ADAPTATION TO OCEAN ACIDIFICATION

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Author's declaration:

A portion of the work referred to in the thesis regarding the concept of the blindspot of International Relations and International Law has been submitted in support of a BA degree, however this research focuses on an entirely different aspect of ocean acidification.

Abstract

Ocean acidification is an often overlooked environmental problem which has severe effects on marine ecosystem and thus the livelihoods of those who depend on the ocean biosphere. Its complex background of land-based sources and ocean-based effects makes it difficult to address by research and policy as well. Adaptation to it is therefore even harder; with little awareness and no reduction of atmospheric CO_2 in sight, options are limited. If we are to solve this problem, a synthesis of different fields of sciences are needed, which include Earth System Sciences, International Relations and International Law. By exploring the subject with a multidisciplinary approach and reviewing the contemporary research on the subject, important recommendations can be made to tackle ocean acidification, from introducing acidity thresholds to amending fishing quotas and reforming the UNCLOS.

Acknowledgements

I owe gratitude to my supervisor Professor László Pintér who helped me a great deal with my research, especially by sorting through the ideas of adaptation frameworks with me. I also thank my wonderful parents for cheering me up and supporting me all the way through.

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Introduction

The Earth's environment is in a constant state of change but humans often tend to see it as a static entity. Indeed, seventy to eighty years of existence offers little insight into processes that span across millions of years, or even a few hundred. Although significant progress has been made since the Enlightenment in a short period of time, abstract thinking is still a challenge for humanity, not just in the temporal dimension. The interest of science has predominantly been aimed towards things we can witness first hand: gravity, flight, stars. Rarely did we look below, deep into the waters which cover seventy percent of our planet. As always, this was not a result of a general disgust with marine environments, but rather a practical approach throughout the centuries. When needed, shipping and navigation, along with astronomy and cartography has developed, as in the Hellenic times or in the Colonial era. Progress in ocean science however, was slow, since waters were an area of transportation, not the subject of inquires; what was below did not matter, besides fishing. In the 20th century the Cold War brought a bipolar world order which subjugated everything under a constant threat of mutually assured destruction, including scientific progress, and after all, a highly possible end to civilization seemed neigh, which made environmental protection fairly irrelevant, or so it was thought. This distorted world order had such influence, that it even changed our perception of the world;

in cartography this was the golden age of the azimuthal polar projection, which showed the alarming proximity of the two reigning superpowers. This half a century imperial narrative had tremendous impact on the politics of science. It shifted the already materialistic focus of science to a whole other level. Oceans became sinks for waste we did not want to see and nuclear tests we did not want to be near. The focus of exploration was something extra-terrestrial, beyond our planet: space. Everybody heard of the Space Race, but the closest thing to an Ocean Race was in the 17th century. It is no surprise that so far more than 500 people have been to space versus less than 10 in the deep ocean. The oceans still hold many secrets and potential, from natural resources to biological discoveries. An excellent summary can be read in an article from Naomi Oreskes "Scaling Up Our Vision" :

"For centuries the deep ocean remained almost entirely inaccessible, so it was perhaps inevitable that scientists' inability to reach it would be rationalized by many as unimportant. In the mid-nineteenth century many scientists thought the deep ocean carried no life; in the early twentieth century many scientists thought it had no currents; and at midcentury many still thought that various forms of waste—including the radioactive sort—could be dumped into the oceans with impunity. […]

[…]When some of these same historians organized a session on the history of ocean science at the American Historical Association meeting in 2010, the audience consisted of a grand total of one person." (Oreskes 2014)

Therefore, the socioeconomics and geopolitics of the world destined the oceans and its inhabitants to be less important than others; not that terrestrial biospheres receive the proper care and attention universally.

Fortunately, significant progress has been made since the end of the Cold War, however oceans are handicapped still. Despite covering 70% of our globe, researchers still tend to focus on land. Furthermore, since the rather late development of oceanography and its connected fields, multidisciplinary approaches are yet to be observed. Ocean-related problems are seldom observed from multiple perspectives. This especially true to the approaches in social sciences. My previous research has focused on this gap from a point of view of International Relations, which holds multidisciplinarity its core principle, however fails to integrate this into its environmental subfield.

A prime example of this is the topic of this thesis: ocean acidification. In social science, a blindspot exists in International Law between land and ocean based regulations, creating a divide between cause-and causality relating to the carbon cycle (Békés 2015). If we are to tackle this contemporary problem, we must broaden our perspectives and integrate different fields of science, from Biochemistry to International Law[1]. In terms of natural sciences, Earth Systems Science is a multidisciplinary and comprehensive approach, therefore a good starting point; however, social sciences must be incorporated, such as International Relations, International Law and Political Science. Overall, we can see the ocean as a neglected environment, therefore serious environmental problems are often neglected as well, which brings us to the point of ocean acidification. Through this thesis, I will guide the Reader through the complex systems which are connected to the problem, and then I will offer possible solutions for the betterment of the situation.

[1] International Law and International Relations are written with capital initials, because they are used in common language as well, therefore it is important to differentiate between the field of science and the common usage and meaning of these terms. Consequently, I felt obliged to capitalize the initials of other sciences as well.

Methodology

Research question and aims of research

As stated in the introduction, the ocean biosphere is a neglected environment. Besides the significant discoveries humanity could make by further study, we are also faced with an impending crisis of anthropogenic origin due to excess emissions we produce; this has grave consequences not just for terrestrial, but marine environments as well, but until awareness is raised and proper measures are not taken, we will not be able to stop the degradation of 70% of the Earth. Therefore, the aim of this thesis is dual. First, raising awareness about a contemporary problem, often dubbed the “evil twin of climate change” (Smith 2013). Second, to explore adaptation possibilities are there, whether they be geoengineering or altering local fishing quotas in developing countries. The question of course is can we adapt to ocean acidification without significant changes either in the marine environment[2] or the standard of living of those who are interconnected with the oceans? We shall see. Currently there are only a handful of studies that deal with ocean acidification in a multidisciplinary way, especially examining it from a social science perspective. Synthetizing adaptation efforts and possibilities with environmental politics, International Relations, Earth Systems Science and Biochemistry is even rarer.

[2] Changes in the marine environment is predominantly focused on maintaining the level of biodiversity and biomass concentration in the oceans, since naturally changes occur regardless.

Theoretical structure

This thesis is predominantly qualitative in nature, as it explores mostly uncharted territory with finding possible adaptation measures to ocean acidification. However, to reach well-informed conclusions, quantitative research will be used as well, by reviewing existing literature. Therefore, I explored sources related to natural sciences, International Relations, Earth Systems Science. Readers will be able to clearly differentiate between the dominating themes in the research and check the validity, quality and perspective of different disciplines involved, which are established along these lines, but interact with each other in the text seamlessly.

In the first chapter, I will give a broad overview of the literature of the complex relationships that place ocean acidification as one of the most pressing issues, yet one of the most neglected ones. Supporting data and arguments will be presented here from natural and social sciences as well. First, the biogeochemical process will be explored, to give a background to readers how exactly does ocean acidification affect the marine biosphere, what trends can we see and how what does the future bring. This will be followed by the effects on biogeochemical processes. It will present how different organisms react to acidification and how will they do so in the future. Furthermore, I will look at what interactions can be found between species when under acidification stress. In addition, the cofactors will be explored as well, since marine organisms are under threat from multiple sources of human activity, such as ocean acidification, warming, pollution, deoxygenation, habitat destruction and overfishing. Special attention will be given to research conducted at coral reefs, since the high biomass density of these locations make the biodiversity hotspots, which are crucial in the marine ecosystem. Therefore, we cannot allow to lose them, and it is the most economical to protect hotspots in vast oceans where there is often no governmental control or any form of governance. Finally, the socioeconomic consequences are discussed. These are wide ranging, therefore effect on fisheries, livelihoods and international security are all discussed.

The second chapter will analyze the contemporary state of International Relations, International Law and Environmental Politics of ocean acidification. Information gathered through previous research on International Relations and International Law will be incorporated as well- this established how International Relations has a fundamental flaw when it comes to ocean acidification, and environmental protection in general. This problem plagues any solution to be developed, since it creates research, funding and legal gaps. To illustrate this, three instruments of International Law will be presented. The London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 1972 The United Nations Convention on the Law of Sea of 1982 and the United Nations Framework Convention on Climate Change of 1992. These three all have a specific element that would be required for a satisfying solution to the problem, however due to several reasons, they do not. Moreover, in this chapter I will explore how science policies are inadequate to support the research effort of ocean acidification. I will also look at problems in financing as well. There are several studies to reinforce my argument that quantify public, professional and political interest in marine sciences, and particularly ocean acidification. The possible reasons for this is are presented in the introduction.

In the third chapter mitigation possibilities will be presented. Even though adaptation is the focus of this thesis, it is on the same theoretical level as mitigation. Moreover, several mitigation measures that involve geoengineering do little against ocean acidification, or even acidify it further, therefore it is a topic worth mentioning. Naturally, possible reduction of CO_2 will be discussed, but only briefly; the reason for this is that in my opinion meaningful mitigation is unlikely, and the long-term effects will occur regardless; additionally, current schemes of reduction put little emphasis on interactions with the marine biosphere.

I will also present arguments how to reform scientific research and its policies to better marine science, based on the problems outlined in the previous chapter.

In the last chapter, adaptation possibilities will be discussed. Focus will be put on fisheries and biodiversity hotspots, since these are the most important areas that will be significantly affected. Moreover, developing states will be disproportionately hit, therefore adaptation measures tailored to these countries and societies in terms of socioeconomic adaptation is crucial. I will propose possible solutions through analysis of risk management and adaptation measures already developed, but also by adopting practices from other fields where pressures were from different stressors, but socioeconomic effects were similar, therefore a synthesis of the two could be made. Finally, original solutions through gathered data will be attempted as well.

In the conclusion, I will summarize my findings related to ocean acidification, and how to adapt to it. In my thesis by that point I will cover a wide range of subjects, fields of science and literature, and I will make a point on how to better protect the ocean environment with the multidisciplinary approach it deserves.

Throughout the thesis, the interdisciplinary will be a key factor, since it is a crucial element to understanding a complex problem. Several studies also support research based on different approaches, especially social sciences combined with Earth Systems Science. Since the effects of acidification are in water, but the source of the problem is on land, there is a discrepancy that the international community has a hard time even comprehending, let alone solving.

Limitations

As it will be shown in the four main chapters of thesis, limitations are present regarding ocean acidifications. First, the system boundaries of the research are very broad. Ocean acidification is a global problem that originates on land but effects marine environments. Its effects are extremely wide-ranging, and most of it unexplored. In general, oceans are less known then terrestrial biospheres, but acidification's effects on species is limited, since not many have been examined. Moreover, there are several co-occurring factors that are almost impossible to model to the high number of variables, such as warming, pollution and overfishing. These occur with various intensity and location, therefore adding dimensions of temporality and special distribution. With the current amount of funding and research focus, there are only a handful of studies that deal with multiple stressors, however the results of those are extremely alarming. (This gives room for the precautionary principle, which would be a good approach to protect environments that are already under significant stress.) Therefore, I can only present those effects which we do know, however that does not mean that there are no additional ones; hence this is a limitation. Furthermore, it is difficult to differentiate between effects of acidification and other factors. This affects the projections of impacts on marine organisms and humans alike. Consequently, adaptation measures are often aimed at ameliorating combined effects, which of course still provides valuable insight. Finally, since the scope of the thesis is large, there are necessary omissions and it is not intended to be a complete summary of all known effects, circumstances and solutions related to ocean acidification, even if it is a comprehensive review of the most crucial points and scientific arguments, which is outstanding among the literature I have come across so far. Finally, some results are educated opinions based on the literature reviewed and data examined; the peculiar nature of acidification is that there is no escaping it, we can only deal with consequences, therefore are no satisfying or complete solutions, but hypotheses, trails, and perhaps even failures along the way. The goal is to be as certain as possible about the results to provide the affected entities the best chance possible.

Chapter I. Review of the literature on the wide-ranging effects of ocean acidification

As it was stated in the introduction, this thesis is discussing a very under-researched problem, therefore literature that specifically deals with ocean acidification adaptation is virtually non-existent. Therefore, I must piece the puzzle together myself, using the multidisciplinary approaches to gain a holistic understanding, and this is reflected in the use of literature as well. To succeed, I am utilizing different approaches that all contribute to the subject, both from quantitative and qualitative researches, and in multiple fields.

One of the core studies I will be relying upon discusses the changes in ocean biochemistry in this century. It is titled Biotic and Human Vulnerability to Projected Changes in Ocean Biogeochemistry over the 21st Century. It includes projections on different stressors per different climate models and scenarios, and even predicts possible socioeconomic impacts. The strength of this quantitative research piece is that it was conducted by a large number of experts, it deals with multiple stressors as variables and their combinations, it compares accuracy of different climate model simulations and concludes that averaging them provides the most accurate results, while also venturing slightly into social science, and establishing research limitations which set up this work's topic (Mora et al. 2013). Besides this, most other sources are not as dominant, as they all set up different sections of the arguments presented.

What is ocean acidification?

Ocean acidification is a contemporary environmental problem that is the direct consequence of anthropogenic carbon dioxide emissions. The water absorbs carbon dioxide, and through the chemical process pictured in Figure 1, it transforms it into carbonic acid (H_2CO_3).

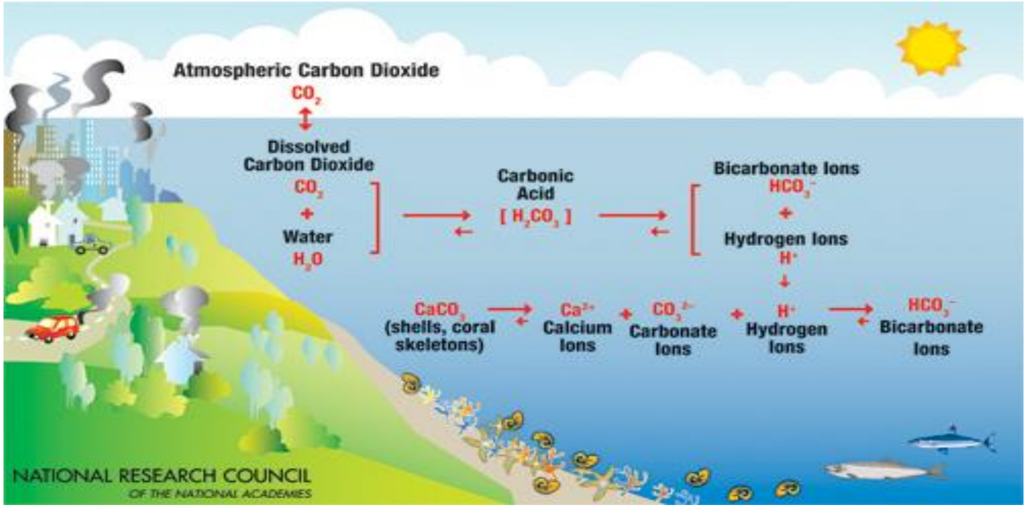

figure 1 Carbon dioxide absorption by water (National Research Council 2010)

Currently an estimated 30-40% of atmospheric CO2 is dissolved in the water (Millero 1995).

The process of acidification of the oceans is rapidly increasing. Since the beginning of the industrial age pH of the oceans have already decreased by 0.11 units, accounting **to a**

28.8% increase in hydrogen ion concentration (indicator of acidification) (S.C.O.R. Biological Observatories 2009) Furthermore, this process is accelerating, and by the end of the century pH may be decreased by up to another 0.3 units (Orr et al. 2005). Even more troubling is the fact that the chemistry of the ocean is changing more rapidly than at any period in **the past 20 million years** (Feely et al. 2004).

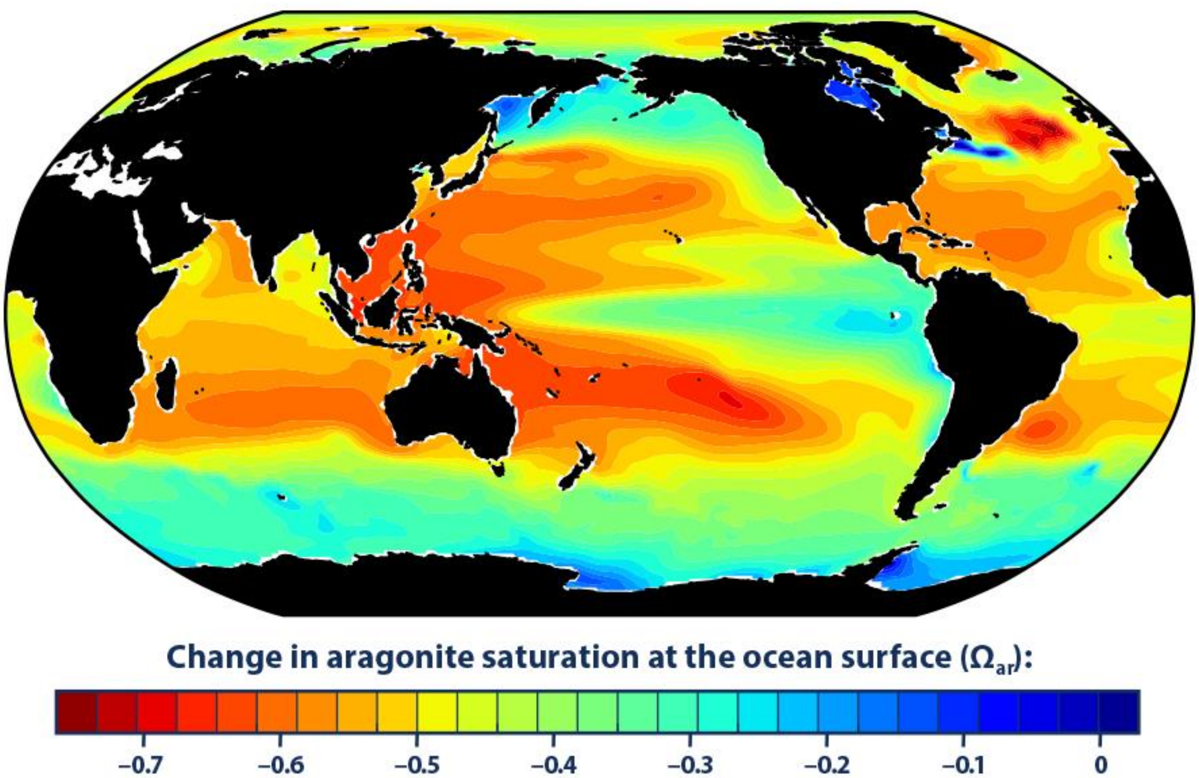

figure 2 Changes in Aragonite Saturation of the World's Oceans, 1880–2015

(U.S. EPA)

Effect of the biogeochemical processes

The main problem is, that carbonic acid has severe negative consequences for many of the oceans' inhabitants, especially those with calcifying shells, which the acid dissolves at a certain concentration.

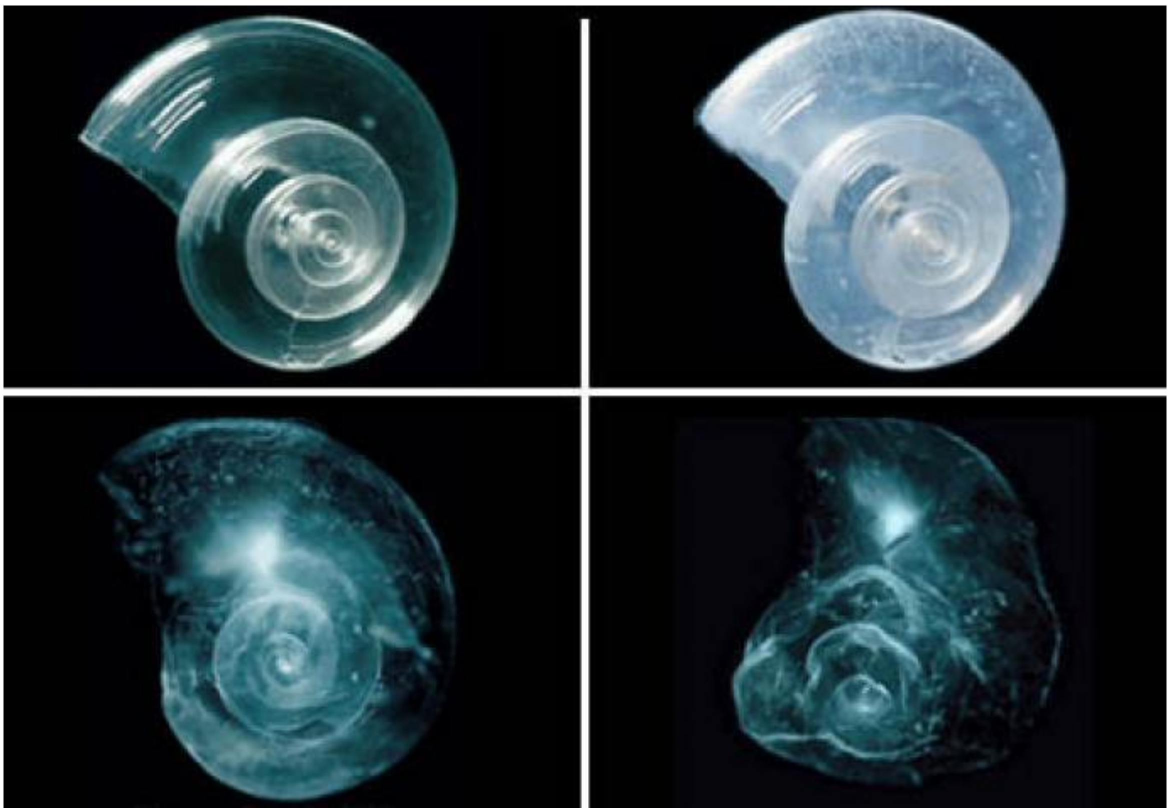

figure 3„In a lab experiment, a sea butterfly (pteropod- Limacina helicina) shell placed in seawater with increased acidity slowly dissolves over 45 days at projected pH level in 2100. (Liittschwager 2007)

However, many more species are susceptible to changes in pH, and this will lead to a catastrophic collapse of the oceans' biosphere. Several animals' immune systems are weakened, such as the jumbo squid's (Rosa et al.), multiple elements of the food chain are affected, from top to bottom, including organisms such as coccolithophores, corals, foraminifera, echinoderms, crustaceans and molluscs (Mora et al. 2013). Moreover, corals may be affected as well, which provide many species with a natural habitat, so it spirals towards others (Doney et al. 2011). Dwindling populations of sea animals combined with serious overfishing, many species would go extinct. Although ocean warming will increase metabolism, but combined with lower levels of dissolved oxygen and food availability and acidification, it leads to smaller body size.

A problem that we face regarding ocean acidification is the **high level of uncertainty of its effects**. Research gaps are significant, even if research is progressing steadily (Mora et al. 2013). There are several reasons for this. First of all, the aforementioned historical factors have predestined all ocean sciences to less significance. Another problem is that all species have different reactions to changes in pH. Some are already known, but most are not. Furthermore, a study suggests, that the single-specie focused approach to examining the effects of ocean acidification are not effective, since organisms are codependent on each other (Godbold et al. 2013). This codependence can be significant especially in food chains. Another aspect we have to consider is the effect of cofactors/stressors. For example, ocean acidification and ocean warming together have very specific effects on certain marine organisms that would not occur otherwise, as in the case of marine invertebrates, where embryos survive exposure to warming but succumb to acidification if they are affected by it in larval stage (Dupont et al. 2008). Resilience of species may be lower to combined effects. Finally, another problem is that some organisms modify the pH value of the surrounding waters. Also, point sources of pollution exist in coastal areas, especially estuaries, where outflows comprised of industrial waste, communal materials may alter the waters' chemistry.

Therefore, most studies advise to conduct multi species, multi stressor and spatially sensitive studies. Naturally, these factors present a very high number of variables, especially if the goal is not observation, but prediction of further conditions. Most studies therefore concentrate on aragonite concentrations globally or regionally at most. However, different habitats have been proven to be affected differently (Mcleod et al. 2013). This is especially important in the case of biodiversity hotspots, such as coral reefs, where many factors determine the vulnerability of the reef, including the type of coral in question, since some are more resilient than others (Mcleod et al. 2013).

A comparative study shows that anthropogenic emissions will result in net negative and cumulative effects, as shown in Figure 3. The smallest effect is expected in deep seas (but the atmospheric ozone depletion may change that, as noted elsewhere), and the largest changes will occur in shallow waters such as seagrass beds, soft-bottom benthos and rocky reefs. The largest hotspot exposure is expected to happen to euphausiid (i.e., krill; a critical element of food webs at mid and high latitudes) (Mora et al. 2013). Diverse ecosystems are prone vulnerable to disturbances and will produce reduced functionality (Mora et al. 2011).

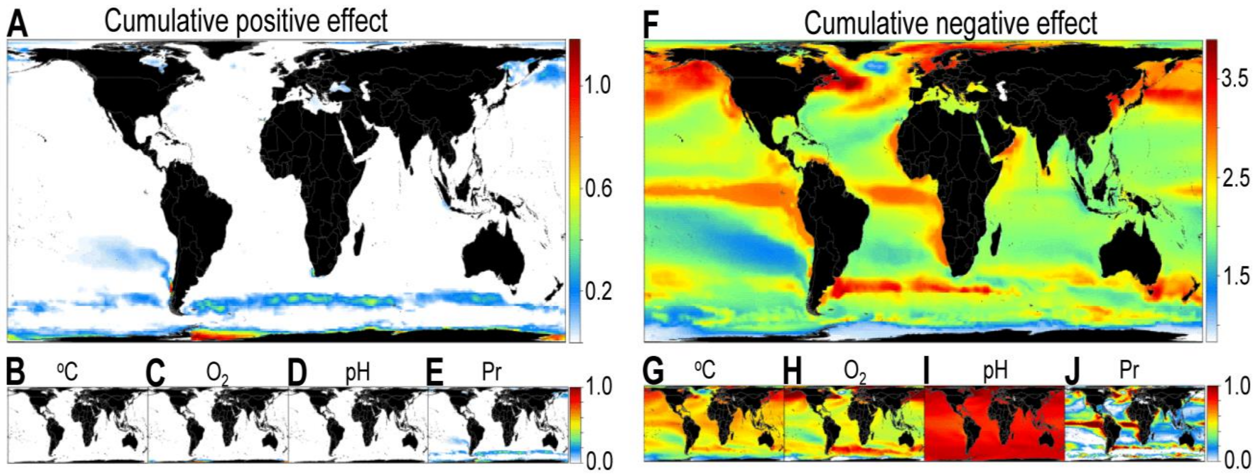

figure 4 Co-occurring ocean biogeochemical changes to the year 2100 under the RCP85. For these plots, we separated absolute changes shown in Figure 2A–D between those that will be positive (i.e., cooling, basification, oxygenation, and productivity increase; Plots A–E) and negative (i.e., warming, acidification, oxygen depletion, and primary food reduction; Plots F–J). Resulting absolute changes were scaled between 0 and 1 (Plots B–E, G–J), 0 being zero absolute change and 1 being the extreme 97.5% observed value globally. The resulting scaled scores from each variable were added to provide a global composite map of co-occurring positive (Plot A) and negative (Plot F) changes in ocean biogeochemistry. These cumulative change maps ranged from 4 (i.e., the maximum predicted change in all four parameters occurred in that cell) to 0 (i.e., no negative or positive change (Mora et al. 2013)

Effects on the carbon cycle

The oceans can only take up a certain amount of carbon from the atmosphere before becoming saturated. The dissolving carbon dioxide is absorbed in water through a mechanism called a solubility pump (Intergovernmental Panel on Climate Change 2017), a physico-chemical process which transports inorganic carbon from surface to deep water. There is also an organic carbon pump and a biological pump, as shown in Figure 4, but the inorganic one is the most dominant in the exchange. Acidification results in a decrease in the deposition of carbonate sediments, and the dissolution of existing ones

(Ridgwell et al. 2007), causing a rise in ocean alkalinity (the quantitative capacity of an aqueous solution to neutralize an acid). Therefore, the CO_2 absorption capacity of the oceans will decrease, and this will lead to an increase in global warming. Furthermore, rising atmospheric CO_2 concentration leads to global warming, which increases sea temperature in all layers due partly to the thermohaline circulation, reducing CO_2 solubility in the ocean, therefore, global warming started a cataclysmic cycle (Archer 2005).

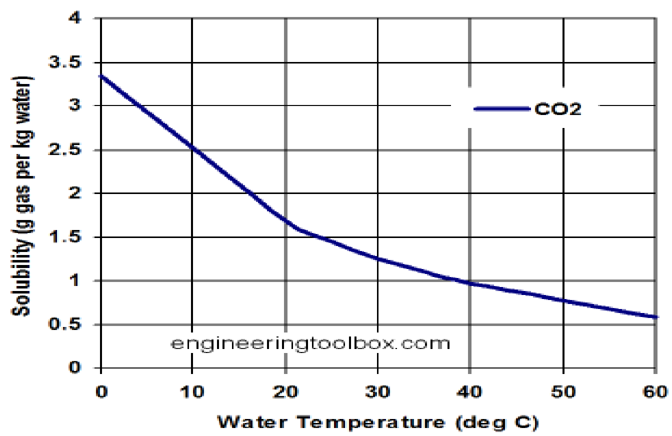

figure 5 Solubility of Carbon Dioxide - CO_2 - in Water (The Engineering ToolBox 2017)

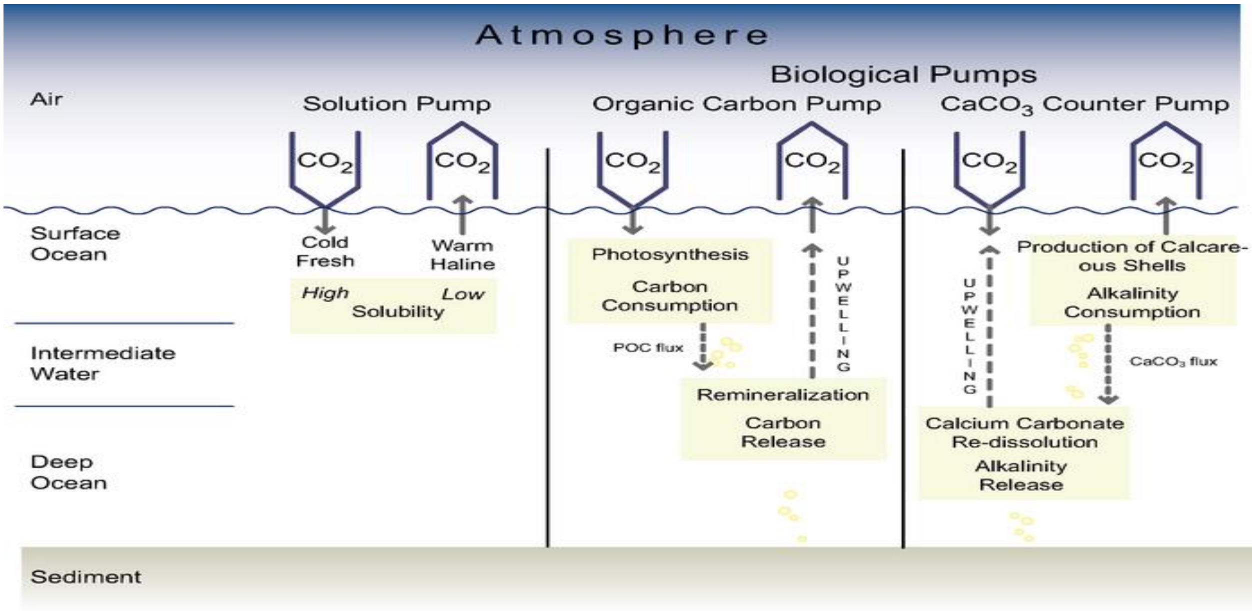

figure 6 Three main ocean carbon pumps govern the regulation of natural atmospheric CO2 changes by the ocean "the solubility pump, the organic carbon pump and the CaCO3 'counter pump'. The oceanic uptake of anthropogenic CO2 is dominated by inorganic carbon uptake at the ocean surface and physical transport of anthropogenic carbon from the surface to deeper layers. For a constant ocean circulation, to first order, the biological carbon pumps remain unaffected because nutrient cycling does not change. If the ocean circulation slows down, anthropogenic carbon uptake is dominated by inorganic buffering and physical transport as before, but the marine particle flux can reach greater depths if its sinking speed does not change, leading to a biologically induced negative feedback that is expected to be smaller than the positive feedback associated with a slower physical downward mixing of anthropogenic carbon. Reprinted with permission, copyright 1991 American Geophysical Union." (Intergovernmental Panel on Climate Change 2017)

Moreover, despite the fluctuation of CO_2 concentration over centuries, which climate change deniers try to exploit, ocean acidification is an even clearer evidence of anthropogenic influence on the carbon cycle, with devastating consequences, and this can hardly be denied.

Finally, we may be able to gain a small glimpse at the future of acidified oceans, even with substantial gaps in knowledge, interacting stress factors and inaccurate computers models. There is a place on Earth were waters naturally have lower pH value, and for a consistent time period. This place is in the vicinity of the underwater vents in Mount Vesuvius in Italy. pH value is 7.4, and although organisms do live there, so, biodiversity is 30% lower than of non-acidified waters, and the adaptation time was much longer. Also, there is a significant shift away from corals and large fish, toward organisms such as algae, sea grass, and small marine worms- more complex lifeforms would have a hard time functioning in such environments, and certain organisms outcompete all others due to the surplus CO_2 (Ogden 2013).

Socioeconomic impacts

Ocean acidification will have severe impacts on human populations as well. Since a wide variety of species are affected, and often in unknown ways, this will affect fisheries immensely. For example, 73% of fish caught in US commercial fisheries in 2007 were calcifiers and their direct predators (Fabry et al. 2007).

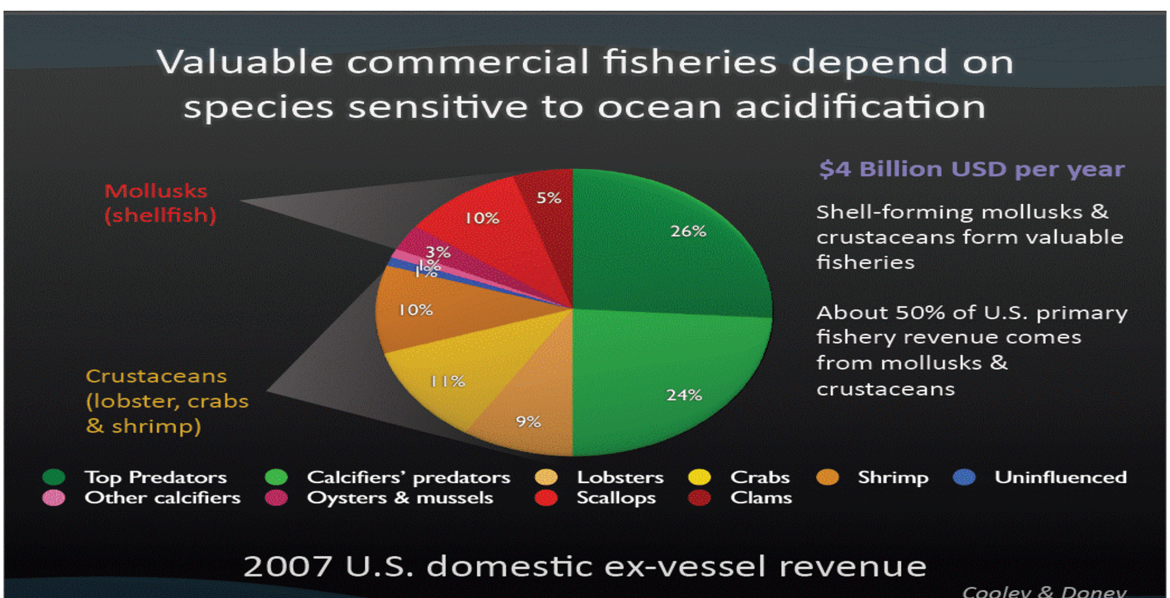

figure 7 Valuable commercial fisheries depend on species sensitive to ocean acidification **(Romm 2009)**

Several ocean goods and services are likely to be undermined by future ocean acidification potentially affecting the livelihoods of some 400 to 800 million people depending upon the emission scenario (Mora, 2013). How many people will be affected is debatable, however the numbers are minimum of hundreds of millions, depending on the emissions scenario and model. According to a thorough study conducted in 2013, 470 to 870 million of the poorest people in the world will be affected by multiple negative consequences of oceanic change of biochemistry. They are heavily reliant on seas for food, work and income. Their results showed that approximately 1.4 billion people live in the coastal areas of countries whose Exclusive Economic Zones will experience medium to high ocean biogeochemistry change by 2100 under the RCP45 climate model. Out of these people, 690million live in nations with a medium to high ocean dependency, and of these, 470 million live in low-income countries. The more pessimistic RCP85 shows

(Mora et al. 2013)

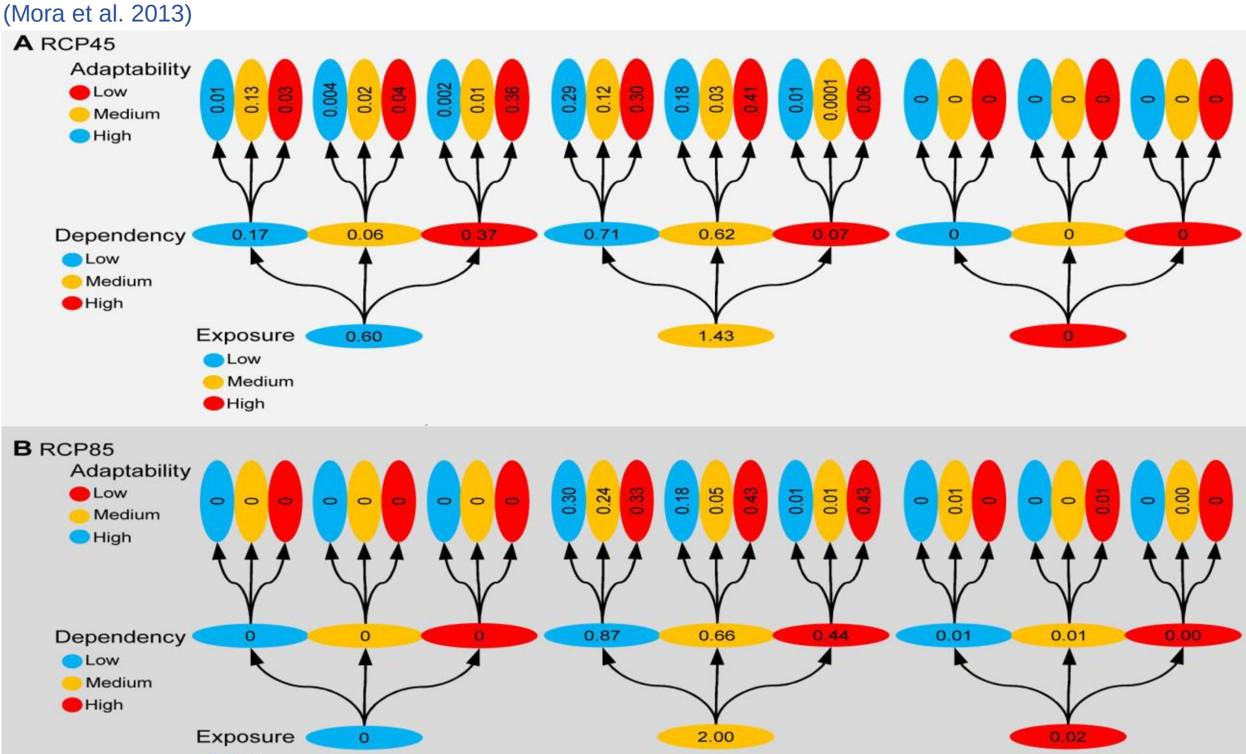

figure 8 Vulnerability of humans to projected ocean biogeochemistry change. This plot illustrates the total number of people likely to be vulnerable through exposure to ocean biogeochemistry change according to RCP45 (Plot A) and RCP85 (Plot B). Numbers in the plot are in billions (summations may not be exact owing to rounding). Categorization of people according to their levels of exposure to biogeochemical changes, dependency on ocean goods and services

dramatically worse results, which shows that 2.02 billion coastal people will live in countries with medium to high ocean biogeochemistry change; of those, 1.12billion live in countries of medium to high ocean dependence; and of these, 870 million live in low-income countries (Mora et al. 2013), as shown in Figure 5.

This dependence is more than just of sustenance through fisheries. There is grave concern that degradation of coral reefs will have devastating effects on tourism. Environmental economist Luke Brander found that coral reef tourism was valued at US$ 11.5 billion. The shoreline protection value of reefs was estimated at $9 billion a year, and reef-supported fisheries at 30 billion. Therefore, it is important to quantify as much of the costs incurred as possible, to provide incentive for mitigation and adaptation (Winner 2010).

Another problem of acidification is that it will affect developing countries more than others by its physical and its socioeconomic characteristics as well (Mora et al. 2013). Therefore, already impoverished countries, who have done little to contribute to the contemporary state of the environment, will suffer the most from a wide range of factors from biochemical changes to sea level rise. This will cause destabilization nationally and regionally as well, causing political turmoil, armed conflict and mass migration internally and externally as well, on an unprecedented scale.

Finally, as a summary, the following table shows the consequences of ocean acidification and the chances of occurrence for these effects.

Statement	Level of evidence	Level of agreement	Level of confidence
Chemical aspects			
Ocean acidification occurred in the past	Robust	High	Very high
Ocean acidification is in progress	Robust	High	Very high
Ocean acidification will continue at a rate never encountered in the past 55 Myr	Robust	High	Very high
Future ocean acidification depends on emission pathways	Robust	High	Very high
The legacy of historical fossil fuel emissions on ocean acidification will be felt for centuries	Robust	High	Very high
Biological and biogeochemical responses			
Ocean acidification will adversely affect calcification	Medium	High	High
Ocean acidification will stimulate primary production	Medium	High	High
Ocean acidification will stimulate nitrogen fixation	Medium	High	Medium
Some species or strains are tolerant	Robust	High	Very high
Some taxonomic groups will be able to adapt	Low	Medium	?
Ocean acidification will change the composition of communities	Robust	Medium	High
Ocean acidification will impact food webs and higher trophic levels	Limited	High	?
Ocean acidification will have biogeochemical consequences at the global scale	Medium	High	Medium
Policy and socio-economic aspects			
There will be socio-economic consequences	Limited	Medium	?
An ocean acidification threshold that must not be exceeded can be defined	Limited	High	?

figure 9 Summary of the knowns and unknown (Turley et al. 2012)

Chapter II. Analysis of contemporary policies

To understand what needs to be done, we need to review the existing international context for an international problem. Naturally, implementation of adaptation needs localization, but for general measures the overview is justified.

International Relations

As stated in the introduction, the discipline of International Relations has yet to fully integrate environmental aspects into its core, especially when highly multidisciplinary problems are presented, such as ocean acidification. Therefore, the synthetizing effect of this science is limited here, and most social scientists do not even know about this phenomenon, and if they do, they do not connect it to international law, diplomacy or international relations. There is often a missing link between land-based sources of pollution and ocean-based effects. I call this the blindspot of International Relations.

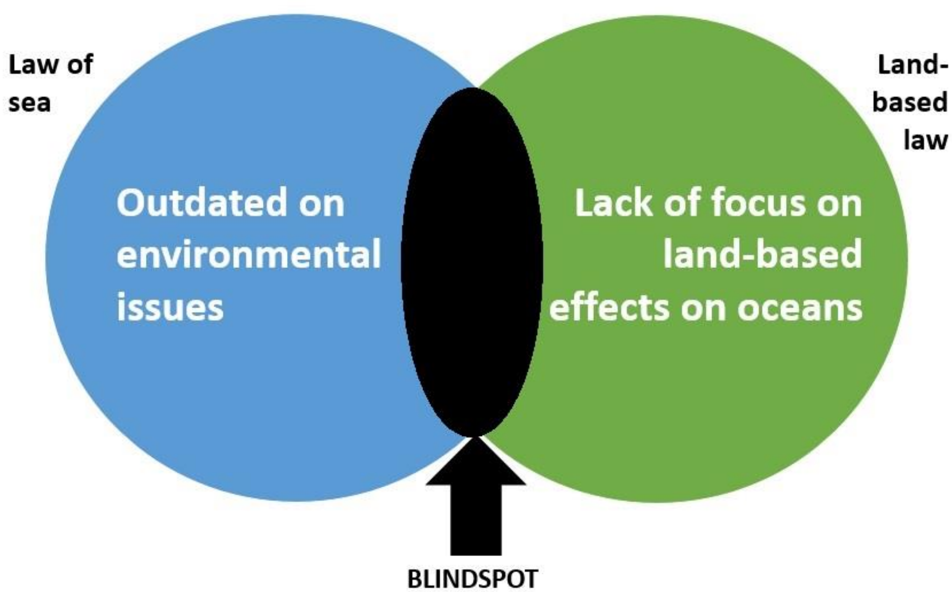

figure 10 Blindspot in International Relations

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Professor Mary Durfee

International Relations itself is relatively new; it became an academic discipline in 1919 with the founding of the first professorship in IR – the Woodrow Wilson Chair at Aberystwyth, University of Wales (University of Aberystwyth 2017) . Later on it became predominantly focused on the bipolar world order, and the Realist school was almost an extension of the US's political agenda; other schools, such as Liberalism, Marxism and Constructivism followed later on. Almost all agree on one aspect, however; that the nation state is the basis of International Relations, and that the international world order is in anarchy, without much hope for any centralized power (Gold et al. 2017)[3].

International Law

There is no explicit treaty on ocean acidification. In fact, it is a blindspot of international relations, as mentioned. Therefore, we must look at other treaties which might incorporate indirectly ocean acidification, or at least they have the potential to codify the problem. First, we take a law which recognizes the link between land and sea: T**he London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 1972** (London Convention 1972). This law was instrumental in establishing clear boundaries on what can be placed in marine environments, and described three categories of pollutants. The 1996 protocol strengthened regulations and integrated the

[3] There are some examples of theoretical power centralization in the literature though, such as the Hegemonic Stability Theory (raised by Charles P. Kindleberger and Robert Keohane, among others), which states that if one state becomes powerful enough to establish military and economic interdependence globally, then it is mutually beneficial for all parties to uphold this status quo. Also, the Constructivist and Neo-Gramscian approach states that from a historical perspective, hegemonic power blocks have ruled the world over certain periods of time, such as the British Empire (Gold et al. 2017).

precautionary and the polluters pay principle[4]. With 89 parties to the convention, it is a strong international agreement, and is considered customary international law. However, its main limitation in the context of ocean acidification is that CO_2 is not considered as a pollutant. In fact, only recently has science labeled it as such to signal the dangers of global warming. Therefore, the convention has no significance whatsoever in this regard, unless another protocol is adopted.

Another possible instrument of international law to consider is the United Nations Convention on the Law of Sea of 1982 (United Nations 1982). It is the most important treaty regarding oceans and seas. It is a widely-accepted piece of International Law, and it is considered customary. It has binding clauses and an enforcement mechanism as well. It covers matters of environment, natural resources and business. It was concluded in 1982 and entered into force in 1994, at the signature of the 60th party. So far 166 countries have joined the Convention. However, in terms of environmental protection it leaves a lot to be desired. It is a very marginal topic in the text, and its clauses are outdated. 33 years ago at its drafting conditions were substantially different. Even with wide ratification, it remains ineffective at addressing key problems of the oceans, such as acidification. A few examples can highlight how wording, emphasis and soft laws weaken the Convention on environmental grounds.

The text mentions in part XII Protection and Preservation of the Marine Environment, Section 5. International Rules and National Legislation to Prevent, Reduce and Control

[4] The precautionary principle and the polluters pay principle were first introduced by the Rio Convention (principle 15 and 16), which is otherwise known as the United Nations Conference on Environment and Development (UNCED), in the Rio Declaration on Environment and Development. It contained 27 principles regarding a more sustainable future for the world.

Pollution of the Marine Environment, Article 222: Pollution from or through the atmosphere that:

"1. States shall adopt laws and regulations to prevent, reduce and control pollution of the marine environment from or through the atmosphere, applicable to the ***air space under their sovereignty*** *and to vessels flying their flag or vessels or aircraft of their registry, taking into account internationally agreed rules, standards and recommended practices and procedures and the safety of air navigation.*

2. States shall take other measures as may be necessary to prevent, reduce and control such pollution.

3. States, acting especially through competent international organizations or diplomatic conference, shall endeavour to establish global and regional rules, standards and recommended practices and procedures to prevent, reduce and control such pollution. "

(United Nations 1982a)

This means that countries have the obligation to prevent pollution to territories under **their sovereignty.**

Clearly, only traditional sources of pollution are considered, such as chemicals, radiation or oil. It is strange that spillover effects due to ocean currents were not considered, and territoriality was the baseline of all contamination. Of course, if we look at the history of oceanography described in the introduction, we can see how this field of science was in its early stages, and research on the relations to the atmosphere and ocean currents were in their infancy, developing in the nineteen-seventies, as computer science was advancing (Weart, 2008). Furthermore, CO_2 was not even remotely considered to be a pollutant, which set the system boundaries to exclude even theoretically including it. However, pollution is not territorial, especially CO_2. Of course one can argue that the **Sic utere tuo ut alienum non** laedas (translated as "use your property so that the property of others is not damaged.") principle may apply here as part of international customary law, since the Trail Smelter Case5 (USA vs. Canada 2017) regardless of the type of pollutant; unfortunately, for something to become custom, subjective and objective criteria must be fulfilled. Subjective, as the conviction of states, that their conduct is governed by law, and objective being state practice. The latter condition is not fulfilled at the moment.

Another problem with the UNCLOS is the dynamic of its evolution. As almost all instruments of International Law and Relations, conventions and treaties must be changed to meet the challenges of the present and the future. Usually, there is some temporal hiatus between demand and supply; solutions come later. In the case of the rise of the greenhouse gases, this gap maybe too great to have an effect. Moreover, the evolution of the UNCLOS is not progressing towards including more environmentalism. Environmental issues are phrased in non-specific ways such as "*States shall adopt laws and regulations to prevent, reduce and control pollution*" (United Nations 1982) . Its main focus both in evolution and conflict resolution is the exploitation of natural resources, expressed through debates on Exclusive Economic Zones. The USA did not ratify the Convention, however accepts it except for part XI., regulating the Exclusive Economic Zones. The interest in

[5] The Trail Smelter Arbitration was a landmark intergovernmental case of environmental protection at the Arbitral Tribunal set up to handle the matter. In Canada, Trail, British Columbia the Consolidated Mining and Smelting Company (COMINCO) operated a smelter factory, processing zinc and lead. The manufacturing process damaged forests and soil in the vicinity of the plant, including territories across the border in the state of Washington, USA. The result of the arbitration successfully imposed state responsibility for transnational air pollution, ruling that smoke output should be reduced and affected citizens should be compensated (USA vs. Canada 2017).

seabed mining is fluctuating, however many states have conflicts over territories on sea over geopolitical reasons. The Lomonosov Ridge is contested by Canada, the Kingdom of Denmark (via Greenland) and the Russian Federation; parts of the East China Sea are claimed by China, Japan and South Korea (Martinič, 2015). Emerging economies strive for an expansion of their capabilities through extension of marine territories. These countries often have overlapping claims of Exclusive Economic Zones.

Finally, the United Nations Framework Convention on Climate Change of 1992 (United Nations 1992) could be a good candidate for regulation. There are 197 Parties to the Convention, and the Paris Agreement was ratified by 153 parties (although there are serious doubts about the overall effectiveness of the agreement). It is the most encompassing legal measure taken to address greenhouse gas emissions. Throughout its history from 1992 it has not been a complete success, however. The Kyoto Protocol adopted in 1997 only entered into force in 2005 (UNFCCC 1997), with the second commitment period never entering into force, thus failing. In addition, the Kyoto protocol was also ineffective by principle in solving the problem:
It allows for a reduction of GHG emissions in general, and theoretically allows CO_2 emissions to increase as long as other gases are decreasing (Baird, et al., 2009).

It is practically replaced by the Paris Agreement, which was accepted in 2015, and entered into force on November 4th, 2016 (21st Conference of Parties UNFCCC 2015). The UNFCCC’s strength is the outreach of the framework, supported by the United Nations infrastructure and funds, annual conferences of parties and the Intergovernmental Panel on Climate Change (IPCC), an assisting research body. However, there is a clear lack of emphasis on marine environments. Surely, one could argue the Convention is called Climate Change for a reason, however that is more of an oversight rather than a designed feature. As this thesis and other works have expressed, $CO2$'s effects are just as dangerous in water as they are on land and atmosphere – therefore, the same concern should be shown towards it. On a political and communications level, the UNFCCC does encourage more focus on ocean biosphere, however the Convention's text and negotiations' big data analysis show otherwise. A study looked at the discussions of the Framework from 1995 to 2013 by analyzing texts from the Earth Negotiations Bulletin, published by the International Institute for Sustainable Development (Venturini 2014). The ENB holds daily reports on 33 separate UN negotiations on environment and development. This archive contains thousands of reports on dozens of multilateral agreements. Volume 12 is dedicated to climate negotiations, and contains 594 issues. This groundbreaking research applies digital technology and standardization to examine how certain themes evolved during the negotiations and what kind of power relations were involved, sometimes contrary to the message directed towards the public. Furthermore, the researchers visualized their results for even better understanding. Their results show that the discussions were focusing on five large themes.

- GHGs emissions and Kyoto Protocol
- Fuels and transport sector, energy and technology transfers, and clean development mechanism
- Carbon sinks – Reducing emissions from deforestation and forest degradation and land use, land use change and forests.

- Impacts, vulnerability and adaptation, and funding and equity
- Models and Intergovernmental Panel on Climate Change

None of these addresses specifically the marine environment. Perhaps it was included in one of these macro themes? Research shows otherwise: a frequency analysis of keywords shows that ocean has a count of 17, water 20, among the least frequent expressions; for comparison, the ‘emission’ has the highest value with 990 (Venturini 2014)

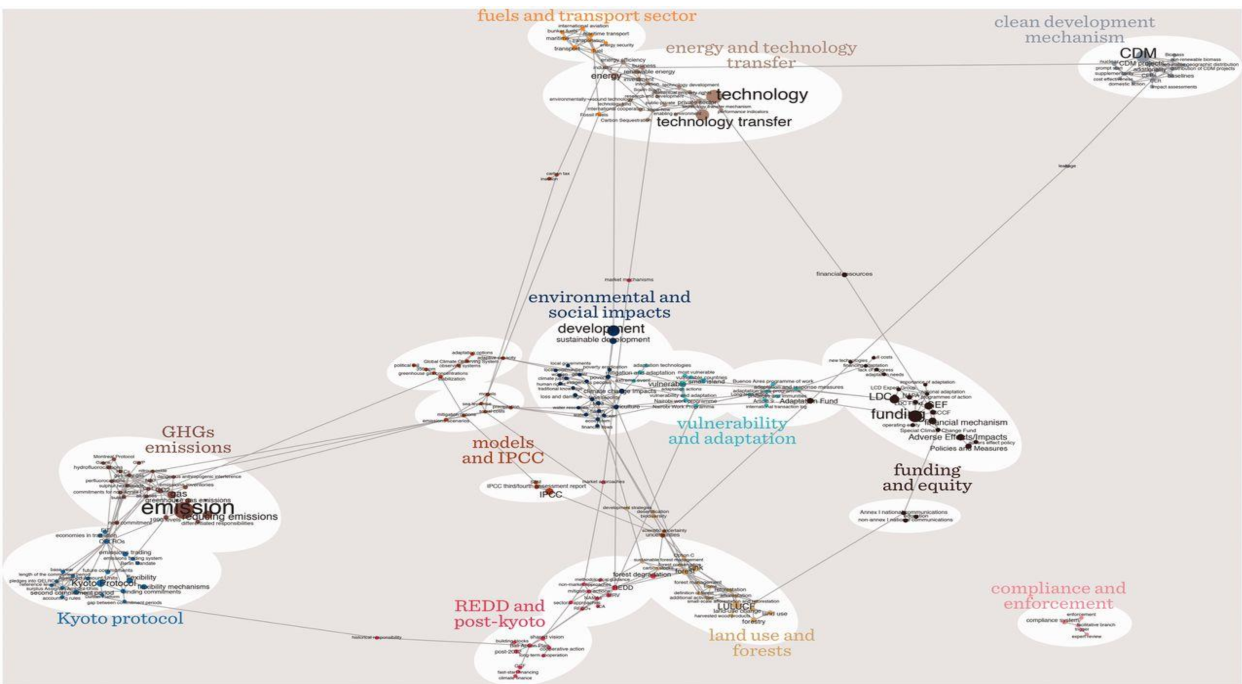


figure 11 Network of co-occuring terms (Venturini 2014)

This lack of focus is a clear shortcoming of the framework, which has to be corrected, especially if we consider how oceans will cease to be a sink when they become saturated with carbon dioxide, thus increasing atmospheric concertation dramatically. Article I. of the UNFCCC Article 4(1)(d) even states that a ‘sink’ is “Any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere." (United Nations , 1992). Theoretically, this encourages the dumping of CO_2 into the oceans, thus also increasing acidification and only delaying the atmospheric problem. Encouraging 'active' ocean sequestration of CO_2 is therefore extremely dangerous, and although not surprising by the lack of marine focus, it is still astonishing that it has not been changed up to date (Baird et al. 2009).

Unfortunately, the Paris Agreement has not brought much relief in the problem at hand. The final document of the conference only mentions oceans once, without addressing ocean acidification. This was so even though the COP21 had a dedicated oceans day, and the final document of the day by the International Working Group on Oceans and Climate stated explicit alarm:

"Ocean acidification will change the chemistry of the ocean, impacting fisheries, corals, and molluscs, as well as sensitive areas such as the Arctic, and will have significant effects on the economy and food security of coastal and island nations around the world. […]

Sustained ocean observation should be included as part of national commitments, particularly within the framework of UNFCCC and Agenda 2030/ SDG 14, in response to the call to increase knowledge to manage marine ecosystems sustainably, and understand the impacts of climate change and ocean acidification […]

Support actions implemented by the Global Ocean Acidification Network (GOA-ON) to facilitate cooperation and coordination between ongoing and planned ocean acidification observing programs and to deliver the results to enable scientists and policy-makers to *develop the best adaptation and mitigation strategies”* (International Working Group on Oceans and Climate 2015)

Therefore, it is unclear why is there a lack of focus, when the conclusions of the dedicated oceans’ day declared alarming statements. Perhaps the lack of emphasis comes from the poor embeddedness of ocean sciences into environmental policy and politics, as it was mentioned in previous chapters. However it is clear that currently this convention is inadequate to protect oceans from harmful GHG emissions (it might be unable to protect anything with nations setting their own targets).

Naturally, there are other notions of International Law besides the highlighted ones, such as predominantly non-binding agreements, declarations, also called soft-law, however these may only provide us with an indication where the international community is heading in terms of binding agreements in a longer term. An example for this is the Stockholm Declaration on the Human Environment, which states in its 21st principle that states have the “responsibility to ensure that activities within their own jurisdiction and control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.”(United Nations 1972). Which is a very progressive thought, however it is hardly enforceable.

Science policies

As the aforementioned focus is missing for ocean sciences, research is lacking in many aspects. We only know a fraction of the species' reaction to ocean acidification, or multiple stressors. We do not know how the species affect each other under acidification or multisource stress. Most studies focus on single stress when examining species, and usually take acidification values based on global aragonite concentrations (Godbold et al. 2013).

Currently many climate models are incomplete because they are not integrating certain aspects of the global biosphere, which might lead to inaccurate data and predictions. The accuracy of projections is crucial, because these estimates serve as the basis for any adaptation measure (Hajima et al. 2014;Lenton et al. 2009).

The lack of awareness is also problematic, since more awareness would result in more funding and research. An ecosystem that is 70% of the Earth has only a fraction of the attention of the terrestrial world. For example, in the United States, less than 1% of the total research and development budget was spent on ocean research in 2015, a number that was similar in the 1980's and 1990's as well (Clayson 2014). That is of course connected to how research interests are formed, and as we can see, there are **approximately 33 times more mentions of global warming than ocean acidification (shown in Figure 8),** although both are effects of CO_2 emissions. (There is steadily increasing awareness though as shown in Figure 7). In comparison with land, less than 11% of published papers between 1995-2004 in each of the fields of ecology, conservation biology, and biodiversity research deal with marine systems from. The IPCC's Fourth

Assessment Report listed 28,586 significant biological changes in terrestrial systems but only 85 from marine and freshwater ones.

It is hard to tell whether funding is low due to lack of interest or the other way around. Albeit it is safe to assume that there is definitely more interest than 1% of the research budget in the US, and more funding would surely generate scientific progress in this field. Public awareness needs to be raised as well to put pressure on decision-makers to invest more in marine sciences. The results of a 10,106-person European survey of public awareness, concerns, and priorities about marine anthropogenic impacts show that

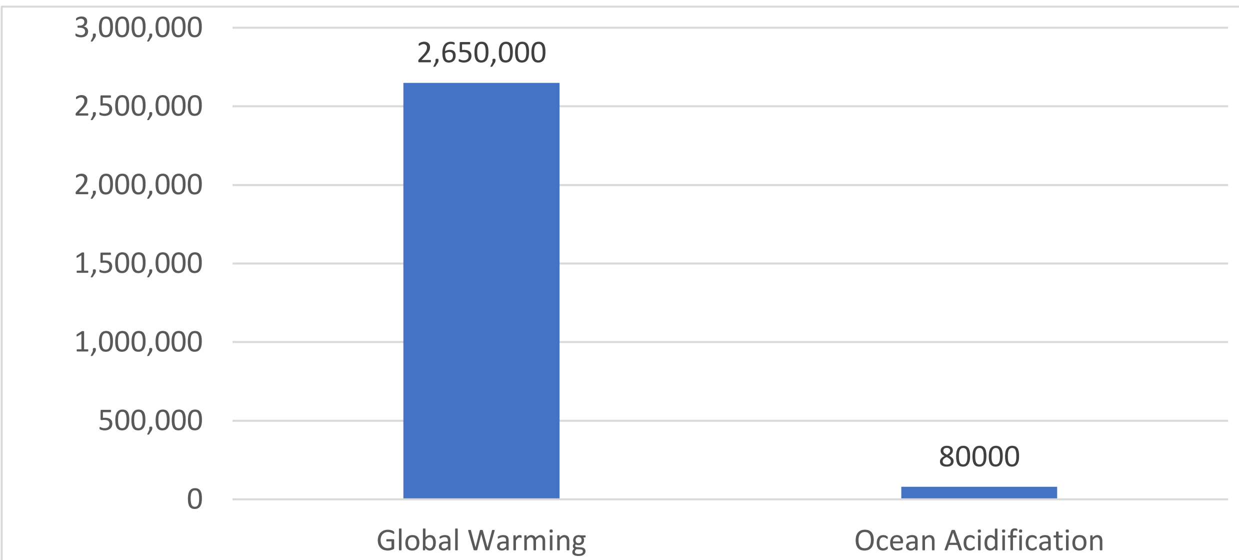
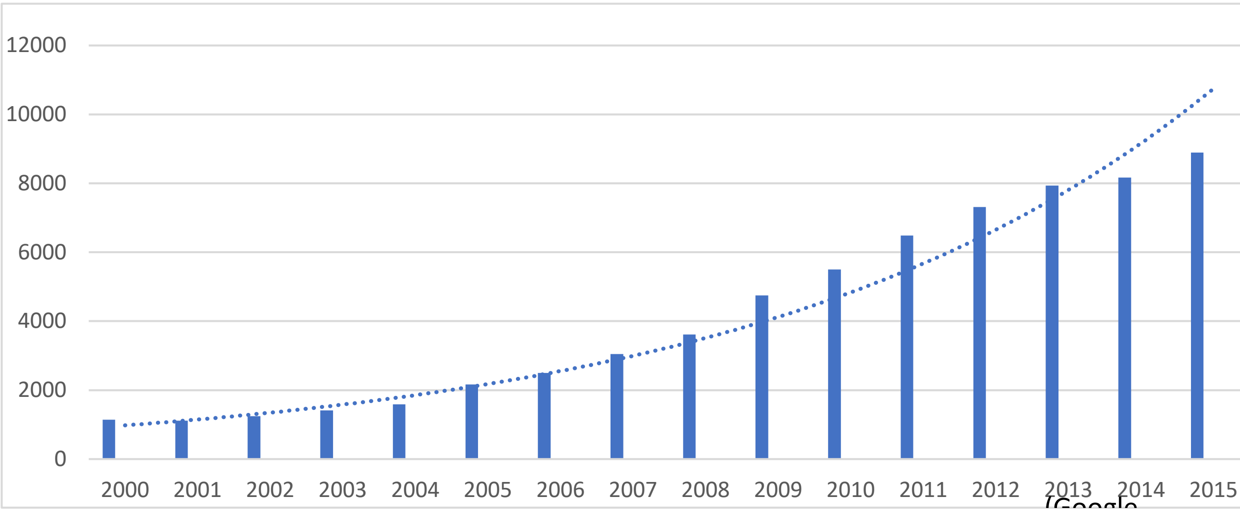


figure 12 Number of Hits for Ocean Acidification on Google Scholar, 2000-2015

Ocean Acidification is one the least known problem, however people do find it troubling, as shown in Figure 9 (Gelcich et al. 2014).



(Google

figure 13: Google Scholar search for keywords, 2016

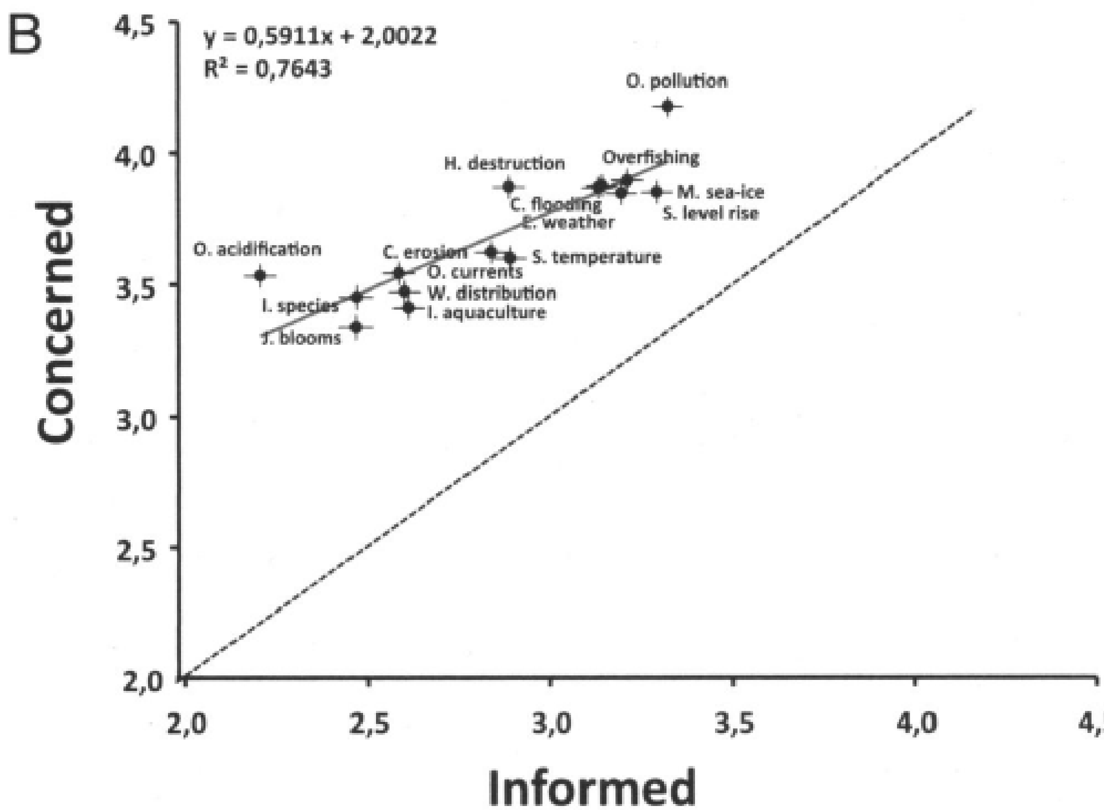


figure 14 Responses to the survey question: "When you think about the coastline or the sea, what are the three most important environmental matters that come to mind? (Gelcich et al. 2014)

Chapter III. Mitigation possibilities

Research policies

Several research policies should be updated to provide a more holistic approach to anthropogenic effects of emissions, especially with increased focus on multidisciplinarity, International Relations and Earth Systems Science.

Integrated modelling and research is needed. Environmental modelling has yet to fully implement Earth System Science (ESS). This framework is required to understand how the Earth is composed of its interacting subsystems. The concept of ESS has been partially realized by Earth system models (ESMs) (Hajima et al. 2014). The rebound effect is of particular interest: To remove 1 ppm of carbon dioxide, one most remove about 2 ppm, since the atmosphere-ocean equilibrium releases the previously absorbed amount of gas(Hajima et al. 2014). This is often not considered with due care. There are some international bodies that attempt to unite researchers, stakeholders and decision-makers, such as the Global Partnership for Oceans, which was launched in 2012, and unfortunately ended in 2015. It was an environmental governance initiative supported by the World Bank. It produced a Blue Ribbon Panel comprised of 21 global experts from 16 countries, coming from non-profit organizations, the private sector, academia, and multi-lateral institutions as well. The Panel produced a comprehensive report on ocean health in 2013, which concluded with the following statement:

"To develop and share the required knowledge and experience, the GPO should lead in the establishment of global networks of expertise and research. Nations face many ocean issues that are not unique to their countries and global partnerships can facilitate knowledge exchange. These centers and networks should help integrate key areas, such as sustainable aquaculture, fisheries reform, combating marine pollution, conserving critical habitat and species, and engaging in integrated ecosystem-based management, which can provide attractive economic development opportunities while also improving sustainable management practices and governance in vulnerable coastal communities."

(Aqorau et al. 2013)

It is very unfortunate that this initiative did not continue, because it had the potential to connect all the parties, and to establish crucial public-private partnerships (Abbott 2014).

Another aspect in modelling is the effect of atmospheric ozone on ocean acidification. Some estimates of future climate that do not consider stratospheric ozone depletion overestimate regional and global oceanic CO2 uptake, and underestimate ocean acidification. Stronger winds on the Southern Ocean result in a particular wind pattern of atmospheric variability called Southern Annular Mode, which has been increasing in the past few decades, and this is caused by higher greenhouse gas concentrations and stratospheric ozone depletion. This increased wind stress causes reduced oceanic carbon uptake, but increased acidification due to the enhanced ventilation of carbon rich deep water (Lenton et al. 2009).

Last, appropriate funding should be provided to research. As mentioned before, in the United States, the total research and development allocation in 2015 for ocean research was under 1%, a number that was similar in the 1980's and 1990's as well (Clayson 2014).

Surely, for more funding, research and all the aforementioned factors to change, more awareness should be raised. NGO-s are making significant progress in this field, however, more could be done.

Reduction of carbon dioxide

Obviously, reduction of atmospheric CO_2 would be the best solution to halt ocean acidification. However, this seems unlikely at the moment for the next 10-20 years, and harmful effects of emissions are already taking their toll. Moreover, stabilizing the carbon cycle through neutralization and sequestration would take a very long time. The mean lifetime of anthropogenic carbon dioxide from fossil fuel sources is about 30 000-35 000 years. However, at 10 000 years it will only be 10% of the original amount. Large portions of CO_2 will dissolve in a relatively short amount of time, with substantial amounts remaining for extreme periods. Therefore a better understanding is that the lifetime of fossil fuel will be ‘‘300 years, plus 25% that lasts forever.’’ (Archer 2005). Therefore, we have to adapt to effects of harmful emissions, including preparing ocean ecosystems and connected people.

Policy measures

There are several measures that can be taken to directly or indirectly combat ocean acidification. One of these is introducing an **acidity threshold** on multiple levels. (Baird, et al., 2009). Any local or international measure to tackle the effects of CO_2 emissions should include such a limit. The aim is twofold: An acidity threshold, along with a temperature or the global atmospheric CO_2 parts per million thresholds, is an indicator that both environments are equally important, thus both are followed closely. Second, this would provide a solid basis for a quantifiable effort to stop this detrimental effect.

In terms of International Law, a logical option would be to form a new treaty should be formed to protect the ocean biosphere from anthropogenic sources such as acidification, warming, pollution, etc., however, that might take too long. Therefore, as a more pragmatic solution one of the existing treaties should be amended, most favorably those that were discussed before. All of them have multiple aspects that would provide room for expansion, and accepting an additional protocol would take considerably less time than a new treaty.

The UNFCCC should include oceanic effects of CO_2 emissions in a more substantial way: add it as an equal environment to terrestrial ones in the final texts of conferences and agreements. Moreover, parts of the framework which encourage active ocean CO_2 sequestration should be removed immediately. An acidity threshold would also help the shifting of emphasis. Adding an international coordination body for policy, diplomacy and research on marine sciences would be also beneficial, to bring the ocean sciences up to the same level as the terrestrial ones. Adaptation efforts in the UN should include acidification, perhaps in the Nairobi Work Programme on impacts, vulnerability and adaptation to climate change (NWP) (Herr et al. 2014).

In the case of the UNCLOS, nation state territoriality should be expanded with principles such as the common heritage of mankind, which could serve as the basis of designation of protected marine areas in international waters. Just because it is no country's territory, it does not mean it is no one's responsibility. Therefore, the protection of these areas is paramount, and it should be reflected in the Convention with perhaps an additional agreement with specific targets and responsibilities.

As for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention), CO_2 should be explicitly stated as a pollutant. This would put great pressure on nations to reduce their emissions significantly, and they would also realize how carbon dioxide has effects besides inducing climate change.

Furthermore, the effect on fisheries as shown in Figure 6 will be heavy, therefore this should be another factor to convince fishing-reliant states to reduce their emissions; Norway, for example is rich in fossil fuels, but also depends on fisheries due to their warm water ports and abundant supplies due to the Norwegian Current; but the country is under at 'moderate' to 'high' risk from ocean acidification (Heinrich et al. 2017).

Another important issue is the traction of the term: global warming potential. Several researchers pointed out that besides CO_2, there are other greenhouse gasses that are in smaller concentration in the atmosphere, but have a significantly greater effect on the climate (UNFCCC 2017). Methane has a global warming potential of 28–36 over 100 years (compared to carbon-dioxide). Contemporary research also finds that there is significantly more methane emissions from arctic tundra than previously thought due to late-season emissions and these are not incorporated into current climate models (Zona et al. 2016). Therefore, focusing on different gases is important. However, Global Warming Potential by principle misses a key point. Only CO_2 has a significant impact on the marine biosphere, whereas the others do not. This is not incorporated into the calculations for the potentials. This is a massive oversight which needs correction, if we are to reliably use global warming potential to address mitigation and adaptation measures. This should be combined with an ocean acidification potential and possibly ocean warming potential (where methane could play a role as well). Only this way could we gain a holistic understanding of how different compounds effect our planet and to best tackle the related issues.

Finally, more research should be done on ocean acidification. Currently we do not know how all species are affected. Furthermore, we do not know how the species affect each other under acidification stress, or how species react to multiple stressors (Mcleod et al. 2013). The Convention on Biological Diversity’s conference of parties has been focusing on ocean acidification from 2008, and has released several materials on the subject, such as Impacts of Ocean Acidification on Marine Biodiversity via the CBD Technical Series, which helped the understanding of the phenomenon. Hopefully the CBD will continue its reporting on acidification. It should upgrade the design of Marine and Coastal Biodiversity and Protected Areas, to include acidification as well. They could strengthen National Biodiversity Strategies and Action Plans) to deal with impacts of ocean acidification, and thus ensure that current regulations are enforced and kept (Herr et al. 2014).

Iron fertilization

Iron fertilization is a proposed experimental geoengineering method to combat CO_2 emissions and ocean acidification. It is important to note this technique so that we can get a full picture of all the surrounding processes. The principle of fertilization is relatively simple: pumping iron in the ocean would increase the activity and number of phytoplankton, which are currently often in high-nutrient, low-chlorophyll regions. The plankton would bloom, and increase photosynthesis would draw increased carbon, afterwards which the ocean's biological pump would carry an unknown amount of it to deeper layers of the waters (Blaustein 2011). Now in principle this sounds like a good solution, however it is deeply worrying that this method could potentially further increase acidification, because the deposition of carbon dioxide in deep water is not granted, its effects there are not well known and by principle it furthers the role of the oceans as a sink for anthropogenic pollution. Several studies have expressed doubts as well citing environmental concerns. e.g. (Buesseler et al. 2008). The National Academy of Sciences in the Unites States has abandoned geoengineering of this kind altogether in 2015, saying "it is not ready for wide-scale deployment" (National Academy of Sciences 2015) . Overall, currently geoengineering is not considered to be a viable alternative to any mitigation or adaptation effort, and judging by the uncertainties in the case of ocean acidification, it is probably for the best.

Chapter IV. Adaptation possibilities

Conceptualizing adaptation

An often-used definition of climate change adaptation is “adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities” (IPCC 2007)

Since there are no explicit frameworks for ocean acidification, therefore we have to adapt the adaptations. Some of these include marine sources of stress, but most deal with effects of climate change, such as sea level rise, shifting climatic conditions, etc. The theories behind these and the reactions of populations still prove to be useful nonetheless.

We can identify two major types of adaptation: planned and autonomous (and public and private). The first being a top-down approach, while the second is the reaction of citizens, which might even be detrimental (this is why proper awareness is crucial).

Several questions must be answered, however. How much can adaptation effort reduce the effects? Are there any adaptations that have negative consequences? How can autonomous and planned adaptation interact? (Malik et al. 2012) These questions can only be answered on the ground and after a certain period of time. This is where we face a core problem of adaptation: uncertainty. This is problematic because adaptation often has a financial component, and financial uncertainty is vastly different from an environmental one: in economics, it means that there are several possible scenarios with set probabilities, however in environmental sciences not even the number of outcomes is known. In a setting with no market imperfections and perfect information, self-interested behavior will lead households and firms to undertake efficient private adaptations. Public adaptation in that case involves local, regional and national levels with proper coordination. Since we do not have perfect information, the imperfections have to be corrected, hence governed adaptation efforts. Imperfections may stem from underdeveloped property rights or restricted access to world markets. Better information also leads to better adaptation; a study shows that farmers who are knowledgeable are more likely to take private adaptation measures (Malik et al. 2012). Another aspect of an adaptation framework is how can it evolve. No concept is perfect; therefore, it needs to adapt to changing circumstances, especially when there is a high level of uncertainty. There are multiple tiers of successful feedback cycles; first, Single-loop learning means a small improvement over time, but only relying on experiences rather than an analysis of causes. Double-loop learning refers to a revisiting of assumptions of cause-causality relations, within a value-normative structure. Finally, triple-loop learning has multiple layers that considers hidden messages, beyond causes and looks for underlying effects that may stem from different world views and cultural aspects; it is also the questioning of the whole methodology by which adaptation was conducted [6] (Pahl-Wostl 2009).

[6] Triple-loop learning would be useful for mitigation measures as well, since as mentioned before, most international instruments of law do not take into account marine effects of pollution such as acidification; therefore, questioning the world view and the belief of entire concepts would be needed. The UNFCCC framework is a prime example of this, since it should not even be called “climate change”, since there is a lot more to anthropogenic harmful emissions than just the climate.

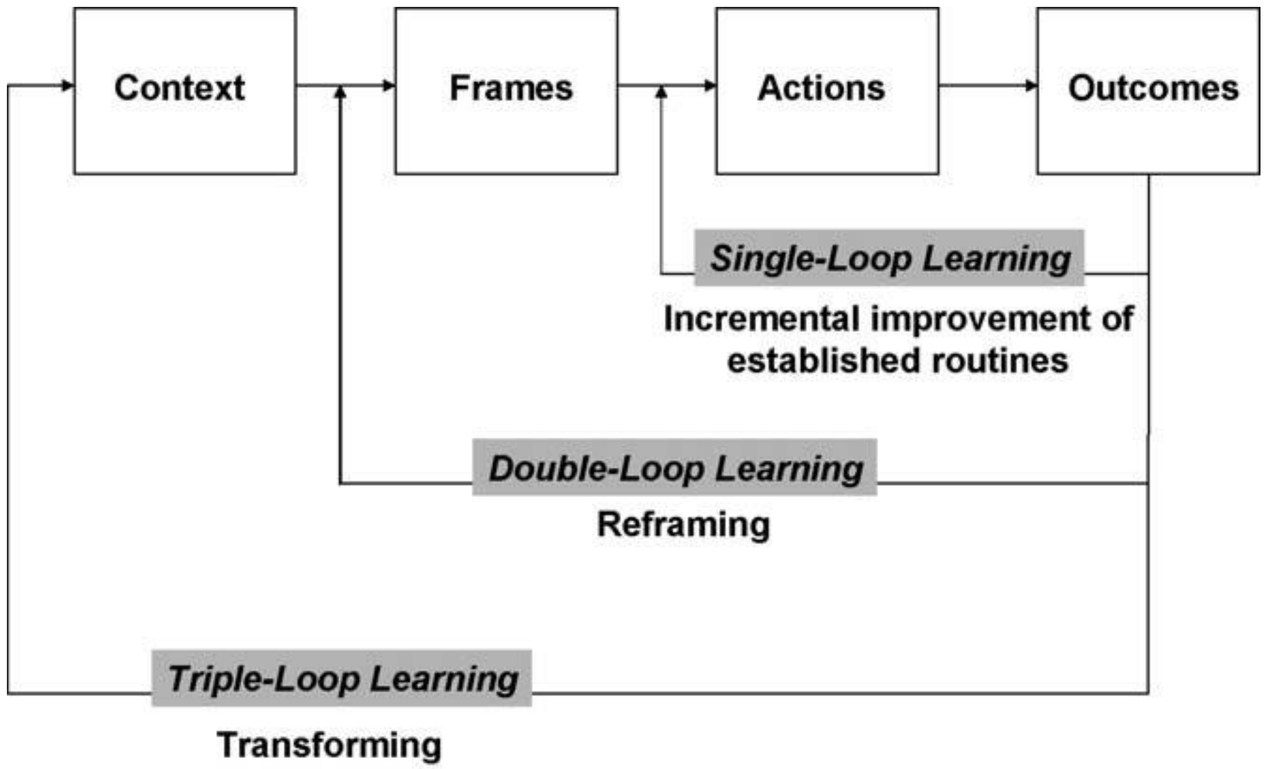


figure 15 Sequence of learning cycles in the concept of triple-loop learning (Pahl-Wostl 2009)

In terms of existing adaptation and assessment frameworks, the Drivers-Pressures-State-Indicators-Responses (DPSIR) could be used to conceptualize acidification. Although not an adaptation model itself, its clear and coherent structure makes it easy to comprehend a synthesis. First, it identifies priority environmental issues, then addresses the state of these currently, afterwards the trends of the problem. Afterwards it examines the what are determining driving factors behind the phenomenon, then the pressures which affect it. This is followed by an analysis of indicators, which provides quantifiable and comparable evidence. This also enables self-reflection because efforts can be checked against different periods of time for effectiveness. Furthermore, it is a simple, intuitive analysis which considers human-environment interlinkages. This simplicity helps any stakeholder to properly understand complex problems with ease. The problem of acidification can easily be placed into this system (Pintér et al. 2007).

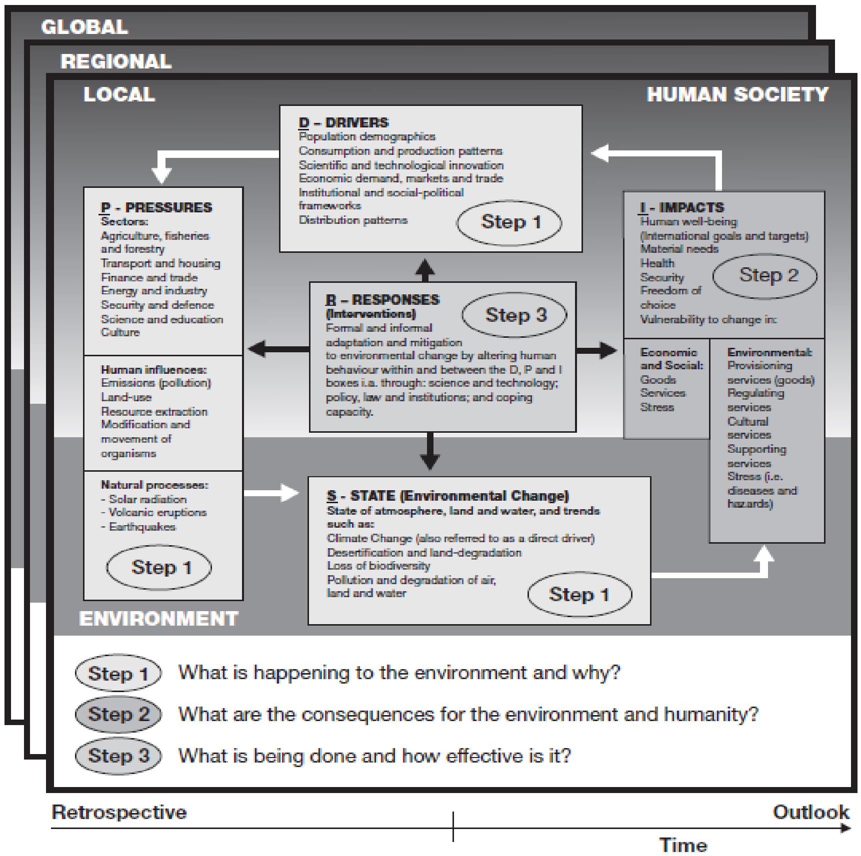


figure 16 Analytical framework for integrated environmental assessment and reporting based on GEO-4 (Pintér et al. 2007)

Fisheries

Ocean acidification is here to stay. With the current state of the fight against GHG emissions, we have to prepare for the worst, as per the precautionary principle. In practice, this means that the business-as-usual scenarios are applied in environmental modelling. By 2100, the oceans will be significantly more acidic than now, and the speed of the process is already faster than any time in the last 20 million years (Feely et al. 2004). Effects of acidification are already present, along with other stressors as well. As presented in chapter I, many people depend on ocean goods, often for sustenance as well.

One of the crucial factors is the fishing policies of states and regions, and how will fisheries adapt to changing conditions such as dwindling populations or decreased body size of catch. The United Nations Food and Agriculture Organization states that over 70% of all fish stocks are fully exploited, depleted or overexploited already (United Nations Food and Agriculture Organization 2006). The share of inland fisheries is considerably lower than of maritime extraction, however it is still a significant proportion of production (36%). Inland production globally is 21% aquaculture and 79% capture based. Trends show that inland fisheries (both types) are almost steadily growing, while the share of maritime (mostly capture) fishing is decreasing (Food and Agriculture Organization of the United Nations 2012). Since all water bodies are prone to acidification[7], inland fisheries and aquaculture do not mean a solution to it. It does give a fighting chance to many

[7] This thesis is about ocean acidification, however other water bodies are affected as well, therefore they are considered in this short section as alternative fishing grounds affected by acidification but still viable alternatives to multi-stressed ocean environments.

organisms, however. Besides, this would fall in line with trend of increasing aquaculture and inland fisheries. In aquaculture, and especially inland fisheries many cofactors can be controlled. The key point is that many species will succumb to multiple stressors, which independently would have less or no effect on them. Therefore, controlling as many factors as possible is a definite advantage. In inland fisheries, pollution can be controlled as well as overfishing, keeping in line with the highest sustainable yields, and since these fisheries can be more tightly controlled, there is less or no risk of rogue fishers upsetting the balance, as is the case in international waters, where there is little to no control over extraction.

Of course, fisheries can be only be effective if fishing quotas are determined correctly. This involves the setting of the highest sustainable yield. Effects of ocean acidification and other stress factors must be integrated into all models, otherwise hidden overfishing might occur. Other suggested adaptation measures such as harvest restrictions, stock translocation, pollution reduction, and habitat protection are also worth attempting (Johnson 2012). A radical approach would to reduce the number of fishermen, and provide them with alternative sources of income, however in developing countries where fishing is a primary food source, this is not a viable option. In the public sector, ways of protecting stocks include reducing overcapacity with vessel buybacks and subsidy reductions, creating marine protected areas, diversifying income by developing marine tourism and aquaculture development. Choosing the right species to fish is also important; with an ecosystems approach to fisheries, more vulnerable fish should be spared, and those who remove pollutants such as shellfish and aquatic plants. herbivorous species have the least impact on the environment, therefore in aquaculture these should be favored (Johnson

2012). As for private initiatives, reactive adaptation is already taking place. Shellfish farmers are adapting to ocean acidification, rise in water temperature, and deoxygenized water by choosing grow-out sites where cold water circulation is stronger from below; fishing at greater depths with specialized technology; Closing off seawater intake systems and recirculating hatchery water when available seawater is low in oxygen or experiences pulse-disturbance pH drop (Johnson 2012).

Biodiversity hotspots

As it was outlined in the current state of research, ocean acidification is not uniform in its effects. There are temporal, seasonal, geographical and specie-specific variations which need to be considered. This is especially important when it comes to biodiversity hotspots, where any effect is magnified through ripples in the food web of concentrated biomass. Research indicates that coral reefs are affected differently, and some are more resilient than others. Moreover, studies conducted on coral bleaching provide valuable insight for acidification adaptation as well. Gradually over the last decade, conservation management evolved to deal with coral bleaching and enhance reef resilience. Although warming of oceans and acidification have the same source, they affect habitats differently. So-called bleaching episodes are induced by sudden surges in warming, with varying spatial distribution. Acidification, on the other hand, is a gradual process. Therefore, the combined effects are called a mixed pulse-and press-type disturbance. However, occasionally acidification can be a temporary pulse disturbance as well, when it originates from costal point sources. Therefore, the study conducted on reef health suggests four adaptation measures for conservation planning:

Criterion I: **protect natural refugia**

Proper action can lessen the effects of bleaching. Communities that are more resilient to bleaching can act as sources of coral larvae to resettle deserted areas. Therefore, resilient reefs must be protected from different stress factors.

Planning criterion 2: maintain ecological connectivity among marine protected areas

Research shows that larval stages of organisms are more sensitive to acidification, therefore mutual replenishing of marine protected areas, thus disturbance recovery should be provided by securing these flows.

Planning criterion 3: protect replicates of major habitat types

Protecting multiple habitats with similar characteristics help further research on stressors. Moreover, areas that are projected to experience a great variation in ocean chemistry besides acidification should be especially protected due to the precautionary principle, since there are significant research gaps concerning the various effects.

Planning criterion 4: prioritize areas where local threats can be effectively managed

Decreasing the number and/or intensity of stressors in a local environment is an effective management strategy, e.g. reducing overfishing, pollution or sedimentation. This includes shutting of point sources of acidification as well in coastal areas, especially estuaries (Mcleod et al. 2013).

As for adapting research priorities, establishing an ocean carbon chemistry baseline is crucial, as it can tell how C02, HC03~, C032-, pH, and aragonite change in the given habitat. Here temporal variability should be addressed as well. Those areas that experience high thermal variability and fluctuation should be prioritized in protection. With an established baseline, we could discover which habitats are naturally more resistant to stress factors, thus increasing the efficiency of management efforts. Furthermore, ecological baselines should be set, to correctly identify how acidification and other contributing factors such as ocean warming affect a variety of characteristics of organisms, such as growth rates, calcification and survival rates. Connected habitats such as mangroves should be examined as well to monitor interactions, since they alter local acidification levels, opening up the potential to biomitigation through planting specific organisms. In shallow waters, local factors may prove to be even more influential than global changes, therefore reefs and their connected habitats should be addressed on a case-by-case basis to provide researchers and policymakers with the most accurate results possible. The synergetic effects, positive or negative, must be explored as well. Acidification proved to be slowing coral growth and decreasing recovery, but also it may create competitive advantage of microalgae over corals (Mcleod et al. 2013). Therefore, the monitoring of microalgae and consequently of herbivories may be a valid management strategy. Occasionally, seaweed mariculture, may favorably effect pH levels as well. Mapping all these factors would provide a visual overview of the management challenges and opportunities (Mcleod et al. 2013).

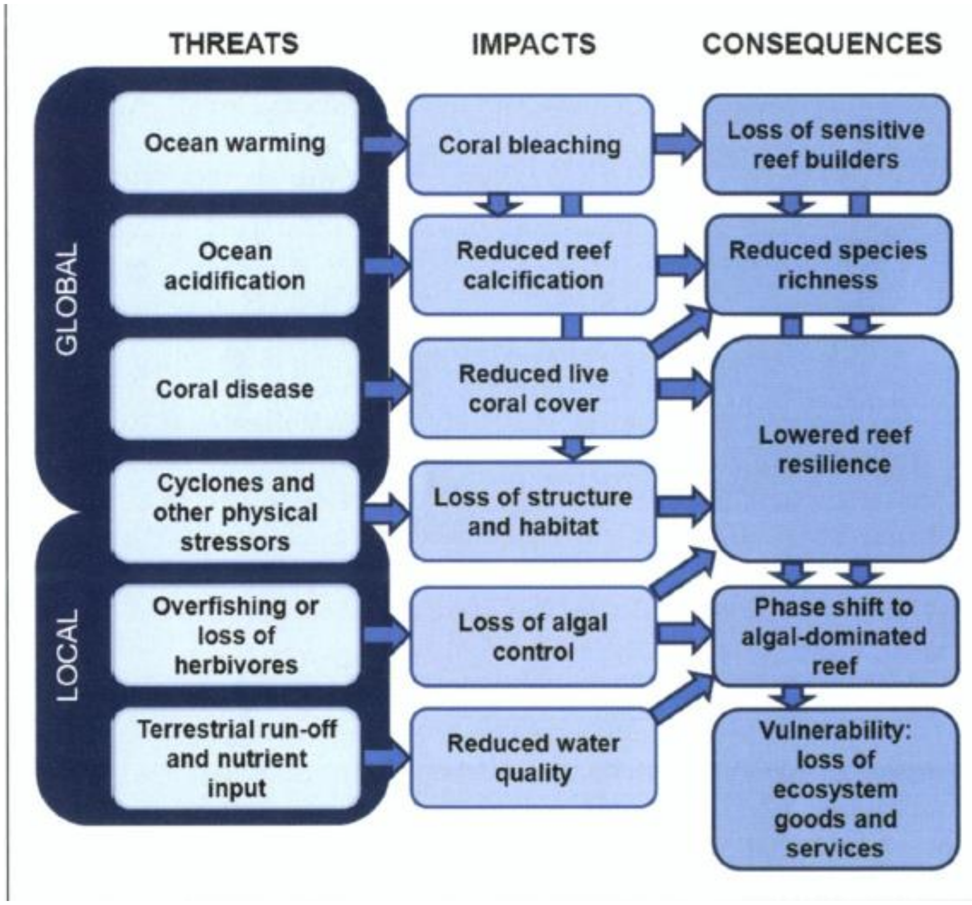


figure 17 Flow diagram of functional links between global and local threats to coral reef ecosystems , biological and ecological impacts , and downstream consequences for ecosystem function (Mcleod et al. 2013a)

Socioeconomic measures

How sensitive a society is a crucial question in adaptation. Vulnerability must be properly assessed for successful adaptation to take place. In the comprehensive study by Mora et al. (2013) mentioned earlier, social adaptability to marine stressors was quantified by per capita GDP, with the proposition that wealthier nations have more capacity for adaptation; their adaptive capacity and coping rangeis larger. The research classified countries and placed them in three categories, and calculated the number of dependent people, and the result was that 870 million live in low-income countries where effects will be medium to high. Therefore, almost a billion people on the planet will be affected by ocean acidification and related stressors. The magnitude of this calls for additional measures to be taken on an international level, such as increased funding for programs that help people transition from sustenance fishing to diversified agriculture or helping fishermen to apply the highest environmental and technological standards. Some of these measures may be educational programs, agricultural support from the FAO by experts on the ground, or development of artificial lakes with aquaculture activity. The encouragement of tourism may also be a viable option. Since the effects of acidification are uncertain, and adaptation to the specificities are hard, some suggest to build resilience by general measures, such as the strengthening of a nation's economy, education of its citizens, building crucial infrastructure such as power plants and hospitals. The extent of enhancing livelihoods and hence building adaptive capacity, may be constrained by national or regional limitations. However, effective efforts can only be undertaken if the local population supports it and provides crucial information about how they are affected (Smit et al. 2006).

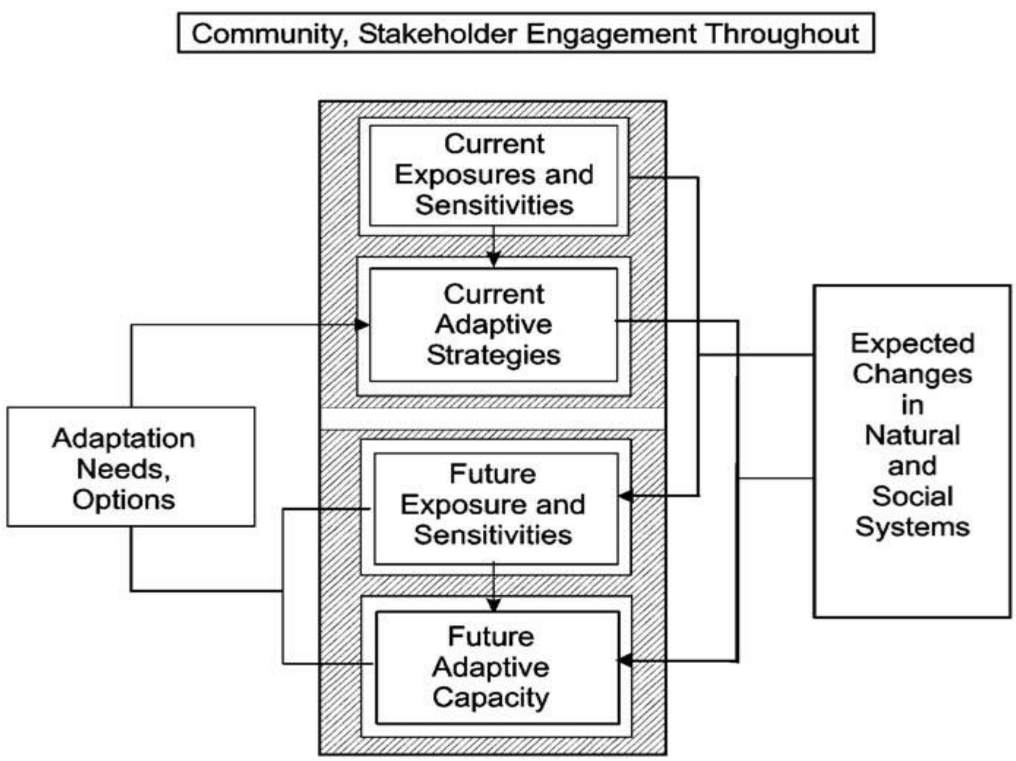


figure 18 Conceptual framework for vulnerability assessment and mainstreaming (Smit et al. 2006)

Conclusion

Ocean acidification is an often overlooked environmental problem which has severe effects on marine ecosystem and thus the livelihoods of those who depend on the ocean biosphere. Its complex background of land-based sources and ocean-based effects makes it difficult to address by research and policy as well. Adaptation to it is therefore even harder; with little awareness and no reduction of atmospheric CO_2 in sight, options are limited. If we are to solve this problem, a synthesis of different fields of sciences are needed, which include Earth System Sciences, International Relations and International Law. I have presented evidence that ocean acidification is a serious threat, yet is not well known among members of the public or policymakers and even scientists. I explored why this phenomenon is so elusive compared to global warming. By examining the various effects of ocean acidification on marine organisms and the socioeconomic impacts, I have established how this problem must be tackled by international cooperation but with the inclusion of localized efforts. This cooperation can take multiple forms, but hopefully one of the mentioned instruments of International Law will be amended to provide strong protections for marine habitats from acidification and other threats. What should the collective effort of stakeholders implement was another question, and the answers come from adapting existing frameworks and know-how to this problem as well, while relying on research that addresses specificities of acidification. Besides reducing CO_2 emissions and reducing all other stressors to increase chances of survival, the most useful measures are searching for resilient species and protecting biodiversity hotspots which are resistant to acidification. Moreover, the introduction of acidity thresholds in international agreements, adjusting highest sustainable yields of fisheries and substantially more funding on research for multi-stressor effects and resilience are also crucial to the effort. Hopefully, with more and more people knowing about ocean acidification and possibly contributing to the growing literature will help to reduce the effects of this phenomenon, before marine ecosystems reach the tipping point.

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