Ocean Acidification

International Policy and Governance Options

D. Herr, K. Isensee, E. Harrould-Kolieb, and C. Turley

IUCN GLOBAL MARINE AND POLAR PROGRAMME

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Executive summary

Environmental problems do not respect national boundaries and as a result the tools best suited to their resolution are international cooperation and international environmental law. Existing international treaties, however, appear ill-equipped to address the ecological threat of ocean acidification, which affects the global ocean, its ecosystems, and those who depend on them.

As the carbon dioxide (CO_2) level in the atmosphere rises, as a result of ongoing burning of fossil fuels and emissions from land-use changes, an increasing amount of the gas is absorbed by the ocean, causing a profound change in its chemistry by making it more acidic. Ocean acidification may come to be understood as one of the most serious human-caused threats to endanger our ocean; a threat, like climate change.

Both the academic challenge as well as the practical urgency to find solutions to ocean acidification within the broader field of environmental law and governance have spurred some initial analysis on this topic. This paper contributes to the growing literature and discussion concerned with the performance and transformational need of ocean governance and policies, and the need to fully incorporate ocean acidification into other pertinent environmental, social and economic deliberations towards a sustainable, low-carbon society.

To date, ocean acidification has not been explicitly included in the mandate of any international treaty, including the United Nations Convention on the Law of the Sea (UNCLOS), the United Nations Framework Convention on Climate Change (UNFCCC) or the Convention on Biological Diversity (CBD). However, several international agreements and institutions have begun to address ocean acidification in various ways. Ocean acidification has been primary included in general calls for concern, and considered through the scientific arms of various conventions and frameworks.

The forum best suited for addressing the root source of the problem of ocean acidification, namely CO_2, is the UNFCCC, with implications and a strong linkage with UNCLOS. Adaptation measures in contrast can be formulated, and implemented, through the suite of existing ocean, conservation and resource management regimes. However they should not stand in isolation to the adaptation efforts discussed and implemented via the UNFCCC.

Specific recommendations for each analyzed convention, as well as policy process, can be found in their respective sections (section 3-6). Section 7 pools together recommendations with respect to 1) Implementation; 2) Collaboration; 3) Mitigation; 4) Adaptation and 5) Risk Assessment and Information Sharing, including the need to:

- Establish a new cross-regime cooperation mechanism dedicated to ocean acidification. Whilst not proposing a new legal agreement for ocean acidification, a forum with representatives from relevant sectoral, conservation, marine and climate change regimes should be created and report annually on relevant efforts. A common global mandate expressed by a UNGA resolution to prompt progress would be useful.

- Create national inter-agency working groups on ocean acidification, involving relevant officials and experts from the climate change field (mitigation and adaptation) as well as from agencies/organizations working on coastal and ocean management, including fisheries and aquaculture, conservation/protection (MPAs), and related fields such as tourism and finance.

- Revise and strengthen climate change mitigation policy measures and mechanisms to align the efforts conducted against ocean acidification and climate change.

  - Set additional indicators, alongside temperature indicators, to reflect ocean acidification.

  - Revised greenhouse gases (GHG) and CO_2 mitigation targets so as to account for the impacts of ocean acidification.

- Increase international planning and financing for adaptation with increased capacity building in vulnerable countries to measure ocean acidification, its local impacts and explore ways for local means for adaptation.

1 Ocean acidification – addressing a new global threat

Environmental problems do not respect national boundaries and as a result the tools best suited to their resolution are international cooperation and environmental law.[1] Since the mid-1980s a suite of ocean related international and regional agreements have been developed, including the UN Convention on the Law of the Sea (UNCLOS) and the Protocol to the Convention on the Prevention of Pollution by Dumping of Wastes and Other Matter of 1994 (London Protocol). These treaties in conjunction with a number of non-ocean specific multilateral environmental agreements, such as the conventions addressing biological diversity and migratory species, create a governance regime that attempts to protect and manage the ocean and its resources. They, however, appear ill-equipped to address the ever growing problem of ocean acidification; a recently recognized threat to the ocean and those who depend on it.

Ocean acidification may come to be understood as one of the most serious human-caused threats to endanger our ocean; a threat that, like climate change, is a result of ongoing burning of fossil fuels and emissions from land-use changes. As carbon dioxide levels (CO_2) in the atmosphere rise, increasing amounts of the gas are absorbed by the ocean, causing a profound change in its chemistry by making it more acidic.

The impacts of ocean acidification are likely to have serious implications for marine biodiversity and their dependent human social and economic systems. Therefore, measures to increase ecosystem and social resilience, and thus adaptive capacity are vitally important. However, without large scale mitigation, via the reduction of carbon dioxide emissions, it could be argued that such measures are nothing but tinkering at the edges of a larger problem. The solutions to ocean acidification are therefore closely linked to international action on climate change, as well as those dealing with biodiversity conservation and sustainable development.

Both the academic challenge as well as the practical urgency to find solutions to ocean acidification within the broader field

1 Sands and Peel 2012.

of environmental law and governance has spurred some initial analysis on this topic. Proposals of how to address regulatory and governance gaps within different regimes, as well as across legal regimes, are now slowly emerging,[2] with the most far-reaching call for an overall new multilateral agreement on ocean acidification.[3] The aim of this paper is to contribute to the growing literature and discussion concerned with the performance and transformational need of ocean governance and policies, and the need to fully incorporate ocean acidification into other pertinent environmental, social and economic deliberations towards a sustainable, low-carbon society.[4] This paper will further provide some reflections on how to strengthen and better inter-link between existing international instruments and discuss possible ways forward.

1.1 Mitigation, adaptation, geoengineering

The most obvious and effective measure to address ocean acidification is a rapid and substantial reduction of global CO_2 emissions,[5] However, adaptation measures[6] have been identified that would improve the resilience of ecosystems or species; these include the reduction of other stressors [7] through the creation of Marine Protected Areas (MPAs)[8] and, in certain circumstances, through the reduction of local sources of acidification.[9] Such actions may help to 'buy time' for CO_2 reduction measures to be implemented. Subsequently, these suggestions will be revisited in the context of international law and policy as the different regimes are being discussed.

Proposed marine geoengineering measures, e.g. carbon injections into the water column or storage in sub-seabed geological formation, as well as ocean fertilization have some implications for ocean acidification[10],[11] (see section on CBD 3.2 and London Protocol 4.4). Geoengineering itself, its impacts on biodiversity, as well as governance and regulatory questions, would fill pages of analysis – as has been done for example by *CBD report on Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matter*.[12]

Without going into the details of a possible design for a future governance framework for geoengineering (see CBD 2012 for further thoughts), a few parallels can be drawn from that discussion relevant to ocean acidification:

Is it preferable to have a centralized or decentralized governance structure to address ocean acidification?

Should there be some sort of forum to ensure ocean acidification is addressed through existing agreements and institutions: what would be the mandate, flexibility?

How can potential regime conflicts (overlapping mandates) be avoided?

These questions will be addressed again later in section 7.

2 Billé et al. 2013, Boyle 2012, Rayfuse 2012; Currie and Wowk 2009, Baird, Simons and Stephens 2009.
3 Kim 2012.
4 WGBU 2013; Freestone 2009.
5 Joos et al. 2011.
6 Billé et al. 2013; Turley & Boot 2010.
7 Turley et al. 2011
8 Smith et al. 2009.
9 Kelly et al. 2011.
10 Royal Society 2009.
11 Based on idealized ocean iron fertilization simulations, Cao and Caldeira (2010) conclude that globally sustained ocean iron fertilization could neither significantly diminish CO2 concentrations, nor reduce the mean surface ocean pH change. Ocean iron fertilization would further acidify the deep ocean without conferring any chemical benefit to the surface ocean.
12 Secretariat of the CBD 2012.

2 Major policy outcomes to date – and why this is not enough


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International agreements addressing environmental issues in general and marine conservation in particular, concentrate on a variety of, often sectorally treated, issues, such as overfishing under the various regional fisheries management organizations (RFMOs), the dumping of wastes and other matter from ships under the London Convention and Protocol or Antarctic ecosystem protection and use under the Convention for the Conservation of Antarctic Marine Living Resources (C-CAMLR). Ocean acidification is not easily addressed by a single treaty as it is not geographically confined, its solutions are interlinked with other global problems and it has implications for numerous fields, including biodiversity conservation and economic and sustainable development. Due to these complex interdependencies ocean acidification will need to be incorporated into the activities of a number of environmental agreements.

To date, ocean acidification has not been explicitly included in the mandate of any international treaty, including the United Nations Convention on the Law of the Sea, the United Nations Framework Convention on Climate Change (UNFCCC) or the Convention on Biological Diversity. However, several international agreements and institutions have begun to address ocean acidification in various ways. This section will briefly present the major international activities around ocean acidification[13] and will be followed by a discussion of the significant policy gaps and possible avenues for remedying the deficiencies in the current governance of ocean acidification.

Throughout the report activities and efforts on ocean acidification exercised through the conventions and agreements are being analyzed and grouped according to:

1. Technical and scientific activities and efforts;
2. Mitigation (CO_2) activities;
3. Adaptation activities; and
4. Political engagement / awareness raising (calls of concern and for general action).

13 See references for summarized activities in dedicated sections further below.

As the following section summarizes, ocean acidification has been primary included in general calls for concern, and considered through the scientific arms of various conventions and frameworks. (see also Figure 4, page 36).

For example, a most common response from many existing international and regional agreements and bodies is to request relevant scientific syntheses or scientific dialogues about the impacts of ocean acidification, such as the 2008 CBD report on "Impacts of ocean acidification on marine biodiversity" or the 2013 United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (UNICPOLOS – short ICP) compilation of "Impacts of ocean acidification on the marine environment".[14] The UNFCCC has cultivated a response to inform States on the scientific information around ocean acidification through its Subsidiary Body on Scientific and Technological Advice (SBSTA) research dialogue, but has not yet developed appropriate mechanisms to ensure that ocean acidification is adequately included in its policy efforts to reduce GHG emissions.

The first concern about the projected adverse effects of ocean acidification on the marine environment and marine biodiversity were expressed by the United Nations General Assembly (UNGA) in 2005. Other conventions, bodies and policy processes such as Convention for the protection of the marine environment of the North-East Atlantic (OSPAR) (2007), Convention for the Conservation of Antarctic Marine Living Resources (C-CAMLR) (2009), CBD (2010) and the Rio +20 Conference followed by including ocean acidification into their concerns and general calls for action.

The most tangible effort with respect to adaptation measures has been developed by the CBD as guidance for practical responses to the impacts of ocean acidification on marine and coastal biodiversity (see section 4.3). Discussions related to technological innovations needed to proceed with CO_2 sequestration, including marine fertilization are being addressed by the London Protocol (see section 5.4).

Ocean acidification is an issue with cross-regime implications. Finding effective and swift solutions to this problem encompasses the challenge insofar as the current legal and policy landscape and related mandates suggest (mostly) a separate treatment of mitigation and adaptation responses through different conventions and agreements. The forum for addressing the root source of the problem of ocean acidification, namely CO_2, is the UNFCCC, with implications and a strong linkage with UNCLOS.[15] Adaptation measures in contrast can be formulated, and implemented, through the suite of existing ocean, conservation and resource management regimes. However should they not stand in isolation to the adaptation efforts discussed and implemented via the UNFCCC.

Nonetheless, due to often unclear mandates and uncoordinated legal responses, ocean acidification has not been adequately addressed in existing international law and policy-making. As commendable the current activities in international law and policy are, they are insufficient to address this challenge and can only be seen as initial steps. A dedicated effort is therefore needed to analyze current political frameworks and legal instruments to ensure a coordinated and cooperative way forward is being identified. This paper attempts to contribute to the slowly growing literature on this topic.

14 Other technical reports and activities include the OSPAR 2006: Effects on the marine environment of ocean acidification resulting from elevated levels of CO2 in the atmosphere; OSPAR 2009: Assessment of climate change mitigation and adaptation;- UNFCCC SBSTA research dialogues 2010, 2011 and 2012; IPCC expert workshop 2011: Impacts of ocean acidification on marine biology and ecosystems; CBD 2011: Joint expert review meeting on the impacts of ocean acidification on marine biodiversity and CBD 2014 (in preparation): Impacts of ocean acidification on biodiversity and ecosystem functions.

15 Rayfuse 2012.

The Science

Environmental law and policy, and its success, depends on various factors. Of particular importance and influence is the science manifesting the problem and solutions.[16] The following chapter therefore summarizes the current state of knowledge on the impacts of ocean acidification, as well as suggested measures.

Chemical reactions

Ocean acidification is the term used to refer to a suite of chemical reactions in the ocean, caused by increasing carbon dioxide (CO_2) levels in the atmosphere,[17] it is usually used in the context of CO_2 emissions caused by human activities. The ocean has absorbed approximately 30% of anthropogenic CO_2 from the atmosphere since the industrial revolution.[18] This results in decreases in pH (i.e. increase in hydrogen ion (H^+) concentration) and carbonate ion concentration and an increase in bicarbonate ion concentration.[19]

Uptake of CO_2 has decreased ocean pH by approximately 0.1 unit (as pH is on a logarithmic scale this is equivalent to a decrease of 30%) over 200 years, fundamentally changing ocean carbonate chemistry across all ocean areas. pH and carbonate ions will continue to decline as CO_2 emissions to the atmosphere increase.[20] Both are of particular significance, since many, but not all, marine organisms expend energy regulating their internal pH and carbonate ions are important to shell and skeleton formation.[21]

Ocean acidification may therefore affect the physiology, energetic allocation for different metabolic processes of organisms, reduce the ability of calcifiers to produce calcium carbonate structures and impacts long-term fitness of some species within the marine food web.[22] Marine calcifying organisms seem particularly at risk, since additional energy will be required to form shells and skeletons, and in many ocean areas, such as polar and sub-polar waters unprotected shells and skeletons will dissolve.[23]

Ocean acidification can lead to acid-base imbalance in many marine organisms such as fish, invertebrates and sediment fauna but some species can modify energetic allocation to compensate for increased energetic costs of ocean acidification although they may need additional food resources to do this.[24] Juveniles seem more susceptible than adults. For example, larval oysters off the west coast of North America are already being impacted with economic cost to hatcheries[25] and the sensory systems and behaviour of coral reef larval fish seem sensitive to ocean acidification levels that will occur this century if mitigation does not occur.[26]

There is high scientific confidence in the knowledge of the underlying chemical processes, the cause, speed and magnitude of change and its future progression based on CO_2 emission scenarios (Figure 1).[27] Ocean acidification is measurable and is happening now and at a rate and magnitude not seen on Earth for at least fifty-five million years.[28]

Ocean acidification is a concurrent problem with a common cause to climate change. Both are triggered by increased anthropogenic CO_2 emissions into the atmosphere at a

16 Sands and Peel 2012
17 Caldera and Wickett 2003; Royal Society 2005.
18 Sabine et al. 2004; IPCC 2013.
19 Zeebe and Wolf-Gladrow 2001.
20 Feely et al. 2009; Rhein et al. 2013.
21 Pörtner et al. 2014.
22 Feely et al. 2009; Wicks and Roberts 2012.
23 Kroeker et al. 2013; IPCC 2014.
24 Wicks and Roberts 2012; Gattuso and Hansson 2011; Pörtner et al. 2014.
25 Barton et al. 2012.
26 Munday et al. 2014.
27 Gattuso et al. 2013.
28 Ridgwell and Schmidt, 2010; Hönisch et al. 2012.

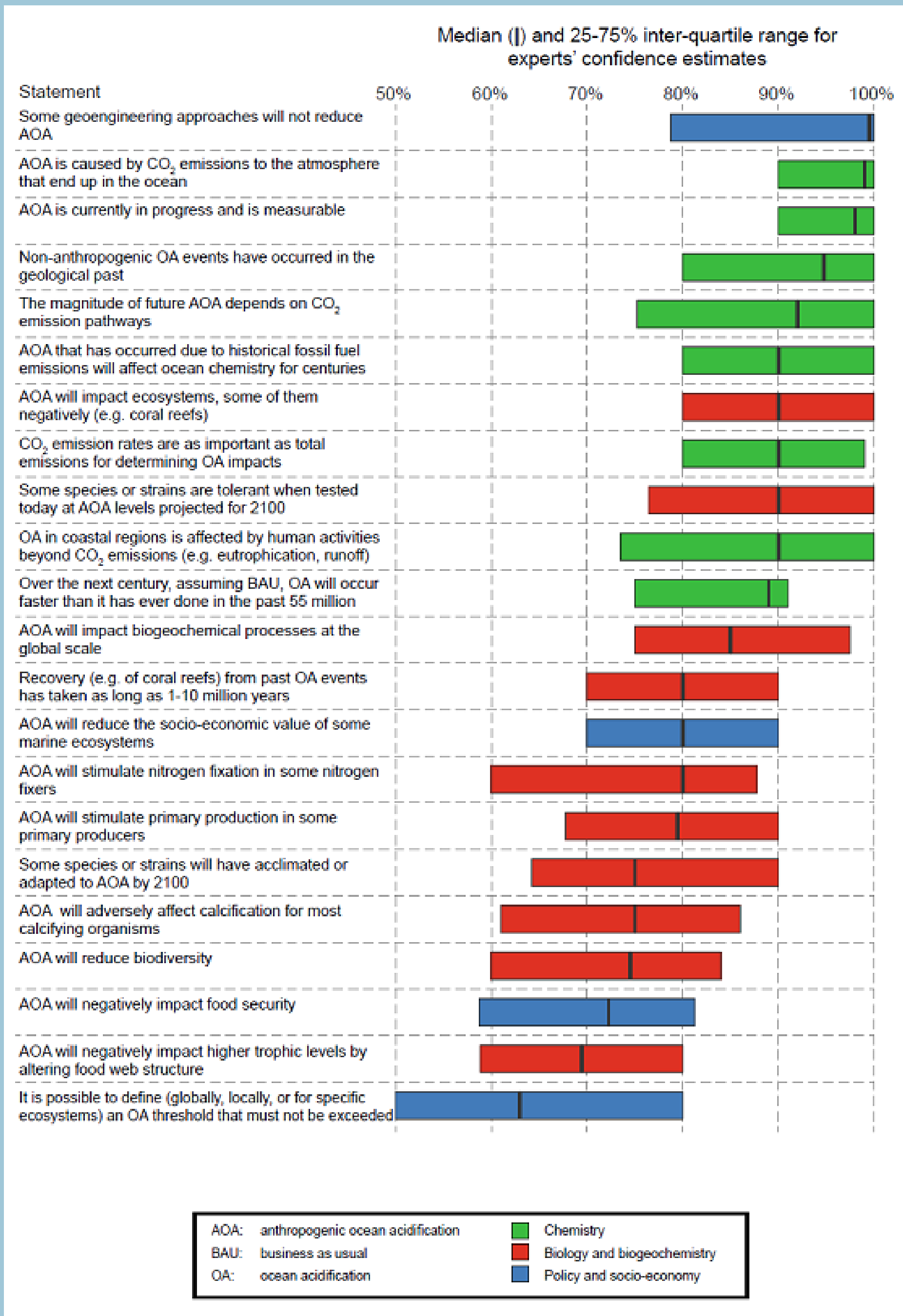


Figure 1. *Summary of confidence in statements on ocean acidification and its impacts by experts (n = 53); data from Gattuso et al. with sequence re-arranged by Williamson et al in order of median confidence estimates. Colour coding relates to topic area; see key.*

Sources: Gattuso et al. 2013, Williamson et al. 2013.

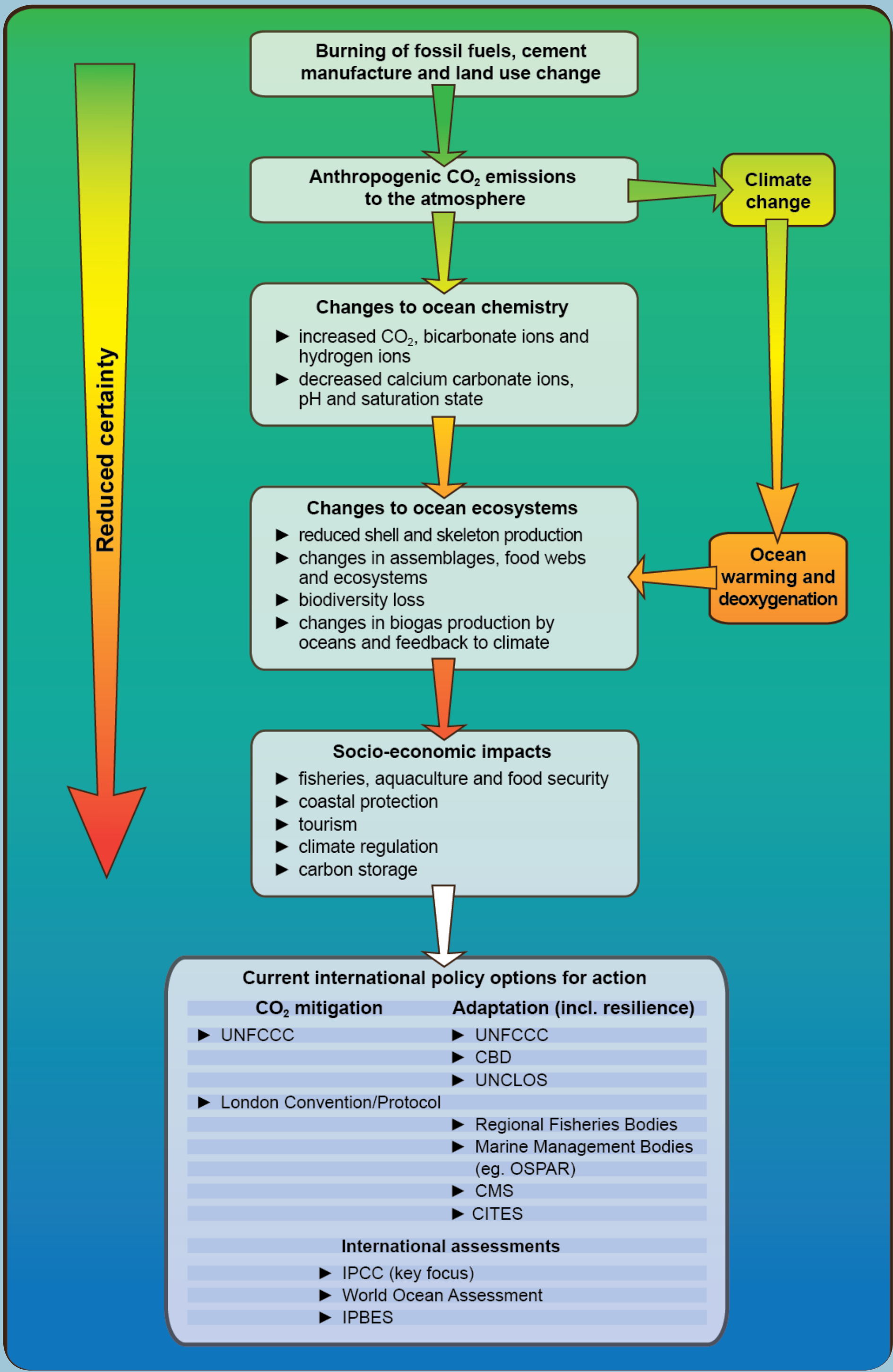


Figure 2. *Showing the direct cause of ocean acidification, the impacts on ocean chemistry, ecosystems and socio-economics and the interaction with climate change through ocean warming and oxygen loss. Note the decreasing certainty from chemistry, through life and social science. The policy options for mitigating ocean acidification are also shown.*

Adapted from Turley and Gattuso 2012.

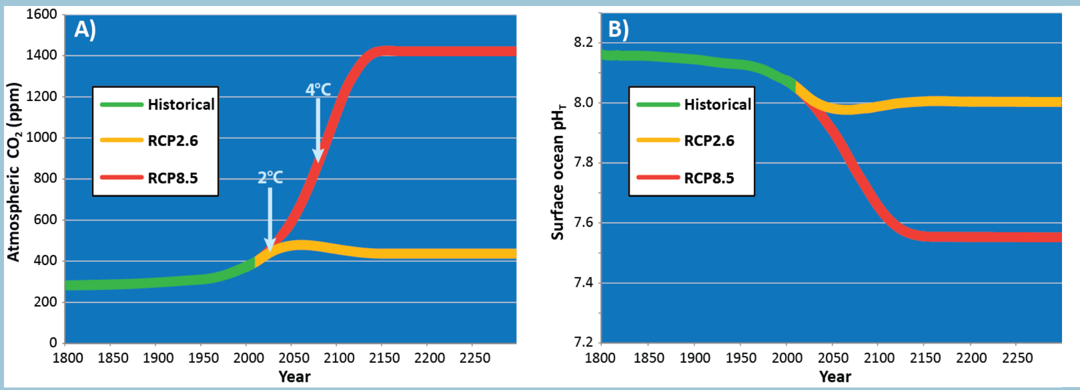


Figure 3. *Global mean values for atmospheric CO_2 concentrations and surface ocean pH for the higher (RCP 8.5) and lower (RCP 2.6) pathways calculated by the Bern2.5CC model are shown from 1800 to 2300. Representative Concentration Pathways (RCPs) are greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC) for its fifth Assessment Report (AR5).*

Sources: Moss et al. 2008; Steinacher et al. 2013.

faster rate than natural removal processes (Figure 2).

The magnitude of future ocean acidification at the global scale will closely depend on the scale of future CO_2 emissions due to human activities (Figure 3). Reducing CO_2 emissions gives a double bonus of both reducing ocean acidification and climate change.[29]

Impacts of ocean acidification

The impacts of ocean acidification on marine biodiversity, food webs, biogeochemical processes, ecosystems and society is less clear than changes in ocean chemistry,[30] though it is likely that some will be negatively affected.[31] This creates a risk to human society through potential impacts on goods and services the ocean provides.[32] For example, many studies show reduction in growth, formation and maintenance of coral reefs with increased ocean acidification which will affect the goods and services that they provide.[33] The most obvious of these are food and livelihoods provision from fisheries and aquaculture,[34] storm protection from reefs and economic benefits from tourism.[35] Calculations conducted in 2009 showed an annual economic damage of ocean-acidification-induced coral reef loss by 2100 has been estimated, to be 870 and 528 billion USD, respectively for the A1 and B2 SRES Emission Scenarios, representing a very large GDP loss for the economies of many coastal regions or small islands that rely on the ecological goods and services of coral reefs.[36]

The ocean also plays a central role in Earth's climate and has absorbed 93% of the extra energy from the enhanced greenhouse effect and the resulting warming of the ocean affects most ecosystems.[37] The combination of warming and ocean acidification is likely to lead to the demise of most coral-based

29 Joos et al. 2011
30 Turley and Gattuso 2012.
31 Kroeker et al. 2010 & 2013; Gehlen et al. 2011; IPCC 2014.
32 Turley and Boot 2010 & 2011; IPCC 2014.
33 Pörtner et al. 2014; Hoegh-Guldberg et al. 2014.
34 Turley & Boot 2010.
35 Turley & Boot 2011
36 Pörtner et al. 2014; Hoegh-Guldberg et al. 2014.
37 Pörtner et al. 2014.

ecosystems.[38] Both warm-water coral reefs and cold-water corals are key habitat formers supporting substantial biodiversity as well as fisheries so that their depletion would also represent a major loss to Earth's biological heritage.

Ocean Acidification is something humankind already experiences, e.g. it is affecting valuable shellfisheries on the west coast of North America[39] and natural wild populations of sea butterflies (called pteropods) in the Southern Ocean,[40] the latter providing a key link in the food web that supports wild salmon. The global cost of production loss of mollusks could be over 100 billion USD by 2100 and models suggest that ocean acidification will generally reduce fish biomass and catch and that complex additive, antagonistic and/or synergistic interactions will occur with other environmental (warming) and human (fisheries management) factors.[41]

38 Hoegh-Guldberg and Bruno, 2010; Hoegh-Guldberg et al. 2014.
39 Barton et al. 2012.
40 Bednaršek et al. 2012.
41 Pörtner et al. 2014.

Other climatic feedbacks

Ocean acidification acts together with other global changes (e.g., warming, decreasing oxygen levels) and with local changes (e.g., pollution, eutrophication) increasing and amplifying risk to marine organisms and ecosystems and the goods and services they provide society.[42] These three global-scale changes – ocean acidification, warming and deoxygenation – to the physics and chemistry of the Earth's ocean are underway now, and likely to cause fundamental changes to the great wealth and diversity of life that the ocean supports.[43]

42 IPCC 2014; Stramma et al. 2012.
43 Gruber 2011.

3 Governance options and existing measures related to framework conventions

Proposals for addressing regulatory and governance gaps with regards to ocean acidification within existing framework conventions and other policy instruments, as well as across legal regimes, are slowly emerging.[44] As a means of structuring the remainder of the report, the relevant framework conventions, namely UNCLOS, UNFCCC and CBD, and their governance structures, as well as their existing activities on ocean acidification, will be examined separately. A brief outlook for further action will be provided for each. The remaining sections of the report will then explore the interactions between these conventions and provide thoughts on desirable future steps. This should enable the development of a more refined and nuanced account of how ocean acidification can be dealt with in the international policy landscape than has arisen to date.

3.1 United Nations Convention on the Law of the Sea

The United Nations Convention on the Law of the Sea (UNCLOS)[45] provides the overarching legal framework for the regulation of activities pertaining to the ocean and seas, including a number of provisions for the protection of the marine environment and the conservation of marine species, such as an obligation for Parties protect and preserve the marine environment.[46] States are thereby required, individually or jointly, to take all measures "necessary to prevent, reduce and control pollution of the marine environment from any source".[47] Since this includes pollution from or through the atmosphere, the uptake of CO_2 by the marine environment arguably falls under the jurisdiction of this Convention.[48] However, despite parties to the Convention having been aware of the threat of ocean acidification as early as 2005[49] (see section 6.1), no direct response or amendments to the Convention have been discussed.

Few scholars have so far further deliberated in much detail about the role of UNCLOS as a regime suited to the governance of ocean acidification – particularly the mitigation thereof. Overall the response is that the Convention should respond to ocean acidification, however as it currently stands is too general and ill-equipped to directly regulate CO_2 emissions.[50] A more proactive role for UNCLOS could only become a reality via an agreement that would enable regulation of land-based sources of pollution, a proposition that remains unlikely.[51] Concerning options to spur adaptation measures in Areas Beyond National Jurisdiction (ABNJ), an implementing agreement to UNCLOS[52] could be constructed to enhance the resilience of marine ecosystems, and related economic resources, to CO_2-induced stressors. Currently there is no structure to apply MPAs, Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA) as crucial tools for enhanced adaptation measures in ABNJ.[53]

In light of this, the role of UNCLOS is better thought of as providing an ancillary role to the convention tasked with the regulation of CO_2

44 Billé et al. 2013, Boyle 2012, Currie and Wowk 2009, Baird, Simons and Stephens 2009.
45 United Nations Convention on the Law of the Sea (adopted 10 December 1982, entered into force 16 November 1994) 21 ILM 1261 (UNCLOS).
46 UNCLOS Art. 192;
47 UNCLOS Art. 194.
48 Boyle 2012; Baird, Simons & Stephens 2009.
49 UNGA 2005.
50 Boyle 2012, Kim 2012, Baird, Simons & Stephens 2009; Rayfuse 2012; Gonzales 2012.
51 Kim 2012
52 Ardron et al. 2014; Currie & Wowk 2009.
53 Currie and Wowk 2009; Ardron et al. 2014.

– currently the UNFCCC.[54] Boyle suggests that UNCLOS - via its dispute settlement procedures – may be able to offer a site for the litigation of non-compliance of emissions reduction targets committed to under the Kyoto Protocol.[55] A failure to realize such targets would provide evidence of not meeting the requirements set out in Articles 194 and 212, which obligate States to protect the marine environment and protect other states from marine pollution damage. However, this may be of very limited use as it is likely that most Annex I (developed country) parties will comply with their current commitments and that developing States are not legally bound to reduce their emissions under Kyoto.[56] In addition litigation would be ineffective against non-signatory States, such as the U.S., which is currently not a party to either UNCLOS or Kyoto.[57] A further complication to the possibility of bringing litigation is that of jurisdiction, this is difficult to determine as the UNCLOS case law is confused.[58] As a result, it is unclear whether a tribunal would agree to hear a case based on a dispute arising within the UNFCCC or whether it would throw it out on jurisdictional grounds.[59]

Despite this, UNCLOS does perhaps offer the potential for promoting/enhancing compliance with new commitments negotiated under a post-Kyoto agreement.

3.2 United Nations Framework Convention on Climate Change

It has been stressed that the main solution to ocean acidification is restricted to measures for reducing or removing CO_2 from the atmosphere. While UNCLOS could play a more significant role towards the compliance of emission reduction commitments (see section on 4.1) as well as adaptation measures in ABNJ, the commitments themselves, as well as the overall mandate to reduce global CO_2 emissions and other greenhouse gases (GHGs) lies with the United Nations Framework Convention on Climate Change (UNFCCC).[60] The UNFCCC requires the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner".[61] The UNFCCC arguably includes an obligation to take into account the impacts of increasing atmospheric CO_2 levels upon the ocean (i.e., ocean acidification), considering:

i) that the ocean, including its marine biodiversity, is an integral part of the global climate system,
ii) that ocean acidification has feedback effects on atmospheric components of climate, as discussed in section 3, and
iii) that the changes in ocean chemistry are a threat to food production and sustainable economic development (see *The Science* section).

Despite the general obligation to reduce GHG emissions, as well as the growing awareness on regarding ocean acidification, States have neither explicitly nor implicitly considered ocean acidification in their emission reduction commitments and dedicated mechanisms and tools.[62]

Since 2005, ocean acidification has emerged as a reoccurring discussion topic of the so-called "research dialogue" between the scientific community and UNFCCC Parties, a session held annually since 2005.[63] Starting in 2010, ocean acidification has also been identified as one of the most pressing

54 Rayfuse 2012.
55 Boyle 2012.
56 Boyle 2012.
57 Boyle 2012.
58 Boyle 2012.
59 Boyle 2012.

60 United Nations Framework Convention on Climate Change (adopted 9 May 1992, entered in force 21 March 1994) 31 ILM 849 (UNFCCC).
61 UNFCCC Art. 2.
62 Baird, Simons & Stephens 2009; Freestone 2009; Harrould-Kolieb & Herr 2010;
63 UNFCCC 2006, Decision 9/CP.11.

emerging scientific issues and priority needs relevant to the UNFCCC.[64]

Ocean acidification does appear within the UNFCCC agreed decisions in the Cancún Agreements, the outcome of the sixteenth Conference of the Parties (COP) to the UNFCCC in 2010, as part of a footnote in which it is listed as one of many 'slow onset events' caused by climate change.[65]

Looking ahead, the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts,[66] agreed in 2013, calls for enhanced knowledge and understanding of comprehensive risk management approaches to address loss and damage, including the collection, sharing, management and use of relevant data and information. This provides an opportunity to ensure the dissemination and inclusion of knowledge and understating, as well as management of the risks – economic and non-economic – associated with ocean acidification.

However – two points need further attention and discussion:

1. The work on loss and damage is being conducted under the adaptation stream of the UNFCCC. Whereas this provides some opportunities (see paragraph above), it does not yet address any targeted mitigation needs.

2. The categorization of ocean acidification as a slow onset event, alongside sea level rise, increasing temperatures, and desertification may be a challenge for future, targeted mitigation activities.

Nonetheless it is unclear whether ocean acidification, being defined as a slow onset event, can be addressed as an *equal* problem to climate change, rather than *just* a consequence thereof. This could have implications for discussions on mitigation targets, in particular concerning a separation between CO_2 and other GHGs. The impacts of ocean acidification have so far not been considered in the setting of international and national targets to tackle climate change. As already pointed out by Harrould-Kolieb and Herr, and further detailed by Steinacher et al., additional indicators, and mitigation targets, are needed alongside temperature indicators to control ocean acidification.[67]

Whether recent scientific findings (see also section 3 and section 7.1) will transpire into concrete UNFCCC policy-making in a speedy manner, especially on the mitigation side, has to be seen. While the Fourth Assessment Report of the IPCC only placed limited emphasis on the impacts of climate change on marine ecosystems, and ocean acidification,[68] the analysis of the Fifth Assessment Report shows a much greater body of evidence (see section 7.1).

While civil society has made a concerted effort to increase the visibility of ocean acidification within the UNFCCC process (e.g. side events and booths)[69], the visibility (and responses) of ocean acidification from within the UNFCCC negotiations is still very limited. [70] Despite an already overburdened institutional system, the overwhelming list of difficult issues negotiated under the UNFCCC and overall tense negotiations, ocean acidification will need to play a more prominent role in both mitigation and adaption discussions.

Ocean acidification would ideally:

1. be integrated in discussions on mitigation targets and indicators as well as related instruments and mechanisms, linked to existing negotiation streams, e.g. the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP) with a mandate to

64 UNFCCC/SBSTA 2010, 2010a, 2010b, 2010c, 2011.
65 UNFCCC 2011, Decision 1/CP.16.
66 UNFCCC 2013 Decision 2/CP.19.
67 Steinacher 2013 et al.; Harrould-Kolieb and Herr 2010.
68 IPCC 2007a, 2007b, 2007c.
69 Turley et al. 2011; Ocean Acidification Reference User Group 2010; Harrould-Kolieb et al. 2010; UNEP 2010.
70 Harrould-Kolieb & Herr 2010; Billé et al 2013.

"develop a protocol, another legal instrument or an agreed outcome with legal force under the Convention applicable to all Parties";

2. influence discussions related to geoengineering methods and regulatory responses – evaluation of mitigation strategies that may exacerbate ocean acidification and strategies which have no direct mitigation effect on ocean acidification such as Solar Radiation Management (SRM);

3. be integrated into adaptation efforts, for example, as part of the *Nairobi Work Programme on impacts, vulnerability and adaptation to climate change* (NWP) - Understanding vulnerability, fostering adaptation.

A full analysis and revision of whether the definition of ocean acidification as a *slow onset event* is hampering any of the recommendations above or not, would provide the full account of this topic under the UNFCCC.

3.3 Convention on Biological Diversity

Given the impacts of ocean acidification on the marine environment and thus biodiversity, the Convention on Biological Diversity (CBD)[71] has to be considered in this assessment as well. The CBD has three objectives: the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources.[72] In 2008 the CBD started to express concern about ocean acidification and recognized it as a threat which may accelerate the loss of marine biodiversity and, by association, may threaten livelihoods and economies dependent on the sustainable use of marine resources and the commercial exploitation of marine genetic resources. Ocean acidification consequently impacts all three objectives of the CBD. In particular, ocean acidification makes it more challenging to implement relevant CBD work programmes and recommendations.[73]

As the CBD has no mandate to be active on the mitigation of ocean acidification, its activities are limited to improving understanding of the issue, increasing adaptive capacity and awareness raising.

The 2008 release of the report Impacts of Ocean Acidification on Marine Biodiversity via the CBD Technical Series, has contributed to a greater understanding of the impacts of ocean acidificaiton.[74] The CBD COP 10 has recently requested a new systematic review document, by 2014, on the impacts of ocean acidification on biodiversity and ecosystem functions. Whilst laudable to ensure that CBD Parties are regularly updated on the impacts of ocean acidification, similar assessments (see further throughout the report as well as in summary in section 2.1) have been commissioned, or are being commissioned. Given budgetary constraints in the current financial climate, as well as the multiple calls for increased collaboration between existing conventions, a stronger effort should be placed on avoiding such duplications and strengthening existing means to exchange information between conventions. For example, the CBD COP requested that the results of their 2014 assessment be provided to the UNFCCC.[75]

Work under the CBD has also provided guidance for adaptation measures to its Parties. By 2012 a Joint Expert Review Meeting on the Impacts of Ocean Acidification on Marine Biodiversity was conducted and triggered the CBD Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) to take "note of […] the guidance for practical responses to the impacts of ocean acidification on marine and coastal biodiversity [developed by the expert review],[76] and encourages Parties, other Governments and relevant organizations to

71 The Convention on Biological Diversity (adopted 22 May 1992, entered into force 29 December, 1993) 31 I.L.M. 818 (CBD).
72 CBD, Art 1.
73 Secretariat of the CBD 2004.
74 Secretariat of the CBD 2009.
75 CBD 2012a, para 24.
76 CBD/SBSTTA. 2012, Annex III.

make use of this guidance, as appropriate, to reduce various threats from ocean acidification to vulnerable ecosystems and to enhance the resilience of ecosystems through a range of area-based or other management measures, in addition to measures to reduce CO_2 emissions".[77] This information could also be brought to other conventions, e.g. the UNFCCC's NWP, to make current knowledge available for a broad audience as well as avoid duplication.

As dedicated adaptation measures (e.g. off-shore buoys acting as an early warning system for shellfish hatcheries, diverting fishing efforts to new or underutilized species) for ocean acidification are scarce, practical responses often refer to reducing other human-induced stressors and improving resilience, including through the designation of MPAs.[78] Numerous reports and policy documents have recommended preserving ecosystem resilience and adaptability by reducing non-CO_2-related environmental threats, e.g. reduction of pollution, sedimentation and over-fishing, especially through the use of marine protected areas integrated with coastal zone management to control both marine- and land-based threats.[79] The CBD has a suite of work programmes, such as Marine and Coastal Biodiversity and Protected Areas, which ought to be revised so as to be more effective at addressing ocean acidification.

The CBD also contains a provision to introduce EIAs for "projects that are likely to have significant adverse effects on biological diversity with a view to avoiding or minimizing such effects".[80] Art 14 1.(e) of the Conventions further states that "the Conference of the Parties shall examine, on the basis of studies to be carried out, the issue of liability and redress, including restoration and compensation, for damage to biological diversity", which could include projects with high CO_2 emissions.

The COP has also attempted to increase action on ocean acidification by calling on its Parties to address "climate-change-related aspects of marine and coastal biodiversity, including the potential adverse impacts on marine and coastal biodiversity of ocean acidification as a direct consequence of the increased concentration of carbon dioxide".[81]

77 CBD/SBSTTA. 2012.
78 Billé et al 2013; Micheli et al. 2012; Cooley et al. 2009.
79 Rau et al. 2012.
80 CBD Art 14.
81 CBD 2010.

In 2012, the COP re-affirmed its concern regarding ocean acidification when they adopted the Strategic Plan including Aichi Targets on Biodiversity Conservation. Aichi Target 10 states that "by 2015, 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".[82]

The COP has also made a number of decisions with regard to ocean fertilization (the deliberate release of nutrients such as iron into low productivity areas to stimulate plankton blooms – also referred to as a type of geoengineering – to increase marine food production and to remove carbon dioxide from the atmosphere[83]) and has urged Governments to follow the precautionary approach and to restrict large ocean fertilization activities until, amongst others, a global, transparent and effective control and regulatory mechanism is in place.[84] A technical report on the Scientific Synthesis of the Impacts of Ocean Fertilization on Marine Biodiversity is also available. [85]

As for the CBD in particular, further emphasize should now be placed on

1. how to communicate the knowledge generated through CBD efforts (e.g. Technical Reports) to other relevant conventions and efforts (UNFCCC, UNCLOS, FAO, RFMOs, CMS, RSCAPS).

2. how to apply gained theoretical knowledge and strengthen existing CBD work programmes to ensure swift incorporation of ocean acidification into the implementation of e.g. MPAs or use of EIAs and Strategic Environmental Assessments (SEAs).

3. how to revise, and strengthen National Biodiversity Strategies and Action Plans (NBSAPs) to respond to impacts of ocean acidification, and thus ensure that existing law and efforts are effectively implemented.

4. how to ensure that the work undertaken by the CBD on geoengineering, especially in relation to ocean acidification (e.g. ocean iron fertilization), is being considered appropriately by other relevant bodies, e.g. London Convention/London Protocol, UNFCCC, and to avoid duplicating efforts (studies).

82 CBD 2012.
83 Royal Society 2009.
84 CBD 2008, section C.
85 Secretariat of the CBD 2009.

4 Regional and sectoral agreements

This section briefly discusses selected regional and sectoral agreements, such as OSPAR and regional fisheries agreements. These regional and sectoral agreements are of importance because they govern and conserve either specific ocean regions and marine fauna and flora, and/or regulate specific human activities in the ocean (marine resource management).

This section does not, however, intend to cover the suite of existing regional and sectoral agreements relevant for marine management, but rather focuses on the most pertinent for reducing the impacts of ocean acidification. This section aims to give a flavour for what is needed as an extended discussion on appropriate responses and coordination regarding ocean acidification.

Similarly to the above, each agreement is discussed individually. The discussion will distinguish between 1) technical capacity, 2) spurring mitigation and 3) adaptation measures, as well as 4) creating a political agenda. A brief outlook for further action will be provided for each.

4.1 Oslo and Paris Conventions

The Convention for the protection of the marine environment of the North-East Atlantic, also known as the OSPAR Convention, is the mechanism by which fifteen Governments of the western coasts and catchments of Europe, together with the European Union, cooperate to protect the marine environment of the North-East Atlantic.[86]

Ocean acidification first appeared in the OSPAR context as part of a technical report distributed in 2006 as effects on the marine environment of ocean acidification resulting from elevated levels of CO_2 in the atmosphere containing an overview of ecosystem sensitivity to CO_2 exposure.[87]

86 1992 OSPAR Convention

87 OSPAR Commission 2006.

2009 saw an elaborated report by OSPAR on the assessment of climate change mitigation and adaptation.[88] Recommendations included the need for additional efforts to enhance knowledge about the vulnerability of species, habitats and ecological processes and the interaction of these with pressures from human activities on the sea. The report further suggested that OSPAR would need to integrate climate change and ocean acidification issues into all its work areas.

On the technical side, OSPAR has further engaged and set up a Joint OSPAR/ICES Ocean Acidification Study Group (SGOA).[89] To support OSPAR assessments of ocean acidification, a first draft of an ocean acidification monitoring and assessment framework was developed with a view to finalization at SGOA 2014.[90] It was recognized that, as an emerging field of research, any OSPAR framework would need to be flexible and responsive to rapidly expanding scientific knowledge and technological developments. The development and application of relevant methods for monitoring ocean acidification has been identified as a priority. The OSPAR Coordinated Environmental Monitoring Programme (CEMP), which aims to deliver comparable data from across the OSPAR maritime area, received an additional appendix on ocean acidification in 2012.[91]

It was further stated that the regional monitoring and assessments efforts should support the development and revision of existing and new regulations of human maritime activities to promote increased resilience of the natural system. [92] Dedicated adaptation measures, beyond business-as-usual conservation measures, should be developed, through e.g. revision or strengthening of MPA designation and management options.[93]

88 OSPAR Commission 2009.

89 ICES 2013.

90 ICES 2013a.

91 OSPAR 2010a.

92 OSPAR Commission 2009.

93 OSPAR 2003; OSPAR 2010.

Following the scientific assessment in 2006, OSPAR Parties, a year later, formally expressed serious concern "by the implications for the marine environment of climate change and ocean acidification due to elevated concentrations of carbon dioxide in the atmosphere".[94] Subsequently OSPAR has highlighted ocean acidification in several policy recommendations as a threat to the protection and restoration of specific species or ecosystems in the OSPAR Maritime Area.[95] OSPAR recognizes the need to consider and integrate the effects of ocean acidification, as well as the need for adaptation and mitigation, in all aspects of their work.[96] OSPAR has similar definition of pollution like UNCLOS, as well as a general obligation to prevent such.[97]

Similar to the CBD and other regional or sectoral agreements, OSPAR's direct mitigation mandate is limited. Therefore activities are restricted to "investigating, monitoring and assessing the rate and extent of these effects"[98] and to considering appropriate responses within the regimes' mandate.

However, OSPAR has taken a great interest in Carbon Capture and Storage (CCS) – a controversial climate change mitigation tool. Given its direct impact on pH levels, the storage of CO_2 in the water column or on the seabed is prohibited by OPSAR.[99] Guidelines have been developed to manage the risks of CCS projects involving geological sub-seabed formations to prevent adverse consequences for the marine environment, human health and other uses of the sea for commercial storage of CO_2.[100]

OSPAR has stressed that CCS is only part of a package of possible measures needed to reduce CO_2 emissions. They should include conservation of energy, renewables and improved energy efficiency. As a Regional Seas Convention, the OSPAR Commission is contributing to international efforts within the EU and global efforts under the London Protocol.

Although OSPAR faces limitations when it comes to setting national CO_2 mitigation measures and targets, it can promote the need to include ocean acidification into deliberations that are developing mitigation strategies and setting international objectives to limit future atmospheric CO_2 levels, as referenced in a 2009 OSPAR report[101]. With the new 2015 deadline to develop a joint climate change agreement under the UNFCCC, OSPAR, as well as other regional and sectoral agreements, have the opportunity to emphasize the urgent need to mitigate ocean acidification as otherwise their own mandate will be in great jeopardy.

94 OSPAR 2007.
95 OSPAR 2010a.
96 OSPAR 2010b.
97 OPSAR Convention Article 2(1)(a); See also Baird et al 2009.
98 OSPAR 2010b.
99 OSPAR 2007.
100 OSPAR 2007b; OSPAR 2007a; Baird et al. 2009.
101 OSPAR Commission 2009

4.2 Convention for the Conservation of Antarctic Marine Living Resources

The Convention for the Conservation of Antarctic Marine Living Resources (C-CAMLR)[102] was established in response to the increasing commercial interest of Antarctic krill in the 1980s, a keystone component of the Antarctic ecosystem and is dedicated to conserving Antarctic marine living resources.[103]

CCAMLR is active on building 1) technical capacity, 2) spurring adaptation measures, and 3) creating a political agenda.

Political attention has been given to ocean acidification since 2009 when the CAMLR Commission expressed concern "that the Southern Ocean will experience increased acidification with possible impacts on its marine ecosystems".[104]

Technical discussions on the impacts of ocean acidification have been advanced under the Working Group on Ecosystem Monitoring and Management with research papers investigating the impacts of ocean acidification on marine resources in the Southern Ocean, for example on krill.[105] Ongoing deliberations within CCAMLR try to identify measures that are able to account for climate change-induced ramifications on Antarctic krill and ecosystems and how the adaptive capacity of the fisheries management of CCAMLR can be enhanced. Recommendations for CCAMLR include that current precautionary management measures need to be maintained, until sufficient knowledge about the population levels of sustainability exists. This includes efforts to establish MPAs in order to increase species and ecosystem resilience by reducing stress from human activities as well as to act as reference areas where the effects of climate change and ocean acidification can be researched and differentiated from the effects of natural variability and human activities.[106] However, negotiations to establish MPAs in the Southern Ocean have been very cumbersome,[107] with short-term economic interests overweighing the need for long-term resilience and precautionary measures. Although being recognized as a serious threat, ocean acidification does not seem to be tipping the iceberg towards faster and larger MPA designations, unless new research shows clear(er) negative impacts to resources harvested under CCAMLR (e.g. krill).[108]

An increased efficiency of the CCAMLR Environmental Monitoring Programme is thus fundamental for a solid science-based management of the fishery. CCAMLR can play a an important technical role in gathering further information on the impacts of ocean acidification and providing additional arguments for adaptation measures, such as establishing MPAs and precautionary harvesting limits for Antarctic marine living resources.

The CCAMLR Climate Change resolution requested "that the Chairman of the Commission writes to the President of the Conference of the Parties of the UNFCCC, to express that the CAMLR Commission considers that an effective global response by the UNFCCC is urgently needed to address the challenge of climate change in order to protect and preserve the Southern Ocean ecosystems and their biodiversity".

A similar, coordinated, effort with other regional organizations, and specifically calling for global attention to the impacts of ocean acidification, could be an additional avenue to encourage the mitigation targets urgently needed.

102 Convention on the Conservation of Antarctic Marine Living Resources (adopted in 20 May 1980, entered into force 7 April 1982) 19 ILM, 841, (CCAMLR).
103 CAMLR Convention 1982
104 CCAMLR 2009
105 Kawaguchi et al. 2012.
106 SC-CAMLR 2011.
107 SC-CAMLR 2013; CCAMLR 2013.
108 Baird et al. 2009.

4.3 Regional Fishery Management Organizations

Recent scientific literature includes a recognition of the possible impact of ocean acidification on fisheries and aquaculture indicating the need for fisheries management bodies to seriously start incorporating ocean acidification into their decisions, e.g. models for fisheries quotas or mechanisms for reducing stress or building resilience of ecosystems and associated species such as the designation of closed areas.[109]

Regional Fisheries Management Organizations (RFMOs), such as the International Commission for the Conservation of Atlantic Tunas (ICCAT) or the North-East Atlantic Fisheries Commission (NEAFC), are international organizations with a mandate to sustainably manage fishery resources in a particular region of international waters, or of highly migratory species. RFMOs adopt fisheries conservation and management measures that are binding on their members.

RFMO members are advised in their activities by their respective scientific bodies. To date, these scientific bodies have not included ocean acidification in their scientific strategies. Scientific working groups or committees of the RFMOs at most focus on the impacts of climate change through the threat of temperature increase. Revisions or introduction of relevant monitoring and environmental impact assessments need to take ocean acidification into account, including how fishing grounds may impact or be impacted by ocean acidification. Fisheries management decisions and decision-making processes should also be re-evaluated with respect to their adaptive management capacity, so to be able to incorporate new knowledge quickly.[110] Similarly for other regional and sector agreements, RFMOs could rally themselves towards stronger calls for emission reductions commitments.

109 Bignami et al. 2013; Miller et al. 2009; Cooley et.al. 2012, 182; Barton et.al. 2012, 698; Currie and Wowk, 2009 387.
110 Rayfuse 2012.

Currently an international initiative lead by the IAEA Ocean acidification aims to bridge the gap between the observed natural and economic impacts of ocean acidification. They attempt to assess ocean acidification impacts on fisheries and aquaculture resources in different regions of the world.[111]

Recommendations targeted at the fisheries sector, including on adaptation and resilience building, targeted research areas as well as stakeholder awareness raising are slowly emerging.[112]

4.4 London Convention and Protocol

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, the London Convention (LC) for short, was one of the first global conventions aimed at protecting the marine environment from human activities.[113] Its objective is to promote the effective control of all sources of marine pollution and to take all practicable steps to prevent pollution of the sea by dumping of wastes and other matter. The London Protocol (LP) was adopted in 1996 to modernize the LC and, eventually to replace it.[114] The two regimes currently work in parallel.[115]

The LC/LP are of importance as proposed marine geoengineering measures, e.g. carbon injections into the water column or storage in sub-seabed geological formations as well as ocean fertilization have implications for ocean acidification[116] and fall within their mandate.

111 Hilmi et al 2013.
112 IAEA 2013.
113 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (adopted on 29 December 1972, entered into force 30 August 1975), 11 ILM 1294 (LC).
114 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (adopted 7 November 1996, entered into force 24 March 2006) 26 ILM 1 (LP).
115 Rayfuse 2012.
116 Royal Society 2009.

Under the LP all dumping is prohibited, except for possibly acceptable wastes on the so-called 'reverse list', which includes CO_2.[117] The amendments regulate the sequestration of CO_2 streams into sub-seabed geological formations from CO_2-capture processes, for permanent isolation. The LP provides a basis in international environmental law to regulate this practice, including for possible application to the capture of CO_2 emissions from large point-sources such as electrical generation plants that use fossil fuels, steel works and fuel processing plants. [118]

The amendments further cite climate engineering as an option in a portfolio of mitigation actions for stabilization of atmospheric GHG concentrations with the potential for significant benefits at the local, regional and global levels over both short and long terms.[119] Geological sequestration of CO_2 streams would be one of a suite of measures to tackle the challenge of climate change and ocean acidification, including, first and foremost, the need to further develop and use low carbon forms of energy and conservation measures to reduce emissions.

It is further stated that CO_2 streams may only be considered for dumping if disposal is into a sub-seabed geological formations, disposal is overwhelmingly of CO_2, and no wastes or other matter are added for the purpose of disposing of them. The risks associated with CO_2 sequestration in sub-seabed geological formations are CO_2 leakage into the marine environment together with other substances in or mobilized by the CO_2 stream. In general, there are different levels of concerns regarding potential leakage that range from the local to the global over both short- and long-terms. [120] [121]

In 2008, ocean fertilization was recognized as a concern by the LC/LP, defining ocean fertilization as "any activity undertaken by humans with the principal intention of stimulating primary productivity in the ocean",[122] with its most likely large-scale purpose being to enhance CO_2 uptake by the ocean to a climatically-significant degree.[123] In 2010, Parties adopted the resolution LC-LP.2 (2010) on the *Assessment Framework for Scientific Research Involving Ocean Fertilization* to guide Parties on the approval process for ocean fertilization research, and to provide detailed steps for completion of an environmental assessment, including risk management and monitoring.

Since 2009, Parties have discussed options for a legally binding measure on ocean fertilization.[124] In 2013, the Contracting Parties adopted resolution LP.4(8), thereby amending the Protocol to include all marine geoengineering activities. A new article 6bis states that "Contracting Parties shall not allow the placement of matter into the sea from vessels, aircraft, platforms or other man-made structures at sea for marine geoengineering activities listed in Annex 4, unless the listing provides that the activity or the sub-category of an activity may be authorized under a permit".[125] Ocean fertilization may only be granted for the purposes of legitimate scientific research as verified by as scientific review procedure.

As the case on marine geoengineering shows, existing agreements can also interpret, adapt or expand their mandate to encompass new activities and regulate related impacts.[126] Direct influence on CO_2 mitigation however cannot be expected by the LC/LP. The dumping regime can address ocean acidification only in so far as it is caused by the dumping of CO_2 wastes at sea[127]. Consequently, this regime can only regulate one relatively small potential driver of ocean acidification.[128] Other marine geoengineering methods, beyond ocean fertilization can

117 1996 London Protocol.
118 LC/LP 2006.
119 LC 2012.
120 LC 2012.
121 Secretariat of the CBD 2012.
122 LICG 2008.
123 London Convention 2008.
124 Rayfuse 2012.
125 LP 2013.
126 Ardron et al. 2014.
127 Simons and Stephens 2009.
128 Simons and Stephens 2009.

however be added to the listed activities.[129] As other fora are discussing this topic, e.g. UNFCCC or CBD, a strong collaboration is needed.

4.5 Other sectoral agreements

Ocean acidification will also have an effect on the regulatory impacts and effectiveness of other sectoral agreements relevant to ocean management. The Convention on the Conservation of Migratory Species of Wild Animals (CMS) and the Convention of International Trade in Endangered Species (CITES) have been reviewed as examples.

As with other regional and sectoral agreements, they have no direct mandate to deal with the reduction of CO_2 emissions, other than to urge the UNFCCC to take appropriate measures. Their focus should lie on raising the profile of ocean acidification by providing relevant technical information to their Parties and develop adequate adaptation measures.

The CMS aims to conserve terrestrial, aquatic and avian migratory species throughout their range. It has several resolutions on climate change, which include the call for adaptation measures to ensure the conservation of migrating animals.[130] They do however not yet make ocean acidification a particular policy concern.

129 LP 2013.
130 CMS 1997; 2005; 2008; 2011.

Nonetheless, in the last few years ocean acidification was discussed as part of several technical workshops and climate change vulnerability papers as potentially having wide-ranging consequences for species, impacting on food webs, most prominently in Arctic Regions.[131] Now dedicated adaptation measures need to follow.

Recent decisions from the Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora,[132] included potential opportunities for the further implementation of the CITES Strategic Vision 2008-2013.[133] One of their goals is to minimize the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification to maintain their integrity and functioning by 2015. Specific action referring to the CITES goals within the scope of ocean acidification are not reported to date.

Similarly to CMS, dedicated technical assessments and adaptation measures should be targeted, benefitted ideally by shared reports from the CBD and other sources.

131 Zoological Society of London 2010.
132 Convention on International Trade in Endangered Species of Wild Fauna and Flora (adopted 3 March 1973, entered into force 1 July 1975)
133 CITES 2007.

5 Policy processes

Other policy making bodies, such as the UNGA, and high-level events, such as the Rio+20, also play significant roles in the process of standard-setting and the codification of international law. These efforts can initiate studies and make recommendations to promote international political cooperation as well as stimulate international action to protect the environment. The following section elaborates on these policy-making processes to assess their role in addressing ocean acidification.

5.1 United Nations General Assembly

The United Nations General Assembly is the main deliberative, policymaking and representative organ of the United Nations and has in the past initiated actions — including environmental — which have affected the lives of millions of people around the world.

As the paragraphs below document, the UNGA has called for collaborative work and support for initiatives on all relevant aspects of ocean acidification (science, monitoring and research, as well as mitigation and adaptation measures). The question remains however, whether the UNGA can further lift ocean acidification on the political agenda.

The 2005 report of the Secretary General on scientific, technical and other aspects of the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction already mentioned the possible impacts of elevated atmospheric CO_2 concentrations on open-ocean phytoplankton and zooplankton, as well as corals.[134]Ocean acidification appeared first in 2006 on the agenda of the UNGA when it expressed "its concern over the projected adverse effects of anthropogenic and natural climate change and ocean acidification on the marine environment and marine biodiversity" in its annual resolution on oceans and law of the sea.[135]

In the following years (2007-2011) UNGA resolutions continued to express concern about ocean acidification in relation to coral reefs, as climate change would weaken them "to withstand ocean acidification, which could have serious and irreversible negative effects on marine organisms, particularly corals, as well as to withstand other pressures, including overfishing and pollution".[136]

The UNGA also took note of the findings of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

134 UNGA 2005, para 152.
135 UNGA 2006, preamble.
136 UNGA 2012a, preamble.

(IPCC) on the acidification of the ocean in 2007. The UNGA has repeatedly encouraged parties "to increase national, regional and international efforts to address levels of ocean acidity and the negative impact of such acidity on vulnerable marine ecosystems, particularly coral reefs".[137]

In its 2012 UNGA Resolution the UNGA made several additional references to the Rio +20 outcome document The Future We Want (see section below); in particular to the call to support initiatives that address ocean acidification and the impacts of climate change on marine and coastal ecosystems and resources.

The 2012 UNGA Resolution reiterated the need for collaborative work to prevent further ocean acidification, and to enhance the resilience of marine ecosystems and dependent communities. The need for increased and collaborative marine scientific research, monitoring and observation of ocean acidification and particularly vulnerable ecosystems is further called for.[138]

It further encouraged States to develop ways and means of adaptation, while using the precautionary approach and ecosystem approaches.[139] On mitigation, the UNGA highlighted the need "to increase national, regional and global efforts to address levels of ocean acidity and the negative impact of such acidity on vulnerable marine ecosystems, particularly coral reefs"[140] while there is a "need to work collectively to prevent further ocean acidification".[141]

Additional attention and discussion has been triggered through a dedicated session (June 2013) of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (UNICPOLOS, short ICP). It focused its discussion on the scientific aspects of the impacts of ocean acidification on the marine environment.[142] Delegates to the meeting however stressed, that the focus of this session should only be on the technical and scientific aspects of ocean acidification, and "that policy or regulatory aspects should not be included".[143]

The ICP, as a non-political venue, was used for sharing information that can then be brought to other fora dealing with the more politically contentious aspects of oceans issues. This narrow focus seemed to have helped facilitate discussions. Delegates, participants and panelists appeared comfortable explicitly identifying CO_2 emissions levels as the key driver of ocean acidification, including the United States, without then discussing mitigation measures.

As pointed out by the Earth Negotiations Bulletin (ENB) analysis of the ICP, "delegates indeed expressed hope that the knowledge and awareness generated during the meeting would serve as a useful foundation for the negotiations of the Oceans and Law of the Sea resolution at this year's meeting of the UNGA. Whether the expressed hope translates into action on ocean acidification may hinge on how well the upcoming General Assembly negotiations can navigate the competing issues on the ocean agenda. Despite this uncertainty, it remains clear that many delegates, benefiting from the safe space created by ICP-14, left New York with a heightened awareness of ocean acidification as a global issue of urgent concern".[144]

The UNGA following ICP-14 reiterated "its serious concern at the current and projected adverse effects of climate change and ocean acidification on the marine environment and marine biodiversity, and emphasizing the urgency of addressing these issues",[145] and stressed previous reflections including on coral reefs, the findings of the IPCC and work of the CBD. New however was the focus on the impacts of ocean acidification on the

137 UNGA 2011, para 134; UNGA 2010, para 129; UNGA 2009, para 113; UNGA 2008, para 99.
138 UNGA 2012a, para 144.
139 UNGA 2012a, para 146.
140 UNGA 2012a, para 143.
141 UNGA 2012a, para 144.
142 UNGA 2013.
143 UNGA 2013, para 9.
144 ENB 2013.
145 UNGA 2013a, preambula.

Polar Regions, as well as a call to support capacity building on ocean acidification.[146]

Extensive consideration of ocean acidification has thus been given over recent years, including during the last session in 2013, within the broader UN context. But the global concern expressed at the UNICPOLOS meeting, and recently strengthened through the sixty-eighth session of UNGA, still waits to be mirrored in concrete political decisions and implementation mainly via the UNFCCC.

5.2 From Rio to Rio +20

The Rio conferences have also been important in setting the stage for new initiatives to be born or become visible. Since 1992 the international community has met every ten years to discuss the world's most pressing environmental issues, starting with the 1992 United Nations Conference on Environment and Development (UNCED), in Rio de Janeiro, and with the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg.

Ocean acidification emerged at the United Nations Conference on Sustainable Development (UNCSD), also called Rio+20, which took place in Brazil once again in 2012. The outcome document of Rio+20 The Future We Want[147] calls for support to research initiatives that address ocean acidification and the need to work collectively to prevent further ocean acidification.[148]

The world community also expressed "profound alarm that emissions of greenhouse gases continue to rise globally" and reiterated that all countries, particularly developing countries, are vulnerable to its adverse impacts, including ocean acidification.[149]

High-level expressions of concerns and calls for collective action – from monitoring ocean acidification to GHG reductions and adaptation strategies – now exist prominently. Concrete actions for further steps to effectively operationalize the existing international policy landscape however, have yet to be proposed in the respective fora.

146 UNGA 2013a para 17.

147 UNGA 2012, para158.

148 UNGA 2012, para 166.

149 UNGA 2012, para 190.

6 Spurring policy decisions

Science is of particular importance and influence in law and policy making[150]. Science-policy interfaces, such as the IPCC, are the most critical vehicles to bring scientific knowledge to policy makers, especially since they undergo government endorsement.

6.1 Science-policy interfaces

IPCC

In 1988, the IPCC was established to provide the world with a clear scientific review and assessment on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. The IPCC inter alia provides scientific advice to Parties to the UNFCCC.

In its 2007 Fourth Assessment Report, the IPCC recognized ocean acidification for the first time as a risk to ecosystems caused by increasing CO_2 emissions. It highlighted that "the main driver of these changes [lower oceanic pH and carbonate ion concentrations] is the direct geochemical effect due to the addition of anthropogenic CO_2 to the surface ocean". In 2011, the IPCC held a dedicated expert workshop on the Impacts of Ocean Acidification on Marine Biology and Ecosystems, reflecting increased interest from governments to address this topic in more depth.[151]

In 2013 and 2014, with the number of ocean acidification publications growing rapidly, a much greater body of evidence was available for inclusion in the IPCC's Fifth Assessment Report.

The Summary for Policy Makers (SPM) for Working Group I (The Physical Science Basis) concludes "Of these cumulative anthropogenic CO_2 emissions, 240 [230 to 250] GtC have accumulated in the atmosphere, 155 [125 to 185] GtC have been taken up by the ocean and 160 [70 to 250] GtC have accumulated in natural terrestrial ecosystems (i.e., the cumulative residual land sink). Ocean acidification is quantified by decreases in pH. The pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era (high confidence), corresponding to a 26% increase in hydrogen ion concentration. Ocean uptake of anthropogenic CO_2 will continue under all four Representative Concentration Pathways (RCPs) through to 2100, with higher uptake for higher concentration pathways (very high confidence).

The SPM for Working Group II (Impacts, Adaptation, and Vulnerability) concludes "For medium- to high-emission scenarios (RCP4.5, 6.0, and 8.5), ocean acidification poses substantial risks to marine ecosystems, especially polar ecosystems and coral reefs, associated with impacts on the physiology, behavior, and population dynamics of individual species from phytoplankton to animals (medium to high confidence)."

With the negotiations for a 2015 agreement in full motion, the scientific support for policy action is even more vital and allows for bold political steps.

Regular Process

At the WSSD in 2002, world leaders agreed in the Johannesburg Plan of Implementation (JPOI), to "establish by 2004 a regular process under the United Nations for global reporting and assessment of the state of the marine environment, including socio-economic aspects, both current and foreseeable, building on existing regional assessments".[152] The first integrated assessment is expected to be completed in 2014. It will contain several chapters discussing ocean acidification.[153]

150 Sands and Peel 2012.
151 IPCC 2011.
152 JPOI 2002, paragraph 36 (b)
153 UNGA 2012b.

States have also agreed to provide a mechanism for keeping policymakers informed with key scientific and technical knowledge related to biodiversity and ecosystem services through the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) established in 2012. IPBES will be an interface between the scientific community and policy makers in order to build capacity for and strengthen the use of science in policy making for the conservation and sustainable use of biodiversity, long-term human wellbeing and sustainable development. IPBES will respond to requests for scientific information related to biodiversity and ecosystem services from governments, relevant multilateral environmental agreements and UN bodies, as well as other relevant stakeholders.

With increasing concern of how ocean acidification may impact human society IPBES is expected to provide a further opportunity to describe the potential future impact of ocean acidification and other ocean stressors on marine diversity and ecosystems and the products and services they provide human society. However, as highlighted throughout the report, there is a real concern of duplication of efforts and resources for similar type of assessments. Strong linkages with the recent IPCC, as well as the CBD report should be made.

6.2 Science Knowledge Generation, Coordination and Access

Whereas the intergovernmental efforts have a direct link to policy making, their efforts are only edited periodically and undergo long review processes. They cannot take newly emerging findings into account. Ongoing research activities and the communication thereof are as important to keep policy-makers informed. Short summaries for policymakers like the recently published Ocean Acidification Summary for Policymakers can serve as resources to follow and publicize recent research findings.[154]

Ocean acidification has been part of several national and international research projects and programmes. Regional and global collaboration between scientists resulted in global projects leading to a fast growing scientific community.[155] Single projects are compiled in regional programmes in order

154 IGBP, IOC, SCOR 2013.
155 for example SOLAS, IMBER, EPOCA

to enhance the communication and to increase the benefit through intersectional collaboration.[156] Within this landscape some guidance and coordination is provided by, for example, the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO) and the Ocean Acidification International Coordination Centre (OA-ICC).

The IOC-UNESCO promotes international cooperation and coordinates programmes in marine research, services, observation systems, hazard mitigation, and capacity development in order to understand and effectively manage the resources of the ocean and coastal areas.

As early as 1979, the IOC-UNESCO and the Scientific Committee on Oceanic Research (SCOR) recognized the importance of the ocean's role in global climate change and formed the first Committee on Climate Change and the Ocean (CCCO) which, in 1984, established a CO_2 Advisory Panel.[157] Already at this time the panel called for a carbon observation program and sampling strategy that could determine the global oceanic CO_2 inventory. Other ocean acidification related projects such as the International Ocean Carbon Coordination Project (IOCCP), the World Climate Research Programme (WCRP) and Global Ocean Observing System (GOOS) followed.

The OA-ICC was launched in 2012 at Rio+20 and tasked to coordinate key overarching activities that must be performed at the international level to make effective use of the science investment at national levels and to build capacity globally. [158] These include, amongst others, the development of a Global Ocean Acidification-Observation Network, the sharing of joint platforms, facilities and experiments, the development of best practices, the facilitation of collaboration between life and social sciences, and the communication of the latest scientific findings to research-users, including policy makers.

156 for example MedSeA, the Future Ocean, UK Ocean Acidification Research Programme, and the NOAA Ocean Acidification Programm, BIOACID.

157 Sabine et al. 2010.

158 IAEA 2012.

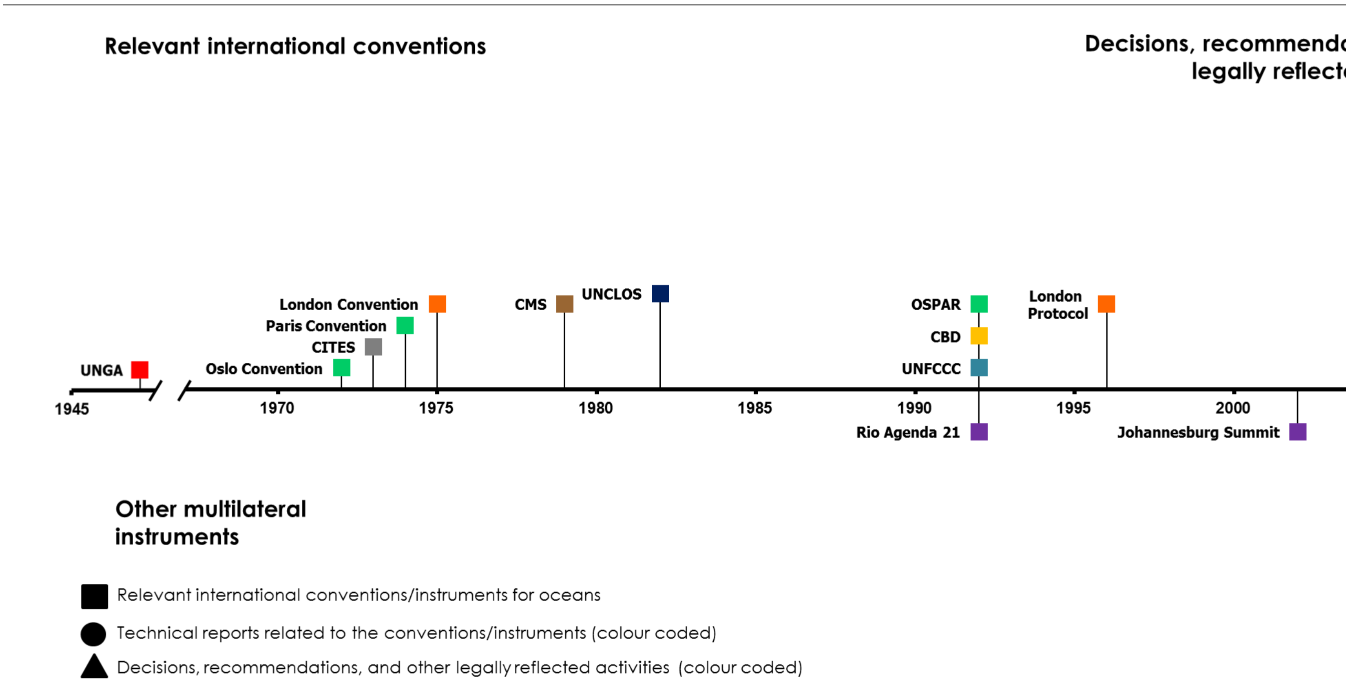
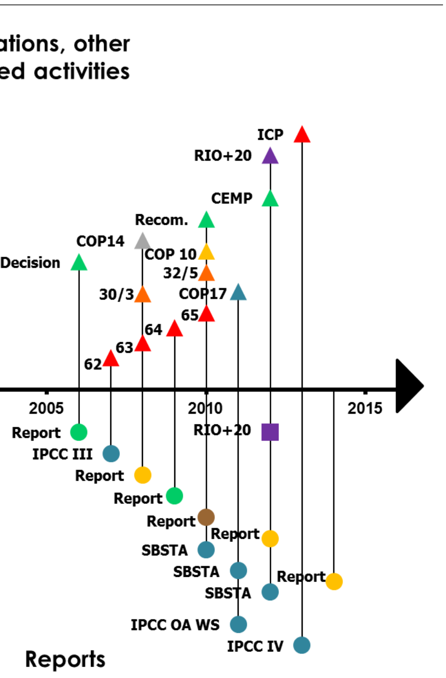


Figure 4. *Overview of international conventions and instruments described in this paper to protect the ocean with their relevant decisions, recommendations or other legally reflected actions (triangle) and issued reports (circles). The rectangles represent the date of adoption of the conventions/instruments. The colours differentiate the conventions/instruments and link them to their respective activities.*



7 A possible way forward

7.1 Implementation

Ocean acidification exists “in an international legal twilight zone”.[159] Given the current policy landscape, and the tensions and unresolved issues surrounding climate change and the reduction of carbon dioxide emissions, it seems “superfluous, confusing and unrealistic”[160] to attempt to set up a new agreement on ocean acidification.[161] Thus, the main challenge for environmental law in many cases is not the articulation of a new treaty, rather, it is the effective implementation of existing ones. [162] As shown, several international, sectoral and regional agreements are applicable to ocean acidification and can be utilized to implement mitigation and adaptation programmes. This extensive suite of regulatory mechanisms needs to be revised and strengthened so as to more effectively address ocean acidification. To do so usefully and in a harmonized way, increased and more efficient collaboration is one of the critical steps ahead.

159 Baird et al. 2009
160 Harrould-Kolieb & Herr 2010.
161 Kim 2012.
162 Baird et al 2009; Currie and Wowk 2009 ; WGBU 2013.

7.2 Collaboration

There is remarkable consensus among scientists regarding the certainty and future severity of ocean acidification and scientifc coordination efforts have moved forward rapidly. Similar coordination by policy makers is now needed to overcome the fragmented policy landscape on ocean acidification by ensuring that existing regimes are modified where necessary to embrace ocean acidification as a regime focus, and above all to operate in concert to address the problem.[163]

163 Baird et al. 2009. Rayfuse 2012.

"To date, cooperation has shown itself to be the Achilles heel of the existing constellation of [marine and conservation] agreements".[164] Parallels can be drawn from ongoing analysis on collaboration needs for sustainable use and conservation of biodiversity in ABNJ. For instance, the agreements described in this paper have cooperation mandates and mechanisms, but have yet to make use of them to address ocean acidification in an efficient, cross-regime manner.

Some suggestions for increased collaboration:

• Use available fora and communication channels, within and across convention secretariats and agreements, as well as between different government agreement liaison and focal points, to exchange relevant information on planned scientific and technical assessments, and to inform on relevant efforts pertinent to ocean acidification.

  • Make ocean acidification a clear topic of the Joint Liaison Group of the Rio Conventions. Other than a brief reference in the 2013 meeting report without further details, ocean acidification seems to have not played a major role in these meetings.[165]

• Achieve greater cooperation through increased use of Memoranda of Understanding (MOUs) between regimes providing for joint meetings, joint work plans, and/or the designation of joint science advisory bodies or processes (as suggested by Ardron et al for issues on ABNJ).

• Establish a new cross-regime cooperation mechanism dedicated to ocean acidification. Whilst not proposing a new legal agreement for ocean acidification,[166] a forum with representatives from relevant sectoral, conservation, marine and climate change regimes should be created and report annually on relevant efforts. A common global mandate from a UNGA resolution to prompt progress would be useful.

164 Ardron et al. 2014.
165 Rio Conventions 2013.
166 Kim 2012.

• Create national inter-agency working groups on ocean acidification, involving relevant officials and experts from the climate change field (mitigation and adaptation) as well as from agencies working on coastal and ocean management, including on fisheries and aquaculture, conservation/protection (MPAs), and related fields such as tourism and finance.

Strengthen and unite the voice of "the ocean agreements" within climate change discussions, expressing the limitations of their own conventions and agreements to exercise their mandate unless CO_2 mitigation efforts are increased significantly.

7.3 Mitigation

Emerging public statements, such as from U.S. Secretary for State John Kerry during an oceans' conference 2014, are very encouraging: "If we want to slow down the rate of acidification on our oceans, protect our coral reefs, and save species from extinction, we have to cut down on greenhouse gas emissions and pursue cleaner sources of energy. It's as simple as that".[167]

The translation into relevant policy regimes is now needed. Possible avenues include:

• Revise and strengthen climate change mitigation policy measures and mechanisms to ensure ocean acidification will be mitigated alongside climate change.

• Set additional indicators, alongside temperature indicators, to reflect ocean acidification.

• Revised GHG and CO_2 mitigation targets so as to account for the impacts of ocean acidification.

• Evaluate climate change mitigation strategies that may exacerbate ocean acidification (e.g. ocean fertilization) and strategies which have no direct mitigation effect on ocean acidification such as Solar Radiation Management (SRM).

167 RTCC 2014.

• Protect natural carbon sinks such as seagrass beds and mangroves. High densities of seagrass can significantly alter the local carbonate chemistry[168], with potential benefit for neighbouring ecosystems, while sequestering and storing carbon mostly in their sediments.[169]

7.4 Adaptation

Regional and sectoral agreements have no direct mandate to deal with the reduction of CO_2 emissions, other than to urge the UNFCCC to take appropriate measures. Their focus should lie on providing relevant technical information to their Parties and develop adequate adaptation measures. Some regimes, such as the CBD have already developed guidelines, whereas others, such as the CMS or CITES do not have these yet. Reasons for this could be that 1) possible scientific impact assessments on relevant flora and fauna are missing, and/or 2) dedicated knowledge on responses measures, beyond business-as-usual resilience and protection measures, are lacking.

Further steps could be taken in the form of:

• Review of existing international policies and mechanisms on their effectiveness to adapt to ocean acidification.

• Increase international planning and financing for adaptation with increased capacity building in vulnerable countries to measure ocean acidification, its local impacts and explore ways for local means for adaptation.

While efforts are needed on a larger scale, such as through the NWP (UNFCCC), or through the CBD work programmes (see section 3.3), essential regional and local action on adaptation and risk management can be taken:[170]

168 Unsworth et al. 2012.

169 Murray et al. 2011.

170 Suggestions from the UNEP 2010 report on ocean acidification have been incorporated.

• Determine biological and socio-economical vulnerabilities of fish-dependent human communities and tourism sectors in terms of exposure, sensitivity and the capacity to adapt to changes resulting from ocean acidification.

• Invest in establishing and strengthening regional forecasting and early warning systems.

• Reduce local sources of acidification.

• Reduce other stressors to the marine environment to enhance overall ecosystem resilience, and improve conservation and protection measures.

• Identify less vulnerable and resistant species for sea food production, such as resistant strains of shellfish; assess how these may affect ecosystems and food security.

• Explore other seafood production options, for example, assess the options for development of environmentally sustainable 'aquaculture' options using species that are resistant to lowered pH or can be kept in conditions of controlled pH, and explore alternative protein sources.

• Consider the viability and negative impacts of a chain of substitute habitats such as artificial reefs to provide the diversity of niches that are found in existing habitats.

7.5 Risk assessment and information sharing

To manage risks from ocean acidification it is necessary to understand the severity of the issue in different regions, and with time, the vulnerability and exposure of marine organisms, ecosystems and human society and their ability to adapt. The establishment of the OA-ICC and global concern expressed through the Rio +20 conference are a positive step towards collective engagement to address ocean acidification. However, additional efforts are needed through increased cooperation and information exchange between and among relevant conventions and bodies to avoid duplicating closely-similar work (e.g. scientific synthesis reports), as well as between and among laboratories, research institutes, NGOs and IGOs. The Global Ocean Acidification Observing Network (GOA-ON)[171] answered the call for a structured and scientifically robust global observation system for ocean acidification and its potential ecosystem responses, to improve the evidence base for policy action. Funding permitted, the work of the GOA-ON will focus on international coordination of studies of ocean stressors including the development and funding of a global ocean acidification monitoring and observation network as an early warning and forecasting system, especially for vulnerable societies and developing countries.

Observation and training measures could become a part of developed countries' overseas aid programmes. At the "Our Ocean" Conference, hosted by Senator Kerry, the Ocean Foundation announced the the Friends of the Global Ocean Acidification Observing Network to mobilize high-level national and international donor commitments that will contribute to the implementation of the GOA-ON.[172]

RFMOs will need to engage more on the topic of ocean acidification and could start by launching respective scientific and technical assessments, as well as bringing it higher up on the political agenda. Any research should however be clearly linked to ongoing processes, and results fed through appropriate channels such as the IPCC, IPBES or the Regular Process.

7.6 National activities, and future needs

National activities, and ultimately the implementation of international law and regulations, are key to address ocean acidification. Each government needs to recognize that ocean acidification is a global problem that will be experienced locally. Encouragingly national plans are starting to emerge, such as the Ocean Acidification Strategic Research Plan by the U.S. Interagency Working Group on Ocean Acidification "to improve the understanding of ocean acidification, its potential impacts on marine species and ecosystems, and adaptation and mitigation strategies".[173]

Further work should go into analyzing these national efforts in more detail,[174] with the purpose of making them more visible, so that they can learn from each other and connect better, and to ensure that they are consequently linked with efforts on international, regional and sectoral scales.

171 http://www.goa-on.org/
172 http://www.oceanfdn.org/ocean-acidification#sthash.RV2hUPZ4.dpuf
173 IWG-OA 2014.
174 See for example discussion on U.S. efforts by Strong et al. 2014.

8 Conclusion

Ocean acidification may come to be understood as one of the most serious human-caused threats to endanger our ocean; a threat that, like climate change, is a result of ongoing burning of fossil fuels and emissions from land-use changes.

This report has shown that ocean acidification is of relevance for a variety of international law and policy regimes. While some have begun to address ocean acidification through scientific assessments, adaptation measures and general calls for concerns, a dedicated mitigation strategy and focused activities via the UNFCCC, on one hand, and greater coordination between existing regimes, on the other hand, are still lacking.

Rather than establishing a new legal agreement for ocean acidification, a cross-regime cooperation mechanism dedicated to ocean acidification would be realistic, feasible and be able to address the issues outlined in this report.

A forum with representatives from relevant sectoral, conservation, marine and climate change regimes should be created and report annually on relevant mitigation and adaptation measures across regimes. A common global mandate from a UNGA resolution to prompt such a forum would be useful. Additional fora, such as the Joint Liaison Group of the Rio Conventions are already established structures that can make ocean acidification their priority.

With this report at hand, further studies and discussion are nevertheless needed to ensure the full inclusion of ocean acidification into pertinent environmental, social and economic deliberations towards a sustainable, low-carbon society performance and transformational need of ocean governance and policies.

Annex I – Abbreviations and acronyms

ABNJ	Area(s) beyond national jurisdiction
ADP	Ad Hoc Working Group on the Durban Platform for Enhanced Action
BIOACID	Biological Impacts Of Ocean Acidification, Scientific Research Programme
CBD	Convention on Biological Diversity
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
C-CAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CCS	Carbon capture and storage
CEMP	Coordinated Environmental Monitoring Programme
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on Migratory Species
CO_2	Carbon dioxide
COP	Conference of the Parties
EIA	Environmental impact assessment
EPOCA	European Project on Ocean Acidification
GHGs	Greenhouse gases
GOA-ON	Global Ocean Acidification Observing Network
GOOS	Global Ocean Observing System
ICCAT	International Commission for the Conservation of Atlantic Tunas
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research
IOC	Intergovernmental Oceanographic Commission of UNESCO
IOCCP	International Ocean Carbon Coordination Project
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
JPOI	Johannesburg Plan of Implementation
LC/LP	London Convention/London Protocol
MPAs	Marine Protected Areas
NBSAPs	National Biodiversity Strategies and Action Plans
NEAFC	North-East Atlantic Fisheries Commission
NWP	Nairobi Work Programme on impacts, vulnerability and adaptation to climate change
OA-ICC	Ocean Acidification International Coordination Centre
RFMOs	Regional Fisheries Management Organizations
RSCAPs	Regional Seas Conventions and Action Plans
SBSTA	Subsidiary Body on Technological Advice, UNFCCC
SBSTTA	Subsidiary Body on Scientific, Technical and Technological Advice, CBD
SCOR	Scientific Committee on Ocean Research
SOLAS	Surface Ocean - Lower Atmosphere Study
UNCLOS	United Nations Convention on the Law of the Sea

UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	General Assembly of the United Nations
UNICPOLOS / ICP	United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea
WCRP	World Climate Research Programme
SRM	Solar Radiation Management

Annex II - References

Ardron, Jeff A., Rosemary Rayfuse, Kristina Gjerde and Robin Warner. 2014. The sustainable use and conservation of biodiversity in ABNJ: What can be achieved using existing international agreements? Marine Policy. 1-11.

Baird, Rachel, Simons, Meredith, and Stephens, Tim. 2009. Ocean Acidification: A Litmus Test for International Law. Carbon & Climate L. Rev. 4:459.

Barton, Alan, Burke Hales, George G. Waldbusser, Chris Langdon, and Richard A. Feely. 2012. The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects. Limnology and Oceanography 57 (3): 698-710.

Bednaršek, Nina, Geraint A. Tarling, Dorothee. C.E. Bakker, Sophie Fielding, E. M. Jones, Hugh J. Venables, Peter Ward, Alan Kuzirian, Bertrand Lézé, Richard. A. Feely, and Eugene J. Murphy. 2012. Extensive dissolution of live pteropods in the Southern Ocean. Nature Geoscience 5: 881–885.

Bignami, Sean, Su Sponaugle, and Robert K. Cowen. 2013. Response to ocean acidification in larvae of a large tropical marine fish, Rachycentron canadum. Global Change Biology 19: 996–1006.

Billé, Raphaël , Ryan Kelly, Arne Biastoch, Ellycia Harrould-Kolieb, Dorothée Herr, Fortunat Joos, Kristy Kroeker, Dan Laffoley, Andreas Oschlies, and Jean-Pierre Gattuso. 2013. Taking Action Against Ocean Acidification: A Review of Management and Policy Options. Environmental Management 52,4: 761-779.

Boyle, Alan. 2012. Law of the Sea Perspectives on Climate Change. The International Journal of Marine and Coastal Law 27:831–838.

Caldeira, Ken and Michael E. Wickett. 2003. Anthropogenic carbon and ocean pH. Nature 425: 365.

Cao, Long and·Ken Caldeira. 2010. Can ocean iron fertilization mitigate ocean acidification? A letter. Climatic Change. DOI 10.1007/s10584-010-9799-4.

CBD. 2008. UNEP/CBD/COP/DEC/IX/16 Biodiversity and climate change. 9th COP, October 2008.

CBD. 2010. UNEP/CBD/COP/DEC/X/29 Marine and coastal biodiversity, 10th COP, October 2010.

CBD. 2012. UNEP/CBD/COP/DEC/X/2 The Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets. 11th COP, October 2012.

CBD. 2012a. UNEP/CBD/COP/DEC/XI/18 Marine and coastal biodiversity: sustainable fisheries and addressing adverse impacts of human activities, voluntary guidelines for environmental assessment, and marine spatial planning. 11th COP, October 2012.

CBD/SBSTTA. 2012. UNEP/CBD/SBSTTA/16/6 Addressing adverse impacts of human activities on marine and coastal biodiversity, including oral bleaching, ocean acidification, fisheries and underwater noise. Executive Summary. 16th meeting, March 2012.

CCAMLR. 2009. Resolution 30/XXVIII Climate change. 28th meeting, October 2009.

CCAMLR. 2013. Report of the Second Intersessional Meeting of the Commission, Bremerhaven, Germany.

CITES. 2007. CITES Strategic Vision: 2008-2013. COP 14, June 2007.

CMS. 1997. Recommendation 5.5 Climate Change and its Implications for the Bonn Convention. COP 5, April 1997.

CMS. 2005. Resolution 8.13 Climate Change and Migratory Species. COP 8, November 2005.

CMS. 2008. Resolution 9.7 Climate Change Impacts on Migratory Species. COP 9, December 2008.

CMS. 2011. Resolution 10.19 Migratory Species Conservation in the Light of Climate Change. COP 10, November 2011.

Cooley, Sarah R., Noelle Lucey, Hauke L. Kite-Powell, Scott C. Doney. 2012. Nutrition and income from molluscs today imply vulnerability to ocean acidification tomorrow. Fish and Fisheries 13(2): 182-215.

Currie, Duncan E.J. and Kateryna Wowk. 2009. Climate Change and CO_2 in the Oceans and Global Oceans Governance Improving Governance of the World's Oceans. CCLR 4:387-404.

Earth Negotiations Bulletin (ENB). 2013. Summary of the 14th Meeting of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea: 17-20 June 2013.

Feely, Richard A., Scott C. Doney, and Sarah R. Cooley. 2009. Present conditions and future changes in a high CO_2 world. Oceanography 22: 36-47.

Freestone, David. 2009. Climate Change and the Oceans. CCLR 4: 383-386.

Gattuso, Jean-Pierre and Lina Hansson. 2011. Ocean Acidification. Oxford University Press, Oxford, pp.326.

Gattuso, Jean-Pierre, Katharine J. Mach, and Granger Morgan. 2013. Ocean acidification and its impacts: an expert survey. Climatic Change 117 (4): 725-738.

Gehlen, Marion, Nicolas Gruber, Reidun Gangstø, Laurent Bopp, and Andreas Oschlies. 2011. Biogeochemical consequences of ocean acidification and feedbacks to the Earth system. In Ocean acidification, edited by Jean-Pierre Gattuso and Lina Hansson, 230-248. Oxford: Oxford University Press.

Gonzales, Verónica. 2012. An alternative approach for addressing CO_2-driven ocean acidification. Sustainable Development Law & Policy 12(2):45, 69.

Gruber, Nicolas. 2011 Warming up, turning sour, losing breath: ocean biogeochemistry under global change. Phil. Trans. R. Soc. A 369: 1980-1996.

Harrould-Kolieb, Ellycia and Dorothée Herr. 2011. Ocean acidification and climate change: synergies and challenges of addressing both under the UNFCCC. Climate Policy. doi:10.1080/14693062.2012.620788

Hilmi N, Allemand D, Betti M, Gattuso J-P, Kavanagh C, Lacoue- Labarthe T, Moschella P, Reynaud S, Warnau M. 2013. 2nd International Workshop on the Economics of Ocean Acidification: Bridging the Gap Between Ocean Acidification Impacts and Economic Valuation "Ocean Acidification impacts on fisheries and aquaculture." Oceanographic Museum of Monaco, 11-13 November 2012.

Hoegh-Guldberg, Ove, and John F. Bruno. 2010. The Impact of Climate Change on the World's Marine Ecosystems. Science 328 (5985): 1523-1528.

Hoegh-Guldberg, Ove., Rongshuo Cai, Peter G. Brewer, Victoria J. Fabry, Karim Hilmi, Sukgeun Jung, Elvira Poloczanska, Svein Sundby. 2014. The Ocean, chapter 30. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Field, C. et al. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Hönisch, Bärbel, Andy Ridgwell, Daniela N. Schmidt, Ellen Thomas, Samantha J. Gibbs, Appy Sluijs, Richard Zeebe, Lee Kump, Rowan C. Martindale, Sarah E. Greene, Wolfgang Kiessling, Justin Ries, James C. Zachos, Dana L. Royer, Stephen Barker, Thomas M. Marchitto Jr., Ryan Moyer, Carles Pelejero, Patrizia Ziveri, Gavin L. Foster, and Branwen Williams. 2012. The geological record of ocean acidification. Science 335: 1058-1063.

IAEA. 2012. IAEA To Launch Centre On Ocean Acidification. Press Release, June 16. Available at http://www.iaea.org/newscenter/pressreleases/2012/prn201218.html, accessed July 9, 2013.

IAEA. 2013. Economics of ocean acidification. Impacts on fisheries and aquaculture. http://medsea-project.eu/wp-content/uploads/2013/10/ebook-ECONOMICS-OF-OCEAN-ACIDIFICATION.pdf

ICES. 2013. Report of the Joint OSPAR/ICES Ocean Acidification Study Group (SGOA), 7–10 October 2013, Copenhagen, Denmark. ICES CM 2013/ACOM:31. 82 pp.

ICES. 2013a. Report of the Joint OSPAR/ICES Ocean Acidification Study Group (SGOA), 11–14 December 2012, Copenhagen, Denmark. ICES CM 2012/ACOM: 83.

IGBP, IOC, SCOR (2013). Ocean Acidification Summary for Policymakers – Third Symposium on the Ocean in a High-CO2 World. International Geosphere-Biosphere Programme, Stockholm, Sweden.

Interagency Working Group on Ocean Acidification (IWG-OA) Subcommittee on Ocean Science and Technology Committee on Environment, Natural Resources, and Sustainability National Science and Technology Council. 2014. Strategic Plan for Federal Research and Monitoring of Ocean Acidification. ftp://ftp.oar.noaa.gov/OA/IWGOA%20documents/IWGOA%20Strategic%20Plan.pdf

IPCC. 2007a. Climate Change 2007 - The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC.

IPCC. 2007b. Climate Change 2007 - Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the IPCC

IPCC. 2007c. Climate Change 2007 - Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the IPCC.

IPCC. 2011. Workshop Report of the Intergovernmental Panel on Climate Change Workshop on Impacts of Ocean Acidification on Marine Biology and Ecosystems. IPCC Working Group II Technical Support Unit, Carnegie Institution, Stanford, California, United States of America. Available at: https://www.ipcc-wg1.unibe.ch/publications/supportingmaterial/OceanAcidification_WorkshopReport.pdf, accessed July 9, 2013.

IPCC. 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker, T.F. et al. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2014. Summary for Policymakers Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Field, C. et al. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Joos, Fortunate, Thomas L. Frölicher, Marco Steinacher, and Gian Kasper Plattner. 2011. Impact of climate change mitigation on ocean acidification projections. In Ocean acidification, edited by Jean-Pierre Gattuso and Lina Hansson, 272-290. Oxford: Oxford University Press.

Kawaguchi, So, Thomas Berli, Rob King, S. Nicol, Patti Virtue and Atsushi Ishimatsu. 2012. Impacts of ocean acidification on Antarctic krill biology: preliminary results and future research directions. CCAMLR - WG-EMM-12/32.

Kelly, Ryan. P., Melissa. M. Foley, William. S. Fisher, Richard. A. Feely, Ben. S. Halpern, George G. Waldbusser, Meg. R. Caldwell. 2011. Mitigating local causes of ocean acidification with existing laws. Science 332: 1036-1037.

Kim, Rakhyun E. 2012. Is a New Multilateral Environmental Agreement on Ocean Acidification Necessary? Review of European Community & International Environmental Law 21(3): 243–258.

Kroeker, Kristy J, Rebecca L. Kordas, Ryan Crim, Iris E. Hendriks, Laura Ramajo, Gerald S. Singh, Carlos M. Duarte and Jean-Pierre Gattuso. 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Global Change Biology 19: 1884-1896.

Kroeker, Kristy J., Rebecca L. Kordas, Ryan N. Crim, and Gerald G. Singh. 2010. Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. Ecology Letters 13: 1419-1434.

LC. 2012. 2012 Specific Guidelines for the Assessment of Carbon Dioxide For Disposal into sub-seabed Geological Formations. Adopted 2 November 2012. (LC 34/15, annex 8)

LC/LP. 2006. Risk Assessment and Management Framework for CO_2 Sequestration in Sub-Seabed Geological Structures (CS-SSGS). (Source LC/SG-CO2 1/7, annex 3).

LICG. 2008. LC 30/4, Report by the Legal and Intersessional Group on Ocean Fertilization (LICG), 25 July 2008.

LP. 2013. Resolution LP4.(8)Amendment to the London Protocol to Regulate Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities. Annex 4.

Micheli, Fiorenza, Andrea Saenz-Arroyo, Ashley Greenley, Leonardo Vazquez, Jose Antonio Espinoza Montes, Marisa Rossetto, and Giulio A. De Leo. 2012. Evidence That Marine Reserves Enhance Resilience to Climatic Impacts PlosONE. DOI: 10.1371/journal.pone.0040832

Miller, A. Whitman, Amanda C. Reynolds, Cristina Sobrino, and Gerhardt F. Riedel. 2009. Shellfish face uncertain future in high CO_2 world: Influence of acidification on oyster larvae calcification and growth in estuaries. PLoS One 4 (5): e5661.

Munday, Philippe L., Alistair J. Cheal, Danielle L. Dixson, Jodie L. Rummer and Katharina E. Fabricius. 2014. Behavioural impairment in reef fishes caused by ocean acidification at CO_2 seeps. Nature Climate Change doi:10.1038/nclimate2195

Murray, Brian.C., Linwood Pendleton, and Samantha Sifleet. 2011. State of the Science on Coastal Blue Carbon: A Summary for Policy Makers. In: Nicholas Institute for Environmental Policy Solutions Report NIR 11-06, P. 1-43,

Ocean Acidification Reference User Group. 2010. Ocean Acidification: Questions Answered. Dan Laffoley and John M. Baxter eds. European Project on Ocean Acidification (EPOCA). 24 pp.

OSPAR 2010a. Recommendation 2010/9 on furthering the protection and restoration of coral gardens in the OSPAR Maritime Area. September 2010.

OSPAR 2010b. Ministerial Meeting of the OSPAR Commission, Bergen: 23-24 September 2010. Bergen Statement.

OSPAR Commission. 2006. Effects on the Marine Environment of Ocean Acidification Resulting from Elevated Levels of CO2 in the Atmosphere. Biodiversity Series. Available at http://www.ospar.org/documents/dbase/publications/p00285_ocean%20acidification.pdf, accessed July 9, 2013.

OSPAR Commission. 2009. Assessment of climate change mitigation and adaptation. Available at http://www.ospar.org/documents/dbase/publications/p00464_climate%20change%20mitigation%20adaptation%20final.pdf, accessed July 9, 2013.

OSPAR. 2003. OSPAR Recommendation 2003/3 on a Network of Marine Protected Areas. ANNEX 9. (Ref. § A-4.44a).

OSPAR. 2007. Decision 2007/1 to Prohibit the Storage of Carbon Dioxide Streams in the Water Column or on the Sea-bed. 2007.

OSPAR. 2007a. Decision 2007/2 on the Storage of Carbon Dioxide Streams in Geological Formations. 2007.

OSPAR. 2007b. Guidelines for Risk Assessment and Management of Storage of CO_2 Streams in Geological Formations. 2007.

OSPAR. 2010. OSPAR Recommendation 2010/2 on amending Recommendation 2003/3 on a network of Marine Protected Areas. OSPAR 10/23/1, Annex 7

Pörtner Hans-O., David Karl, Philippe W. Boyd, William Cheung, Salvador E. Lluch-Cota, Yukihiro Nojiri, Daniela Schmidt, Peter Zavialov. 2014. Ocean Systems, chapter 6. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Field, C. et al. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Rayfuse, Rosemary. 2012. Climate Change and the Law of the Sea. In Rosemary Rayfuse and Shirley V. Scott (eds), International Law in the Era of Climate Change (Edward Elgar Publishers.147, 165.

Rhein, Monika, Stephen R. Rintoul, Shigeru Aoki, Edmo Campos, Don Chambers, Richard A. Feely, Sergey Gulev, Gregory C. Johnson, Simon A. Josey, Andrey Kostianoy, Cecilie Mauritzen, Dean Roemmich, Lynne Talley, Fan Wang. 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Stocker, T.F. et al. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ridgwell, Andy, and Daniela N. Schmidt. 2010. Past constraints on the vulnerability of marine calcifiers to massive carbon dioxide release. Nature Geoscience 3: 196-200.

Rio Conventions. 2013. Twelfth Meeting of the Joint Liaison Group of the Rio Conventions. http://www.cbd.int/doc/reports/jlg-12-report-en.pdf

Royal Society 2009. Geoengineering the climate: science, governance and uncertainty. London.

Royal Society. 2005. Ocean acidification due to increasing atmospheric carbon dioxide. Policy document 12/05. Available at http://eprints.uni-kiel.de/7878/1/965_Raven_2005_OceanAcidificationDueToIncreasing_Monogr_pubid13120.pdf, accessed July 9, 2013.

RTCC. 2014. John Kerry warns of ocean 'dead zones' from pollution and acidification. http://www.rtcc.org/2014/02/26/john-kerry-warns-of-ocean-dead-zones-from-pollution-and-acidification/#sthash.AEH1ShZJ.dpuf Accessed 09 June 2014.

Sabine, Christopher L., Richard A. Feely, Nicolas Gruber, Robert M. Key3 Kitack Lee, John L. Bullister, Rik Wanninkhof, C. S. Wong, Douglas W. R. Wallace, Bronte Tilbrook, Frank J. Millero, Tsung-Hung Peng, Alexander Kozyr, Tsueno Ono, Aida F. Rios. 2004 . The oceanic sink for anthropogenic CO_2. Science 305: 367–371.

Sabine, Christopher.L., Hugh Ducklow, and Maria Hood. 2010. International carbon coordination: Roger Revelle's legacy in the Intergovernmental Oceanographic Commission. Oceanography 23(3): 48–61.

Sands, Philippe, and Jaqueline Peels. 2012. Principles of International Environmental Law. 3rd Edition

SC-CAMLR. 2011. SC-CAMLR-XXX. Report of the 30^{th} Meeting of the Scientific Committee, Hobart, Australia.

SC-CAMLR. 2013. Report of the First Intersessional Meeting of the Scientific Committee, Bremerhaven, Germany.

Secretariat of the CBD. 2004. Addis Ababa Principles and Guidelines for the Sustainable Use of Biodiversity (CBD Guidelines) Montreal: 21 p.

Secretariat of the CBD. 2009. Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity. Montreal, Technical Series No. 46, 61 p.

Secretariat of the CBD. 2012. Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters, Montreal, Technical Series No. 66, 152 pages.

Simons, Meredith and Tim Stephens. 2009. Ocean Acidification: Addressing the Other CO2 Problem. 12 Asia Pacific J Env L 1, 11.

Smith, Scott E., Imèn Meliane, Alan White, Biliana CicinSain, Caitlin Snyder, and Roberto Danovaro. 2009. Impacts of Climate Change on Marine Biodiversity and the Role of Networks of Marine Protected Areas. In Oceans and Climate Change: Issues and Recommendations for Policymakers and for the Climate Negotiations, edited by Biliana Cicin-Sain Global Forum on Oceans, Coasts, and Islands. 131-138. Available at http://www.globaloceans.org/globaloceans/sites/udel.edu.globaloceans/files/Policy-Briefs-WOC2009.pdf, accessed July 9, 2013.

Steinacher, Marco, Fortunate Joos, and Thomas F. Stocker. 2013. Allowable carbon emissions lowered by multiple climate targets. Nature doi:10.1038/nature12269.

Stramma, Lothar, Eric D. Prince, Sunke Schmidtko, Jiangang Luo, John P. Hoolihan, Martin Visbeck, Douglas W. R. Wallace, Peter Brandt, Arne Körtzinger A. 2012. Expansion of oxygen minimum zones may reduce available habitat for tropical pelagic fishes. Nature Climate Change 2: 33–37.

Strong, Aaron L., Kristy J. Kroeker, LidaT Teneva, Lindley A. Mease and Ryan P. Kelly. 2014. Ocean Acidification 2.0: Managing our Changing Coastal Ocean Chemistry. BioScience. Advanced Access.

Turley, Carol and Jean-Pierre Gattuso. 2012. Future biological and ecosystem impacts of ocean acidification and their socioeconomic-policy implications. Current Opinion. Environmental Sustainability 4, 278-286.

Turley, Carol and Kelvin Boot. 2010. Environmental consequence of ocean acidification: a threat to food security. UNEP Emerging Issues Bulletin, 9 pp.

Turley, Carol and Kelvin Boot. 2011. The ocean acidification challenges facing science and society. In Ocean acidification, edited by Jean-Pierre Gattuso and Lina Hansson, 249-271. Oxford: Oxford University Press.

Turley, Carol, Thecla Keizer, Phil Williamson, Jean-Pierre Gattuso, Patricia Ziveri, Robert Monroe, Kelvin Boot, and Matt Huelsenbeck. 2011. Hot, Sour and Breathless – Ocean under stress. Plymouth Marine Laboratory, UK Ocean Acidification Research Programme, European Project on Ocean Acidification, Mediterranean Sea Acidification in a Changing Climate project, Scripps Institution of Oceanography at UC San Diego, OCEANA. Available at http://www.pml.ac.uk/pdf/Ocean%20under%20Stress%20-%20English1.pdf, accessed 9 July 2013.

UNFCCC. 2006. Decision 9/CP.11 Decision 9/CP.11. Research needs relating to the Convention. FCCC/CP/2005/5/Add.1.

UNFCCC. 2011. 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. FCCC/CP/2010/7/Add.1.

UNFCCC. 2013. Decision 2/CP.19. Warsaw international mechanism for loss and damage associated with climate change impacts. FCCC/CP/2013/10/Add.1

UNFCCC/SBSTA. 2010. Update on Developments in Research Activities Relevant to the Needs of the Convention, Submissions from Regional and International Climate Change Research Programmes and Organizations FCCC/SBSTA/ 2010/MISC.6. SBSTA, UNFCCC, Bonn, Germany.

UNFCCC/SBSTA. 2010a. Information on Emerging Scientific Findings and Research Outcomes Relevant to the Needs of the Convention: Update Provided in the Context of the Research Dialogue, Submissions from Regional and International Climate Change Research Programmes and Organizations FCCC/SBSTA/2010/MISC.15. SBSTA, UNFCCC, Bonn, Germany.

UNFCCC/SBSTA. 2010b. Views on Issues Related to the Research Dialogue, Including Possible Ways to Enhance its Effectiveness and the Workshop to be held in Conjunction with SBSTA 34, Submissions from Parties, FCCC/SBSTA/2010/ MISC.12, SBSTA, UNFCCC, Bonn, Germany.

UNFCCC/SBSTA. 2010c. Presentations during the SBSTA 32 dialogue on developments in research activities relevant to the needs of the Convention, Subsidiary Body for Scientific and Technological Advice meeting, United Nations Framework Convention on Climate Change, Hotel Maritim, Bonn, Germany, 3 June 2010. Available at http://unfccc.int/methods_and_science/research_and_systematic_observation/items/5609.php, accessed July 9, 2013.

UNFCCC/SBSTA. 2011. Report on the workshop on the research dialogue, Note by the Secretariat FCCC/SBSTA/2011/ INF.6. SBSTA, UNFCCC, Bonn, Germany.

UNGA. 2005, A/60/63/Add.1. Oceans and the law of the sea. Addendum. 60th session, December 2006.

UNGA. 2006. Resolution adopted by the General Assembly on 20 December 2006. 61/222. Oceans and the law of the sea.

UNGA. 2008. Resolution adopted by the General Assembly on 5 December 2008.63/111. Oceans and the law of the sea.

UNGA. 2009. Resolution adopted by the General Assembly on 4 December 2009.64/71. Oceans and the law of the sea.

UNGA. 2010. Resolution adopted by the General Assembly on 7 December 2010.65/73. Oceans and the law of the sea.

UNGA. 2011. Resolution adopted by the General Assembly on 24 December 2011. 66/231. Oceans and the law of the sea.

UNGA. 2012. A/66/288, The future we want. 66th session, September 2012.

UNGA. 2012a. Resolution adopted by the General Assembly on 11 December 2012. 67/78. Oceans and the law of the sea.

UNGA. 2012b. A/67/87 Report on the work of the Ad Hoc Working Group of the Whole on the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects. Annex II Outline for the First Global Integrated Marine Assessment of the Regular Process. 67th session, September 2012.

UNGA. 2013. Report on the work of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea at its fourteenth meeting Letter dated 17 July 2013 from the Co-Chairs of the Consultative Process addressed to the President of the General Assembly. A/68/159.

UNGA. 2013a. Resolution adopted by the General Assembly on 9 December 2013. 68/70. Oceans and the law of the sea.

Unsworth, Richard K F, Catherine J Collier, Gideon M Henderson, and Len J McKenzie. 2012. Tropical seagrass meadows modify seawater carbon chemistry implications for coral reefs impacted by ocean acidification. Environmental Research Letters 7 (2) 024026.

WGBU - German Advisory Council on Global Change. 2013. World in Transition: Governing the Marine Heritage. Summary. Berlin.

Wicks, Laura .C. and J. Murray Roberts. 2012. Benthic invertebrates in a high CO_2 world. Oceanography & Marine Biology Annual Review 50: 127-188.

Zeebe, Richard .E. and Dieter A Wolf-Gladrow. 2001 CO_2 in Seawater: Equilibrium, Kinetics and Isotopes. Elsevier Oceanography Series, 65, pp.346.

Zoological Society of London. 2010. Climate Change Vulnerability of Migratory Species Assessments. Preliminary Review. A Project Report for CMS Scientific Council 16, Bonn, June,28-30, 2010. Available at http://www.cms.int/bodies/ScC/16th_scientific_council/Eng/ScC16_Inf_08_Executive_Summary_Climate_Change_Vulnerability_of_Migratory_Species.pdf, accessed July 9, 2013.

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