5).

Ocean acidification first began to appear in discussions within the CBD in 2008 when it was considered at the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA)(SBSTTA, 2008). It then made its way on to the agenda of the 9th Convention of the Parties (COP), at which it was requested that the Executive Secretary, in conjunction with others, prepare a synthesis report of available scientific information pertaining to ocean acidification (CBD, 2008). The resulting report, *Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity* (Secretariat, 2009), was considered at the following SBSTTA meeting. At which it was recommended that the COP adopt a decision expressing serious concern about increasing ocean acidification and the potential threat to biodiversity and ecosystems and the consequent impacts on the services they provide (SBSSTA, 2010). SBSTTA also recommended that the COP request the Executive Secretary to, in conjunction with other relevant organisations and scientific groups, develop a series of expert review processes to monitor and assess the impacts of ocean acidification and widely disseminate the result to raise awareness both within the CBD and without. SBSTTA also suggested that given the relationship between atmospheric carbon dioxide concentration and ocean acidification the COP request the Executive Secretary to transmit the findings to the Secretariat of the UNFCCC (SBSSTA, 2010). All of these recommendations were accepted at the 10th COP, at which the COP expressed 'its serious concern that increasing ocean acidification, as a direct consequence of increased carbon dioxide concentration in the atmosphere, reduces the availability of carbonate minerals in seawater…'(CBD, 2010b p.12)

The CBD COP also adopted a list of Ecologically or Biologically Significant Marine Areas (ESBAs) and encouraged their conservation and sustainable use. These areas were identified as serving an important purpose in supporting the healthy functioning of the ocean and included the *Western South Pacific high aragonite saturation state zone*. An area identified as having the highest aragonite saturation state in the ocean today and, therefore, the last to fall below critical thresholds with increasing acidification (CBD, 2012). This area, therefore, may be the slowest to be impacted by ocean acidification and potentially the fastest to recover.

Significantly, the COP also set out a revised and updated strategic plan for biodiversity for 2011-2020, which included establishing new biodiversity targets, the "Aichi Targets"(CBD, 2010c). The Aichi Targets set out a series of goals aimed at halting the loss of biodiversity by 2020. Target 10 recommends that 'the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning' (CBD, 2010c, p.119). The rational provided for this target is that the reduction of stressors affecting ecosystems will help to make them less vulnerable to the impacts of acidification over the short to medium-term, thus, providing more time to address acidification over the longer-term. 'Ultimately the aim of this target is to provide ecosystems with the greatest probability of maintaining their integrity and functioning despite the effects of climate change and/or ocean acidification' (CBD, 2013, p.1). Pollution control, reducing over-exploitation and harvesting, eradication of invasive species are all activities offered as ways to reach this target. While remaining fairly vague, this is

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

significant as it is the first target set by any international institution with a timeframe for responding to ocean acidification.

In response to this target, SBSTTA suggested a series of practical responses available to Parties to meet Target 10 and help reduce threats from ocean acidification. With regards to mitigation, Parties were encouraged to work towards emission reductions of carbon dioxide and to participate in the UNFCCC, IPCC and other related processes. These are relatively vague and aspirational and it appears that mitigation activities have largely been deferred to other bodies, such as the UNFCCC, that are deemed more relevant to the task. However, the guidance offered for maintaining and restoring ecosystem resilience is far more detailed and includes specific activities that governing bodies can implement, including effectively managing coastal runoff, limiting the impacts of unstainable fishing practices and the reduction of local pollutants (SBSSTA, 2012).

3.3 Substantial Gaps in the Response to Ocean Acidification

The substantive activities of the CBD, OSPAR Convention and the LC&P, as summarised in Table 2, are useful first steps in crafting an international response to ocean acidification. However, these policies by themselves are unable to prevent worsening acidification. This is in large part because these activities focus on the protection of species and ecosystems and the regulation of geoengineering efforts and do not tackle the root cause of ocean acidification – rising carbon dioxide emissions. Activities focused on alleviating local pressures, protecting and restoring ecosystems and helping human communities to adapt and respond are critical to ensuring positive outcomes in the face of ocean acidification. However, the success of interventions designed to alleviate the pressure of ocean acidification greatly declines with increasing emissions (Gattuso et al., 2015). Thus, these options are only viable when coupled with substantive action to reduce carbon dioxide emissions. Without measures to reduce carbon dioxide, non-CO_2 interventions become more costly and less effective and are only capable of delaying the worsening impacts of ocean acidification for a short period of time (Kennedy et al., 2013). As a result, non-CO_2 mitigation, protection, adaptation, restoration and reparation efforts, while important, remain largely ancillary to CO_2 reduction efforts and should only be viewed as effective when coupled with CO_2 emission reductions.

Table 2: Policies Initiated with Explicit Intent to Respond to Ocean Acidification

INTERVENTION	OSPAR Convention	LC&P	CBD
CO_2 Mitigation			
Non-CO_2 Mitigation			Recommended minimization of anthropogenic pressures on ecosystems impacted by OA
Adaptation and Protection	Agreed to strengthen the OSPAR network of marine protected areas		Identified Western South Pacific high aragonite saturation state zone for protection
Restoration			
Reparations			
Geoengineering	Prohibited the disposal of carbon dioxide on or above the sea floor	Allowed for the sequestration of CO_2 in sub-seabed geological formations.	

4. Co-Benefits of Non-Ocean Acidification Directed Policies

It is evident that there are substantial gaps in the current governance of ocean acidification, especially in the domains of carbon dioxide mitigation, restoration and reparations. Even within those domains with existent policies there is room for additional efforts to create a more robust response to acidification. However, it is possible that efforts already exist that have been initiated without consideration of ocean acidification, that may actually be deemed relevant to its response.

4.1 CO_2 Mitigation

Most significant is the work being undertaken within the United Nations Framework Convention on Climate Change (UNFCCC)(1992a) to regulate emissions of carbon dioxide. As the main international institution working to regulate carbon dioxide emissions, it is this institution that has the largest potential to determine future levels of ocean acidity. To date, there has been little activity on behalf of the COP to consider ocean acidification in discussions of targets and timelines for emission reductions. Nevertheless, rapid decarbonisation in order to address climate change would also address ocean acidification. In the most recent Paris Agreement, Parties agreed to hold 'the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels'(UNFCCC, 2015a, p.3).

This agreement, paves the way for large-scale emission reductions, resulting in decarbonisation, thereby preventing future acidification. However, the agreement also leaves room for less ambitious action, including surpassing a 1.5^{o}C rise in global temperatures, delaying a reduction to net zero emissions by as late of the end of the century and utilising technologies to remove substantial amounts of carbon dioxide from the atmosphere later in the century. Such scenarios would allow for continued high emissions in the short-term and rapid reductions at a later time, which would result in worsening acidification and irreversible impacts in the near future (Mathesius et al., 2015). The UNFCCC Expert Review suggested that there is a high likelihood of a meaningful difference in impacts resulting from global temperature increases of 1.5 or 2°C. At 1.5°C risk from acidification is likely to be on the verge of high risk, whereas at 2°C the risk would already be high. In addition, an overshoot of the target followed by a rapid reduction in emissions would likely result in impacts from acidification, irreversible for tens of thousands of years due to slow ocean processes (UNFCCC, 2015b). Thus, it is difficult to conclude that the Paris Agreement, unless implemented in its most stringent form, is strong enough to prevent a worsening of acidification into the future. As a result, there is still a need to work towards stronger targets and timelines with consideration of ocean acidification.

There has been additional work to reduce carbon dioxide emissions undertaken within the International Convention for the Prevention of Pollution from Ships (MARPOL)(1973). MARPOL has taken steps to regulate carbon dioxide emissions from the shipping industry, which account for approximately 2.2 percent of global emissions (MARPOL, 2017), via the introduction of operational and technical measures (MEPEC, 2011). While not implemented with reference to ocean acidification, nor comprising a big enough reduction in global emissions to prevent further acidification, this is significant as it is the first mandatory regime for regulating the emissions of a global industry. Such measures will aid in attempts to reduce global emissions and paves the way for other industry specific regulations to occur within other institutions.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

4.2 Non-CO_2 Mitigation

MARPOL has also been instrumental in setting limits on the emissions of sulphur and nitrogen and other pollutants from ships. Again, these regulations have been put in place to reduce air pollution and not as an attempt to respond to ocean acidification. Although a 2010 submission by the United States proposing areas to be designated as Sulphur Emission Control Areas noted that sulphur and nitrogen deposition from ships causes local acidification of marine waters (MPEC, 2010).

4.3 Geoengineering

Along with efforts to reduce carbon dioxide and non-CO_2 emissions a number of efforts have been initiated to regulate marine geoengineering. This is significant as some of these activities are thought likely to exacerbate ocean acidification (Cao and Caldeira, 2010). Concerns have been raised within the CBD and LC&P over the effectiveness and possible negative impacts on the marine environment of iron fertilization (with no mention of ocean acidification). In 2008, the CBD COP requested Parties and urged other governments to 'ensure that ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities'(CBD, 2008). Noting this decision, the LC&P placed a moratorium on all ocean fertilization activities (excluding those conducted for legitimate scientific research purposes)(LC&P, 2008). Further, in 2010 the CBD COP adopted a decision that invited Parties and other Governments to ensure 'that no climate –related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the risks for the environment and biodiversity and associated social, economic and cultural impacts' (CBD, 2010a, p.5). While these steps are useful in regulating geoengineering, it is possible that such efforts will still go ahead, thus there is a need to consider their impacts, positive, negative, or benign, for ocean acidification prior to their deployment.

4.4 Protection, Adaptation and Restoration

Also of relevance to ocean acidification are the multitude of conservation measures that have been implemented under various institutions. Listing all is simply beyond the scope of this paper; however, efforts include establishing marine protected areas, limiting fishery quotas, and restoration of local habitats. These policies may play a role in boosting resiliency and protecting biodiversity from increasing acidity, as well as restoring impacted systems and aiding human communities in adapting to changing conditions. However, conservation measures implemented without consideration of the trajectory and impacts of ocean acidification may allow activities that will exacerbate ocean acidification. In addition, they may simply not be constructed or implemented in a way that helps human and ecological communities to overcome the impacts of ocean acidification. For instance, it is not enough to have areas designated as protected, it is recommended that they be specifically located to avoid hotspots of acidification (Hofmann et al., 2011;Kelly et al., 2011), while simultaneously placed to act as refugia, either by preserving areas that are likely to acidify at a slower rate or by protecting populations that exhibit high levels of genetic diversity and natural resilience (Billé et al., 2013). Thus, if institutions wish to protect and restore ecological communities and aid the human communities dependent upon them, conservation measures need to be designed with ocean acidification in mind.

4.5 Gaps Still Exist

It is evident that there are a number of existing policies, initiated without consideration of ocean acidification, which are able to help lessen worsening acidification and address impacts (See Table 3 for a summary). Efforts

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

Biogeosciences
Discussions
Open Access

to reduce carbon dioxide emissions within the UNFCCC have, to date, not considered ocean acidification and thus, are not strong enough to prevent increasing acidification in the future. Other mitigation policies, including those within MARPOL provide positive steps to reduce industry wide emissions of carbon dioxide, however are not broad enough to capture a large enough segment of emissions so as to prevent future acidification. In addition, general conservation measures are likely to have a positive effect on ecosystems in the face of rising acidity. However, without specific intent to address acidification it is possible that such measures could miss important opportunities with regards to protecting ecological systems. Further, few legally binding restrictions have been placed on deployment of geoengineering efforts and thus, may be used in the future. It is important to understand how such efforts could interact with ocean acidification and ensure that the possible negative impacts are considered prior to their deployment.

Table 1: Existing Policies that Form a Response Ocean Acidification

INTERVENTION	OSPAR Convention	LC&P	CBD	UNFCCC	MARPOL
CO_2 Mitigation				Agreed to rapid reductions of GHG emissions	Operational and technical measures to reduce ship emissions
Non-CO_2 Mitigation			Recommended minimization of anthropogenic pressures on ecosystems impacted by OA		SOx and NOx regulations
Adaptation and Protection	Agreed to strengthen the OSPAR network of marine protected areas		Identified Western South Pacific high aragonite saturation state zone for protection		
Restoration					
Reparations					
Geoengineering	Prohibited the disposal of carbon dioxide on or above the sea floor	-Allowed for the sequestration of CO_2 in sub-seabed geological formations. -Moratorium on iron fertilization and other forms of marine geoengineering	Requested ocean fertilization activities do not occur		

It is appears that while there are a series of policies currently forming an international response to ocean acidification, they are simply not enough, even when coupled with non-acidification directed efforts, to prevent the worsening of ocean acidification or address its impacts. Thus, this paper will now turn to a discussion of existing policies within international institutions that are not currently being utilised to respond to ocean acidification that could be employed to enhance efforts to prevent worsening of ocean acidification and respond to impacts as they occur.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

5. Utilising Existing International Instruments

5.1 CO_2 Mitigation

With regards to the mitigation of carbon dioxide emissions, the UNFCCC remains the venue in which the international community has come together to regulate emissions. As discussed above the Paris Agreement has established a long-term goal for emission reductions that provides a pathway for avoiding unacceptable risks associated with both ocean acidification and climate change. However, the leniencies built into the agreement mean that this is not guaranteed. Thus, there is still a need for the broader incorporation of ocean acidification into discussions within the UNFCCC (Harrould-Kolieb, 2016). This could be worked into the periodic reviews that will take place in regards to strengthening the long-term goal and the timeline for meeting this goal. Some scholars, however, suggest that this is unlikely to occur due to structural limitations of the UNFCCC mandate that effectively prevents a more meaningful consideration of ocean acidification within the workings of the Convention (Baird et al., 2009;Kim, 2012). However, these are narrow readings of the Convention and do not take into account its progressive nature with regards to the incorporation of developing science (Harrould-Kolieb, 2016). Thus, it is possible and critical for ocean acidification to be considered alongside climate change when setting targets, timelines and methods for emission reductions within the UNFCCC.

It is worth noting that a number of other fora, including the United Nations Convention on the Law of the Sea (UNCLOS)(1982) and the United Nations Fish Stocks Agreement (UNFSA)(1995) have been proposed as avenues for limiting carbon dioxide emissions, primarily due to their obligations to protect the marine environment through the regulation of pollutants. These institutions are seen as particularly attractive as they both have binding dispute resolution mechanisms in place that could, it is proposed, essentially be used to compel states to reduce their carbon dioxide emissions (Boyle, 2012;Burns, 2006). However, these institutions are unlikely to be utilised, primarily because of the significant duplication of efforts already being pursued within the UNFCCC to reduce emissions (Boyle, 2012). These institutions are also less widely subscribed to than the UNFCCC, and it is questionable whether the dispute resolution mechanisms could be used to compel some of the largest emitters, including the United States, that have not yet ratified the traty. Thus, the UNFCCC remains the most likely venue for achieving a global reduction in carbon dioxide emissions.

5.2 Non-CO_2 Mitigation

The broad pollution controls offered under UNCLOS, which impose management obligations on Parties to limit marine pollution (UNCLOS, 1982a), could be used to encourage states to make greater effort to reduce non-CO_2 drivers of ocean acidification. Similarly, UNFSA requires Parties to 'minimize pollution' (UNFSA, 1995) and while no definition of pollution is provided within the agreement text, it could be reasonably interpreted to include pollutants that increase coastal acidification, especially as linkages between increasing acidity and impacts to fisheries become more apparent (Branch et al., 2013). In addition, the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA), established by the Washington Declaration on Protection of the Marine Environment from Land-Based Activities (UNEP, 1995), provides a forum for limiting nutrient run-off, indeed, the GPA was tasked with working on 'on nutrients, litter and wastewater' and identified a number of land-based sources of pollution including sewage, nutrients, sediment mobilisation, persistent organic pollutants, oils, litter, heavy metals and radioactive substances on which to focus its work (UNEP, 2015). Similarly, the CBD has agreed in Aichi Target number 8, that nutrient pollution

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

be brought to sustainable levels by 2020 so as not to negatively impact ecosystem function and biodiversity (CBD, 2010c).

These are all existing measures that can easily be understood to include efforts to reduce the local causes of ocean acidification. Further, institutions that manage networks of marine protected areas, including, for example, OSPAR, UNFSA and the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR)(1980a), could incorporate the local reduction of acidity into the MPA management as a regular operating procedure (Billé et al., 2013). It has been suggested that an implementing agreement under UNCLOS could provide an avenue for establishing a series of marine protected areas beyond national jurisdictions (CBD, 2006), such areas would be governed by the objectives of UNCLOS, including limiting pollution to the marine environment. Thus, these MPAs could be established with consideration of ocean acidification and managed with the intent of responding to it.

5.3 Adaptation and Protection

Marine protected areas could also be utilised to enhance resilience and adaptive capacity of ecological and human communities affected by ocean acidification. The identification and protection of areas that may act as refugia or hotspots of biodiversity would act to reduce stressors and encourage greater resilience in the face of ocean acidification. Consideration of ocean acidification could be incorporated into existing strategies and guidelines for designing and managing MPA networks, such as those designated by the IUCN World Commission on Protected Areas, which contain guidelines for best practice in regards to climate change (IUCN-WCPA, 2008) . Similarly, ocean acidification could be incorporated into the General framework for the establishment of CCAMLR Marine Protected Areas, which already recognises the role of MPAs in contributing to sustaining ecosystem structure and function and aims to protect areas in order to maintain resilience or the ability to adapt to the effects of climate change (CCAMLR, 2011). CCAMLR has the ability to designate marine protected areas that can exclude fishing activities, ship discharges and dumping of wastes, as well as setting catch limits and designating open and closed seasons for fisheries (CCAMLR, 1980b). All of which could be useful in protecting species, such as krill, that are likely to be impacted severely by increasing acidity (Kawaguchi et al., 2011;Kawaguchi et al., 2013) and the Southern Ocean areas that are rapidly acidifying (McNeil and Matear, 2008). These treaties could be utilised to create networks of protected areas with the expressed intent of combatting ocean acidification.

The UNFSA and various regional fisheries management organisations (RMFOs) also offer venues for the consideration of the impact of ocean acidification on fisheries and the management options required to ensure functional fisheries into the future. These could include the adjusting of take limits and establishing no take zones to boost resilience in areas most vulnerable to ocean acidification. The CBD could also provide a venue to host a broader discussion about the integration of ocean acidification into biodiversity adaption and protection planning. Specifically via the *Climate Change Adaptation Database* that offers guidance on adaptation options to Parties(CBD, 2017)

5.4 Restoration

The CBD also offers an important venue for initiating activities to restore ecosystems degraded by ocean acidification. Indeed, Article 8(f) of the Convention states that 'each Contracting Party shall […] [r]ehabilitate and restore degraded ecosystems and promote the recovery of threatened species, inter alia, through the

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

development and implementation of plans or other management strategies' (CBD, 1992a). Further, Target 14 of the Aichi Targets requires that 'ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded'(CBD, 2010c). Thus, restoration of species and ecosystems degraded by ocean acidification fall easily within the CBD mandate. The RAMSAR Convention on Wetlands (1971) could also offer a venue for restoration activities pertaining to coral reefs and coastal areas affected by ocean acidification as it contains a very broad definition of wetland that includes coral reefs and marine waters to a depth of six meters at low tide (RAMSAR, 1971).

5.5 Reparations

The UNFCCC COP has initiated efforts to consider ways to address the loss and damages experienced in developing countries due to climate change (UFCCC, 2017). Interestingly, ocean acidification appears as part of this discussion; listed as a slow onset event that could result in loss and damage(UNFCCC, 2010). This is the only mention of ocean acidification in any outcome documents of the COP to date. Here the COP recognised the need for greater effort to better understand and reduce the loss and damage associated with, among other things, the impacts of slow onset events, including ocean acidification. In 2013, following two years of deliberations, the Warsaw International Mechanism for Loss and Damage was established (UFCCC, 2014). It is, as yet, unclear how the mechanism will progress (Surminski and Lopez, 2014) and how and to what extent ocean acidification will be factored in. However, this could provide an avenue for addressing issues of reparations associated with loss and damage resulting from ocean acidification.

5.6 Geoengineering

Geoengineering, like ocean acidification, presents numerous governance challenges as it is a cross-sectional issue that falls under the interest areas of many international institutions while, simultaneously not fitting neatly within the mandate any one. As yet, there is no clear governance framework applicable to geoengineering. However, it has been suggested that the use of international environmental impact assessment (EIA) mechanisms could be an avenue for increasing geoengineering governance (Craik, 2015). This could also offer a pathway for assessing whether individual geoengineering schemes are likely to be positive, negative or neutral with regards to ocean acidification.

There are a series of institutions that offer EIA mechanisms that could be utilised for this purpose, including UNCLOS that imposes an obligation on states to assess the potential effects of planned activities that 'may cause substantial pollution of or significant and harmful changes to the marine environment' (UNCLOS, 1982b). The CBD also requires states to 'introduce appropriate procedures requiring environmental impacts assessment of its proposed projects that are likely to have significant adverse effects on biological diversity' (CBD, 1992b). There is also a clause in the UNFCCC that makes reference to undertaking impact assessments in order to minimize adverse effects resulting from projects or measures undertaken to mitigate or adapt to climate change (UNFCCC, 1992b). For regional impacts, the Protocol on Environmental Protection to the Antarctic Treaty (1991b) offers EIA requirements for all activities occurring within the Antarctic Treaty area that could have even a 'minor or transitory impact' (ATS, 1991). The Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention)(1991a) may also be applicable as it offers processes to deal with transboundary impacts, which may occur due to the deployment of geoengineering mechanisms.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

5.7 Filling the Gaps

This section has proposed a series of existing instruments that could be utilised in order to enhance the current, but wanting, international response to ocean acidification. These suggestions include utilising instruments within institutions that are already responding to ocean acidification, such as the CBD. Opportunities exist within this institution to expand efforts to mitigate the non-CO_2 causes of ocean acidification as well as adaptation and protection, restoration and geoengineering efforts. Other institutions, such as UNCLOS, that have previously been inactive with regards to ocean acidification, also offer avenues for increasing the governance of ocean acidification. UNCLOS offers opportunities for action within efforts to reduce both carbon dioxide emissions and the non-CO_2 causes of rising acidity. UNCLOS can also enhance efforts to adapt and protect human and ecological systems from acidification, as well as the regulation of geoengineering via environmental impact assessments.

These previously untapped opportunities offer the potential for addressing each of the six policy domains that constitute a comprehensive response to ocean acidification. This is visualised in Table 4. The CBD and UNCLOS are venues that could take on multifaceted responses to ocean acidification. Indeed, these two institutions could act to guide the wider response across the international community. The UNFCCC is central to this response with regards to reducing carbon dioxide emissions and is, currently, the only venue discussing the issue of reparations with relations to loss and damage suffered due to climate change. It is also likely that the UNFCCC will be abreast of any deployment of geoengineering schemes, and thus, incorporating ocean acidification into the UNFCCC impact assessment will be an effective way of ensuring impacts with regards to ocean acidity are considered. While the other institutions listed offer more ancillary avenues to responding to ocean acidification, they do represent additional opportunities for creating a comprehensive response.

Table 2: International Institutions Capable of Contributing to a Response to Ocean Acidification

INTERVENTION	CBD	UNCLOS	UNFCCC	OSPAR	UNFSA	MARPOL	CCAMLR	LC&P	GPA	RAMSAR	ATS	Espoo
CO_2 Mitigation		X	X		X	X						
Non-CO_2 Mitigation	X	X		X	X	X	X		X			
Adaptation and Protection	X	X		X	X		X					
Restoration	X									X		
Reparations			X									
Geoengineering	X	X	X	X				X			X	X

6. Conclusion

This review of activities related to ocean acidification within the UN General Assembly and across the UN family found that substantive action (rule-making or implementation) to prevent worsening ocean acidification and to respond to impacts has largely not occurred. Indeed, only three institutions, the London Convention and Protocol, the OSPAR Convention and the Convention on Biological Diversity, were found to have initiated any rule making and implementation activities in direct response to ocean acidification. These are useful first steps in crafting an international response to ocean acidification. However, these policies by themselves are unable to

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

prevent worsening acidification. This is in large part because these activities focus on the protection of species and ecosystems and the regulation of geoengineering efforts and do not tackle the root cause of ocean acidification – rising carbon dioxide emissions.

In addition to these activities there are a number of existing policies, initiated without consideration of ocean acidification, which are able to help lessen worsening acidification and address its impacts. However, these activities, in most cases, including carbon dioxide reduction efforts within the UNFCCC, have been found not to be strong enough to guarantee prevention of ocean acidification in the future. Other mitigation policies, including those within MARPOL provide positive steps to reduce industry wide emissions of carbon dioxide, however are not broad enough to capture a large enough segment of emissions so as to prevent future acidification. In addition, general conservation measures are likely to have a positive effect on ecosystems in the face of rising acidity. However, without specific intent to address acidification it is possible that such measures could miss important opportunities with regards to protecting ecological systems. Further, few legally binding restrictions have been placed on deployment of geoengineering efforts and thus, may be used in the future. It is important to understand how such efforts could interact with ocean acidification and ensure that the possible negative impacts are considered prior to their deployment. Thus, this range of activities were found wanting with regards to offering a strong, comprehensive response to rising ocean acidity and its impacts.

Therefore, a series of options for enhancing the current international response to ocean acidification utilising, as yet, untapped instruments was explored. This found, most importantly, that the CBD and UNCLOS could both take on a substantial amount of work to craft a response to ocean acidification. These two institutions are readily applicable to responding to ocean acidification due to their interests in conserving biodiversity and protecting the marine environment. These two institutions could also serve as focal points for and guide a wider international response to acidification. A number of other institutions were found to have instruments that could be utilised in responding to rising acidity and its impacts. Including, the UNFCCC that will need to remain the venue for the mitigation of carbon dioxide with regards to ocean acidification as it is the site of international efforts to regulate carbon dioxide as a response to climate change.

While this piecemeal approach responding to ocean acidification is perhaps far from ideal it is important to acknowledge that existing institutions are limited to some extent by their mandates in their capacity to initiate a holistic response to ocean acidification. For instance, being a regional agreement the OSPAR Convention is prevented from protecting marine ecosystems globally. The LC&P are limited to governing substances dumped into the ocean and do not have the capacity to regulate land-based emissions of carbon dioxide. Similarly, the CBD, while very broad in scope, is probably limited in its ability to regulate carbon dioxide. Despite the lack of a single institution able to tackle to problem of ocean acidification, this work has found there are a number of institutions capable of taking on different aspects of a response. Together these efforts, if employed, could cover all six policy domains that comprise a comprehensive response to acidification. It is unlikely that an existing institution can or will take on a comprehensive response to ocean acidification. Thus, this piecemeal approach, while far from ideal, offers a pathway forward that is politically feasible and achievable in the short- to medium-term – a critical timeframe with regards to this issue.

References

Convention on Wetlands of International Importance especially as Waterfowl Habitat, entered into force 1975, 1971.

United Nations Convention on the Law of the Sea (UNCLOS), entered into force 1994, 1982.

Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention), entered into force 1997, 1991a.

Protocol on Environmental Protection to the Antarctic Treaty, entered into force 1998, 1991b.

Convention for the Protection of the Marine Environment of the North-East Atlantic, entered into force 1998, 1992.

Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, entered into force 2001, 1995.

Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972, entered into force 2006, 1996.

ATS: Article 8: Environmental Impact Assessment, Protocol on Environmental Protection to the Antarctic Treaty, 1991.

Baird, R., Simons, M., and Stephens, T.: Ocean Acidification: A litmust test for international law, Carbon and Climate Law Review, 4, 459-471, 2009.

Barton, A., Waldbusser, G. G., Feely, R. A., Weisberg, S. B., Newton, J. A., Hales, B., Cudd, S., Eudeline, B., Langdon, C. J., and Jefferds, I.: Impacts of coastal acidification on the Pacific Northwest shellfish industry and adaptation strategies implemented in response, Oceanography, 28, 146-159, 2015.

Bednaršek, N., Feely, R., Reum, J., Peterson, B., Menkel, J., Alin, S., and Hales, B.: Limacina helicina shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem, Proc. R. Soc. B, 2014, 20140123,

Billé, R., Kelly, R., Biastoch, A., Harrould-Kolieb, E., Herr, D., Joos, F., Kroeker, K., Laffoley, D., Oschlies, A., and Gattuso, J.-P.: Taking action against ocean acidification: a review of management and policy options, Environmental management, 52, 761-779, 2013.

Boyle, A.: Law of the Sea perspectives on climate change, The International Journal of Marine and Coastal Law, 27, 831-838, 2012.

Branch, T. A., DeJoseph, B. M., Ray, L. J., and Wagner, C. A.: Impacts of ocean acidification on marine seafood, Trends in ecology & evolution, 28, 178-186, 2013.

Burns, W. C.: Potential Causes of Action for Climate Change Impacts Under the United Nations Fish Stocks Agreement, Sustainable Dev. L. & Pol'y, 7, 34, 2006.

Cai, W.-J., Hu, X., Huang, W.-J., Murrell, M. C., Lehrter, J. C., Lohrenz, S. E., Chou, W.-C., Zhai, W., Hollibaugh, J. T., and Wang, Y.: Acidification of subsurface coastal waters enhanced by eutrophication, Nature Geoscience, 4, 766-770, 2011.

Caldeira, K., and Wickett, M. E.: Oceanography: Anthropogenic carbon and ocean pH, Nature, 425, 365-365, 2003.

Cao, L., and Caldeira, K.: Can ocean iron fertilization mitigate ocean acidification?, Climatic Change, 99, 303-311, 2010.

CBD: Convention on Biological Diversity, entered into force 1993, 1992a.
CBD: Article 14. Impact Assessment and Minimizing Adverse Impacts, Convention on Biological Diversity, 1992b.
CBD: Decision VIII/24. Protected areas Convention on Biological Diversity, UNEP/CBD/COP/DEC/VIII/24, 2006.
CBD: Decision IX/16. Biodiversity and climate change, Convention on Biological Diversity, UNEP/CBD/COP/DEC/IX/16, 2008.
CBD: Decision X/33. Biodiversity and climate change Convention on Biological Diversity, UNEP/CBD/COP/DEC/X/33, 2010a.
CBD: Decision X/29. Marine and coastal biodiversity, Convention on Biological Diversity, UNEP/CBD/COP/DEC/X/29, 2010b.
CBD: Decision X/2. The Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets, Convention on Biological Diversity, UNEP/CBD/COP/DEC/X/2, 2010c.
CBD: Decision XI/17. Marine and coastal biodiversity: ecologically or biologically significant marine areas Convention on Biological Diversity, UNEP/CBD/COP/DEC/XI/17, 2012.
CBD: Quick guide to the Aichi Biodiversity Targets: Target 10 Pressures on vulnerable ecosystems reduced, Convention on Biological Diversity, 2013.
Climate Change Adaptation Database: Integrating Biodiversity into Climate Change Adaptation Planning. https://adaptation.cbd.int, access: 2017, 2017.
CCAMLR: Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), entered into force 1982, 1980a.
CCAMLR: Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), Article IX, 1980b.
CCAMLR: Resolution 30/XXVIII (2009): Climate Change, 2009.
CCAMLR: Conservation Measure 91-04 (2011): General framework for the establishment of CCAMLR Marine Protected Areas, Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), 2011.
Craik, N.: International EIA Law and Geoengineering: Do Emerging Technologies Require Special Rules?, Climate Law, 5, 111-141, 2015.
De'ath, G., Lough, J. M., and Fabricius, K. E.: Declining coral calcification on the Great Barrier Reef, Science, 323, 116-119, 2009.
Doney, S. C., Mahowald, N., Lima, I., Feely, R. A., Mackenzie, F. T., Lamarque, J.-F., and Rasch, P. J.: Impact of anthropogenic atmospheric nitrogen and sulfur deposition on ocean acidification and the inorganic carbon system, Proceedings of the National Academy of Sciences, 104, 14580-14585, 2007.
Doney, S. C., Fabry, V. J., Feely, R. A., and Kleypas, J. A.: Ocean acidification: the other CO2 problem, Marine Science, 1, 2009.
Ekstrom, J. A., Suatoni, L., Cooley, S. R., Pendleton, L. H., Waldbusser, G. G., Cinner, J. E., Ritter, J., Langdon, C., Van Hooidonk, R., and Gledhill, D.: Vulnerability and adaptation of US shellfisheries to ocean acidification, Nature Climate Change, 5, 207, 2015.
Gattuso, J. P., Magnan, A., Bille, R., Cheung, W. W. L., Howes, E. L., Joos, F., Allemand, D., Bopp, L., Cooley, S. R., Eakin, C. M., Hoegh-Guldberg, O., Kelly, R. P., Portner, H.-O., Rogers, A. D., Baxter, J. M.,

Laffoley, D., Osborn, D., Rankovic, A., Rochette, J., Sumaila, U. R., Treyer, S., and Turley, C.: Contrasting futures for ocean and society from different anthropogenic CO_2 emissions scenarios, Science, 349, aac4722-4721-4710, 2015.

Harrould-Kolieb, E. R.: Ocean Acidification and the UNFCCC: Finding Legal Clarity in the Twilight Zone, Wash. J. Envtl. L. & Pol'y, 6, 613, 2016.

Hassellöv, I. M., Turner, D. R., Lauer, A., and Corbett, J. J.: Shipping contributes to ocean acidification, Geophysical Research Letters, 40, 2731-2736, 2013.

Haugan, P., Turley, C., and Pörtner, H.-O.: Effects on the marine environment of ocean acidification resulting from elevated levels of CO2 in the atmosphere, OSPAR intersessional correspondence group, 2006.

Hofmann, G. E., Smith, J. E., Johnson, K. S., Send, U., Levin, L. A., Micheli, F., Paytan, A., Price, N. N., Peterson, B., and Takeshita, Y.: High-frequency dynamics of ocean pH: a multi-ecosystem comparison, PloS one, 6, e28983, 2011.

IMO: Report of the 27TH Consultative Meeting of the Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, International Maritime Organization LC 27/16, 2005.

IMO: Notification of amendments to Annex 1 to the London Protocol 1996 International Maritime Organization, LC-LP.1/Circ.5, 2006.

IUCN-WCPA: Establishing Marine Protected Area Networks—Making It Happen, IUCN World Commission on Protected Areas, National Oceanic and Atmospheric Administration and The Nature Conservancy, Washington, D.C., 118 pp., 2008.

Joos, F., Frölicher, T. L., Steinacher, M., and Plattner, G.-K.: Impact of climate change mitigation on ocean acidification projections, Ocean acidification, 272-290, 2011.

Kawaguchi, S., Kurihara, H., King, R., Hale, L., Berli, T., Robinson, J. P., Ishida, A., Wakita, M., Virtue, P., and Nicol, S.: Will krill fare well under Southern Ocean acidification?, Biology Letters, 7, 288-291, 2011.

Kawaguchi, S., Ishida, A., King, R., Raymond, B., Waller, N., Constable, A., Nicol, S., Wakita, M., and Ishimatsu, A.: Risk maps for Antarctic krill under projected Southern Ocean acidification, Nature Climate Change, 3, 843, 2013.

Kelly, R. P., Foley, M. M., Fisher, W. S., Feely, R. A., Halpern, B. S., Waldbusser, G. G., and Caldwell, M. R.: Mitigating local causes of ocean acidification with existing laws, Science, 332, 1036-1037, 2011.

Kennedy, E. V., Perry, C. T., Halloran, P. R., Iglesias-Prieto, R., Schönberg, C. H., Wisshak, M., Form, A. U., Carricart-Ganivet, J. P., Fine, M., and Eakin, C. M.: Avoiding coral reef functional collapse requires local and global action, Current Biology, 23, 912-918, 2013.

Kim, R. E.: Is a New Multilateral Environmental Agreement on Ocean Acidification Necessary?, Review of European Community & International Environmental Law, 21, 243-258, 2012.

Lamirande, H. R.: From sea to carbon cesspool: Preventing the world's marine ecosystems from falling victim to ocean acidification, Suffolk Transnat'l L. Rev., 34, 183-273, 2011.

LC: Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention), entered into force 1975, 1972.

LC&P: Resolution LC-LP.1(2008): On the Regulation of Ocean Fertilization London Convention and London Protocol, 2008.

MARPOL: International Convention for the Prevention of Pollution from Ships (MARPOL), entered into force 1983, 1973. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Default.aspx, 2017.

Mathesius, S., Hofmann, M., Caldeira, K., and Schellnhuber, H. J.: Long-term response of oceans to CO2 removal from the atmosphere, Nature Climate Change, 5, 1107-1113, 2015.

McNeil, B. I., and Matear, R. J.: Southern ocean acidification: a tipping point at 450-ppm atmospheric CO_2, Proceedings of the National Academy of Sciences of the United States of America, 105, 18860-18864, 2008.

MEPEC: Resolution MEPC.203(62): Inclusion of regulations on energy efficiency for ships in MARPOL Annex VI International Convention for the Prevention of Pollution from Ships (MARPOL), MEPC 62/24/Add.1, 2011.

MPEC: Interpretations of, and Amendments to, MARPOL and Related Instruments: Designation of an Emission Control Area for Nitrogen Oxides, Sulphur Oxides and Particulate Matter, Submitted by the United States, International Convention for the Prevention of Pollution from Ships (MARPOL), MEPC 61/INF.9, 2010.

Narita, D., Rehdanz, K., and Tol, R. S.: Economic costs of ocean acidification: a look into the impacts on global shellfish production, Climatic Change, 113, 1049-1063, 2012.

OSPAR: Meeting of the Biodiversity Committee (BDC), OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, BDC 05/13/1-E, 2005.

OSPAR: OSPAR Guidelines for Risk Assessment and Management of Storage of CO2 Streams in Geological Formations, OSPAR Commission, Reference Number: 2007-12, 2007a.

OSPAR: Decision 2007/1 to Prohibit the Storage of Carbon Dioxide Streams in the Water Column or on the Sea-bed, Meeting of the OSPAR Commission ANNEX 5 (Ref. §2.9b), 2007b.

OSPAR: The North-East Atlantic Environment Strategy: Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010–2020, OSPAR Commission, OSPAR Agreement 2010-3, 2010.

RAMSAR: Convention on Wetlands of International Importance especially as Waterfowl Habitat, Article 1, 1971.

Rau, G. H., McLeod, E. L., and Hoegh-Guldberg, O.: The need for new ocean conservation strategies in a high-carbon dioxide world, Nature Climate Change, 2, 720-724, 2012.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., and Schellnhuber, H.: Planetary boundaries: exploring the safe operating space for humanity, Ecology and Society, 14, 32, 2009.

SBSSTA: Report of the Fourteenth Meeting of the Subsidiary Body on Scientific, Technical and Technological Advice, Convention on Biological Diversity, UNEP/CBD/COP/10/3, 2010.

SBSSTA: Report of the Expert Meeting to Develop a Series of Joint Expert Review Processes to Monitor and Assess the Impacts of Ocean Acidification on Marine and Coastal Biodiversity, Convention on Biological Diversity, UNEP/CBD/SBSTTA/16/INF/14, 2012.

SBSTTA: Report of the Subsidiary Body on Scientific, Technical and Technological Advice on the Work of its Thriteenth Meeting, Convention on Biological Diversity, UNEP/CBD/COP/9/3, 2008.

Secretariat: Global Biodiversity Outlook 1, Secretariat of the Convention on Biological Diversity, Montreal, 2001.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

Secretariat: Scientifc Synthesis of the Impacts of Ocean Acidifcation on Marine Biodiversity, Technical Series No. 46, Secretariat of the Convention on Biological Diversity, Montreal, 2009.

Surminski, S., and Lopez, A.: Concept of loss and damage of climate change–a new challenge for climate decision-making? A climate science perspective, Climate and Development, 1-11, 2014.

Sutherland, W., Adams, W., Aronson, R., Aveling, R., Blackburn, T. M., Broad, S., Ceballos, G., Cote, I., Cowling, R., and Da Fonseca, G.: One hundred questions of importance to the conservation of global biological diversity, Conservation Biology, 23, 557-567, 2009.

UFCCC: Decision 2/CP.19: Warsaw international mechanism for loss and damage associated with climate change impacts United Nations Framework Convention on Climate Change, FCCC/CP/2013/10/Add.1 2014.

Approaches to address loss and damage associated with climate change impacts in developing countries particularly vulnerable to the adverse effects of climate change. http://unfccc.int/adaptation/workstreams/loss_and_damage, access: 2017, 2017.

UNCLOS: United Nations Convention on the Law of the Sea (UNCLOS), PART XII: Protection and Preservation of the Marine Environment: Article 194: Measures to prevent, reduce and control pollution of the marine environment, 1982a.

UNCLOS: Article 206: Assessment of potential effects of activities, United Nations Convention on the Law of the Sea (UNCLOS), 1982b.

UNEP: Washington Declaration on Protection of the Marine Environment from Land-Based Activities United Nations Environment Programme, 1995.

UNEP: Progress in implementation of the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA) and specifically the Manila Declaration, United Nations Environment Programme, UNEP/WBRS.17/5/Rev.1, 2015.

UNFCCC: United Nations Framework Convention on Climate Change, entered into force 1994, 1992a.

UNFCCC: ARTICLE 4 – COMMITMENTS, United Nations Framework Convention on Climate Change, 1992b.

UNFCCC: Decision 1/CP.16: The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention, United Nations Framework Convention on Climate Change, FCCC/CP/2010/7/Add.1 2010.

UNFCCC: Paris Agreement, 12 December 2015, Paris, 2015a.

UNFCCC: Report on the structured expert dialogue on the 2013–2015 review: Note by the co-facilitators of the structured expert dialogue, United Nations Framework Convention on Climate Change, FCCC/SB/2015/INF.1, 2015b.

UNFSA: Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, PART II: Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks: Article 5: General Principles: (f), 1995.

UNGA: Sixty-first session: Agenda item 71 (a): Oceans and the law of the sea A/61/L.30, 2006.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-230
Manuscript under review for journal Biogeosciences
Discussion started: 9 June 2017

The Author declares no competing interests.

The author would like to acknowledge funding for her research provided by an Australian Post-Graduate Award.