CBD

UNEP

Convention on Biological Diversity

Distr.
GENERAL

UNEP/CBD/SBSTTA/20/INF/25
8 April 2016

ENGLISH ONLY

SUBSIDIARY BODY ON SCIENTIFIC, TECHNICAL AND TECHNOLOGICAL ADVICE
Twentieth meeting
Montreal, Canada, 25-30 April 2016
Item 4.2 of the provisional agenda*

BACKGROUND DOCUMENT ON BIODIVERSITY AND ACIDIFICATION IN COLD-WATER-AREAS

Note by the Executive Secretary

1. At its eleventh meeting in 2012, the Conference of Parties to the Convention on Biological Diversity requested the Executive Secretary to prepare, in collaboration with Parties, other Governments and relevant organizations, a draft specific workplan on biodiversity and acidification in cold-water areas, building upon the elements of a workplan on physical degradation and destruction of coral reefs, including cold-water corals and in close linkage with relevant work under the Convention, such as the description of areas meeting the scientific criteria for ecologically or biologically significant marine areas, and with relevant work of competent organizations, such as the Food and Agriculture Organization of the United Nations for its work on vulnerable marine ecosystems (VMEs), and to submit the draft specific workplan on biodiversity and acidification in cold-water areas to a future meeting of the Subsidiary Body on Scientific, Technical and Technological Advice for consideration prior to the thirteenth meeting of the Conference of the Parties.

2. Pursuant to the above request, the Executive Secretary issued a notification 2015-053 requesting scientific and technical information and suggestions from Parties, other Governments and relevant organizations on the development of a draft specific workplan on biodiversity and acidification in cold-water areas. Information in response to this notification was received from Argentina, Australia, Brazil, Canada, Colombia, France, Mexico, New Zealand, the United Kingdom of Great Britain and Northern Ireland, the European Union, the International Atomic Energy Agency, the OSPAR Commission and the UN Division on Ocean Affairs and the Law of the Sea.

3. Based on information submitted in response to the above notification and incorporating additional relevant scientific and technical information from various sources, the Executive Secretary prepared the following information document to provide background to inform the discussions of the Subsidiary Body on the development of a specific workplan on biodiversity and acidification in cold-water areas. The document was prepared by the Secretariat through commissioning a consultancy, with financial resources from the European Commission, and made available for peer-review from 5 February to 17 March 2016.

4. This information document has been revised in response to peer-review comments provided by Canada, the United Kingdom of Great Britain and Northern Ireland and the Food and Agriculture Organization of the United Nations, and is being submitted as information to the Subsidiary Body at its twentieth meeting.

* UNEP/CBD/SBSTTA/20/1/Rev1.

BACKGROUND DOCUMENT ON BIODIVERSITY AND ACIDIFICATION IN COLD-WATER AREAS

Prepared by
J. Murray Roberts, Heriot-Watt University
Marjo Vierros, United Nations University
Sebastian Hennige, Heriot-Watt University

For the Secretariat of the Convention on Biological Diversity

With financial resources from the European Commission

April 2016

EXECUTIVE SUMMARY

Cold-water biodiversity and ecosystems

1. **This study considers biodiversity in cold-water areas in the deep and open ocean, excluding polar seas and coastal ecosystems.** While cold-water biodiversity includes many pelagic and benthic organisms and habitats, specific attention has been provided to cold-water habitats supporting benthic organisms, due to their biodiversity supporting roles. While the impacts of acidification on cold-water biodiversity are the main focus of this study, discussion on other environmental and human induced stressors are included, as they will all impact biodiversity in cold-water areas. Existing policy and management responses to the identified existing and potential pressures to cold-water area biodiversity are highlighted.
2. **Cold-water areas contain many very ecologically important habitats, a very few of which are cold seeps, hydrothermal vents, cold-water corals and sponge fields.** However the associated biodiversity of these habitats is relatively very high, with cold-water coral reefs becoming well understood, while work on the functional ecology and biodiversity of cold-water sponge fields, seeps and vents is expanding.
3. **Cold-water coral and sponge habitats, seeps and vents are typically more biodiverse than surrounding seabed habitats and support characteristic animal groups.** For example cold-water coral reefs support rich communities of suspension-feeding organisms including sponges, bryozoans and hydroids. Seeps and vents have specialized fauna and a highly diverse bacterial community dependent on sulphur-based energy sources.
4. **Cold-water coral and sponge habitats can play functional roles in the biology of fish.** New evidence shows that some fish are found in greater numbers in cold-water coral habitats and some species use cold-water coral reefs as sites to lay their eggs while it has been known for some time that some fish use sponge grounds for feeding on the rich associated fauna and for refugia, while some fish species directly consume sponge tissue.

Pressures and threats to biodiversity in cold-water areas

Environmental pressures

5. **Ocean acidification has increased by ~26% since pre-industrial times.** Increased releases of CO_2 due to the burning of fossil fuels and other human activities is leading to increases in upper ocean temperatures and ocean acidification.

6. **The saturation state of carbonate in seawater varies by depth and region.** The saturation state is typically lower in polar and deep waters due to lower temperatures. When carbonate becomes undersaturated, calcium carbonate, which many organisms use to form shells and skeletons, will dissolve if unprotected.
7. **Increases in ocean temperature will lead to decreases in gas exchange at the sea surface**. This will lead to increased upper-ocean stratification, decreased vertical mixing and decreased export of carbon to the ocean interior through particle sinking.
8. **Increased ocean temperature contributes to deoxygenation, by decreasing oxygen solubility at the surface and enhancing stratification.** This leads to a decrease in the downward oxygen supply from the surface, meaning less oxygen is available for organism respiration at depth, and areas with lowered oxygen levels may expand.
9. **The combination of ocean acidification, increases in upper-ocean temperature, stratification, and deoxygenation of sub-surface waters can lead to significant changes in organism physiology and habitat range in cold-water areas.** Ocean acidification is detrimental to many marine species, with impacts on their physiology and long-term fitness. Shoaling of the aragonite saturation horizon will also leave many calcifying species in potentially corrosive seawater. Increases in temperature can impact the physiology of many organisms directly, and indirectly lead to increasing deoxygenation and expansion of low oxygen zones. This can lead to community shifts, changes in nitrogen cycling, and modification of habitat ranges. Ocean acidification, temperature, salinity, stratification and mixing can be influenced by natural variability, so that changes may differ strongly between regions.

Human pressures

10. **Harmful fishing practices can significantly impact in vulnerable marine ecosystems.** Cold-water ecosystems can be characterized by species with slow growth rates, and recovery from impacts may take decades to hundreds or even thousands of years. Decreases in biodiversity, biomass and habitats (through destruction) could have potential consequences for broader biogeochemical cycles.
11. **There are potential impacts on marine biodiversity and ecosystems in the deep-sea from marine mining.** Impacts may include habitat destruction, ecotoxicology, changes to habitat conditions, discharge of nutrient enriched deep-water to surface communities and potential displacement or extinction of local populations. In addition to point source mining impacts, understanding the consequences of mine tailings disposal over wide areas is particularly important.
12. **Hydrocarbon exploitation can impact cold-water biodiversity on different geographic scales**. While drill cuttings can cover and disturb local benthos

around platforms, accidents, such as the Gulf of Mexico Deepwater Horizon oil spill, can create larger environmental impacts at great depths over many hundreds of square kilometres and through the water column.

13. Although to date far smaller in its scale of impact, **bioprospecting** in the deep ocean to explore for novel compounds, for instance from deep-sea sponge grounds, should be undertaken in a minimally invasive manner to avoid local damage to these communities and their associated biodiversity.

Impacts of ocean acidification on cold-water biodiversity

14. **Exposed cold-water coral skeletons will dissolve in undersaturated water.** A large proportion of cold-water coral habitat is dead coral skeleton no longer covered in protective living tissue. This bare skeleton will dissolve as the aragonite saturation horizon becomes shallower and the exposed skeletal remains are subjected to undersaturated seawater.
15. **Cold-water coral reef framework becomes weaker in undersaturated water**. The dissolution of the exposed cold-water coral skeletons makes them weaker, and more likely to break. This could mean that reefs in undersaturated water become smaller, and less able to support the high levels of biodiversity they sustain today.
16. **Cold-water corals can continue to grow in undersaturated water.** Live cold-water corals can continue to grow in carbonate undersaturated water, but their skeletal structure changes, which may indicate that energetic budgets are changing as the corals acclimate to new conditions.
17. **The aragonite saturation horizon is projected to become much shallower by 2100, leaving about 70% of cold-water coral reefs in undersaturated seawater.** This will mean the majority of cold-water coral reefs will suffer dissolution and weakening of their supporting exposed skeletal framework, with potential loss of habitat for other species.
18. **Ocean acidification will impact sponge processes and occurrence**. While ocean acidification can increase the erosion efficiency of some bio-eroding sponges, some species may not tolerate low pH levels, as has been demonstrated in shallow environments by a change in sponge cover near volcanic CO_2 vents.
19. **Fish may be subject to direct and indirect impacts by environmental stressors.** Ocean acidification can directly impair behaviour and sensory functions in some fish species, as well as the development of some species' juveniles, but in general, fish are considered relatively resilient to projected ocean acidification. If ocean acidification has detrimental impacts to a key food source, this could indirectly lead to a change in habitat use and potential fish migration.
20. **Mesopelagic fish stocks could be larger than previously thought, and are relatively unstudied.** Mesopelagic fish remain one of the least studied components of open ocean ecosystems, and migrating species have a close

relationship with primary production and transfer of energy to the deep sea. Mesopelagic species represent a research priority to discern what potential impacts environmental change may have on them.

21. **Some squid species may be particularly impacted by increased CO_2 concentrations.** Carbon dioxide can interfere with O_2 binding within squid gills, leading to reduced metabolic rates and activity levels.
22. **Pteropod (planktonic sea snail) shells are at risk of dissolution in undersaturated water, and are at particular risk from ocean acidification.** Pteropods are a food source for many marine organisms, so impacts on pteropods, through the dissolution of their shells, could indirectly affect many pelagic species.
23. **Many krill species will be at potential risk from ocean acidification.** Krill species are also important species in marine food webs. They are broadcast spawners that release eggs that sink into deeper, colder waters. Research to date has demonstrated that increased CO_2 levels can decrease hatching rate and slow development. More research is needed on potential impacts of climate change to global krill populations and the food webs of which they are apart, including the potential for adaptation.

Global monitoring of ocean acidification

24. **Global monitoring of ocean acidification is increasing but there is a need for further development of predictive models**. A well-integrated global monitoring network for ocean acidification is crucial to improve understanding of current variability and to develop models that provide projections of future conditions in surface waters and at depth. Emerging technologies and sensor development increase the efficiency of this evolving network. There is need for greater cross-sectoral partnership between government, industry and academia to achieve the ambitious goals of fully global monitoring.
25. **Seawater pH shows substantial natural temporal and spatial variability.** The acidity of seawater varies naturally on a diurnal and seasonal basis, on local and regional scales, and as a function of water depth and temperature. Only by quantifying these changes can we understand what conditions marine ecosystems are subjected to currently. This in turn will increase understanding of how marine ecosystems will change in a future climate.

Resolving uncertainties

26. **Impacts of ocean acidification need to be studied on different life stages of cold-water organisms.** Early life stages of a number of organisms may be at particular risk from ocean acidification, with impacts including decreased larval size, reduced morphological complexity, and decreased calcification. Further work needs to be done on understanding the reproductive life cycles of many cold-water organisms, complemented by experimentation on different life stages.

27. **Existing variability in organism response to ocean acidification needs to be investigated further, to assess the potential for evolutionary adaptation.** Multi-generational studies with calcifying and non-calcifying algal cultures show that adaptation to high CO_2 is possible for some species. Such studies are more difficult to conduct for long-lived organisms or for organisms from the deep sea. Even with adaptation, community composition and ecosystem function are still likely to change.

28. **Research on ocean acidification increasingly needs to involve other stressors, such as temperature and deoxygenation, as will occur under field conditions in the future.** Acidification may interact with many other changes in the marine environment both at local and global scales. These "multiple stressors" include temperature, nutrients, and oxygen. *In situ* experiments on whole communities (using natural CO_2 vents or CO_2 enrichment mesocosms) provide a good opportunity to investigate impacts of multiple stressors on communities, to increase our understanding of future impacts.

29. **Substantial natural temporal and spatial variability exists in seawater pH.** Greater understanding of these changes is needed on regional and local scales, and information on such changes should be incorporated into future climatic projections and experiments.

30. **Greater understanding of food webs, their resilience, and the interaction between species within them is needed.** Whether an impact of climate change on one organism will impact the fitness of other organisms is poorly understood at present, as are the properties that confer resilience on species and ecosystems.

Initiatives to address knowledge gaps in ocean acidification impacts and monitoring

31. **There are a growing number of national and international initiatives to increase understanding of future impacts of climate change.** Through linking national initiatives, which include experimentation, modelling and monitoring, to international coordinating bodies, addressing global knowledge gaps and monitoring become more effective.

Existing management and needs

32. **The legal and policy landscape relating to addressing impacts to cold-water biodiversity includes largely sectoral global and regional instruments.** While instruments related to integrated management approaches exist, they do not presently comprehensively cover the entirety of cold-water ecosystems.

33. **Reducing CO_2 emissions remains the key action for the management of ocean acidification and warming**. Additional management options, such as reducing stressors at the national and regional level, can be used to help marine ecosystems adapt and buy time to address atmospheric CO_2 concentrations.

34. **Our understanding of the impacts of individual stressors is often limited, but we have even less understanding of the impacts that a combination of these stressors will have on cold-water marine organisms and ecosystems and the goods and services they provide.** There is a pressing need to understand the interactions and potentially cumulative or multiplicative effects of multiple stressors.

35. **Because individual stressors interact, managing each activity largely in isolation will be insufficient to conserve marine ecosystems**. Multiple stressors must be managed in an integrated way, in the context of the ecosystem approach.

36. **Scientific studies suggest that priority areas for protection should include areas that are predicted to be less impacted by of climate change, and thus act as refuges of important biodiversity**. In cold-water coral reefs, this may include important reef strongholds (reef areas likely to be less impacted by acidification by being located at depths above the aragonite saturation horizon), or areas important for maintaining reef connectivity and gene flow, which may be crucial for coral species to adapt to the changing conditions.

37. **Management strategies should also protect representative habitats**. Representative benthic habitats that are adjacent or connected to impacted areas can act as important refuges and source habitat for benthic species and may promote recovery.

38. **There is an urgent need to undertake management activities that could support ecosystems in adapting to changes, including by reducing other stressors and identifying refugia sites nationally, regionally and globally**. Efforts to describe and identify biologically/ecologically important marine areas, including through the CBDs work on EBSAs and the FAOs work on VMEs, may help regional and global efforts to identify the location of habitats that may be resilient to the impacts of acidification and ocean warming, or that may help in maintaining gene flow and connectivity.

39. **Cold-water biodiversity supports economies and well-being, and thus all stakeholders have a role in its management**. Awareness-raising and capacity building on all levels are important for future management effectiveness.

Table of Contents

1. Introduction and scope of study

This background document builds upon the elements of a workplan on physical degradation and destruction of coral reefs, including cold-water corals (as contained in annex I, Appendix 1 of decision VII/5).

The geographic scope of this document encompasses cold-water areas in the deep and open ocean, and includes both benthic and pelagic biodiversity. Polar seas, and coastal ecosystems and species, are outside the scope of this study.

Environmental and human induced stressors can all potentially impact biodiversity in cold-water areas. Here we discuss some of the potential pressures and threats related to ocean acidification, ocean warming, unsustainable fishing (overfishing, destructive fishing practices, IUU fishing), deep-sea mining, bioprospecting, hydrocarbon exploitation and shipping, all within the geographical scope of this report. This background document scientifically reviews the biodiversity and habitats present in cold-water areas (as defined by the geographic scope noted above) coupled with their present status. Discussion will focus on the pressures (as noted above) affecting the sustainability of biodiversity in cold-water areas, and provide analysis of existing policy and management responses to the identified existing and potential pressures to cold-water area biodiversity. The research for preparation of this document was undertaken with financial support from the European Commission.

2. Overview of pressures and threats and implications for the biodiversity of cold-water areas

Cold-water areas of the world's oceans support a diverse range of marine species with certain key habitats, like deep-water coral and sponge grounds, being particularly important in locally enriching species diversity. However, as the scientific community begins work in earnest to understand these habitats and their associated biodiversity there is mounting evidence that cold-water areas of the global ocean are being substantially altered, from both direct human pressures and from wider impacts of global climate change.

Increased atmospheric concentrations of CO_2 are leading to increases in sea surface temperature and ocean acidification[1], often referred to as the "other CO_2 problem"[2]. Changes in temperature and ocean acidity are not the only environmental change that organisms will experience in the future, since it will occur in combination with other stressors (e.g. deoxygenation)[1]. The biological effects of multiple stressors occurring together cannot be assumed to be additive. Instead, due to interactions, their combined impacts may be amplified or diminished. In addition to these environmental stressors, which can vary naturally on spatial or temporal scales between regions and locales, the extent to which biodiversity and sustainability of cold-water ecosystems will be impacted by direct human interactions, such as unsustainable fishing practices, Illegal, Unreported and Unregulated (IUU) fishing, pollution, invasive species and deep-sea mining, also need to be considered.

2.1 Pressures and threats

Ocean acidification. As atmospheric CO_2 increases, more CO_2 dissolves in the ocean across the sea surface. Carbonic acid is formed, which dissociates to form carbonate, bicarbonate and hydrogen ions (H^+), resulting in an increase in ocean acidity. Since pre-industrial times, the mean pH in the surface ocean has dropped by 0.1 units, a linear-scale increase in acidity of ~26% [3]. While mean surface pH is projected to fall even if greenhouse gas emission are stabilised, mean surface pH could fall by ~0.3 units by 2100 unless CO_2 emissions are rapidly curtailed [4–6].

The saturation state of carbonate in seawater, which impacts calcification and dissolution processes [3] varies by region and depth. Typically, the saturation (Ω) of carbonate, which is the ratio between dissolved abundances of calcium and carbonate ions and their solubility product constants (which are temperature specific), is lower in polar and deep water areas due to low temperatures. In areas where the Ω is > 1.0, carbonate is supersaturated and unprotected $CaCO_3$ is stable. Where $\Omega < 1.0$, carbonate is undersaturated and unprotected $CaCO_3$ will dissolve [3]. The depth at which $\Omega = 1.0$ is called the saturation horizon. Cold and deep-water areas are particularly vulnerable to the projected shallowing of the saturation horizon[7], and it is projected that by the end of the century, the saturation horizon of aragonite (a polymorph of calcium carbonate) will have shallowed by >2000 m to ~ 100 m in the North Atlantic, and from ~150 m, to the near surface in the North Pacific [7]. Aragonite and calcite are two forms of calcium carbonate, and differ in their sensitivity to ocean acidification, so that the aragonite saturation horizon (ASH) is shallower than the calcite saturation horizon (CSH).

CBD Technical Series Report No. 75: “An updated synthesis of the impacts of ocean acidification on marine biodiversity” found that ocean acidification represents a serious threat to marine biodiversity, yet many gaps remain in our understanding of the complex processes involved and their societal consequences. Ocean acidification is currently occurring at a geologically unprecedented rate, subjecting marine organisms to an additional, and worsening, environmental stress. Experimental studies to date show the variability of organisms’ responses to simulated future conditions: in general, some are impacted negatively, some positively, and others are apparently unaffected. Importantly, responses to ocean acidification can interact with other stressors, such as temperature and deoxygenation, and vary over time.

Increasing Temperatures – in general, ocean warming due to increases in atmospheric temperatures through the greenhouse effect has increased over the last decades. The resultant increase in sea temperatures causes decreases in ocean mixing due to stratification, the exchange of gases between the ocean surface and the atmosphere (increases in temperature reduce the solubility of CO_2 and O_2), the export of carbon to the ocean interior, and the increase in thermal expansion and sea level rise [1,3,8,9]. Ocean warming will also impact aspects of marine organism physiology, with potential impacts upon their growth, long-term fitness, geographic distribution and behaviour [3,9]. The change in the biogeography of key zooplankton food stocks due to temperature, such as copepods, could contribute to substantial modifications on the abundance of fish species which feed upon them [10]. Distribution shifts over latitudes and depths have already occurred for nearly two-thirds of both exploited and non-exploited fish in the North Sea due to recent increases in temperature [11].

Deoxygenation - Increases in ocean temperature decrease oxygen solubility in addition to enhancing stratification. This stratification can result in decreased mixing between ocean layers, decreasing the downward oxygen supply from the surface. Impacts of decreased oxygen will mean that less oxygen is available for organism respiration and areas of low oxygen can extend, leading to community shifts towards low oxygen tolerant microorganisms. This may have consequences for the nitrogen cycle through increased production of methane and nitrous oxide (greenhouse gases) [1,3,12]. It is predicted that the average ocean oxygen content may decline by ~1-7%, depending upon the model used [1,12,13], although uncertainties exist with regard to the extent and location of such declines, in addition to the ecological impacts. Due to expansion of low oxygen zones, there has already been a shift in the habitat ranges of some species depending upon their hypoxia tolerance. For example, the hypoxia-tolerant Humboldt squid has expanded its habitat while certain intolerant fish species have seen their habitats compressed [14–16].

Fishing practices – Pressures from unsustainable fishing practices are also a concern in cold-water areas in the deep and open ocean[17]. In areas far from shore it can be difficult to enforce fishing activities, which can lead to resource depletion and environmental damage of vulnerable marine ecosystems by poorly managed or IUU fishing [18,19].

Cold and deep-water organisms often live in food-limited environments characterised by slow growth and low recruitment rates [17]. Such organisms and ecosystems may therefore take a very long time to recover from detrimental impacts [20,21]. Impacts of trawling on cold-water coral reefs, which support high levels of biodiversity [22], are intrinsically damaging because of the weight and force at which trawl nets are dragged over the seabed, and recovery can take several hundreds of years, if at all [22]. The potential damage to solid framework and sedimentary habitats can cause a loss in associated infaunal diversity, and negatively impact fisheries production in the long-term [23,24]. Primary impacts of longer-term, poorly-managed trawling may include severe reduction in the biomass of the species that are targeted by the trawl fishery [25], with potential secondary consequences on biogeochemical cycles [24]. In some coral habitats, trawling has had a dramatic impact on the seamount benthos, such as a two orders of magnitude reduction in coral cover, three-fold declines in associated species richness, and a change in megabenthos assemblages [20]. Effects were long-lasting, and in areas where trawling ceased, there was no clear signal of recovery of the megabenthos; communities remained impoverished, comprising fewer species at reduced densities [20]. Other methods that contact the seafloor (e.g. demersal longlines) have also been reported to cause structural damage to benthic megafauna, although they are generally thought to be less damaging than trawl gear [26–28]. The response of some nations and regional fisheries management organizations has been to close cold-water coral habitats to bottom fishing [22,29].

Deep-sea mining - Deep sea mining is an emerging industry whereby mineral deposits are harvested from the deep sea [30]. These include metal rich manganese nodules, cobalt crusts, seafloor massive sulphides, metal rich muds and marine phosphates [17]. They occur in different locales, including mid-ocean ridges, abyssal plains, seamounts, basins and on continental slopes. There remain many knowledge gaps with regards to the potential impacts of deep-sea mining to marine biodiversity, including the impacts and recovery to the habitats, the long term ecotoxicology implications of metals associated with the process, the coupling (and indeed the initial baseline mapping) of the ecosystems to neighbouring habitats which are considered mining targets, and the interaction between geo and bioprocesses [17]. The potential threat of mining towards marine benthic ecosystems has already led to some countries declining consent to mine [31].

The extraction of polymetallic sulphide deposits will also rely on new technologies and methods; their impacts are as yet unknown. It is expected that the drifting particles produced by deep-sea sulphide mining have the potential to smother, clog, and contaminate nearby vent communities. Organisms surviving these perturbations would be subject to a radical change in habitat conditions with hard substrata being replaced by soft particles settling from the dispersing plume. Mining could also potentially alter hydrologic patterns that supply vent communities with essential nutrients and hot water. A further problem may arise during dewatering of ores on mining platforms, resulting in discharge of highly nutrient enriched deep-water into oligotrophic surface waters, which can drift to nearby shelf areas. Because many invertebrates at vents may be rare or endemic species, habitat destruction by mining can be potentially devastating to local and regional deep-sea biodiversity.

Oil and gas exploitation, pollution and shipping- Hydrocarbon exploitation can impact cold-water marine organisms on different geographic scales. The drill cuttings produced can cover the area in the immediate surroundings of the platform, leading to significant disturbance of the benthos [32]. Detrimental impacts of drill cuttings to life on the seafloor however do not prevent the support structures of the platform themselves being colonised by marine organisms such as cold-water corals [33]. Larger events, such as the Deepwater Horizon accident in the northern Gulf of Mexico at 1,525 m where a deep-sea oil plume was created from the seabed blowout, highlight detrimental impact to marine organisms on a larger scale. Severe reductions of faunal abundance and diversity was found up to 3 km away from the wellhead in all directions, covering an area of 24 km^2 [34]. Recovery of the benthos around this site is expected to take decades or longer. Other impacts may come from the exploitation of subsurface gas hydrate deposits. These reserves of methane ice occupy significant volumes within the seabed off continental margins worldwide. Recent global estimates of gas hydrate reserves greatly surpass total known world petroleum reserves [35]. Although exploitation of subsea gas hydrates is probably many decades away, their extraction could involve large-scale disturbance of the seabed and consequent effects on seep communities [35].

Other pollution aspects for cold and deep-water areas include microplastics from terrestrial uses, as deep-sea sediments have been documented as containing microfibres in abundances (per unit volume) up to four orders of magnitude higher than contaminated surface waters [36]. There is also evidence of the accumulation of other pollutants such as heavy metals, persistent organic pollutants and polychlorinated biphenyls [17,37], where they can be taken up by deep-sea organisms such as fish and crustaceans and are subject to accumulation up the food chain.

The International Maritime Organisation (IMO) has introduced a number of regulations with regard to shipping to decrease the risk of invasive species introduction (e.g. International Convention for the Control and Management of Ships' Ballast Water and Sediment, 2004). Two major pathways for marine bioinvasion are discharged ballast water and hull fouling. Invasive species have caused species extinctions and damage to ecosystems and livelihoods, health and economics in coastal areas throughout the world [38]. It is estimated that ~50% of the non-indigenous species which have been introduced into European seas have been as a result of shipping [17]. While research on the impacts of invasive species has focussed on coastal areas, further investigation is warranted in cold and deep-water areas. Other impacts of shipping may include noise pollution, incidental oil pollution and air pollution [39]. A need for more information and more efficient data gathering has been highlighted as a requirement for future assessment of shipping on the marine environment [39].

Biological prospecting - Marine bioprospecting, the exploration of biodiversity for commercially valuable genetic and biochemical resources has increased rapidly over the last decade, probably due to technical advances facilitating more efficient exploration of the ocean floor and recovery of samples under specialised conditions [37]. Bioprospecting for novel compounds and enzymes often takes place as part of scientific research in areas of the deep ocean where extremophiles can be found, and there is a risk that the collection of organisms may, in some cases, disrupt localised habitats. While there is little documentation about environmental impacts of this activity, they are thought to be relatively minimal at the early biodiscovery stages of collection, where the size of samples collected is small. If a given species has shown biotechnological potential, repeated collection may require larger quantities, raising the likelihood of environmental impact at a local level. However, in many cases a synthetic or a derivative is produced, eliminating the need for further collection in the field. Impacts remain a concern if the target organism is rare, has a restricted distribution, and/or the collection is focused on a particular population [40], and may include impacts from survey trawls and submersible lights [41].The legal implications of potential impacts from bioprospecting must be a consideration for decision makers in drafting future policies to regulate this activity [42], within the context of regulatory framework that does not hinder scientific research and allows the flow of ideas and products for future compounds to treat disease.

2.2 Cold-water habitats and biodiversity

Habitat providing organisms, such as cold-water corals, support substantial biodiversity, and are at particular risk from ocean acidification [3]. Their habitat-provisioning role extends beyond the lifetime of individual corals and sponges (the dead framework and spicule mats respectively continue to provide habitat). Cold seeps and hydrothermal vents offer specialized habitats that have unique associated fauna and high biodiversity compared with surrounding areas. In pelagic cold-water areas (excluding polar regions), various organisms, both with direct commercial importance (e.g. fisheries) and indirect importance (key food organisms for fisheries) are also under potential threat from climate change, and will also be reviewed.

Benthic biodiversity

Cold-water coral reefs: Cold-water corals, such as *Lophelia pertusa,* form complex three-dimensional frameworks that support high biodiversity [18,22] and commercially important species [43]. These vulnerable marine ecosystems [44] are found throughout the world's oceans to 3000 m depth [18,22] and live both at lower temperature (4-12ºC) and aragonite saturation states ($\Omega_{aragonite}$) than tropical coral species. Cold-water corals, also often referred to as deep-water corals, are found in all of the world's oceans [18,45,46], with new information on their distribution being updated through national mapping programmes such as MAREANO in Norway (www.mareano.no), The Deep Sea Coral Research and Technology Program (USA), and through European Union projects including HERMES, HERMIONE, CoralFISH and the newly developing ATLAS project.

Many cold-water coral species require hard substrate for attachment and growth, and in general they thrive where there are strong currents that supply them with food, disperse eggs, sperm and larvae, remove waste products and keep the surfaces of the coral free of sediments. This means that they are often found on parts of the continental slope or on the summits of seamounts where currents are strongest. It has often been assumed that these deep-water habitats are relatively stable in terms of their carbonate chemistry, but recent evidence suggests that within and between habitats, a significant amount of variability can exist, even on a daily basis [47,48].

Cold-water scleractinian coral reef systems are structurally complex environments including gorgonian and stylasterid hydrocorals, sponges and a variety of fish and invertebrates that meet the criteria of vulnerable marine ecosystems (VMEs). Their distribution extends into the Arctic and sub-Arctic [18,22,43]. Despite their global distribution the functional ecology of cold-water coral (CWC) ecosystems is not well-understood. Much of the focus on CWCs has been on the reef frameworks built by a small group of scleractinians, in particularly *Lophelia pertusa,* since this species dominates many CWC reefs and mounds. These CWC structures are now known to be rich in local biodiversity and important in the life cycles of certain deep-water fish, although our understanding of these relationships remains very poorly developed compared with that of shallow, tropical coral reefs [49].

However, cold-water corals are very probably more at risk than tropical corals to ocean acidification, due to their depth range and proximity to the aragonite saturation horizon. Over 95% of cold-water coral reefs currently live above the aragonite saturation horizon, but it is projected that this will become shallower, and that up to 70% of cold-water coral reefs will be in undersaturated water by the end of the century [7,22].

Research to date has identified how corals have specialised calcifying cells semi-isolated from the surrounding seawater environment [50], and thus the growing skeleton is not in direct contact with seawater. Since the coral tissue protects the skeleton from potential dissolution [51,52], it is not obvious why coral calcification should be affected by ocean acidification occurring in the exterior seawater [3,53]. A possible mode of action is through the process of calcium transportation to the site of calcification, with removal of hydrogen ions that elevates pH [54–56], which is an energetic cost to the coral [55–58].

Although scleractinian corals can up-regulate their internal pH at the sites of calcification through energy intensive processes [55,59,60], the regulation only applies for coral skeleton that is covered by living coral tissue [61]. Cold-water coral (CWC) framework reefs are typically composed of a significant amount of bare, dead skeleton beneath the living material (Figure 1) that would start to dissolve in undersaturated conditions and be eroded with increased efficiency by bio-eroding sponges [62]. Net reef accretion in aragonite-undersaturated conditions ($\Omega_{aragonite}$ <1) will thus only occur if coral calcification exceeds dissolution and bioerosion of exposed dead skeleton. Identifying the timing and chemical threshold where net coral ecosystem calcification ceases is critical, and represents a tipping point where the persistence of coral reefs can no longer be sustained [63] With little or no information on the evolutionary capacity of cold-water corals to adapt to future ocean conditions, their future viability below the ASH thus remains hotly debated. This, combined with the vulnerability of exposed dead skeletons to dissolution, raises significant questions over the medium to long-term future of these vulnerable marine ecosystems and the associated biodiversity they support [9].

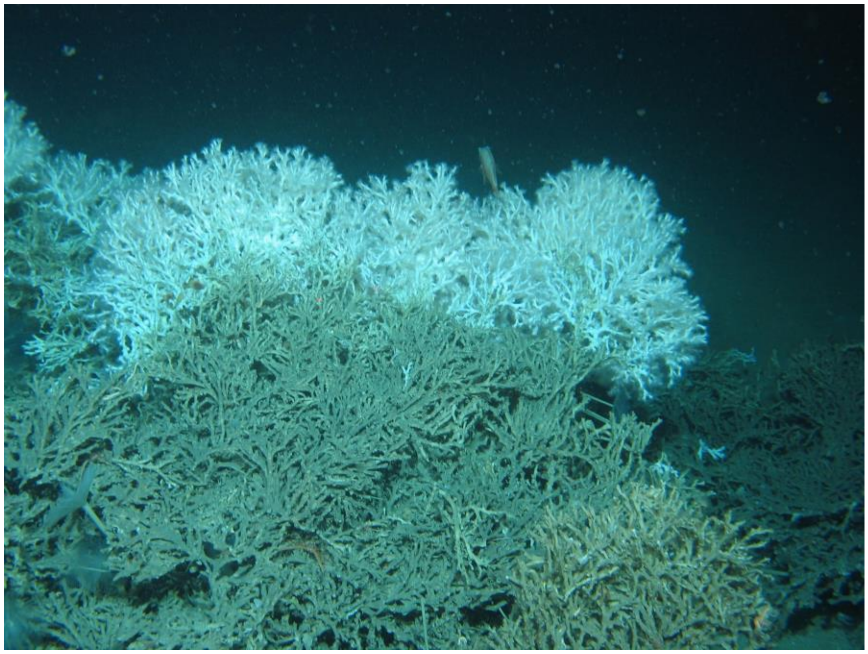


Figure 1. Image of live *Lophelia pertusa* with underlying dead framework (Rockall Bank, NE Atlantic). Source: 2012 Changing Oceans Expedition; UK Ocean Acidification research programme.

Impacts of single and multiple stressors to cold-water corals - the abundant cold-water coral *Lophelia pertusa* is one of the key habitat formers supporting rich biodiversity in cold- and deep-water areas. The general consensus from studies examining impacts from single and multiple stressors of ocean acidification or warming, is that while considerable variability exists between individuals with regard to respiration and calcification rates over different experimental time scales, *L. pertusa* has the ability to acclimatise to stressors over a period of months [61,64–71].

Considering literature to date, experimental time scales are important when assessing whether corals can acclimatise or not, as short-term experiments may produce results (for example a detrimental impact of ocean acidification upon key processes), which may not appear in long-term studies, as organisms have undergone alterations in key regulatory processes to acclimatise [72]. This makes it very useful to compare both short and long term research, and with regard to *L. pertusa,* most significant changes in respiration and calcification occur in the short term, from 24-hour experiments to 4 weeks. Beyond 4 weeks, decreases in calcification and respiration (with regard to ocean acidification) have not been observed in studies to date [61,66–68,71]. However, even when acclimatisation has been demonstrated, it may come at a cost to other processes and may therefore not be sustainable in the long-term. With regard to this, recent research has demonstrated that although growth rates can continue as normal under low pH conditions over a period of 12 months, skeletal biomineralisation, molecular-scale bonding and skeletal structure, all change [61]. The breakdown in the relationship between respiration and calcification in long-term experiments may also indicate that 'normal' energetic strategies are circumvented in the long term, possibly due to other processes using energetic reserves [61,68]. This remains an important gap to address in future studies.

In addition to potential energetic implications for the live coral, the dead, exposed skeletal framework which supports the reef itself and provides important structural habitat [18] may be at risk from ocean acidification. Exposed skeleton cannot acclimatise or adapt to future conditions, and its dissolution is a purely biogeochemical process [73]. The dissolution and weakening of the exposed skeleton observed after long-term ocean acidification exposure [61] when combined with bio-erosion [62,74], is likely to mean that reefs of the future will be smaller than currently, and consequently unable to support the rich biodiversity found today. For species such as *Galeus melastomus,* the blackmouth catshark, which use cold-water coral reefs as a spawning ground [43], the potential loss of habitat in which eggs are laid could cause changes in long term fitness or geographic range. While the ecologically significant ability of adult *L. pertusa* to skeletally fuse [75] helps strengthen the framework as a whole, and may mean that reef structures would maintain integrity in the short to mid-term of being exposed to water beneath the ASH, the fact that over 95% of cold-water coral reefs are found above the saturation horizon depth [7] infers that, in the long-term, net reef growth cannot normally be maintained in undersaturated water.

Projections of near seabed aragonite saturation states ($\Omega_{aragonite}$) based on the Norwegian Earth System Models (NorESM, [29,76,77]) using coarse saturation states for the OSPAR area (Figure 2), highlight that present day cold-water coral reefs of *L. pertusa* are found in $\Omega_{aragonite}$ >1.0. Results from different Representative Concentration Pathways (RCPs from 2.6 (large mitigation efforts) to 8.5 (very high emissions pathway)) are shown for the end of the century in Figure 2. These RCPs describe four different 21st century pathways of greenhouse gas emissions and atmospheric concentrations, air pollutant emissions and land use [78]. The Paris Agreement (see section 3.1), with its long-term goal to reduce greenhouse gas emissions, will feed into future RCP assessments. Working within current RCPs, it is evident that many of the *L. pertusa* reefs in the OSPAR area will be subjected to corrosive seawater by the end of the century, with the extent depending on the RCP pathway. The potential destabilisation and loss of many of these marine habitats will be detrimental to important ecological functions and services [29]. To understand which reefs are likely to be most at risk and to facilitate effective management plans, higher resolution models incorporating variability in chemistry and regional hydrodynamics are needed, alongside ocean acidification monitoring programmes in the field.

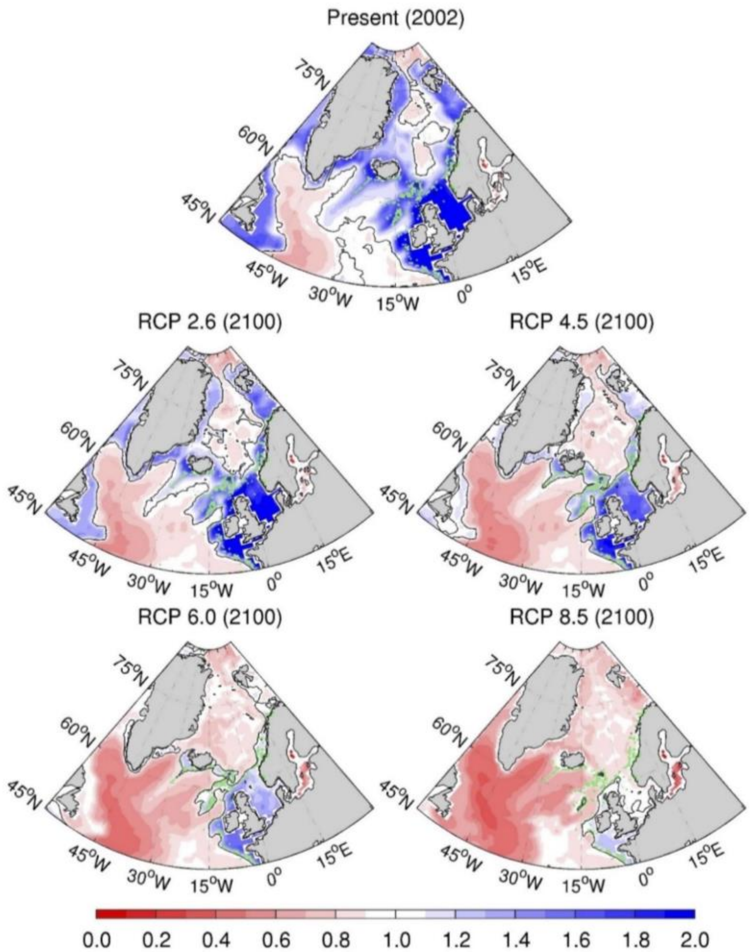


Figure 2: OSPAR area near-seabed aragonite saturation states observed in 2002 and projected for 2100 using the Transient Steady State approach under four different Representative Concentration Pathways (RCP). The black isolines represent saturation state of one, and the green markers represent locations of reef habitats extracted from the 2013 OSPAR priority habitats map published through EMODnet. Reproduced from ICES[29] (figure prepared by Jerry Tjiputra, Are Olsen University of Bergen; *Lophelia* reef and carbonate mound spatial data sourced EMODNET).

Potential for adaptation - While the ability of *L. pertusa* to acclimatise to ocean acidification conditions in laboratory mesocosms (albeit with subsequent impacts on their physiology) has been established, their ability to evolve and adapt to future conditions has not been addressed. *Lophelia pertusa*, like many long-lived species, has high levels of phenotypic plasticity [18] which allow it to thrive over a wide geographic distribution and research to date has focused on their ability to cope with ocean acidification within this existing plasticity. This acclimatisation is important because although adaptation to changing conditions can occur over subsequent generations, the slow growth of CWCs coupled with the projected rapid change in ocean acidification and warming [3], means that reef survival will depend heavily on the acclimatisation capacity of currently living CWCs. The dearth of documented *L. pertusa* reefs below the ASH, raises the question of whether they can adapt to projected ocean acidification if the ASH shoals above them. Since the most likely future climate scenario involves changes in both temperature and CO_2 [78], it is vital to understand whether CWCs can acclimatise to multiple stressors simultaneously, what the cost is to other processes [79], and whether they have the potential to adapt in the longer term. To assess the acclimatisation and adaptation abilities of organisms, it is vital to conduct long-term experiments.

Intrinsically linked to the potential for adaptation is the question of how reproduction is impacted by environmental stressors. No experiments to date on cold-water corals have considered impacts of climate change on reproductive fitness or connectivity. Considering that early life stages of marine invertebrates including tropical corals are particularly vulnerable to ocean acidification [3], this needs to be investigated in CWC as a matter or urgency. However, there are serious logistical constraints with regard to this, as it is not feasible to collect fresh reproductive material at the time of spawning due to the often-unsuitable weather, and few laboratories can reliably harvest gametes from aquaria-kept CWC specimens.

Other cold-water coral species - While gorgonians and stylasterids have not been well-studied with regard to ocean acidification compared to *Lophelia pertusa*, the stability of their calcium carbonate and proteinaceous structures also merit further attention, as they contribute towards habitat and biodiversity provision and can survive below saturation levels [80]. Detailed analysis of the reef-forming scleractinian *Solenosmilia variabilis* in Australian waters also indicates that it can survive and grow in undersaturated conditions (no more than 15% undersaturated), but will only develop extensive reefs above the saturation horizon [81]. An absolute low tolerance limit of ~40% undersaturation also seems to exist for corals below saturation horizons [80]. The relationship between acidification and coral growth and survival is complex, with variable impacts observed across different taxa [80].

The solitary CWC *Desmophyllum dianthus* has generally shown similar abilities to *L. pertusa* to acclimate to projected ocean acidification under natural temperature conditions [82] but can be found in aragonite-undersaturated waters with pH ranging from 7.4 to 8.3 [59,80,83,84]. While growth was found to stay the same under low pH conditions [71,82,85], young, fast-growing polyps reduce their growth rate after long incubations [71], possibly due to a proportionally larger energetic investment in growth. Expression of calcification and metabolism genes also changed when exposed to elevated pCO_2 conditions, and may indicate a possible mechanism by which *D. dianthus* can maintain growth and metabolism through a shift of substrates for metabolism [85,86]. While growth rates of *D. dianthus* do not change in response to elevated pCO_2, elevated temperatures can significantly reduce the calcification rate in *D. dianthus* over long (8 month) time periods [60,85], indicating that the relationship between temperature and CO_2 is not simple both within and between species.

Sponge grounds - Deep-sea sponge-dominated communities (grounds, aggregations and gardens) form a variety of vulnerable marine ecosystems widespread in areas such as shelves, slopes, seamounts, mid-ocean ridges, canyons and fjords which often coincide with fishing and other human activities. Their biodiversity, ecological importance and biotechnological potential is assumed to be similar to or even higher than other deep-sea ecosystems such as cold-water coral reefs or vents/seeps systems. However, in contrast to those, sponge grounds have so far received relatively little scientific or conservation attention. In many areas sponges are by far the dominant organism in terms of abundance (up to 16 individuals/m^2) and biomass (over 90% of total invertebrate biomass[161]) forming structurally complex ecosystems known as sponge grounds, gardens, aggregations and reefs. These ecosystems are very diverse not only in terms of community composition and structure, but also in terms of the geomorphological features they inhabit and the extent of their geographical and bathymetric distributions. Sponges are present in all marine environments, from the coast to abyssal locations up to 8,840 m deep, including near hydrothermal vents, caves and canyons [87]. Sponge dominated ecosystems are found globally along continental shelves, slopes, seamounts, mid-ocean ridges and even canyons and deep fjords, at depths varying from 30 to approximately 3000 m, which places them in direct contact with some of the most important commercial fisheries. In the northwest Atlantic sponge grounds form extensive habitats along the continental slopes from Newfoundland to the eastern Arctic[162], while in the northwest Pacific glass sponge reefs form extensive and unique habitats[163,164] and replace framework and other cold-water corals in benthic ecosystems.

Most sponge species colonise hard substrata [87], and water quality, movement and food availability are important in controlling species distribution [88]. The complex three-dimensional structures of sponge fields create important deep-sea benthic habitats that support a rich variety of organisms in a similar manner to cold-water coral habitats [18,22]. Sponges also co-occur with cold-water corals and provide an additional biodiversity provision within these habitats. For example, in the NE Atlantic, the demosponge *Spongosorites coralliophaga* was recently found to provide habitat for 91 species, belonging to 12 phyla including Foraminifera, Nematoda and Brachiopoda [89]. Shallow sponges have been exploited since antiquity [90], but recent harvesting of deep-sea species has increased in the effort to produce new drugs from their secondary metabolites [91].

In addition to their biodiversity functions, sponges play dominant roles in bentho-pelagic coupling [92] and sequestration. Due to their large filter-feeding capacity (up to 14 l seawater g^{-1} h^{-1}), a diet mainly composed of dissolved organic matter, and a silicified skeleton, sponges are known to be major players in bentho-pelagic coupling, contributing significantly to biogeochemical cycles such as the nitrogen, carbon and silicon cycles [165, 166, 167] . For instance, the recent discovery (in tropical coral reefs) of a “sponge loop” showing that sponges efficiently retain, transform and transfer most of the available carbon to higher trophic levels, has helped solved the long-standing paradigm of how biodiversity hotspots are maintained under oligotrophic conditions[93]. This may also prove to be the case in the generally food-poor deep-sea environment. Similarly, sponges were shown to accumulate impressive silicon standing stocks in their populations and sponge grounds have been estimated to uptake dissolved silicon at rates similar or even higher than those measured from diverse diatom assemblages. There have only been a few studies on the impacts of ocean acidification to sponges to date. Results using naturally occurring CO_2 vents have indicated that sponge cover decreases significantly as water becomes more acidified, with some species of sponge being more vulnerable than others [94]. This decrease may represent an impact to sponge regeneration mechanisms, and consequent potential to recover from disturbances [94].

Other, shallow-water studies have found that 'bioufouling' calcareous sponges may benefit from a drop in pH, with *Leucosolenia sp.* increasing in abundance in pH 7.7 relative to controls [95]. On a wider scale, in bioeroding sponges across latitudes and biogeographic areas, results suggest that ocean acidification accelerates their bioerosion processes. This would have a significant impact on global carbonate (re)cycling [96].

Sponges also provide societal goods in the form of pharmaceuticals. Sponges and their associated microorganisms are the richest and most prolific source of marine natural products with human health applications, with more than 30% of the total number—or nearly 5000 compounds—discovered to date[168]. More than 75% of the marine natural products discovered from deep-sea organisms since 2008 showed potent bioactivity, including some of the known "sponge ground" compounds, like barettin and ianthelline, which have anti-fouling and anticancer properties[169,170]. In addition to products with pharmaceutical application, there is an increasing biotechnological interest in the use of other sponge bioproducts and processes, for example, the use of sponge collagen in medicine, food science, and cosmetics, as a biomimetic platform for bone cell attachment and growth, and as an organic template for silicification.

Cold Seeps - Cold seeps occur mostly along continental margins, and vary in their chemistry which can produce methane or methanehydrate ice (methane-seeps), hydrogen sulphide (sulphide-seeps), or other hydrocarbon-rich fluid seepages from the sediments[171]. The pore water is of a similar temperature to the surrounding water and such areas are referred to as 'cold' to distinguish them from the hydrothermal vent areas. Seep environments exhibit a fauna taxonomically similar to that of hydrothermal vents, including the presence of vestimentiferan tubeworms, and vesicomyid and mytilid bivalves, where there is evidence of their use of carbon from methane through symbiotic bacteria. Generally, the dominant cold-seep species are large bivalves (families Vesicomyidae and Mytilidae) but there are also symbiont-containing species of other bivalve families, pogonophoran worms, crabs and sponges[172,173]. However, unlike hydrothermal vents, specialized carnivores have not been reported in high abundance[172]. Where the pore water that escapes from the sea floor is rich in sulphide, there is a zonation around the seep with those organisms which tolerate the highest concentrations of otherwise toxic sulphide being found closest to the seep site. Seeps are vulnerable to the pressures of intense research activity, bioprospecting, and mineral exploration[171].

Hydrothermal Vents - Hydrothermal vents occur on mid-oceanic ridges, back-arc basins, volcanic arcs and active seamounts, and play an important role in transferring mass and energy from the crust and mantle to the oceans. The hot, reducing, metal-rich, magnesium- and sulphate-poor hydrothermal fluids that exit “black smoker” and “white smoker” chimneys are formed through interactions of seawater with oceanic crust. Hydrothermal plumes form above sites of venting and ultimately disperse laterally. Hydrothermal fluids are enriched in several key tracers (e.g., Mn, Fe, CH_4, H_2, 3He) relative to typical oceanic deep waters, allowing for their detection at significant distances away from hydrothermal vent sites[174]. These interactions modify the composition of oceanic crust, affect ocean chemistry, form metal-rich deposits, and provide energy sources for biological communities in the deep sea, which are important even after the vents become inactive. Specifically, hydrothermal circulation has proven to be an important sink for Mg and a source for other elements such as Fe, Mn, Li, Rb, and Cs[176].

In the North Atlantic, the hydrothermal vents lie along the Mid-Atlantic Ridge (MAR). While some have been visually surveyed and studied, several remain unconfirmed and are inferred based on detection of a chemical signature from the plume in the overlying water column. The actual number of hydrothermal vents and locations remains unknown both in the North Atlantic and elsewhere[177]. About 350 vent fields have been discovered identified in the world's oceans to date.

Hydrothermal vents are habitats dominated by temperatures much warmer than those of the surrounding deep-sea and characterized by a highly toxic sulphur-rich chemistry. A small number of endemic taxa are adapted to these inhospitable environments and can occur at high density and biomass. Globally only about 600 species from hydrothermal areas have been described from hydrothermal areas[177-179]. Many of the invertebrates among them, which host chemoautotrophic bacteria as epi- or endosymbionts and are endemic to the vents and vent communities, can be divided into major hydrothermal provinces based on faunal composition[179]. These vent communities are dependent on chemosynthetic production of microbial biomass which on the MAR has been found to occur in warm water emissions, loosely rock-attached flocculent material, dense morphologically diverse bacterial mats covering the surfaces of polymetal sulphide deposits, and filamentous microbes on the carapaces of shrimp. The bacterial mats on polymetal sulphide surfaces contained unicellular and filamentous bacteria which appeared to use as their chemolithotrophic electron or energy source either dissolved reduced minerals from vent emissions, mainly sulphur compounds, or solid metal sulphide deposits, mainly pyrite[180]. Together, these habitats create highly diverse communities compared with surrounding areas. As for seeps, they are vulnerable to the pressures of intense research activity, bioprospecting, and mineral exploration.

2.3 Pelagic habitats and biodiversity

Fish

According to recent IPCC AR5 findings, the projected impacts of climate change on fisheries and aquaculture are negative on a global scale [97], including displacements of stocks and mortality of shellfish from acidic water, although in some regions fish stocks may increase. Fish may be impacted by climate change and acidification directly or through changes to their food sources. Changes to the environment could result in migration change or habitat usage [98].

It was recently highlighted that mesopelagic fish probably account for much more of the world total of fish biomass than previously thought [99]. These mesopelagic (200 - 1000 m water depth) fish have major knowledge gaps with regard to their biology and adaptations, and more research on them is needed, particularly on the diel migrating species which directly transfer energy from the surface waters to the deep sea. Recent research has proposed a close relationship between the biomass of these fish and primary production, with a higher than previously reported energy transfer from phytoplankton to fish, equating to an estimate that ~10% of primary production may be respired by them [99].

With the updated assessments of high abundances of fish in mesopelagic areas, it is clear that there remains significant research to be done on the impacts of climate change to these stocks, especially since recent research in the Atlantic has highlighted that changes in pH are significant within this depth range [100]. As the role of migrating species is important in oceanic carbon flux, by actively transporting organic matter in the top layer of the water column, it is important to include them into biogeochemical cycling modelling in conjunction with climate change.

In general, fish are considered to be more resilient to direct effects of ocean acidification than many other marine organisms because they do not have an extensive skeleton of calcium carbonate, and they possess well-developed mechanisms for acid-base regulation [3,101]. It is therefore also important to consider indirect effects of ocean acidification, such as through changes in foodweb relationships (see pteropod section below).

The effects of ocean acidification on development, growth and survival of marine fish has largely focused on larval and juvenile stages, because they are predicted to be more sensitive to elevated pCO_2 than adults [101,102]. Despite this prediction, recent studies have found that the early life-history stages of some fish are resilient to projected future levels of ocean acidification. Development, growth and survival of larvae and juveniles of the pelagic cobia [103] and walleye pollock [104] appear relatively robust to near-future

CO_2 levels (≤1000 µatm CO_2). It is also important to conduct studies where the parental, in addition to the offspring, generations are exposed to projected CO_2 conditions, as emerging evidence on warm-water fish has highlighted that reduced growth and survival of juveniles reared at high CO_2 levels was reversed when the parents experienced the same CO_2 conditions as the juveniles [105].

There are three areas in which consistent effects of elevated CO_2 have been detected for marine fish: (1) exposure to elevated CO_2 causes sensory and behavioural impairment in a range of marine fish [106]; (2) otolith (earbone) size is consistently larger in larval and juvenile fishes reared under elevated CO_2; (3) vision and retinal function appears to be negatively impacted by ocean acidification [107–109].

While results indicate that most fish are probably able to maintain sufficient oxygen delivery at CO_2 levels predicted to occur in the near-future, the effect on squid may be more pronounced. The epipelagic squid (e.g. *Ommastrephidae, Gonatidae, Loliginidae*) are considered to be most severely impacted by the interference of CO_2 with oxygen binding at the gills [110]. The respiratory pigment haemocyanin, used for blood oxygen transport, is very sensitive to CO_2 as demonstrated in the Pacific jumbo squid *Dosidicus giga,* which had significant reduction of metabolic rates and activity levels when subjected to <1000 µatm of CO_2 [111]. Importantly, elevated CO_2 could also affect squid paralarvae, as demonstrated by abnormal shapes of aragonite statoliths in the Atlantic Longfin squid *Doryteuthis pealeii*, which are critical for balance and detecting movement [112].

Pteropods - commonly called 'sea-butterflies', pteropods are a group of gastropods (i.e. snails) that can be found from the sea surface down to at least 1000 m [113]. Pteropods occur throughout the global ocean but they are most abundant in sub-Arctic and sub-Antarctic to Antarctic waters where they can form a significant part of the zooplankton and are important foodstocks for fish and other predators [3,114,115]. Due to their geographic range they can occur in water that may already be undersaturated for periods, due to deep-water upwelling [113]. Their depth range also means that they are at risk of being exposed to undersaturated waters in non-Arctic and non-Antarctic water over the coming century. Due to their thin aragonitic shells [116] pteropods represent a group of organisms likely to be severely affected by ocean acidification. Experimental evidence confirms this, with studies demonstrating that pteropod shell dissolution does occur [3,5,113,117]. Calcification is also inhibited at significantly higher levels of $\Omega_{aragonite}$ [118–120], and a modelling study using high emission-based scenarios (SRES A2) for the end of the century, with data on the likely impact on pteropod calcification, concluded that "there appears little future for high-latitude shelled pteropods" [121] if emissions are high. This will impact upon the many organisms that use pteropods as a food source, including large copepods, herring, North Pacific juvenile salmon, whales and birds.

Krill – Krill provide a direct link between primary producers and higher trophic levels. Although vast amounts of krill biomass occurs in polar seas, krill occur in many other areas such as the North Atlantic and North Pacific (FAO)[122]. Uses of krill can include human consumption, bait for sport fishing and as a food source in aquaculture (FAO)[122]. Although krill are often found in the top 200 m of the oceans, they can aggregate below this depth [123,124] and their vertical and horizontal migration patterns means they can be exposed to variable carbonate chemistry [125]. Many krill species are broadcast spawners, and release their eggs into the water column where they sink. This means that the eggs would be exposed to water where the carbon dioxide partial pressure is greater than surface waters. The limited research done to date on how increased carbon dioxide levels would impact the fate of these eggs (using Antarctic krill) was that hatching rate decreased and that embryonic development was delayed when eggs were exposed to projected future conditions in the laboratory [125]. While krill might exhibit some acclimatization to future environmental conditions, their genetic similarity at large spatial scales indicates that rapid adaptation through natural selection of tolerant genotypes is a remote possibility. These findings raise concerns over the potential future of other krill species in non-polar seas, which have similar spawning stages.

2.4 Ocean acidification monitoring

Effective monitoring of ocean acidification across a range of spatial, depth and temporal scales is crucial to better understand current variability, and modelling how this will change over the coming century. Observations of ocean acidification are not yet on a fully global scale, not only because of the relatively short time of awareness of the importance of such changes, but also due to the high cost of research expeditions; the inaccessibility of many regions; the relative unavailability of highly accurate and reliable pH sensors; and the current limitations of autonomous monitoring techniques [3]. In addition to long-term time series monitoring changes in marine carbon systems in the Central Pacific (Hawaii Ocean Time series, HOT) and North Atlantic (Bermuda Atlantic Time-series Study, BATS; European Station for Time-series in the Ocean, ESTOC), international efforts aim to extend and complement existing programmes. Relevant activities are being initiated and implemented at the regional level, for example, through the US Ocean Margin Ecosystems Group for Acidification Studies (OMEGAS), and the Study Group on Ocean Acidification (SGOA) set up by OSPAR/ICES. The SGOA has recognised that monitoring in the OSPAR region should be coherent with other regional and global monitoring activities. This includes the US Strategic Plan for Federal Research and Monitoring of OA and the recently established Global Ocean Acidification Observing Network (GOA-ON) (Figure 3). GOA-ON aims to provide an understanding of ocean acidification conditions and the ecosystem response, as well as to deliver the data needed to optimise ocean acidification modelling. Since the potential scope for biological observing is extremely wide, GOA-ON will build on, and work in close liaison with, the Global Ocean Observing System (GOOS) and its Framework for Ocean Observation. Other bodies contributing to the development of the network include the IAEA Ocean Acidification International Coordination Centre (OA-ICC), IOC-UNESCO, the

International Ocean Carbon Coordination Project (IOCCP), and a range of national funding agencies [3]. From Figure 3, it is clear that there exist many gaps in current efforts to monitor ocean acidification globally, and much of the instrumentation deployed is coastal. To better understand how processes are occurring in cold-water areas, expansion of existing monitoring efforts is needed in an integrated effort across international monitoring organisations and through collaborative partnerships between government, industry and academia.

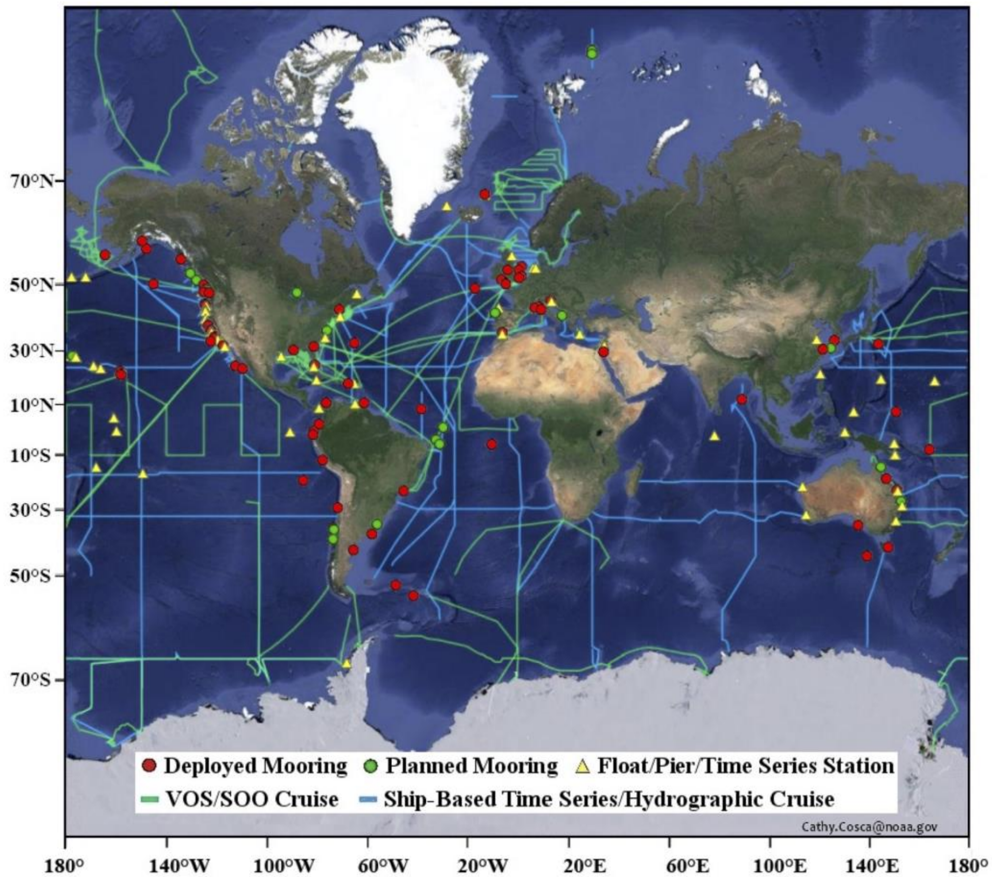


Figure 3. Components of the developing Global Ocean Acidification Observing Network (GOA-ON), including moorings, time-series stations, and ship-based surveys, by voluntary observing ships (VOS), ships of opportunity (SOO) and research vessels.

2.5 Knowledge gaps

Despite recent research advances, there are still major knowledge gaps to be explored before any certain inferences can be made as to the long-term survival and ecological role of many cold-water ecosystems and the biodiversity they support. Some knowledge gaps are summarised below.

Knowledge area	Issue	Degree of current understanding	Potential action
1. Discovery and documentation of existing cold-water ecosystems and habitats	The depth of many cold-water ecosystems and habitats makes discovery and characterisation difficult and costly. Without knowledge of what exists, management will be ineffective	Adequate in some regions and for some ecosystems such as cold-water coral reefs, but more ecosystems and habitats such as sponge and sea pen grounds still being discovered and documented	More surveys in uncharacterised areas of the seafloor
2.Environmental variability (e.g. temperature, chemistry, currents)	The degree of environmental variability experienced (daily or seasonal timescales) could impact acclimatisation and adaptation potential of organisms	Patchy - some areas well characterised with modelled and observed data. Other areas are not well characterised.	Expand upon long-term monitoring networks to include more key cold-water areas
3.Biodiversity characterisation	A firm understanding of what biodiversity is present in cold-water habitats and ecosystems, from macro to megafauna, is needed to base biodiversity supporting management strategies upon	Some key habitats (e.g. some CWC reefs and seamounts) becoming relatively well characterised. Many others with only partial information available	More benthic and pelagic surveys are needed to characterise regional and local biodiversity
4. Will the marine food web be	How will an impact on one organism impact on others up	Poor. While general food chains (webs)	More region specific research is

impacted?	the food web?	are understood, specific impacts will vary by region and will depend upon points 1 & 3	needed to understand how organisms are linked through a food web
5. What are the impacts of multiple stressors on marine organisms?	Will the impact of multiple stressors on cold-water organisms be additive, synergistic or antagonistic?	Organism dependent. Some species have moderate understanding (e.g. CWC *L. pertusa*), others only subject to single stressors	More laboratory based research needed
6.Energetic budgets	In research to date, does acclimatisation to stressor come at the expense of energetic reserves or other processes?	Organism dependent. This is often dependent upon laboratory experiments being over a long time period (months)	More long-term laboratory based research needed
7.Evolutionary potential of key cold-water habitat providers (e.g. corals)	For key habitat providing organisms that are long-lived (e.g. cold-water corals), it is unknown whether they have the potential to adapt to rapid changes in environmental conditions	Poor. Population genetics combined with experimental manipulations needed to address this	More research required assessing natural populations along environmental gradients coupled with laboratory experiments
8.Susceptibility of different life stages to environmental stressors	Evidence exists that for many marine organisms, early life stages may be more susceptible to projected environmental changes.	Organism dependent, but majority of research conducted on coastal	More research required on cold and deep-water species

		organisms	
9. Altered deep-water circulation	Global climate change may lead to altered patterns of overturning circulation with potentially far-reaching effects on all marine ecosystems. For benthic cold-water species like corals and sponges this has far-reaching consequences for connectivity and multiple scales from regional to ocean basin and beyond.	Limited evidence often hampered by lack of sufficient numbers of high quality samples for population genetic analysis	Integrated ocean basin scale research equipped with suitable deep-sea ROV and/or submersible sampling equipmen
10. How has ocean acidification in the past shaped biodiversity?	By looking into past ocean acidification events, and how this may have impacted biodiversity at the time, we will increase our understanding of the impacts of current ocean acidification	Good with regard to some types of organisms (e.g. foraminifera) in specific regions, but there are no past events which occurred in similar timescales to current change	More research required on a wider range of organisms in more regions

A key area for development is the discovery, documentation and characterisation of existing and new cold-water habitats. The inaccessibility of many ecosystems below 200 m, and the economic cost associated with researching these areas means that data are patchy on many ecosystems, while only few are well-characterised. The recent discovery of a 12 km long glass sponge reef in Chatham Sound, British Columbia, Canada, (making it one of the largest in the world, second only to the prehistoric reefs in nearby Hecate Strait), and the continuing discovery of cold-water coral reefs (e.g. via the Norwegian MAREANO programme, www.mareano.no), highlights how much is still to be discovered even in what were believed to be well-understood regions like offshore Canada and Norway. Characterising biodiversity at all of these locations remains intrinsically difficult due to their accessibility and the equipment available, and requires coordinated international efforts to ensure that taxonomic characterisation is consistent globally. While variability in carbonate chemistry is starting to be incorporated into coastal studies, many cold-water areas lack spatial and temporal resolution in data collected to allow this to happen, and this remains a key area to develop.

The current understanding of how food webs will be impacted due to climate change is poor, due in part to the complexity of food webs and the difficulty of subjecting communities to experimental conditions. While this has been successfully performed with mesocosms in Arctic waters [126,127], this remains a substantial knowledge gap in and between many ecosystems.

The impact of multiple stressors on cold-water organisms is a further key knowledge gap. While some species have relatively well-studied (such as *L. pertusa*) [61], other species have only been subjected to single stressor experiments or none at all. Linked with this is the importance of conducting long-term experiments in conjunction with multiple stressors that look at the energetic budgets of organisms, and if possible examine multiple life stages, as larvae and juveniles may be more susceptible than adult stages [3]. This would help develop understanding of whether the long-term fitness of cold-water taxa will be impacted by projected multiple stressors.

At wider oceanographic scales, the impacts of climate change need to be explored and modelled for different ocean circulations, to assess whether cold-water ecosystems could be subjected to dramatic changes in connectivity to other systems, food supply and water chemistry [128].

2.6 Initiatives to address knowledge gaps

Initiatives to address recognised knowledge gaps are occurring globally. These range from national to trans-global initiatives, and occur on most of the major continents. Some of these are described briefly below, and aim to address knowledge gaps identified by recent and on-going international and national efforts, including the recent European Commission's "European Project on Ocean Acidification" (EPOCA)), which brought together more than 160 scientists from 32 countries, the German programme Biological Impacts of Ocean Acidification (BIOACID); EU Framework 7 research programmes CoralFISH and MedSea; AUS research support (via NSF and NOAA), mandated by the 2009 Federal Ocean Acidification Research and Monitoring (FOARAM) Act; the UK Ocean Acidification Research Programme (UKOA); and other programmes and projects in Australia, China, Japan, Republic of Korea, Norway and elsewhere. A summary of national involvement in ocean acidification research is discussed in CBD Technical Series Report No. 75: "An updated synthesis of the impacts of ocean acidification on marine biodiversity" (2014).

Linkages between these research efforts worldwide on ocean acidification have been encouraged at the intergovernmental level as well as by national funders and non-governmental science bodies, particularly the SOLAS-IMBER Ocean Acidification Working Group (SIOA-WG), which helped to establish the Ocean Acidification International Coordination Centre (OA-ICC) of the IAEA, based in Monaco. Current IAEA activities include the facilitation of global observation and monitoring; joint-use research platforms and experiments; definition of best practices; data management; capacity building; dissemination and outreach. OA-ICC liaison with policy-makers, the private sector and other stakeholders is assisted by the Ocean Acidification international Reference User Group (OA-iRUG). OA-iRUG publications aim to provide key policy-relevant messages on ocean acidification to decision makers.

Current initiatives in the southern hemisphere include a coral modelling work programme in New Zealand, that will provide up-to-date coral distribution models into the future using the latest global climate models. It will eventually provide a scenario of what ocean acidification could do to New Zealand's protected corals, to inform risk assessment approaches to protected coral species to result in beneficial mitigation, management and conservation. This has built upon reports that have already classified different coral types into low, medium and high risk categories with regard to deep-water bottom trawling. Underpinning this type of modelling and planning is the ongoing collaboration between New Zealand's NIWA (National Institute of Water and Atmospheric Research) and Australia's CSIRO (Commonwealth Scientific and Industrial Research Organisation) to standardise deep-water coral taxonomic nomenclature and predictive mapping of coral distribution, community recovery from fishing and environmental impacts.

In Brazil, a National Action Plan for the Environment Conservation Coral Reefs (PAN Reef) is being coordinated to provide a list of strategic actions with the specific purpose of assessing the vulnerability of key environments to climate change and identify adaptation measures, including shallow, mesophotic and deep reefs. The Action Plan, under coordination of Ministério do Meio Ambiente (MMA) will include actions to reduce the vulnerability of natural systems to the effects of climate change. The plan includes measures specific to coral reefs to achieve Aichi Targets.

In Colombia, INVEMAR (Instituto de Investigaciones Marinas Y Costeras) has developed several initiatives to understand processes that will impact the marine environment, including climate change, biodiversity changes, physicochemical systems and socioeconomic systems. The creation of Burdwood Bank (Argentina) as a Marine Protected Area has also spurred initiatives to develop predictive modelling of future climate change impacts, building capacity for collecting real-time data and to adopt strategies for sustainable use of biological resources.

Building upon regional initiatives such as examples above, the Latin-American Ocean Acidification Network (LAOCA Network), was established in 2015 and includes Argentina, Brazil, Colombia, Ecuador, Peru, Mexico, and Chile, with support from the International Atomic Energy Agency (IAEA) through the Ocean Acidification International Coordination Centre (OA-ICC), the Intergovernmental Oceanographic Commission (IOC-UNESCO), the Center for the Study of Multiple-Drivers on Marine Socio-Ecological Systems (MUSELS), and the Millennium Institute of Oceanography (IMO) from Chile. The goals of the LAOCA Network include the synthesis of information about ocean acidification impacts in Latin-America, to encourage the implementation of long-term dataset of carbonate chemistry in Latin-America, evaluation of impacts on different ecosystems and the inclusion of ocean acidification on the political agenda of network members.

In the northern hemisphere, The Coral and Sponge Conservation Strategy in Canada is outlining the current state of knowledge of corals and sponges, providing international and national context for coral conservation, and highlighting new and existing research and conservation efforts in eastern Canadian waters. Complementary projects supported through the Strategic Program for Ecosystem-Based Research and Advice (SPERA) and the International Governance Strategy (IGS) have the stated goal of expanding knowledge of coral distribution. Significant benthic areas of corals and sponges have been mapped in eastern Canadian waters using species distribution models to extrapolate to unsampled areas. Within the United States, specific strategies to increase the long-term resilience of fisheries also exist, such as the National Oceanographic and Atmospheric Administration (NOAA) Fisheries Climate Science Strategy. This strategy aims to increase the production, delivery, and use of climate-related information in fulfilling NOAA Fisheries mandates. The Strategy identifies objectives which will provide decision-makers with the information they need to reduce impacts and increase resilience in a changing climate and is designed to be customized and implemented through Regional Action Plans that focus on building regional capacity, partners, products and services. By increasing the production, delivery, and use of climate-related information, NOAA Fisheries and partners aim to reduce impacts and increase the resilience of valuable living marine resources and the communities that depend on them [129].

Within Europe, the French National Museum of Natural History (MNHN) and the Research Institute for Development (IRD) are conducting research on the biological diversity of the bathyal zone of the Pacific Ocean to characterise the structure of the biodiversity of deep habitats and connectivity patterns in New Caledonia. Further initiatives from the Ministry of Ecology, Sustainable Development and Energy, will also improve knowledge sharing between the different actors (scientists, fishermen, vessel owners and other stakeholders including NGOs) in an efficient format by developing concrete initiatives on the impact of climate change and acidification on ecosystems and their resilience. This will highlight existing knowledge gaps and find more effective short- and long-term solutions to impacts, and develop innovative operations for engagement of the general public in marine and coastal biodiversity through project participatory and citizen science.

A new European Commission research Initiative, “ATLAS” (A Trans-Atlantic assessment and deep-water ecosystem-based spatial management plan for Europe) joins multinational industries, SMEs, governments and academia together to assess the Atlantic’s deep-sea ecosystems and Marine Genetic Resources to create the integrated and adaptive planning products needed for sustainable Blue Growth, in conjunction with North American partners to foster trans-Atlantic collaboration and the wider objectives of the Galway Statement on Atlantic Ocean Cooperation. ATLAS will gather diverse new information on sensitive Atlantic ecosystems (incl. VMEs and EBSAs) to produce a step-change in understanding of ecosystem connectivity, functioning and responses to future changes in human use and ocean climate. In addition to using trans-Atlantic oceanographic arrays to understand and predict future change in living marine resources, ATLAS will enhances their capacity with new sensors to make measurements directly relevant to ecosystem function. An annual ATLAS Science-Policy Panel in Brussels will take the latest results and Blue Growth opportunities identified from the project directly to European policy makers. Finally, ATLAS has a strong trans-Atlantic partnership in Canada and the USA where both government and academic partners will interact closely with ATLAS through shared research cruises, staff secondments, scientific collaboration and work to inform Atlantic policy development.

Another European Commission research incentive, “SponGES” (Deep –sea Sponge Grounds Ecosystems of the North Atlantic) will map and investigate the sponge ecosystems in the North Atlantic, increasing the knowledge base of sponge grounds, their potential for biotechnological applications and their consideration in management and conservation practices. The proposed integrated ecosystem based approach will provide decision support tools for management and sustainable use of marine resources, and will study sponge grounds throughout the entire North Atlantic from Portugal and Florida to the Arctic. The function of the sponge ground ecosystems and the goods and services they provide to the North Atlantic system will be quantified, including the role of sponge grounds for the major biogeochemical cycles, silicon, carbon and nitrogen, as well as total community productivity and respiration. Using paleoclimatic data obtained from sediment cores at multiple sites and linking it to the Atlantic Meridional Overturning Circulation the project will investigate how sponge aggregations formed, persisted and functioned throughout the Holocene, further uncovering major events in these ecosystems such as species shifts and population expansions/retractions which may help to predict future climate change impacts.

3. Analysis of existing policy and management responses to the identified existing and potential pressures and threats and identification of gaps

The policy and management responses to threats to cold-water biodiversity are undertaken in the context of national laws and policies, as well as international and regional agreements. The latter include, in addition to the CBD, the United Nations Convention on the Law of the Sea (UNCLOS), the United Nations Framework Convention on Climate Change (UNFCCC), and regional conventions related to environmental protection and fisheries. In addition, the United Nations General Assembly (UNGA) as the main deliberative, policymaking and representative organ of the UN, has adopted resolutions of relevance to cold-water biodiversity. The substantive work in preparation for these resolutions has been carried out through several GA-mandated working groups that include the Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction, the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea (the Consultative Process), and the Open Working Group on Sustainable Development Goals (SDGs).

The following provides a summary of the global and regional policy context, which covers the role of organizations, instruments and processes in relation to cold-water biodiversity.

3.1 Global instruments and processes

United Nations Convention on the Law of the Sea

The provisions of the United Nations Convention on the Law of the Sea (UNCLOS) set out the legal framework within which all activities in the oceans and seas must be carried out. Of particular relevance to cold-water biodiversity is the legal framework for the protection and preservation of the marine environment set out in Part XII of UNCLOS. Part XII sets out the general obligation for States to protect and preserve the marine environment (article 192), and includes a number of provisions which elaborate on this obligation. In particular, UNCLOS requires States to take, individually or jointly as appropriate, all measures consistent with UNCLOS that are necessary to prevent, reduce and control pollution of the marine environment from any source, using for this purpose the best practicable means at their disposal and in accordance with their capabilities (article 194) – these measures include those necessary to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life (articles 194(3) and 212). It should be noted that UNCLOS defines “pollution of the marine environment” as the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities (article 1).

Also of relevance is Part XIII of UNCLOS, which provides an extensive framework for marine scientific research, including with regard to the conduct of such research and the publication and dissemination of information and knowledge resulting therefrom. In addition, Part XIV of UNCLOS on the development and transfer of marine technology provides that States shall promote the development of the marine scientific and technological capacity of States which may need and request technical assistance in this field, particularly developing States, including land-locked and geographically disadvantaged States, with regard to, *inter alia*, the protection and preservation of the marine environment, marine scientific research and other activities in the marine environment compatible with UNCLOS (article 266).

UN Framework Convention on Climate Change

The UN Framework Convention on Climate Change (UNFCCC) is of importance to cold-water biodiversity because it will be the primary mechanism for country collaboration in reducing greenhouse gas emissions. At the Twenty-first Session of the Conference of the Parties (COP 21) delegates reached consensus on the landmark Paris Agreement. The Paris Agreement commits, for the first time, all nations to reduce their rates of greenhouse gas emissions to “well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius above pre-industrial levels,” and puts into place a system of monitoring and verification of national emissions, as well as significant guidance and tangible commitments on mitigation, adaptation, financing, and capacity development and technology transfer.

The new Paris Agreement includes recognition for the ocean within the Preamble and in the Agreement itself, under the banner of Ecosystem Integrity. Articles 4 and 5 provide that Parties should promote sustainable management, and “take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases . . . ” This provides a basis for further attention on the need for marine protection (as the ocean is one of the Earth’s largest reservoirs of carbon) and should help to move the ocean onto the agenda for future meetings.

United Nations General Assembly

The United Nations General Assembly (UNGA) has undertaken a number of resolutions of importance to cold-water biodiversity and the pressures and threats it faces. These resolutions included:

- Resolution 69/245 on oceans and the law of the sea (29 December 2014) is one of many recent resolutions calling for a number of actions to address risks to, *inter alia*, coral reefs and cold-water corals. It has reaffirmed the need for States, individually or through competent international organisations, to urgently consider ways to integrate and improve, based on best available scientific information and precautionary approach and in accordance with UNCLOS and related agreements and instruments, the management of risks to cold-water corals (paragraph 221).
- Resolution 69/245 also encouraged States and competent international organisations and other relevant institutions, individually and in cooperation, to urgently pursue further research on ocean acidification, especially programmes of observation and measurement, and to increase national, regional and global efforts to address levels of ocean acidity and the negative impact of such acidity on vulnerable marine ecosystems, particularly coral reefs (paragraph 165). It has also urged States to make significant efforts to tackle the causes of ocean acidification, recognising countries national circumstances and respective capabilities, and to further study and minimise its impacts, to enhance local,

national, regional and global cooperation in this regard, including the sharing of relevant information and the development of worldwide capacity, including in developing countries, to measure ocean acidification, and to take steps to make marine ecosystems healthier and, as a result, more resilient, to the extent possible, to the impacts of ocean acidification (paragraph 169).

- Resolution 69/109 on sustainable fisheries (9 December 2014) urged States, either directly or through appropriate subregional, regional or global organisations or arrangements, to intensify efforts to assess and address, as appropriate, the impacts of global climate change and ocean acidification on the sustainability of fish stocks and the habitats that support them, in particularly the most affected ones (paragraph 5). The Assembly has emphasised the importance of developing adaptive marine resource management strategies and enhancing capacity-building to implement such strategies in order to enhance the resilience of marine ecosystems to minimise the wide range of impacts on marine organisms and threats to food security caused by ocean acidification, in particular the impacts on the ability of calciferous plankton, coral reefs, shellfish and crustaceans to build shells and skeletal structures and the threat this could pose to protein supply (paragraph 174).
- The General Assembly has addressed the impacts of bottom fishing on vulnerable marine ecosystems and the long-term sustainability of deep-sea fish stocks in its resolutions on sustainable fisheries. It has called upon States to take action immediately, individually or through regional fisheries management organisations and arrangements (RFMO/As), and consistent with the precautionary and ecosystem approaches, to continue to implement the 2008 International Guidelines for the Management of Deep-Sea Fisheries in the High Seas of the Food and Agriculture Organization of the United Nations in order to sustainably manage fish stocks and protect vulnerable marine ecosystems, including seamounts, hydrothermal vents and cold-water corals, from destructive fishing practices, recognising the immense importance and value of deep-sea ecosystems and the biodiversity they contain (paragraph 154). The General Assembly has also specified concrete actions to be taken by States and RFMO/As, in particular in resolutions 61/105, 64/72, 66/68. These resolutions have been supplemented by the actions taken by the Food and Agriculture Organization of the United Nations and RFMO/As.
- The General Assembly has conducted reviews of actions of States and RFMO/As in response to the relevant provisions of the above resolutions in 2009 and 2011. Furthermore, recalling its decision in paragraph 137 of resolution 66/68 to conduct a further review of the actions taken by States and RFMO/As in response to paragraphs 113, 117 and 119 to 124 of resolution 64/72 and paragraphs 121, 126, 129, 130 and 132 to 134 of resolution 66/68, with a view to ensuring effective implementation of measures therein and to make further recommendations, where necessary, the General Assembly recognised the value of preceding such a review with a two-day workshop. The General Assembly

> consequently decided to conduct such a review in 2016 (paragraph 162) and requested the Secretary-General to convene a two-day workshop in the second half of 2016 in order to discuss implementation of these paragraphs (paragraph 163). It also requested the Secretary-General to prepare a report for consideration by the Assembly at its seventy-first session, on the actions taken by States and RFMO/As in response to the above-mentioned paragraphs of resolutions 64/72 and 66/68 (paragraph 164).

In addition to the above, The United Nations summit for the adoption of the post-2015 development agenda was held from 25 to 27 September 2015, in New York and convened as a high-level plenary meeting of the General Assembly. As part of this summit, the General Assembly adopted the Sustainable Development Goals (SDGs). SDG 14 pertains to conserving and sustainably using the oceans, seas and marine resources for sustainable development. While there are a number of pertinent targets listed under SDG 14, perhaps the most important for this paper include 14.2: By 2020 sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans; and 14.3: Minimise and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels.

Convention on Biological Diversity

The Convention on Biological Diversity (CBD) addresses conservation and sustainable use of biodiversity, and in this regard, UNCLOS and CBD are complementary instruments with respect to the conservation and sustainable use of marine biodiversity. The CBD emphasizes the ecosystem and precautionary approach with regards to conservation and sustainable use of biodiversity and the management of various activities that may affect biodiversity and ecosystems. Parties to the CBD are encouraged to develop and implement National Biodiversity Strategies and Action Plans (NBSAPs). There are various elements of work carried out under the CBD that are relevant to better understanding of biodiversity and ecosystems in cold-water areas, pressures affecting these areas and potential ways to mitigate and minimize these pressures. These include the work related to the impacts of ocean acidification on marine and coastal biodiversity, impacts and implications of climate change for biodiversity, description of ecologically or biologically significant marine area (EBSAs), voluntary guidelines on biodiversity inclusive environmental impact assessments (EIAs) and strategic environmental assessments (SEAs), guidance on development of networks of marine protected areas, tools and guidance related to marine spatial planning. The Conference of the Parties to the CBD will also be focusing, at its thirteenth meeting in 2016, on issues related to mainstreaming biodiversity in various sectors, including fisheries, and the development of a specific workplan for biodiversity and acidification in cold-water areas.

Food and Agriculture Organization of the United Nations

The Food and Agriculture Organization of the United Nations (FAO) plays an important role in supporting sustainable management practices for fisheries so that ecosystems and marine living resources are protected from irreversible damage while ensuring livelihoods and food security.

The FAO Code of Conduct for Responsible Fisheries, adopted in 1995, sets out principles and international standards of behaviour for responsible practices with a view to ensuring the effective conservation, management and development of living aquatic resources, with due respect for the ecosystem and biodiversity. After two decades since its adoption, the Code continues to be a reference framework for national and international efforts, including in the formulation of policies and other legal and institutional frameworks and instruments, to ensure sustainable fishing and production of aquatic living resources in harmony with the environment. The Code is voluntary and is to be interpreted and applied in conformity with international law, the provisions of which form an integral part of the Code (FAO, 2015). A range of technical guidelines have been developed to assist the international community in taking the necessary practical steps to implement the provisions foreseen in the Code, including on the Ecosystem approach to fisheries and to aquaculture (EAF/EAA). Furthermore, a variety of “soft law” instruments have been developed within the framework of the Code including four International Plans of Action (IPOAs) which are voluntary instruments that apply to all States and entities and to all fisheries relating to reducing incidental catch of Seabirds in long-line fisheries (IPOA-seabirds), conserve and manage Sharks (IPOA-sharks), manage fishing capacity (IPOA-capacity) and prevent, deter and eliminate Illegal, Unreported and Unregulated fishing (IUU fishing) (IPOA-IUU).

The FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas provide recommendations on governance frameworks and management of deep-sea fisheries with the aim to ensure long-term conservation and sustainable use of marine living resources in the deep sea and to prevent significant adverse impacts on vulnerable marine ecosystems (VMEs). The Guidelines are a voluntary and constitute an instrument of reference to help support States and Regional Fisheries Management Organizations (RFMOs) in formulating and implementing appropriate measures for the sustainable management of deep-sea fisheries in the high seas. The FAO also maintains a VME database, which is a global inventory of fisheries measures adopted in areas beyond national jurisdiction to prevent significant adverse impacts of bottom fisheries on vulnerable marine ecosystems.

Other binding instruments of relevance include the compliance agreement that aims to strengthen the implementation of responsibilities of flag States for fishing vessels flying their flag and operating on the high seas and the agreement on port state measures to prevent, deter and eliminate IUU Fishing. The Agreement stipulates minimum port States measures.

International Maritime Organization

International rules and regulations concerning maritime safety, the efficiency of navigation and the prevention and control of marine pollution from ships have been developed under the auspices of the International Maritime Organization (IMO). The IMO is considered the competent international body under UNCLOS to establish special protective measures in defined areas where shipping presents a risk.

From the perspective of cold-water biodiversity, the main threats relate to introduction of invasive species, incidental oil pollution and noise pollution.

Discharges from ships, both accidental and intentional, are regulated by the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78). MARPOL 73/78 regulates vessel design, equipment and operational discharges from all ships. It also provides for the designation of Special Areas where more stringent discharge rules apply, including in respect of oil, noxious liquid substances, and garbage from ships. Special Areas are defined as areas where, for technical reasons relating to their oceanographic and ecological condition and to their sea traffic [130], the adoption of special mandatory methods for the prevention of sea pollution is required (UNEP).

In addition to the Special Areas described above, the IMO has adopted a resolution providing for the designation of Particularly Sensitive Sea Areas (PSSAs). According to the IMO, a PSSA is “a comprehensive management tool at the international level that provides a mechanism for reviewing an area that is vulnerable to damage by international shipping and determines the most appropriate ways to address that vulnerability”.

The International Convention for the Control and Management of Ship’s Ballast Water and Sediments (2004, not yet in force) aims to prevent, minimise and ultimately eliminate the transfer of harmful aquatic organisms and pathogens due to ballast water exchange. The Convention requires ships to conduct ballast water exchanges at least 200 nautical miles from the nearest land and in waters deeper than 200 m, wherever possible (Regulation B-4, Annex).

It should be noted that the ratification of this Convention has been slow, and despite its importance in blocking (or at least greatly reducing) one of the major vectors for introduction of invasive alien species, it has yet to enter into force.

The *Guidelines for the control and management of ships' biofouling to minimise the transfer of invasive aquatic species* (Biofouling Guidelines) were adopted by the Marine Environment Protection Committee (MEPC) at its sixty-second session in July 2011 and were the result of three years of consultation between IMO Member States (resolution MEPC.207(62)). The guidelines represent a first step towards IMO regulations that address the transport of invasive aquatic species on ship hulls. However, at the present time, compliance is mainly voluntary.

In addition to the above, the "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972", (London Convention), in force since 1975, was one of the first global conventions to protect the marine environment from human activities. Its objective is to promote the effective control of all sources of marine pollution and to take all practicable steps to prevent pollution of the sea by dumping of wastes and other matter. In 1996, the Contracting Parties adopted a Protocol to the London Convention (London Protocol) to further modernize the Convention and, eventually, replace it. The London Protocol came into force in March 2006. Currently 87 States are party to the Convention and 44 States are party to the Protocol.

Importantly for cold-water biodiversity, the London Convention has addressed the issue of ocean fertilization. In 2008, the London Convention/ London Protocol noted in resolution LC-LP.1 (2008) that that knowledge on the effectiveness and potential environmental impacts of ocean fertilisation is currently insufficient to justify activities other than legitimate scientific research. This non-binding resolution states that ocean fertilisation activities, other than legitimate scientific research, "should be considered as contrary to the aims of the Convention and Protocol and do not currently qualify for any exemption from the definition of dumping".

International Seabed Authority

The International Seabed Authority (ISA) is the organisation through which States Parties to UNCLOS control activities in the Area (the seabed and subsoil beyond national jurisdiction), particularly with a view to administering its resources. A principal function of the Authority is to regulate deep-seabed mining and to give special emphasis to ensuring that the marine environment is protected from any harmful effects which may arise during mining activities, including exploration. The Authority has entered into 15-year contracts for exploration for polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts in the deep seabed with 23 contractors.

Fourteen of these contracts are for exploration for polymetallic nodules with 13 of these in the Clarion-Clipperton Fracture Zone and one in the Central Indian Ocean Basin. There are five contracts for exploration for polymetallic sulphides in the South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge and four contracts for exploration for cobalt-rich crusts in the Western Pacific Ocean.

To date, the Authority has issued *Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area* (adopted 13 July 2000), which was later updated and adopted 25 July 2013; the *Regulations on Prospecting and Exploration for Polymetallic Sulphides in the Area* (adopted 7 May 2010) and the *Regulations on Prospecting and Exploration for Cobalt-Rich Crust*s (adopted 27 July 2012).

As part of its substantive work programme, the Secretariat of the Authority also carries out detailed resource assessments of the areas reserved for the Authority; maintains a specialised Database (POLYDAT) of data and information on the resources of the international seabed area and monitors the current status of scientific knowledge of the deep sea marine environment as part of its ongoing development and formulation of the Central Data Repository.

3.2 Regional instruments and processes

Regional Fishery Bodies

Regional Fishery Bodies (RFBs) are cooperative mechanisms through which States or organizations that are parties to an international fishery agreement or arrangement work together towards the conservation, management and/or development of fisheries and related issues.

There are some 50 RFBs worldwide, most providing only advice to their members. However, regional fishery management organizations (RFMOs), an important subset of RFBs, do have a mandate and the capacity for their members to adopt binding conservation and management measures based on best scientific evidence.

While some of these bodies have been established under Article VI of the FAO Constitution (advisory bodies-RFBs) and Article XIV (management bodies-RFMOs), many of them are not under the FAO framework and are financially and functionally independent.

The scope of each RFMO's conservation responsibilities varies in accordance with the associated convention. Some have competence over most or all marine living resources, while others manage fisheries exploiting particular species. Some are mandated to develop measures based on ecosystem and precautionary approaches, while others manage a target fishery resource without extensive consideration for ecosystem effects. In response to concerns about declining fisheries and biodiversity in the oceans, there have been recent efforts within the international community to strengthen the conservation and management regimes of RFMOs, and to improve the performance of RFMOs in accordance with the demands of international fishery instruments. The 2006 Review Conference on the UN Fish Stocks Agreement agreed that RFMOs should undergo performance reviews on an urgent basis, including independent evaluation ensuring that results would be publicly available. The 2006 UN General Assembly Resolution on Sustainable Fisheries also called upon countries to develop and apply best practice guidelines for RFMOs, and to undertake performance reviews of these bodies, based on transparent criteria. As a result, many RFMOs are taking steps to strengthen governance through implementing the ecosystem approach to fisheries and adopting the precautionary approach, while some others have reviewed their mandate and scope to address international concerns and support their members in the implementation of international instruments for fisheries management and conservation. The UN General

Assembly is scheduled to further review work of these bodies in 2016.

In accordance with the FAO International Guidelines for the Management of Deep-sea Fisheries in the High Seas, and relevant UN General Assembly resolutions Parties to RFMOs use the best scientific and technical information available to identify areas where vulnerable marine ecosystems (VMEs) are known or likely to occur and adopt conservation and management measures to prevent significant adverse impacts on such ecosystems or to close such areas to fishing and not to authorize bottom fishing activities until such measures have been implemented.

RFMOs, which have taken management action to apply ecosystem and precautionary approaches and close vulnerable areas to bottom fishing include North East Atlantic Fisheries Commission (NEAFC), the Northwest Atlantic Fisheries Organization (NAFO), South East Atlantic Fisheries Organisation (SEAFO), South Pacific Regional Fisheries Management Organisation (SPRFMO), the General Fisheries Commission for the Mediterranean (GFCM) and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR).

Regional Seas Conventions

There are currently 18 regional seas agreements and programmes, 13 of which have been established under the auspices of the United Nations Environment Programme (UNEP). Some agreements, such as those in the North-East Atlantic and the Antarctic, predate the establishment of UNEP. Most Regional Seas have adopted binding framework conventions, while others have non-binding action plans as a basis for their cooperation. Several have protocols related to specially protected areas and wildlife. Most contain provisions for conservation tools such as marine protected areas and species protection measures, as well as for the control of pollution.

Of the Regional Seas Conventions and Action Plans, only the OSPAR Convention area (North-East Atlantic) is located in its entirety in a cold-water area. Other regional seas conventions, such as the South-East Pacific (Lima Convention), West and Central Africa (Abidjan Convention), Eastern Africa (Nairobi Convention), Mediterranean (Barcelona Convention), Northwest Pacific (NOWPAP-Northwest Pacific Action Plan) and Pacific (Apia Convention) also contain cold-water area.

OSPAR, together with the International Council for the Exploration of the Sea (ICES) has set up a joint study group on ocean acidification (SGOA), and is currently considering implementing an Ocean Acidification monitoring strategy based on the SGOA recommendations (see fuller discussion in section 3.4). This work recognises the importance of monitoring, including indicators, as part of the response to ocean acidification. OSPAR has also put in place a representative network of marine protected areas, which includes important cold-water habitat.

3.3 National action in support of management of cold-water biodiversity

This section will consider practical management action undertaken on the national level to increase the resilience of cold-water biodiversity to single and multiple threats and pressures. In addition, recent research related to the management of multiple stressors in cold-water environments will be included. National and regional actions for management of global stressors, including ocean warming and acidification, will also be considered. While reducing CO_2 emissions is the key action for the management of ocean acidification and warming, other management options can be used to help marine ecosystems adapt and to buy time, e.g. by relieving the pressure of other stressors [131].

As is evident from the analysis of legal and policy instruments, the management of human impacts on biodiversity in the ocean is characterised by sectoral actions. CBD National Reports, in particular the most recent 5th National Reports, and the responses to Notification 2015-053 indicate that countries with cold-water biodiversity have undertaken a number of actions to protect vulnerable biodiversity from identified sectoral impacts. These actions range from closing identified cold-water coral and sponge reef areas to bottom fishing and mining activities, further actions to map, model and describe cold-water areas, including evaluation of their ecological and biological significance and vulnerability to risk, as well as actions to reduce pollution from land and sea-based sources. One example of sectoral national action includes the declining of consent to mine phosphorite nodules on the Chatham Rise in an area dominated by protected stony corals by New Zealand's Environment Protection Authority (EPA) in 2015. In this case it was determined that mining would cause significant and permanent adverse effects on the existing benthic environment. Other examples include bottom fishing closures on Norwegian and many other countries' cold-water coral reefs, and some protection afforded to known coral reefs in the EU through the use of Marine Protected Areas (Special Area of Conservation in the Habitats Directive) with associated fishery closures under the Common Fisheries Policy (CFP).

The table below provides a summary of common management responses to sectoral stressors to cold water biodiversity. Note that the list is indicative rather than exhaustive.

Stressor	Management response
Impact of bottom fisheries on cold water corals, sponge reefs and other vulnerable marine ecosystems	- Mapping and identification of vulnerable marine ecosystems (VMEs), and subsequent closure of the VME to trawl and other bottom contact fisheries - Bycatch limits for corals and sponges - Encounter protocols whereby if a certain predetermined amount of coral/sponge bycatch is caught in a single trawl, the rest of the fleet is alerted and the area is considered for closure.

Overexploitation and/or declines in abundance of species	- Stock recovery and restoration plans, including adjusting these plans to adapt to ocean warming and acidification
Impacts from oil and gas industry	- Environmental impact assessment and strategic environmental assessment - Implementation of proactive management measures, including exclusion of oil and gas exploration and extraction from vicinity of reefs
Impacts from cable laying	- Siting of cables in such a manner that they do not damage coral or sponge reefs, or other vulnerable habitats

While the instruments and activities to address sectoral stressors on the national and regional levels will benefit from strengthening, many are either in place or are being considered. Management responses to global stressors, including ocean warming and acidification, are more complex and difficult to manage on national or regional scales. The interaction between more localised stressors, such as pollution, unsustainable fishing and mining, and global stressors, such as ocean acidification and warming, presents additional complexity to management responses.

Understanding of the impacts of individual stressors is often limited, but we have even less understanding of the impacts that a combination of these stressors will have on cold-water marine organisms and ecosystems and the goods and services they provide. The need to understand the interactions and potentially cumulative or multiplicative effects of multiple stressors has been identified as one of the most important questions in marine ecology today [132]. The combined effect of multiple stressors can be additive, synergistic or antagonistic. When effects of stressors are additive, their combined impact is equal to the sum of their individual effects. With synergistic impacts, the combined impact is greater than the sum of each individual impact. And with antagonistic impacts, the combined impact is less than the sum of individual effects [133].

Because individual stressors interact, managing each activity largely in isolation will be insufficient to conserve marine ecosystems, or even to meet individual sector goals [134]. Multiple stressors must be managed in an integrated way, in the context of the ecosystem approach. Precautionary and integrated management through tools and approaches such as marine protected areas has been put in place in many countries, including, for example, protection of the Darwin Mounds in Scotland as an important habitat in 2004 and the establishment of the Gully Marine Protected Area (MPA) in 2004 in Canada, to protect vulnerable cold-water habitat. In Australian waters, several MPAs, including the Tasman Fracture Commonwealth Marine Reserve and the Huon and Flinders Commonwealth Marine Reserves protect biodiverse cold water habitats. More recently, the Parque Nacional Natural Corales de Profundidad (PNNCP) was declared in 2013 in Columbia to protect deep-water corals, and the Reserva de la Biosfera Zona Marina Profunda Pacífico Transicional Mexicano y Centroamericano is proposed in Mexico. These are but few examples of national activities to put in place MPAs to protect cold-water biodiversity.

There is some evidence from recent studies that priority areas for protection should include areas that may be most resilient to the impacts of climate change, and thus act as refuges of important biodiversity. This would imply that climate change be taken into account in decisions related to design and management of marine protected areas, and in broader applications of the ecosystem approach, such as in marine spatial planning. For example, Jackson et al. [135] argue that unmanaged pressures such as ocean acidification and global warming should be incorporated into marine management decisions, with a focus on the protection of cold-water coral reefs to ensure long-term survival of these habitats. A similar approach could be taken for other iconic marine habitats in the face of climate change.

Jackson et al. [135] demonstrated this approach through an analysis of spatial interactions between known and predicted cold-water coral reef distribution, the predicted impacts of acidification, trawling activity, and marine protected areas (MPAs) in the Northeast Atlantic. They suggested that management efforts be focused on removing trawling pressure from areas which may be either important reef strongholds (reef areas likely to be less impacted by acidification by being located at depths above the aragonite saturation horizon), or important for maintaining reef connectivity and gene flow, which may be crucial for coral species to adapt to the changing conditions.

In another example, Australian scientists undertaking work to protect benthic communities found that coral-based seamount systems have a low ecological resilience compared to most other marine systems subject to disturbance by bottom trawling, with little ecological recovery of damaged seamounts even after decades or more of repair [20,21]. However, research by Williams and colleagues [21] indicates that appropriate approaches to benthic spatial planning can result in recovery outcomes, despite the slow rate of coral growth. Spatial closures post-trawling can be beneficial, if they include areas of connected, intact, habitat over a range of depths. In order to maximize survival of corals in these areas, the scientists proposed prioritising communities at depths above the aragonite saturation horizon for protection [21].

There is also evidence that the protection of representative habitats is important, as is replication to prevent biodiversity from being lost as a result of isolated disturbances [136]. Furthermore, a management system that provides sufficient protection of representative benthic habitats that are adjacent or connected to trawled areas can also act as important refuges and source habitat for benthic species [137]. Other research has supported prioritised protection of certain benthic ‘zones’. Thresher and colleagues [138] found that species *richness* in deep water off south-east Australia is highest on substrate at ‘intermediate’ depth (1000–1300 m), but also found that *abundance* peaked at a deeper, less diverse zone at 2000–2500 m.

Deciding on priorities for management action depends on the lead time required for implementation and externalities such as international or national policy frameworks and budget constraints [139]. Actions such as translocating coral species to depths above the aragonite saturation horizon is theoretically possible, but technically challenging and expensive, and thus unlikely to be feasible on a large scale. A stakeholder workshop to assess and prioritise options for conserving legislatively protected deep-sea coral reefs off southeast Australia prioritised the following actions as being both high benefit and low risk [139]. These actions seek to increase the system’s adaptive capacity by changing regulatory/policy frameworks.

1. Minimise impacts of other anthropogenic stressors on the system;
2. Maximise the likelihood of survival of the species and its associated biota at other sites globally, and
3. Identify and protect possible future refugia regionally.

In the context of the CBD, extensive scientific work has already been undertaken to describe ecologically or biologically significant marine areas (EBSAs), some of which are located in cold-water areas. While the description and identification of EBSAs is purely a scientific exercise, countries and regional organisations may wish to further use the EBSA data, along with other relevant data and information, to help assess the location of habitats that may be resilient to the impacts of ocean acidification and warming, or that may help in maintaining gene flow and connectivity. Using MPAs and other tools to protect future refugia sites requires that these sites be known, and thus there is an urgent need to identify them nationally and regionally. These factors could be taken into account by the appropriate bodies in implementation of the ecosystem approach, including through marine spatial planning. Similarly, data collected by the FAO and RFMOs to identify VMEs could assist in this process.

It is evident that future management activities will need to aim to understand and manage cold-water ecosystems and species in the context of multiple impacts, and will need to include actions to increase ecosystem resilience at the national and regional levels. Concurrently, management strategies will also need to address global impacts, particularly ocean warming and acidification, through action to reduce emissions at the global level. It should also be kept in mind that that cold-water biodiversity supports economies and well-being, and that all stakeholders have a role in its management. In the sectoral context this means, for example, that fisheries management methods need to consider climate change impacts and habitat destruction as added threats to marine populations in order to sustain healthier ecosystems, mitigate threats to the ocean, and ensure that ocean-dependent people are able to adapt to changes. In addition, awareness-raising and capacity building on all levels are important for future management effectiveness, and should be undertaken as a priority.

Appendix 1: Summary of responses of Parties to CBD Notification 2015-053

This appendix provides brief descriptions of submissions by Parties in response to CBD notification 2015-053, "Submission of information and suggestions on the development of a specific workplan on biodiversity and acidification in cold-water areas," issued on 6 May 2015 (https://www.cbd.int/doc/notifications/2015/ntf-2015-053-marine-en.pdf). Information from these and other submissions was also incorporated into the main text of the background document, where appropriate.

Australia

Australia is well-known for its tropical coral reefs, notably the Great Barrier Reef on the eastern seaboard and Ningaloo Reef on the west. These shallow-water tropical reefs are built predominantly of stony scleractinian corals, but support a rich biodiversity, including erect and branching octocorals. These coral-associated communities are familiar to Australians and are an important part of national and world heritage. However, Australia also has significant deep cold-water coral communities. In waters off Tasmania, CWC communities are concentrated around 1,000 m depth, but the occurrence of some species extends below 3,000 m.

Surveys over the last two decades have significantly improved understanding of deep-water coral species composition and distribution within Australian waters. The new information has mainly come from six large deep-water biodiversity surveys (>80 m) carried out by the Commonwealth Science and Industrial Research Organisation (CSIRO), in collaboration with other institutions, between 1997 and 2008. The collections of deep-water octocorals obtained during these surveys [140] have been examined at CSIRO, together with historical museum collections obtained from the Great Australian Bight and Coral Sea between 1909 and 2014. This information has been used to generate a taxonomically cross-referenced database of species distributions that covers most known samples from Australian waters; the distribution of sample locations is shown in Figure 4. A few relatively minor or very recent collections are yet to be examined and added to the database. CSIRO data demonstrate that Australia's deep-water coral assemblages are highly diverse and may display high levels of endemism, based on both geographic distance and bathymetry [140].

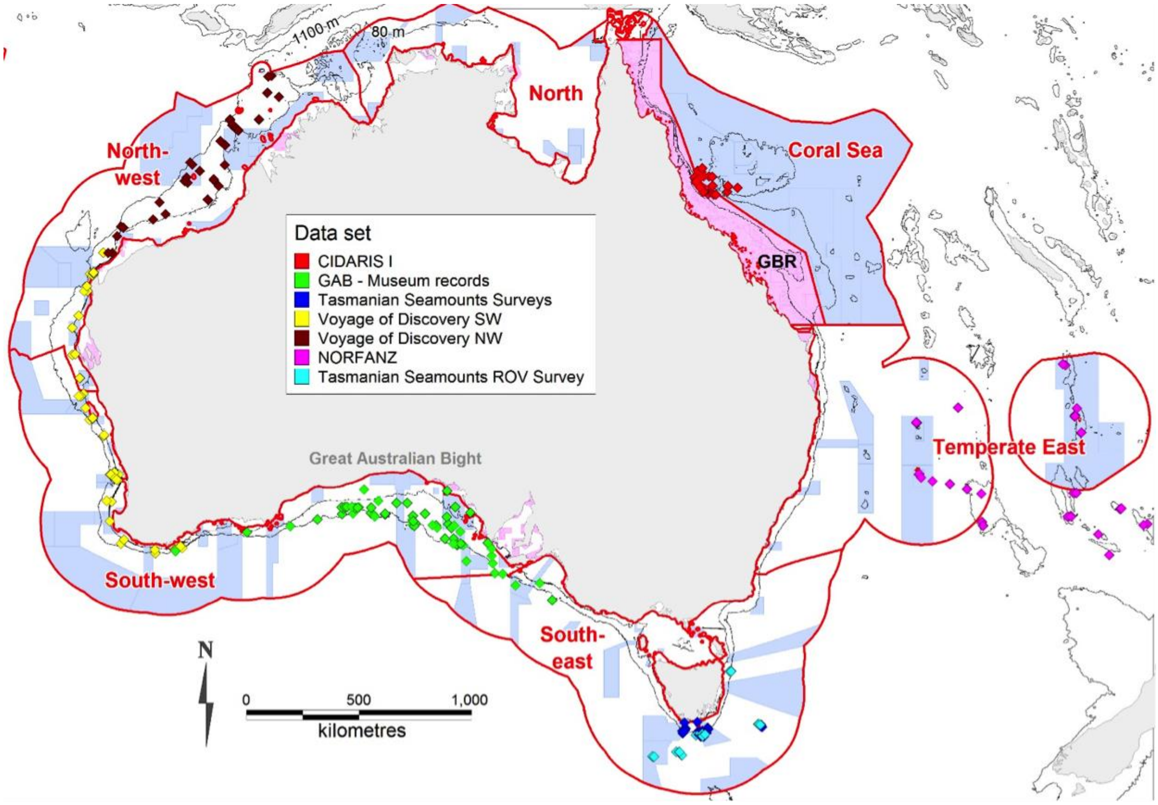


Figure 4: The distribution of deep-water coral samples held by CSIRO and the sampling gears used. These samples were collected from six biodiversity surveys between 1997 and 2008. The red line represents Australia's Exclusive Economic Zone boundary (excluding Heard, Macquarie and Christmas Islands). Source: CSIRO.

Additional taxonomic assessment, using both morphological and molecular techniques, is needed to develop a clearer understanding of phylogenetics and biogeography in deep-water coral communities [140]. These aim for ongoing taxonomic work being progressed by CSIRO in Australian waters, and for the south-west Pacific region, by CSIRO and the National Institute of Water and Atmosphere in New Zealand. Key elements of this collaboration include standardisation of deep-water coral taxonomic nomenclature, but also predictive mapping of coral distributions, ecological studies of community recovery from fishing impacts and environmental factors (including acidification) influencing coral production and survival.

Australian State of the Environment Reports are produced on a five-year cycle and these reports consider, among many other things, the status of the marine environment and biodiversity of coral communities. Although deep-water corals are not considered separately to tropical or temperate shallow-water corals in all cases, the report provides a useful high-level and national-scale assessment. The most recent report published in 2011 assessed the condition of coral reef habitats in Australian waters and provided an indication of status and trend. The condition of fringing reefs of the coast and islands were assessed as *"good, with a stable trend and medium to high confidence in the* *assessment".* Coral reefs (generally) as well as deep-water corals and sponges were both assessed as *"good, with a stable trend and medium confidence"*. A condition rating of 'good' indicates: *"There is some habitat loss, degradation or alteration in some small areas, leading to minimal degradation but no persistent, substantial effects on populations of dependent species"* [141]. This assessment indicates that there is variation in the condition of corals across different areas of Australia's marine environment. Reef-building as an ecological process, due to the action of calcifying organisms, was also assessed and was rated as *"good, with a stable trend and medium confidence"* [142].

More specifically, Thresher and colleagues [143] noted, based on detailed surveys to 4,030 m conducted using an autonomous underwater vehicle and a remotely-operated vehicle, that the deep-water reefs in the Huon and Tasman Fracture Marine Reserves generally appear to be healthy, with impacts of trawling limited to depths less than 1,200 m and very sparse marine debris in the area.

Argentina

In the South Atlantic, the Burdwood Bank extends east from Cape Horn for around 600 km. It was recognised for its biological richness by scientific expeditions in the early 20th Century, findings borne out by more recent surveys [147], which have recorded cold-water corals, sponges and other marine benthic species. Human activities in this area include fisheries using longline and bottom trawl approaches and exploration and production of offshore oil and gas. Notable fisheries include mid-water trawling for the benthopelagic Southern blue whiting (*Micromesistius austrolis*). Burdwood Bank has been recently desribed as an ecologically and biologically significant marine area (EBSA) and since 2008 fishery controls have been established in key areas, for example on the western edge of the bank there is a closure prohibiting trawling for Patagonian toothfish (*Dissostichus eleginoides*).

Brazil

Deep-water coral reefs have been reported in several places on the Brazilian upper continental slope with notable occurrences in the Campos Basin [157–160]. Biogeographic and phylogenetic analyses have revealed that the azooxanthellate scleractinian corals in Brazilian waters represent a transitional fauna between the species that characterise polar settings to the south to the coral fauna more typical of northern Atlantic water masses [159]. Coral species richness increases with depth across the outer continental shelf to depths of around 500 m whereupon it falls. It is important to note that sites off Brazil may be very important in the overall connectivity between deep coral populations across the entire Atlantic Ocean [128]. This will only be understood if future research embraces full ocean basin scale and integrates objectives internationally.

Canada

In 2015, Canada's Department of Fisheries and Oceans (DFO) developed a Coral and Sponge Conservation Strategy for Eastern Canada. This outlines the available information on cold-water corals and sponges and puts relevant conservation measures in context both nationally and internationally. Several relevant research projects have been conducted including work to create species distribution models in areas including the Eastern Arctic, Newfoundland and Labrador, the Gulf of St Lawrence and the Scotian Shelf. Researchers at DFO have monitored ocean acidification for over ten years in key areas including the Gulf of St Lawrence, coast of British Columbia and the Arctic Ocean. Work is now expanding to include implications of other stressors (hypoxia or warming) on commercial marine invertebrates (northern shrimp and scallops).

Colombia

Exploration of deep Caribbean sites in Colombian waters began in the 1970s through expeditions from the University of Miami's Rosenstiel School of Marine and Atmospheric Science aboard the RVs *Oregon* and *Pillsbury*. There followed a series of expeditions using the RV *Ancon* between INVEMAR, CIOH and the Smithsonian Institution in 1995 and the MACROFAUNA I and II cruises carried out between 1998 and 2002 [148]. These first expeditions identified several coral species that provide structural habitat on the Colombian continental shelf and margin including *Anomocora fecunda*, *Cladocora debilis*, *Coenosmilia arbuscula*, *Lophelia pertusa*, *Madracis asperula*, *Madracis brueggemanni*, *Madracis myriaster*, *Madrepora carolina* and *Madrepora oculata* (INVEMAR)[149].

INVEMAR research has now located three cold-water coral reef sites where both fish and invertebrate diversity are significantly enriched. The first is found on the continental shelf at 200 m depth in the vicinity of the Tayrona National Park, jurisdiction of the Department of Magdalena. This reef is dominated by *Madracis myriaster* with 12 other scleractinian corals and 102 other species of fish and invertebrates. *Madracis myriaster* is an important habitat-forming species in other regions [46,150] and its functional role in this site makes it a conservation priority [151,152]. The second reef site is found at shallower continental shelf depths of around 70 m in the jurisdiction of the Municipality of Dibulla. Here *Cladocora debilis* is dominant with 156 other species including corals (scleractinians, antipatharians, octocorals), molluscs, echinoderms, byrozoans and fish. The third site is located at 160 m depth between the continental shelf edge and slope facing the Gulf of Morrosquillo and the San Bernardo Archipelago, jurisdiction of the Department of Sucre. This cold-water coral reef is dominated by *M. myriaster* with 18 other scleractinian corals and 115 species of invertebrates and fish [148].

To date, while dead skeletal fragments of the cosmopolitan cold-water coral *Lophelia pertusa* have been recovered in Colombian waters from the jurisdiction of the Department of La Guajira [153], this species has not been found living in the three deep reef sites of Magdalena, Dibulla or Sucre. Given the occurrence of *L. pertusa* reefs elsewhere in the Caribbean [150], further research is needed to explore the possibility of *L. pertusa* reef occurrence in Colombian waters.

Thus, while substantial advances in mapping and understanding deep coral reefs in the Colombian Caribbean has been in the last decade much remains inadequately mapped and characterised [46]. Although deep corals are underrepresented in Colombian Marine Protected Areas there are examples that include these important ecosystems. For instance the Archipelago of San Bernado's deep structural coral habitats were selected as a priority site for conservation of marine and coastal biodiversity in Colombia [154]. These habitats were also selected as a significant biodiversity area [155] since they met five of the 10 relevant biological criteria: biodiversity (about 150 species), natural condition (no significant anthropogenic degradation), representation and habitat heterogeneity (special or rare habitats), quality or uniqueness (presence of live *M. myriaster* coral bank) and exclusivity (lack of deep communities), see Urriago et al. [156] for details.

Following an evaluation process that started in 2008 the National Natural Park for Deep Corals (PNNCP) was declared in April 2013 through Resolution 0339 of the Ministry of Environment, Housing and Territorial Development (MADS). This park extends over 142 thousand hectares on the edge of the continental shelf and slope off the Gulf of Morrosquillo and the Archipelago of San Bernardo in the Department of Sucre. The park is located 12 km from the Natural National Park Corales del Rosario and San Bernardo and 32 km from the nearest point on the mainland (Peninsula Baru).

France

France has been part of several major coral reef research efforts. These include CoralFISH, MEDSEACAN and CORSEACAN. CoralFISH is assessing the interaction between cold water corals, fish and fisheries, in order to develop monitoring and predictive modelling tools for ecosystem based management in the deep waters of Europe and beyond. MEDSEACAN-CORSEACAN is exploring the canyons of the Mediterranean, providing new scientific information about these ecosystems. A key objective was to use the results of these programs to identify deep reefs for possible designation as Natura 2000 sites. Other habitats with reefs were also discovered through these research efforts. More information is available at to http://wwz.ifremer.fr/peche/Projets/Coralfish2 http://mio.pytheas.univ-amu.fr/gisposidonie/?p=443.

In addition, the Agency for Marine Protected Areas (AMPA), the Scientific Interest Group "Posidonia", the Mediterranean Institute of Ecology and Biodiversity (MNHN) are engaged in a partnership to draft a guide to habitats and species of Mediterranean canyons.

Eventually, deep species distribution data will be posted on the National Inventory of Natural Heritage site (http://inpn.mnhn.fr/).

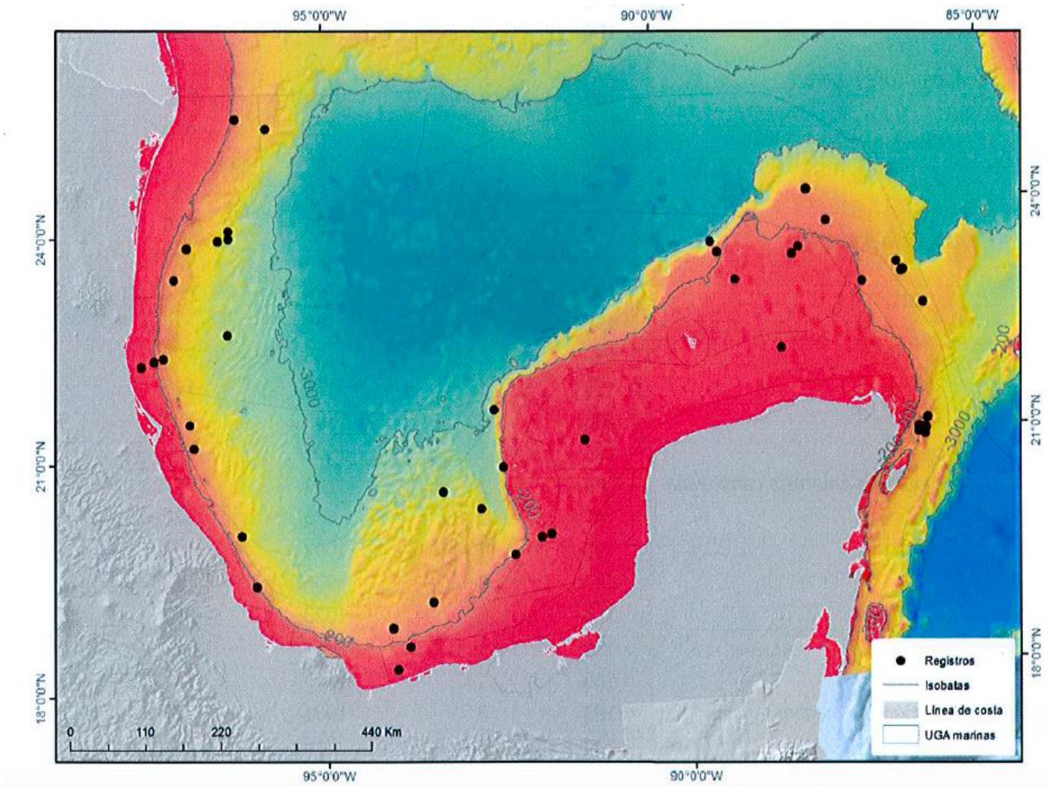
In addition, the MNHN produced with the support of the French Research Institute for Exploitation of the Sea (IFREMER), a report on the indicator species of vulnerable marine ecosystems in the North-East Atlantic, which includes an identification guide for onboard observers. This report is available at: http://spn.mnhn.fr/spn_rapports/archivage_rapports/2014/SPN%202014%20-%2022%20-%20Guide_EMV_profond_Atl_NE_2014.pdf. This report was presented to the International Council for the Exploration of the Sea (ICES / ICES) last year. In parallel, a project led by the MNHN on the sensitivity of benthic habitats (including deep habitats) will provide information about these habitats for management processes.

Overseas, MNHN and the Research Institute for Development (IRD) are conducting research on the biological diversity of the bathyal zone of the Pacific Ocean. This work is ongoing, and provides for the characterization of the structure and biodiversity of deep habitats and connectivity patterns in New Caledonia.

The Ministry of Ecology, Sustainable Development and Energy, will launch before the end of the year a call for research ideas on ocean acidification and its consequences. This call will be followed by exchanges in order to improve knowledge sharing between the different actors (scientists, fishermen, vessel owners, other stakeholders including NGOs, etc.) in an efficient format by developing concrete initiatives on the impact of climate change and acidification on ecosystems and their resilience.

Mexico

Information was provided on the location and condition of deep-water corals in the waters of Mexico. The map below shows the locations of known deep-water corals in the Gulf of Mexico and a separate table provided information about the species present. The Ocean Biogeographic Information System (OBIS) and other cited literature that informed to the mapping efforts were also included in the submission. The information contributed to the proposal to establish the protected area Reserva de la Biosfera Zona Marina Profunda Pacífico Transicional Mexicano y Centroamericano.



New Zealand

New Zealand is a biodiversity hotspot for many cold-water corals. All hard corals occurring within New Zealand's Territorial Sea and Exclusive Economic Zone are strictly protected under the Wildlife Act 1953. The 2014 Coral Identification Guide covers the key coral groups found in the New Zealand region [144]. New Zealand's hydrocoral fauna is one of the most diverse in the world, and 80% of the more than 50 native species are endemic. A review of protected deep-sea coral species in the New Zealand region was undertaken in 2006 by Consalvey et al. [145]. The review presented a comprehensive summary of research information on the distribution of the main protected taxa, an examination of likely factors that determine their distribution, and a list of all coral species in New Zealand waters. Coral protection in New Zealand was extended and clarified in 2010 as a result of this work [146].

References:

1. Bijma, J., Portner, H. O., Yesson, C. & Rogers, A. D. Climate change and the oceans - What does the future hold? *Mar. Pollut. Bull.* **76,** 436–505 (2013).
2. Doney, S. C., Fabry, V. J., Feely, R. A. & Kleypas, J. A. Ocean acidification: The other CO_2 problem. *Ann. Rev. Mar. Sci.* **1,** 169–192 (2009).
3. Secretariat of the Convention on Biological Diversity. *An updated synthesis of the impacts of ocean acidification on marine biodiversity (Eds. Hennige S.J., Roberts, J.M., Williamson, P.)*. *CBD Technical Series 75* (2014).
4. Sabine, C. L. *et al.* The oceanic sink for anthropogenic CO_2. *Science* **305,** 367–71 (2004).
5. Feely, R. A. *et al.* Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans. *Science* **305,** 362–6 (2004).
6. Gattuso, J.-P. & Hansson, L. Ocean Acidification. *Oxford Univ. Press* (2011).
7. Guinotte, J. M. *et al.* Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? *Front. Ecol. Environ.* **4,** 141–146 (2006).
8. IPCC. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. 996 (2007).
9. Turley, C. M., Roberts, J. M. & Guinotte, J. M. Corals in deep-water: will the unseen hand of ocean acidification destroy cold-water ecosystems? *Coral Reefs* **26,** 445–448 (2007).
10. Beaugrand, G., Reid, P. C., Ibañez, F., Lindley, J. A. & Edwards, M. Reorganization of North Atlantic marine copepod biodiversity and climate. *Science* **296,** 1692–1694 (2002).
11. Perry, A. L., Low, P. J., Ellis, J. R. & Reynolds, J. D. Climate change and distribution shifts in marine fishes. *Science* **308,** 1912–5 (2005).
12. Turley, C. M. *et al.* Hot, sour and breathless - Oceans under stress. *Plymouth Marine Laboratory UK Ocean Acidification Research Programme, European Project on Ocean Acidification, Mediterranean Sea Acidification in a Changing Climate Project, Scripps Institute of Oceanography, UC San Diago, Oceana.* 6pp (2013).
13. Keeling, R. F., Kortzinger, A. & Gruber, N. Ocean deoxygenation in a warming world. *Ann. Rev. Mar. Sci.* **2,** 199–229 (2010).
14. Stramma, L. *et al.* Expansion of oxygen minimum zones may reduce available habitat for tropical pelagic fishes. *Nat. Clim. Chang.* **2,** 33–37 (2012).
15. Gilly, W. F., Beman, J. M., Litvin, S. Y. & Robison, B. H. Oceanographic and biological effects of shoaling of the oxygen minimum zone. *Annu. Rev. Mar. Sci.* **5,** 393–420 (2013).

16. Levin, L. A. & Le Bris, N. The deep ocean under climate change. *Science.* **350,** 766–768 (2015).
17. Rogers, A. *et al.* Delving deeper: Critical challenges for 21st century deep-sea research. *Position Paper 22 Euopean Marine Board* (2015).
18. Roberts, J. M., Wheeler, A., Freiwald, A. & Cairns, S. D. Cold-water corals: The biology and geology of deep-sea coral habitats. (Cambridge University Press, 2009).
19. Carreiro-Silva, M. *et al.* Variability in growth rates of long-lived black coral leiopathes sp. from the azores. *Mar. Ecol. Prog. Ser.* **473,** 189–199 (2013).
20. Althaus, F. *et al.* Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting. *Mar. Ecol. Prog. Ser.* **397,** 279–294 (2009).
21. Williams, A. *et al.* Seamount megabenthic assemblages fail to recover from trawling impacts. *Mar. Ecol. Evol. Perspect.* **31,** 183–199 (2010).
22. Roberts, J. M., Wheeler, A. J. & Freiwald, A. Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science.* **312,** 543–547 (2006).
23. Maynou, F. & Cartes, J. E. Effects of trawling on fish and invertebrates from deep-sea coral fades of *Isidella elongata* in the western Mediterranean. *J. Mar. Biol. Assoc. United Kingdom* **92,** 1501–1507 (2012).
24. Pusceddu, A. *et al.* Chronic and intensive bottom trawling impairs deep-sea biodiversity and ecosystem functioning. *Proc. Natl. Acad. Sci. U.S.A.* **111,** 8861–8866 (2014).
25. Koslow, J. A. *et al.* Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Mar. Ecol. Prog. Ser.* **213,** 111–125 (2001).
26. Anderson, O. F. & Clark, M. R. Analysis of bycatch in the fishery for orange roughy, *Hoplostethus atlanticus*, on the South Tasman Rise. *Mar. Freshw. Res.* **54,** 643–652 (2003).
27. Mortensen, P. B., Buhl-Mortensen, L., Gebruk, A. V & Krylova, E. M. Occurrence of deep-water corals on the Mid-Atlantic Ridge based on MAR-ECO data. *Deep. Res. Part II-Topical Stud. Oceanogr.* **55,** 142–152 (2008).
28. Clark, M. R. *et al.* The impacts of deep-sea fisheries on benthic communities: a review. *ICES J. Mar. Sci. J. Cons.* (2015).
29. ICES. Final Report to OSPAR of the Joint OSPAR/ICES Ocean Acidification Study Group (SGOA). ICES CM 2014/ACOM:67. 141 pp. (2014).
30. Smith, C. R. *et al.* Biodiversity, species ranges, and gene flow in the abyssal Pacific nodule province: predicting and managing the impacts of deep seabed mining. In *Int. Seabed Authority, Tech. Study 3,* 38p (2008).
31. Decision on marine consent application Chatham Rock Phosphate Limited to mine phosphorite nodules on the Chatham Rise. *Environ. Prot. Authority, New Zeal.* (2015). <http://www.epa.govt.nz/eez/EEZ000006/EEZ000006_CRP Final Version of Decision.pdf>
32. Bakke, T., Klungsoyr, J. & Sanni, S. Environmental impacts of produced water and drilling waste discharges from the Norwegian offshore petroleum industry. *Mar.*

Environ. Res. **92,** 154–169 (2013).

33. Gass, S. E. & Roberts, J. M. The occurrence of the cold-water coral *Lophelia pertusa* (Scleractinia) on oil and gas platforms in the North Sea: Colony growth, recruitment and environmental controls on distribution. *Mar. Pollut. Bull.* **52,** 549–559 (2006).
34. Montagna, P. A. *et al.* Deep-sea benthic footprint of the Deepwater Horizon blowout. *PLoS One* **8,** (2013).
35. Juniper, K. S. Background paper on deep-sea hydrothermal vents. In Managing risks to biodiversity and the environment on the high sea, including tools such as marine protected areas: Scientific requirements and legal aspects. (Eds. Thiel, H. & Koslow, A.) (German Federal Agency for Nature Conservation, 2001).
36. Woodall, L. C. *et al.* The deep sea is a major sink for microplastic debris. *R. Soc. Open Sci.* **1,** DOI: 10.1098/rsos.140317 (2014).
37. Ramirez-Llodra, E. *et al.* Man and the last great wilderness: Human impact on the deep sea. *PLoS One* **6,** e22588 (2011).
38. Kaluza, P., Kolzsch, A., Gastner, M. T. & Blasius, B. The complex network of global cargo ship movements. *J. R. Soc. Interface* **7,** 1093–1103 (2010).
39. OSPAR. Assessment of the impacts of shipping on the marine environment. *Monit. Assess. Ser.* **440,** 33 (2009).
40. Hunt, B. & Vincent, A. C. J. Scale and sustainability of marine bioprospecting for pharmaceuticals. *Ambio* **35,** 57–64 (2006).
41. Herring, P. J., Gaten, E. & Shelton, P. M. J. Are vent shrimps blinded by science? *Nature* **398,** 116 (1999).
42. UNEP. Deep-sea biodiversity and ecosystems: A scoping report on their socio-economy, management and governance. *UNEP-WCMC Biodiversity Series No. 28* (2007).
43. Henry, L., Navas, J. M., Hennige, S., Wicks, L. C. & Roberts, J. M. Shark spawning grounds on cold-water coral reefs: a compelling case for protection of vulnerable marine ecosystems. *Biol. Conserv.* **161,** 67–70 (2013).
44. United Nations Sixty-first session. Agenda item 71 (b). Oceans and the law of the sea: sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December.
45. Rogers, A. D. The biology of *Lophelia pertusa* (LINNAEUS 1758) and other deep-water reef-forming corals and impacts from human activities. *Int. Rev. Hydrobiol.* **84,** 315–406 (1999).
46. Freiwald, A., Fosså, H., Grehan, A., Koslow, T. & Roberts, J. M. Cold-water coral reefs: out of sight-no longer out of mind. *UNEP-WCMC* (2004).
47. Findlay, H. S. *et al.* Fine-scale nutrient and carbonate system dynamics around cold-water coral reefs in the northeast Atlantic. *Sci. Rep.* **4,** (2014).
48. Findlay, H. S. *et al.* Tidal downwelling and implications for the carbon biogeochemistry of cold-water corals in relation to future ocean acidification and warming. *Glob. Chang. Biol.* **19,** 2708–2719 (2013).
49. Wicks, L. C. & Roberts, J. M. Benthic invertebrates in a high-CO_2 world. *Oceanogr.*

Mar. Biol. An Annu. Rev. **50,** 127–188 (2012).
50. Tambutté, S. *et al.* Coral biomineralization: From the gene to the environment. *J. Exp. Mar. Bio. Ecol.* **408,** 58–78 (2011).
51. Ries, J. Acid ocean cover up. *Nat. Clim. Chang.* **1,** 294–295 (2011).
52. Rodolfo-Metalpa, R. *et al.* Coral and mollusc resistance to ocean acidification adversely affected by warming. *Nat. Clim. Chang.* **1,** 1–5 (2011).
53. Erez, J., Reynaud, S., Silverman, J., Schneider, K. & Allemand, D. Coral calcifcation under ocean acidification and global change. In *Coral Reefs, an Ecosyst. transition.* (Eds. Dubinsky, Z. & Stambler, N.) (2011).
54. Venn, A., Tambutte, E., Holcomb, M., Allemand, D. & Tambutte, S. Live tissue imaging shows reef corals elevate pH under their calcifying tissue relative to seawater. *PLoS One* **6,** e20013 (2011).
55. McCulloch, M., Falter, J., Trotter, J. & Montagna, P. Coral resilience to ocean acidification and global warming through pH up-regulation. *Nat. Clim. Chang.* **2,** 623–633 (2012).
56. Venn, A. A. *et al.* Impact of seawater acidification on pH at the tissue-skeleton interface and calcification in reef corals. *Proc. Natl. Acad. Sci. U. S. A.* **110,** 1634–1639 (2013).
57. Cohen, A. L. & Holcomb, M. Why corals care about ocean acidification: Uncovering the mechanism. *Oceanography* **22,** 118–127 (2009).
58. Vidal-Dupiol, J. *et al.* Genes related to ion-transport and energy production are upregulated in response to CO_2-driven pH decrease in corals: new Insights from transcriptome analysis. *PLoS One* **8**, e58652 (2013).
59. Anagnostou, E., Huang, K. F., You, C. F., Sikes, E. L. & Sherrell, R. M. Evaluation of boron isotope ratio as a pH proxy in the deep sea coral Desmophyllum dianthus: Evidence of physiological pH adjustment. *Earth Planet. Sci. Lett.* **349,** 251–260 (2012).
60. McCulloch, M. *et al.* Resilience of cold-water scleractinian corals to ocean acidification: Boron isotopic systematics of pH and saturation state up-regulation. *Geochim. Cosmochim. Acta* **87,** 21–34 (2012).
61. Hennige, S. J. *et al.* Hidden impacts of ocean acidification to live and dead coral framework. *Proc. R. Soc. B Biol. Sci.* **282,** 20150990 (2015).
62. Wisshak, M., Schoenberg, C. H. L., Form, A. & Freiwald, A. Ocean acidification accelerates reef bioerosion. *PLoS One* **7,** e45124 (2012).
63. Andersson, A. J. & Gledhill, D. Ocean acidification and coral reefs: effects on breakdown, dissolution, and net ecosystem calcification. *Ann. Rev. Mar. Sci.* **5,** 321–348 (2013).
64. Dodds, L. A., Roberts, J. M., Taylor, A. C. & Marubini, F. Metabolic tolerance of the cold-water coral *Lophelia pertusa* (Scleractinia) to temperature and dissolved oxygen change. *J. Exp. Mar. Bio. Ecol.* **349,** 205–214 (2007).
65. Maier, C., Hegeman, J. & Weinbauer, M. G. Calcification of the cold-water coral Lophelia pertusa under ambient and reduced pH. *Biogeosciences* **6,** 1671–1680 (2009).

66. Form, A. U. & Riebesell, U. Acclimation to ocean acidification during long-term CO_2 exposure in the cold-water coral *Lophelia pertusa*. *Glob. Chang. Biol.* **18,** 843–853 (2012).
67. Maier, C. *et al.* End of the century pCO_2 levels do not impact calcification in Mediterranean cold-water corals. *PLoS One* **8,** e62655 (2013).
68. Maier, C. *et al.* Respiration of Mediterranean cold-water corals is not affected by ocean acidification as projected for the end of the century. *Biogeosciences* **10,** 5671–5680 (2013).
69. Hennige, S. *et al.* Short term metabolic and growth responses of the cold-water coral Lophelia pertusa to ocean acidification. *Deep Sea Res. II* **99,** 27–35 (2014).
70. Lunden, J. J., McNicholl, C. G., Sears, C. R., Morrison, C. L. & Cordes, E. E. Acute survivorship of the deep-sea coral Lophelia pertusa from the Gulf of Mexico under acidification, warming, and deoxygenation. *Front. Mar. Sci.* **1,** 78 (2014).
71. Movilla, J. *et al.* Resistance of two Mediterranean cold-water coral species to low-pH conditions. *Water* **6,** 59–67 (2014).
72. Widdicombe, S. & Spicer, J. I. Predicting the impact of ocean acidification on benthic biodiversity: What can animal physiology tell us? *J. Exp. Mar. Biol.* **366,** 187–197 (2008).
73. Eyre, B. D., Andersson, A. J. & Cyronak, T. Benthic coral reef calcium carbonate dissolution in an acidifying ocean. *Nat. Clim. Chang.* **4,** 969–976 (2014).
74. Silbiger, N. J. & Donahue, M. J. Secondary calcification and dissolution respond differently to future ocean conditions. *Biogeosciences* **12,** 567–578 (2015).
75. Hennige, S. J. *et al.* Self recognition in corals facilitates deep-sea habitat engineering. *Sci. Rep.* **4,** 6782 (2014).
76. Bentsen, M. *et al.* The Norwegian Earth System Model, NorESM1-M - Part 1: Description and basic evaluation of the physical climate. *Geosci. Model Dev.* **6,** 687–720 (2013).
77. Tjiputra, J. F. *et al.* Evaluation of the carbon cycle components in the Norwegian Earth System Model (NorESM). *Geosci. Model Dev.* **6,** 301–325 (2013).
78. IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.
79. Gates, R. D. & Edmunds, P. J. The physiological mechanisms of acclimatization in tropical reef corals. *Am. Zool.* **39,** 30–43 (1999).
80. Thresher, R. E., Tilbrook, B., Fallon, S., Wilson, N. C. & Adkins, J. Effects of chronic low carbonate saturation levels on the distribution, growth and skeletal chemistry of deep-sea corals and other seamount megabenthos. *Mar. Ecol. Prog. Ser.* **442,** 87–99 (2011).
81. Thresher, R. E., Guinotte, J. M., Matear, R. J. & Hobday, A. J. Options for managing impacts of climate change on a deep-sea community. *Nat. Clim. Chang.* **5,** 635–639 (2015).
82. Rodolfo-Metalpa, R. *et al.* Calcification is not the Achilles' heel of cold-water

corals in an acidifying ocean. *Glob. Chang. Biol.* 21, 2238–2248 (2015).
83. Jantzen, C. *et al.* Occurrence of a cold-water coral along natural pH gradients (Patagonia, Chile). *Mar. Biol.* **160,** 2597–2607 (2013).
84. Fillinger, L. & Richter, C. Vertical and horizontal distribution of *Desmophyllum dianthus* in Comau Fjord, Chile: a cold-water coral thriving at low pH. *PeerJ* **1,** e194 (2013).
85. Gori, A. *et al.* Physiological response of the cold-water coral *Desmophylum dianthus* to thermal stress and ocean acidification. *PeerJ* **4**, e1606 (2016).
86. Carreiro-Silva, M. *et al.* Molecular mechanisms underlying the physiological responses of the cold-water coral *Desmophyllum dianthus* to ocean acidification. *Coral Reefs* **33,** 465–476 (2014).
87. Van Soest, R. W. M. *et al.* Global diversity of sponges (Porifera). *PLoS One* **7,** (2012).
88. Kahn, A. S., Ruhl, H. A. & Smith, K. L. Temporal changes in deep-sea sponge populations are correlated to changes in surface climate and food supply. *Deep. Res. Part I-Oceanographic Res. Pap.* **70,** 36–41 (2012).
89. Kazanidis, G., Henry, L.-A., Roberts, J. M. & Witte, U. F. M. Biodiversity of Spongosorites coralliophaga (Stephens, 1915) on coral rubble at two contrasting cold-water coral reef settings. *Coral Reefs* **1,** 193-208 (2016).
90. Voultsiadou, E. *et al.* Aegean bath sponges: historical data and current status. *Rev. Fish. Sci.* **19,** 34–51 (2011).
91. Turk, T. *et al.* Biological activities of ethanolic extracts from deep-sea Antarctic marine sponges. *Mar. Drugs* **11,** 1126–1139 (2013).
92. Pile, A. J. & Young, C. M. The natural diet of a hexactinellid sponge: Benthic-pelagic coupling in a deep-sea microbial food web. *Deep. Res. Part I-Oceanographic Res. Pap.* **53,** 1148–1156 (2006).
93. Rix, L. *et al.* Coral mucus fuels the sponge loop in warm- and cold-water coral reef ecosystems. *Sci. Rep.* **6,** 18715 (2016).
94. Goodwin, C., Rodolfo-Metalpa, R., Picton, B. & Hall-Spencer, J. M. Effects of ocean acidification on sponge communities. *Mar. Ecol. Evol. Perspect.* **35,** 41–49 (2014).
95. Peck, L. S. *et al.* Acidification effects on biofouling communities: winners and losers. *Glob. Chang. Biol.* **21,** 1907–1913 (2015).
96. Wisshak, M., Schonberg, C. H. L., Form, A. & Freiwald, A. Sponge bioerosion accelerated by ocean acidification across species and latitudes? *Helgol. Mar. Res.* **68,** 253–262 (2014).
97. Holmyard, N. Climate change: implications for fisheries and aquaculture. (2014). <www.cisl.cam.ac.uk/ipcc>
98. Organisation for Economic Cooperation and Development (OECD). The economics of adapting fisheries to climate change. (OECD Publishing, 2011).
99. Irigoien, X. *et al.* Large mesopelagic fishes biomass and trophic efficiency in the open ocean. *Nat. Commun.* **5,** 3271 (2014).
100. Woosley, R. J., Millero, F. J. & Wanninkhof, R. Rapid anthropogenic changes in CO_2 and pH in the Atlantic Ocean: 2003-2014. *Global Biogeochem. Cycles* **30,** 70-90

(2016).

101. Melzner, F. *et al.* Physiological basis for high CO_2 tolerance in marine ectothermic animals: pre-adaptation through lifestyle and ontogeny? *Biogeosciences* **6,** 2313–2331 (2009).

102. Ishimatsu, A., Hayashi, M. & Kikkawa, T. Fishes in high-CO_2, acidified oceans. *Mar. Ecol. Prog. Ser.* **373,** 295–302 (2008).

103. Bignami, S., Sponaugle, S. & Cowen, R. K. Response to ocean acidification in larvae of a large tropical marine fish, *Rachycentron canadum*. *Glob. Chang. Biol.* **19,** 996–1006 (2013).

104. Hurst, T. P. *et al.* Resiliency of juvenile walleye pollock to projected levels of ocean acidification. *Aquat. Biol.* **17,** 247–259 (2012).

105. Miller, G. M., Watson, S.-A., Donelson, J. M., McCormick, M. I. & Munday, P. L. Parental environment mediates impacts of increased carbon dioxide on a coral reef fish. *Nat. Clim. Chang.* **2,** 858–861 (2012).

106. Munday, P. L., McCormick, M. I. & Nilsson, G. E. Impact of global warming and rising CO_2 levels on coral reef fishes: what hope for the future? *J. Exp. Biol.* **215,** 3865–73 (2012).

107. Chung, W. S., Marshall, N. J., Watson, S. A., Munday, P. L. & Nilsson, G. E. Ocean acidification slows retinal function in a damselfish through interference with GABA(A) receptors. *J. Exp. Biol.* **217,** 323–326 (2014).

108. Hamilton, T. J., Holcombe, A. & Tresguerres, M. CO_2-induced ocean acidification increases anxiety in rockfish via alteration of GABAA receptor functioning. *Proc. Biol. Sci.* **281,** 20132509 (2014).

109. Knight, K. Ocean acidification will interfere with fish eyes. *J. Exp. Biol.* **217,** 311–312 (2014).

110. Portner, H. O. & Zielinski, S. Environmental constraints and the physiology of performance in squid. *South African J. Mar. Sci.* **20,** 207–221 (1998).

111. Rosa, R. A. & Seibel, B. A. Synergistic effects of climate-related variables suggest future physiological impairment in a top oceanic predator. *Proc. Natl. Acad. Sci.* **105,** 20776 (2008).

112. Kaplan, M. B., Mooney, T. A., McCorkle, D. C. & Cohen, A. L. Adverse effects of ocean acidification on early development of squid (*Doryteuthis pealeii*). *PLoS One* **8,** (2013).

113. Bednarsek, N. *et al.* Extensive dissolution of live pteropods in the Southern Ocean. *Nat. Geosci.* **5,** 881–885 (2012).

114. Hunt, B. P. V *et al.* Pteropods in Southern Ocean ecosystems. *Prog. Oceanogr.* **78,** 193–221 (2008).

115. Arctic Monitoring and Assessment Programme (AMAP) assessment 2013: Arctic ocean acidification. Oslo, Norway. viii + 99 pp. (2013).

116. Teniswood, C. M. H., Roberts, D., Howard, W. R. & Bradby, J. E. A quantitative assessment of the mechanical strength of the polar pteropod *Limacina helicina* antarctica shell. *Ices J. Mar. Sci.* **70,** 1499–1505 (2013).

117. Orr, J. C. *et al.* Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* **437,** 681–6 (2005).

118. Comeau, S., Gorsky, G., Jeffree, R., Teyssié, J.-L. & Gattuso, J.-P. Impact of ocean acidification on a key Arctic pelagic mollusc (*Limacina helicina*). *Biogeosciences* **6,** 1877–1882 (2009).
119. Comeau, S., Gorsky, G., Alliouane, S. & Gattuso, J.-P. Larvae of the pteropod *Cavolinia inflexa* exposed to aragonite undersaturation are viable but shell-less. *Mar. Biol.* **157,** 2341–2345 (2010).
120. Comeau, S., Jeffree, R., Teyssié, J.-L. & Gattuso, J.-P. Response of the Arctic pteropod *Limacina helicina* to projected future environmental conditions. *PLoS One* **5,** e11362 (2010).
121. Comeau, S., Gattuso, J.-P., Nisumaa, A.-M. & Orr, J. Impact of aragonite saturation state changes on migratory pteropods. *Proc. R. Soc. B Biol. Sci.* **279,** 732–738 (2012).
122. FAO. Fisheries Technical Paper 367. Krill fisheries of the world. (1997).
123. Gutt, J. & Siegel, V. Benthopelagic aggregations of krill (*Euphausia superba*) on the deeper shelf of the Weddell Sea (Antarctic). *Deep. Res. Part I - Oceanogr. Res. Pap.* **41,** 169–178 (1994).
124. Greene, C. H., Wiebe, P. H., Burczynski, J. & Youngbluth, M. J. Acoustical detection of high-density krill demersal layers in the submarine canyons off Georges Bank. *Science.* **241,** 359–361 (1988).
125. Kawaguchi, S. *et al.* Risk maps for Antarctic krill under projected Southern Ocean acidification. *Nat. Clim. Chang.* **3,** (2013).
126. Riebesell, U., Gattuso, J. P., Thingstad, T. F. & Middelburg, J. J. 'Arctic ocean acidification: pelagic ecosystem and biogeochemical responses during a mesocosm study' Preface. *Biogeosciences* **10,** 5619–5626 (2013).
127. Brussaard, C. P. D. *et al.* Arctic microbial community dynamics influenced by elevated CO_2 levels. *Biogeosciences* **10,** 719–731 (2013).
128. Henry, L. A. *et al.* Global ocean conveyor lowers extinction risk in the deep sea. *Deep. Res. Part I-Oceanographic Res. Pap.* **88,** 8–16 (2014).
129. Link, J., Griffis, R. & Busch, S. NOAA fisheries climate science strategy. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-F/SPO-155, 70p. (2015).
130. Kimball, L. A. The international legal regime of the high seas and the seabed beyond the limits of national jurisdiction and options for cooperation for the establishment of Marine Protected Areas (MPAs) in marine areas beyond the limits of national jurisdiction. *Secretariat of the Convention on Biological Diversity, Montreal, Technical Series no. 19*, 64 pages. (2005).
131. Billé, R. *et al.* Taking action against ocean acidification: A review of management and policy options. *Environ. Manage.* **52**, 761–779 (2013).
132. Darling, E. S. & Côté, I. M. Quantifying the evidence for ecological synergies. *Ecol. Lett.* **12**, 1278–1286 (2008).
133. Ban, S. S., Graham, N. A. J. & Connolly, S. R. Evidence for multiple stressor interactions and effects on coral reefs. *Glob. Chang. Biol.* **20,** 681-697 (2014).
134. Halpern, B. S. *et al.* A global map of human impact on marine ecosystems. *Science.* **319,** 948–952 (2008).

135. Jackson, E. L., Davies, A. J., Howell, K. L., Kershaw, P. J. & Hall-Spencer, J. M. Future-proofing marine protected area networks for cold water coral reefs. *ICES J. Mar. Sci.* **71,** 2621–2629 (2014).
136. Freiwald, A., Fosså, J. H., Grehan, A., Koslow, T. & Roberts, J. M. Cold-water coral reefs. UNEP-WCMC, Cambridge, UK. 84pp (2004).
137. Department of the Environment (DoE), Australian Antarctic Division(AAD) and the Fisheries Research and Development Coroporation (FRDC). Demersal fishing interactions with marine benthos in the Australian EEZ of the Southern Ocean: An assessment of the vulnerability of benthic habitats to impact by demersal gears. *Australian Antarctic Division,* Hobart, Australia. (2014).
138. Thresher, R. *et al.* Strong depth-related zonation of megabenthos on a rocky continental margin (∼700-4000 m) off southern Tasmania, Australia. *PLoS One* **9,** e85872 (2014).
139. Thresher, R. E., Guinotte, J. M., Matear, R. J. & Hobday, A. J. Options for managing impacts of climate change on a deep-sea community. *Nat. Clim. Chang.* **5,** 635–639 (2015).
140. Alderslade, P., Althaus, F., Mcennulty, F., Gowlett-Holmes, K. & Williams, A. Australia's deep-water octocoral fauna: historical account and checklist, distributions and regional affinities of recent collections. *Zootaxa* **3796,** 435–52 (2014).
141. State of the Environment Committee (SOEC). Australia State of the Environment 2011. Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities (DSEWPaC), Canberra. *Assessment Summary 6.1* p393-393 (2011).
142. State of the Environment Committee (SOEC). Australia State of the Environment 2011. Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities (DSEWPaC), Canberra. *Assessment Summary. 6.3* p402-403 (2011).
143. Thresher, R. E., Williams, A. & Gowlett-Holmes, K. Chapter 4. An assessment of the general health and threats to the viability of the deep reef in the Huon and Tasman Fracture Marine Reserves. In: Biodiversity and conservation ecology of the deep ocean environments within the Huon and Tasman Fracture Commonwealth Marine Reserves. *Final Report to Australian Department Environment, Water, Heritage and the Arts.* 57–62 (2009).
144. Coral Identification guide. http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/fishing/coral-id-guide-updated.pdf. (2014).
145. Consalvey, M., MacKay, K. & Tracey, D. Information review for protected deep-sea coral species in the New Zealand region. *Report prepared by the National Institute of Water and Atmospheric Research for the New Zealand Department of Conservation.* (2006).
146. http://www.beehive.govt.nz/release/protection-status-changes-wildlife-act.
147. Zamponi, M. O. Cnidaria. In: Los Invertebrados Fósiles. (Ed. H. Camacho. Fundación de Historia Natural Félix de Azara. *Universidad Maimónides, 1st*

Edición. Buenos Aires. 800p. (2008).
148. Reyes, J. *et al.* Southern Caribbean azooxanthellate coral communities off Colombia. In: *Cold-Water Corals and Ecosystems* 309–330 (2005).
149. INVEMAR-ANH*.* Especies, ensamblajes y paisajes de los bloques marinos sujetos a exploración de hidrocarburos – Fase II – Caracterización de la megafauna y el plancton del Caribe colombiano. *Informe Técnico Final INVEMAR –ANH Fase II, Santa Marta, 342*. (2010)
150. Lutz, S. & Ginsberg, R. State of deep coral ecosystems in the Caribbean region: Puerto Rico and the U.S. Virgin Islands. In: The state of deep coral ecosystems of the United States. *NOAA Technical Memorandum CRCP-3, Silver Spring, MD 307-365* (2007).
151. Alonso D., L.F. Ramirez, C. Segura-Quintero y P. Castillo-Torres. Planificación Ecorregional para la conservación de la biodiversidad in situ marino costera del Caribe continental colombiano. Informe técnico final. *INVEMAR-TNC. Santa Marta, Colombia*. (2007).
152. INVEMAR y Parques Nacionales*.* Elaboración de documento síntesis como insumo principal para la declaratoria de áreas marinas protegidas con presencia de bancos de corales de profundidad en el Caribe colombiano. *Diseño e implementación de un Subs*. (2012)
153. Flórez P. y N. Santodomingo. Cnidaria: corales escleractinios, antipatarios, anémonas, zoantídeos, octocorales e hidroides. Pp (151-180). En INVEMAR. Biodiversidad del margen continental del Caribe colombiano. *Serie de Publicaciones Esp*. (2010)
154. Alonso D., L. Ramírez, C. Segura-Quintero, P. Castillo-Torres, J.M. Diaz y T. Walschburger. Prioridades de conservación in situ para la biodiversidad marina y costera de la plataforma continental del Caribe y Pacífico colombiano. *Instituto de Invest*. (2008).
155. Alonso D., Segura-Quintero, C., Torres, C., Rozo-Garzón, D., Espriella, J., Bolaños, J. & A. López. Áreas significativas para la Biodiversidad. 393-423 p. En INVEMAR Biodiversidad del margen continental del Caribe colombiano. (2010)
156. Urriago, J., N. Santodomingo y J. Reyes. Formaciones coralinas de profundidad: criterios biológicos para la conformación de áreas marinas protegidas del margen continental (100-300 m) en el Caribe colombiano. *Bol. Invest. Mar. Cost.* ***40****(1), 89-113.* (2011).
157. Castro, C. *et al.* Cnidaria: Corais. In Biodiversidade bentônica da região Cent. da Zo. Econômica Exclus. Bras*.* (Eds. Lavrado, H. P. & Ignacio, B. L.) (2006).
158. Kitahara, M. V. New records of azooxanthellate corals (Anthozoa, Scleractinia) from the southern Brazilian continental shelf and slope. *Biotemas* **19,** 55–63 (2006).
159. Kitahara, M. V. Species richness and distribution of azooxanthellate scleractinia in Brazil. *Bull. Mar. Sci.* **81,** 497–518 (2007).
160. Kitahara, M. V. The deep-sea demersal fisheries and the azooxanthellate corals from southern Brazil. *Biota Neotropica* **9,** 35–43 (2009).

161. Murillo, F.J., P. Duran Munoz, F.J. Cristobo, P. Rios, C. Gonzalez, E. Kenchington & A. Serrano. 2012. Deep-sea sponge grounds of the Flemish Cap, Flemish Pass and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): distribution and species composition. Marine Biology Research 8:842-854.
162. Knudby, A., E. Kenchington & F. J. Murillo. 2013. Modeling the distribution of *Geodia* sponges and sponge grounds in the northwest Atlantic Ocean. PLoS ONE 8(12):e82306. DOI:10.1371/journal.pone.0082306.
163. Conway. K.W., J.V. Barrie, W.C. Austin, J.L. Luternauer. 1991. Holocene sponge bioherms on the British Columbia continental shelf. Coastal Shelf Research. 11(8):771-790.
164. Conway, K.W., Barrie, J.V., Hill, P.R., Austin, W.C., Picard, K. 2007. Mapping sensitive benthic habitats in the Strait of Georgia, coastal British Columbia: deep-water sponge and coral reefs. Geological Survey of Canada. Current research. 2007-A2. 8pp.
165. de Goeij, J.M., van den Berg, H., van Oostveen, M.M., Epping, E.H.G., van Duyl, F.C. 2008. Major bulk dissolved organic carbon (DOC) removal by encrusting coral reef cavity sponges. Mar. Ecol. Prog. Ser. 357:139-151.
166. Hoffmann et al. 2009. Complex nitrogen cycling in the sponge *Geodia barretti*. Environmental Microbiology 11: 2228–2243.
167. Maldonado et al. 2012. Nutrient fluxes through sponges: Biology, budgets, and ecological implications. Adv. Mar. Biol. 62: 114-182.
168. Mehbub M., Lei J., Franco C. and Zhang W. 2014. Marine sponge derived natural products between 2001 and 2010: Trends and opportunities for discovery of bioactives. Marine Drugs 12(8):4539-4577.
169. Hanssen K.Ø., et al. 2014. The bromotyrosine derivative Ianthelline isolated from the Arctic marine sponge *Stryphnus fortis* inhibits marine micro- and macrobiofouling. Marine Biotechnology, 16(6), 684-694.
170. Sjögren M., Goransson U., Johnson A.L., Dahlstrom M., Andersson R., Bergman J., Jonsson P.R. and Bohlin L. 2004. Antifouling activity of brominated cyclopeptides from the marine sponge *Geodia barretti*. Journal of Natural Products 67(3): 368-372.
171. Banoub, J.H. 2010. Hydrothermal Vent Ecosystems. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/050. vi + 25 p.
172. Martin, J.B., Kastner, M., Henry, P., Le Pichon, X., and Lallemant, S. 1996. Chemical and isotopic evidence for sources of fluids in a mud volcano field seaward of the Barbados accretionary wedge. J. Geophys. Res. 101: 325-345.
173. Tunnicliffe, V., McArthur, A. G., and McHugh, D. 1998. A biogeographical perspective of the deep-sea hydrothermal vent fauna, Adv. Mar. Biol. 34: 353-441.
175. Baker, E.T., C.R. German and H. Elderfield. 1995. Hydrothermal plumes over spreading-center axes: Global distributions and geological inferences. U.S. Dept. of Commerce / NOAA / OAR / PMEL / Publications. Seafloor Hydrothermal Systems: Physical, Chemical, Biological, and Geological Interactions, Geophysical Monograph 91, AGU, 47-71, 1995.

176. Von Damm, K.L. 1995. Controls on the chemistry and temporal variability of seafloor hydrothermal fluids. Pp. 222–247 in Seafloor Hydrothermal Systems: Physical, Chemical, Biological, and Geological Interactions. S.E. Humphris, R.A. Zierenberg, L.S. Mullineaux, and R.E. Thomson, eds. AGU Monograph Series, No. 91, American Geophysical Union, Washington, DC.
177. ICES. 2013. Report of the ICES\NAFO Joint Working Group on Deep-water Ecology (WGDEC), 11–15 March 2013, Floedevigen, Norway. ICES CM 2013/ACOM:28. 95 pp.
178. Desbruyères, D., M. Biscoito, J.-C. Caprais, A. Colaço,T. Comtet, P. Crassous, Y. Fouquet, A. Khripounoff, N. Le Bris, K. Olu, R. Riso, P.-M. Sarradin, M. Segonzac, and A. Vangriesheim. 2001. Variations in deep-sea hydrothermal vent communities on the Mid-Atlantic Ridge near the Azores plateau. Deep Sea Research Part I 48:1,325–1,346.
179. Desbruyères, D., M. Segonzac, and M. Bright, eds. 2006. Handbook of Deep-Sea Hydrothermal Vent Fauna, Second edition, Denisia 18, State Museum of Upper Austria, Linz, 544 pp.
179. Desbruyères, D., J. Hashimoto, and M.-C. Fabri. 2007. Composition and biogeography of hydrothermal vent communities in western Pacific back-arc basins. Pp. 215–234 in Back-Arc Spreading Systems; Geological, Biological, Chemical, and Physical Interactions. D.M. Christie, C.R. Fisher, S.-M. Lee, and S. Givens, eds, Geophysical Monograph Series, Volume 166, American Geophysical Union, Washington, DC.
180. Wirsen, C. O., H. W. Jannasch, and S. J. Molyneaux. 1993. Chemosynthetic microbial activity at Mid-Atlantic Ridge hydrothermal vent sites. J. Geophys. Res. 98(B6): 9693–9703.

____