30X30 A BLUEPRINT FOR OCEAN PROTECTION

How we can protect 30% of our oceans by 2030

UNIVERSITY OF OXFORD

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30x30: A Blueprint for Ocean Protection

Executive summary
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PART 1: Background
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PART 2: Designing a marine protected area network for the high seas
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Giant Pacific octopus
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ACRONYMS

ABMT	Area-Based Management Tool
ABNJ	Areas Beyond National Jurisdiction
AIS	Automatic Identification System
BBNJ	Ad Hoc Open-Ended Informal Working Group to study issues relating to the conservation and sustainable use of the marine biological diversity beyond areas of national jurisdiction
CBD	Convention on Biological Diversity
CMS	Convention on Migratory Species
CoML	Census of Marine Life
DSCC	Deep Sea Conservation Coalition
DSM	Deep Seabed Mining
EBSA	Ecologically and Biologically Significant Area
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
FAD	Fish Aggregating Device
FAO	Food and Agriculture Organisation
FSA	Fish Stocks Agreement
GDAC	Global Data Assembly Centre
GIS	Geographic Information System
GTOPP	Global Tagging of Pelagic Predators
HSA	High Seas Alliance
IMO	International Maritime Organisation
IMR	Institute of Marine Research
ISA	International Seabed Authority
IUCN	International Union for the Conservation of Nature
IUU	Illegal, Unreported and Unregulated fishing
IWC	International Whaling Commission
MiCO	Migratory Connectivity in the Ocean
MGR	Marine Genetic Resources
MPA	Marine Protected Area
OMZ	Oxygen Minimum Zone
PCB	Polychlorinated Biphenyl
POP	Persistent Organic Pollutant
REE	Rare Earth Elements
RFMO	Regional Fisheries Management Organisation
ROV	Remotely Operated Vehicle
SBSTTA	Subsidiary Body on Scientific, Technical and Technological Advice (of the CBD)
SDG	Sustainable Development Goal
SMS	Seafloor massive sulphide
TOPP	Tagging of Pacific Predators
UNCLOS	United Nations Convention on the Law of the Sea
UNFSA	UN Fish Stocks Agreement
VME	Vulnerable Marine Ecosystem
WDPA	World Database on Protected Areas
WSSD	World Summit on Sustainable Development

KEY FINDINGS

→ The high seas encompass **43%** of the Earth's surface, and **70%** of the living space on the planet including land and sea. These huge spaces are home to a complex marine world, with richness and diversity of life to rival coastal waters and land.

→ High seas marine life drives the ocean's biological pump, capturing carbon at the surface and storing it deep below – without this essential service, our atmosphere would contain **50%** more carbon dioxide and the world would be uninhabitably hot.

→ The high seas face growing exploitation from a handful of mainly rich nations: fishing and the emerging deep seabed mining industry join wider threats from climate change, acidification, plastic and other pollution and more.

→ Ocean sanctuaries are a key tool for protecting habitats and species, rebuilding ocean biodiversity, helping ocean ecosystems recover and maintaining vital ecosystem services.

→ By initiating an international legally binding instrument to enable the protection of marine life and habitats outside national jurisdiction, the United Nations has an opportunity to put in place robust structures to create and govern ocean sanctuaries on the high seas.

→ Scientists are calling for at least **30%** of the world's oceans to be protected as ocean sanctuaries, and this study charts how this **30%** figure could be achieved to protect the full spectrum of marine life on the high seas.

→ The study is based on biological, oceanographic, biogeographical and socio-economic data, such as the distributions of sharks, whales, seamounts, trenches, hydrothermal vents, oceanic fronts, upwellings, biogeographic zones, commercial fishing pressure, mining claims etc.

→ The protected area network design process builds in resilience to wider environmental change and uncertainty with a bet hedging approach to habitat selection, large coverage to promote connectivity and refuges of last resort, and the use of sea surface temperature data to identify places likely to change more slowly or adapt more readily under rising temperature stress.

→ Areas intensively used by high seas fishing fleets were avoided to reduce possible disruption to fishing activity. An interim moratorium on seabed mining is proposed to ensure that options are left open as a network of protection is built.

→ The findings in this report show that it is entirely feasible to design an ecologically representative, planet-wide network of high seas protected areas to address the crisis facing our oceans and enable their recovery. The need is immediate and the means readily available. All that is required is the political will.

Great white shark
© Ralf Kiefner/Greenpeace

EXECUTIVE SUMMARY

Humpback whale, Indian Ocean
© Paul Hilton/Greenpeace

FAR BEYOND THE EDGE OF OUR LAND-BOUND WORLD LIE AREAS BEYOND NATIONAL JURISDICTION, COMMONLY KNOWN AS THE HIGH SEAS.* FOR MOST PEOPLE, FOR MOST OF HISTORY, THE HIGH SEAS HAVE BEEN INVISIBLE, POPULATED BY THE IMAGINATION WITH MONSTROUS FISH, WRATHFUL GODS OR PRECIPITOUS PLUMMETS INTO THE IMMENSITY OF SPACE. OVER CENTURIES OF EXPLORATION BY ADVENTURERS, HUNTERS, TRADERS AND SCIENTISTS, THAT IMAGINED REALM OF FEAR AND DANGER HAS BEEN EXPLOITED, MAPPED AND PROBED, YIELDING UP SECRETS AND BANISHING TERRORS.

The high seas form a vast global commons that covers 61% of the area of the ocean and 73% of its volume. They encompass an astonishing 43% of the Earth's surface and occupy 70% of the living space on our planet, including land and sea. These international waters are home to a stunning wealth of marine life and ecosystems, and by virtue of their enormous expanse, are essential to the healthy functioning of Planet Earth. But in recent decades that life has dwindled under the rising impact of multiple human stresses, prompting an historic effort by the United Nations to increase protection and reform management.

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* The term 'high seas' in this study is used to refer to 'areas beyond national jurisdiction' (ABNJ). ABNJ are composed of the high seas (waters beyond the zones of national jurisdiction) and the Area (the seabed, ocean floor and subsoil thereof beyond the limits of national jurisdiction). This means our study considers all habitats from the seabed to surface waters.

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> "WITHOUT THESE CREATURES, THE ATMOSPHERE WOULD CONTAIN AN ESTIMATED 50% GREATER CONCENTRATION OF THE GREENHOUSE GAS CARBON DIOXIDE AND THE WORLD WOULD BE FAR HOTTER."

Why the high seas matter

For most of us, our only experience of the high seas is a vast canvas of blue seen from the window of a plane. The monotony is interrupted here or there by the crawling dot of a container ship or the patterned white crests of storm-driven waves. But it is the ultramarine emptiness that asserts itself most strongly upon the psyche, a point reflected in the blank blocks of blue that colour the high seas in maps.

This apparent uniformity conceals a more complex submarine world with richness and diversity to rival that of coast and land. In the sunlit upper layers of the high seas there are places, including oceanic fronts and upwelling areas, where currents drag nutrients to the surface causing great plankton blooms. These explosions of plankton growth, which may cover thousands of square kilometres and are easily visible from space, fuel oceanic food webs.

The vast scale of the high seas and the patchiness of feeding grounds and suitable breeding areas means that many marine animals travel incredible distances. Whales, elephant seals, tunas, billfish, eels, sharks, turtles, penguins and albatross are among the great nomads of the high seas, some criss-crossing entire ocean basins, congregating at oceanic hotspots and then moving on. The whalers of old were first to discover these teeming concentrations of life, hunting sperm whales across the equatorial Pacific upwelling, right whales in the turbulent transition between warm south Atlantic and cold Southern Ocean, and humpback whales in the Coral Sea. Modern satellite tracking of seabirds, sharks, seals and turtles has added detail and depth to our understanding, picking out oceanic highways and flyways, oases and deserts.

Life in the sunlit surface layer sustains a twilight and midnight world that extends to the floor of the abyss, four to six thousand metres down, and then further still into trenches deeper than the Himalayas are tall. Just below the productive surface, the twilight zone is home to a bizarre menagerie which undertakes the greatest migration on Earth. Every night, under cover of darkness, a huge variety of creatures move upward from depths of several hundred metres to feast on plankton or prey upon other animals in the productive surface layer, then retreat to the depths as morning nears. They include lanternfish with flashlight patterned skins, bioluminescent jellyfish, blood red squid as big as tuna or grape-sized with bodies like glass. Despite the lack of sunlight, perhaps 90% of the world's fish by weight inhabit these twilit depths. Their daily migrations – feeding at the surface, pooping deep down – contribute to a phenomenon known as the biological pump, removing carbon from the atmosphere and transferring it to the deep sea where it may be locked away. Without these creatures, the atmosphere would contain an estimated 50% greater concentration of the greenhouse gas CO_2 and the world would be far hotter.

In the midnight world deeper down, the water chills to a few degrees above freezing and pressures rise hundreds of times higher than that of the atmosphere. Despite the extreme conditions, creatures eke a meagre living there from the downward drizzle of organic matter, or flourish in unexpected abundance around plumes of water hundreds of degrees hotter than boiling point. In the frigid darkness, life is glacial and fish can live for hundreds of years and corals exceed a thousand. For most of history, this fragile world lay unseen, far beyond the reach of human influence or harm. But now, even the remotest places in the sea and its deepest depths are under threat, as activities such as bottom trawling destroy habitats before we have a chance to explore and understand them.

Lion's mane jellyfish, Arctic Ocean
© Alexander Semenov

Deep-sea trawling in the Tasman Sea
© Roger Grace/Greenpeace

"THE GROWING THREATS AND CONCERN OVER INEFFECTIVE AND FRAGMENTED GOVERNANCE HAVE PAVED THE WAY FOR A ONCE-IN-A-GENERATION OPPORTUNITY TO SAFEGUARD LIFE IN INTERNATIONAL WATERS."

High seas under threat

People have long pursued fame, power or riches at the edges of the known world, revelling in the absence of laws restraining their plunder. On land, most frontiers have long been settled, tamed and their freedoms curtailed by law. But beyond the reach of national control, the world's last frontier – the high seas and deep sea – is still a place where weak laws and poor governance allow plunder to continue almost unchecked. Here a handful of mainly rich nations exploit marine life for profit under a freedom granted by the United Nations Convention on the Law of the Sea (UNCLOS). That same convention, however, entails duties which have largely been ignored: to conserve living marine resources and protect and preserve the environment, including rare or fragile ecosystems and habitats.

As a consequence of management neglect allied with opportunity and greed, high seas and deep-sea marine life has suffered. Many of our most iconic species, like albatrosses, turtles and sharks have undergone dramatic declines in the space of a few decades. Deep sea habitats like cold-water corals and sponge fields, sometimes centuries old, have been smashed by heavy fishing gear being dragged along the seabed. Even species meant to be under close management have declined, highlighting the failure of the organisations charged to oversee their exploitation to deliver even on this narrow mandate. For example, the Pacific bluefin tuna has collapsed to less than 3% of its historic abundance, yet still, even in this dangerously depleted state, continues to be fished. Resources that belong to the whole world are being squandered.

Fishing is the longest-standing and still one of the most severe of human threats to high seas life, alongside global warming, ocean acidification, deoxygenation, shipping, noise, plastic and chemical pollution, and deep seabed mining. Together, they have put marine life under an increasing barrage of stresses that cannot be addressed in isolation, nor adequately managed by the bodies charged with governance of the high seas and deep ocean.

Bluefin tuna
© Gavin Newman/ Greenpeace

Arctic tern
© Bernd Roemmelt/ Greenpeace

Global Ocean Treaty

Recognising the ongoing decline of biodiversity, the rising tide of impacts and the enduring absence of effective governance leading to a fragmented approach, countries of the world under the United Nations have convened an Intergovernmental Conference on the Protection of Biodiversity Beyond National Jurisdiction. Its aim is to develop an international legally binding instrument to enable the protection of marine life and habitats outside national jurisdiction. The first of four meetings was held in September 2018, and the process is expected to end in 2020.

Issues for negotiation include the need for comprehensive environmental impact assessments for activities on the high seas, capacity building for management and conservation, the international sharing of benefits from marine genetic resources and the use of area-based management tools, including marine protected areas (MPAs). With regard to the latter, in its deliberations the UN Intergovernmental Conference must consider how to develop mechanisms for conservation that enable the world to meet international obligations under UNCLOS to protect wildlife of the high seas and deep sea. It must also create a mechanism to fill a gaping hole in the provisions of the UN Convention on Biological Diversity (CBD). The CBD is intended to protect the world's wildlife but can only be applied by nations in their own territories or on vessels carrying their flag. That leaves nearly half of the surface of Earth virtually unprotected.

Importance of ocean sanctuaries

The growing threats and concern over ineffective and fragmented governance have paved the way for a once-in-a-generation opportunity to safeguard life in international waters. This report explores the potential and application of MPAs in the high seas and deep sea and provides context and support for negotiations at the UN Intergovernmental Conference.

The value of MPAs and, in particular, fully protected marine reserves (ocean sanctuaries) as a key tool in protecting habitats and species, rebuilding ocean biodiversity, helping ocean ecosystems recover and maintaining vital ecosystem services, is widely acknowledged and explicitly reflected in the UN Sustainable Development Goal 14 and Aichi Target 11 under the CBD Strategic Plan for Biodiversity 2011–2020. Scientists are calling for full protection of 30% of the ocean by 2030, a call endorsed by a resolution of the International Union for the Conservation of Nature (IUCN) World Conservation Congress in 2016. A successful outcome of negotiations at the UN Intergovernmental Conference is essential for the designation, effective management and enforcement of a network of high seas protected areas.

The study

To inform discussions and scope the idea of marine protected area network building in the high seas, a systematic conservation planning exercise was undertaken by a group of scientists led by experts from the University of York in the UK. The research summarised below is described in detail in the technical section of this report.

To safeguard the full spectrum of marine life, MPAs must be established in networks that represent all the habitats and species present in a region. While individual MPAs can be established based only on local information, systematic planning using computers is required to make network design possible. This is because the number of possible designs for a protected area network quickly increases to something impossibly complex for the human mind to grasp as numbers of conservation features and locations grow. Fortunately, there are well-tested computer-assisted methods for systematic conservation planning, an approach we adopt here.

Methods

We employed a widely used program for MPA network design, called Marxan, to explore options for high seas protection. This method aims to represent a defined proportion of the spatial extent of all the conservation features that are included (e.g. species or habitat distributions or proxies thereof, such as environmental conditions like depth and sea surface temperature) while minimising network size and socio-economic costs.

To develop the network, we divided the high seas into nearly 25,000 planning units, each 100x100km (10,000km^2). We then gathered up-to-date, globally distributed biological, oceanographic, biogeographical and socio-economic data, such as the distributions of sharks, whales, seamounts, trenches, hydrothermal vents, oceanic fronts, upwellings, biogeographic zones, commercial fishing pressure, mining claims etc. and mapped them in a Geographic Information System. Each planning unit was assigned a value relating to the overall extent of each conservation feature that overlapped it and input to Marxan. We ran the program hundreds of times to develop network designs that for any given set of inputs achieved the targets set while minimising costs.

We explored two target levels for protection, 30% and 50% coverage of each of 458 conservation features. These figures were chosen because they correspond to widely discussed ambitions for future global conservation targets following expiry of the Sustainable Development Goal 14 and CBD target for 10% ocean protection by 2020. Places already receiving protection were locked into runs, and places slated for deep-sea mining were locked out of some runs.

By generating hundreds of well-optimised network designs from which to choose, Marxan helps identify those which most efficiently meet the targets set, while enabling planners to incorporate constraints and stakeholder inputs. The resulting designs are in no way definitive, but simply illustrate some of the options available. Factors not captured within input data layers, such as additional socio-economic considerations or expert knowledge, will affect designs. Marxan is a decision-support tool, not a decision-making tool.

Figure 1 shows the most efficient network designs produced from 200 runs of Marxan for the 30% and 50% protection scenarios. These networks lock in existing high seas MPAs designated in the Southern Ocean and North Atlantic, as well as Vulnerable Marine Ecosystems closed to fishing by Regional Fisheries Management Organisations (RFMOs), and Areas of Particular Environmental Interest established in the Pacific Ocean by the International Seabed Authority to protect representative habitats from deep-sea mining. We also applied a 'cost' to limit selection of areas intensively used by high seas fishing fleets, so reducing possible disruption to fishing activity, which in turn requires significant improvement in its management by RFMOs.

> "WHILE HUMANKIND AT LARGE WILL BENEFIT FROM EFFECTIVE MARINE PROTECTION, IT IS PRIMARILY A HANDFUL OF WEALTHY NATIONS THAT ARE CURRENTLY REAPING THE BENEFITS DERIVED FROM EXPLOITING HIGH SEAS RESOURCES."

Significant features of the networks

The results produced well-distributed candidate MPA networks that extend from pole to pole and across the full extent of the oceans, incorporating the complete range of habitats, species and environmental conditions specified. While the designs demonstrate the practicality of creating networks based on existing information, they are not specific proposals for protection.

In setting target levels for coverage, we followed the World Conservation Congress resolution of 2016, which states that MPA networks "should include at least 30% of each marine habitat". As our results show, however, in practice it is impossible to achieve this goal with only 30% of the high seas protected: networks that met the 30% goal covered in the range of 35 to 40% of the high seas, while those that met the 50% target covered 55 to 60%.

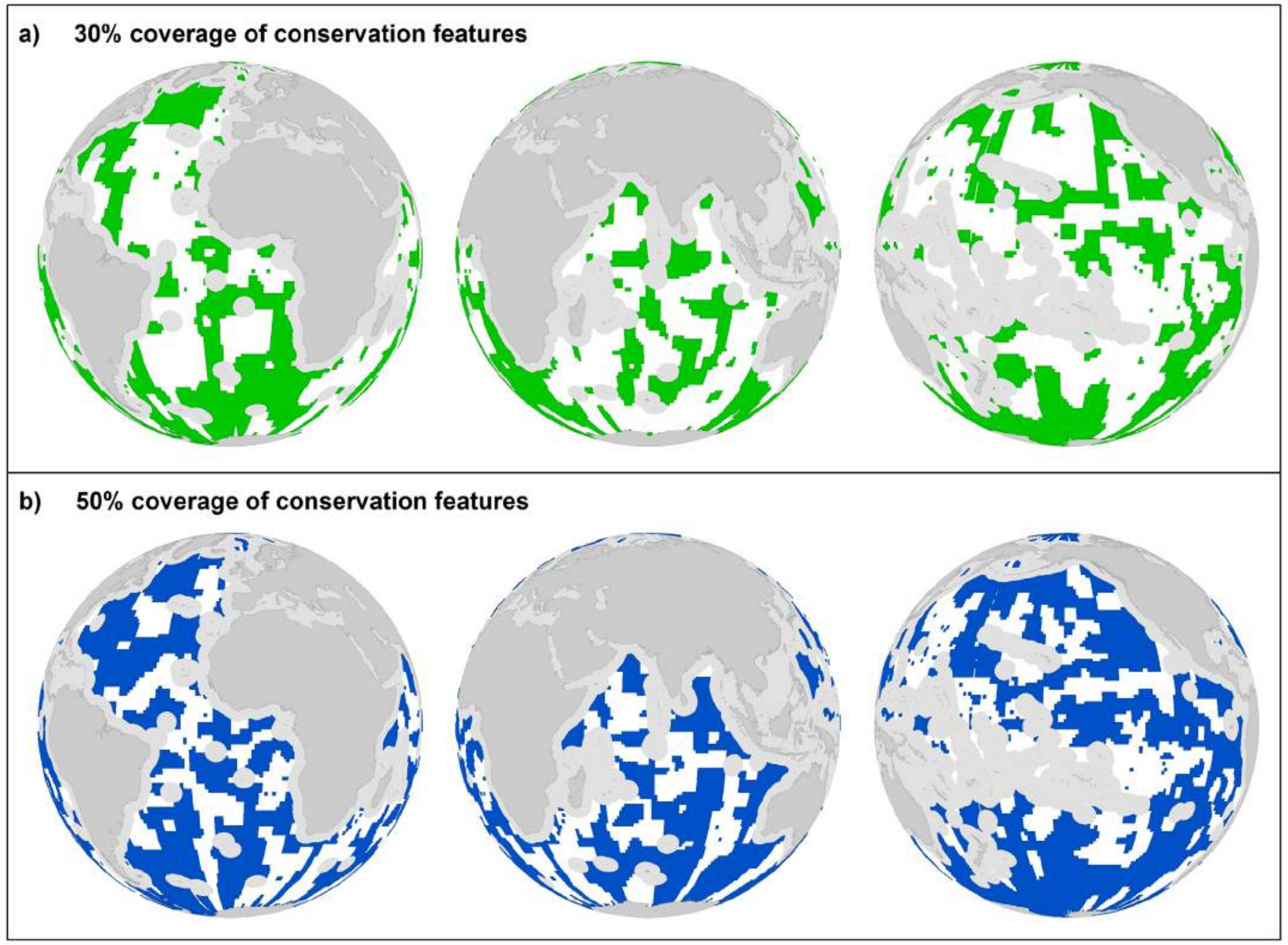


***Figure 1:** Example MPA network designs for (a) 30% and (b) 50% coverage of each included conservation feature with existing management units locked in/out, based on the 'best' solutions identified by Marxan.*

The pursuit of these ambitious but scientifically justified coverage targets produced a novel outcome. The prevailing conservation paradigm on land and in coastal regions is one in which protected areas represent islands of sanctuary in a land or seascape of human influence and threat. Our high seas networks are different in that they produce interconnected nets of protection with embedded zones of human use and impact. In many places these protective nets span ocean basins and are well suited to safeguard the highly mobile and migratory species that roam the high seas. This reversal of conservation practice should also be seen in light of the fact that while humankind at large will benefit from effective marine protection, it is primarily a handful of wealthy nations that are currently reaping the benefits derived from exploiting high seas resources.

Protection on this large scale also confers other benefits. Crucially, it affords resilience to rapidly changing environmental conditions. The world today is changing faster and in more ways than in all of human history. This is causing species shifts in range and depth distributions making ecosystem restructuring and unforeseen outcomes highly probable. Designing protected area networks around present conditions therefore risks future failure.

Protected area network designs must continue to provide their protective function no matter what the future holds. In the face of uncertain future conditions, investors build portfolios to spread risks. MPA networks must do the same. Our network designs deal with environmental change and uncertainty in three ways: (1) by portfolio building (i.e. representing a range of habitats, places and conditions across the world's oceans) as a bet hedging/risk reduction approach, (2) through large coverage which promotes connectivity, stepping stones, corridors for travel and refuges of last resort, and (3) with the novel use of historical sea surface temperature data. In this new approach to climate change resilience, we identified two kinds of areas for extra protection: places with relatively high natural temperature variability, which represent ecosystems that may be inherently resilient to future change because species are adapted to fluctuating conditions, and places with low variability, where change may be slower and ecosystems have more time to adapt. Collectively, these network design principles increase the chances of species and ecosystems surviving and adapting to global change.

Accommodating exploitation

High seas fisheries account for only 4.2% of annual marine capture fisheries and human exploitation of the high seas is limited to wealthy countries and industrial corporations. Nonetheless, some high seas fisheries, such as those for pelagic tunas, are of global significance. The establishment of a network of ocean sanctuaries will displace fishing effort, but the impacts of high seas effort displacement are likely to be less than in coastal zones because fleets already travel very long distances to fishing grounds and rerouting may not increase travel time or costs. However, displacement may move fishers from higher- to lower-yielding areas. To reduce possible negative socio-economic impacts, fishing effort, using publicly available data on trawl, purse-seine and longline fishing from globalfishingwatch.org was built in as a cost in the development of the example networks. The resulting network designs only displaced around 20% or 30% of existing fishing effort, demonstrating that networks representative of biodiversity can be built with limited economic impact. Many of the costs of establishment will in any case be offset by gains from protection, such as fish stock rebuilding and improved ecosystem health.

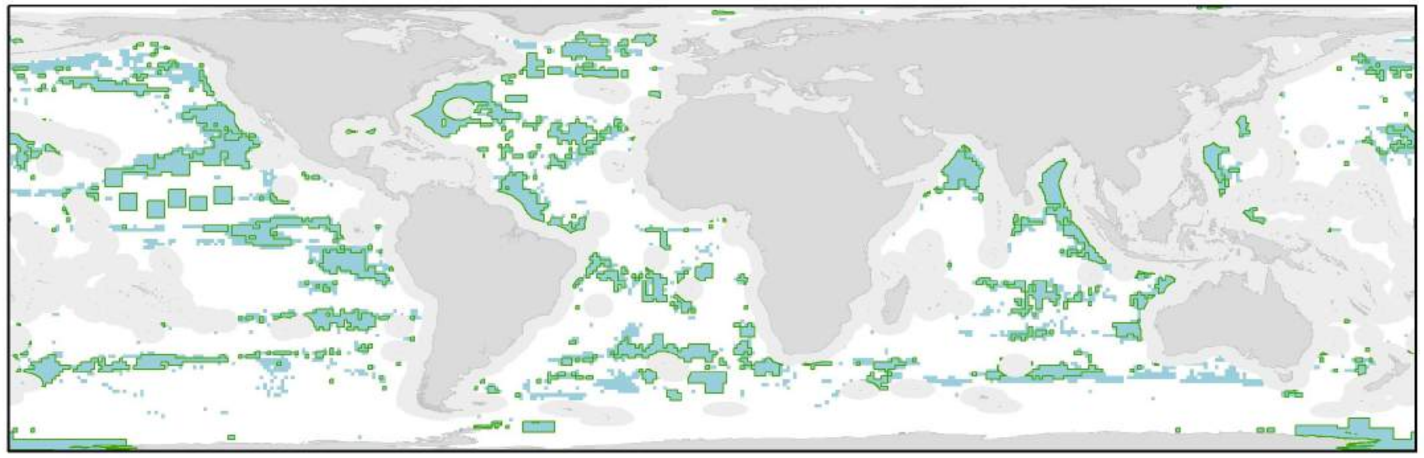
Deep seabed mining is an emerging industry which will inevitably damage vulnerable deep-ocean ecosystems. Huge swathes of the seabed are being licensed for mineral exploration, many of them, as our study shows, in areas with high biodiversity value. Excluding them from potential MPA networks may seriously impact our ability to represent wild nature and ecosystem function beyond national jurisdiction and could therefore undermine efforts to protect biodiversity. An interim moratorium on mining would be appropriate to ensure that all options for protection remain open as a high seas MPA network is built.

A composite approach to network design

Some well-known hotspots for wildlife, such as the Costa Rica Dome upwelling region or the White Shark Café in the Eastern Pacific, did not always come up in the network examples generated by our analyses. This was principally because our data layers indicated presence of species or features, not the intensity of use by those species. Places known to be critically important wildlife aggregation sites argue for a composite selection approach to be developed that combines bottom-up site selection based on local knowledge and stakeholder input with high-level, coordinated systematic planning.

The systematic planning approach used here complements bottom-up knowledge, drawing attention to areas that may have been overlooked but are important within network designs. Figure 2 shows planning units selected to be part of MPA networks in more than 75% of runs of the program, indicating a high value for meeting the conservation targets we set within the constraints imposed. These places warrant targeted research to better understand their biodiversity value and could form kernels around which MPAs can be formed.

Figure 2: *Areas of importance (>75% selection frequency of each planning unit) for 30% (outlined green areas) and 50% (solid blue areas) coverage of all conservation features with management units locked in/out. Results are based on 200 runs of Marxan for each scenario.*



Ghost fishing nets in the Great Pacific Garbage Patch
© Justin Hofman/ Greenpeace

> "TO AVERT THE LOOMING CRISIS WE MUST IMPLEMENT EFFECTIVE PROTECTION AT A COMMENSURATE SCALE AND WITH URGENCY."

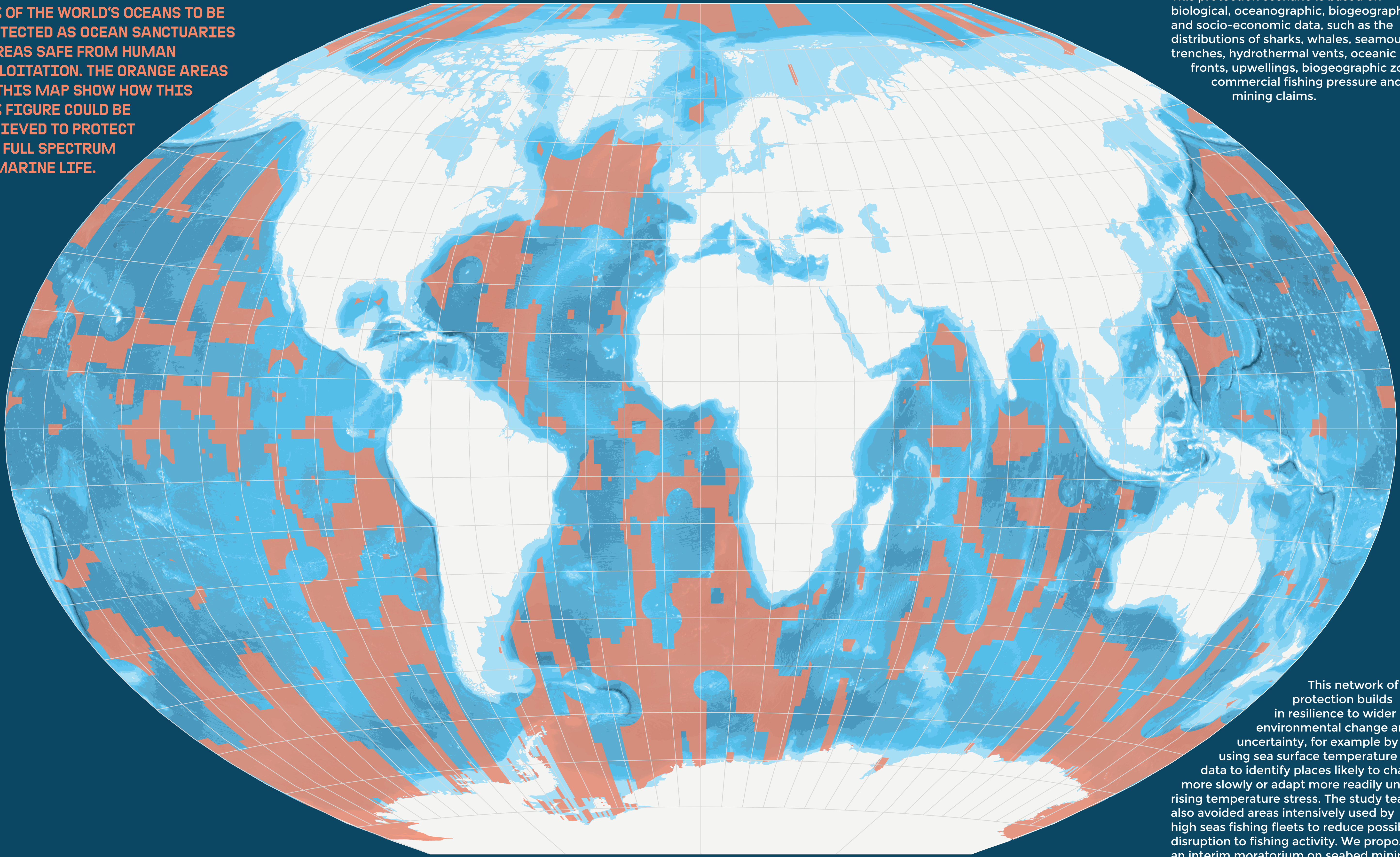
Conclusion

Increasing human pressures exerted on the high seas have led to a swift and alarming decline of wildlife and degradation of habitats. Not only are these pressures detrimental to the wellbeing of ocean life, they compromise the ability of the high seas to deliver key ecosystem services that sustain us all, a problem that will be further exacerbated by global change. To avert the looming crisis we must implement effective protection at a commensurate scale and with urgency.

Our analyses show that it is possible to use the increasingly sophisticated and spatially well-resolved data available to design an ecologically representative, planet-wide network of high seas protected areas. Systematic conservation planning offers a key tool to inform planning decisions in a cost-effective, transparent and defensible way. However, the complexity of the task and the necessities of cost-efficiency point to the need for a global mechanism whereby governments are collectively responsible for designating ocean sanctuaries and putting in concrete measures to protect them. That body will need to work with existing global and regional governance structures and other stakeholders in a composite approach that combines site-specific nominations with systematic planning to deliver holistic protection to the wildlife of international waters.

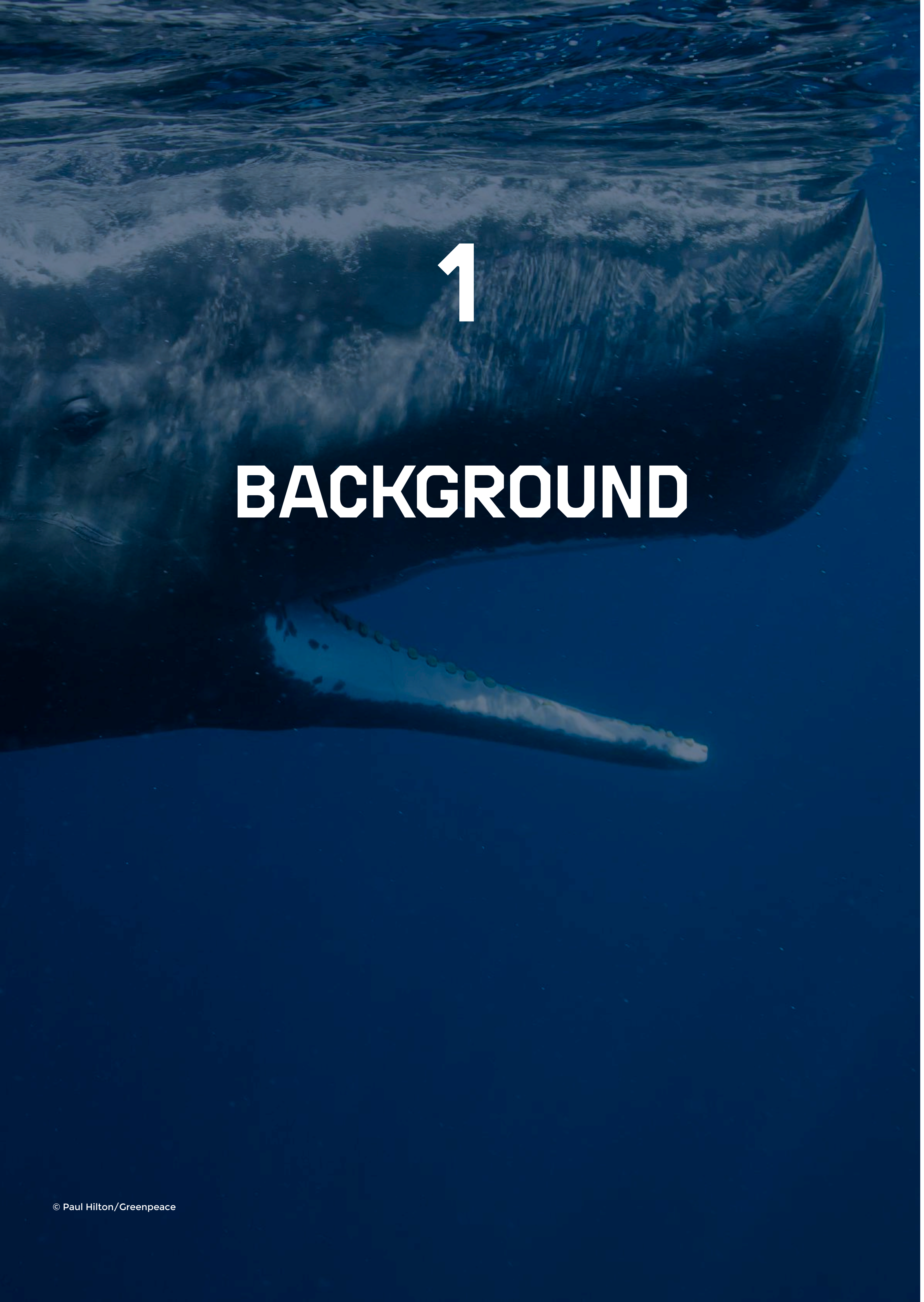
WHAT 30% OCEAN PROTECTION COULD LOOK LIKE

SCIENTISTS ARE CALLING FOR AT LEAST 30% OF THE WORLD'S OCEANS TO BE PROTECTED AS OCEAN SANCTUARIES – AREAS SAFE FROM HUMAN EXPLOITATION. THE ORANGE AREAS ON THIS MAP SHOW HOW THIS 30% FIGURE COULD BE ACHIEVED TO PROTECT THE FULL SPECTRUM OF MARINE LIFE.



This protection scenario is based on biological, oceanographic, biogeographical and socio-economic data, such as the distributions of sharks, whales, seamounts, trenches, hydrothermal vents, oceanic fronts, upwellings, biogeographic zones, commercial fishing pressure and mining claims.

This network of protection builds in resilience to wider environmental change and uncertainty, for example by using sea surface temperature data to identify places likely to change more slowly or adapt more readily under rising temperature stress. The study team also avoided areas intensively used by high seas fishing fleets to reduce possible disruption to fishing activity. We propose an interim moratorium on seabed mining to ensure that options are left open as a network of protection is built.



1

BACKGROUND

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TOWARDS PROTECTION

Roadmap to Recovery

In 2006, the Greenpeace International document *Roadmap to Recovery* was launched at the 8th Convention on Biological Diversity in Curitiba, Brazil which represented the first scientific effort to identify candidate areas for a future representative global network of highly protected marine reserves (ocean sanctuaries) on the high seas – i.e. international waters beyond national jurisdiction.[1] The work was done by a team of scientists from York University (led by Professor Callum Roberts) in collaboration with Greenpeace International. The network design was based on a wide variety of data sets and underpinned by key principles of marine reserve science. It was created using Marxan computer software supplemented by expert knowledge.

The original report also provided some context on the need for a network of marine reserves including summarising the threats and the lack of an effective governance regime. Key achievements of *Roadmap to Recovery*:

- Used criteria to identify Marine Protected Areas (MPAs) that were very similar to those later adopted by the Convention on Biological Diversity (CBD)
- Rebuked the claim that insufficient scientific information existed to identify priority areas for protection on the high seas
- Foresaw the need to develop a new UN Treaty to protect marine life in international waters and specifically the need for a new mechanism to implement marine reserves on the high seas
- Underscored the qualitative difference between highly protected marine reserves and other forms of marine protection
- Emphasised that large-scale protection in the region of 40% coverage is required for the high seas

The protected area network created in *Roadmap to Recovery* was always intended for modification over time as new and improved data became available, and since its publication, much has materialised. Alongside this, international support for ocean protection has also increased. For example, negotiations are currently taking place for a Global Ocean Treaty to protect high seas biodiversity.[2] To help inform this process, the Environment Foundation Greenpeace has funded *30x30: A Blueprint for Ocean Protection* to update the previous project, with work again done by the University of York, under the leadership of Professor Callum Roberts.

Political and historical context

The high seas and seabed, also known as marine Areas Beyond National Jurisdiction (ABNJ), are the international waters that lie beyond any country's jurisdiction and amount to 61% of the area of the world's oceans. However, despite their great biological importance and enormous value to humankind, high seas ecosystems are mostly unprotected or poorly so. For example, there is currently no comprehensive global framework to protect marine biodiversity in international waters, and the few high seas MPAs that do exist have so far been achieved through regional seas conventions. However, these agreements differ greatly in scope whereby the rules and standards they apply are not uniform.[3] For example, the process to establish MPAs in the North-East Atlantic and to develop appropriate management measures alongside them was complex, and clearly illustrated gaps in the current governance regime for the high seas and the need to create a more integrated framework.[4] It should also be noted that the regional seas conventions only cover a small proportion of the high seas and there is no mechanism in place for creating, let alone effectively managing, MPAs in most ABNJ.

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A Global Ocean Treaty to protect the biodiversity of the high seas

After more than a decade of concerted effort from a wide range of international stakeholders, in 2015 UN Member States agreed to develop a legally binding agreement for the conservation of marine life beyond national waters, including a framework for the establishment of MPAs.[5,6] This Global Ocean Treaty could enable the establishment of a global network of MPAs including highly protected marine reserves in ABNJ and create global rules for environmental impact assessments (EIAs) to prevent human activities causing harm to marine life. This represents an historic opportunity to change ocean governance from a system primarily geared towards rights for fishing and mineral extraction, to one where marine conservation and sustainable use of fragile ocean life are front and centre. A UN action with implications for the conservation of marine life on the high seas at such scale had not been made since the conclusion in 1995 of the UN Fish Stocks Agreement.

The long path towards the new Global Ocean Treaty

To arrive at the point where the world's governments are negotiating a Global Ocean Treaty is the culmination of multiple processes and the considerable effort of many governments, NGOs and individuals working in multiple fora. Increased understanding of the value of the ocean, including ABNJ and the benefits they provide to humankind, the need to implement existing commitments on the establishment of MPAs, acknowledgement of the current governance gaps and a massive increase in public support for ocean protection have all been major drivers, helping build the momentum.

The table on the next page gives the chronology of the key political steps leading to the formal negotiations at the UN.

Key steps towards an international legally binding instrument on marine biodiversity in areas beyond national jurisdiction

Year	Forum	Key outcomes
2002	UN Open-ended Informal Consultative Process on Oceans and the Law of the Sea (ICP)	Discusses protection of the marine environment
2004	ICP	Ad Hoc Open-Ended Informal Working Group to study issues relating to the conservation and sustainable use of the marine biological diversity beyond areas of national jurisdiction (BBNJ) is established
2006	BBNJ	Meets for the first time and urges action on governance gaps
2006	United Nations General Assembly (UNGA)	Adopts Resolution 61/105 on bottom fishing in areas beyond national jurisdiction
2008	BBNJ	Recognises urgency and debates new Implementing Agreement (IA)
2010	BBNJ	Calls for progress on legal regime
2010	Convention on Biological Diversity (CBD)	CBD Convention of the Parties (CoP) 10 agrees Aichi targets and calls for expedited BBNJ process
2011	BBNJ	Breakthrough meeting where a 'package' of elements for BBNJ process is agreed
2012	Rio+20 Conference on Sustainable Development in Rio de Janeiro	'Future we want' commits States to addressing "the issue of the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction (ABNJ), including by taking a decision on the development of an international agreement (IA) under UNCLOS", the United Nations Convention on the Law of the Sea, before September 2015.
2013	BBNJ	Holds inter-sessional workshops
2013	BBNJ	Meets twice
2014	International Union for the Conservation of Nature (IUCN) Congress	'Promise of Sydney' calls for new instrument (see section: Targets for Marine Protection)
2015	BBNJ concludes	Adoption of UNGA Resolution 69/292 which recommends the development of an IA and the establishment of a PrepCom to develop a new treaty
2016–2017	Series of four PrepComs	These meetings are held to elaborate elements of new treaty
2017	Final PrepCom	Concludes in July with a recommendation to the UNGA to convene an Intergovernmental Conference (IGC)
2017	UNGA	24 December adopts modalities Resolution 72/249 for the IGC and in April organisational meeting on procedural issues occurs
2018–2020	IGC	Formal negotiations for treaty are underway. IGC to convene four meetings over this period. The first happened in September 2018.

Source: High Seas Alliance http://highseasalliance.org/resources

Targets for marine protection

In 2002, at the World Summit on Sustainable Development (WSSD), a commitment was made to establish global networks of representative marine protected areas in recognition of the growing threats to the ocean and the multiple benefits these would provide.[7] A year later, in September 2003, at the 5th World Parks Congress in Durban, South Africa, participants agreed a ten-year strategy to promote the development of a global representative system of high seas MPA networks.[8] This strategy consisted of several core components, one of which was to:

> *Cooperate to develop and promote a global framework or approach, building on the UNCLOS, the CBD, the UN Fish Stocks Agreement, Convention of Migratory Species and other relevant agreements, to facilitate the creation of a global representative system of high seas MPA networks consistent with international law, to ensure its effective management and enforcement, and coordinate and harmonize applicable international agreements, mechanisms and authorities in accordance with modern principles of precautionary, ecosystem-based and integrated management and sound governance as defined in the UN principles.*

Building on these initiatives, the Convention on Biological Diversity's 7th Conference of the Parties (CBD CoP 7) in 2004 committed to the establishment of a global network of MPAs by 2012 (Decision VII/28). In 2010 the CBD reaffirmed its support for MPAs by agreement of the Aichi targets on protected areas, which disappointed many with their low level of ambition, particularly with respect to percentage coverage.[9]

> *Aichi Target 11: By 2020, at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape.*

The UN's Sustainable Development Goals (SDGs) will be the driving force behind much of the global work on sustainable development and conservation until 2030 and SDG 14, namely 'Life below water – conserve and sustainably use the oceans, seas and marine resources for sustainable development', reinforces the global commitment on MPAs in target 14.5, which is: "By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on best available scientific information."[10]

Several other marine SDG targets implicitly provide extra arguments for the need for stronger marine protection, making the wider case for marine reserves and MPAs as providers of sustainable fishing, coastal protection and carbon storage. In particular, marine reserves and MPAs will be vital if target 14.2 is to be achieved, namely: "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."

In 2014, a strong call for marine protection emerged from the marine Cross-cutting Theme at the IUCN World Parks Congress in Sydney. Most notably, this declared a need to: "urgently increase the ocean area that is effectively and equitably managed in ecologically representative and well-connected systems of MPAs or other effective conservation measures. This network should target protection of both biodiversity and ecosystem services and should include at least 30% of each marine habitat. The ultimate aim is to create a fully sustainable ocean, at least 30% of which has no extractive activities."[11] The recommendation reflected a building international consensus around the need to protect 30% of the ocean by 2030. Support for this '30x30' approach was demonstrated when the recommendation was adopted in a resolution of the IUCN World Conservation Congress in Hawaii in September 2016.[12] Here an overwhelming number of governments (129) and NGOs (621) voted in favour as only 16 and 37 respectively were against.[13]

The 'Half-Earth' proposal

The esteemed biologist Edward O. Wilson has recommended that 50% of the world should be dedicated to nature if humanity wants to save our imperilled biosphere.[14] In his book, Wilson describes ecological theory to note that as nature reserves are reduced in area, the diversity within them declines to a mathematically predictable degree such that by protecting half the world, more than 80% of species populations would become stabilized, thereby saving full representation of the world's ecosystems. In this vein Wilson also argues that given the enormity of threats to global biodiversity problems cannot be addressed in a piecemeal way, a view also expressed in the First Global Integrated Marine Assessment, but instead demand a bold solution on a commensurate scale.[15] Overall, Wilson's 'Half-Earth proposal' provides an inspirational goal for humanity which Wilson believes would help put fears and anxieties to rest, if the plan was implemented.[16]

Coverage of marine protection

Over the last couple of decades, the number of MPAs designated has increased substantially and likewise their spatial extent. Although this development is welcome, the big picture is not so encouraging, and especially not for ABNJ.

The World Database on Protected Areas (WDPA), a joint project between UN Environment and the IUCN, is the global authority on reporting protected area coverage and where these occur. As of September 2018, the WDPA lists 15,334 MPAs across the globe, representing ocean coverage of 7.44%.[17] The WDPA notes that most MPAs are located in national waters as they are more difficult to create in ABNJ due to the complex legal framework that applies there. The WDPA-calculated figure for MPA coverage in ABNJ amounts to just 1.18%, which falls far short of the 10% coverage enshrined in the Aichi target. This in turn is barely off the starting blocks compared to growing scientific consensus for the need to protect 30%.

The Atlas of Marine Protection (MPAtlas), a project of the Marine Conservation Institute, was launched in 2012 to provide a more nuanced picture of global marine protection by presenting information on actual protection afforded by specific designations. For this, MPAtlas uses WDPA data as a starting point then examines certain regions in more depth, replacing WDPA records with information from national or regional databases if that information is more up-to-date or provides greater detail. As part of this, information within MPAtlas includes accounting for newly proposed, committed or designated areas as they are announced, carefully tracking areas that are proposed or promised, identifying areas that are legally designated but as yet unimplemented on the water, and those areas that are fully implemented and in force on the water. MPAtlas is therefore able to better track strongly protected and fully implemented MPAs and was recognised in the Malta Declaration as "the most accurate and widely accepted tally of all MPAs".[18]

As of February 2019, MPAtlas reports that 4.2 % of the ocean is within MPAs, i.e. substantially less than the WDPA figure, and that approximately 2.2% of the ocean is within fully protected MPAs.[19] For ABNJ, MPAtlas calculates there is 1.2% MPA coverage with 0.8% fully protected.

As of March 2019, the only MPAs to have been established in international waters are the Pelagos Sanctuary in the Mediterranean, which is subject to an agreement between Italy, Monaco and France, those established by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) in the Southern Ocean and those by OSPAR, the mechanism by which fifteen Governments cooperate to improve protection of marine environment of the North-East Atlantic. CCAMLR differs from the other regional seas conventions in that it has the mandate to both establish MPAs and regulate activities such as fishing within those areas (see Southern Ocean, p22), whereas the management measures to control fishing and other activities, to achieve objectives set for OSPAR's MPAs in ABNJ, have to be adopted by the relevant international organisations that have authority to manage those activities, e.g. the North East Atlantic Fisheries Commission (NEAFC). Unfortunately, a situation has arisen whereby the NEAFC areas closed to fishing only partially overlap the OSPAR MPAs.[20]

CURRENT MPAS IN INTERNATIONAL WATERS

Name	Location	Designation	Total area km^2	No-take area km^2
Pelagos Sanctuary	Mediterranean	Agreement between Italy, Monaco and France	87,500	None
South Orkney	Southern Ocean	CCAMLR MPA (2009)	93,818	93,818
Altair Seamount	North-East Atlantic	OSPAR MPA (2010)	4,409	None
Antialtair Seamount	North-East Atlantic	OSPAR MPA (2010)	2,208	None
Josephine Seamount	North-East Atlantic	OSPAR MPA (2010)	19,370	None
Mid-Atlantic Ridge North of the Azores (MARNA)	North-East Atlantic	OSPAR MPA (2010)	93,416	None
Milne Seamount Complex	North-East Atlantic	OSPAR MPA (2010)	20,913	None
Charlie-Gibbs North	North-East Atlantic	OSPAR MPA (2012)	178,651	None
Ross Sea	Southern Ocean	CCAMLR MPA (2016)	1,550,000	1,117,000

Source: MPAtlas[21]

Southern Ocean

The Southern Ocean, like the Antarctic continent which it surrounds, has a special status under international law and is the exception when it comes to the establishment of protected areas in international waters due to the unique provisions available under the Antarctic Treaty System (ATS). Under the ATS, any activities in the Antarctic must be performed in a way that limits harmful impacts and any future activities must be planned with sufficient information about their possible impacts. Importantly, all activities relating to mineral extraction – except for those conducted for scientific research – are prohibited, but fishing is still allowed. The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) was established in 1982 and is a key component in the ATS. It was set up with the objective of conserving Antarctic marine life, a response by the international community to concerns about increasing commercial interest in Antarctic krill *(Euphausia superba)*, which are a keystone component of the Antarctic ecosystem.[22]

Article II of the CCAMLR Convention states that the term 'conservation' includes rational use and makes clear that fishing and associated activities are not prohibited, provided that they are designed and conducted to meet the principles of conservation set forth in paragraph 3 of Article II. As the body responsible for managing all Antarctic fisheries, CCAMLR is considered an international leader in its precautionary and ecosystem-based approach to fisheries management, and markedly different from the RFMOs. As set out in the Convention text, area protection is integral to this approach and in 2009 CCAMLR set itself the target of 2012 to achieve a representative system of MPAs within the Convention Area.[23] Subsequently, CCAMLR agreed a conservation measure (CM 91-04, 2011), which lays out a general framework for the establishment of CCAMLR MPAs. Within this conservation measure are six objectives relating to the protection of representative or otherwise significant marine ecosystem areas and features of various kinds, the establishment of scientific reference areas for monitoring natural variability or the effects of harvesting, and the protection of areas for maintaining resilience or the ability to adapt to the effects of climate change.

In 2009, CCAMLR adopted the South Orkney Islands Southern Shelf MPA, the world's first wholly high seas MPA.[24] The designation was also significant as it is a no-take reserve where no fishing activities and no discharge or refuse disposal from fishing vessels is allowed. In October 2016, after five years of discussion and refinement, CCAMLR reached consensus on the adoption of the Ross Sea region marine protected area (RSRMPA). This came into force on 1 December 2017 and covers 1.55 million km², 72% of which is a 'no-take' zone whereby all fishing is prohibited. The remaining area permits specified harvesting of fish and krill for scientific research.[25] While this situation represents major progress in marine protection, CCAMLR still hasn't fulfilled its commitment for a representative system of MPAs throughout the Southern Ocean, having failed at its 2018 meeting to adopt strong proposals for MPAs situated in East Antarctica and the Weddell Sea.[26]


Adélie penguin colony, Antarctica
© Christian Åslund/ Greenpeace

The high seas of the Mediterranean Sea – a special case for protection

Although it constitutes less than 1% of the world's ocean area, the Mediterranean Sea contains nearly 8% of known marine species making it highly biodiverse.[27, 28] Around 17,000 marine species occur there with about one-fifth of them endemic.[29] The wide range of climatic and hydrological conditions in the Mediterranean Sea help allow co-occurrence of both temperate and subtropical organisms.[30, 31] For the most part, the Mediterranean is warmer, saltier and lower in nutrients than the Atlantic Ocean and as a result has low primary productivity, particularly in the Eastern basin, a characteristic which renders the sea as a whole particularly vulnerable to over-exploitation.

Emblematic fauna of the Mediterranean Sea include several species of cetacean and sea turtle, eastern Atlantic bluefin tuna *(Thunnus thynnus)* which has crucial spawning grounds in the region, and the critically endangered Mediterranean monk seal *(Monachus monachus)*.[32]

The oceanography of Mediterranean Sea is characterised by narrow continental shelves and a large area of open sea where the average depth is around 1,500m. The deepest part reaches 5,267m in the Calypso Deep in the Ionian Sea. These waters contain fragile seamounts, seabed methane seeps and submarine trenches which scientists have barely begun to explore.[33]

A small and semi-enclosed sea, joined to the Atlantic only through the Straits of Gibraltar, which at their narrowest measure a mere 13km across, the Mediterranean Sea is surrounded by 24 countries which have benefited from its rich biodiversity and productivity over millennia. However, in recent times its coasts have become among the most populated on earth. Nevertheless, they and the Mediterranean Sea in its entirety still support many economically important activities including ones of cultural significance. For several complex reasons, no Mediterranean country has given effect to an exclusive economic zone (EEZ) claim in the Mediterranean Sea, making most of its waters fall under ABNJ.

The Mediterranean is distinctly different from the rest of the high seas and its biogeography operates on a different scale to the major ocean basins. Therefore, in line with previous studies, the Mediterranean has been excluded from the network of high seas protected areas that our study has designed.[34, 35, 36] However, this is problematic because the Mediterranean is urgently in need of very strong protection, for reasons that are discussed below.


***Paramuricea Clavata* coral in the Mediterranean Sea**
© Greenpeace/ Alessandro Giani

The combination of impacts from multiple historical and current stressors have led to the Mediterranean being described as 'under siege'.[37] Unsustainable and destructive fishing practices, habitat loss and degradation, pollution, eutrophication, the introduction of alien species and climate change effects are the most significant and all taking their toll. A worrying analysis undertaken by scientists from the European Commission's Joint Research Centre and published in Nature's *Scientific Reports,* suggests that the multiple pressures on the Mediterranean Sea might push the ecosystem beyond the point of no return and cause a collapse of fish populations vital to the fisheries sector.[38] The analysis found that 93% of the assessed fish stocks are overexploited and shows how over the past 50 years the Mediterranean has lost 41% of the number of marine mammals and 34% of the total amount of fish. The largest reductions were found in the Western Mediterranean Sea and the Adriatic Sea (-50%), while the reduction was much less in the Ionian Sea (-8%).[39] The Mediterranean has also undergone substantial changes due to the introduction of nearly 1,000 alien species through a combination of pathways – shipping, aquaculture and the opening of the Suez Canal – which has altered food webs, ecosystem functioning and the provision of ecosystem services.[40]

These and other similar findings have raised considerable concern and there have been multiple calls by Greenpeace, WWF, Oceana and others for greatly improved management and the creation of a comprehensive and effective network of protected areas to safeguard the biodiversity of the high seas of the Mediterranean Sea.

Since Greenpeace International first outlined its proposal for a representative network of highly-protected marine reserves throughout the high seas of the Mediterranean in 2006 (a separate exercise to *Roadmap to Recovery*), there have been other initiatives to identify areas of importance and that should be considered as priorities for protection.[41] For example, a useful 2013 analysis of the various proposals and mapping initiatives, including the Ecologically and

Dolphins in the Pelagos Sanctuary, Mediterranean
© Greenpeace/Paul Hilton

Biologically Significant Areas (EBSA) process, identified 10 areas encompassing 10% of the Mediterranean Sea, that were consistently identified among the then available proposals, with an additional 10% selected by at least five proposals.[42]

There is strong scientific evidence from existing protected areas across the Mediterranean Sea including Côte Bleue Marine Park, France, Columbretes, Spain, Torre Guaceto, Italy and Taza National Park, Algeria which indicate that further designation of strongly protected areas would bring multiple conservation, social and economic benefits to the region.[43] For example, one part of the Mediterranean which has been identified as likely to benefit from the creation of one or more large marine protected areas (LMPAs) is the Adriatic, where strong protection could help reverse ecological and socio-economic decline.[44]

In 2016, an assessment of the status of MPAs and other area-based conservation measures was published using MPA figures from the October 2016 release of the database on sites of interest for the conservation of the marine environment in the Mediterranean Sea, which is known as MAPAMED.[45] The study showed a tenfold increase over the past 15 years in the area of Mediterranean MPAs, whereby 6.5% of the sea receives some kind of protection. However, much of this is currently nominal as many designated MPAs have not been implemented and/or enforced. Furthermore, only 0.04% of the MPAs by area are intended to receive full protection and their average size is a mere 5km^2. A greater proportion of the Mediterranean countries' territorial waters is covered by MPAs (95,418km^2 or 14.74%) than is covered beyond the 12nm limit (84,381km^2 or 4.51%).

The Pelagos Sanctuary, which covers 87,500km^2, was established in 1999 through a joint agreement between France, Italy and Monaco with the aim of protecting fin whales and other cetaceans, and has the distinction of being the world's first high seas MPA. However, this distinction is marred by the fact that it is legally weak, given governance of the area does not allow for the development of a truly international form of management, and is sometimes described as a 'paper park'.[46, 47]

There are far more MPAs in the western half of the Mediterranean and since 2012, 391 Natura 2000 sites have been designated under the EU Habitats Directive, although these rarely afford strict restrictive measures.[48] Collectively the MPAs in the Mediterranean Sea do not form a cohesive or representative network and fall far short of delivering the level of protection required to protect marine life.

MPAs in the Mediterranean have been designated through a wide range of mechanisms at the national, regional and international levels and as such have very different protection levels associated with them. Different types of designation often overlap, which reflects the complexity of governance for the Mediterranean Sea. In common with high seas governance in general, jurisdiction of the Mediterranean involves many different organisations with competencies for a variety of different sectors.[49] Among key organisations are the General Fisheries Council for the Mediterranean (GFCM) and the International Commission for the Conservation of Atlantic Tunas (ICCAT), which are responsible for fisheries, the Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS), and the Barcelona Convention, which is responsible for conservation. Through the Barcelona Convention, 35 Specially Protected Areas of Mediterranean Importance (SPAMIs), proposed by 10 countries, have been created since 2001 with the basic aim of conserving the Mediterranean's natural heritage.[50] Sites on the SPAMI list may be designated if they are:

→ Important for conserving components of biological diversity in the Mediterranean

→ Ecosystems specific to the Mediterranean or habitats of endangered species

→ Of special interest for scientific, aesthetic, cultural or educational reasons

The SPAMI designation is intended to secure the shared responsibility of all contracting parties to the Barcelona Convention to implement regulations in these areas. Collectively the SPAMIs confirm existing designations that cover about 3.57% (or 89,856km^2) of the Mediterranean, but only one, the Pelagos Sanctuary for marine mammals, encompasses any high seas waters.

In conclusion, survival of the Mediterranean Sea's rich biodiversity and the maintenance of its ecosystem services for the millions who depend on them requires immediate, strong and coordinated action to tackle the enormous and increasing pressures affecting the region and the failure of governance there to deliver effective protection at the scale required. Certainly, to achieve their international conservation targets, Mediterranean countries will have to collaboratively increase the size of existing Mediterranean MPAs and the amount of full protection within these, as otherwise, poor ecological benefits will accrue. Central to all MPA effort must be strong enforcement of management regulations.

Ecologically and Biologically Significant Areas (EBSA) process

The 2004 commitment by parties to the CBD to establish a global network of MPAs by 2012 was a significant step towards securing protection for the oceans by the global community and kickstarted further work by the CBD towards identifying areas that may require enhanced conservation and management measures, including area-based management tools such as MPAs and environmental impact assessments. The CBD notes that this work is an open and evolving process that should be continued to allow ongoing improvement and updating as new scientific and technical information becomes available.[51]

In 2008, the 9th Conference of the Parties (CoP) to the CBD adopted scientific criteria to identify Ecologically or Biologically Significant Marine Areas (EBSAs) in open-ocean waters and deep-sea habitats following long discussions in the CBD Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) (Annex 1 to CBD decision IX/20).[52] The seven criteria established are:

→ Uniqueness or rarity

→ Special importance for life-history stages of species

→ Importance for threatened, endangered or declining species and/or habitats

→ Vulnerability, fragility, sensitivity or slow recovery

→ Biological productivity

→ Biological diversity

→ Naturalness

Two years later in 2010, the 10th CoP produced the scientific guidance to apply EBSA criteria and mandated a series of regional workshops to describe marine EBSAs. As part of this the CoP noted that application of EBSA criteria is a 'scientific and technical exercise' and emphasised that their identification and conservation and management measures is a matter for States and competent intergovernmental organisations, in accordance with international law, including the UN Convention on the Law of the Sea.

Between 2012 and March 2018, over 270 EBSAs were identified from 14 regional workshops and efforts to update information and establish more EBSAs is ongoing. The workshops were convened to cover the following regions: Western South Pacific, wider Caribbean & Western Mid-Atlantic, Southern Indian Ocean, Eastern Tropical & Temperate Pacific, North Pacific, South-Eastern Atlantic, Arctic, North-West Atlantic, Mediterranean, North-East Indian Ocean, North-West Indian Ocean and adjacent Gulf areas, seas of East Asia, Black Sea and Caspian Sea and the Baltic Sea. Some EBSAs lie wholly or partially within ABNJ and individual EBSAs can overlap each other. It has been noted that knowledge gaps exist for representativity of EBSAs as a whole and especially for those in ABNJ.[53]

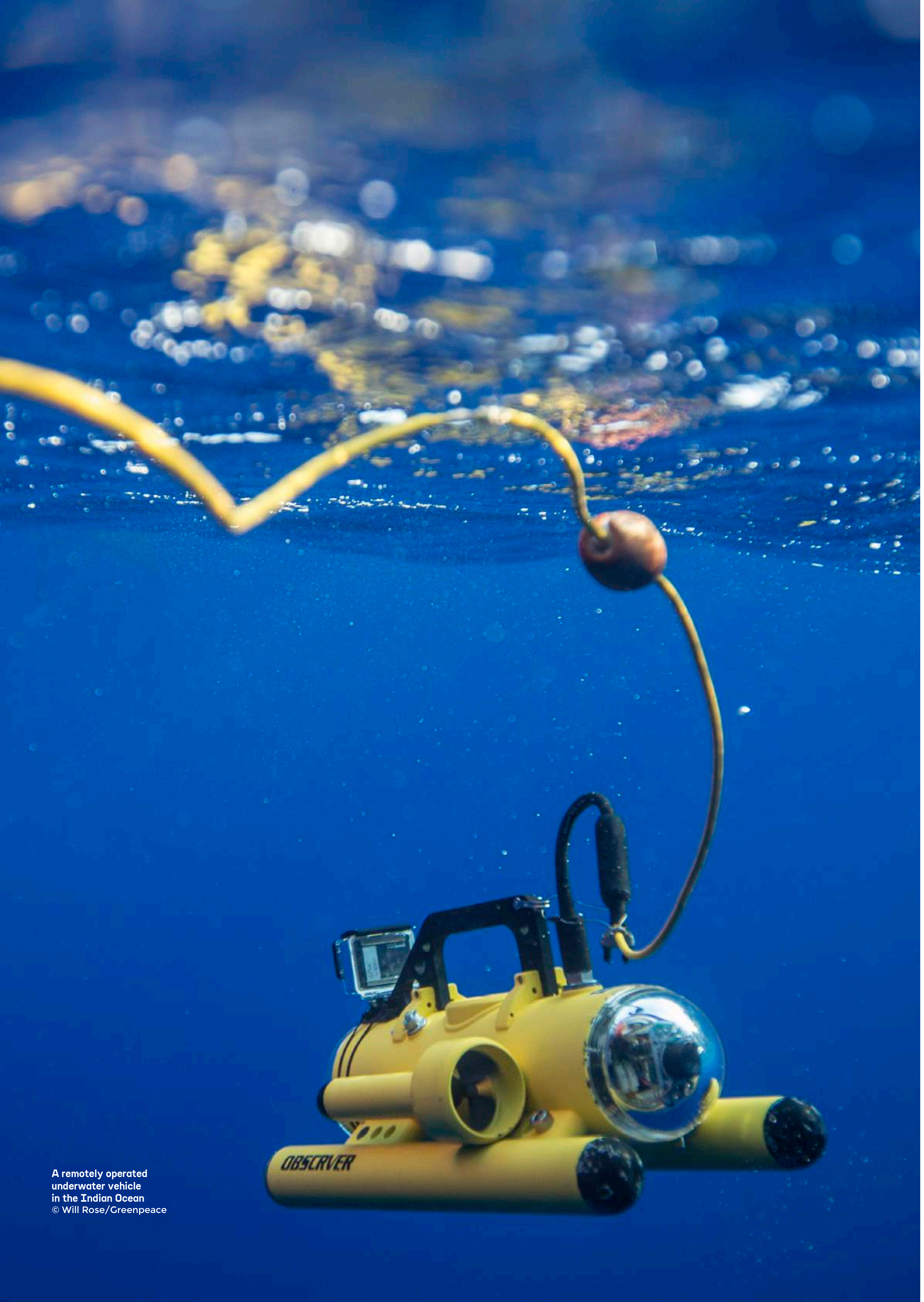
The approach used to identify EBSAs recognises their complex and dynamic nature and that small or vast expanses can both be appropriate. For example, a single seamount might be sufficient for an EBSA or a whole chain might be required if connectivity between individual seamounts is critical for conservation success. Similarly, EBSAs need not be static as it may be more appropriate to have their boundaries change, in line with seasonal, annual or longer-term oceanography or with climatic features, such as patterns of sea ice. This way, EBSA description can accord more accurately with the natural variability of its ecological characteristics.

EBSA descriptions are placed in the CBD's EBSA Repository and the information used to inform international and domestic decisions about ocean management and spatial protection.[54] For example, EBSAs should play a central part in the identification of areas in need of protection under a new Global Ocean Treaty.

Other area-based assessments to identify areas of high ecological importance in the high seas

Additionally, Birdlife International has developed a methodology to standardise the analysis of seabird tracking data to identify sites of conservation importance at global and regional scales.[55] Over 500 of Birdlife International's marine Important Bird and Biodiversity Areas (IBAs) have been incorporated into the EBSAs described, with several EBSAs based solely on seabird data.[56] Another science-based assessment that is being progressed is one to identify important marine mammal areas.[57]

Arctic tern
© Bernd Roemmelt/ Greenpeace



A remotely operated underwater vehicle in the Indian Ocean
© Will Rose/Greenpeace

LIFE ON THE HIGH SEAS

A new age of ocean exploration

Although the high seas account for almost two-thirds of the sea, they have received scant scientific exploration and are not well understood. That said, the importance of the high seas for valuable ecosystem services is well appreciated, as is the importance of conserving the connections and dependencies between marine organisms and their environment, which are essential to maintain ecosystem function.[58, 59]

Despite being poorly explored the high seas are known to support high levels of species richness, due in a large extent to the very high levels recorded for the deep sea as a whole.[60] Actual figures for biodiversity have been collated by organisations such as the Census of Marine Life (CoML), which has collaborated with hundreds of scientists from dozens of countries, finding more than 6,000 new species in the 10 years of the project between 2000 and 2010, which clearly portrays how much is still to be discovered about marine biodiversity.[61]

Research efforts are also being directed towards study of physical changes now occurring in the ocean and atmosphere, with the global observing system Argo being a key component of this. Argo is a broad-scale global array of close to 4,000 temperature/salinity profiling floats, distributed roughly every three degrees (300km), which are taking systematic measurements of temperature, salinity and velocity of the upper ocean.[62] All data collected by Argo floats are publicly available in near real-time via the Global Data Assembly Centres (GDACs) located in Brest, France and Monterey, California for use in climate analysis.

State-of-the-art technology is greatly aiding researchers in all aspects of locating, mapping and studying high seas fauna and their habitats.[63] For example, manned submersibles, remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) equipped with advanced camera technology are all helping marine biologists acquire better in-situ visuals of life in the open ocean and deep seas. Hydrophones, deployed singly or in arrays, enable acoustic monitoring, while the Acoustic Doppler Current Profiler (ADCP) measures the speed and direction of ocean currents using the principle of Doppler shift. Side-scan sonar is used to create images of large areas of the sea floor and underwater samples are collected via trawls, submersibles and semipermeable membrane devices. Environmental satellites can record sea surface temperature and information on sea ice extent and chlorophyll-a concentrations (phytoplankton's photosynthetic pigment), while other satellites relay data from tags on marine life or from ocean sensors across the world.

An exciting application of genetic techniques in the marine environment is knowledge provided from environmental DNA (eDNA). This uses traces of DNA present in the water column from sources such as skin cells, scales, faeces, slime, etc. which can be analysed to determine what types of organisms are or were recently present in the location sampled. Results can be obtained in hours to weeks and can shed light on species' presence/absence, migratory patterns, habitat preferences and spawning events.[64]

This plethora of ocean research comes at a time when the true extent of the multiple human-imposed threats to the ocean is also being uncovered. For example, 'Global Fishing Watch' is an initiative which utilises satellite technology, cloud computing and machine learning to monitor the global commercial fishing fleet and offers near real-time tracking of fishing activity.[65] A similar output is provided by 'Project Eyes on the Sea', which combines satellite monitoring and imagery data with information, such as fishing vessel databases and oceanographic data, to help authorities detect suspicious fishing activity.[66] Hence these and similar initiatives are able to reveal where in the sea pressure from fishing is greatest.

Ocean zones

Epipelagic

The epipelagic zone is the upper 200m of the open ocean down to which there is enough sunlight to allow photosynthesis. While biomass and species diversity are both typically lower compared to the continental shelf (neritic zone), the vast extent of the high seas means that in total the epipelagic zone supports very high productivity, biomass and biodiversity.[67] Phytoplankton production is limited by sunlight and nutrients such as nitrate, phosphate, silicate, calcium and iron, which are not evenly distributed across the high seas. In general, the epipelagic zone is low in nutrients, due in part to loss of dead organisms to the deep. However, in places such as oceanic fronts where cold and warm water collide, and upwellings, where deep, dense, cooler and usually nutrient-rich water moves towards the ocean surface, there are sufficient nutrients to cause plankton blooms which fuel oceanic food webs.[68]

Phytoplankton are consumed by zooplankton such as amphipods, krill, copepods, salps, jellyfish and larval forms of marine organisms. Zooplankton in turn are eaten by a huge variety of animals, which in the pelagic realm range from small fish like sardines to giants such as manta rays and whale sharks. Other predators include squid, tuna, marlin, sharks, seabirds, dolphins and toothed whales.

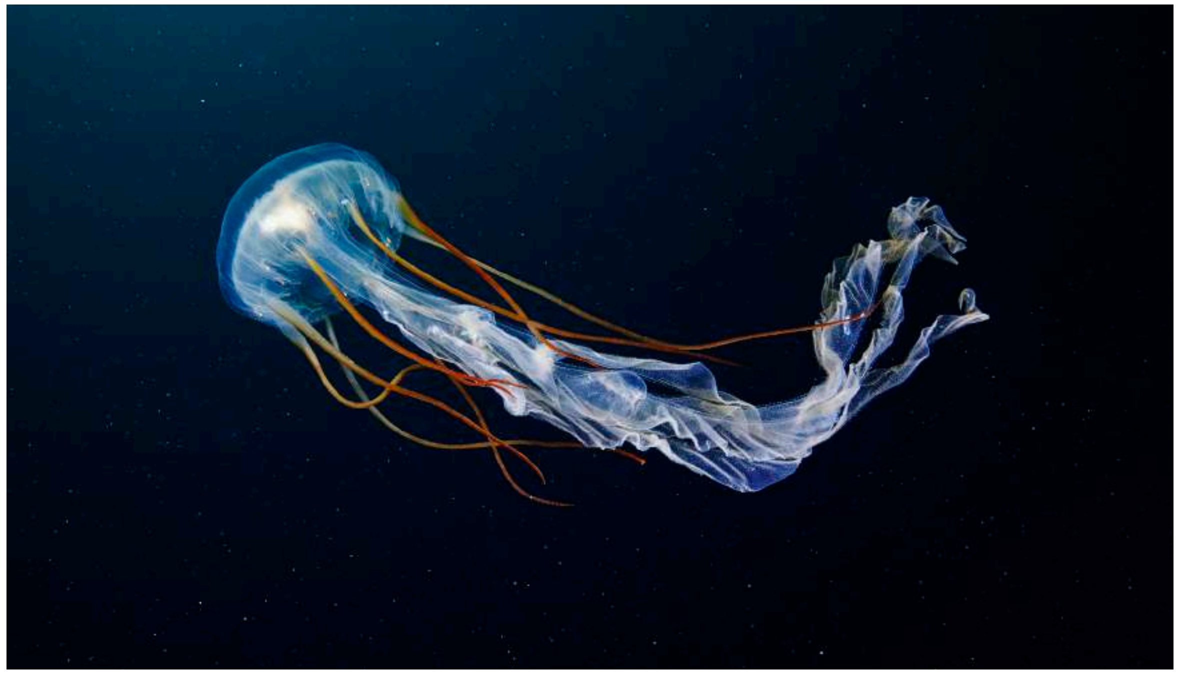
Tuna, sharks, billfish, turtles, whales, seals, penguins and albatross are among the migratory species groups that occur in the high seas. For example, Pacific bluefin tuna (*Thunnus orientalis*) spawn in the Sea of Japan then migrate 8,000km across the Pacific Ocean to the California coast where they spend several years feeding and growing, before travelling down the coast to Mexico and sometimes up towards Washington State. At around the age of seven they return to their spawning grounds, a journey made possible because this species is warm-blooded and therefore able to withstand periods of cold water. The world's largest fish, the whale shark, is another ocean wanderer. Over a period of 2.3 years, scientists tracked the 20,000km migration, primarily via the North Equatorial Current, of a female whale shark tagged at Coiba Island, Panama in the Eastern Tropical Pacific to the western Mariana Trench in the Indo-Pacific.[69]

Whale shark
© Paul Hilton/Greenpeace

Bluefin tuna
© Greenpeace/Roger Grace

The Global Tagging of Pelagic Predators (GTOPP) programme builds on the earlier Tagging of Pacific Predators (TOPP) programme, which was one of the field projects of the CoML.[70] GTOPP combines data from a diverse number of highly migratory species and overlays them with oceanographic data to make the resulting datasets accessible to the global research and educational community. Another initiative looking at migratory species to understand how they use the high seas is The Migratory Connectivity in the Ocean (MiCO) system,[71] which is collating and synthesising data on all the migratory fish, marine mammals, seabirds and sea turtle species that use the high seas to identify aggregation areas used for particular activities (termed nodes) and 'corridors' between these. The data come from studies that include telemetry, mark/recapture, stable isotope and genetic analysis, and acoustic sampling. MiCO notes that over 50% of the species it has reviewed are on the IUCN Red List, with 20 of these categorised as Endangered and 13 Critically Endangered.

Scyphozoan jellyfish, Arctic
© Alexander Semenov



Mesopelagic

In combination the open oceans and deep sea, i.e. waters deeper than 200m, cover the majority of the Earth's surface and provide 98.5% of its habitat by volume.[72] The deep sea is the least understood environment on our planet and, until recently, experts thought there was insufficient information on organisms occupying the mesopelagic and about abiotic drivers that shape communities of the mesopelagic to develop a meaningful biogeographic classification for the realm. However, recently this has been attempted.[73]

Species found in the mesopelagic belong to many different phyla but as very little sunlight penetrates there, all animals present are either carnivores, detritivores or herbivores which migrate to the surface to feed at night. New research is revealing that the species-richness of deep ocean bacteria surpasses that of the surface open ocean, and the role of microbes in deep pelagic ecosystems is very important.[74] Copepods, amphipods and ostracods are among the types of crustacean that occur there, along with arrow worms and large gelatinous animals, including comb jellies, jellyfish, colonial siphonophores and salps. Among these drifting organisms are the active swimmers, referred to collectively as the 'nekton', and these include many fish species including some deep-sea sharks, krill, shrimps and various cephalopods such as dumbo octopuses and vampire squid, which collect and feed on the marine snow using two long sticky filaments.[75, 76]

Mesopelagic fish have long been thought to dominate the world's fish biomass, with estimates derived from sampling with trawl nets putting total biomass at ~1,000 million tonnes, whereby lantern fish (*Myctophidae*) dominate.[77] However, recently this has been challenged as an underestimate about an order of magnitude out. The new figure, based on information collected during a Spanish Circumnavigation Expedition between December 2010 and July 2011, used acoustic sampling techniques for more accurate data.[78]

The large biomass of unexploited mesopelagic fish in the deep ocean is of obvious interest to the fishing industry, with feelers underway from Pakistan and Norway.[79, 80, 81] Mesopelagic fish play a crucial role in the biological carbon pump. It has been estimated that without the biological carbon pump, present day atmospheric CO_2 concentrations would be approximately 200ppm (~50%) higher.[82] However, as many experts have warned, fishing for mesopelagic species needs to be sustainable and should not compromise the ocean's ability to sequester carbon. In the words of Professor Carlos Duarte, "Because the stock is much larger it means this layer must play a more significant role in the functioning of the ocean and affecting the flow of carbon and oxygen in the ocean."[83]

The deep ocean is known to support large deep-water squid which include the giant squid (*Architeuthis dux*) and the colossal squid (*Mesonychoteuthis hamiltoni*), the latter of which is the largest known invertebrate with an estimated maximum length of 12–14m and weight of 750kg. Several lines of evidence indicate that populations of deep-water squid in general may be very large.[84] Interestingly, a genetic analysis of the giant squid suggests that individuals all belong to a single global population of substantial size.[85]

Among deep-diving marine mammals that feed in the mesopelagic are sperm whales, which are highly voracious predators of squid, including giant species. A study based on analysis of the stomach contents of 36 sperm whales involved in two mass stranding events on the Tasmanian coast found squid beaks of varying sizes from a wide range of cephalopod species.[86] One estimate of the annual amount of deep-sea squid consumed by sperm whales was in excess of the total landings of fisheries worldwide.[87] Northern elephant seals have been recorded to feed at a depth of 1,754m and Cuvier's beaked whales hold the record amongst marine mammals for feeding at depth by diving to 2,992m.[88, 89]

Bathypelagic

The bathypelagic refers to open-ocean waters deeper than 1,000m. No sunlight penetrates the zone, which is also referred to as ‘midnight’ or ‘dark’. The only light present in the bathypelagic zone comes from bioluminescent flashes produced by marine animals themselves.[90] While bioluminescence occurs in many marine organisms at all ocean depths, it is important in the bathypelagic for a large proportion of species.[91] Here uses include: attracting a mate, flashing a warning, illuminating or luring prey and acting as a defence mechanism.

Female humpback anglerfish (*Melanocetus johnsonii*), like all anglerfish, possess an elongated first dorsal fin with a bacteria-filled lure that can be hidden or revealed and is used to attract pelagic crustaceans, fishes and other prey.[92] This species exhibits extreme sexual dimorphism, the male is much smaller (3cm compared to the female which is 18cm long). The male has highly developed sensory organs that allows him to find a female, at which point the couple will temporarily attach themselves to each other allowing him to fertilise her eggs, which she then releases into the deep ocean.[93] In 2009, seven new species of swimming annelid worms were found in waters below 1800m. Five were ‘green bomber’ worms which have organs that produce brilliant green bioluminescence when autotomized, a behaviour that enables them to escape harm.[94]

Bioluminescence is known to have evolved on at least 40 separate occasions and a recent study discovered that it has evolved on 27 separate occasions within just the ray-finned fish.[95] Some animals can produce chemical reactions within their own bodies that cause the glow, while others have developed symbiotic relationships with bioluminescent bacteria that they engulf, which then go on to live on or in their bodies, making light for them. Deep-sea lantern and kitefin sharks, however, use a combination of hormones and neurotransmitters.[96]

Below the bathypelagic zone is the abyssal plain, which continues to 6,000m, and beneath this the hadal zone extends to the ocean’s deepest trenches and canyons. Species of starfish, tube worms and other invertebrates occur at these extreme depths. Fish species present at these depths include the Mariana snailfish (*Pseudoliparis swirei*) which has been videoed swimming at depths of 8,178m in the Mariana Trench. It is currently not understood how fish withstand the intense pressure at these depths, which has been described as similar to an elephant standing on your thumb.[97] The Mariana snailfish is the top predator of the Mariana trench and large aggregations have been recorded feeding on swarms of amphipods.[98]

Seafloor/benthic habitats

The deep seabed underlying the high seas was until recently thought to be relatively devoid of life, but deep-sea research continues to reveal this is not the case.

Continental slope

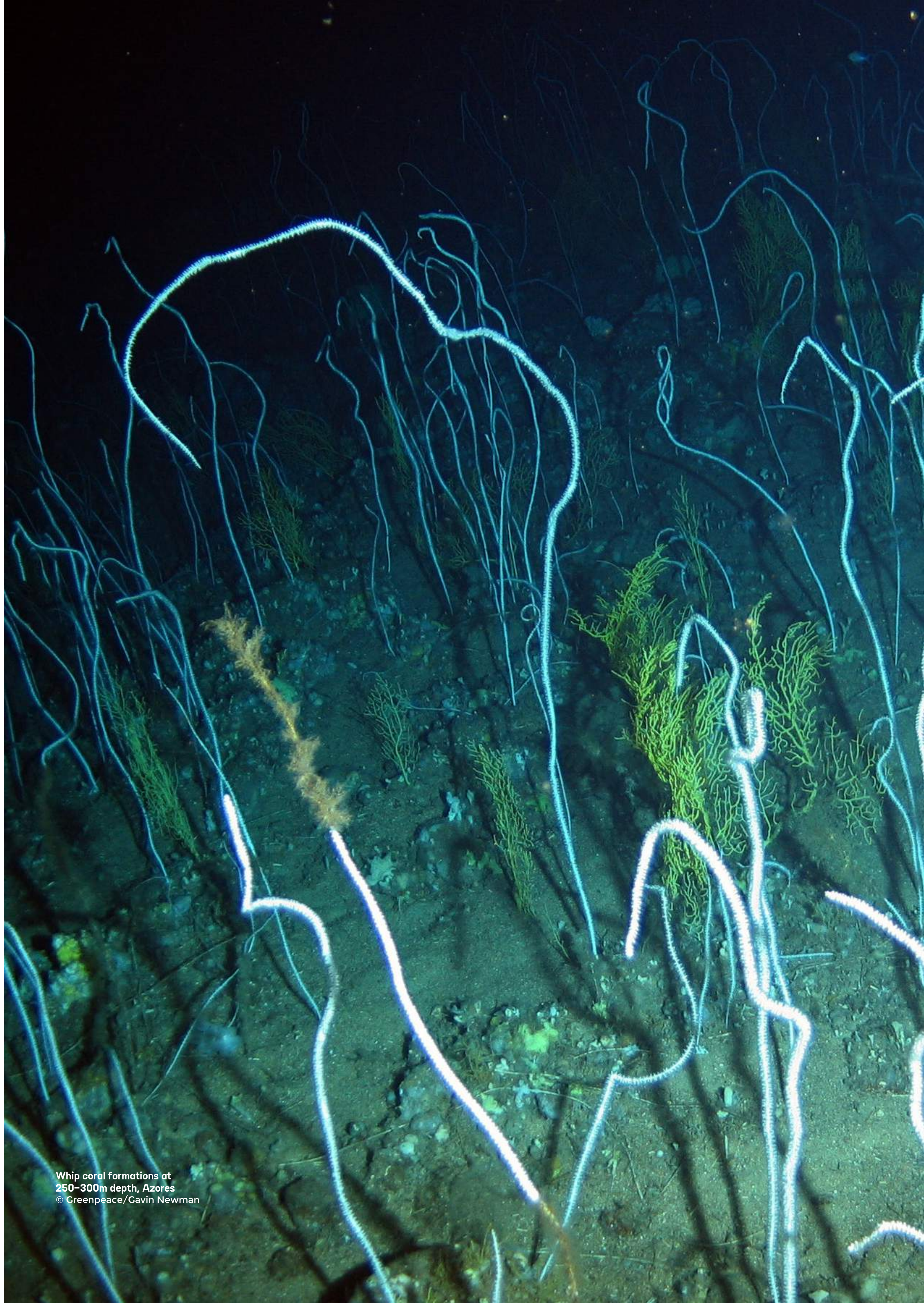
The continental slope extends from the shelf break to the abyssal plain and includes a variety of habitats with specific and distinct physicochemical, geological and biological characteristics. Consisting mainly of sediments which are derived from erosion on land, the continental slope is mostly angled between 1 and 10 degrees and is structured by the cross-cutting of submarine canyons and sediment slides. At 3,000–4,000m there is a gradual decrease in the gradient of the slope (sometimes called the continental rise) until eventually the seabed becomes relatively flat and the abyssal plains begin.[99]

Different substrate types – soft sediments, boulders and exposed rock faces – provide a wide range of surfaces on which different species can settle or attach to. The continental slope may harbour a rich abundance of marine life. In situations where there are favourable oceanographic conditions with a plentiful supply of nutrients, for example where nutrients are either cascading down from shallower nutrient-rich waters, or upwelling from the nutrient-rich waters of the deep ocean, the continental slope can provide habitat for rich biodiversity.

Submarine canyons

Submarine canyons cut into continental margins and some oceanic islands. Globally there are more than 9,000 large canyons covering 11.2% of continental slopes.[100] Each canyon, due to its steep and complex topography, is unique, providing habitat types that range from rocky walls and outcrops to soft sediment.[101] Two of the largest canyons in the world, Zhemchug and Pribilof, cut into the edge of the continental shelf in the south-eastern Bering Sea. At 2.6km deep the Zhemchug canyon is deeper than the Grand Canyon (1.83km deep). All canyons act as conduits for carrying material from the productive continental shelves down continental slopes to the more stable deep seafloor.

The characteristics of submarine canyons mean that they are often associated with high biodiversity and species richness. Sponge fields and cold-water corals may be found in submarine canyons and commercially important species present in these regions can include lobster, crab, shrimp, hake, tilefish and flounder. For these and other species, canyons can act as spawning grounds and nurseries.[102] Canyons may also be important to cetaceans, with a recent review suggesting that toothed whales may be attracted to them because canyons may concentrate prey and some cetaceans tend to aggregate in these areas year-round. By contrast, baleen whales tend to occur in canyons seasonally.[103]



Whip coral formations at 250–300m depth, Azores
© Greenpeace/Gavin Newman

Abyssal plains

Below the continental slope, at depths between 3,000 and 6,000m, lies the vast expanse of abyssal plain which is blanketed in sediment. Far from shore, sediment accumulates by the sinking of dead organisms and faeces (marine snow) from the epipelagic. Underneath areas where surface productivity is high, sediment can build up relatively fast, but offshore above the vast abyssal plains, sediment accumulation is normally exceedingly slow. For example, a rate of ~0.14cm per year has been recorded for the Porcupine Abyssal Plain where the sediments are almost exclusively of oceanic origin.[104]

While biomass of the abyssal plains is thought to be relatively low, biodiversity there is high. The relative homogeneity of the ecosystem means that larvae, juveniles and adults of abyssal species may float over huge distances, resulting in potentially less endemic species in and on the abyssal plains than other deep-sea habitats.[105] As well as supporting a plethora of microbes, the abyssal plains accommodate a multitude of small invertebrate organisms living in or burrowing through the seabed, including nematodes, polychaete worms, crustaceans and molluscs. One transparent anemone (*Losactis vagabunda*) tunnels its way through sediment and can eat worms six times its own mass.[106] Larger animals found on the surface include sea cucumbers, brittle stars, urchins, decapod crustaceans and fish. Where there are hard substrates, crinoids, sponges and anthozoans can also occur.[107]

In recent years, scientists have uncovered much about the dynamics of abyssal plain communities. For example, it was recently found that occasional events, such as algal blooms and a die-off of salps, produce sporadic feasts for the seafloor communities that can sustain them for years or even decades.[108]

While the abyssal plain is often thought of as flat, much of Ireland's Porcupine Abyssal Plain in the Atlantic Ocean has been found to consist of gentle rolling hills a few hundred metres high. Although the same species live on these hills as occur on the flat plain, they occur at the two locations (plain and hilly regions) in different proportions, with smaller-bodied animals concentrated on the plain and larger-bodied ones on the hills. The biomass of hill species has been recorded at more than three times the level of that on the plain regions.[109] If this pattern holds throughout the Porcupine Abyssal Plain, then deep-sea biomass there could be twice what was previously thought, which would change our fundamental understanding of ecosystem function in these regions.[110]

WHALE FALLS

The presence of whale carcasses that have sunk to the bottom of the ocean provide significant inputs of organic nutrients to localised spots of the deep ocean floor. These attract a succession of specialised organisms that feed on decaying flesh and bone over months and years. First to arrive are scavengers such as hagfish and sleeper sharks, which eat soft tissues. Then follow opportunists which colonise bones and surrounding sediments. Among 'whale fall' specialists is the remarkable 'bone-eating' worm (*Osedax spp.*), which was first discovered in 2002 living on the bones of a gray whale (*Eschrichtius robustus*) at nearly 3,000m. Commonly known as 'zombie worms', these animals secrete an acid from their skin that dissolves bone, freeing up the fat and protein trapped inside that symbiotic bacteria contained within the worms' bodies then digest. Finally, there is the 'sulfophilic stage' which occurs when bacteria anaerobically break down organic-enriched sediments and the lipid-rich skeleton to produce hydrogen sulfide in the process. The sulfide then allows for growth of sulfide-dependent communities of clams, limpets and other animals, some of which overlap with those found around hydrothermal vents and cold seeps. This has prompted some scientists to propose that whale falls may act as stepping stones for vent species to colonise other areas.[111]

Chemoautotrophic whale-fall community, including bacteria mats, vesicomyid clams in the sediments, galatheid crabs, polynoids and a variety of other invertebrates.
© NOAA/Craig Smith, University of Hawaii

Mid-Ocean Ridge system

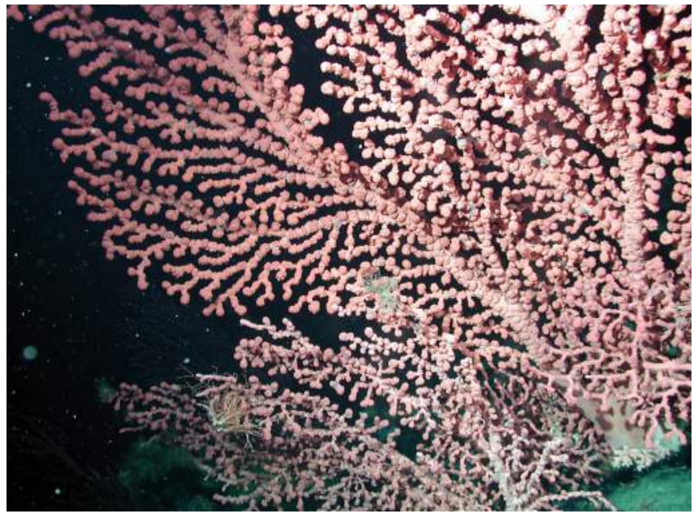
At 65,000km long, the Mid-Ocean Ridge is the longest mountain range in the world, more than 90% of which is underwater. The average water depth of the ridge is 2,500m.[112] The Mid-Ocean Ridge snakes through every ocean in the world. Ridges occur where two tectonic plates are moving apart, and along these divergent plate boundaries, earthquakes and volcanic activity cause molten rock to spew from the resulting fissures creating new ocean crust at the ragged edge of the plates. The topography of each mid-ocean ridge depends on the rate that the plates involved are spreading. A slowly spreading ridge, such as the Mid-Atlantic Ridge, displays a steep irregular topography and is relatively narrow, while a faster spreading rate, as found along the East Pacific Rise, produces a much wider profile and more gentle slopes.

Seamounts

Seamounts are undersea mountains, mostly volcanic in origin and usually found within a few hundred kilometres of mid-ocean ridges. They are formed by tectonic lift of the oceanic crust along slow and ultra-slow spreading ridges. True seamounts rise >1000m from seafloor, whereas rises less than this but >500m are referred to as knolls and those that are <500m from seafloor are referred to as hills.[113] Seamount habitats are estimated to constitute approximately 4.7% of the ocean floor, whilst knolls cover 16.3%, with a disproportionate number of these located in the Southern Ocean.

Our knowledge of the ecology of seamounts has increased over the past quarter of a century, with recent studies shedding light on seamount-associated communities and processes.[114] Seamounts can be considered as islands of shallower seafloor surrounded by deep ocean, and until recently they were thought to support extremely high levels of endemism, with high numbers of new species identified whenever new seamounts were explored. However, as studies have been conducted on an increased number of seamount sites, it has become apparent that some seamount species are widely distributed with high levels of connectivity over large geographic ranges. Conversely, it appears that some seamount fauna, such as many benthic sessile invertebrates, do have limited dispersal so are restricted in their distribution.[115, 116]

Seamounts are often considered biodiversity hotspots in the open ocean, but biodiversity richness can be variable and comparisons of species richness with the continental slope are not always higher.[117] Multiple factors influence the productivity and composition of seamounts, but normally these ecosystems support diverse benthic communities and abundant fish populations.[118] Seamounts cannot be considered a single entity and differences in their location, depth and morphology and the way the latter interact with steady and variable currents result in different mechanisms that may lead to enhanced primary productivity above the seamount. One mechanism is that the supply of plankton and suspended organic matter associated with seamounts provides a good supply of food to their benthic and benthopelagic communities.[119]



Gorgonian coral at Davidson Seamount
© NOAA and MBARI

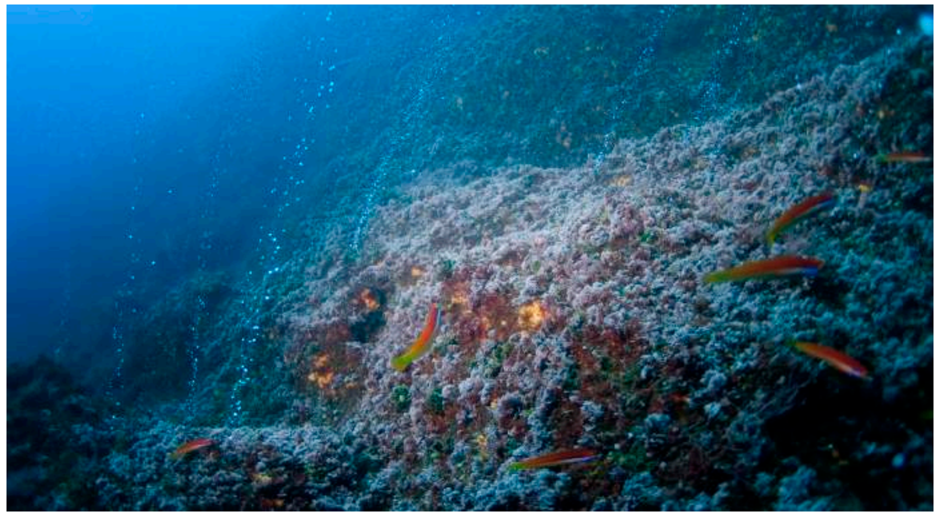
The steep slopes and accelerated currents that characterise many seamounts means they can provide sediment-free substrate to suspension-feeding corals, crinoids, hydroids, ophiuroids and sponges which often dominate space. Some of these species, such as cold-water stony corals, form reefs and thickets that provide a diverse habitat for other animals. A recent study of the Annan Seamount in the Equatorial-Atlantic using a ROV identified over 30,000 animals living on the surface of this seamount.

Many pelagic and benthopelagic predators occur in the vicinity of seamounts in part due to the enhanced feeding opportunities they provide. One process that helps fuel seamount food webs is the concentration and trapping of vertically migrating micronekton around the seamount summit, as appears to occur at the Condor and Gigante seamounts in the Azores.[120] Nocturnal migrants which actively swim or are passively transported towards the surface above the seamount and slopes at night may be retained at the surface due to the flow of water, and so provide food for a wide range of marine life.

Associations with seamounts have been described for some tunas, billfishes, sharks, marine mammals and seabirds.[121] For example, seamounts may be used as waypoints by some migratory species, and humpback whales migrating from the breeding areas of New Caledonian population to the Southern Ocean may use them as foraging areas.[122]

The last quarter of a century has seen our understanding of seamount ecosystems grow considerably, but this has to be viewed in perspective of the tiny fraction of seamounts that have been sampled. It is estimated that only about 0.002% of seamounts have been surveyed of the 170,000 estimated to occur.[123] To better understand the complexities of seamounts, a major international effort over many years involving multidisciplinary teams will be required.

Hydrothermal vents, Azores
© Greenpeace/Gavin Newman



Hydrothermal vents, Azores
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Hydrothermal vents

Hydrothermal vents and the specialist biological communities associated with them were first discovered in 1977 on an expedition to the Galápagos in the manned submersible *Alvin*. The scientists did not include a biologist because nobody had thought that marine life could flourish in the extreme environment being investigated.[124] In reality, the expedition found thriving communities of clams, crabs, and human-sized tubeworms (*Riftia pachyptila*) at the five hydrothermal vents discovered.

Hydrothermal vents form in volcanic areas along the mid-ocean ridge system where two tectonic plates are either moving apart or towards each other. Cold seawater can thus seep into cracks in the seafloor to become superheated by the underlying hot magma, sometimes up to a temperature of 400ºC. At these temperatures chemical reactions occur and minerals are pulled out from subsurface rocks, dissolved and concentrated. When the percolating mineral-rich waters are blocked in their downwards path they spew back out through vent openings. As the particle-laden vent fluids come into contact with near-freezing seawater, the fine-grained minerals cool and precipitate, forming chimneys known as smokers. 'Black smokers' are sometimes tens of metres high and formed from deposits of black iron sulfide, while cooler 'white smokers' precipitate from deposits of barium, calcium and silicon, which are white.

Deep-sea vents are usually clustered in vent fields. These vary in size, sometimes having vent chimneys packed into a small area that is just a couple of hundred metres across, whereas in other places vent chimneys can be spread over several kilometres.[125] Vent fields may be separated from each other by a few kilometres in some regions, or by several hundred kilometres if vent activity is lacking in between. This means that vent fields and associated biological communities function as islands on the seafloor.

Chemosynthesis fuels the biological communities of hydrothermal vents via a process where chemosynthetic bacteria derive energy from the chemical bonds of hydrogen sulphide. Some of these bacteria are suspended in the water column, while others form dense bacterial mats or biofilms on hard rock or animal surfaces that are grazed on by copepods, amphipods and shrimps. Other chemosynthetic bacteria have evolved symbiotic relationships with vent fauna. For example, vent tubeworms which have no mouth or gut are entirely dependent for their nutrition on the symbiotic bacteria that live within their tissues. The dense aggregations of shrimp found at hydrothermal vents along the Mid-Atlantic Ridge are also dependent on symbiotic bacteria which are cultivated within their enlarged gill chambers, on the outside of their carapace and on mineral particles that they ingest.[126] The vesicomyid clams and bathymodiolid mussels found around hydrothermal vents, while deriving some energy from symbiotic bacteria, are also filter feeders, though the reduced digestive system of the clam suggests it is more dependent on the bacteria than the mussels. Some vent ecosystems also support larger predators such as the zoarcid fish (*Thermarces cerberus*) which feeds on limpets and crustaceans.[127] The crabs and squat lobsters which are localised to vents prefer to feed on clams and tubeworms, as do more wide-ranging octopuses. When vent activity begins to decline, scavenging decapods, gastropods and copepods will move in.

Hydrothermal vents are sometimes referred to as 'oases of the deep' on account of the high density of exotic species they support. While research is still very limited, it shows that the general pattern of biodiversity at vents is low but with a very high degree of endemism, estimated at ~85%.[128] New studies of hydrothermal vents invariably produce new species, be it at previously studied sites or at new ones.[129]

The discovery of hydrothermal vent ecosystems has attracted the interest of the deep seabed mining industry, which is looking to extract valuable minerals from the seafloor massive sulfide (SMS) deposits that make up vent chimneys and associated rubble around them. In addition, bioprospectors are looking at the potential for commercial applications of genetic resources found in organisms that have evolved to live in the extreme hydrothermal vent conditions.

> "BALEEN WHALES STORE CARBON OVER EQUIVALENT CENTENNIAL TIMESCALES TO TREES ON LAND"

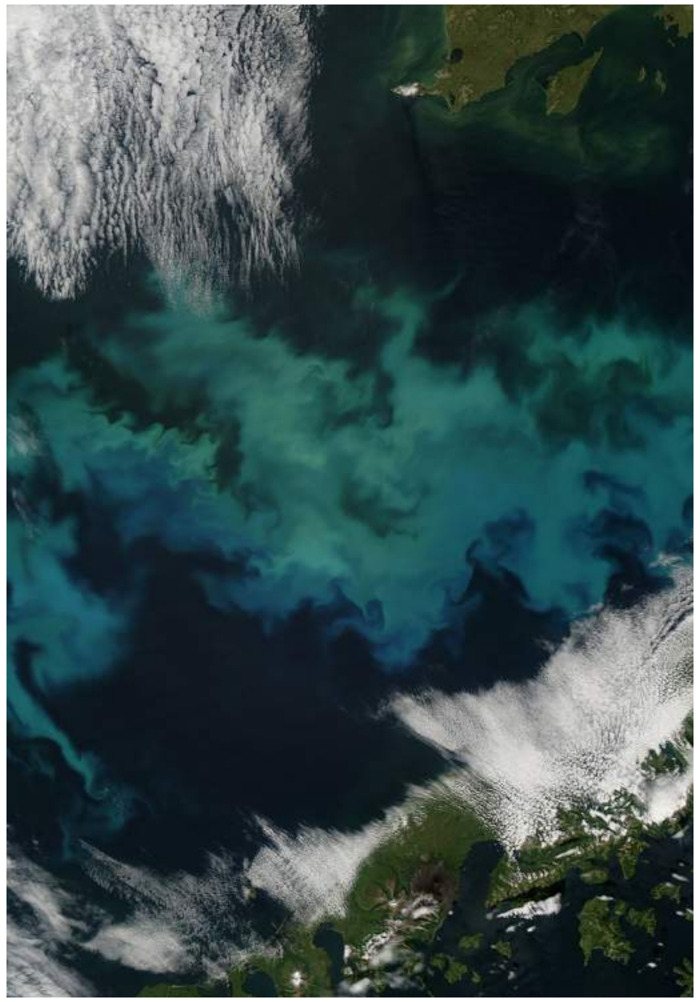
© Alex Hofford/Greenpeace

ECOSYSTEM SERVICES

Ecosystems provide a range of goods and services, both directly and indirectly, that sustain and benefit humans, and these are known as ecosystem services. Over the last 30 years research has begun to reveal the extent of these and how they are maintained by healthy and functioning ecosystems and their associated living organisms. As our understanding of the ecology of the high seas grows so does our appreciation of the high social and economic value that its ecosystem services provide.

A widely used framework for classifying ecosystem services was developed by the Millennium Ecosystem Assessment for the United Nations in 2005.[130] This framework classifies ecosystem services into four functional groups: provisioning services provide food, genetic resources and other raw materials; regulating services support processes such as climate regulation and water purification; and cultural services allow for recreation, education and cultural heritage. The fourth group, namely supporting services, encompasses processes, such as nutrient cycling and primary production, which underpin the production of all other ecosystem services. To ignore the value of any, but the latter in particular, would drastically undervalue the importance of the deep ocean to humanity.[131]

In 2014, a report for the Global Ocean Commission defined 15 ecosystem services, including two in a separate habitat services category, provided by the high seas as shown in the table below.[132]



Phytoplankton, Bering Sea. In waters above 200m, phytoplankton, through the process of photosynthesis, transform dissolved CO$_2$ into organic carbon
© Geoff Schmaltz/NASA

Summary of high seas ecosystem services

Ecosystem Service Category (ES)	Definition
Provisioning services	
1. Seafood	All available marine fauna and flora extracted for the specific purpose of human food consumption
2. Raw Materials	The extraction of any biologically mediated material from the high seas, excluding material covered by ES 5
3. Genetic Resources	Any material that is extracted from the high seas for use in non-marine, non-medicinal contexts, excluding the research value associated with ES 15
4. Medicinal Resources	Any material that is extracted from the high seas for its ability to provide medicinal benefits, excluding the research associated with ES 15
5. Ornamental Resources	Any material that is extracted from the high seas for use in decoration etc.
Regulating services	
6. Air Purification	Removal from the air of natural and anthropogenic pollutants by the high seas
7. Climate Regulation	Contribution of the biotic elements of the high seas to the maintenance of a favourable climate via its production and sequestration of climate-influencing substances
8. Waste Treatment	Bioremediation by the high seas of anthropogenic pollutants
9. Biological Control	Contribution of the high seas to the maintenance of natural, healthy population dynamics that support ecosystem resilience by maintaining food webs
Habitat services	
10. Lifecycle Maintenance	Contribution of the high seas to migratory species' populations through the provision of essential habitat for reproduction and juvenile maturation
11. Gene Pool Protection	Maintenance of viable gene pools through natural selection/evolutionary processes
Cultural services	
12. Recreation & Leisure	Provision of opportunities for recreation and leisure that depend on the state of the high seas
13. Aesthetic Information	Contribution to the surface or subsurface of a landscape. This includes informal Spiritual Experiences but excludes that which is covered by ES 12, 14 & 15
14. Inspiration for Culture, Art and Design	Existence value of environmental features that inspire elements of culture, art and/or design. This excludes that which is covered by ES 5, 12, 13 & 15
15. Information for Cognitive Development	Contribution to education, research and learning. This includes the contribution of the high seas to the research into ES 3 & 4

Source: Rogers et al. (2014)

The list of ecosystem services provided by the high seas gives some sense of their importance; however, attempting to quantify and estimate a value for these services is problematic for various reasons. One is the lack of scientific information on the routes and pathways through which an ecosystem service is delivered and the overall level of provision of the service. Difficulties also exist in teasing out the high seas portion of benefits from a service which is also derived from coastal or EEZ waters, and adjusting for when an ecosystem service may also have a detrimental effect on another ecosystem service or services. For example, the oceans absorb CO_2, drawing down carbon from the atmosphere, but in doing so, this process causes the seawater to become acidified. Ocean acidification is known to cause significant harm to many marine organisms.

Despite the difficulties described above and the inherent problems with a process that some view as 'the commodification of nature', increasing effort is being put into understanding the economic value of marine ecosystems.[133] Expressing the value of ecosystem services in monetary units can be an important tool in raising awareness and conveying the relative importance of ecosystems and biodiversity to policy makers. More specifically it can substantially improve the management of critical marine resources, guide governance, help regulate emerging ocean policy and, importantly, provide a better understanding of the potential economic challenges that are the consequences of a rapidly changing ocean environment.[134]

According to some estimates, coastal and ocean biomes may provide as much as two-thirds of the ecosystems that make up the planet's natural capital.[135] According to a 2015 study published by WWF, our oceans are worth at least US$24 trillion, with goods and services from coastal and marine environments amounting to about $2.5 trillion each year.[136] If equated to Gross Domestic Product (GDP) this places the ocean as the seventh largest economy in the world. These figures are an underestimate as the analysis did not include assets for which data were not available or values for intangibles such as the ocean's role in climate regulation, the production of oxygen or the temperature stabilization of our planet.

So far, most attention in applying an ecosystem services approach to the marine environment has been given to evaluating coastal ecosystems as opposed to open-ocean and deep-sea areas. This is demonstrated by an analysis of the value of ecosystem services of 10 main biomes expressed in monetary units, which drew from 168 estimates for inland wetlands but only 14 for marine ecosystems.[137] However, Alex Rogers and colleagues have produced estimates for the natural carbon sequestration by the marine life in the high seas, one of the key ecosystem services provided by the high seas. They estimate that the total social benefit of carbon sequestration by the high seas amounts to US$148bn per year in constant 2010 dollars (with a range of US$74bn to US$222bn for mid-estimates).[138]

Natural carbon sinks – a vital ecosystem service

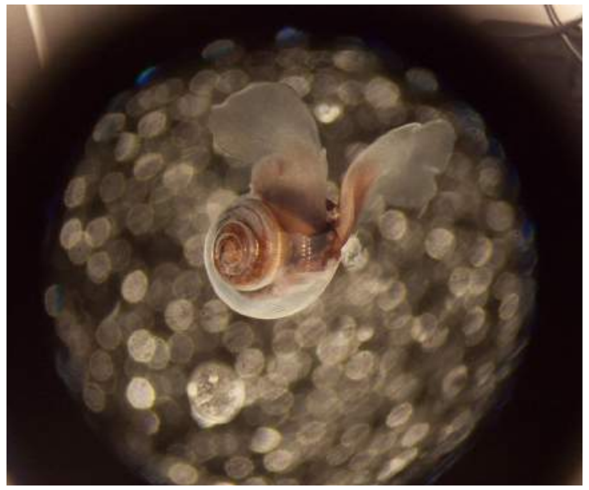
The global ocean plays an extremely important part in the Earth's carbon cycle and thus provides a crucial ecosystem service. A complex suite of processes transfer atmospheric carbon from the surface to the deep ocean where it can be stored, or sequestered, for millennia. The deep ocean zones constitute the largest reservoir of stored carbon on Earth, storing more than 50 times the amount of carbon in the atmosphere and more than one order of magnitude more than all the carbon held in terrestrial vegetation, soils and microbes combined.[139] This ability of the ocean to capture and store carbon reduces rates of increase of atmospheric CO_2 and can slow changes in global temperature, plus buffers against other consequences associated with climate change, which means the ocean has an important role to play in climate change mitigation. Estimates suggest that roughly one-quarter of all the anthropogenic CO_2 emitted over the past 20 years has been taken up by the global oceans.[140] Unfortunately, the uptake of anthropogenic CO_2 from the atmosphere by the ocean is resulting in the ongoing increase in the sea's acidity (decrease in the sea's pH), with worrying implications for ocean ecosystems (see Ocean acidification, p55–56).

The absorbtion and sequestration of carbon by the oceans involves both physical and biological processes and ocean carbon is found in both inorganic and organic forms. The vast majority of the carbon in the ocean is in the form of inorganic compounds (carbonic acid, bicarbonate ions and carbonate ions) resulting from atmospheric CO_2 dissolving in the surface waters of the ocean. That absorbed by the ocean is not evenly distributed and some oceans have a higher concentration of dissolved CO_2 than others. For example, the North Atlantic stores 23% but the Southern Ocean only 9%, while the Pacific, despite being the largest ocean, absorbs just 18% (Feely et al., 2001).[141, 142] Ocean currents transport warm water from tropical regions towards colder areas at the poles, during which time the seawater cools and absorbs atmospheric CO_2. This CO_2 dissolves twice as readily in cold water at the poles than in warm waters near the equator. Cool water at the poles sinks to the deep sea, taking with it the dissolved CO_2 where it may remain locked away from the atmosphere for hundreds to thousands of years.

Marine organisms also play a critical role in the global carbon cycle and the sequestration of carbon in the deep ocean via the biological carbon pump. In the sunlit waters above 200m, phytoplankton, through the process of photosynthesis, transform dissolved CO_2 into organic carbon and marine food webs develop. Marine species at all levels in the food web are vital to the retention, cycling and long-term storage of 'blue carbon' and its transfer from the surface to deep ocean waters and sediments. As fixed carbon passes through food webs, a very large proportion is converted back into CO_2 through respiration and is lost again to the atmosphere. However, a small fraction of the organic matter formed in the upper ocean becomes particulate organic carbon (POC) that is transported to deep waters (>1000m), where a proportion is sequestered from the atmosphere over long timescales. Long-term carbon sequestration, whereby microbial degradation of organic matter gives rise to gas hydrates and carbon from decomposed plankton is mineralised to form oil, may take millions of years. Approximately 1% of the total organic carbon production at the sea surface is buried in the sediment.[143]

Additionally there is a carbonate pump by which various open-ocean calcifiers, namely coccolithophores (a type of phytoplankton), pteropods (a type of zooplankton) and foraminifera (single-celled animals which are mostly benthic but can be planktonic) act as significant carbon pools, transporting calcium carbonate through the water column to the deep sea and its sediments for long-term geological storage.[144] Coccolithophores are enclosed in a mosaic, or cage, of microscopic plates made from calcium carbonate. Similarly, some pteropods – sometimes referred to as sea butterflies – have a calcium carbonate shell, and foraminifera possess a test made from calcium carbonate. Although the process of calcification itself leads to the release of CO_2 from dissolved inorganic carbon in seawater, an equivalent amount of carbon becomes part of the shells of these organisms, some of which will reach the bottom of the ocean. Eventually, tectonic processes of high heat and pressure transform calcium carbonate sediments into limestone.

While the main source of calcium carbonate in the ocean comes from the shells of calcifying planktonic organisms, bony fish (rather than the cartilaginous sharks and rays) precipitate carbonates within their intestines and excrete these at high rates. It has been estimated that marine fish contribute 3 to 15% of total oceanic carbonate production and this helps provide a pH buffer against ocean acidification.[145] Essentially the biological carbon pump is complex and all species in the marine ecosystem play a role.


Sea butterfly in a marine research lab at Ny-Ålesund, Norway
© Nick Cobbing/Greenpeace


Krill in the Antarctic
© Christian Åslund/Greenpeace

Across the global ocean the mesopelagic community (see Mesopelagic, p29) is important in carbon sequestration because the foraging behaviour of many mesopelagic species moves carbon from surface to deeper waters. Mesopelagic organisms repackage organic carbon into faecal pellets that sink more quickly than the original material and fragment large, aggregated particles into small, slow-sinking particles.[146, 147] In the Southern Ocean, the huge numbers and biomass of Antarctic krill coupled with their behavioural patterns whereby krill undertake significant daily migrations through the water column, suggest that krill play an important role with respect to global carbon.[148, 149] The high density of individuals in krill swarms likely results in a 'rain' of faecal pellets (marine snow) which may overload detrital zooplankton that consume the faecal pellets, causing them to pass mostly undisturbed through the upper mesopelagic (i.e. the intermediate depths between 200m and 1,000m). This would explain the high numbers of krill pellets collected in sediment traps in the meso- and upper bathypelagic zones (i.e. down to 4,000m). Recent research shows that krill faecal pellets can make up a large component of the carbon flux in the South Orkneys marginal ice zone (MIZ) region in spring.[150]

The role that large vertebrates have in the cycling and sequestration of carbon in the marine environment is poorly understood, but research over the last decade is beginning to shed light on how vertebrate activity and natural life processes provide pathways, pumps and trophic cascades that enhance uptake and long-term storage of atmospheric carbon by plankton and facilitate transport of biological carbon from ocean surface to deep water and sediment.[151]

As large vertebrates move both horizontally and vertically through the marine environment, they are moving carbon. While carbon stored in the biomass of marine vertebrates is viewed as 'temporary carbon', the largest and the longest-lived of these animals, such as baleen whales, store carbon over equivalent centennial timescales to trees on land. Andrew Pershing and colleagues have estimated that populations of large baleen whales now store 9.1×10^6 tonnes less carbon than before commercial whaling and that rebuilding whale populations would remove 1.6×10^5 tonnes of carbon each year through sinking whale carcasses (see Whale falls, p32).[152]

Marine vertebrates also enhance the uptake of carbon by phytoplankton through 'biomixing', which describes the process of animals mixing water and nutrients as they move through the water column, which sometimes brings nutrients from the deep to otherwise nutrient-limited surface waters. According to William Dewar of Florida State University, loss of biomixing through decimation of populations of big fish and whales over the past couple of centuries could have had effects on our climate.[153]

Large whales are particularly important 'ecosystem engineers', helping maintain healthy ecosystems through the redistribution of nutrients both vertically and horizontally through the ocean.[154] When whales return to the surface from feeding at depth, the faecal matter they release in shallow water supplies iron and nitrogen to microorganisms there. This is known as the 'whale pump'. A similar process called the 'great whale conveyor' also operates whereby some species of whale, such as humpback whales, redistribute nitrogen and other nutrients from their rich feeding grounds near the poles to their warmer, low latitude, nutrient-poor breeding and calving grounds through release of their urea, dead skin cells and placentas. Through these processes whales may help to buffer marine ecosystems from destabilizing stresses and enhance rates of productivity in locations where they aggregate to feed and give birth.

Studies of coastal vegetative ecosystems (seagrass, saltmarsh and mangroves) that capture and store atmospheric carbon have pointed to the critical importance of predation by grazing animals in maintaining and increasing reserves of blue carbon.[155] Although the roles of top predators in the carbon and other biogeochemical cycles are largely unquantified, the movement of marine species such as billfish, tuna, sharks and rays, which often travel great distances across the ocean and may dive deep into the meso- and even bathypelagic realms, suggest it is likely that they, like mesopelagic fish and whales, also influence carbon cycling in the open ocean.[156]

Although scientific uncertainties surrounding quantitative estimates of carbon storage within many open-ocean and deep-sea ecosystems remain high, it is without doubt that these ecosystems play an important and irreplaceable role in cycling and storing carbon over short, medium and long timescales. It should also be noted that the amount of carbon in the ocean, and the amount that is sequestered in sediments, varies spatially and temporally. Carbon cycling is highly dynamic, and some areas of the seabed can be either a net sink or source of carbon depending upon season, sea surface temperature, ocean currents and turbulence from storms. For this reason, more research, including long-term and more geographically comprehensive monitoring, is needed to fully understand the processes that drive these changes.[157]


Humpback whale, Indian Ocean
© Paul Hilton/
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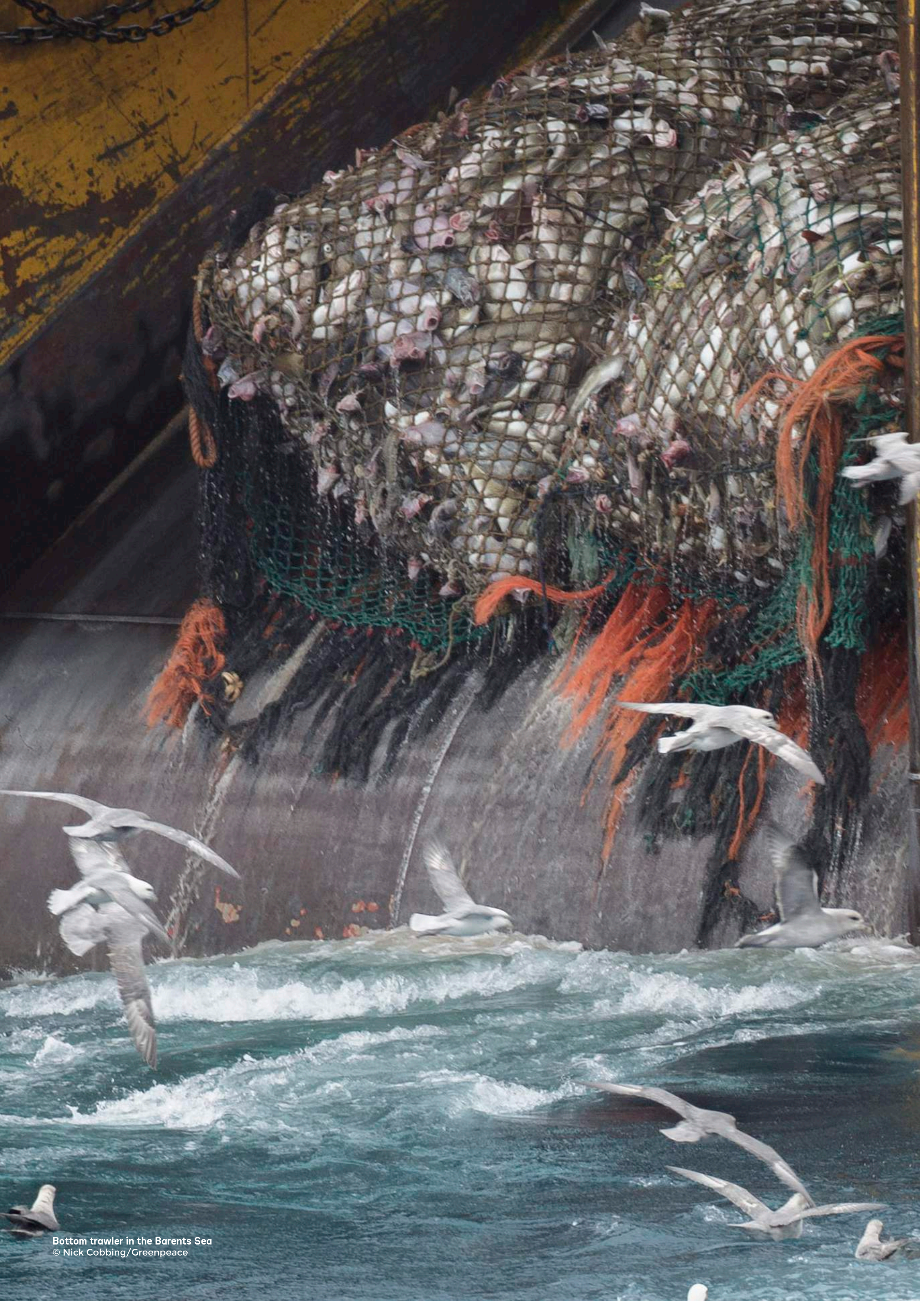
Bottom trawler in the Barents Sea
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PRESENT STATUS OF THREATS ON THE HIGH SEAS

Despite their vast expanse, the high seas face increasing impacts from a range of human activities including fishing, shipping, chemical, plastic and noise pollution, deep-sea mining and bioprospecting, plus the massive problems related to climate change and ocean acidification. In 2008, Ben Halpern and colleagues developed an ecosystem-specific, multiscale spatial model to synthesise 17 global data sets of anthropogenic drivers of ecological change for 20 marine ecosystems, which showed that no area of the sea is unaffected by human influence and a large fraction (41%) is strongly affected by multiple drivers.[158] The study showed that areas of highest human impact were coastal waters of the most industrialised regions such as the North Sea, with high latitude waters around the poles less impacted, although here too shipping, fishing and climate change are causing deleterious effects.

Fishing on the high seas

Marine fisheries provide food, employment, livelihoods and wealth and play a hugely important role in global food security, both directly as a source of essential nutrients and also indirectly as a source of income for food.[159] However, a recent analysis of high seas catches and trade data to determine the contribution of the high seas catch to global seafood production shows that the total catch from the high seas accounts for only 4.2% of annual marine capture fisheries production.[160] Furthermore, the fishing fleets that operate in ABNJ are dominated by vessels belonging to industrial corporations from wealthy countries.[161, 162]

THE GLOBAL FISHERIES CRISIS

"Commercial overexploitation of the world's fish stocks is severe, with many species hunted down to fractions of their original populations. More than half of global fisheries are exhausted, and a further third are depleted," said UN Secretary General Ban Ki-moon in May 2012.[163] The precarious state of global fisheries is widely recognised, with the Food and Agriculture Organization (FAO) stating that the percentage of stocks fished at biologically unsustainable levels increased from 10% in 1974 to 33.1% in 2015.[164] Furthermore, the FAO notes that stocks fished at levels corresponding to the Maximum Sustainable Yield (sometimes referred to as fully fished stocks) accounted for 59.9% and (so-called) underfished stocks for 7.0% of stocks assessed.

The FAO estimated that total capture production in marine waters was 81.5 million tonnes in 2014, a slight increase on the previous two years, but, as Daniel Pauly and Dirk Zeller's catch reconstructions have revealed, there are major flaws in the FAO's methods and global marine fisheries catches are higher than reported and declining.[165, 166] Pauly and Zeller's work with the 'Sea Around Us' project suggests a degradation of marine fisheries and, if trends continue, a crisis in the status of fisheries resources by mid-century.[167] The most recent FAO estimate puts the world total marine catch at 79.3 million tonnes in 2016, representing a decrease of almost 2 million tonnes from the estimated 81.2 million tonnes in 2015.[168]

Unfortunately, overfishing and destructive fishing practices have had a massively detrimental impact on global fish populations and marine ecosystems, including those in the high seas. Multiple drivers have caused the massive changes in the global fishing industry over the past century leading to the current global fisheries crisis. The ever-growing demand for seafood, a consequence of both a growing global population and the result of increased economic development and living standards, whereby wealthier parts of society are able to buy more fish, is a major driver. Furthermore, the additional demand for fishmeal and fish oil to supply the expanding aquaculture industry and produce livestock feeds looks set to increase.[169] To satisfy these demands there has been a massive increase in fishing effort, enabled in part by the adoption of ever more advanced technologies such as freezer trawlers, radar and acoustic fish finders and support from satellite sensors.[170] Transhipment, whereby a fishing vessel offloads its catch onto another fishing vessel or an auxiliary refrigerated vessel (known as a 'reefer') at sea, enables it to continue fishing rather than returning to port, and so contributes to overfishing. Transhipment can also facilitate illegal, unreported and unregulated (IUU) fishing by obscuring the origin of catches and masking illicit practices. In the worst instances, transhipment enables slavery at sea, as crews can be kept at sea for months or even years at a time without getting back to a port.[171]

The findings of an analysis of global fishing capacity and fishing effort from 1950–2012 show that both have continued to rise in number, particularly in Asia and the developing nations.[172] When viewed against landings data, this increase in capacity and effort suggests a considerable reduction of overall efficiency of the global fishing fleet as fishing efficiency, in terms of tonnes of wild caught marine landings per watt day of fishing effort, is now less than it was in 1950, despite the technological advances and the expansion of fishing into new waters over that period.

The second half of the 20th century saw a huge geographical expansion of marine fisheries, including into offshore waters, partly spurred by the depletion of fisheries in coastal waters. A 2010 study highlighted the global scale of this expansion, from the coastal waters of the North Atlantic and West Pacific to the waters in the Southern Hemisphere and into the high seas.[173] The southward expansion of fisheries occurred at a rate of almost one degree latitude per year, with the greatest expansion in the 1980s and early 1990s. This was primarily driven by increased open-ocean fishing, until that slowed down in 2005, at which point only the most inaccessible and least commercially viable waters such as the South Atlantic and polar oceans had relatively few fishing vessels.

In early 2018, researchers from Dalhousie University in a partnership with Global Fishing Watch, The University of California, Stanford University, National Geographic Society, SkyTruth and Google produced the first-ever dataset of global industrial fishing activities derived from satellite-sensed automatic identification system (AIS) positions, machine learning and computing power.[174] The data revealed that at least 55% of the ocean is covered by fishing activities, a global footprint that is at least four times as large as that of agriculture, and it was estimated that fishing vessels travelled more than 460 million kilometres in 2016 – a distance equivalent to going to the moon and back 600 times.[175]

Whale shark caught as bycatch by a purse seiner in the Pacific
© Greenpeace

DEPLETION OF PREDATORY FISH

Not only are many target species overfished but many modern fishing methods are highly destructive, damaging marine habitats and often killing countless marine organisms as bycatch. One of the most startling impacts on ocean ecosystems of the massive expansion of fishing capacity and effort over the past century is the reduction in biomass of large, predatory fish. A team of scientists interested in determining the scale of this decline conducted an analysis of more than 200 published food-web models from all over the world, which included more than 3,000 species, and found that in the 20th century humans reduced the biomass of predatory fish by more than two-thirds and that most of this alarming decline has occurred since the 1970s.[176] Concurrent with declines in larger predatory species has been an increase in smaller prey fish, showing fishing down of food webs.

It is only recently through new technologies such as satellite tracking and the use of AIS and vessel monitoring systems (VMS) that it has been possible to determine the composition of the high seas fishing fleet. The four most commonly used fishing gears in the high seas are: longlines, purse seine, squid jiggers and trawls, with six fishing powers (China, Taiwan, Japan, Indonesia, Spain and South Korea) accounting for 77% of the global high seas fishing fleet and 80% of all AIS/VMS-inferred fishing effort.[177]

Longlines can be up to 100km in length and carry several thousand baited hooks. By contrast, a purse seine is a net set around a school of fish which is drawn up beneath them like a traditional purse. Tuna fishing on the high seas takes high levels of unwanted, unmanaged or discarded bycatch. Precise estimates of bycatch are difficult to quantify for the high seas because of the difficulties of collecting data due to poor observer coverage, especially in longline operations.

Above water, longline fisheries have been estimated to kill 50,000–100,000 seabirds annually despite implementation of mitigation methods and massive reductions in some fisheries, most notably in the Southern Ocean.[178] Of 61 species of seabirds affected by longline fisheries, 26 are threatened with extinction, including 18 of the 22 species of albatross.[179] Sea turtles, marine mammals, elasmobranchs (sharks and rays) and at least 650 species of bony fish also get caught on longline fishing gear.

The global tuna fishery is very large, with annual catches of tuna and tuna-like species levelling off at around 7.5 million tonnes after a maximum peak in 2014.[180] The seven most economically important species of skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacores*), albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*) and bluefin (*Thunnus orientalis, Thunnus thynnus, Thunnus maccoyii*) are traded globally and, based on information gathered on tuna fisheries and markets for 2012 and 2014, believed to contribute at least US$42bn in end value to the global economy each year.[181] Purse seines are the most commonly used to catch tuna, and helicopters, bird sonar, GPS and drones are used to help boats to locate schools around which to set the nets. In addition, fish aggregating devices (FADs) are widely used to attract tuna and other target species which concentrate around them for the ease of fishing. FADs are simply floating objects such as logs or mats of seaweed and it has been estimated that between 81,000 and 121,000 of them were deployed globally in 2013, with at least a fourfold increase in both the Atlantic and Indian Oceans in the seven years between 2007 and 2013.[182, 183] Various negative impacts, including exacerbation of overfishing, high catches of juvenile tunas, high bycatch of vulnerable species such as turtles and sharks, modification of tuna habitat and the introduction of litter into the ocean are all associated with tuna fishing using FADs. May Lim and a group of researchers in the Philippines have modelled the effect of FADs in the western Pacific and concluded that "when the fishery is already overfished, using FADs can only accelerate fisheries collapse".[184]

As fisheries expanded further into the high seas, fishing gear reached into increasingly deeper waters, creating a linear increase in the mean depth of fishing of 62.5m per decade, corresponding to an increase of about 350m for the period since 1950.[185] Bottom trawling, which involves dragging a large net and heavy gear across the sea floor, is generally considered the most destructive fishing method and is known to significantly impact fragile deep-sea habitats.[186] Slow growing and slow to reproduce deep-sea species such as pelagic armourhead (*Pseudopentaceros wheeleri*), orange roughy (*Hoplostethus atlanticus*), alfonsino (*Beryx splendens*), oreos (*Pseudocyttus maculatus, Allocyttus niger*) and grenadiers (*Coryphaenoides rupestris*) have all been targeted by this method, often with catastrophic results.[187] As an analogy, deep-sea bottom trawling is often compared to clear-cutting forest on land because both indiscriminately remove everything in their path, in the case of trawling destroying thriving communities that would have contained animals such as corals, sponges, sea stars, sea cucumbers and anemones.[188] Research published in the *Proceedings of the National Academy of Sciences* has also noted the potential consequences of deep-sea trawling on biogeochemical cycles and concluded that it "represents a major threat to the deep seafloor ecosystem at the global scale".[189] Since 2006, a number of UN General Assembly Resolutions have called on States to stop authorising bottom fisheries on the high seas unless sufficient action has been taken to prevent damage to vulnerable marine ecosystems and to ensure that fisheries targeting deep-sea fish stocks are being managed sustainably. A review of the implementation of these resolutions in 2016 shows that significant shortcomings remain, leaving many areas containing vulnerable marine ecosystems open to trawling and many deep sea-species depleted.[190]

As FAO statistics demonstrate, the world's fisheries are in a poor state. Ineffectual fisheries management is partly responsible, with high seas fisheries management failing due to a highly complex and fragmented governance regime which among other things is too slow and unwieldy to keep up with changes in fisheries practice.[191] In particular the RFMOs which manage particular fisheries in their appointed regions have shown poor performance. This can be attributed to factors such as: lack of fishing compliance with international rules, lack of enforcement capability, excess capacity and inappropriate subsidy of fishing fleets, prioritisation of short-term economic interest over long-term conservation and a lack of political leadership to engage effectively in multilateral cooperation.[192] An evaluation of the world's 18 RFMOs noted they have "failed to contribute through consultation and cooperation to the optimal utilisation, rational management and conservation of the fishery resources of the Convention area".[193] In a study which examined how RFMOs measure up with respect to bycatch governance, it was found there has been nominal progress in transitioning to an ecosystem approach to fisheries management, including accounting for broader, indirect ecosystem-level effects of bycatch mortality.[194] While almost all RFMOs have conservation as part of their mandate, the priority of their membership has been for exploitation.

As well as the unsustainable fishing that takes place under the auspices of RFMOs there is also the problem of illegal, unreported and unregulated fishing or IUU fishing. This practice of illegal fishing encompasses activities that violate national, regional or international laws such as fishing out of season; harvesting prohibited species; using banned gear or techniques; catching more than a set quota; and fishing without a licence. Unreported fishing is that which is not declared, or is misreported, to the relevant authority or RFMO. Unregulated fishing relates to fishing in areas where no regulations for this occur or on unregulated stocks, as well as the activities of vessels that are not flagged to a state. The unregulated category also includes the non-party problem whereby states which carry out high seas fishing fail to participate in governance arrangements for where they fish, effectively 'freeloading'. In relation to this, it is worth noting that as of July 2018, there are 168 Parties to UNCLOS yet only 89 signed up to the provisions of the UN Fish Stocks Agreement (UNFSA), which establishes general principles including an ecosystem approach, and specifically mandates the application of the precautionary approach to fisheries conservation and management.[195] In addition to the environmental problems of IUU fishing, the practice also has far-reaching social consequences that disadvantage legal fishers and can be associated with terrible practices such as slavery at sea and other criminal acts. Global losses from IUU fishing have been estimated at between US$10bn to US$23.5bn annually, which is between 10 and 22% of total fisheries production.[196] The problem of IUU fishing has received growing attention over recent years and there have been some positive moves, most significantly with the 2009 Agreement on Port State Measures to prevent, deter and eliminate IUU Fishing which entered into force on 5 June 2016.[197]

The negative impacts of overfishing and the use of destructive fishing practices are being keenly felt across the globe, including in the high seas. Kristina Gjerde and colleagues note that the downward spiral of ocean health is the result of the combined and cumulative impacts of various human activities and so fishing needs to be considered in the wider context of the earth processes and life-systems that a healthy marine environment supports.[198] This is one reason why they see a new implementing agreement for the conservation and sustainable use of biodiversity in areas beyond national jurisdiction as a lynchpin for driving reform in high seas fisheries management.

> "WITHOUT (SUBSIDIES) AS MUCH AS 54% OF THE PRESENT HIGH SEAS FISHING GROUNDS WOULD BE UNPROFITABLE AT CURRENT FISHING RATES"

Suggestions to improve fisheries management on the high seas have identified the need to include fish demography and ecology (including population genetics, environmental relationships and interspecific interactions) into the process alongside consideration of spatial movements and strategies of international fishing fleets.[199, 200] Highly protected marine reserves also need to play a part in proceedings as, when added to existing fishery management measures, they can help foster sustainable catches (see Fisheries benefits, p63).

Generally speaking, high seas fishing vessels travel longer distances, spend longer searching for fish, and therefore burn more fossil fuels and incur a higher cost per unit weight of fish caught than vessels fishing solely within EEZs.[201] The carbon footprint of different fisheries varies enormously and has rightfully become a subject for study, with calls for this aspect to be incorporated into seafood sustainability certification schemes and eco-labels.[202]

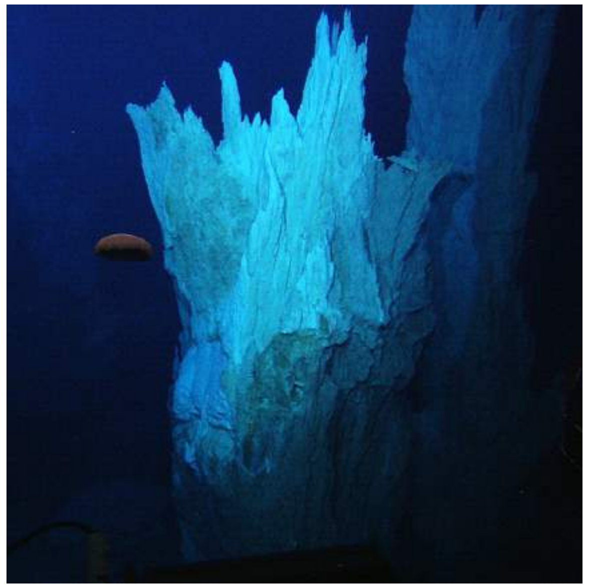
In 2018, a significant paper was published which characterised the global high seas fleet in in detail and estimated the economic benefit of high seas fishing.[203] Using recently available satellite data and developments in machine learning, the authors tracked individual vessels on the high seas in near real-time, which had not previously been possible. Using reconstructed estimates of the global fishing catch and its landed value, the costs of fishing based on satellite-inferred fishing effort and vessel characteristics, and estimates of government subsidies, the researchers constructed a comprehensive picture of the profitability, or not, of high seas fishing. Results suggest that high seas fishing at the current scale is enabled by large government subsidies, without which as much as 54% of the present high seas fishing grounds would be unprofitable at current fishing rates. While profitably varies widely between countries, types of fishing and distance to port, deep-sea bottom trawling emerged as highly dependent on subsidies.

Taking a broad approach and combining our understanding of the various aspects of high seas fishing, there is a compelling case for radical changes to the current complex, fragmented and largely failing management regime.

Deep seabed mining

One of the important discoveries of the *HMS Challenger* expedition (1872–1876) was that polymetallic nodules were found to occur in most oceans of the world.[204] This led the expedition chemist John Young Buchanan to speculate on their possible future value.[205] Since then, interest in the possibility of mining minerals from the deep ocean has waxed and waned over time. A burst of interest in the 1960s following the publication of *The Mineral Resources of the Sea* by American geologist John L. Mero, which suggested the ocean could supply the world's mineral needs. This in turn inspired Ambassador Arvid Pardo of Malta to deliver a speech to the First Committee of the UN General Assembly, in which he called for resources of the deep seabed to be designated as the "common heritage of mankind".[206] As part of this Pardo urged for international regulation to prevent more technologically advanced countries from colonising and monopolising deep seabed resources to the detriment of developing states. After this the process began which led to the eventual formation in 1994 of the International Seabed Authority (ISA), the body established under the UNCLOS to regulate seabed mining activities in 'the Area', i.e. "the seabed and ocean floor and the subsoil thereof, beyond the limits of national jurisdiction".

Today three major types of mineral deposit are of interest to states and companies looking to develop deep seabed mining (DSM). These deposits are: seafloor polymetallic sulfides located around hydrothermal vents, cobalt-rich crusts found on the margins of seamounts, and fields of manganese nodules distributed on abyssal plains.[207] These mineral deposits cannot be considered in isolation of the distinctive, and in some cases unique, assemblages of associated marine species. Indeed, vulnerable marine ecosystems (VMEs) are known to occur in many of the regions identified for future seabed mining.



Lost City vent field
©NOAA/OAR/OER

While there are differences in extraction technology and methods used between different deep-sea mineral types and projects, seabed mining actions that may cause harmful effects include:[208]

- → Direct removal of seafloor habitat and organisms
- → Alteration of substrate and its geochemistry
- → Modification of sedimentation rates and food webs
- → Creation of changes in substrate availability, heterogeneity and flow regimes
- → Release of suspended sediment plumes
- → Release of toxins and contamination from extraction and removal processes
- → Noise pollution
- → Light pollution
- → Chemical leakage from mining machinery

A recent scientific analysis – *Deep-Sea Mining with No Net Loss of Biodiversity – An Impossible Aim* – demonstrates that biodiversity loss from DSM will be unavoidable and that mining with no net loss of biodiversity is an unattainable goal.[209] The authors also point out that ecological consequences of deep-sea biodiversity are unknown and will have inter-generational consequences, making it hard to see how DSM can be socially or scientifically acceptable.

Over the last decade DSM has moved from being a much-discussed concept towards becoming a practical reality. This is due to massive technological advances taken from developments in the offshore oil and gas industries. Furthermore, advocates of DSM have argued that the economics of the practice is becoming increasingly viable due to a growing demand for the various minerals that can be derived from the deep ocean and an expected reduction in supply of high-grade ores from terrestrial mines. While both the growing consumer appetite, especially in developing countries, for tech items and the rapid growth in the renewable energy sector – which utilises copper and other metals as well as rare earth elements (REEs) found in high-grade deposits in the deep sea – are used to argue for investment in DSM, notable experts believe that demand can be satisfied without exploiting deep-sea mineral resources. For example, conservation biologist Richard Steiner proposes reducing the demand for raw materials through better (eco-) product design, sharing, repairing and better re-use of goods, recycling and landfill mining. Fundamental changes towards smart energy and mobility systems are needed so that consumption of such minerals is reduced.[210] In 2016, an authoritative report from the Institute of Sustainable Futures in Sydney provided evidence to dispel the claim that deep-sea mining is vital to the development of renewable energy technologies necessary to combat climate change.[211] The report, *Renewable Energy and Deep-Sea Mining: Supply, Demand and Scenarios*, found that projected demand for silver and lithium to 2050 will take up just 35% of known terrestrial resources so can easily be met from existing supply. The demand for other metals – copper, cobalt, nickel, specialty and rare earth metals – is less than 5% of the existing and accessible resources. Production of silver, lithium and some rare earth metals will need to expand as the world 'scales up' the use of renewable energy, but increased recycling could help meet the demand for these metals. The report concludes that "even with the projected very high demand growth rates under the most ambitious energy scenarios, (i.e. a 100% renewable energy economy globally by 2050), the projected increase in cumulative demand – all within the range of known terrestrial resources – does not require deep-sea mining activity".

Many countries and private corporations have a specific policy objective to ensure a secure long-term supply of raw materials. This policy may, to some extent, explain the increasing interest in rapidly developing the DSM industry.

This surge in interest for DSM is reflected in the number of exploration leases issued by the ISA. Originally, six 'pioneer claims' for minerals exploration were issued in 1984, each relating to an area of 75,000km^2. Those claims transferred into official leases when the ISA became a legal entity 10 years later, following the 1994 Agreement relating to the Implementation of Part XI of the UNCLOS. The ISA issued no further leases until 2011, the year that the ISA completed regulations governing exploration. Currently the ISA has issued 29 exploration leases for polymetallic nodules and sulphides and cobalt-rich ferromanganese crusts in the deep seabed. Seventeen of these contracts are for exploration for polymetallic nodules in the Clarion-Clipperton Fracture Zone (16) and Central Indian Ocean Basin (1). There are seven contracts for exploration for polymetallic sulphides in the South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge, and five contracts for exploration for cobalt-rich crusts in the Western Pacific Ocean.[212]

Before any commercial mining can take place in 'the Area', the ISA has to complete the Mining Code. The Mining Code is the comprehensive set of rules, regulations and procedures that will regulate all the aspects of deep seabed mining – prospecting, exploration and exploitation – in the international seabed Area. The exploitation regulations are not the only part of the framework that still needs to be developed: in addition, the ISA needs to further develop proposals on the level of fees and royalties that contractors will have to pay, and most importantly the ISA will need to put in place robust environmental safeguards.

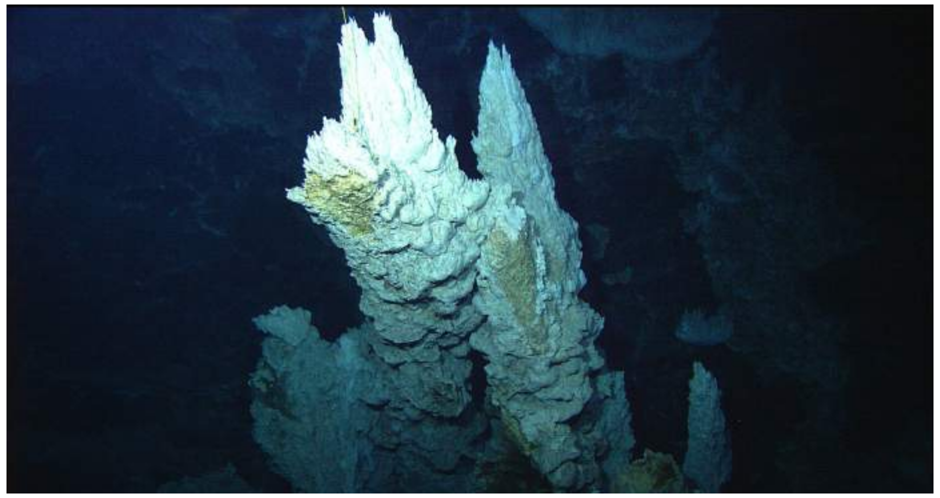
The Deep Sea Conservation Coalition (DSCC) is a coalition of over 80 non-governmental organisations concerned with protection of the deep sea. DSCC has been an observer organisation to the ISA since 2014. In the DSCC briefing for the 24th Session of the ISA, it notes that in order to keep in line with the UN 2030 Agenda, the priority global approach to the consumption of mineral resources should be one of sustainability, reuse, improved product design and recycling of materials.[213] If DSM is permitted to occur, the DSCC states, it should not take place until appropriate and effective regulations for exploration and exploitation are in place to ensure the effective protection of the marine environment, and that the full range of marine habitats, biodiversity and ecosystem functions is protected, including, but not limited to, establishment of a network of MPAs and reserves. In April 2018, 50 NGOs from across the globe called on the ISA to substantially reform its operations and establish a process to debate fundamental questions about the need for DSM and its long-term consequences for the planet and humankind.[214] Furthermore, the ISA should undertake a full assessment of more sustainable alternatives and ensure the findings are fed into the debate in an open and transparent manner. In the meantime, the ISA should stop granting contracts for deep-sea mining exploration and not issue contracts for exploitation.

While steps need to be completed before any deep sea mining can occur in international waters, it should be noted that Japan Oil, Gas and Metals National Corp (JOGMEC) has successfully deployed excavators to extract ore rich in zinc, gold, copper and lead from depths of 1,600m in waters close to Okinawa within the EEZ of Japan.[215] Another venture, the Solwara-1 project, is also currently underway in Papua New Guinea's waters by a Canadian company called Nautilus, although this has repeatedly experienced setbacks from financial troubles. Nautilus shares hit a new low on 23 July 2018, days after the company announced that it had received a loan from Deep Sea Mining Finance for US$650,000, under a previously announced credit facility of up to US$34m between the company, two of its subsidiaries and the lender. This reflects the high risks associated with DSM for investors.[216, 217]

At present, DSM activities are regulated differently depending on whether they are in the Area (under ISA rules) or on continental shelf areas (under a diversity of national jurisdictions); this should be harmonised to avoid inconsistent, fragmented regulation within regions.[218] Furthermore, activities impacting the seabed cannot be managed without consideration of the overlying waters or other stressors such as ocean acidification, climate change and pollution.[219]

LOST CITY HYDROTHERMAL FIELD

Discovered in 2000 during a National Science Foundation expedition to the Mid-Atlantic Ridge by the research vessel *Atlantis*, Lost City has elicited much excitement in the scientific community due the fact that this hydrothermal vent field is characterised by a combination of extreme conditions never seen before in the marine environment.[220] Named for its spectacular array of actively venting, chalky chimneys that resemble an abandoned metropolis, as well as the name of the research vessel and its location, ~800m under the waves near the summit of the Atlantis Massif seamount, which itself rises 4,267m from the seafloor, Lost City is packed with unusual life forms.[221, 222]



Carbonate spires in the Lost City vent field
©NOAA/OAR/OER

> "SCIENTISTS HAVE WARNED THAT ANY MINING RISKS DESTROYING THIS UNIQUE ECOSYSTEM BEFORE IT IS PROPERLY UNDERSTOOD"

Lost City is a 'white smoker', (see Hydrothermal Vents p35), the result of seawater trickling deep into the massif where it reacts with magnesium-rich mantle rock (peridotite) that is 1.5 million years old. The reaction releases heat and dissolves some of the minerals in the rock to form hot, alkaline water which can reach 90°C and pH 9–10.8. This then rises from fractures in the sea floor, visible as white plumes. When this hot water, rich in calcium, methane and hydrogen mixes with cooler seawater, it results in carbonate precipitation and the growth of tall chimneys, graceful pinnacles, fragile flanges and beehive-shaped deposits.[223] The core of the Lost City Hydrothermal Field is dominated by Poseidon, an active chimney which towers 60m above the seafloor and is 15m in diameter at its top, making it the largest vent structure discovered so far. Dating shows Lost City to be the most long-lived submarine hydrothermal system known in the world's oceans, with carbon dating indicating that venting has been ongoing for at least 30,000 years, with individual chimneys active for at least 300 years, and modelling results suggesting that the system could remain active for up to one million years.[224]

The carbonate chimneys of Lost City are packed full of microbes, their porous interior walls harbouring biofilms dominated by a single phylotype of archaea (microbes that have no cell nucleus) which subsist on hydrogen and methane, whereas the outer walls of the chimneys, where the chemistry is different, are packed full of bacteria which oxidise sulphur and methane to produce energy.[225] While the biomass of larger forms of marine life is lower than at most vent sites, the large surface area and highly sculpted forms of the Lost City structures provide multiple pores, cracks and crevices for small creatures to make their home, though many have transparent or translucent shells making them difficult to see with a ROV. Several species of gastropod and amphipod dominate the active chimneys, while rarer, larger animals include crabs, shrimp, sea urchins, eels and a diverse array of corals. A 2005 assessment at Lost City shows that ~58% of the fauna are endemic.[226]

Alkaline hydrothermal vents, similar to Lost City, have been suggested as the birthplace for life on Earth and has attracted the interest of the US National Aeronautics and Space Administration (NASA) who are interested in the vent field's chemistry to help them identify the chemical signatures that might indicate the possibility of life on other planets and moons.[227]

The Lost City's rarity and importance has been recognised by the international community as an EBSA, and UNESCO has recognised its outstanding universal value in discussing potential World Heritage Sites in the high seas.[228] However, mining companies and some governments have a growing interest in extracting minerals and metals from the seabed on the Mid-Atlantic Ridge in the vicinity of Lost City. The Government of Poland was granted a 15-year licence on the 12 February 2018 by the ISA to explore a 10,000km^2 area, which includes Lost City, for polymetallic sulphides.[229]

Scientists have warned that any mining risks destroying this unique ecosystem before it is properly understood and some have suggested that the precautionary approach be applied and all active vents protected from both direct and indirect mining impacts on account of their vulnerability, their individual and potentially equal importance, as well as their outstanding cultural and scientific value to all humanity.[230, 231]

Bioprospecting

Bioprospecting is the search for biochemical and genetic material in nature from which commercially valuable products can be developed, with application in pharmaceutical, agricultural, and cosmetic industries and other applications. The process has gone through rapid expansion in recent years with the marine environment providing a massive reservoir of marine genetic resources (MGR) for the industry to explore.[232] A recent study by the Stockholm Resilience Centre has found that 47% of the patents associated with MGR have been registered by a single transnational corporation (BASF, the world's largest chemical manufacturer) and that 98% of the patents associated with MGR are held by entities located in just 10 wealthy countries.[233]

The study also revealed that a considerable portion of marine patent sequences (11%) are derived from species associated with deep-sea and hydrothermal vent ecosystems. Because organisms in these environments have to withstand extreme conditions (high pressure, high or low temperature, and high concentrations of inorganic compounds) depending on their key habitat, most have evolved physiological characteristics that will enable them to cope with the conditions. It is these specific traits that are coded for within the genomes of these organisms (often called 'extremophiles') that are often the focus of interest for bioprospectors. For example, the chemical, food, pharmaceutical, paper and textile industries are interested in thermostable enzymes present in the deep sea, some of which can withstand temperatures in excess of 90°C.[234]

While bioprospecting for MGR offers potential socio-economic benefits, it simultaneously poses a significant environmental threat to targeted organisms and their habitats which may be highly vulnerable to overharvesting, habitat disturbance, alteration of local hydrological and environmental conditions (including introduction of alien species) and pollution.[235]

At present there is an absence of clear rules governing the use of deep seabed genetic resources and there are major issues around the access to these resources and how the benefits of research or economic value should be distributed.[236] Establishing a legal framework for the access and benefit sharing of MGR is a fundamental issue during international negotiations on a new Global Ocean Treaty.

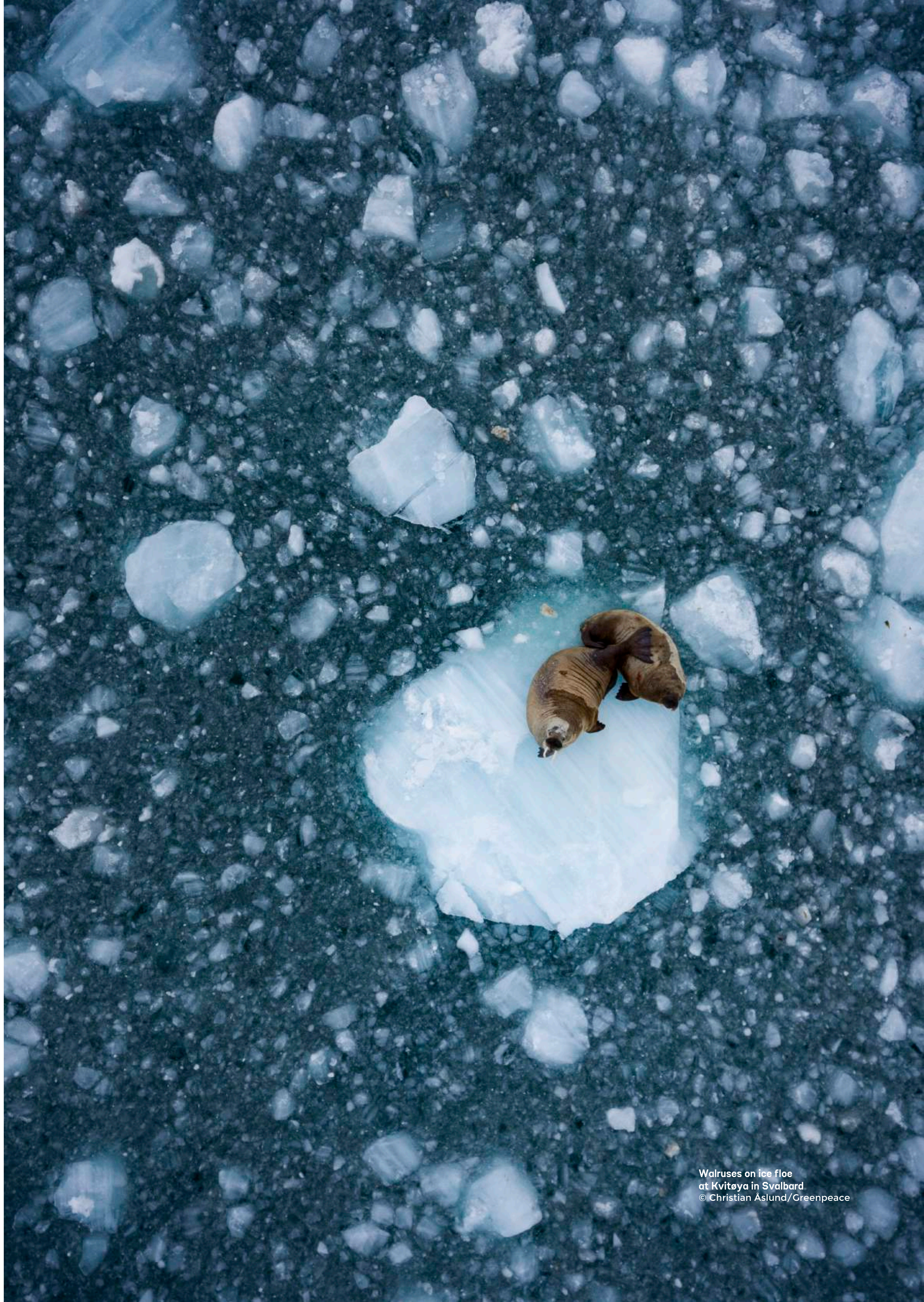
Climate change

In its 2014 summary for policy makers the International Panel for Climate Change (IPCC) boils down the impacts of climate change on marine systems over the next few decades to the text set out below, attributing degrees of confidence to the various broadscale predictions.[237]

> "Due to projected climate change by the mid-21st century and beyond, global marine-species redistribution and marine-biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem services (*high confidence*). Spatial shifts of marine species due to projected warming will cause high-latitude invasions and high local-extinction rates in the tropics and semi-enclosed seas (*medium confidence*). Species richness and fisheries catch potential are projected to increase, on average, at mid and high latitudes (*high confidence*) and decrease at tropical latitudes (*medium confidence*). [See Figure SPM.6A.] The progressive expansion of oxygen minimum zones and anoxic "dead zones" is projected to further constrain fish habitat. Open-ocean net primary production is projected to redistribute and, by 2100, fall globally under all RCP[i] scenarios. Climate change adds to the threats of over-fishing and other non-climatic stressors, thus complicating marine management regimes (*high confidence*)."

The text, though sobering, does not fully convey the scale and scope of the changes being wrought on the ocean by climate change. The annual emission of gigatons of carbon into the atmosphere has led to a multitude of physical changes including increasing global temperature, perturbed regional weather patterns, rising sea levels, changed nutrient loads and altered ocean circulation.[238] Furthermore, because oceanic and atmospheric gas concentrations tend towards equilibrium, increasing levels of atmospheric CO_2 drives more CO_2 in to the ocean, leading to profound changes in ocean chemistry (see Ocean acidification, p55).

The ocean absorbs almost as much CO_2 as all land-based forests and plants combined, and absorbed about 93% of the combined extra heat stored by warmed air, sea, land and melted ice between 1971 and 2010.[239] While the upper-ocean temperature (and hence its heat content) varies over multiple time scales, including seasonal, inter-annual (such as those associated with the El Niño-Southern Oscillation), decadal and centennial periods, all ocean basins have experienced significant warming since 1998, with this greatest in the southern oceans, the tropical/subtropical Pacific Ocean and the tropical/subtropical Atlantic Ocean.[240, 241] Over the period 1971 to 2010, the upper 75m warmed by 0.11°C [0.09 to 0.13°C] per decade.[242] As



Walruses on ice floe
at Kvitøya in Svalbard
© Christian Åslund/Greenpeace

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[i] A Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC for its fifth Assessment Report (AR5) in 2014.

waves, tides and currents constantly mix ocean waters, so heat is transferred from warmer to cooler latitudes and to deeper levels, with most of the heat absorbed in the upper 700m. The heat absorbed by the ocean is moved around the planet but is not lost to Earth. The dynamic relationship between the ocean and the atmosphere means that some of that heat will directly reheat the atmosphere and heat already stored in the ocean will eventually be released, committing additional planetary warming in the future.[243]

Climate change case study: The Arctic

The Arctic is responding to climate change more rapidly, and likely more severely, than anywhere else on Earth. Polar seas are particularly vulnerable to climate change due to their sensitivity to sea-ice retreat.[244] Ice sheets at both poles have reduced in size and mass as a result of climate change and this, together with glacier melt and thermal expansion of seawater, is leading to sea level rise at the rate of about 3mm per year.[245] In the Arctic, the Greenland Ice Sheet has been retreating at an unprecedented rate and is directly contributing to sea level rise.[246] Summer temperatures in the Arctic Ocean are now 2–3°C warmer than the 1982–2010 mean and there has been a corresponding reduction in summer sea ice extent of nearly 50% from the late 1970s to 2017.[247] Declines in the extent and thickness of sea ice is exacerbated by a feedback loop whereby a smaller area of ice decreases the global albedo, where less heat is reflected back from the surface which leads to further thawing of the permafrost. Added to this, thinner and less compact ice is more vulnerable to breaking up from strong winds. Overall there has been a fundamental shift in the Arctic sea ice regime, from one which was dominated by thick, multi-year ice to one controlled by thinner, more dynamic, first-year ice.

The Arctic Ocean is changing in other ways. Analysing data obtained from tethered moorings, researchers have found that warm water from the Atlantic, which has traditionally been separated from melting ice because of the halocline layer, namely a barrier that exists between deep salty water and fresher water closer to the surface, has been penetrating the barrier into Arctic waters causing the ice to melt from below.[248] This 'Atlantification' of the Eurasian Basin of the Arctic Ocean helps explain the rapid decimation of Arctic ice and is also likely to cause substantial biogeochemical and geophysical changes which will affect marine life of the region. For example, phytoplankton blooms may occur in new locations.

The changes described above, together with other issues such as a reduced nutrient flux from increased stratification caused by increased freshwater entering the Arctic Ocean, will all cause upheavals in Arctic marine ecosystems. As climate change can affect marine organisms through many different processes that are interlinked, there are likely to be many unanticipated changes.[249] Within food webs, climate change has affected primary productivity and the distribution, abundance and body condition of top predators. One of the most significant changes has been a shift from polar to temperate primary production patterns, with an increase of 30% in annual net primary production over the Arctic Ocean between 1998 and 2012.[250, 251]

Changes in primary productivity and planktonic communities can impact top predators and many iconic marine species. Little auks (*Alle alle*), known in the US as dovekies, have been found to make longer foraging trips in areas of the Atlantic where their preferred copepod prey items, the lipid-rich *Calanus glacialis* and *C. hyperboreus*, have been replaced by less nutritious *Calanus finmarchicus*. *Calanus finmarchicus* is a smaller copepod species and is more abundant in waters warmed by the increased inflow of waters derived in the Atlantic.[252] Changes in foraging behaviour, particularly where individuals have to make longer trips, expending more energy, can have population-level impacts on species that are yet to be fully understood.

Climate change impacts on ice-dependent marine mammals

The iconic Arctic marine mammals that are most closely associated with the sea ice are the narwhal, beluga, bowhead whale and the ice-dependent seals (for example the ringed, bearded, spotted, ribbon, harp and hooded seals), the walrus and the polar bear. A 2015 study investigated data relating to all populations of these Arctic marine mammals and the availability of suitable sea ice habitat for the circumpolar region except the central Arctic basin.[253] The authors found that for many sub-populations the population data are poor. These findings are not surprising given the wide distribution and cryptic behaviour of many species and the challenging logistics of surveying in the Arctic environment. This lack of baseline data makes it difficult to determine population trends. In the 2015 study, the researchers quantified loss of sea ice habitat based on timing of the seasonal change between winter and summer sea ice conditions and found significant trends in the dates of spring sea ice retreat and autumn sea ice advance for the period from 1979 to 2013. For all but one of the regions studied, the Bering Sea being the exception, researchers found profound changes to sea ice. The period of reduced summer ice was extended by 5–10 weeks and by more than 20 weeks in the Russian Barents Sea. Responses by Arctic marine mammals to these climate change driven changes in sea ice will vary and may even be positive in the short term for some species if ecosystem productivity increases.

For the ice-dependent (or pagophilic) seals, the timing of sea ice break-up is vital because they need sufficient time to wean their pups prior to it breaking up. Any shortening of the period of suitable pupping habitat can reduce pup survival rates. Ringed seals can only make their lairs in specific conditions in ice and snow. Pacific walrus forage in shallow waters using ice floes to rest. In recent years, as the summer ice retreats, walrus have been forming large colonies onshore earlier in the year than previously recorded. Potential overcrowding is a concern as it can lead to stampedes in which individuals are crushed and die.[254]

Polar bear in the Arctic
© Daniel Beltrá/Greenpeace

The polar bear, which is listed as vulnerable on the IUCN Red List of Threatened Species, is especially dependent on sea ice, using it as a platform from which to hunt, find a mate, and rear young. In short, the ice is a platform for the bear's entire life cycle.[255] To survive the extreme conditions of their Arctic home, polar bears have high energy demands which are satisfied by consumption of high-fat prey such as seals, which are relatively easy for the bears to find on sea ice.[256] However, changing sea ice conditions are causing bears to invest more energy into finding sufficient prey. The increased investment is affecting this species' finely tuned energy balance, with population-level impacts. For example, retreating ice in the Beaufort and Chukchi Seas is forcing bears to make marathon journeys, which is increasing mortality of polar bear cubs and putting immense stress on adults. One female polar bear is known to have swum for a record-breaking nine days straight, traversing 426 miles (687km) of water.[257] Climate change and reductions in summer sea ice are thought by scientists to be likely drivers for increasing numbers of polar bears occurring at four study sites on the west coast of Spitzbergen (Svalbard) and a site in east Greenland. In these places some bears appear to be adapting their feeding behaviour to changing environmental conditions and opportunistically predating on nests of barnacle goose, common eider and glaucous gull. In years when the bears arrive before the eggs have hatched, as many as 90% of nests may have been predated.[258] The long-term effects of this change in feeding behaviour are not fully understood, but the example illustrates a possible cascading ecosystem effect from climate change.

Fish populations on the move

The multiple environmental changes occurring in the Arctic Ocean due to climate change are likely to lead to significant changes in the distribution of various commercially important fish species. Changes are likely to be complex and non-linear, with indirect effects of climate on the food web likely to be important in addition to the direct effects of seawater temperature in determining areas of habitat suitability for fish species.

One possible effect of ice-free conditions in the Arctic Ocean is the potential for interchange of Pacific species into the Atlantic and vice versa, something that the cold temperatures and low nutrient levels of the Arctic Ocean have prevented for millennia.[259]

Paul Wassmann and colleagues produced a useful summary in 2011 of some of the observed changes that have occurred in the Arctic marine ecosystem as a result of climatic drivers.[260] The review addresses fish, birds and mammals, and notes that changes in distribution of some predators will be determined by the availability of preferred prey species. Observed changes to fish species collated by this study include the northward spread of Atlantic cod and their increased recruitment and length in the Barents Sea, and the replacement of cod by shrimp off west Greenland. The snake pipefish (*Entelurus aequoreus*) is another species that has made a northward range shift and it can now be found west of Svalbard. On the Pacific side, walleye pollock (*Gadus chalcogrammus*) has exhibited a northward range shift in the Chukchi and Bering Seas and the biomass of this species has increased in the Bering Sea. Whereas warming temperatures and ice changes in the Bering Sea have driven an increase in the spawning biomass of Greenland turbot (*Reinhardtius hippoglossoides*), they appear to have had the opposite effect on Pacific cod, which have decreased in abundance. Altered currents, warming and sea ice changes have impacted the snow crab (*Chionoecetes opilio*), which has decreased in the southern part of its range.

The main gateways into the Arctic Ocean by sub-Arctic species are through the Bering Straits for the Pacific organisms and through the Norwegian and Barents Seas for ones from the Atlantic. Six species, including Pacific cod, walleye pollock and Bering flounder (*Hippoglossoides robustus*), are recorded by the National Oceanic and Atmospheric Administration (NOAA) as recently having extended their ranges through the Bering Straits into the Beaufort Sea.[261] On the Atlantic side, several sub-Arctic species now occur in waters around the Svalbard archipelago. In 2013, biologists of the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research reported that large numbers of juvenile Atlantic cod were present in waters around Spitzbergen.[262] Another group of researchers from Norway and Scotland has recorded Atlantic mackerel (*Scomber scombrus*) in Isfjorden in Svalbard for the first time. This is the northernmost record of this commercially important fish species and represents a possible northward expansion of circa 5° latitude.[263]

Haddock (*Melanogrammus aeglefinus*) is another commercially important species from the Barents Sea and has been less well studied than Atlantic cod. A 2014 investigation into how climate and abundance is impacting the Barents Sea haddock stock found that the long-term trend indicated a north-eastward shift in distribution boundaries, probably related to the coinciding increase in water temperature.[264] Expansion of the range of haddock, as for other demersal species such as Atlantic cod, will be restricted by the extent of the continental shelves, meaning further expansion is expected to be limited to an eastward direction along the Siberian shelf.

Capelin (*Mallotus villosus*) is a pelagic species that inhabits the margins of colder Arctic waters. Like the polar cod, which is more static in distribution and associated with the icy sub-zero waters, capelin feed on zooplankton, including copepods, and are themselves an important prey species for fish, birds and mammals. Capelin appear to react quickly to environmental change, extending their distribution further north in warm years. Capelin can undergo large population fluctuations in response to a variety of factors, especially predator-prey interactions. A 2013 study noted that the Barents stock had been very high for a few years, in the range of 3–4 million tonnes, which together with above-normal temperatures explained why the main concentration of capelin was located very far north.[265] In 2011 the core concentration of capelin was found between 77° and 81°N, which is farther north than from 1972 until then. Previously, in the period 2007–2011, some capelin had been detected north and northwest of Svalbard, but only in small numbers.

Other possible species that might enter the Arctic Ocean during feeding migrations are the beaked redfish (*Sebastes mentella*) and the Greenland halibut. Both of these are commercially important, deep-water species that at times live near the sea floor and at others in the pelagic realm.[266]

A recent study focused on fish communities of the northern Barents Sea and the changes that have taken place between 2004 and 2012.[267] The study noted that recent warming has led to boreal fish that inhabit the continental shelf expanding their ranges northwards. The authors suggest that large, migratory predators of these fish may be able to take advantage of shifting production and prey species. Arctic fish species may experience higher predation levels as a result of becoming key prey for more boreal species, and their distributions could be retreating northwards and eastwards. The community-wide shifts are occurring at a higher pace than predicted, even under a high-range climate scenario, and are comparable to the estimates for fastest-shifting species, the blue whiting (*Micromesistius poutassou*) in the North Sea. In summary, the significant changes in the structure of the fish communities and the changes in food-web interactions have resulted in a borealization of the Arctic ecosystem. The recorded changes in the distribution of many fish species in the Arctic follow a trend that shows many species shifting their core distributions towards the poles or deeper waters under ocean warming.[268]

Oxygen minimum zones

Oxygen minimum zones (OMZs) are ‘pools’ of water where oxygen concentrations fall from the normal range of 4–6mg/l to below 2mg/l, and they occur worldwide at depths of about 200 to 1,500m from biological processes that lower oxygen concentration and physical processes that restrict water mixing between the OMZ and surrounding areas. Often located in the eastern boundary of an ocean basin, OMZs are expanding as a result of climate change.[269] The location of these zones are due to a combination of factors. Firstly, as ocean waters the water holds less oxygen; secondly, increasing surface temperatures lead to increased stratification (and less mixing). Finally, increased CO_2 at the surface or nutrients from coastal runoff leads to increased phytoplankton production. As the phytoplankton die and sink there is a commensurate increase in bacterial activity which leads to lower levels of oxygen in the OMZ.

The expansion and shoaling of ocean OMZs experienced over the last 50 years is predicted to continue with increasing global temperatures, and this is like to have major and far-reaching consequences. Among the multiple effects will be altered microbial processes that produce and consume key nutrients and gases, changes in predator-prey dynamics, and shifts in the abundance and accessibility of commercially fished species.[270] As with other climate-related changes, there will be winners and losers.

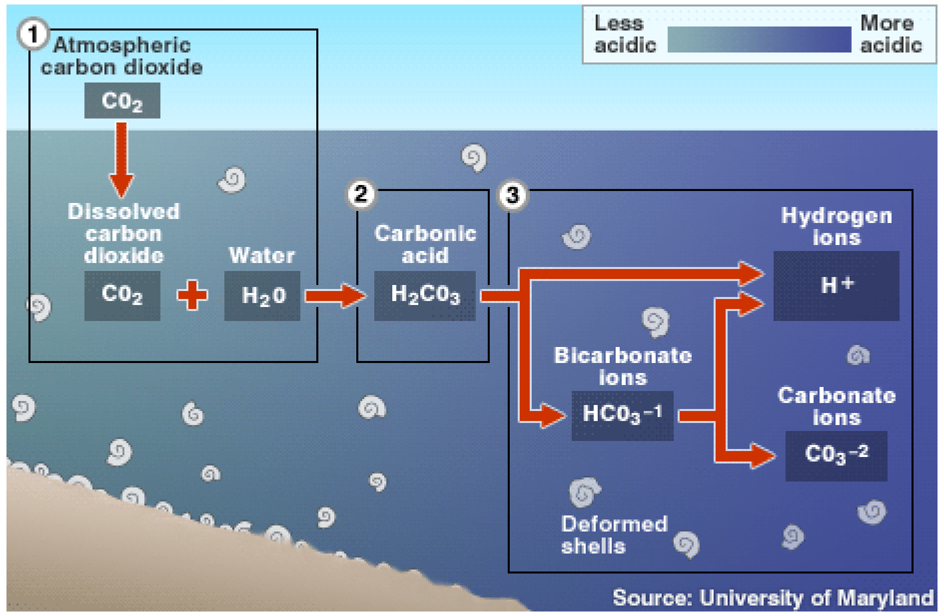
For example, an interdisciplinary collaboration between oceanographers, fisheries biologists and animal taggers has shown how the expansion of OMZs may have reduced available habitat for tropical pelagic fishes such as tuna and billfish by ~15% for the period 1960–2010.[271] The researchers found that shoaling of OMZs concentrates both predators and prey in progressively shallower surface areas, which could lead to overly optimistic abundance estimates derived from surface fishing gear. Blue marlin (*Makaira nigricans*) may dive as deep as 800m if there is plenty of oxygen available but if this is limited then that can constrain their dives to around 100m deep, hitting the boundary of the deeper OMZ. Changes in behaviour can mean that some commercially important species, such as sharks, are more available to fishermen as they are found higher in the water column due to avoiding OMZs.

Other ecologically important species that are likely to be affected by the expansion and shoaling of OMZs include krill and myctophid fishes, which carry out diel vertical migrations from the upper regions of OMZs to epipelagic waters above. The vertical compression suitable habitat for certain species that require well-oxygenated waters can alter predator-prey relationships by concentrating prey in the near-surface waters.[272]

Ocean acidification

The term ocean acidification is used to describe the ongoing increase in acidity (decrease in ocean pH) caused by the ocean absorbing a proportion of the atmospheric CO_2 produced by burning of fossil fuels. While this might be viewed as positive in terms of lessening CO_2 levels in the atmosphere and thus reducing climate change impacts, ocean acidification has the potential to cause widespread and profound impacts on marine ecosystems. Ocean acidification, like climate change, is a dire consequence of living in a high CO_2 world and for this reason, ocean acidification has been dubbed as the ‘evil twin of climate change’.

THE CHEMISTRY OF OCEAN ACIDIFICATION



Source: University of Maryland

When CO_2 is absorbed by seawater, a series of chemical reactions occur: to achieve chemical equilibrium, some CO_2 reacts with the water (H_2O) to form carbonic acid (H_2CO_3): $CO_2 + H_2O \leftrightarrow H_2CO_3$. Carbonic acid then dissolves rapidly to form H+ ions (an acid) and bicarbonate HCO_3^{-1} (a base). Seawater is naturally saturated with another base, the carbonate ion (CO_3^{-2}) that acts like an antacid to neutralise the H+, forming more bicarbonate. As carbonate ions become depleted, seawater becomes undersaturated with respect to two calcium carbonate minerals, aragonite and calcite, which many marine organisms use for building their shells and skeletons.

The net reaction looks like this:
$CO_2 + H_2O + CO_3^{-2} \rightarrow 2HCO_3$

The average pH of ocean surface waters has already fallen by about 0.1 units, from about 8.2 to 8.1 since the beginning of the Industrial Revolution. This is very significant as the pH scale is logarithmic, meaning a drop of just 0.1 pH units represents a 25% increase in acidity. Surface ocean acidity has already increased by around 30% since pre-industrial times, with recent changes occurring faster than at any time in at least the last 400,000 years.[273]

Recently researchers from Cardiff University set out to reconstruct levels of ocean acidity and atmospheric CO_2 levels over the past 22 million years by studying the fossils of tiny marine creatures that once lived near the ocean surface and analysing the chemistry of their shells to determine the acidity of the seawater in which they lived.[274] By looking at their results in the context of future carbon-emission scenarios that are recognised by the Intergovernmental Panel on Climate Change (IPCC), the researchers found that the predicted ocean pH of less than 7.8 under a business-as-usual scenario in 2100 is at a level not experienced since the Middle Miocene Climatic Optimum period around 14 million years ago, a time when global temperatures were around 3°C warmer than today due to the Earth's natural geological cycle.

The predicted change in basic ocean chemistry is likely to have far-ranging impacts on marine species and ecosystems, whereby organisms could respond by: migrating to a less affected or unaffected area, adapting to the new conditions or becoming extinct.[275] Species will respond to ocean acidification differently, but the global nature of ocean acidification coupled with the rate of change means that some species will lose out while others will be able to ride the changes or even prosper. Overall these effects will alter food webs with the potential to impact ecosystem function.

Marine organisms such as calcareous plankton, sea angels, shellfish, sea urchins, crustaceans and deep-sea corals that rely on dissolved carbonate for building their shells or external skeletons are the ones at most risk from ocean acidification.

Recent research indicates that ocean acidification could threaten around 70% of deep-water coral living below 1,500m in the North Atlantic by 2050.[276] These animals build their fragile external skeletons with aragonite but are only able to do so when the seawater is sufficiently saturated with it, namely above 'aragonite saturation horizon' (ASH). Below this boundary the seawater is under-saturated, meaning that it can dissolve hard corals. Using observational data from 2002–2016, researchers have found that the depth of the ASH is rising in some parts of the North Atlantic. For example, in the Irminger Sea off the southern coast of Iceland it has risen by 10–15m per year.[277] As the ASH rises so the proportion of corals that will be exposed to corrosion will increase. Looking at future emissions scenarios for CO_2, it has been concluded that within three decades North Atlantic cold-water corals could become severely threatened.

Sea angel, Arctic
© Alexander Semenov

The detrimental impacts of ocean acidification extend well beyond those associated with secretion of calcium carbonate structures, whereby impacts include:[278]

- Reduced survival in the larval stages of marine species, including commercial fish and shellfish
- Impaired developmental in invertebrates at fertilisation, egg and larval stages, settlement and reproduction
- Excessive CO_2 levels in the blood of fish and cephalopods which can cause sufficient toxicity to significantly reduce growth and fecundity in some species

Ocean acidification is of particular concern in regions, like the California coast, where seasonal upwelling occurs. Here strong winds cause surface waters to move away from the shoreline causing colder, nutrient-rich, deeper water to rise from below. This water is also rich in dissolved CO_2 and has a naturally lower pH compared to the water it replaces. Upwelling regions are biologically important because the nutrient-rich waters rising to the surface support diverse populations of marine life. There is growing concern that human-caused ocean acidification from burning fossil fuels might amplify the acidity of these upwelling areas and thus damage marine life in them.

Pollutants

Many human activities cause the release of synthetic hazardous substances into the ocean or the redistribution of naturally occurring substances that may have a deleterious effect on marine life. Such pollutants include: chemicals, oil, radioactive substances, nutrients, plastics and other debris and their effects may sometimes kill organisms directly or harm them in a way that undermines ecosystem integrity.

Synthetic chemicals that are toxic, long-lived and bioaccumulate are collectively known as persistent organic pollutants (POPs), and these include chemicals used as flame retardants, solvents and pesticides, which are readily transported to and move within the marine environment and have even been found in the tissues of amphipods living in two of the ocean's deepest trenches.[279]

Polychlorinated biphenyls (PCBs) – once widely found in electrical equipment – are among the list of a dozen POPs that in 2004 more than 90 countries agreed to phase out and dispose of under the Stockholm Convention. However, they are still produced and with their slow breakdown, are persistent in the sea. Apex predators such as orcas (killer whales) carry high concentrations of PCBs in their tissues and this has been suggested as possibly contributing to low recruitment and decline in the numbers of some populations. A recent study investigating PCB burdens in populations of killer whales around the world has found that over half studied are severely affected by PCBs and that because of this, the species may disappear from some areas within decades.[280] PCB concentrations in killer whales around the world reflect proximity to PCB production and usage, as well as an animal's diet. This means that populations of killer whales inhabiting waters close to highly industrialised areas such as around the UK, the Strait of Gibraltar and Pacific Northwest are more contaminated than those living in remote waters such as around Antarctica. Transient killer whale populations that inhabit the high seas, eating marine mammals, tuna and shark are more contaminated due to biomagnification than those eating fish.

Mercury enters the ocean mostly by deposition from the atmosphere, though some arrives from river drainage. While some of it comes from natural sources, mercury is also produced from industrial processes including coal combustion, with mercury concentration in waters shallower than 100m three times what it was in preindustrial times.[281, 282] When it arrives in the ocean mercury is mostly in an inorganic form but a portion gets converted to methylmercury (MeHg) by marine microbes. Although methylmercury is found in very small concentrations in the ocean – less than a billionth of a gram per litre – it is present in much larger concentrations in the fish we eat. The crucial role of marine plankton in methylmercury uptake and trophic transfer is described in a 2018 study which notes that phytoplankton end up with 500–500,000 times higher methylmercury concentrations than the surrounding water.[283] Zooplankton consume the phytoplankton ingesting the methylmercury at a faster rate than they can eliminate it from their cells. This leads to bioaccumulation and magnification of methylmercury concentrations in zooplankton compared to the phytoplankton. The same process happens at each level in the food chain, with highest concentrations of the compound found in large, long-lived predators such as tuna and swordfish. This has health implications for people as methylmercury exposure is associated with adverse effects on neurodevelopment and cardiovascular health. A 2018 study confirms that the largest fraction of US methylmercury exposure is from seafood derived from open-ocean fisheries (45%).

Oil pollution and shipping

In recent decades, enabled by advances in deep-water technology, oil and gas exploration and production has expanded into ever-deeper waters but does not extend beyond the continental shelf or outside of EEZs. However, this does not mean that high seas are free from oil pollution. Oil and the polycyclic aromatic hydrocarbons (PAHs) it contains, enter the open ocean either via chronic, continuous pollution from shipping or as a result of accidents, such as when the Iranian oil tanker *Sanchi* caught fire and sank in the East China Sea in January 2018, eight days after a collision with a cargo ship.[284]

The Deepwater Horizon oil spill which occurred in the Gulf of Mexico in 2010 was unprecedented because the oil outflow originated from an ultra-deep well at 1500m and also because of the large volume of oil released (about 4.9 million barrels). Research following the disaster has provided new insights regarding how oil pollution behaves in the open ocean. One was discovering how a proportion of the PAHs from the spill became incorporated into marine snow which was either ingested by marine organisms or settled on the seafloor, impacting both benthic organisms and sediment bio-geochemistry.[285] More than 150 whales and dolphins and more than 600 turtles were found dead following the Deepwater Horizon spill, and research by NOAA indicates that populations of several marine mammals and sea turtles will take decades to rebound, illustrating the devastating impacts of an oil spill for endangered species.[286]

Turtle and plastic
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Marine debris and ocean plastics

Marine debris is the name given to solid materials, mostly waste, that pollute the marine environment; this is a pervasive problem that harms and kills marine life worldwide. Synthetic materials are a common type of marine debris, and plastics are the most problematic. A recent study conducted to provide baseline data and assist in prioritising future plastic debris monitoring and mitigation strategies has estimated that between 1.15 and 2.41 million tonnes of plastic waste currently enters the ocean every year from rivers, with over 74% of emissions occurring between May and October.[287] The top 20 polluting rivers, mostly located in Asia, account for 67% of the global total. The scale of the ocean plastic problem is vast, contaminating everywhere from the tropics to the polar oceans. Ocean currents carry floating ocean plastics vast distances, depositing them on remote beaches and concentrating them within ocean gyres. Some plastic sinks down to the seabed, and in 1998 a plastic bag was photographed at a depth of 10,898m in the Mariana Trench.[288] It is not possible to quantify how much plastic occurs in the ocean but one study, based on data collected from 24 expeditions between 2007–2013, has estimated figures of 5.25 trillion particles weighing 268,940 tonnes afloat at sea.[289]

The impacts of ocean plastics on marine life are wide-ranging and include entanglement, internal blockage after ingestion and acting as a pathway for alien species to invade.[290] Encounters with marine debris have been recorded for at least 690 species, according to a 2015 review, and 92% of these were with marine plastic.[291] At least 17% of impacted species are listed on the IUCN Red List as near threatened or more endangered than this. In a photographic study of 626 North Atlantic right whales, conducted over 29 years, 83% of showed signs of plastic entanglement.

Smaller plastic particles or microplastics, commonly defined as pieces of plastic with a diameter of 5mm or less, are a very pervasive form of plastic pollution in the sea.[292] They include primary things like raw nurdles which are pre-production plastic pellets, and microbeads deliberately added to cosmetics and many cleaning products, plus secondary microplastics produced by the weathering and disintegration of large plastic pieces by wind, waves and ultraviolet light. Microplastics occur globally, including in the remotest places, and from surface waters to sediment.[293, 294]

Microplastics can potentially be ingested by all marine creatures and have been found in a wide range of animals, from zooplankton, such as copepods, to turtles and marine mammals.[295, 296] This is problematic in part because microplastics can adsorb and subsequently desorb toxic contaminants (adsorb is the term used when a plastic attracts a chemical compound that 'sticks' to the plastic; desorption occurs when the plastic 'releases' the adsorbed chemical), and leach chemicals that have been added during the manufacturing process.[297] At present it is not thought that microplastics pose a health risk to people via consumption of contaminated seafood. However, research into the fate and impacts of microplastics in marine food webs and humans is still very limited.[298]

Noise pollution

Over the last century, human use of the sea has greatly increased the noise there. Shipping, seismic testing, use of military sonar, offshore drilling and pile driving for construction are all sources of underwater noise pollution which is now recognised as a worldwide problem for a wide range of creatures, where effects depend on sound intensity and frequency and range from none to fatal.[299, 300] For example, cetaceans have died following military use of sonar.[301]

Generally speaking, the importance of sound to marine organisms is poorly understood, with more known about impacts on marine mammals than any other taxa.[302] In the case of fish, it is thought that sustained anthropogenic noise may have wide-ranging effects on deterring them from important feeding and reproduction areas, interrupting critical activities, or causing stress-induced reduction in growth and reproductive output.[303] While knowledge gaps are big, it is recognised that sound is very important to many species of fish and that impeding their ability to hear biologically relevant sounds might interfere with critical functions such as acoustic communication, predator avoidance and prey detection.[304] Hence as fish use acoustic cues to learn about their environment, any inference with these could have significant impacts at individual, population and possibly ecosystem levels. While little is known about how sound affects invertebrates, these creatures are sensitive to it.[305]

Anthropogenic underwater noise and its impacts have received increasing attention from various intergovernmental forums at the global and regional levels including the CBD, the Convention on Migratory Species, (CMS), the International Whaling Commission (IWC) and the International Maritime Organisation (IMO). In March 2018, the UN Secretary General report on Anthropogenic Ocean Noise was published to inform discussions of the UN Open-ended Informal Consultative Process on Oceans and the Law of the Sea.[306] In subsequent deliberations some countries spoke of the need to address noise pollution in a global and harmonised manner, noting that negotiations for the Global Ocean Treaty will provide opportunities to address ocean noise.[307] Specifically, ocean noise could be incorporated within the elements regarding area-based management tools (ABMTs) and environmental impact assessments (EIAs). Different approaches have been suggested as to how ABMTs could be used to address ocean noise, including designating 'quiet zones' to protect open-ocean migratory corridors for cetaceans and fish where a particular vulnerability has been identified and protecting the quietest ocean areas to keep them noise free.[308, 309] While human-generated noise is best tackled at source, marine reserves and MPAs could provide havens from which the most injurious forms of sound production are excluded, acting as buffers from the effects of noise generated by activities in the surrounding waters or seabed.

Geoengineering

Marine geoengineering is defined as "a deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts, and that has the potential to result in deleterious effects, especially where those effects may be widespread, long-lasting or severe".[310] The environmental risks and uncertainties associated with marine geoengineering, such as large-scale deployment of ocean fertilisation (i.e. enhancing ocean productivity by stimulating phytoplankton growth in the open ocean through nutrient addition) or the modification of upwelling, remain high and are only likely to sequester relatively modest amounts of CO_2 in the view of the authors of a 2016 technical report to the CBD.[311] Due to the risks and uncertainties, ocean fertilisation other than for 'legitimate scientific research' is prohibited, and such scientific research is very tightly regulated at an international level under the London Protocol. The debate continues among scientists and policy makers as to how best to regulate other proposed forms of marine geoengineering so as to comply with a precautionary approach and safeguard ocean health.

The impacts of multiple stressors

The high seas are now affected by multiple anthropogenic stressors and unprecedented stressor levels that do not operate in isolation.[312] The impacts of increasing CO_2 emissions from burning of fossil fuels, including ocean warming, acidification and hypoxia, all potentially interact with each other and with other human impacts including overfishing, pollution and the establishment of invasive species.[313] Predicting the cumulative and interactive effects of these stressors and the potential for resistance or resilience of individual organisms or ecological communities is highly complex, especially as effects may be additive, synergistic or antagonistic.[314]

Synergistic effects occur when the combined impact of two or more stressors on an ecological response (e.g. diversity, productivity, abundance, survival, growth, reproduction) is greater than the sum of impacts from individual stressors. Such synergistic effects occur because a change caused at the physiological or ecological level by one stressor increases the severity or occurrence of effects of a second stressor. How organisms respond to multiple stressors will depend on their magnitude and timing, with synergistic effects most common when stressors occur close together in time.[315]

The possibility that multiple co-occurring stressors may have synergetic effects is of particular concern because they could provoke unpredictable 'ecological surprises' and cascading impacts that could accelerate biodiversity loss and impair the functioning of ecosystems.[316]

Scientists have found that climate change and overfishing are likely to be responsible for a rapid restructuring of a highly productive marine ecosystem in the North Sea, and others have demonstrated how the synergistic impacts between ocean acidification, global warming, and expanding hypoxia will compress the habitable depth range of the jumbo squid (*Dosidicus gigas*), a top predator in the Eastern Pacific.[317, 318] These examples of detrimental synergistic effects show that concern is not misplaced, and more are being added from around. For instance, the British Antarctic Survey (BAS) is currently running a project to investigate the synergistic impact of nanoplastic and ocean acidification on marine ecosystems in the Southern Ocean.[319]

Coral reef
© Paul Hilton/Greenpeace

OCEAN SANCTUARIES – A KEY TOOL IN SECURING OCEAN HEALTH

Marine protected area (MPA) is a term now ubiquitous in relation to marine conservation and ocean management. However, what exactly the term defines is variable, with a wide range of associated protection measures that may confer an equally wide range of benefits, or in the case of 'paper parks' very limited or no benefit at all.[320] To help dispel the confusion, it is helpful to refer to the IUCN, which states that for an area to be recognised as an MPA it must be:

"a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values."[321]

This definition is explained and elaborated in the IUCN document *Applying IUCN's Global Conservation Standards to MPAs* which synthesises information from the existing IUCN *Green List Standard for Protected and Conserved Areas*, together with current relevant policies taken from approved IUCN Resolutions and Guidance documents.[322] This document underscores the essential characteristics that MPAs need to have, namely:

- → Conservation-focused with nature as the priority
- → Defined goals and objectives which reflect these values
- → Suitable size, location and design that will enable conservation of values
- → A defined and fairly agreed boundary
- → A management plan or equivalent, which addresses the need for conservation of a site's major values and achievement of its social and economic goals and objectives
- → Resources and capacity to implement

While MPAs are a crucial part of the continuum of management needed to help sustain ocean health, they are different from other area-based management measures in that their primary focus must be the conservation of biodiversity. This means that where area-based management measures are implemented primarily to achieve a different goal – such as sustainable fishing – that area is not an MPA.

MPAs can range from highly protected sites, to places that are zoned and so allow for some multiple use in which levels of protection can vary. This means that if fishing or any other extractive activity occurs in an MPA, it must have a low ecological impact, and be sustainable and compatible with the MPA's objective(s). Certainly, environmentally damaging activities and development is incompatible with an MPA.

MPAs are a key tool in protecting habitats and species, rebuilding ocean biodiversity and helping ocean ecosystems recover such that vital ocean processes essential to healthy ecosystem functioning are maintained. This is widely acknowledged and explicitly reflected in the UN SDG 14 and Aichi Target 11 under the Strategic Plan for Biodiversity 2011–2020 of the UN Conventions (see Targets for marine protection, p20).

MPAs – differences between levels of protection

While multiple-use MPAs may generate benefits in certain contexts, scientific evidence consistently shows that the greatest ecological benefits from protection are derived from strongly or fully protected areas, commonly referred to as no-take zones, marine reserves or ocean sanctuaries.[323, 324] By excluding extractive activities and removing or minimising other human pressures, these enable species to maintain or recover abundance, biomass and diversity.[325] For example, a meta-analysis of scientific studies showed that the biomass of fish assemblages is, on average, 670% greater within marine reserves than in unprotected areas, and 343% greater than in partially protected MPAs. Fish biomass is a powerful metric to use in assessing MPA success because it provides a strong indicator of the health of fish assemblages and thus ecosystem health.[326, 327] The elimination of extractive and damaging activities protects marine life from the sea surface to the seabed, preserving the important ecological and biogeochemical links, ensuring protection of the whole ecosystem and related ecosystem processes.[328] Furthermore, highly protected areas allow species to age naturally which enhances population structure, leading to higher reproductive outputs from big old fat fecund female fish (BOFFFFs).[329]

Ecosystem complexity can be restored within marine reserves, as has occurred in coastal marine reserves in the Mediterranean and New Zealand where urchin barrens have been restored to algal forests with much higher associated biodiversity once urchin predator populations have rebounded.[330, 331] Large-bodied animals are critical to ecosystem function due to their preferential position at the top of food webs, the role they play in nutrient cycling and other key ecosystem processes.[332] They help maintain ecosystem balance in open-ocean ecosystems and rebuilding their numbers may lead to healthy and more complex food webs.[333, 334] How to make protective area networks effective for marine top predators is a subject for active research and presents various challenges, not least because many of these species, including marine mammals, sharks and seabirds, travel vast distances and require protective measures appropriate to their life histories.[335]

WHITE SHARK CAFÉ

One area of the high seas where a marine reserve would clearly be helpful to an important top predator is the 'White Shark Café'. Located in the mid-Pacific Ocean halfway between Baja California and Hawaii, the area was discovered in 2002 by researchers studying the great white shark via satellite tags.[336] Data from these showed that in December a large proportion of California's great white shark population, both adults and juveniles, travel thousands of miles into open water to congregate in an area with a radius of approximately 250km to 'hang out' for several weeks before returning to their Californian coastal feeding grounds. Initially the place was thought to have low productivity and be unable to provide sufficient food for great white sharks, until further study revealed that the primary lure for the sharks is an extraordinary abundance of squid and small fish that undergo diurnal migration from the mesopelagic.[337]

Great white shark
© Ralf Kiefner/Greenpeace

Fisheries benefits

Marine reserves can benefit fisheries as well as conservation, although not being a panacea they need to be supplemented with good fishery management to aid in this arena.

Fisheries-related benefits of effectively designed and implemented marine reserves may include:

- → Increased biomass of target species and stock replenishment, restoring fisheries productivity and the recovery of populations
- → Spill-over of adults and juveniles across the reserve boundary, which may lead to increased yields in adjacent waters
- → Export of eggs or larvae to areas beyond the reserve boundary
- → Restoration of the natural age structure of exploited populations and maintenance of BOFFFFs, whose eggs tend to show the highest levels of fertilisation and best survival rates
- → Conservation of genetic diversity
- → Maintenance of essential fish habitat important to key life stages, e.g. spawning and nursery grounds, migration bottlenecks and feeding grounds
- → Recovery of habitat damaged by fishing
- → Maintenance of biodiversity and ecosystem function and processes, so conferring resilience in the face of ecological change
- → Provision of reference sites for measuring the effects of fisheries-induced changes
- → An insurance policy as marine reserves provide a hedge against uncertainty (including resource assessment uncertainty) and risk of fishery collapse
- → Better compliance with regulations when stakeholders are involved in their designation and implementation

(For further information see Roberts et al. 2005)[338]

Scientists are increasingly looking at how establishing marine reserves in international waters might aid fisheries management. This is partially driven by the widely acknowledged failure of traditional fisheries management tools and organisations to address issues such as the bycatch of endangered species and destruction of vulnerable deep-sea habitats.

The case for creating marine reserves to protect vulnerable deep-sea fish species and their habitats from bottom trawling is widely accepted, but their use in fisheries management for wide-ranging pelagic species such as billfish and tuna has been the subject of much debate.[339] An examination of the purse seine fleet's behaviour in relation to the Galápagos Marine Reserve shows that vessels are increasingly fishing along the reserve's boundary, with tuna catches there higher than in surrounding areas against a backdrop of increased fishing effort and declining tuna recruitment and productivity across the wider region.[340] The researchers concluded the Galápagos Marine Reserve has had a positive effect for neighbouring pelagic fisheries and supports the case to establish large-scale MPAs as tools for both fisheries management and biodiversity conservation.

A 2014 modelling study by Crow White and Christopher Costello suggested that completely closing the high seas to fishing might provide a sufficiently large refuge for high seas fish populations to recover and be maintained at levels that would help maximise fishery returns in coastal waters.[341] Furthermore, they found that completely closing the high seas to fishing would simultaneously give rise to large gains in profit (>100%), yields (>30%) and stock conservation (>150%) of fisheries. The authors of course acknowledge the difficulties in implementing such a policy, but their work should give food for thought to policy makers. In related work, Rashid Sumaila and colleagues have investigated the outcomes of full high seas protection, taking into account that their waters are connected to those of countries' EEZs and that many species, including some of the most commercially important, are highly migratory so move between the two. The study examined how global catch might change if catches of straddling species or taxon groups increase within EEZs as a result of high seas protection,[342] and found that <0.01% of the quantity and value of commercial fish taxa are obtained from catch taken exclusively in the high seas, and if the catch of straddling taxa was to increase by 18% on average following closure, there would be no loss in global catch as there would be a spillover of fish from the high seas into EEZs. Unsurprisingly, the analysis suggested that some countries would gain while others would lose from a full high seas fisheries closure but that most coastal countries stand to gain, including many of the world's least-developed countries, which would bring about gain in equity.

Putting large areas of the high seas off-limits to fishing could deliver significant benefits at little cost. For example, a 2007 study estimated that closure of 20% of the high seas might lead to the loss of only 1.8% of globally reported catches and a decrease in profits to the high seas fleet of only about US$270m per year, a sum equivalent to just over a quarter of the US$1bn that Americans spend on fireworks on 4th July every year.[343, 344] To ensure that fishing effort removed from a high seas protected area is not displaced to elsewhere on the high seas, strong regulations that include permanent capacity reductions, and effective surveillance with enforcement of regulations, are vital.

Climate change mitigation and resilience

The pervasive problems of climate change and ocean acidification must be addressed at source by drastically cutting greenhouse gas emissions, and alongside this the establishment of highly protected areas can help the oceans to mitigate and adapt to climate change.[345] As part of this a network of highly protected areas in the high seas and seabed will be very helpful in maintaining ocean carbon sequestration and storage processes and preventing loss of stored carbon. The main mechanisms to describe how highly protected areas can help the oceans to mitigate and adapt to climate change and aid carbon sequestration are:

- Reduction of other stressors such as fishing and mining in marine reserves prevents biodiversity loss, promotes ecosystem recovery and so maintains vital ecosystem services, conferring resilience
- Large species populations found in marine reserves are more resistant to extinction than smaller ones as they provide a better buffer against declining numbers and their greater reproductive output helps make populations more resilient
- By maintaining genetic diversity, the chances of species adapting to changing sea temperatures and other environmental changes is increased
- Protected areas can act as refuge stepping stones for migratory species and provide safe ‘landing zones’ for climate migrants
- Identifying areas of the ocean where conditions are most stable may provide climate refugia, e.g. the Ross Sea MPA for Antarctic ice-dependent species
- Protection of the seabed from disturbance by DSM or heavy fishing gear, which will prevent the release of carbon held in sediments
- The protection of mesopelagic fish in open-ocean marine reserves may enhance CO$_2$ absorption and buffer acidification near the surface through the excretion of gut carbonates
- Marine reserves can form an important network of observatories and ecological and climate monitoring stations

Coral bleaching, Indian Ocean
© Uli Kunz / Greenpeace

Until recently, neither decision makers nor MPA managers have directly considered climate change and ocean acidification in the design, management or monitoring of MPAs or MPA networks, but this is beginning to change. A recent study shows that strictly protected marine reserves are considered essential for climate change resilience and will be necessary as scientific reference sites to understand climate change effects and that strictly protected reserves managed at an ecosystem level are the best option for an uncertain future.[346]

Taking the above into account, the establishment of a network of highly protected high seas marine reserves provides a viable, low-tech, cost-effective adaption strategy for ‘future-proofing’ our oceans in the face of massive environmental change, and could make a significant contribution to the pledges made by countries under the Paris Agreement to conserve ocean biodiversity and bolster ocean resilience.[347]

The importance of large-scale protection

While small marine reserves may deliver multiple benefits, the establishment of large-scale MPAs (LSMPAs) is crucial if we are to address the depth, breadth and cumulative impacts of multiple threats to the marine environment at a range of scales as set out in this report.[348] In the high seas, large protected areas match the scale of large ecosystems. For example, a strong case has been presented for conferring large-scale protection to the Sargasso Sea where the ‘floating golden forest’ of Sargassum weed provides food, shelter and a nursery for important species, many of which are endangered.[349] Wide-ranging and highly migratory species, including whales, turtles, seabirds, sharks and tuna, are most feasibly protected with LSMPAs.[350] LSMPAs reflect and can protect large proportions of these species’ ranges and provide protected corridors that connect different habitats in a way smaller areas cannot.[351] LSMPAs mitigate threats over larger areas or maintain pristine areas, and may capture shifts associated with SST and other environmental changes. Given the uncertainty of climate change impacts, increasing human use of ABNJ and the cumulative impacts of all these different stressors, LSMPAs, by protecting ecologically functional swathes of ocean, act as an insurance policy for the future.[352]

The level of protection and size are two key factors that are vitally important in determining the conservation outcomes of an MPA, but they are not the only features that are important. A study of 87 MPAs worldwide found that conservation success, as indicated by fish biomass, improves exponentially when an MPA had five key characteristics, while those with four were more successful than those with fewer, but not as successful as those with all five.[353] The characteristics in question were:

- No fishing is allowed
- Enforcement is good
- Is more than 10 years old
- Is larger than 100km^2 (i.e. is relatively large)
- Is isolated from fished areas by habitat boundaries, such as deep water or sand

In summary, how effective marine reserves will be in delivering their objectives crucially depends on levels of compliance and enforcement, which need to be adequately financed and resourced.[354] The feasibility of ensuring that remote and large-scale marine reserves in the high seas are enforceable has recently been greatly enhanced by the development of new technologies which include satellite imaging, remote sensing and use of drones.[355] The benefits, opportunities and advantages of well-established and managed marine reserves are proven and documented to grow over time, and are an essential component of the ecosystem-based management portfolio that will deliver healthy and sustainably managed oceans.

Leatherback turtle
© Greenpeace/
Jacques Fretey


© NASA

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DESIGNING A MARINE PROTECTED AREA NETWORK FOR THE HIGH SEAS

AIMS AND OVERVIEW

This research explores options for high seas[ii] protection with MPAs to inform negotiations at the UN on the nature of a legal instrument to protect high seas life. We develop a systematic conservation plan for high seas MPAs using globally distributed biological, oceanographic, geographical and socio-economic data.[356] We explore two target levels for protection, 30% and 50% coverage of each conservation feature, as these correspond to widely discussed ambitions for future global conservation.[357, 358] We highlight areas that are important for conservation by identifying places frequently selected within MPA network designs. We consider how high seas MPAs could be selected in the future based on a combination of site-specific nominations and coordinated network design. Finally, we show how ambitious protection targets produce MPA networks that interconnect across ocean basins, reversing MPA designation practices typical in coastal systems of isolated patches of protection within a sea of impact.

METHODS

Study area

Areas beyond national jurisdiction (ABNJ), excluding the Mediterranean Sea, formed the study area. The areas beyond national jurisdiction in the Mediterranean Sea was excluded because, being a semi-enclosed sea, its biogeography operates on a different scale to much of the rest of the high seas.[359] Hence, the study area occupies approximately 222 million km^2, or 61% of the global ocean surface, and has a depth range of 1m to 8,631m.

Procedure used for computer-assisted design of a network of marine protected areas

Systematic conservation planning is a widely used tool for MPA network design that aims to select places that represent a defined proportion of the spatial extent of included conservation features (e.g. species or habitat distributions or proxies thereof), while minimising size and socio-economic costs.[360] We used Marxan, a commonly used decision-support tool for systematic conservation planning, to identify high seas MPA network designs that met our specified conservation targets.[361]

To use Marxan, a number of key pieces of information need to be defined (see Variables defined within Marxan, p68), and the area being considered for an MPA network needs to be subdivided into smaller components of space, known as planning units. We divided our study area into 24,528 planning units. To do this, the world was divided into 100x100km units and then this grid was clipped to the shape of ABNJ. This meant that although the majority of planning units were equally sized, smaller units were present where they overlapped with EEZ boundaries and the Antarctic coastline. In addition, given that the world does not divide equally into 100x100km units, smaller planning units were also present at 90°N and the anti-meridian. Conservation features (see Data, p69) were mapped and assigned to these planning units so that Marxan knew which features, and how much of their total area, would be represented if a unit was selected for protection. In the high seas, fishing is the most widespread human activity that would be impacted by

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[ii] The term 'high seas' is used to refer to 'areas beyond national jurisdiction' (ABNJ). Legally, ABNJ are composed of the high seas (waters beyond the zones of national jurisdiction) and the Area (the seabed, ocean floor and subsoil thereof beyond the limits of national jurisdiction). This means our study considers all habitats from the seabed to surface waters.

MPA designation. As the socio-economic value of the sea varies spatially, so too will the impact of restricting fishing. To account for this, and to minimise potential negative socio-economic impacts of MPA network designs, a cost was assigned to each planning unit based on recent fishing effort within it. To assign this cost we used publicly available fishing effort data for trawl, purse-seine and longline fishing between 2015 and 2017.[362]

VARIABLES DEFINED WITHIN MARXAN

- Conservation targets for each feature, expressed as percentage coverage
- The cost of using each planning unit. This is typically defined using a proxy for economic costs; here we used fishing effort
- A boundary length modifier (BLM) to coerce Marxan into creating more clumped MPAs and avoid highly fragmented solutions with limited feasibility or connectivity
- A penalty factor to force coverage targets to be met by imposing a cost on the network if targets are missed
- Number of runs (unique solutions) and iterations (repetitions of the optimisation procedure)
- Planning unit status to specify whether or not the planning unit must be included in the final design. This allows priority areas for protection or existing areas subject to management to be locked in to network designs and/or unfavourable areas to be locked out

Planning units were then assigned a status of 'available', 'locked out', or 'locked in' to tell Marxan whether they were available for selection, or whether they had to be included or excluded, in the final network design. To build MPA network designs around current high seas management efforts (see Existing management units and mining areas), we locked in existing management units, such as MPAs. We locked out mining exploration leased and reserved areas in the tropical Pacific to avoid areas already identified for future extractive activity that would thus be unlikely to be protected or whose protection might result in negative socio-economic impacts (see Existing management units and mining areas). We set conservation targets for each feature at 30% and 50% coverage. Marxan was then used to develop MPA network designs that met all targets while minimising the total cost.

EXISTING MANAGEMENT UNITS AND MINING AREAS

Existing management units were MPAs, vulnerable marine ecosystem (VME) fishery closures, and areas of particular environmental interest (APEIs) closed to deep-sea mining. We locked out areas leased and reserved for mining exploration in the tropical Pacific from planning solutions, given that this area is well advanced in terms of exploration claims and there has already been a process around finding and agreeing APEIs[363]. Excluding these areas prevents network design solutions from incursion into mining areas by aggregating around the locked-in APEIs. We did not lock out leased and reserved areas for mining elsewhere as they have not been subject to the same level of scrutiny regarding APEI designation. We selected planning units overlapping with any part of each management unit and locked them in or out as appropriate. Where planning units contained both APEIs and leased or reserved areas, and therefore could be either locked in or out, they were locked in to prioritise conservation over exploitation.

Marxan produces two major outputs. The first is a selection frequency for each planning unit, showing how often each planning unit was selected across the total number of MPA network solutions (i.e. runs). Selection frequency is often referred to as high irreplaceability, indicating the relative importance of each planning unit to meeting the targets set. The second output is a 'best' solution, which shows the MPA network design that meets conservation targets at the lowest cost for a given scenario (e.g. target level).

To design the MPA network we assumed that management would be consistent across the water column and seabed, and spatially fixed, so that a selected planning unit incorporates all conservation features within it regardless of depth.

DATA

Using Marxan, we sought to identify potential areas of conservation importance by aiming to represent the full spectrum of biogeographic regions, habitats and species in ABNJ. We therefore chose conservation features to represent specific physical ecosystem characteristics known to be important to high seas marine life, species or habitat distributions, or proxies for ecosystems likely to have distinct biodiversity. In total, we included 458 conservation features representing oceanographic, biogeographic, biological and biophysical features (see table below). Global distributions of oceanographic and biophysical features were subdivided by biogeographic region or ocean area to separate them into groups likely to have distinctive marine life. Ocean areas defined were the North Atlantic, South Atlantic, North Pacific, South Pacific, Indian, Arctic and Southern. Biological features and biogeographic regions were not subdivided.

Summary of conservation features included in analyses with rationale for use and method of selection. Full details of data are provided in O'Leary et al.[391]

Feature category	Feature	Rationale for use and method of data selection
Oceanographic	Sea surface temperature gradient	Used to identify the fronts, convergence zones and upwellings typically associated with high wildlife abundance. Planning units containing the top 10% of values based on steepness of gradient within each ocean area were used. All cells from one ocean area were considered as one conservation feature.
	Areas of high/low interannual variability in long-term sea surface temperature	Used to represent ecosystems that may be inherently resilient to, or buffered from, future environmental change. Planning units containing the top/bottom 10% of values based on sea surface temperature variation within each pelagic province were used. All cells from one province were considered as one conservation feature.
	Net primary productivity	Influences the distribution of marine life diversity and abundance. Planning units containing the top 10% of values based on primary productivity within each ocean area were used. All cells from one ocean area were considered as one conservation feature.
	Downwelling areas (intermediate/deep-water formation)	Important areas for oceanic nutrient transport and deep ocean ventilation and are often sites of aggregations of marine life and plant matter. Each downwelling area was considered an individual conservation feature.

Feature category	Feature	Rationale for use and method of data selection
Biophysical	Hydrothermal vent field distribution	Important hotspots of endemism and biodiversity that are vulnerable to disturbance and damage and may contain valuable deposits of minerals/ores. Subdivided by bathyal, abyssal, and hadal biogeographic provinces. One hydrothermal vent field was shallower than available benthic biogeographies. This was considered as one conservation feature.
	Seamount distribution	Important hotspots of endemism and biodiversity that are vulnerable to disturbance and damage. Subdivided by bathyal, abyssal, hadal, mesopelagic, pelagic and coastal biogeographic ecoregions/provinces.
	Seagrass distribution	Unique habitat within the high seas that supports high productivity and likely represents a key feeding, breeding and nursery habitat and refuge area for many species. Considered as an individual conservation feature.
	Cold-water coral distribution	Important structural habitats that can support high productivity and diversity and are vulnerable to disturbance and damage. Subdivided by bathyal, abyssal and hadal biogeographic provinces. Shallower than available benthic biogeographies, subdivided by depth ranges 0–200m and 200–800m.
	Seabed complexity	Linked with higher species diversity due to the availability of refugia and microhabitats. Planning units containing the top 10% of values based on mean seabed complexity within each ocean area were used. All cells from one ocean area were considered as one conservation feature.
Biological	Oceanic shark and ray distributions (n=30)	Represent species of conservation concern, commercial importance and biodiversity more broadly. Species were chosen that had more than 25% of their global range in the high seas. Each species' range was considered as an individual conservation feature.
	Pinniped distributions (n=9)	
	Cetacean distributions (n=49)	
	Tuna and billfish distributions (n=19)	
	Other fish distributions (n=21)	
	Turtle distributions (n=1)	
Biogeographic	Coastal ecoregions (n=19)	Each province/ecoregion considered as an individual conservation feature.
	Pelagic provinces (n=32)	
	Mesopelagic ecoregions (n=29)	
	Bathyal benthic provinces (n=14)	
	Abyssal benthic provinces (n=13)	
	Hadal benthic provinces (n=7)	

RESULTS

The conservation features we included reflect the great variety and variability of the biodiversity and conditions encountered in the high seas (Figure 3). Of the species we included, many overlap in range and have widespread distributions, particularly in the tropics and sub-tropical convergence zones (Figure 3a). Epipelagic, mesopelagic and benthic biogeographies coalesce and overlap forming identifiable concentrations of features (Figure 3b), while biophysical (Figure 3c) and oceanographic features (Figure 3d) have more constrained spatial extents.

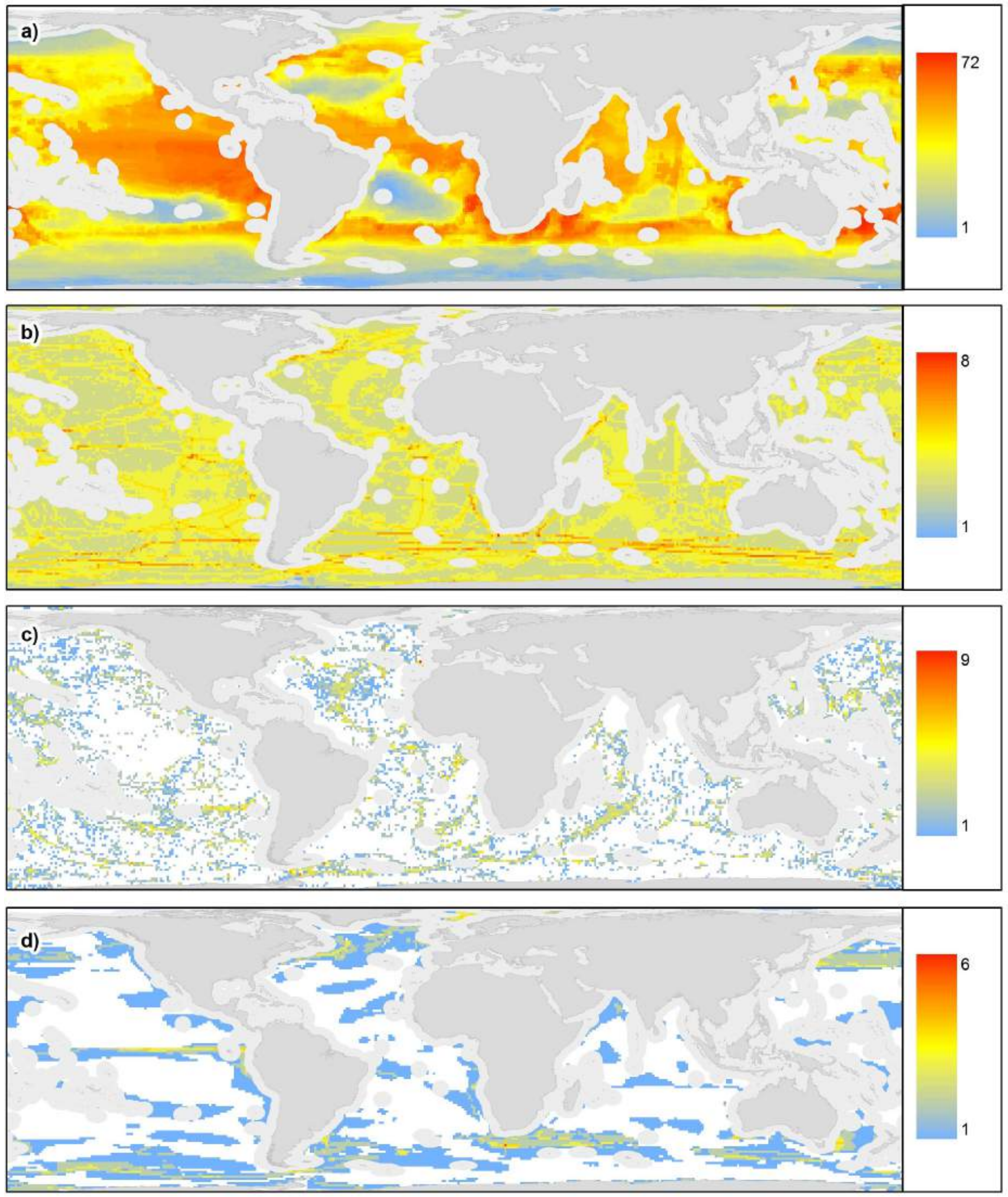

***Figure 3:** Total number of conservation features per 100x100km planning unit across areas beyond national jurisdiction for (a) biodiversity features, (b) biogeographic regions, (c) biophysical features and (d) oceanographic features.*

Areas of importance for meeting conservation targets

Planning units that have a high selection frequency across planning solutions can be considered as having high importance for meeting the conservation targets set. Figure 4 shows units chosen in the majority (≥75%) of runs. These units covered 13.8% of ABNJ within planning solutions for 30% coverage of each conservation feature and they are selected frequently because without them, it becomes more difficult to meet the targets set. It is important to note, however, that these high selection frequency planning units cannot meet all conservation targets on their own and instead need to be combined with areas selected less frequently to form a representative network of MPAs. Areas selected less frequently by Marxan are those where there is more flexibility as to which planning units are included in network designs to meet conservation targets. When targets were set at 50% coverage of each conservation feature, planning units which covered 23.7% of ABNJ were chosen in more than 75% of runs.

Many areas of known ecological importance (e.g. ecologically and biologically significant areas and important bird and biodiversity areas) were strategically selected as important by Marxan. Other areas of the sea that were frequently selected were chosen because they ensured that coverage targets for a conservation feature or features could be met. While these places are not necessarily of greater ecological importance than others, they can be considered irreplaceable or nearly so in terms of representation of our conservation features. Such areas could form foci for new field studies to characterise their importance to biodiversity more fully and inform their inclusion, or not, in an MPA network design. Systematic conservation planning therefore helps draw attention to regions that may have been overlooked. In contrast, some places known to have high ecological importance, such as the Costa Rica Dome or White Shark Café, were not frequently selected in planning solutions.[364] This is probably because the biological conservation features that we used to generate network designs include no information on intensity of use by wildlife because this is not comprehensively available across ABNJ or species.

Systematic conservation planning offers a key tool to inform decision making through which a representative high seas MPA network could be designed in a cost-effective, transparent and defensible way.[365] However, to improve the ability of systematic conservation planning to more fully represent knowledge about marine life and important places, it will be most effective within a composite selection approach that combines site selection based on scientific and expert knowledge and stakeholder consultation.

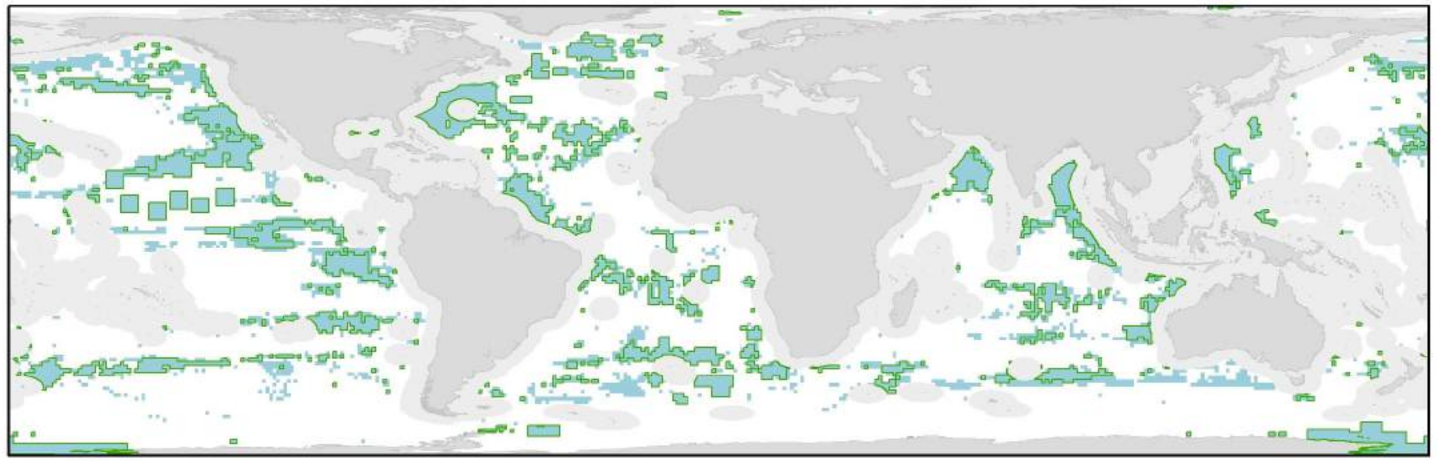

***Figure 4:** Areas of importance for meeting conservation targets based on the selection frequency of each planning unit for 30% (outlined green areas) and 50% (solid blue areas) coverage of all conservation features with management units locked in/out. Results are based on 200 runs with a BLM of 0. Only planning units selected in ≥75% of solutions are shown.*

Key areas selected by Marxan and their conservation features

As Figure 4 shows, Marxan selected many places as important for meeting the conservation targets we set. From them, we highlight and describe 16 key areas within the high seas as examples. These key areas were chosen to provide examples from around the world based on planning units selected in more than 90% of planning solutions when conservation targets were set to 30% coverage of each conservation feature. We chose ≥90% as the threshold to highlight those places that are selected as being irreplaceable in almost all planning solutions. For some cases, clusters of nearby areas were grouped for the purposes of description, such as the Equatorial Pacific region (number 2 on Figure 5), the area South of the Galápagos (number 3) and the Sala y Gomez Ridge (number 4).

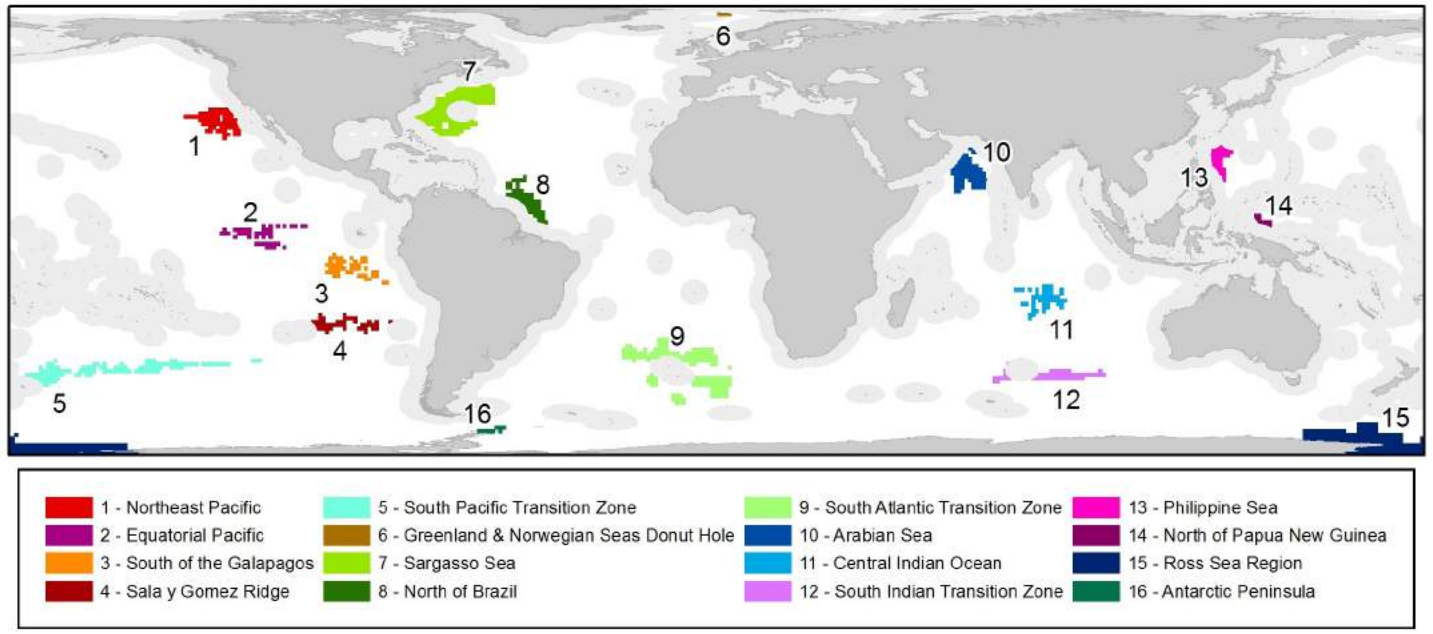

***Figure 5:** Example areas key to meeting set conservation targets. Each colour represents areas considered as one unit. Numbers should be cross-referenced with the table on pp74–77 which provides more information on the conservation features included in each key area.*

Information on, and conservation features within, example key areas described in Figure 5. Numbers should be cross-referenced with Figure 5.

	Ocean area	Conservation features represented			
		Oceanographic features	**Species**	**Biophysical features**	**Biogeographic regions**
1.	North Pacific	High net primary productivity Area of high interannual variability in long-term sea surface temperature (i.e. areas with species and communities potentially well adapted to variability and future change) Area of low interannual variability in long-term sea surface temperature (i.e. areas potentially buffered from future change)	17x Shark and rays 23x Cetaceans 11x Tuna and billfish 3x Other fish 1x Pinniped 1x Turtle	Seamounts Cold-water corals High seabed complexity	3x Pelagic provinces 2x Mesopelagic ecoregions 1x Bathyal benthic province 2x Abyssal benthic provinces
2.	Equatorial Pacific	High sea surface temperature gradient High net primary productivity Area of high interannual variability in long-term sea surface temperature (i.e. areas with species and communities potentially well adapted to variability and future change)	24x Shark and rays 23x Cetaceans 11x Tuna and billfish 3x Other fish 1x Turtle	Seamounts High seabed complexity	2x Pelagic provinces 1x Mesopelagic ecoregion 3x Bathyal benthic provinces 2x Abyssal benthic provinces
3.	South Pacific	High net primary productivity	25x Shark and rays 24x Cetaceans 13x Tuna and billfish 4x Other fish 1x Turtle	Seamounts High seabed complexity	2x Pelagic provinces 3x Mesopelagic ecoregions 1x Bathyal benthic province 1x Abyssal benthic province
4.	South Pacific	Area of low interannual variability in long-term sea surface temperature (i.e. areas potentially buffered from future change)	18x Shark and rays 24x Cetaceans 13x Tuna and billfish 5x Other fish	Seamounts Cold-water corals High seabed complexity	2x Pelagic provinces 1x Mesopelagic ecoregion 2x Bathyal benthic provinces 1x Abyssal benthic province
5.	South Pacific	High sea surface temperature gradient High net primary productivity Area of high interannual variability in long-term sea surface temperature (i.e. areas with species and communities potentially well adapted to variability and future change) Area of low interannual variability in long-term sea surface temperature (i.e. areas potentially buffered from future change)	15x Shark and rays 29x Cetaceans 12x Tuna and billfish 7x Other fish 1x Pinniped 1x Turtle	Seamounts Cold-water corals High seabed complexity	2x Pelagic provinces 2x Mesopelagic ecoregions 2x Bathyal benthic provinces 1x Abyssal benthic province 1x Hadal benthic province
6.	Arctic	High sea surface temperature gradient Downwellings Area of high interannual variability in long-term sea surface temperature (i.e. areas with species and communities potentially well adapted to variability and future change)	9x Cetaceans 2x Other fish 1x Pinniped	Seamounts High seabed complexity	1x Pelagic province 1x Mesopelagic ecoregion 1x Bathyal benthic province 1x Abyssal benthic province
7.	North Atlantic	High sea surface temperature gradient High net primary productivity Area of high interannual variability in long-term sea surface temperature (i.e. areas with species and communities potentially well adapted to variability and future change) Area of low interannual variability in long-term sea surface temperature (i.e. areas potentially buffered from future change)	22x Shark and rays 30x Cetaceans 12x Tuna and billfish 7x Other fish 1x Turtles	Seamounts Cold-water corals High seabed complexity	3x Pelagic provinces 3x Mesopelagic ecoregions 1x Bathyal benthic province 1x Abyssal benthic province
8.	North Atlantic	N/A	22x Shark and rays 21x Cetaceans 11x Tuna and billfish 2x Other fish 1x Turtles	Seamounts	1x Pelagic province 2x Mesopelagic ecoregions 1x Bathyal benthic province 1x Abyssal benthic province

	Ocean area	Conservation features represented			
		Oceanographic features	**Species**	**Biophysical features**	**Biogeographic regions**
9.	South Atlantic	High sea surface temperature gradient Downwellings Area of high interannual variability in long-term sea surface temperature (i.e. areas with species and communities potentially well adapted to variability and future change)	18x Shark and rays 34x Cetaceans 11x Tuna and billfish 9x Other fish 4x Pinniped 1x Turtles	Seamounts Hydrothermal vent fields Cold-water corals High seabed complexity	4x Pelagic provinces 4x Mesopelagic ecoregions 2x Bathyal benthic provinces 4x Abyssal benthic provinces
10.	Indian	High net primary productivity Area of low interannual variability in long-term sea surface temperature (i.e. areas potentially buffered from future change)	22x Shark and rays 19x Cetaceans 10x Tuna and billfish 4x Other fish 1x Turtle	Seamounts	2x Pelagic provinces 3x Mesopelagic ecoregions 1x Bathyal benthic province 1x Abyssal benthic province
11.	Indian	Area of high interannual variability in long-term sea surface temperature (i.e. areas with species and communities potentially well adapted to variability and future change)	24x Shark and rays 17x Cetaceans 11x Tuna and billfish 7x Other fish	Seamounts High seabed complexity	2x Pelagic provinces 2x Mesopelagic ecoregions 1x Bathyal benthic province 1x Abyssal benthic province 1x Hadal benthic province
12.	Indian	High net primary productivity Area of low interannual variability in long-term sea surface temperature (i.e. areas potentially buffered from future change)	14x Shark and rays 29x Cetaceans 11x Tuna and billfish 8x Other fish 2x Pinniped	Seamounts Hydrothermal vent fields	2x Pelagic provinces 2x Mesopelagic ecoregions 1x Bathyal benthic province 1x Abyssal benthic province
13.	North Pacific	Area of low interannual variability in long-term sea surface temperature (i.e. areas potentially buffered from future change)	24x Shark and rays 9x Cetaceans 11x Tuna and billfish 3x Other fish	Seamounts High seabed complexity	1x Pelagic province 1x Mesopelagic ecoregion 1x Bathyal benthic province 1x Abyssal benthic province 1x Hadal benthic province
14.	North Pacific	Area of low interannual variability in long-term sea surface temperature (i.e. areas potentially buffered from future change)	21x Shark and rays 11x Cetaceans 10x Tuna and billfish 2x Other fish	N/A	1x Pelagic province 1x Mesopelagic ecoregion 1x Bathyal benthic province 1x Abyssal benthic province
15.	Southern	High sea surface temperature gradient Downwellings High net primary productivity Area of low interannual variability in long-term sea surface temperature (i.e. areas potentially buffered from future change)	14x Cetaceans 4x Other fish 6x Pinniped	Seamounts Hydrothermal vent fields Cold-water corals High seabed complexity	2x Coastal ecoregions 2x Pelagic provinces 1x Mesopelagic ecoregion 1x Bathyal benthic province 3x Abyssal benthic provinces
16	Southern	Downwellings	11x Cetaceans 3x Other fish 6x Pinniped	Seamounts Hydrothermal vent fields Cold water corals High seabed complexity	2x Coastal ecoregions 1x Pelagic province 1x Mesopelagic ecoregion 1x Bathyal benthic province 1x Abyssal benthic province

The high seas network design

Figure 6 shows example MPA network designs for the high seas based on coverage targets of 30% and 50% for each conservation feature.[iii] These designs have been chosen because they meet coverage targets for all the conservation features we included with the lowest cost. However, multiple network configurations of MPAs can be designed to meet the same coverage targets with similar costs. As the ones shown are not the only possible designs they are included as examples that might inform initial stakeholder consultations.

These example high seas MPA network designs cover 41.8% of ABNJ when the target set was to include 30% of each conservation feature in designs, and 59.2% for a 50% target. They achieve good latitudinal and longitudinal representation across all ocean areas suggesting that although there are gaps in our knowledge of the high seas, it is possible to gather globally distributed spatial data on conservation features to inform MPA network design. Nonetheless, given that there are data gaps, conservation features should be supplemented by existing detailed knowledge from experts and stakeholders in a composite selection approach.

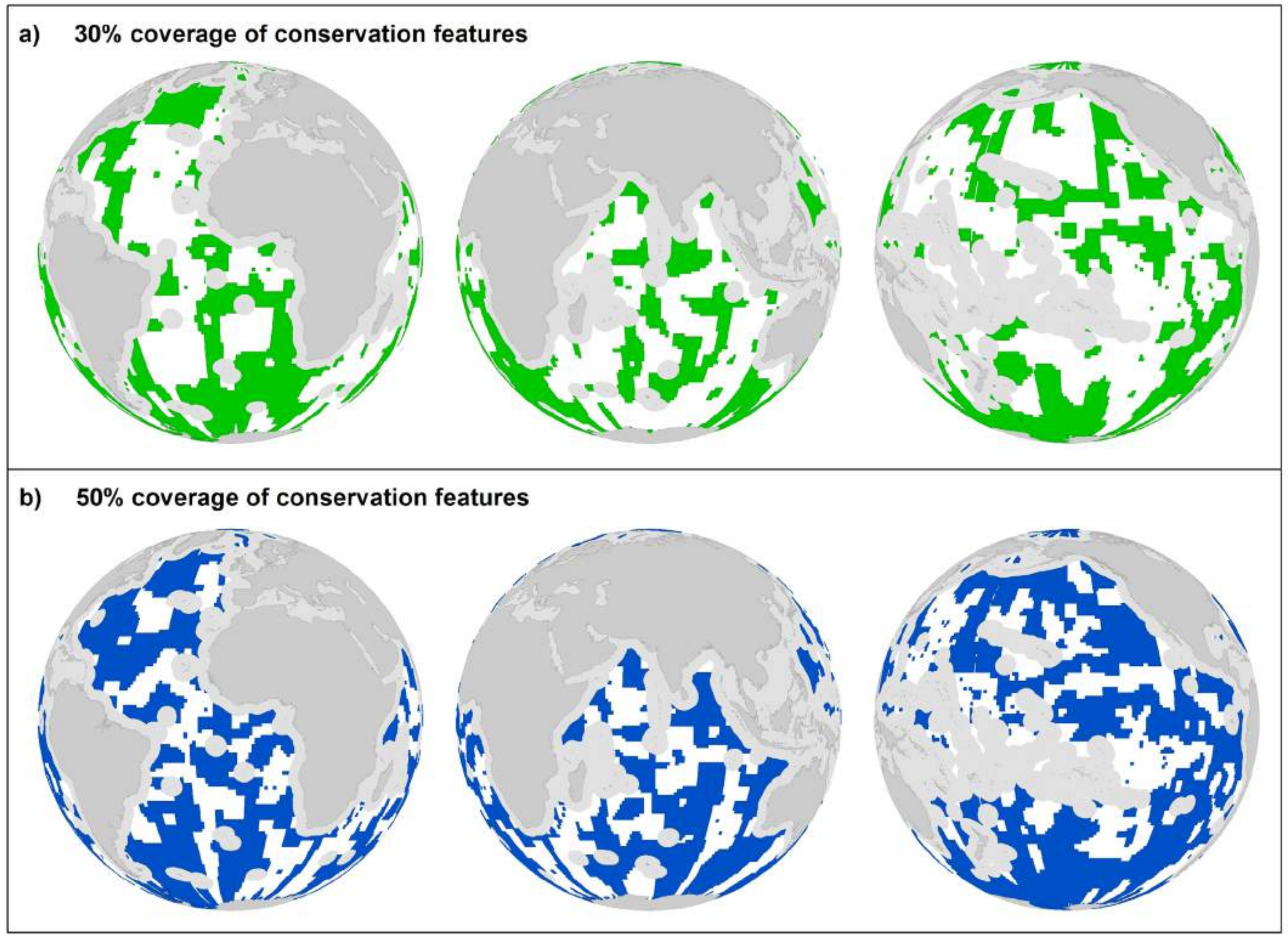

Figure 6: Example MPA network designs for (a) 30% and (b) 50% coverage of each included conservation feature with existing management units locked in/out. Based on the 'best' solutions identified by Marxan. BLM was set at (a) 0.050 and (b) 0.025. Penalty factors were (a) 825 and (b) 1,400.

The MPA network configurations that emerge from high coverage targets reverse management and conservation practices typical of coastal systems. With high target coverage levels there is a transition from small protected areas embedded within extensive areas of human use to nets of protection with embedded zones of human use. This approach produces large, reticulated and contiguous areas of high seas MPAs which could facilitate connectivity over long distances, and partly addresses problems of conservation for wide-ranging and migratory ocean-going species like tunas or whales.[366] Such designs also increase the likelihood that ecosystem structure, processes and services will be safeguarded and create corridors and stepping stones that allow space for wildlife to adapt to changing environmental conditions, while also protecting refuges of last resort.

When coverage targets were set at 30%, Marxan included within the example MPA network design 35.5% of the area in which high seas fishing fleets operated between 2015 and 2017. With 50% coverage targets, the example network design covered 54.2% of the recent high seas fishing footprint. However, because fishing effort is not uniform across space, and because we applied a cost to planning units with high fishing effort (hours spent fishing) to ask Marxan to avoid the most valuable units for fishing wherever possible, actual fishing effort was affected less by example MPA network designs. For the 30% coverage target scenario, 22% of the total number of hours spent fishing would be displaced by the example MPA network design shown (Figure 6a), while for the 50% coverage, this was 32% (Figure 6b).

The example MPA network designs for 30% and 50% conservation targets cover 6% and 10% of areas earmarked for deep-sea mining. However, when we ran Marxan without considering mining (i.e. by locking out areas leased and reserved for mining and locking in APEIs in the Pacific), network designs covered 41% and 60% of leased and reserved areas. This suggests that many mining licences have been granted in areas which are important for representing our conservation features, and that have high value to biodiversity or ecosystem function.[367, 368]

The knock-on socio-economic effects of high seas MPA designation will differ in nature from those for coastal waters. For example, high seas fishing vessels already travel large distances to fishing grounds, and therefore redirection to alternative fishing grounds following MPA creation may not cost more in terms of fuel and time spent to access them. Furthermore, fishery landings from ABNJ only account for <5% of annual marine catches and human exploitation of the high seas is limited to wealthy countries and industrial corporations.[369, 370, 371] While there will be a cost to high seas fishing fleets from large-scale MPA designation, there are also large potential global and national social, economic and ecological benefits that may arise from high seas protection.[372, 373, 374, 375] Through their conservation of marine life, high seas MPAs could therefore help reduce inequality and redistribute fisheries benefits to countries not exploiting ABNJ, and provide greater global benefits through preservation of ecosystem services.

Selecting and implementing high seas MPAs

As discussed earlier, we consider that a composite site selection approach based on expert knowledge and stakeholder consultation combined with systematic conservation planning would best ensure network designs that fully represent high seas marine life. As part of this approach, outcomes from stakeholder consultations could be used with systematic planning to iteratively revise network designs to make sure conservation targets are still met, expert knowledge is incorporated, and social and political acceptance is achieved. This approach was successfully trialled in rezoning Australia's Great Barrier Reef Marine Park.[376]

In some cases, places identified as having high irreplaceability, such as the Sargasso Sea (Figure 4 and Figure 5), might form stand-alone MPAs.[377] Others might form kernels around which larger MPAs could be built or, in the case of the Sala y Gomez/Nazca Ridge, high seas MPAs could straddle existing MPAs within national waters.[378] High seas MPAs could also be used to bolster national marine management and conservation efforts by moving the high seas fleet further from EEZ boundaries, thereby increasing the chances of survival for fish moving outside national waters, and helping to reduce the likelihood of illegal incursions.

High seas MPA network designs must be developed to not only accommodate present conditions but also take into account rapid alterations in ocean conditions from climate change, ocean acidification, and their related effects.[379] Given the changes already being experienced by the oceans, together with those predicted, it is certain that marine ecosystems of the future will be different to those of today. That said, uncertainty in likely rates and patterns of change in mean conditions, and in variability at local and regional scales, make direct predictions of change challenging, particularly given that unforeseen ecological outcomes are also likely to arise from species' range shifts and subsequent ecosystem restructuring.[380]

[iii] While each example network can be described in terms of area coverage, effect on fishing effort displacement and coverage of mining areas, for example, it is important to note that these results are not directly comparable. That is, relationships may not be drawn between the two scenarios. This is because the settings (i.e. boundary length modifier and penalty factors) of the problems given to Marxan for the two different scenarios, 30% and 50% coverage, have been altered and therefore the optimisation calculation that Marxan runs is different.

Our network designs deal with environmental change and uncertainty in three ways:

- By portfolio building (i.e. representing a range of habitats, places and conditions across the world's oceans) as a bet hedging/risk reduction approach[381]
- Through large coverage which promotes connectivity, stepping stones and corridors for travel[382, 383]
- With the novel use of historical sea surface temperature data to identify areas of relatively high and low natural variability which represent ecosystems that may be inherently resilient to, or buffered from, future change[384, 385]

The effectiveness of all high seas management, including MPAs, as well as monitoring, control and surveillance will be directly related to the mechanisms and governance structure established by the new UN-negotiated international legally binding instrument. While technology will make it increasingly easier to monitor human use of ABNJ, the political will to sign and ratify, and then adopt and enforce MPAs and management measures will be required.[386, 387] In reality, coordinating the selection, establishment and management of a joined-up global high seas MPA network in a composite selection approach is probably impossible within the current fragmented regulatory framework. That view is supported by the failure, despite years of trying, to protect specific places such as the Sargasso Sea under the present governance system.[388] A new global institutional framework developed through an international legally binding instrument for ABNJ will therefore be required to facilitate MPA selection, establishment and management. Collaborating in MPA design across jurisdictions has also been shown to lead to substantial efficiencies over uncoordinated action.[389, 390] Taking a global, rather than regional, approach to high seas MPA design through this new global institutional framework, would help minimise the total area that any future high seas MPA network would cover and its associated socio-economic impact.

Finally, effective high seas biodiversity protection will also require greatly enhanced management ambition and capacity outside of MPAs. The international legally binding instrument for ABNJ currently being negotiated by the UN presents the opportunity to augment and strengthen the ability of organisations that manage different areas of the sea and the human activities in it to effectively adopt and enforce sound regulations. This would give industry clearer direction as to where it can and cannot operate, while delivering sustainable management in areas that remain open to human use.

Yellowfin tuna, Pacific
© Paul Hilton/Greenpeace

CONCLUSIONS

1. Systematic conservation planning offers a key tool to inform decision making through which a representative high seas MPA network could be designed in a cost-effective, transparent and defensible way.
2. Setting coverage targets at the level of individual conservation features means that overall coverage of MPA network designs will be larger than the targets used.
3. The spatial extent of MPA network designs that emerge from high coverage targets reverses MPA designation practices typical in coastal systems. There is a transition from small protected areas embedded within extensive areas of human use to large nets of protection with embedded zones of human use.
4. Change and uncertainty arising from climate change, ocean acidification, and their related effects, can be dealt with in the MPA design process by: (a) portfolio building as a bet hedging/risk reduction approach; (b) having large coverage which promotes connectivity, stepping stones and corridors; and (c) representing ecosystems that will respond differently to future change.
5. Systematic conservation planning enables MPA network designs to be optimised to reduce socio-economic impact. For instance, example network designs presented here only displaced 22% and 32% of recent fishing effort for the 30% and 50% coverage target scenarios respectively due to the cost applied to planning units with high fishing effort. However, there is a need for sustainable management outside any MPA network to mitigate potential effects of displacement and ensure that activities are not shifted to or concentrated into more vulnerable areas.
6. Existing spatial management in the high seas can be complemented strategically by future MPA designations to achieve conservation targets. However, many mining licences have been granted in areas with high importance for representing conservation features and that have high value to biodiversity or ecosystem function. Given the likely impacts of mining, areas earmarked for exploration and exploitation should be re-evaluated so as not to constrain conservation.
7. Systematic conservation planning tools can only inform the development of an MPA network as factors not captured within input data layers, such as additional socio-economic considerations or expert knowledge, will affect designs.
8. A composite MPA selection approach that combines bottom-up site selection and stakeholder consultation with systematic planning will result in a high seas MPA network design that best meets conservation targets for features with spatial data, addresses spatial data gaps with expert information, and has greatest social and political acceptance.
9. A new global institutional framework will be required to lead MPA selection, establishment and management.
10. Taking a global, rather than regional, approach to high seas design would help minimise the total area coverage needed to meet protection targets and reduce associated socio-economic impact of any future network.

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The high seas form a vast global commons that covers 61% of the area of the ocean and 73% of its volume. They encompass an astonishing 43% of the Earth's surface and occupy 70% of the living space on our planet, including land and sea. These international waters are home to a stunning wealth of marine life and ecosystems, and by virtue of their enormous expanse, are essential to the healthy functioning of planet Earth. But in recent decades that life has dwindled under the rising impact of multiple human stresses, prompting an historic effort by the United Nations to increase protection and reform management.

Ocean sanctuaries are a key tool for protecting habitats and species, rebuilding ocean biodiversity, helping ocean ecosystems recover and maintaining vital ecosystem services. This report shows that it is entirely feasible to design an ecologically representative, planet-wide network of high seas protected areas to address the crisis facing our oceans and enable their recovery. The need is immediate and the means readily available. All that is required is the political will.

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