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European policies and legislation targeting ocean acidification in european waters - Current state

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A B S T R A C T

Ocean acidification (OA) is a global problem with profoundly negative environmental, social and economic consequences. From a governance perspective, there is a need to ensure a coordinated effort to directly address it. This study reviews 90 legislative documents from 17 countries from the European Economic Area (EEA) and the UK that primarily border the sea. The primary finding from this study is that the European national policies and legislation addressing OA is at best uncoordinated. Although OA is acknowledged at the higher levels of governance, its status as an environmental challenge is greatly diluted at the European Union Member State level. As a notable exception within the EEA, Norway seems to have a proactive approach towards legislative frameworks and research aimed towards further understanding OA. On the other hand, there was a complete lack of, or inadequate reporting in the Marine Strategy Framework Directive by the majority of the EU Member States, with the exception of Italy and the Netherlands. We argue that the problems associated with OA and the solutions needed to address it are unique and cannot be bundled together with traditional climate change responses and measures. Therefore, European OA-related policy and legislation must reflect this and tailor their actions to mitigate OA to safeguard marine ecosystems and societies. A stronger and more coordinated approach is needed to build environmental, economic and social resilience of the observed and anticipated changes to the coastal marine systems.

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1. Introduction

Around the end of the 18th century, with the design of the steam engine by James Watt, the geological age of the Anthropocene started [1,2]. This period has resulted in unprecedented changes to the natural environment, including the ocean, which plays a vital role in the global carbon cycle. The ocean has already been affected by a 0.1 pH decrease since the Pre-Industrial Period, of which ~30% is due to its absorption of anthropogenic CO_2 emissions [3]. Due to this sequestration of atmospheric CO_2, the term Ocean Acidification (OA) was coined to describe the increase of hydrogen ions, which reduces the pH of ocean waters and decreases the saturation of calcium carbonate minerals [4–6]. From a geological perspective, the rate of OA is two magnitudes faster than any previous event in the last 20 million years [7], and is currently at levels last seen at the Paleocene Eocene Thermal Maximum (PETM, ~56 million years ago) during which a massive CO_2 injection was dissolved in the ocean [8]. This event led to major turnovers of marine species, with mass extinctions of some species and population growth in others [9]. It took tens of thousands of years afterwards for the ocean to recover [10].

As such, we know that the biological consequences of OA are vast, including the reduction of marine biomineralization (e.g. Ref. [11–13], habitats and marine biodiversity loss [14,15], reduced bioavailability of essential trace metal to marine primary producers [16], and the alterations of complex marine food webs [17]. We already see these changes affecting marine ecosystems and coastal communities today, by threatening the ability of the ocean to continue to provide economic resources and ecosystem services on which human welfare depends [18]. How OA will specifically affect ecologically and economically important organisms in different coastal habitats is more difficult to predict. This is because carbonate chemistry can be highly variable in coastal waters, and conditions that organisms are actually exposed to are difficult to measure. In addition, organism sensitivity can vary across life history stages and in combination with other stressors [19–23].

Despite an improved understanding of the causes and threats posed by OA, public understanding of the concept and its implications are still limited [2,24]. European-led research projects such as EPOCA (2008–2012) and MEDSEA (2011–2014), and national projects such as British UKOA (2010–2015), the German BIOACID (2012–2015) and the Italian ACID.IT have paved the way, but internationally coordinated OA research is still critical to understand local and global patterns, prepare adaptation and mitigation strategies, and communicate key concepts to the general public. Substantial knowledge generated from such research shows that the geographical distribution of OA is not the same everywhere [25–27], indicating the need for a collaborative approach to governance. There have also been reviews on the options to mitigate local causes of OA (e.g. Ref. [28] and to explore new ocean conservation strategies to increase ecosystem resilience, adaptability and damage compensation in the face of unavoidable acidification (e.g. Ref. [29,30]. In addition, it has been considered that the economic cost of inaction is greater than the environmental and social degradation caused by OA [31–36]. This is compounded by the social injustices caused by the disproportion of top CO_2 emitters compared to societies most affected by OA [37], accessibility to mitigating infrastructures and technologies [38], and conflicts of interest between the Sustainable Development Goals (SDGs) [39].

In light of this, the current article assesses the regulatory setting relating to OA with a focus on the European level. Given the challenges and uniqueness of OA as a policy domain, an analysis of institutional gaps is therefore an important first step for a critique of the European governance framework in place at the national level to address OA. This analysis involved a review of the status of global efforts as well as past and current EU policies and laws relevant to OA. The analysis of national policy and legislative responses to OA by individual European countries has enabled a comparative analysis of 1) the potential effectiveness and/or limitations of national level responses, and 2) the barriers and opportunities that were identified during their implementation. The operational results of this comparative analysis are presented with reference to the EU's Marine Strategy Framework Directive [72]Qualitative Descriptor number 7. The main goal of the Marine Directive is to achieve Good Environmental Status (GES) of EU marine waters by 2020 using an ecosystem-based approach and sustainable use of marine resources [73]. Descriptor 7 refers to those coastal pressures that are able to permanently change the hydrographical conditions of the coast or seabed. It is worthwhile noting that the MSFD does not impose any GES monitoring Descriptors that specifically target the assessment and impact of OA in EU national waters.

1.1. Governance efforts towards abating OA

Global efforts to address OA are surprisingly absent still, despite the detrimental effects of OA. Some have suggested it be dealt with through the United Nations Framework Convention on Climate Change (UNFCCC) [40], since OA is considered an effect of change in 'the state of the climate system'. The UNFCCC was after all adopted with the aim of stabilizing GHG emissions in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.[1] In 1997, the Kyoto Protocol to the UNFCCC established binding quantified GHG emission reductions and limitations for developed countries for the period 2008 to2012.[2] In 2015, the Paris Agreement was agreed upon, with the goal of keeping the increase in global average temperature to well below +2 °C pre-industrial levels, with the inspirational aim of 1.5 °C. The Paris Agreement aims to both mitigation and adaptation,[3] through Nationally Determined Contributions, i.e. national pledges that are subject to a review process every 5 years.

Another major global governance landmark came in 2015 with the adoption of the UN Sustainable Development Goals (SDG), where the marine realm has gained the greatest social and political momentum of the last 15 years. In particular, SDG 14 - Life Below the Water, deals with ocean sustainability, including Target number 14.3 which specifically says to *Reduce Ocean Acidification*. This target aims to minimise the impacts of OA through enhanced scientific cooperation at all levels. It is hoped that the forthcoming effort by the UN as part of its Decade of Ocean Science for Sustainable Development (2021–2030) will be instrumental in further prioritizing this pressing problem at EU level.

Nevertheless, though the international community for decades has been aware of the challenges of climate change, in particular since the creation of the International Panel on Climate Change (IPCC) in 1988 and the adoption of the UNFCCC in 1992, we still have not found a solution to this problem. Despite the urgency of the issue and the role of the ocean in climate regulation and human livelihood, OA has been generally sidelined in the development of climate change and related environmental policies at both the national and international level [41].

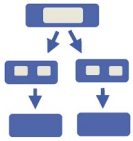
The acknowledgment by the European Environment Agency [74] that OA is a problem led to its inclusion in Europe's "10 messages for 2010" as part of its new challenges in favour of marine biodiversity. This communication refers to the need for continued scientific understanding of this problem (e.g. Refs. [42]. However, in spite of its aim to create a positive climate action and to evaluate its relevance, effectiveness, and policy coherence, EU-wide actions remain still incomprehensible and uncoordinated [43]. Specifically, no supportive national legislation that specifically deals with the mitigation and management of OA in European waters has been made, resulting in stakeholder conflicts in EU waters accompanied by an overall lack of participation, ownership, and

[1] UNFCCC 1992, Article 2.

[2] Kyoto Protocol, 1997. The agreement entered into force in 2005, without the ratification of the United States of America. A second commitment period (The Doha Amendment) was agreed in 2012, however it has not entered into force due to lack of countries joining.

[3] Also loss and damage. Paris Agreement, Article 8.

Table 1
The three-step framework used for analysing the national initiatives by European Member States and EEA countries to directly or indirectly address the OA problem.

	Step 1	Step 2	Step 3
Research question	 How is OA being addressed by European countries?	 What policies, strategies, research and legislative frameworks are in place to address OA?	 Are there gaps associated with the governance of OA at the European level?
Methodological approach	• Strategic review of the governance system in relation to OA and GES • Identify primary sources of information and expertise	• Identify and understand frameworks and their cross-linkage	• Gauge potential effectiveness of national frameworks • Assess level of scientific monitoring efforts to understand the OA problem

compliance with key EU Directives, such as, for example, the MSFD and the Water Framework Directive (WFD) [43–45].

Despite international and regional governance efforts at the level of climate change more generally, OA remains a truly global problem with profoundly negative environmental, social, and economical consequences that has not been tackled as a separate issue. Without mitigation, societies are likely to experience major economic losses through reduced shoreline protection [46] and the loss of nursery grounds for fisheries caused by OA-induced habitat destruction [47,48]. Important mariculture species such as shellfish [49] and ecologically significant species such as corals and foraminifera [12,13,50,75]; will be depleted as a result of reduced calcification [46] caused by OA. This sentiment – and fact – is echoed often especially by representatives of Pacific Small Island Developing States (PSIDS) during the negotiations for a treaty towards biodiversity protection in areas beyond national jurisdiction (BBNJ) [51,52].

Higher levels of OA will also lead to disruptions to the oceanic carbon cycle which is estimated to cost €1 trillion by 2100 [33,34] and will have lasting impact upon future generations. On the other hand, it has been estimated that the beneficial contribution of oceanic biological processes to sequester carbon ranges between 100 and 1500 million € per year [35]. Therefore, it is clearly in the interests of governments to scale up efforts to mitigate OA. Because of the lack in global and regional priorities towards the issue, however, it has not received much political and legal attention at the national level either, and it is doubtful whether today's efforts are sufficient to abate the effects of CO_2 on the ocean [53].

2. Methodology

Though there is much scholarly attention to the topic of OA, we know that this translation into the public sphere and uptake by the general population and local policy makers is low [2]. The current study therefore chose to take a top-down approach to address the current status of OA governance. We wanted to map the initiatives at a European level to highlight where the challenges rest with policy uptake from the scientific community, and thereby contribute to the literature on the importance of the science-policy nexus as well.

We first assessed 90 governmental documents from 15 of the 27 participating EU Member States plus Norway and the UK to identify the current systems in place to mitigate OA. On a country-by-country basis, a critique was made of the adopted policies, strategies, and legislative frameworks that are deemed to directly or indirectly mitigate OA at either the national, regional, or sectoral level. For example, we used the Good Environmental Status (GES) as an effort in part to see how Member States are seeking to identify and understand the OA problem (see Ref. [54]; SWD/2018/461). This evaluation aims to identify positive changes and gaps associated with the mitigation of OA. The primary sources are limited to national policy and/or legal programmes/strategies, national research programmes deliverables, and cross-sectoral policy and/or law. The approach for the study followed a three-step process (Table 1) and used the qualitative criteria shown in (Table 2).

Table 2
The qualitative criteria used for critiquing current public policies, strategies, and legislative frameworks related to OA by European Member States and EEA countries.

Qualitative dimensions	
Potential effectiveness	What is the current state of the national governance framework to reduce the OA problem?
Approach towards understanding	What is the effort made to understand the OA problem?

2.1. Step 1: status quo of european OA governance and GES

A total of 90 national legal regulations, agreements, conventions, policies, plans, programmes, and research projects were assessed based on the first qualitative dimension. In addition, an analysis of OA monitoring was carried out by taking note of actions directed towards Descriptor 7 in the MSFD Initial Assessment, GES, and Indicators Report as submitted by individual European Member States in 2013. This was assessed in accordance with an independent report published by Dupont et al. [55], commissioned by the European Commission, by checking whether 1) information related to the current understanding (second qualitative dimension in (Table 2) of OA in European waters was included in the independent report, and 2) whether the information provided was consistent with and adequate within the objectives of the MSFD. This analysis yielded results on the governance actions of each Member State which were then evaluated to check their direct and indirect impact on OA within an overarching national climate action. A similar methodological approach has been applied to the analysis of OA governance problems in Chile earlier [56], whereas in the case of Gelcich et al. [57], textual data mining was used.

2.2. Step 2: OA mitigation frameworks and their links with national climate initiatives

The existence of key linkages between various climate change

Table 3
Range and interpretation of country scores. Scoring is applied to the overall country result per theme.

Colour code	[Score] Potential effectiveness	[Score] Understanding
	[0] no country information	[0] no report submitted
	[1] poor reference to OA and cross-linkage with other sectors	[1] no information on OA reported
	[2] medium reference to OA and cross-linkage with other sectors	[2] Inadequate reporting
	[3] strong reference to OA and cross-linkage with other sectors	[3] partially adequate reporting but with significant gaps in knowledge on OA
	NA	[4] adequate information reported

initiatives and actions that would likely lead to the mitigation of OA were first assessed. This step assumed that OA governance is best carried out by actions that favour climate change mitigation and adaptation, such as reducing GHG emissions, building environmental, social, and economic adaptation and resilience.

2.3. Step 3: mapping the status quo of OA governance

The potential effectiveness and level of understanding of the OA problem was based on the above analysis of national legal documents, MSFD Initial Assessment Reports, GES, and indicators related to OA as submitted by EU Member States. The approach used in this research is an adaptation of the methodology used by Le Gounais & Wach [77] to rank these two variables as categorised in (Table 3). The two country scores were imported into ESRI® ArcMap® to generate geographic maps [58] using the shapefiles provided by GISCO of Eurostat[4] and Flanders Marine Institute, 2018.[5]

2.4. Limitations

The methods applied here are based on the analysis of extensive international legal documents to generate information about policy action, potential gaps, governmental involvement, and national legislation related to OA. However, some methodological barriers and limitations arose during this study. The methods applied in this work follow those of Dupont et al. [55], and other approaches such as Ekstrom et al. [76] and Gelcich et al., [57]; all of which are subject to both advantages and disadvantages. It was not possible at this stage to include data on all 27 EU Member States; nevertheless, it is worth noting that this study represents the majority of countries in this region with coastal borders. A pan-European database on institutions dealing with OA is lacking and therefore this study relied on a network of experts from around Europe to source the relevant material. As this study focused on a top-down approach we note that bottom-up mitigation strategies have not been accounted for. Another limitation is that not all management can be deduced from an analysis of laws, and not all laws are implemented equally across the countries assessed.

[4] http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/countries

[5] http://marineregions.org/

Table 4
Potential effectiveness of EU country policies and legislative frameworks to abate OA. See Appendix A for detailed information about each country.

COUNTRY	SCORE	NOTES
Belgium, Croatia, Czech Republic, Denmark, Germany, Greece, Malta, Poland, Portugal, Romania, Slovenia,	1	poor reference to OA and cross-linkage with other sectors
France, Italy, Republic of Ireland, Spain, United Kingdom	2	medium reference to OA and cross-linkage with other sectors
Norway	3	strong reference to OA and cross-linkage with other sectors

3. Results

The following (Table 4) gives an overview of the national scores in terms of their OA policies and legislative frameworks to abate OA. The numbers are on a scale from 1 to 3 as specified in (Table 3).

3.1. (a) European country policies and legislative frameworks to abate OA

The comprehensive assessment of OA abating measures in all 17 countries can be found in full detail in Appendix A. These assessments are qualified on the basis of the potential effective governance of the problem of OA in coastal waters and mapped to show in a holistic manner, its geographical distribution (Fig. 1). Countries with no data are excluded.

The analysis shows that the policies of European coastal states listed in (Table 4) are poorly or at most moderately engaging with respect to the OA problem. Whilst countries such as Belgium, Germany and Greece demonstrate a good number of climate-related national policies and legal frameworks in favour of positive climate action (including a national climate plan, national climate change adaptation strategy, mitigation and climate energy plans), they lack specific reference to, or action towards direct OA abatement. Further analysis shows that these countries have supported successful research activities to further understand the OA problem in territorial waters.

On a more positive note, countries like France, Ireland and Spain, which are similarly hampered by weak governance and adaptation policies as far as OA is concerned, have a national strategy for ocean and

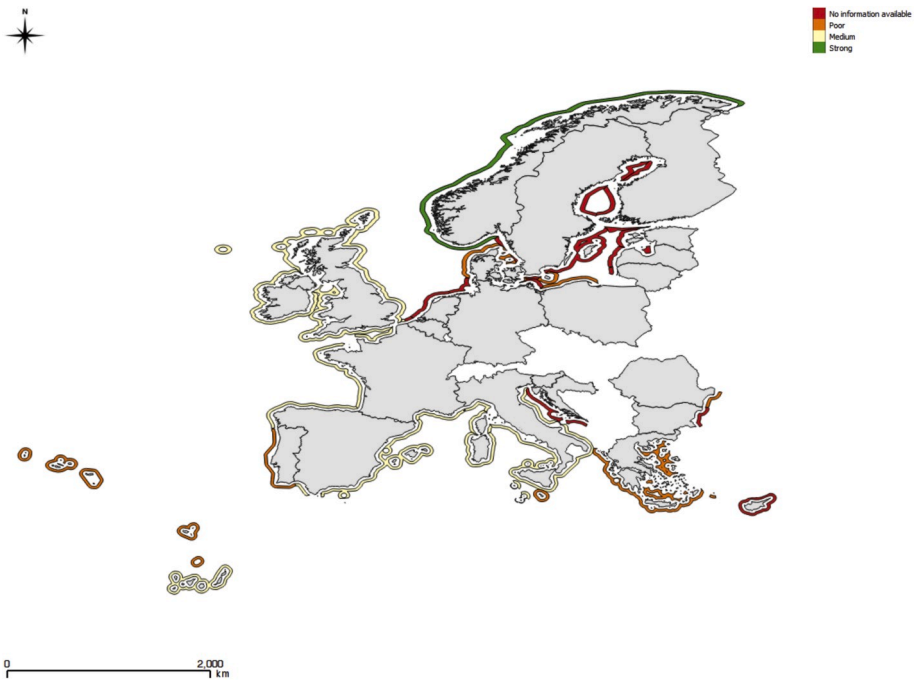


Fig. 1. Here: Geographical coverage of the current effectiveness of OA governance in European national waters. Shapefiles provided by GISCO of Eurostat and Flanders Marine Institute, 2018.

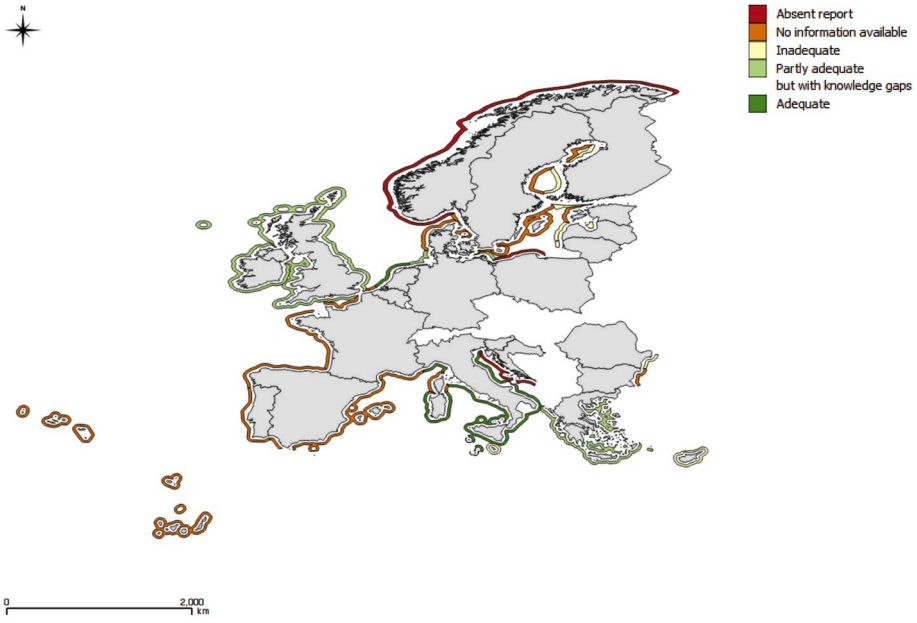


Fig. 2. Here: Degree of actions related to ocean acidification as part of the MSFD Article 12 reporting on Descriptor 7. Shapefiles provided by GISCO of Eurostat and Flanders Marine Institute, 2018.

coastal sustainability that: addresses OA through specific research and specific mitigation actions within sectoral policies and legislation (e.g. France), contains specific obligations to regional conventions (e.g. Ireland), and identifies OA as an important impact in a climate change adaptation strategy (e.g. Spain).

Norway positively stands out in view of its documented strong research and legislative framework to combat OA in spite of the fact that OA observed across the Arctic Ocean has become increasingly apparent, based on the most recent and extended time-series [59]. Evidently, more work is needed to mitigate OA and its impacts in this regional sea.

It is interesting to note that national policies rarely emphasised the overarching element of the MSFD, which is seen as a binding Directive that supports Europe's Integrated Maritime Policy. The little emphasis given to the MSFD by the country responses leads us to think whether this Directive still needs time to immerse itself in the overall essence of marine protection in Europe. Perhaps this is because MSFD's regulatory ambition remains highly restrictive, often understood as a supplementary community legal framework within which existing and future community measures towards environmental conservation are to be further developed and enhanced. Moreover, the way to determine GES ultimately rests on each of the Member States, based on the Descriptors set out in Annex 1 of the Directive. Further limitations are described

below [6,7].

3.2. (b) MSFD Initial Assessment, good environmental status, and targets

The analysis of the MSFD Initial Assessment Reports highlight firstly the *level of understanding* and secondly the implementation, if any, of initial steps to successfully address all GES Descriptors since the adoption of the MSFD Directive by EU Member States.

The mapped qualitative results based on the analysis of the country reports under Article 12 - Technical Assessments of MSFD (Descriptor 7 - Hydrography), is shown in (Fig. 2). While the Initial Assessments published by Italy and the Netherlands were considered as having adequate information of hydrographical changes including pH, countries like Germany, Greece, and the UK have been found to be partially adequate and with significant gaps in knowledge about the problem of OA. Inadequate information on OA was found in the Initial Assessments submitted by Finland, Latvia, Lithuania, Romania, Cyprus and Malta. At the other extreme, there was a complete lack of reporting on the state of OA by countries like Sweden, Denmark, Belgium, France, Spain, Portugal, Bulgaria, Czech Republic and Estonia. Norway has been omitted from this part of the analysis since, as an EEA country, it has not adopted the MSFD as a management framework for marine governance.[8,9]

4. Discussion and conclusions

We know that OA is a highly complex physico-chemical and geopolitical [60] issue touching upon environmental, economic, and social impacts [37]. Without the oceanic sequestering of almost a quarter of anthropogenic CO_2 emitted, the planet would be experiencing more severe effects of planetary warming and climate change than we already are today. The risks of GHG emissions and particularly CO_2 have been known in the international sphere since 1950; however, discussions about mitigation and adaptation addressing OA did not occur until the United National General Assembly in 2005 [61], and EU-financed research programmes did not initiate targeted programmes on OA until 2008 [62]. Yet, even after the initiation of these research programmes, there are still many unknowns surrounding the effects of OA either in the exclusive economic zones of the EU Member States or in marine areas beyond national jurisdiction [52]. The problems associated with and the solutions needed to address OA are unique and cannot be bundled together with traditional climate change responses and measures. Therefore, tailor-made actions are necessary to specifically address the imminent problem of OA and EU policy and legislation must reflect this.

Our analysis of EU Member States' action on OA (details in Appendix A) shows that: 1) the current status of European national policies and legislation addressing the OA problem is, where existent, uncoordinated; and 2) although the OA problem is acknowledged at the higher levels of governances (e.g. The European Commission, 2019[10]), it is greatly diluted at EU Member State level. Indeed, OA is hardly a priority area for action for many EU Member States, including inland States and marine regions and sub-regions under the MSFD whose (non-) contribution to OA is indisputable. To safeguard marine ecosystems, it is evident that stronger multi-level governance is required to build environmental, economic, and social resilience of the observed and anticipated changes to the coastal marine systems.

Since the inception of the climate change legal regime, a number of multilateral agreements have been adopted by the EU, but which albeit lead only to a fraction of the solution needed to curb the OA problem. Positive climate action, such as the European Commission's position in April 2009 on adaptation to climate change [63] and the adoption of the Adaptation Strategy Package COM/2013/216 by the European Union, has seen a move towards reducing the European Union's vulnerability to the impacts of climate change in general. The latter action by the European Union emphasizes that climate change adaptation decisions must be based on solid scientific and economic analysis, of which this one document touches upon water, coasts, and marine issues. The European Green Deal[11] and the recent Commission Proposal for a European Climate Law[12] intend to give a greater role to climate adaptation in EU policy. However, no specific framework for OA has yet been included.

Despite the lack of direct action, OA has emerged as a reoccurring topic of the annual "research dialogue" between the scientific community and UNFCCC Parties [64], subsequently leading to a number of research initiatives at the pan-European level to try to understand the state and impact of ocean acidification. These include MEDSEA[13] (concluded in 2014), VECTORS[14] (concluded in 2015) and MEECE.[15] For example, the MEDSEA project assessed uncertainties, risks, and thresholds related to Mediterranean OA at the organism, ecosystem, and economic levels; while, VECTORS focused on the effect of OA on biodiversity, fisheries, and aquaculture; and MEECE addressed issues such as the effects of climate change on marine ecosystems and human activities in the Mediterranean Sea, the Atlantic Ocean, the Baltic Sea, and the Black Sea. Other past 'flagship' research projects include EPOCA[16] (concluded in 2012), BIOACID[17] (concluded in 2017), and UKOA[18] (concluded in 2015). Through the Horizon 2020 Research and Innovation Programme and the COPERNICUS (Global Monitoring for Environment and Security) major advances have been made to improve data collection and processing of the ocean and its resources.[19] A major contribution made through the Horizon 2020 Research and Innovation Programme to climate-related ocean observations is through the ATLANTOS project[20] (concluded in 2019). Other Horizon 2020-funded projects include the INTAROS project[21] (ongoing till 2021), which extended the observations collected through ATLANTOS to the Arctic Ocean. Regarding the impact of climate change on fisheries and aquaculture, there are also other Horizon 2020 funded projects (CERES[22]; ongoing till 2020) which address the threats and opportunities that the aquatic primary production sector is facing and develop adaptation strategies.

[6] http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/countries

[7] http://marineregions.org/

[8] http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/countries

[9] http://marineregions.org/

[10] https://ec.europa.eu/commission/commissioners/2014-2019/vella/announcements/speech-commissioner-vella-high-level-conference-climate-change-and-oceans-preservation_en

[11] Commission (EU), 'The European Green Deal' (Communication) COM (2019) 640 final, 11 December 2019.

[12] Commission (EU) Proposal for a 'Regulation Establishing The Framework For Achieving Climate Neutrality And Amending Regulation (EU) 2018/1999 (European Climate Law) COM(2020) 80 final, 4 March 2020.

[13] http://medsea-project.eu/

[14] http://www.marine-vectors.eu/

[15] http://www.meece.eu/

[16] https://www.oceanacidification.de/epoca-european-project-on-ocean-acidification/?lang=en

[17] https://www.oceanacidification.de/

[18] http://www.oceanacidification.org.uk/

[19] 21 February 2017; European Union and its Member States contribution for the 2017 United Nations Informal Consultative Process on Oceans and the Law of the Sea - 'The effects of climate change on oceans': European Union.

[20] https://www.atlantos-h2020.eu/

[21] http://cordis.europa.eu/project/rcn/205992_en.html

[22] http://ceresproject.eu

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Programme of the European Union

4.1. The science-policy nexus and the lag effect

Clearly, there are limitations in governance addressing OA, as this study shows how the OA problem is still not seen as a priority by many EU Member States. A review of some important and relevant EC communications shows that they completely miss the OA problem (such as the Report from the Commission to the European Parliament and the Council on the implementation of the EU Strategy on Adaptation to Climate Change: COM/2018/738) while others mention OA as one of the climate change effects and problems, without proposing any related climate proofing actions (such as Report from the Commission to the European Parliament and the Council on the Implementation of the EU Strategy on Adaptation to Climate Change: SWD/2018/460). This is hardly surprising given 1) the moderate understanding of OA at local, regional and global scales, and its ramifications into socio-political spheres; and 2) challenges associated to governance of a situation that inconveniently sits at the intersection between water and air quality issues. The lack of any rapid responses directly aimed to curb OA is perhaps due to untimely political and/or unclear scientific repercussions into the extent and impacts of OA [65]. Diaz and More [66] draw attention to actions that can be challenging or impossible to implement for those impacts that have no historical analogue or where the spatial or temporal variation of the climate driver is insufficiently large, such as the case for OA. The work of the European Marine Board (http://www.marineboard.eu) as the leading think tank in marine science policy becomes therefore highly relevant and timely in this respect.

For example, there is still a significant lack of studies that look at the designation of future marine refugia [67] or where Marine Protected Areas (MPAs), should be assigned to assist the regeneration of ecosystems that are threatened by OA [68]. According to Naritaa & Rehdanz [69], studies that quantify the economic impact of OA are also lacking. The limitation of the above aspects has hindered research based strategic solutions in order to build resilience. Currently at the European level there is no structure to apply MPAs, Strategic Environmental Assessments (SEA), and Environmental Impact Assessments (EIA) as crucial tools for enhanced adaptation measures in areas beyond national jurisdiction [70].

In view of the seriousness of the OA problem, a way forward could be to enact specific legislation that would be able to steer OA mitigation through continued assessments in understanding the nature of the risks posed by OA in local, regional and international waters. To this end, vulnerability assessments will help identify gaps where further research could be most useful and show whether appropriate adaptation strategies are giving the desired results. There is no shortage of justifications in favour of this approach and legislation, which could refer to economic factors, such as the detrimental impact of OA on millions of jobs and livelihoods, cultures and ways of life that are dependent on ocean resources [71]. Within a European dimension, this process could well mimic the development of the Nitrates Directive (91/676/EEC), which is one key instrument in the protection of waters against agricultural pressures leading to eutrophication. In a similar way, an OA Directive could well be a new instrument for the WFD towards the reduction of aquatic pollution (in this case by increased dissolution of CO_2).

The EU MSFD could also be used more comprehensively towards OA abatement. As seen from this study, national responses however, scarcely acknowledge or refer to the potential overarching impact that the MSFD can have in the monitoring and assessment of OA in European waters as part of its goal to achieve Good Environmental Status (GES) by 2020. This is carried out by establishing environmental targets and associated indicators using an appropriate monitoring programme within an adaptive management framework that requires reviewing every 6 years. However, out of a total of 11 indicators the closest ones that relate to OA are primarily indicator D7 ('protect hydrographical conditions'), followed by D1 ('maintain biological diversity'), and D5 ('minimise human-induced eutrophication and their adverse effects').

Given the centrality of the MSFD in achieving good marine environment status in waters of the EU Member States, we can start by considering the expected synergies between the MSFD and a number of relevant Directives such as the WFD and the Nitrates[23] Directives (ND), which are likely to influence OA in coastal locations of the EU. Both the WFD and ND share a close connection with the MSFD in terms of content, objectives and regulatory design with the aim of managing interlinked ecosystems. In this regard, the MSFD is seen by many as the next cohesive framework aimed at ecosystem-oriented management of water resources at the European level, which stipulates an increased resilience of coastal ecosystems against an increasingly acidic ocean environment as long as GES is achieved. However, criticism is often directed towards the general lack of efficacy of the MSFD. This is due to the fact that 1) no quantitative thresholds are set in this Directive, thus making the attainment of GES and its targets as qualitative at best; 2) the environmental targets are only trend-based or interim; and 3) it does not promote regional or any sub-regional cooperation to facilitate that attainment of GES. These facts are hereby seen as significant hurdles to combat OA at the EU level.

Given this, we suggest a number of recommendations for policy-makers in both coastal and inland European countries. First, incentivise continued collaborative OA-focused research and build a European-wide ocean resilience program that addresses OA, including inland European Member States. Secondly, encourage greater transnational marine corridors and transitional societies to adjust to the long-term consequences of OA. Third, ameliorate European-wide coordinated governance and improve national GES and MSFD reporting on OA. Fourth, raise awareness among policy-makers of the unique threat, actions, and solutions needed to mitigate OA; make a stronger and coordinated EU policy and legislation directly addressing OA; and finally, raise public awareness of the social-economic and environmental impacts of OA. In allowing for the public dissemination of scientific knowledge as a tool to inform and update the public of the current state and future actions of the EU to combat OA, we might bridge the science-policy gap in the case of OA, and perhaps make people a case about the topic – even in the age of the plasticene.

[23] Especially with reference to its definition of Nitrate Vulnerable Zones; http://ec.europa.eu/environment/water/water-nitrates/index_en.html

Author contributions

C.G. and R.G. conceived the study and were in charge of overall direction and planning. C.R., R.T. and F.M. made a substantial contribution to revising the manuscript prepared by C.G. All authors made a substantial contribution to the acquisition of country data, discussed the results and provided input to the manuscript.

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Appendix A

Belgium: This country has a good number of national policies and legal frameworks in favour of positive climate action: from the policy side, Belgium has its own National Climate Plan,[24] the Flemish Mitigation Plan (2013–2020),[25] the Air Climate Energy Plan (2016–2022),[26] the Walloon Air Climate Energy Plan (2016–2022),[27] the Brussels Regional Air Climate Energy Plan (2016)[28] all of which are supported by an appropriate legislative framework. Such policies however, do not mention the problem of OA, nor does it feature in Belgium's Law for the Protection of the Marine Environment (1999).[29] It is good to point out that the other laws designated to protect the marine environment, such as the two Royal Decrees concerning the maritime strategy for Belgian maritime zones (2010) and the determination of a framework for achieving good surface water status do partly address the understanding and mitigation of the OA problem. The Belgian National Adaptation Strategy (2010)[30] and Plans (2017–2020)[31] detail the main impacts of climate change and related adaptation measures needed for different Belgian sectors, including those concerning ocean and coastal zones, but not specifically directed towards the OA problem. The latter continues to be ignored even from recent reporting on climate action, such as the MIRA Climate Report of 2015 on perceived and future climate changes[32] and Belgium's 7th National Communication and Third Biennial Report on Climate Change under the UNFCCC, published in2017.[33] From a monitoring point of view, Belgium has participated in the Joint OSPAR/ICES Ocean Acidification Study Group (2015)[34] and has been active in the monitoring of a number of physico-chemical parameters including oxygen (since the 1980s), pH (since 1985), nutrients (since end 1980s), DOC/POC (since 2000), PN (since 2000), total alkalinity (since 2014), organic pollutants (since approximately 1985), chlorophyll, salinity, temperature, and conductivity.[35] The 5th National Report to the Convention on Biological Diversity (2014)[36] mentions the need to focus on 'Target 10' of the Convention (i.e. ocean acidification) and to this effect, the Federal Government has taken steps to start monitoring marine ecosystems beyond Belgian waters. Score: 1.

Croatia: Nineteen national climate-related laws and policies addressing energy efficiency, alternative fuels, renewable energy, air protection, environmental protection, and forestry, amongst others are currently keeping the Croatia in line with positive climate action. The Air Protection Act[37] sets the goals and priorities for the protection of air, the ozone layer, and mitigation of climate change containing among others measures that reduce individual pollutants that cause adverse effects of acidification of the environment. The Nature Protection Act[38] defines nine categories of spatial protection, and includes water and coasts. In 2017 the Ministry of Environment and Nature Protection published a white paper for Strategy for climate change adaptation for the period 2040 with a view to 2070[39]. This white paper addresses in a consistent manner the impact of increased acidity to coastal and marine resources as well as possible responses to mitigate this. The Strategy and Action Plan for the Protection of Biological and Landscape Diversity (NBSAP)[40] is the fundamental document for nature protection and lays down long-term objectives and guidelines for the conservation of such diversity, and methods for implementation thereof, in accordance with sustainable development practices with particular emphasis on marine fisheries and water management. The 5th National Report to the Convention on Biological Diversity of 2014[41] that focuses on the latest developments in biodiversity conservation shows that the synergy between nature protection and the marine fishery sector is growing. It is only in the latter Report that the OA problem is mentioned, specifically under Target 8 (KZ 10 & CBD [C]), namely to reduce by 2020 land-based pollution to the extent that is not detrimental to ecosystem function and biodiversity. Score: 1.

Czech Republic: A total of four legislative and policy documents related to positive climate action in general were analysed. As an EU member country since 2004, the Czech Republic is obliged to curb greenhouse gases in line with the Energy and Climate Package of the European Commission as well as aligning its legislation with all relevant Directives. It has also put in place a number of policies and strategies aimed at reducing carbon emissions as well as minimizing the risk of climate change as stipulated by the National Strategy on Adaptation to Climate Change of 2015[42] and the National Action Plan for Adaptation

[24] http://www.klimaat.be/files/6513/8235/7976/NKP_2009-2012-2.pdf
[25] https://www.vlaanderen.be/nl/publicaties/detail/vlaams-mitigatieplan-2013-2020
[26] http://www.awac.be/images/Pierre/PACE/Plan%20Air%20climat%20%C3%A9nergie%202016_2022.pdf
[27] http://www.awac.be/index.php/en/thematiques/politiques-actions/plan-pace
[28] http://environnement.brussels/thematiques/air-climat/laction-de-la-region/air-climat-et-energie-visionintegree?view_pro=1&view_school=1
[29] http://www.ejustice.just.fgov.be/cgi_loi/loi_a.pl?language=nl&caller=list&cn=1999012033&la=n&fromtab=wet&sql=dt=%27wet%27&tri=dd+as+rank&rech=1&numero=1
[30] http://www.klimaat.be/files/1513/8269/7947/NASpublicatiedruk.pdf
[31] http://www.klimaat.be/files/4214/9880/5755/NAP_EN.pdf
[32] https://en.vmm.be/publications/mira-climate-report
[33] http://www.klimaat.be/files/4315/1549/8156/NC7_EN_LR.pdf
[34] http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2014/SGOA/sgoa_finalOSPAR_2015.pdf
[35] http://www.mumm.ac.be/datacentre/
[36] https://www.cbd.int/doc/world/be/be-nr-05-en.pdf
[37] http://extwprlegs1.fao.org/docs/pdf/cro104988.pdf
[38] https://www.hah.hr/pdf/Nature_Protection_Act.pdf
[39] http://prilagodba-klimi.hr/wp-content/uploads/docs/Draft%20CC%20Adaptation%20Strategy.pdf
[40] https://www.cbd.int/doc/nbsap/nbsapcbw-eur-02/nbsapcbw-eur-02-hr-01-en.pdf
[41] https://www.cbd.int/doc/world/hr/hr-nr-05-en.pdf
[42] https://www.mzp.cz/en/strategy_adaptation_climate_change

to Climate Change of 2017. However, only the National Strategy on Adaptation to Climate Change makes specific mention of the impact of greenhouse emissions on increased risks due to OA. Interestingly, the Czech Republic has a National Climate Programme aimed at acquiring and monitoring climate data over its territory to estimate the impacts of the climate on society. As far as the sectoral management of the problem is concerned, Czech legislation omits OA due to the fact that the country is an inland State and therefore such a topic is not too frequently discussed at both public and institutional levels, in comparison to other adverse climate change impacts, such as extreme weather events. Score: 1.

Denmark: As an EU member State, Denmark has adopted legislation in line with EU directives aimed at both mitigating emissions of GHGs from sources and increasing uptake by sinks. In 2008 Denmark adopted its Strategy for Adaptation to Climate Change, followed by an Action Plan for a climate-proof Denmark, launched in 2012.[43] The Strategy sets up national guidelines for adaptation, i.e. a framework where municipalities have the role to develop specific rules of adaptation. This means that adaptation is understood in a municipality-local way and the focus is mainly on hydrological flooding. OA is not mentioned in any of these documents. Similarly, the Greenlandic initiative 'Opportunities for climate change adaptation in the fisheries and hunting industry' does not include acidification. No specific mention is reported as part of national research programmes on climate change by the three main Danish institutes namely the Danish Centre for Environment and Energy, the Danish Meteorological Institute, nor the Danish Council on Climate Change. Moreover, no integration of OA into sectoral policy and laws is reported. Following the Danish Climate Policy Plan: Towards a Low Carbon Strategy adopted in 2014, Denmark adopted the Danish Climate Change Act as the legal framework for climate action devoted to mitigation. OA does not feature per se in this piece of legislation. In December 2019, a new climate instrument[44] was adopted aiming mostly at mitigation and carbon neutrality. Score: 1.

France: One of the primary initiatives that contribute to mitigate OA is the National Low-Carbon Strategy adopted in 2015.[45] Although it covers ocean and coastal areas, this strategy does not explicitly mention OA. In the same way, France's National Adaptation Plan to Climate Change[46] adopted in 2011 (and currently under review), does not relate to OA per se but at strengthening the management of MPAs. The 2017 National Strategy for the ocean and coasts mentions OA and the French National Research Agency generally includes the study of OA in territorial coastal waters as part of its national research programmes.[47] Specific capacity building towards the further understanding and evaluating the extent and impact of OA was also conducted through the 2015–2016 Joint Research Call on ocean OA point of interest is the inclusion of actions to mitigate OA within sectoral policies and laws in order to address the existing gap of current policies and laws as far as their effectiveness is concerned. France has participated and lead European Research Projects on Ocean Acidification, such as (EPOCA; 2008–2012), and in the Ocean Acidification International Coordination Centre (OA-ICC) led by IAEA. Score: 2.

Germany: A rather ambitious national approach has been put in place in Germany in the form of a Climate Protection Plan 2050.[48] In 2016 the Federal Government activated national objectives for carbon neutrality for 2050, which includes paths of transformation and framing objectives for a range of sectors including energy, industry, agriculture, transport, and agriculture. In this plan there is no reference to OA regardless that its success depends on a long-term integrated and systematic approach that considers the SDGs 14 & 15. The German Ocean Protection and Sustainable Fishing (10 Point Action Plan) takes a global perspective as far AS assisting partner countries to reduce pollution, adapt to climate change, promote sustainable fisheries, and promote the development of marine protected areas, among others. In line with this Plan, the Federal Government is committed to fund research projects that are focussed on the relationship between ocean warming and acidification, including abrupt and irreversible damage to marine ecosystems with the aim of identifying ways of dealing with potential ecological tipping points. Another important national action that addresses OA is the German Climate Adaptation Strategy (2008), which states the need to limit all factors and activities which lead to warming and acidification,[49] by considering the development of strategies for dealing with uncertainties. It is interesting to note that the urgent mitigation of OA was one of the core messages issued by the German Advisory Council on Global Change in 2006. Germany has lead in European research consortiums on Ocean Acidification for example (BIOACID; 2012–2015). Score: 1.

Greece: Actions refer to those national policies and measures aimed at mitigating future GHG emission projections at sources and by sinks[50]. As above, these approaches are not specifically tailored to reduce OA. Greece's climate change policy, strategy and programme plans are set out as part of its National Climate Change Programme, with a latest revision in 2007.[51] Although positive climate action in favour of coastal areas has been specifically included in this Programme (see section 4.7), mitigation and adaptation measures related to OA are only indirectly mentioned. The recent publication of the national annual report that looks at the environmental, economic and social impacts of climate change in Greece does not mention those arising from continued OA in territorial and offshore waters.[52] Score: 1.

Italy: In 2015 Italy published its national policies and measures to mitigate future GHG emissions from sources and removal by sinks.[53] However, mitigation of OA is reported to be beyond the remit of these policies and strategies. Both the evaluation of the current state and actions towards increasing the resilience of the marine ecosystems to climate change impacts do feature in both the national Adaptation Strategy[54] and Plan for Climate Change of 2016[55] as well as by the 6th National Communication to UNFCCC[56]; however, they do not mention any reduction of, or adaptation to expected reduction of OA. The Communication Report highlights a number of scientific research consortia and programmes aimed at assessing climate change impacts, vulnerability and adaptation in terrestrial and ocean environments. National reports make a specific mention of Italian participation in a number of important research programmes including the European Project on Ocean Acidification (EPOCA; 2008–2012), in the European

[43] http://www.klimatilpasning.dk/

[44] Aftale om Klimalov, 6 December 2019. https://kefm.dk/media/12965/aftale-om-klimalov-af-6-december-2019.pdf

[45] https://www.ecologique-solidaire.gouv.fr/sites/default/files/SNBC_France_low_carbon_strategy_2015.pdf

[46] https://www.ecologique-solidaire.gouv.fr/adaptation-france-au-changement-climatique#e4

[47] https://www.ecologique-solidaire.gouv.fr/sites/default/files/SNML-Brochure-.pdf

[48] https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_bf.pdf

[49] https://www.bmu.de/fileadmin/bmu-import/files/pdfs/allgemein/application/pdf/das_gesamt_bf.pdf

[50] http://cdr.eionet.europa.eu/gr/eu/ghgmm/envsg1jtq/20090515_Resubmission_of_GHG_Projections_and_PAMS_May_2009.pdf

[51] http://www.ypeka.gr/LinkClick.aspx?fileticket=crbjkiIcLlA%3d&tabid=303&language=el-GR

[52] http://www.bankofgreece.gr/BogDocumentEn/PrefaceSummary.pdf

[53] http://cdr.eionet.europa.eu/it/eu/mmr/art04-13-14_lcds_pams_projections/envvt4naa/2015_Italy_Climate_Policy_Progress_Report_IT.pdf

[54] http://unfccc.int/files/national_reports/annex_i_natcom/submitted_natcom/application/pdf/ita_nc6_resubmission.pdf

[55] http://www.minambiente.it/sites/default/files/archivio/allegati/clima/documento_SNAC.pdf

[56] http://unfccc.int/files/national_reports/annex_i_natcom/submitted_natcom/application/pdf/ita_nc6_resubmission.pdf

Mediterranean Sea Acidification in a changing climate (MEDSEA; 2011–2014) and in the Ocean Acidification International Coordination Centre (OA-ICC) led by IAEA. These programmes address issues related to the measurement and impacts of OA. The Ministry responsible for scientific research has funded a two-year national program specifically addressing impact of OA in Italian seas (ACID.it 2014–2017) and the impact of OA is explicitly mentioned in at least one regional plan for climate change. Score: 2.

Malta: Both the latest National GHG Emissions and Removals Inventory of 2016 and the National Strategy for Policy and Abatement Measures aim focus on climate change mitigation.[57] However, both measures do not specifically address the protection of the coastal zones, nor the reduction of OA. The National Climate Change Adaptation Strategy[58] published in 2012 does not make any reference to OA. While the recently enacted Climate Action Act of 2015 addresses climate change mitigation and adaptation as far as coastal and marine ecosystems are concerned, this important piece of legislation does not specifically address the OA problem. As far as current local knowledge on trends and impacts of climate change is concerned, knowledge about OA in coastal waters is considered to be very poor. It is encouraging to note that OA is addressed by Malta's National Biodiversity Strategy and Action Plan for the period 2012–2020.[59] Mitigation of the OA problem is actually part of the Strategic Goal No. 2 of this Action Plan. Score: 1.

Norway: Unlike other countries, the state of OA and its impacts on the marine environment are frequently referred to by Norwegian climate-related policies[60]. In fact, the country has committed itself to several international treaties and programmes that address OA. These include OSPAR,[61] RAMSAR,[62] and CBD.[63] The work programmes of national research programmes on climate change, such as Klimaforsk,[64] MarineForsk,[65] and Framsenter[66] furthermore specifically address research activities dedicated to OA for the period 2014–2024. The Norwegian government has also strived to integrate the mitigation of OA into sectoral policy and legislation that deal with the sustainability of regional seas. The Norwegian Environmental Agency for example, is responsible for the monitoring of OA with the aim to study the current distribution, levels, and rates of change in pH and of the carbonate system in all Norwegian oceanic and coastal areas.[67] The coastal monitoring programme for ecosystem sustainability (Økokyst[68]) which has been active since 2013, partners closely with the national OA monitoring programme. Score: 3.

Poland: Upon investigation of national legal documents, policies, and strategies, Poland does not mention OA other than the importance for integration of the ocean and coastal zones in its Climate Policy and Strategy for Adaptation to Climate Change.[69] The National Urban Adaptation Plans[70] address the implementation of adaptation plans to climate change for which the sustainability of the ocean and the coastal zones is highlighted, but which fail to mention specifically the need to mitigate and adapt to OA. However, Poland is currently addressing indirectly this problem through a good number of EU[71] and international obligations such as OSPAR, HELCOM, and UNFCCC. Its 2014 monitoring programme for national marine waters under the MSFD framework refers to monitoring of pH in its coastal waters.[72] Score: 1.

Portugal: Portugal has its own National Adaptation Strategy for the period 2020–2030. This strategy is multisectoral in nature and aims at collection of information and knowledge, minimizing vulnerability and strengthening responsiveness, and national awareness-raising. The National Strategy for Climate Change (2020–2030), for example, brings together a set of sectoral implementations of policies and measures. The Strategic Framework for Climate Policy establishes guidelines in favour of an integrated framework of climate policy by 2030, including the compliance with the Kyoto Protocol and the Paris Agreement. Although generic in nature, mitigation can indirectly lead to the reduction of impacts due to OA. The Azores Regional Strategy for Climate Change[73] and the CLIMA-Madeira Strategy[74] define some priority actions for the implementation of climate-action strategies in a number of relevant sectors. However, specific actions towards the mitigation of OA and its impacts in territorial waters in national and regional documents are missing. Score: 1.

Republic of Ireland: Several national policies, strategies and legislation addressing energy efficiency, sustainable transport and agriculture were assessed for any direct references or links to the abatement of OA in national waters. The key documents were considered to be the National Mitigation Plan of 2017 (which seeks to decarbonise the economy by 2050) and the 4th National Energy Efficiency Action Plan of 2017 in line with EU's Energy and Climate Package. The Climate Action and Low carbon Development Act of 2015 (which is the legal basis for the corresponding 2014 National Policy position of Ireland) was also reviewed. However, all fail to mention the problem of OA. On the other hand, the transportation of the MSFD in 2011 and Ireland's obligations to the OSPAR Convention of 1992 bind the country to address the environmental status of its coastal waters, particularly the problem of OA. The OSPAR 2012 Quality Status Report for the North East Atlantic also identifies OA as a key threat on the preservation of marine ecosystems (p.21[75]). It is encouraging to note that in its 2010 publication entitled 'Ocean Acidification: An Emerging Threat to our Environment',[76] the Irish Marine Institute recognises the problem of OA. The Institute also acknowledges the need to identify appropriate monitoring and research requirements by recommending practical actions to mitigate and avoid OA impacts. Therefore, it seems that Ireland's

[57] https://environment.gov.mt/en/Document/Repository/Malta_Climate/Change/Adaptation/Strategy/National/Climate/Change/MITIGATION/Strategy.pdf

[58] https://environment.gov.mt/en/Document_Repository/Malta/Climate/Change/Adaptation/Strategy/National/Adaptation/Strategy.pdf

[59] https://www.cbd.int/doc/world/mt/mt-nbsap-01-en.pdf

[60] https://www.regjeringen.no/no/dokumenter/meld-st-21-2011-2012/id679374/sec1

[61] https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/climate-and-ocean-acidification/climate-and-ocean-acidification-summary-headlines/

[62] http://www.ramsar.org/news/ramsar-focuses-on-arctic-wetlands

[63] http://old.unep-wcmc.org/impacts-of-ocean-acidification-on-marine-biodiversity_154.html

[64] https://www.forskningsradet.no/prognett-klimaforsk/Programme_description/1253987906604

[65] https://www.forskningsradet.no/prognett-marinforsk/Home_page/1254009007177

[66] http://www.framsenteret.no/havforsuring-i-nordlige-farvann.178638.no.html#.WgGfZabrt9A

[67] http://www.miljodirektoratet.no/no/Tema/Miljoovervakning/Naturovervaking/Hav-og-kyst/Havforsuringsovervakning/

[68] http://www.miljodirektoratet.no/no/Tema/Miljoovervakning/Naturovervaking/Hav-og-kyst/Okoystemovervaking-i-kystvann/

[69] https://klimada.mos.gov.pl/wp-content/uploads/2014/12/ENG_SPA2020_final.pdf

[70] http://klimada.mos.gov.pl/en/mpa-project-urban-adaptation-plans/

[71] http://cdr.eionet.europa.eu/pl/eu/

[72] http://cdr.eionet.europa.eu/pl/eu/msfd_mp/msfd4text/envvypola/Program_monitoringu_wod_morskich_-_RM.pdf

[73] ComClima, 2011. Estratégia Regional para as Alterações Climáticas (ERAC). Região Autónoma dos Açores (RAA). Comissão para as Alterações Climáticas (ComClima). 31p. http://servicos-sraa.azores.gov.pt/grastore/SRAM/Resolu%C3%A7ao%20-%20estrat%C3%A9gia%20para%20as%20altera%C3%A7%C3%B5es%20clim%C3%A1ticas.pdf

[74] Gomes, A., Avelar, D., Duarte Santos, F., Costa, H. e Garrett, P., 2015. Estratégia de Adaptação às Alterações Climáticas da Região Autónoma da Madeira. Secretaria Regional do Ambiente e Recursos Naturais. 146 p. http://clima-madeira.pt/uploads/public/estr_clima_web_yeyxxt.pdf

[75] https://qsr2010.ospar.org/en/media/chapter_pdf/QSR_complete_EN.pdf

[76] https://oar.marine.ie/bitstream/handle/10793/80/No.%206%20Ocean%20Acidification%20Foresight%20Report.pdf?sequence=1&isAllowed=y

recognition of the threat of OA to marine life seems to be strongly research-driven. More recently, the Declaration of a Climate and Biodiversity Emergency resulted in the preparation and adoption of a Climate Action Plan (June 2019) which commits Ireland to achieving a net zero carbon energy systems objective. However, the Climate Action Plan makes no direct reference to OA and no specific objectives appear to be included to mitigate the problem. Therefore, the policy response to date on reducing OA is firmly focussed on lowering greenhouse gas emissions by implementing sectoral action plans that have been devised to transition Ireland to a 'climate resilient and low carbon economy'. Score: 2.

Romania: The recent Law on Industrial Emissions of 2013 (LEGE 278/2013) that[77] addresses an integrated prevention and control of such pollution. However, it does not provide any references to neither ocean nor coastal zones, nor specifically to OA. Another important piece of national legislation which unfortunately omits the issue of OA in Black Sea is the Emergency Ordinance for the Transposition of the European Marine Strategy of 2012[78] with the scope of transposing the MSFD into Romanian legislation. An official communication issued by the Romanian Government in 2014 shows that the country has completed an update of its national monitoring programme (Art. 11)[79] to address the MSFD requirements in coastal waters. However, this programme, which also responds to other obligations (such as those imposed by the European Water Framework Directive and the Convention for the Protection of the Black Sea against Pollution), does not mention any specific actions directed towards the assessment and abatement of marine acidification. A similar situation is met when considering the Integrated Coastal Management Act of 2013,[80] which is naturally aimed at the sustainable development of the coastal zone, including the comprehensive preservation of its ecological integrity but only in generic terms. Additional Romanian legislation based on the transposition of Directives such as the Bathing Water Directive (transposed in Romanian legislation in 2015[81]), the Nitrates Directive (91/676/EEC) and the Habitats Directive (92/43/EEC) fail to address the OA problem directly. A unique, official document that seriously considers both this problem and the need to assess the state of OA in territorial waters is the 2012 publication of a document published by the National Institute for Marine Research and Development.[82] Score: 1.

Slovenia: As part of EU's Energy and Climate Package, the country has adopted the Decision 406/2009/EC to mitigate the emissions of GHGs.[83] Even though this Decision does not mention OA *per se*, the reduction of GHG emissions can be partly seen as a measure leading to the reduction of OA. Slovenia's National Climate Change Adaptation Strategy[84] of 2016 has been specifically formulated in a way to reduce exposure, sensitivity and vulnerability to climate change impacts and an increase in the resilience and adaptive capacity of society. Nevertheless, it does not specifically refer to any actions that particularly mitigate the OA problem. An interesting aim is that of Slovenia's plan to analyse by 2019 the projected climate change impacts on the coastal zone, amongst others. Although not yet specified, the projected impacts of OA could well be included in the list of projected impacts. It is being reported that the important Decree on the marine environment management plan of 2017 does not make any specific reference to the problem of OA.[85] Score: 1.

Spain: Measures contributing to sustainable development within the climate and clean energy theme are being supported by the Spanish Climate Change and Clean Energy Strategy.[86] This strategy aims to ensure the reduction of GHG emissions as well as the adoption of related measures and within various sectors. Substantial reference is given by this Strategy to ocean and coastal zones; however, OA is only referred to once in the document, as part of a general measure in support of sustainable development. No reference to OA is found in the Spanish National Climate Change Adaptation Plan published in 2006[87] in spite of the fact that Spain is currently developing a strategic plan, as part of its third work programme (2014–2020), for the adaptation to climate change impacts. Worth mentioning is the Strategy for the adaptation of the coast to climate change impacts (recently adopted in July 2017) that identifies OA as a factor of change related to climate.[88] Of particular relevance is Spain's Law of 2013 for the Protection and Sustainable Use of the Littoral[89] that deals with the adaptation to climate change impacts on the coast. Even though this piece of legislation is considered to be the most important legal instrument to tackle the problem of climate change in Spanish coastal areas, there is as yet no mention of the phenomenon of OA. The Spanish Law for the Protection of the Marine Environment of 2010[90] does consider OA as an essential parameter to monitor and abate in order to achieve good environmental status as requested by the Marine Strategy Framework Directive. Since 2012, the Spanish government has provided annual research funding aimed at mitigating GHG emissions from sectors that are not subjected to the ETS. No information is available as to the effectiveness of the past funded projects to mitigate the OA problem. Score: 2.

United Kingdom: The basis of UK's approach to tackling and responding to climate change is through its Climate Change Act of 2008.[91] This legislation addresses both the curbing of emissions of GHGs as well as the adaptation needed towards risk reduction. In addition, the Act requires the Government to assess the risks and opportunities arising from climate change. This is done by means of the National Adaptation Programme of 2013 which sets out what government businesses and society are doing to adapt better to the changing climate. There are many instances where this programme refers to the actions needed to combat OA since the latter is seen as one of the main risks arising from a changing climate (CCRA Risk: MA3; p71[92]). In UK, scientific work on OA and its impacts has been carried out by a wide range of public and private UK research groups,[93] which has been primarily brought together by the 5-year long UK Ocean Acidification research programme (UKOA 2010–2015). The objectives of this programme were to increase the understanding of the OA process and to reduce the uncertainties in predicting its impacts in the marine environment. However, the integration of OA into sectoral policies and legislation seems to be deficient. For example, some potentially pertinent pieces of legislation including

[77] http://www.lege-online.ro/lr_LEGE_278_2013_(152286)_(1).html
[78] http://www.mmediu.ro/beta/wp-content/uploads/2012/06/2012-06-01_OUG_71_2010.pdf
[79] http://apepaduri.gov.ro/wp-content/uploads/2014/07/Directiva_cadru_strategie_marinaOK.pdf
[80] http://apepaduri.gov.ro/wp-content/uploads/2014/07/oug-2002-zona-costiera.pdf
[81] http://mmediu.ro/new/?page_id=3595
[82] http://www.mmediu.ro/beta/wp-content/uploads/2012/07/2012-07-17_evaluare_impact_planuri_evaluareinitialamediumarin.pdf
[83] http://www.mop.gov.si/si/delovna_podrocja/podnebne_spremembe/delitev_bremen_med_drzavami_clanicami_za_zmanjsevanje_emisij_toplogrednih_plinov/
[84] http://www.mop.gov.si/fileadmin/mop.gov.si/pageuploads/podrocja/podnebne_spremembe/SOzP_ang.pdf
[85] http://www.pisrs.si/Pis.web/pregledPredpisa?id=URED6974
[86] http://www.mapama.gob.es/es/cambio-climatico/publicaciones/documentacion/cle_ene_pla_urg_mea_tcm7-12478.pdf
[87] http://www.mapama.gob.es/es/cambio-climatico/temas/impactos-vulnerabilidad-y-adaptacion/folleto_pnacc_ing_tcm7-197095.pdf
[88] http://www.mapama.gob.es/es/costas/temas/proteccion-costa/estrategiaadaptacionccaprobada_tcm7-464463.pdf
[89] https://www.boe.es/boe/dias/2013/05/30/pdfs/BOE-A-2013-5670.pdf
[90] https://www.boe.es/boe/dias/2010/12/30/pdfs/BOE-A-2010-20050.pdf
[91] http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf
[92] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/209866/pb13942-nap-20130701.pdf
[93] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/584281/uk-climate-change-risk-assess-2017.pdf

the Marine and Coastal Access Act of 2009,[94] the Nature Conservation Law of 1949, and the Wildlife and Countryside (Amendment) Act of 1991[95] do not refer to the OA problem. Score: 2.

References

[1] P.J. Crutzen, The "Anthropocene", in: E. Ehlers, T. Krafft (Eds.), Earth System Science in the Anthropocene, Springer Berlin Heidelberg, Berlin, Heidelberg, 2006, pp. 13–18, 2006.

[2] R. Tiller, F. Arenas, C. Galdies, F. Leitão, A. Malej, B.M. Romera, C. Solidoro, R. Stojanov, V. Turk, R. Guerra, Who cares about ocean acidification in the Plasticene? Ocean Coast Manag. 174 (2019) 170–180, https://doi.org/10.1016/j.ocecoaman.2019.03.020.

[3] IPCC, in: R.K. Pachauri, L. Meyer (Eds.), Climate Change 2014: Synthesis Report. Contribution of Working Gorups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change., Core Writing Team, IPCC, Geneva, Switzerland, 2014, p. 151, 2014.

[4] K. Caldeira, M.W. Wickett, Oceanography: anthropogenic carbon and ocean pH, Nature 425 (2003) 365–368, https://doi.org/10.1038/425365a.

[5] S.C. Doney, V.J. Fabry, R.A. Feely, J.A. Kleypas, Ocean acidification: the other CO_2 problem, Annu. Rev. Mar. Sci. 1 (2009) 169–192, https://doi.org/10.1146/annurev.marine.010908.163834.

[6] R.E. Zeebe, A. Ridgwell, Past changes of ocean carbonate chemistry, Ocean acidification (2011) 1–28.

[7] J.C. Orr, K. Caldeira, V. Fabry, J.-P. Gattuso, P. Haugan, P. Lehodey, S. Pantoja, H.-O. Portner, U. Riebesell, T. Trull, E. Urban, M. Hood, W. Broadgate, Research priorities for understanding ocean acidification, Summary from the second symposium on 'The Ocean in a High-CO2 World' Oceanography 22 (2009) 182–189, https://doi.org/10.5670/oceanog.2009.107.

[8] Bärbel Hönisch, et al., The geological record of ocean acidification, Science 335 (2012) 1058.

[9] G.J. Arreguín-Rodríguez, E. Thomas, S. D'haenens, R.P. Speijer, L. Alegret, Early Eocene deep-sea benthic foraminiferal faunas: recovery from the Paleocene Eocene Thermal Maximum extinction in a greenhouse world, PloS One 13 (2) (2018), e0193167, https://doi.org/10.1371/journal.pone.0193167.

[10] D.E. Penman, B. Hönisch, R.E. Zeebe, E. Thomas, J.C. Zachos, Rapid and sustained surface ocean acidification during the Paleocene-Eocene, Therm. Maximum Paleoceanography 29 (2014) 357–369.

[11] J.B. Ries, A.L. Cohen, D.C. McCorkle, Marine calcifiers exhibit mixed responses to CO2-induced ocean acidification, Geology 37 (12) (2009) 1131–1134, https://doi.org/10.1130/G30210A.1.

[12] C.E. Reymond, A. Lloyd, D.I. Kline, S. Dove, J.M. Pandolfi, Decline in growth of foraminifer Marginopora rossi under eutrophication and ocean acidification scenarios, PANGAEA (2013), https://doi.org/10.1594/PANGAEA.833683. Supplement to: Reymond, CE et al. (2013): Decline in growth of foraminifer Marginopora rossi under eutrophication and ocean acidification scenarios. Global Change Biology, 19(1), 291-302,, https://dx.doi.org/10.1111/gcb.12035.

[13] C.E. Reymond, et al., Decline in growth of foraminifer Marginopora rossi under eutrophication and ocean acidification scenarios, Global Change Biol. 19 (1) (2013) 291–302, https://doi.org/10.1111/gcb.12035.

[14] J.P. Barry, S. Widdicombe, J. Hall-Spencer, Effects of ocean acidification on marine biodiversity and ecosystem function, in: J.-P. Gattuso, L. Hansson (Eds.) vol. 344, 2011, pp. 192–209, 5, Chapter in Book "Ocean Acidification".

[15] J.M. Sunday, K.E. Fabricius, K.J. Kroeker, K.M. Anderson, N.E. Brown, J.P. Barry, S.D. Connell, S. Dupont, B. Gaylord, J.M. Hall-Spencer, T. Klinger, M. Milazzo, P. L. Munday, B.D. Russell, E. Sanford, V. Thiyagarajan, M.L.H. Vaughan, S. Widdicombe, C.D.G. Harley, Ocean Acidification Can Mediate Biodiversity Shifts by Changing Biogenic Habitat. Nature Climate Change, 2016/11/21/online, vol. 7, 2017, p. 81, https://doi.org/10.1038/nclimate3161.

[16] L. Hoffmann, E. Breitbarth, P. Boyd, K. Hunter, Influence of ocean warming and acidification on trace metal biogeochemistry, Mar. Ecol. Prog. Ser. 470 (2012) 191–206. Retrieved from, http://www.jstor.org/stable/24876212.

[17] H. Ullah, I. Nagelkerken, S.U. Goldenberg, D.A. Fordham, Climate change could drive marine food web collapse through altered trophic flows and cyanobacterial proliferation, PLoS Biol. 16 (1) (2018), e2003446, https://doi.org/10.1371/journal.pbio.2003446.

[18] R. Tiller, R. Richards, Ocean futures: exploring stakeholders' perceptions of adaptive capacity to changing marine environments in Northern Norway, Mar. Pol. (2018), https://doi.org/10.1016/j.marpol.2018.04.001.

[19] G.G. Waldbusser, J.E. Salisbury, Ocean Acidification in the coastal zone from an organism's perspective: Multiple system parameters, frequency domains, and habitats, Annu. Rev. Mar. Sci. 6 (2014) (2014) 221–247, https://doi.org/10.1146/annurev-marine-121211-172238.

[20] J.-P. Gattuso, Taking action against Ocean Acidification: a review of management and policy options, Environ. Manag. 52 (2013) (2013) 761–779, https://doi.org/10.1007/s00267-013-0132-7.

[21] J.-P. Gattuso, A. Magnan, R. Bille, W.W.L. Cheung, E.L. Howes, F. Joos, et al., Contrasting futures for ocean and society from different anthropogenic CO2 emissions scenarios, Science 349 (2015), https://doi.org/10.1126/science.aac4722 aac4722–aac4722.

[22] S. Zunino, D.M. Canu, V. Bandelj, C. Solidoro, Effects of ocean acidification on benthic organisms in the Mediterranean Sea under realistic climatic scenarios: a meta-analysis, Reg. Stud. Mar. Sci. 10 (2017) 86–96.

[23] S. Zunino, D.M. Canu, V. Zupo, C. Solidoro, Direct and indirect impacts of marine acidification on the ecosystem services provided by coralligenous reefs and seagrass systems, Glob. Ecol. Conserv. 18 (2019), e00625.

[24] S.B. Capstick, N.F. Pidgeon, A.J. Corner, E.M. Spence, P.N. Pearson, Public understanding in Great Britain of ocean acidification, Nat. Clim. Change 6 (8) (2016) 763–767, https://doi.org/10.1038/nclimate3005.

[25] O. Hoegh-Guldberg, P.J. Mumby, A.J. Hooten, Coral reefs under rapid climate change and ocean acidification, Science 318 (2007) 1737–1742.

[26] R.A. Feely, S.C. Doney, S.R. Cooley, Ocean acidification: present conditions and future changes in a high-CO2 world, Oceanography 22 (4) (2009) 36–47, https://doi.org/10.5670/oceanog.2009.95.

[27] G. Cossarini, P. Lazzari, C. Solidoro, Spatiotemporal variability of alkalinity in the Mediterranean Sea, Biogeosciences 12 (2015) 1647–1658, https://doi.org/10.5194/bg-12-1647-2015.

[28] R.P. Kelly, M.R. Caldwell, Ten ways states can combat Ocean Acidification (and Why they should), Harv. Environ. Law Rev. 37 (2013) 58–103.

[29] G.H. Rau, E.L. McLeod, O. Hoegh-Guldberg, The need for new ocean conservation strategies in a high-carbon dioxide world, Nat. Clim. Change (2012), https://doi.org/10.1038/NCLIMATE1555.

[30] N. Oral, Ocean Acidification: falling between the legal cracks of UNCLOS and the UNFCCC? Ecol. Law Q. 45.1 (2018) (2018) 9–30.

[31] S.R. Cooley, S.C. Doney, Anticipating ocean acidification's economic consequences for commercial fisheries, Environ. Res. Lett. 4 (2009), 024007, https://doi.org/10.1088/1748-9326/4/2/024007.

[32] L.C. Rodrigues, J.C. van den Bergh, A. Ghermandi, Socio-economic impacts of ocean acidification in the Mediterranean Sea, Mar. Pol. 38 (2013) 447–456, https://doi.org/10.1016/j.marpol.2012.07.005.

[33] Secretariat of the Convention on Biological Diversity, in: S. Hennige, J.M. Roberts, P. Williamson (Eds.), An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity vol. 75, 2014, p. 99. Montreal, Technical Series No.

[34] Secretariat of the Convention on Biological Diversity, Global Biodiversity Outlook 4, 2014. Montréal, 155 pages. Available at: https://www.cbd.int/gbo/gbo4/publication/gbo4-en.pdf. (Accessed 31 October 2019).

[35] D.M. Canu, A. Ghermandi, P.A.L.D. Nunes, P. Lazzari, G. Cossarini, C. Solidoro, Estimating the value of carbon sequestration ecosystem services in the Mediterranean Sea: an ecological economics approach, Global Environ. Change 32 (2015) 87–95, https://doi.org/10.1016/j.gloenvcha.2015.02.008.

[36] F. Bosello, E. Delpiazzo, F. Eboli, Acidification in the Mediterranean sea: impacts and adaptation strategies, Review of Environment, Energy Econ. (2015), https://doi.org/10.7711/feemre3.2015.03.001.

[37] R. Baird, M. Simons, S. Tim, Ocean Acidification: a litmus test for international law (December 2010). Carbon and climate law review, in: Climate Change and the Law of the Sea, 3, 2009, pp. 459–471. No. 4.

[38] Hoffert, et al., Advanced Technology paths to global climate stability: energy for a greenhouse planet, Science (New York, N.Y.) 298 (5595) (2002) 981–987.

[39] G.G. Singh, A.M. Cisneros-Montemayor, W. Swartz, W. Cheung, J. Adam Guy, T. Kenny, C.J. McOwen, R. Asch, J. Laurens Geffert, C.C.C. Wabnitz, R. Sumaila, Q. Hanich, Y. Ota, A rapid assessment of co-benefits and trade-offs among Sustainable Development Goals, Mar. Pol. 93 (2018) 223–231, https://doi.org/10.1016/j.marpol.2017.05.030.

[40] E.R. Harrould-Kolieb, Re-Framing ocean acidification in the context of the United Nations framework convention on climate change (UNFCCC) and Paris agreement, Clim. Pol. 19 (10) (2019) 1225–1238, https://doi.org/10.1080/14693062.2019.1649994.

[41] R.E. Kim, Is a new multilateral environmental agreement on ocean acidification necessary? Rev. Eur. Comm. Int. Environ. Law 21 (3) (2012) 243–258.

[42] P. Burkill, T. Tyrrell, M. Edwards, the EPOCA Consortium, European time series of calcareous organisms and carbonate chemistry, in: J.-P. Gattuso, L. Hansson (Eds.), European Project on Ocean Acidification (EPOCA). Objectives, Products, and Scientific Highlights. Oceanography, 22, 2009, p. 195 (4).

[43] T. Markus, S. Schlacke, N. Maier, Legal implementation of integrated ocean policies: the EU's marine strategy framework directive, Int. J. Mar. Coast. Law 26 (1) (2011) 59–90, https://doi.org/10.1163/157180811X541404.

[44] J. Hadden, Networks in Contention, Cambridge University Press, 2015, 1107461103 235.

[45] P.J.G. Tiquio, N. Marmier, P. Francour, Management frameworks for coastal and marine pollution in the European and South east Asia regions, Ocean Coast. Manag. 135 (2017) 65–78.

[46] J.M. Hall-Spencer, B.P. Harvey, Ocean acidification impacts on coastal ecosystem services due to habitat degradation, Emerg. Topics in Life Sci. (April 2019) (2019), https://doi.org/10.1042/ETLS20180117.

[47] J.M. Roberts, A.J. Wheeler, A. Freiwald, S.D. Cairns, Cold water corals: the biology and geology of deep-sea coral habitats, Science 312 (2009) 543–547, https://doi.org/10.1017/CBO9780511581588.

[48] Q. Ding, X. Chen, R. Hilborn, Y. Chen, Vulnerability to impacts of climate change on marine fisheries and food security, Mar. Pol. 83 (2017) 55–61.

[49] F. Hopkins, R. Ellis, E. Pope, E. Papathanasopoulou, Ocean acidification and shellfish: effects on UK aquaculture? Shellfish News 35 (2013) 39–42.

[94] https://www.legislation.gov.uk/ukpga/2009/23/pdfs/ukpga_20090023_en.pdf

[95] http://www.legislation.gov.uk/ukpga/1991/39/pdfs/ukpga_19910039_en.pdf

[50] J.J. Lunden, S.E. Georgian, E.E. Cordes, Aragonite saturation states at cold-water coral reefs structured by *Lophelia pertusa* in the northern Gulf of Mexico, Limnol. Oceanogr. 58 (1) (2013) 354–362, https://doi.org/10.4319/lo.2013.58.1.0354.
[51] E. Mendenhall, E. De Santo, E. Nyman, R. Tiller, A soft treaty, hard to reach: the second inter-governmental conference for biodiversity beyond national jurisdiction, Mar. Pol. 108 (2019) 103664.
[52] R. Tiller, E. De Santo, E. Mendenhall, E. Nyman, The once and future treaty: towards a new regime for biodiversity in areas beyond national jurisdiction, Mar. Pol. 99 (2019) 239–242.
[53] J. Rochette, R. Bille, Bridging the gap between legal and institutional developments within regional seas frameworks, Int. J. Mar. Coast. Law 28 (3) (2013) 433–463.
[54] Report from the Commission to the European Parliament and the Council on the implementation of the Eu Strategy on adaptation to climate change, SWD/2018/461, 2018. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018SC0461&from=EN. (Accessed 16 November 2019).
[55] C. Dupont, A. Belin, B. Vermonden, G. Moreira, S. Cochrane, L. Wilson, C. Emblow, B. Kater, S. Des Clercs, W. Parr, C. Le Visage, N. Green, J. Cools, F. Thomsen, Article 12 Technical Assessment of the MSFD 2012 Obligations, Milieu Ltd, Brussels, 2014, p. 67.
[56] J.A. Ekstrom, B.I. Crona, Institutional Misfit and environmental change: a systems approach to address Ocean Acidification, Sci. Total Environ. 576 (2017) 599–608.
[57] S. Gelcich, F. Reyes-Mendy, R. Arriagada, B. Castillo, Assessing the implementation of marine ecosystem based management into national policies: insights from agenda setting and policy responses, Mar. Pol. 92 (2018) 40–47.
[58] S. Micallef, A. Micallef, C. Galdies, Application of the coastal hazard Wheel to assess erosion on the Maltese coast, Ocean Coast Manag. 156 (2018) 209–222.
[59] M. Nicholls, L.G. Anderson, R. Bellerby, L.J. Falkenberg, M.C. Hänsel, H. P. Huntington, B.A. Kaiser, E.B. Osborne, N.S. Steiner, P. Wallhead, Conclusions, knowedlge gaps and recommendations, in: AMAP Assessment 2018: Arctic Ocean Acidification, Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway, 2018, pp. xx–yy.
[60] N. Hilmi, D. Allemand, C. Kavanagh, D. Laffoley, M. Metian, D. Osborn, S. Reynaud (Eds.), Bridging the Gap between Ocean Acidification Impacts and Economic Valuation: Regional Impacts of Ocean Acidification on Fisheries and Aquaculture, IUCN, Gland, Switzerland, 2015, p. 136.
[61] UNGA, Oceans and the Law of the Sea, 2013. Report of the Secretary-General. A/68/71. Available at: https://www.un.org/ga/search/view_doc.asp?symbol=A/68/71. (Accessed 31 October 2019).
[62] Cordis/Ec, Available at: https://cordis.europa.eu/project/rcn/87798/factsheet/en, 2019. (Accessed 29 July 2019).
[63] European Union, European Commission for the Environment, Adapting to Climate Change: towards a European Framework for Action (White Paper 52009DC0147), 2009. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52009DC0147:EN:NOT. (Accessed 29 July 2019).
[64] UNFCCC, Report of the Conference of the Parties on its Eleventh Session, Held at Montreal from 28 November to 10 December 2005. Addendum Part Two: Action Taken by the Conference of the Parties at its Eleventh Session, 2006, p. 21. Decision 9/CP.11.
[65] D. Bernie, J. Lowe, T. Tyrrell, O. Legge, Influence of mitigation policy on ocean acidification, Geophys. Res. Lett. 37 (2010) L15704, https://doi.org/10.1029/2010GL043181.
[66] D. Diaz, F. Moore, Quantifying the economic risks of climate change, Nat. Clim. Change (2017), https://doi.org/10.1038/NCLIMATE3411.
[67] C.L. Hurd, Slow-flow habitats as refugia for coastal calcifiers from ocean acidification, J. Phycol. 51/4 599 (2015) 604, https://doi.org/10.1111/jpy.12307.
[68] E. Olsen, I.C. Kaplan, C. Ainsworth, G. Fay, S. Gaichas, R. Gamble, R. Girardin, C. H. Eide, T.F. Ihde, H.N. Morzaria-Luna, K.F. Johnson, M. Savina-Rolland, H. Townsend, M. Weijerman, E. Fulton, J.S. Link, Ocean futures under Ocean Acidification, marine protection, and changing fishing pressures explored using a Worldwide suite of ecosystem Models, Frontiers in Marine Science 5 (2018) 64. DOI=10.3389/fmars.2018.00064.
[69] D. Naritaa, K. Rehdanz, Economic impact of ocean acidification on shellfish production in Europe, J. Environ. Plann. Manag. 60 (No. 3) (2017) 500518, https://doi.org/10.1080/09640568.2016.1162705.
[70] D. Herr, K. Isensee, E. Harrould-Kolieb, C. Turley, Ocean Acidification: International Policy and Governance Options, IUCN, Gland, Switzerland, 2014 iv + 52pp.
[71] US House Committee on Science, Space, and Technology's Subcommittee on Environment, CHAIR FLETCHER STATEMENT FOR MARKUP OF OCEAN ACIDIFICATION LEGISLATION, 2019. Last accessed on 29 July 2019, https://science.house.gov/news/press-releases/chair-fletcher-statement-for-markup-of-ocean-acidification-legislation.
[72] MSFD (Marine Strategy Framework Directive), Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 Establishing a Framework for Community Action in the Field of Marine Environmental Policy, 2008.
[73] European Commission, Our Oceans, Seas and Coasts. Legislation: the Marine Strategy Framework Directive., 2020. https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm. (Accessed 24 April 2020).
[74] EEA, 10 Messages for 2010 Marine Ecosystems., 2010. ISBN 978-92-9213-143-2.
[75] L. Hoffmann, E. Breitbarth, P. Boyd, K. Hunter, Influence of ocean warming and acidification on trace metal biogeochemistry. Mar. Ecol. Prog. Series 470 (2012) 191–206. http://www.jstor.org/stable/24876212.
[76] J.A. Ekstrom, B.I. Crona, Institutional misfit and environmental change: a systems approach to address ocean acidification, Sci. Total Environ. 576 (2017) 599–608.
[77] A. Le Gouais, E. Wach, A qualitative analysis of rural water sector policy documents, Water Altern. 6 (3) (2013) 439–461.