Government
Office for Science

Foresight

Foresight Future of the Sea

A Report from the Government Chief Scientific Adviser

Contents

Ministerial Foreword

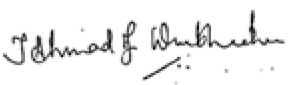
The UK is a leading maritime nation. We have a proud history of exploration, innovation, and marine science that dates back to the expeditions of Captain James Cook aboard the HMS Endeavour. In many ways the UK's accomplishments at sea have helped to build our modern world.

The sea remains a key part of our life in the UK and across our Overseas Territories. It supports tourism, livelihoods and trade. Its beautiful environment captures our imagination, and underpins life on Earth.

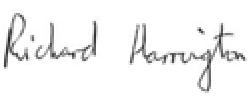
However that relationship is ever-changing. Autonomous vessels and other emerging technologies are creating a new generation of economic activity. The marine environment is under threat from climate change, pollution and over-fishing. It is vital that, as a nation, we are able to proactively respond to these changes, and be prepared to meet new challenges and take advantage of new opportunities. That is why, as we grow our marine and maritime economy, tackle climate change and pollution, implement the Blue Belt, and improve our sustainable use of resources, we welcome this timely report from GO-Science.

The UK can flourish, building on our many strengths to create a thriving 21st century marine and maritime economy and leading the global response to environmental change. As ministers, we are already looking to this future. We have set out policies that reduce plastic pollution and continue to play a leading role in negotiating international measures to reduce harmful emissions from ships. We encourage the development of autonomous technology, have established marine protected areas, and expanded our scientific understanding of the sea. However there is more to be done. This report shows the opportunities on offer if we are ambitious, and underlines the benefits of co-operation between departments, sectors, and nations to deliver on this ambition.

The UK has a great history at sea, and we are committed to delivering a successful future.



Lord Ahmad,
Minister of State for the Commonwealth and United Nations, Foreign and Commonwealth Office



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Preface

The sea is critical to the UK, and its future will fundamentally affect ours. Science and innovation will have an important part to play in shaping that future.

Science holds the key to understanding the impact of a changing marine environment, and informing our response to it. Emerging technology will bring opportunities for new marine industries to develop and stimulate economic growth. It will also improve our marine science capability, not least through the marine autonomous vehicles that will allow us to observe and map previously unexplored places.

This report brings together the evidence to inform the UK's response to a diverse range of global challenges and opportunities. To be successful, it is clear that industry, science and policy will need to work together. Countries around the world are recognising the growing importance of the sea and the need to take a strategic approach to managing their marine interests. There are many opportunities for science, industry and policy to collaborate more closely to achieve greater marine exploration, protection and economic output. They all have a shared interest in a productive, healthy and well-understood sea. However, to be successful it is therefore important that the UK has the necessary coordination mechanisms in place.

The UK has world-leading marine scientists and institutions. This report is the product of this excellence. It reflects the best available evidence across a range of disciplines, including 11 peer-reviewed evidence papers and thought pieces by industry leaders. We are grateful to the many people who have given their time, not least attendees at our expert meetings and workshops in coastal communities. In particular, we would like to thank the other members of the project's expert advisory group for their considerable input and insight throughout.

Sir Mark Walport,
Government Chief
Scientific Adviser
(2013-2017)

Professor Ian Boyd,
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- Professor Angela Hatton, National Oceanography Centre
- Professor Gideon Henderson, University of Oxford
- Professor Edward Hill, National Oceanography Centre
- Rear Admiral Neil Morisetti, University College London
- John Murray, Chief Executive of the Society of Maritime Industries

The project team was led by Henry Green and included Amy Chadwick, Jessica Lawrence, Dr Joanna Cagney, Jack Laverick, Amber Cobley, Emily White, Mo Dowlut, Dr Daniel Maxwell, Laurie Mousah, Owen Parsons, Ben Taylor.

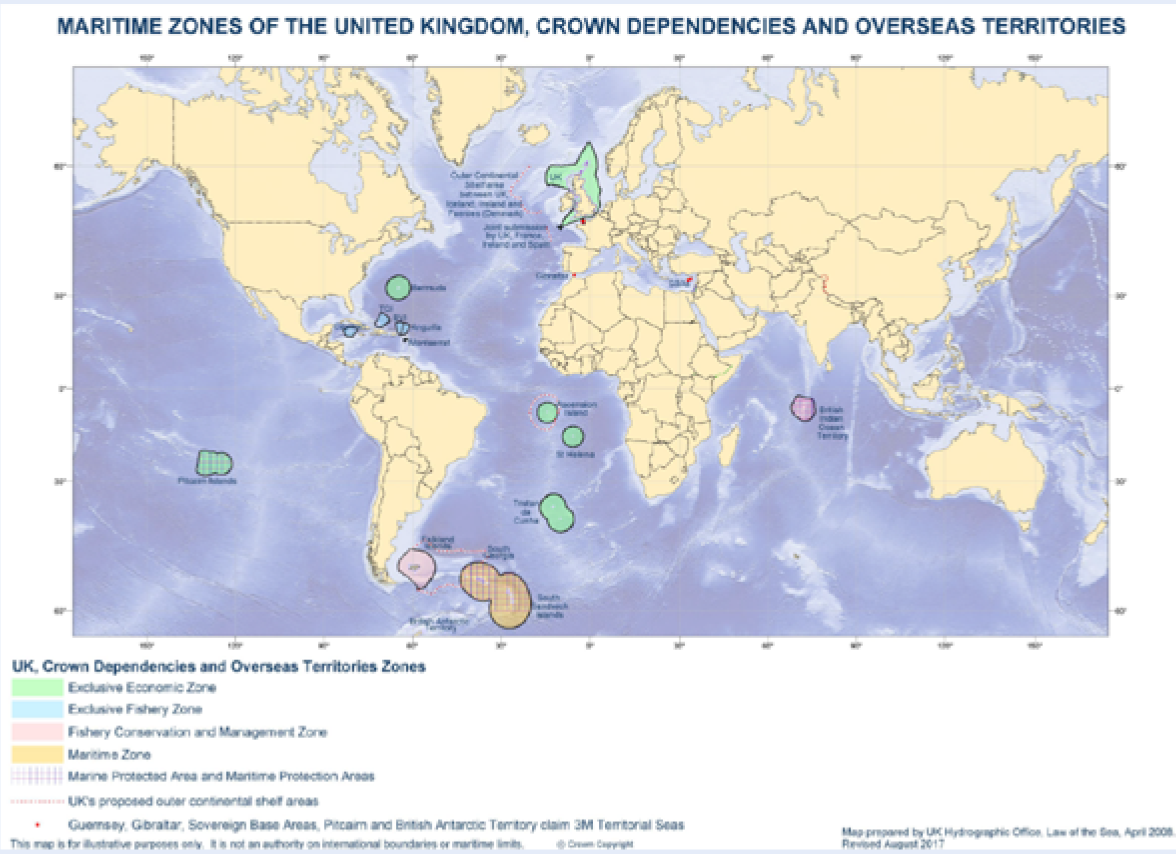
With additional input from Dr Ben Milligan, University College London; Rachael Squire, Royal Holloway, University of London; Zoe Henderson, University College London; Katherine Maltby, University of Exeter; Liz Talbot, Plymouth Marine Laboratory.

Executive Summary

From Captain Cook, to Turner and the Royal Navy, the sea is embedded in our culture and history, but what will it mean for the UK to be successful maritime nation in the 21st century, and beyond? That is the key question that this report seeks to answer.

We anticipate many new opportunities for the UK to benefit economically from the sea, and to show leadership on the global stage. We are well placed to succeed. Including the British Overseas Territories, the UK has one of the largest marine spaces of any country in the world (see Figure 1) – a rich and diverse area that offers new opportunities for exploration, protection and economic activity. Many of the UK's relevant technological and scientific capabilities are world leading. However business as usual is not an option if the UK wants to fully capitalise on these opportunities, and be a successful marine and maritime nation in the future.

FIGURE 1
British Overseas Territories and UK maritime limits



***Source**: UK Hydrographic Office, Law of the Sea (2017 [2008])*

The future sea will be busier, with new technology opening it up for greater exploration and exploitation. Its resources will be more in demand from a growing global population. Its environment is expected to be transformed by climate change, with major implications for the industries and communities that depend on it, both in the UK and globally. These trends expose **four structural** issues that the UK, often in partnership with the rest of the world, must address in order to adapt and succeed in the future.

First and foremost is our 'sea blindness', a widespread lack of understanding of the sea and its value. This is best demonstrated by the fact that the seabed is less mapped than the surface of Mars. The consequence of this is an increased risk of policy makers, industry and the public underestimating the opportunities from the sea, and the implications of damaging its environment.

The second challenge is coordination. Industry, academia, governments and the public all have a stake in the future of the sea, and there are complex inter-dependencies between their interests. A strong, modern economy, coupled with a safe, resilient environment, requires decision making and planning that reflects this. For Government, this means ensuring that policy siloes are avoided, clear strategies are developed and, where beneficial, departments and devolved governments make strategic decisions together. For a successful future of the sea, relevant and enforceable domestic and international legislation needs to be in place – without which the necessary good governance cannot be assured.

The third challenge is ensuring a long-term approach to decision making. This is important from an economic and environmental perspective. While the impacts of climate change are already visible, the marine environment changes over inherently long timescales. This means that the full implications of human activity and policy decisions may not be felt for decades or centuries. Emerging industries also require a long-term commitment in order to be successful. They are often slow to develop, partly as a result of increased costs associated with innovating in the marine environment. They can also require significant infrastructure investment.

Finally, the issues described in this report are overwhelmingly global. The UK shares the marine environment, trade, security challenges and opportunities with its global partners. The long-term success of the UK's marine and maritime interests will, to a large extent, therefore depend upon global action and collaboration. Through our marine science expertise, strategically important industries and diplomatic relationships, we are well placed to take a leading role.

The evidence presented in this report, supports a new, more strategic approach to UK marine and maritime policy – prioritising an improved recognition of the sea and its value, coordination within and between sectors, strategic direction, long-term consistency, and international collaboration. This would guide our response to key upcoming decision points, and ideally be delivering a set of shared principles. Without this, the UK risks missing out on opportunities and being exposed to new strategic threats. This summary report by the Government Chief Scientific Adviser is not a statement of government policy, and the commentary contained within it is not necessarily consistent with existing, or planned changes to policy.

Recommendations

1. ***The UK should develop a more strategic position, with clear priorities, with regards to its marine interests.*** This would underpin all the other recommendations made in this report.

Economy

The global '**ocean economy**' (as defined by the OECD, which includes all maritime, fishing and offshore oil and gas) is projected to double in size to $3 trillion by 2030. It is difficult to measure accurately, but in the UK all the combined sectors are estimated to be worth around £47 billion gross value added (GVA) (~2.7 per cent of total UK GVA). The diverse sectors that rely on the sea range from the established (shipping, fishing, etc.) to the emerging (offshore renewable energy, deep-sea mining, etc.). The UK economy relies on the sea – 95 per cent of trade is seaborne.

Key long-term trends

- ***Growing reliance on the sea for resources*** driven by a growing global population[1] and resource demand,[2] and facilitated by innovations in offshore energy, aquaculture,[3] and seabed mining[4]
- ***Doubling of the global 'ocean economy'*** to $3 trillion by 2030, including strong growth in emerging sectors where the UK has shown leadership, e.g. offshore wind[5]
- ***Busier seas***, including a doubling of global trade by 2031[5] and new infrastructure related to marine resource extraction
- ***Autonomy and robotics*** will improve our understanding of the marine environment, facilitate new and more-efficient economic activity, and pose new challenges for communication at sea and the UK's skills base
- ***Climate change*** and other human activities will compound declining fish stocks, coastal infrastructure, and other economic activities that rely on a healthy and resilient marine environment.

Recommendations

2. ***Identify and work with key sectors to create a long-term platform for UK businesses to capitalise on growing global opportunitie***s for goods and services. These include maritime business services, high-value manufacturing, autonomy and robotics, satellite communication, marine science, and hydrographic surveying and mapping.
3. ***Capitalise on the significant potential of the offshore renewable energy sector***, building on and learning from the UK's experience in offshore wind. Promote innovation and growth in the sector to generate economic growth, build a UK supply chain, reduce emissions to meet UK climate change ambitions, and support local communities.
4. ***Support mechanisms to address insufficient join up*** between the diverse sectors of the marine economy around common research, infrastructure and skills needs. This includes encouraging a collaborative approach to find technological responses to shared needs and to develop shared uses for space and infrastructure.
5. ***Address local issues in coastal communities*** that could limit the potential of the marine economy, particularly meeting changing skills needs in communities that are on average older,[6] and addressing digital and physical connectivity challenges.[7]

6. ***Better capitalise on the UK's science, technology and engineering base*** to ensure the strengths are effectively translated into innovation and growth in the marine economy.

Environment

The marine environment is facing unprecedented change as a result of direct human activity and climate change. Based on current projections, these challenges will have major implications for global biodiversity, infrastructure, human health and wellbeing and the productivity of the marine economy, with direct and indirect consequences for the UK.

Key long-term trends

- ***Marine biodiversity*** will face growing threats linked to human activities. Over-exploitation is the key threat, but will be compounded by climate change. The decline and, in some cases, extinction of marine organisms will damage the long-term health of the oceans and its services, such as carbon sequestration and food provision.
- ***Sea level rise*** is expected to increase the regularity of coastal flooding (especially when coupled with extreme weather events), affecting transport networks, housing and other important infrastructure.[8]
- ***Ocean warming*** of 1.2–3.2°C, depending on emissions, is projected by 2100. Evidence shows that this causes decline in cold-water fish species, coral bleaching, and is likely to lead to new species in UK waters.[9]
- ***Plastic in the ocean*** is projected to treble between 2015 and 2025. Plastic does not decompose, instead breaking down into ever smaller pieces. The full effects are not understood, but there is growing evidence of plastic harming sea creatures and restricting their movement,[10] as well as polluting beaches.
- ***Chemical pollution*** is an ongoing issue, as pollutants can persist in the oceans for decades after their use is restricted by legislation.[11] The list of chemicals deemed to be persistent organic pollutants (POPs) continues to grow.[12]

Recommendations

7. ***Address the key threats to biodiversity*** and protect marine ecosystems to preserve the long-term sustainability of the sea. This will require an internationally targeted effort, focused on improved monitoring and fisheries management, and addressing activities on land as well as at sea. It includes supporting public awareness campaigns about marine protection – addressing the out of sight, out of mind challenge.
8. ***Reduce plastic pollution in the sea***, which is projected to treble in a decade without further intervention. The major response is likely to lie in preventing it from entering the sea, introducing new biodegradable plastics, and potentially public awareness campaigns about marine protection – again addressing the out of sight, out of mind challenge.
9. ***Develop accurate and useful valuations of the marine environment*** through the goods and services it provides (including food, capturing carbon, mitigating flooding, and supporting human health) so that environmental externalities can be made clear and their value incorporated into decision making.

10. ***Ensure the Overseas Territories are resilient to growing environmental risks linked to climate change***. The risk to the Overseas Territories was further exposed by the 2017 Atlantic Hurricanes, and the nature of their economies and locations makes them more vulnerable than much of the UK mainland.

International Engagement

The future of the sea is a global issue. **Stable and effective international governance** is critical for creating the enabling environment for successful marine policy interventions. UK has an important role in many international governance fora and the International Maritime Organization is the only UN body headquartered in the UK. The sea's importance in **international development** was highlighted by the UN Sustainable Development Goal (SDG) 14, which committed to 'conserve and sustainably use the oceans, seas and marine resources for sustainable development'. Approximately 28 per cent of the world's population live within 100 km of the coast, and below an elevation of 100 m.[13]

Key long-term trends

- ***The impacts of climate change***. For example, fisheries loss threatens to destabilise countries that rely on them, and sea level rise is likely to shift coastlines and in some cases threaten the existence of small island states.
- ***The growing value of marine territory*** linked to growing demand for marine resources and new technology to extract and identify them. This creates the risk of growing global tension over existing disputed areas, e.g. in the South China Sea.
- ***A growing ability to monitor illegal activity at sea***. Policing large spaces is inherently problematic, but developments in satellites and other technologies are likely to make policing illegal fishing and other activities easier. This will require robust mechanisms for enforcing the law.
- ***The growing trend for exploration of resources in the deep sea***, which may require new legal instruments.
- ***The potential for global instability*** linked in particular to flooding of low-lying coastal regions, and food insecurity in seafood-dependent regions.

Recommendations

11. ***Promote, support and enforce stable and effective global governance***. UK interests are directly affected by the economy, environment and security of seas around the world. Good governance at global and country levels is therefore critical. The UK is actively engaged in this already but, in line with this report's overall recommendation, would benefit from ensuring a strategic approach in this area that delivers on national priorities.
12. ***Ensure that, when the UK leaves the EU, any new regulation is robust for the long-term challenges and opportunities in the sea.*** Some of the UK's marine interests are currently subject to EU regulation. As the UK leaves the EU, it had the opportunity to reassess its marine priorities and create replacement legislation that reflects this.

13. ***Lead the development of new regulation for emerging industries and technologies*** such as autonomous vehicles and deep-sea mining. This will help to ensure that the UK's economic and environmental priorities are reflected in international law.

14. ***Use UK expertise and technology strengths to build marine capacity in developing countries***. Effective fisheries management in tropical developing countries will be especially important, as a reduction in catch is highly likely,[14] but there are also opportunities from climate mitigation, hydrography and sustainable coastal and marine management practices.

15. ***Ensure international development activities and UK marine priorities are aligned***. The UK is directly affected by what happens in other countries' seas. In the developing world, 60 per cent of people obtain more than 30 per cent of their protein supply from fish,[15] and the projected drop in catch abundance has the potential to lead to political insecurity.[16, 17]

Marine Science

Marine science and research has a crucial role in determining how successfully the world manages many long-term challenges and opportunities. While global collaboration is required, the quality of UK marine science means it is well placed to actively lead these efforts. The opportunities primarily relate to understanding global-scale change, variability and impacts, identifying new marine resources and the implications of their exploitation, improving predictive capability for hazards and disasters, and developing transformational new technologies to facilitate new activity at sea.

Key long-term trends

- ***Rapid, poorly understood changes to the sea***. There is currently insufficient evidence to understand the full implications of the chemical, biological and physical changes described in this report.
- ***Big data and modelling***. Industry projects a 40-fold increase in the amount of data collected annually by 2020.[18] In the sea, this will be supplemented by autonomous vehicles that allow for more regular data collection and greater access to the deep sea and other inhospitable marine environments.[19] This has implications for our understanding and modelling of the marine environment, and for the economy.
- ***The threat from climate change***. This is likely to increase demand for science and research to address uncertainty about its impacts.
- ***Demand for technological solutions to enable autonomy***. Autonomy is likely to be the single most important marine technological development. There are a range of challenges associated with introducing autonomy, including a need for improved battery technology, electric propulsion technology, data transfer and inter-device connectivity.[20]

Recommendations

16. ***Ensure scientific activity is joined up and positions itself to deliver UK priorities***. UK interdisciplinary expertise across the natural, physical, social and health sciences is likely to be critical for global capacity building, sustainably managing marine resources, addressing

key uncertainties relating to the climate and marine environment, and developing the technologies needed for the future marine economy. Science has a key role to play in developing policy and industry. The interfaces between science and policy, and science and industry, should therefore be strengthened.

17. ***Prioritise key research needs:***

- Improved modelling of sea level rise and coastal flooding, to inform planning of infrastructure and reduce uncertainty for coastal communities
- Technologies to enable modern communication at sea, and improve data transfer and battery power
- The interactions between different stressors, e.g. ocean warming and ocean acidification, and their cumulative impact on the marine environment
- The 'tipping points' at which marine ecosystems will be unable to recover from projected damage
- Valuation of marine ecosystems and assets
- A minimum understanding of the environmental impacts of emerging sectors, to facilitate adequate regulation

18. ***Ensure international scientific collaboration***. The shared, global nature of many issues affecting the future of the sea means that there are likely to be significant benefits to UK science from working in collaboration with international partners and multilateral organisations on shared future issues.

19. ***Enable big data to be a driver of innovation***, including ensuring that the UK has the necessary storage capacity, analytical skills, and coordination between sectors and within Government.

20. ***Improve our understanding of the sea*** through UK contributions to systematic, globally coordinated and sustained global ocean observations and seabed mapping. Collecting more information will allow for greater investigation of fundamental long-term and large-scale processes, provide baselines upon which interventions and investments can be grounded, information for sustainable exploitation of natural resources, and improve our understanding of climate change and its impact.

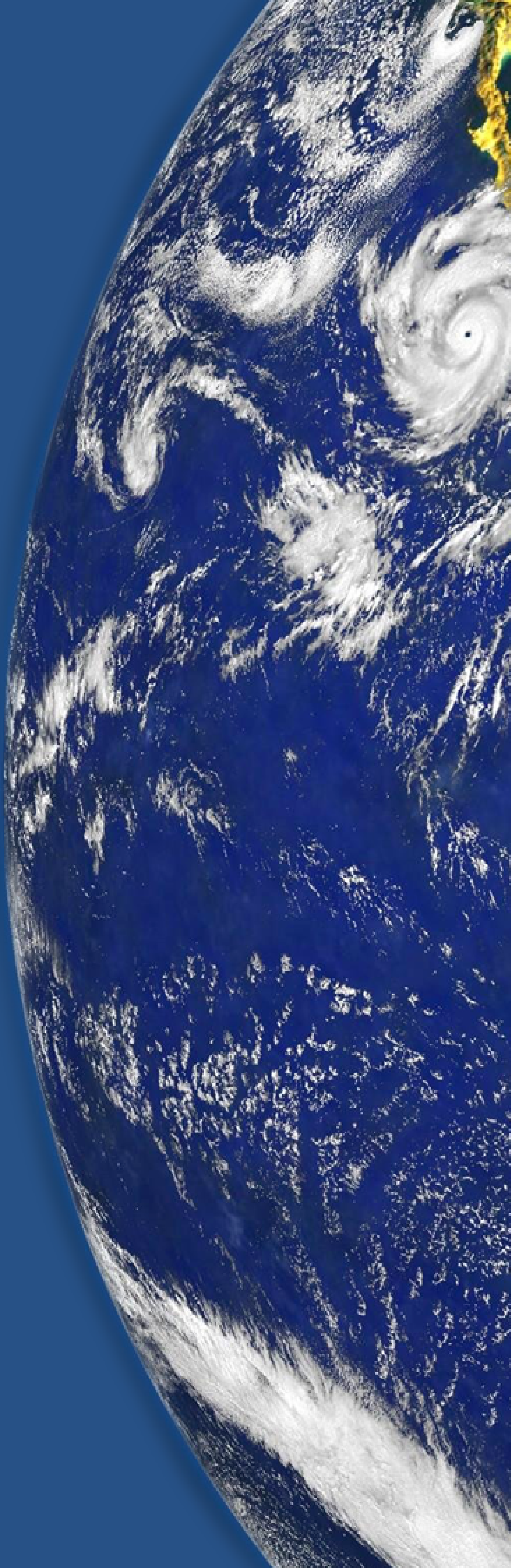
Discussion: Understanding the sea

The rise and fall of the seafloor creates a diversity of underwater terrains and ecosystems, from the sunlit shallows to pitch-black trenches reaching up to 11,000 m below sea level. The sea can be divided into different layers (see Figure 2).

Sunlight Zone (~0–200 m)
Sunlight penetrates this zone to an approximate depth of 200 m. This is the only part of the ocean where photosynthesis happens and hence where food and oxygen is produced.

The Twilight Zone (~200–1000 m)
Below 200 m, sunlight penetration decreases, finally stopping below ~1,000 m. Sunlight intensity in this zone is too low to support photosynthesis, leading some species to move up into the Sunlight Zone to feed.

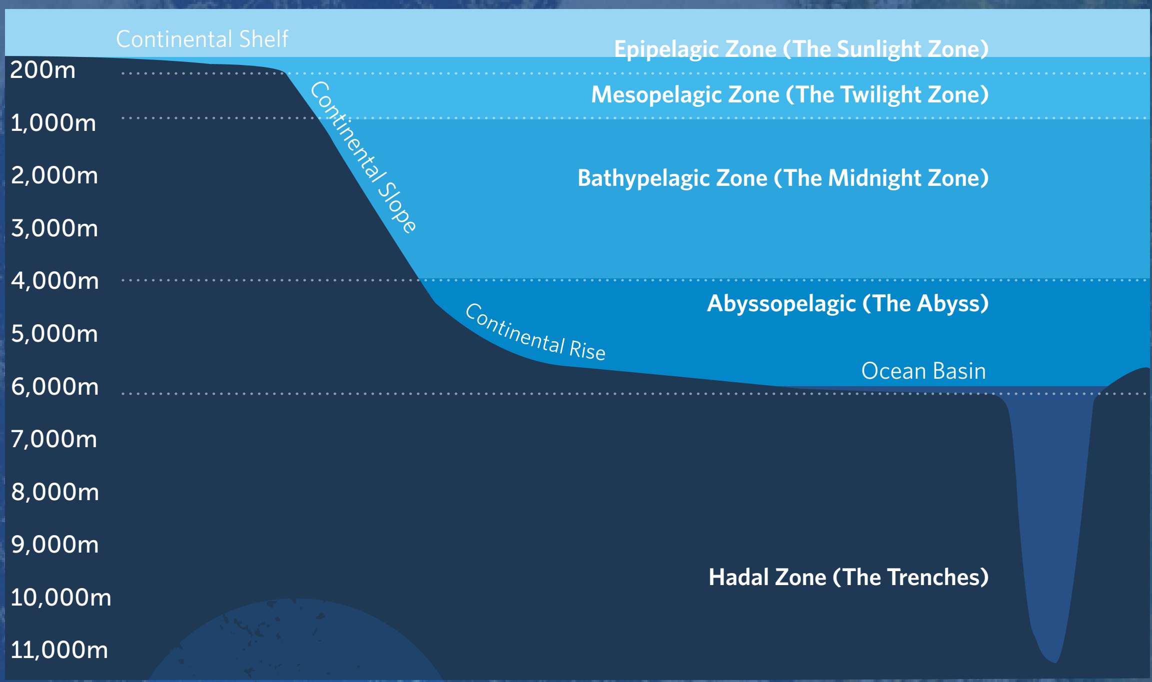
The Midnight Zone (below ~1,000 m)
Temperatures here are near freezing and pressure is more than 400 times greater than at sea level. The only light is from bioluminescent organisms, and life primarily relies on 'marine snow' (dead organic material or faecal matter falling from above). Despite this, diverse ecosystems exist around underwater mountains and hydrothermal vents. Thirty-three deep trenches exist in this zone, primarily in the Pacific Ocean, representing the very deepest places on Earth.



Unlike land, we cannot measure the entire seafloor directly from satellites to a high resolution, and rely instead on sonar attached to marine vessels. This means that while the entire surface of Mars is mapped to ~100 m resolution, our seabed is only entirely mapped to a resolution of 5 km (meaning everything that size or larger is identifiable). Less than 0.05 per cent of the seafloor has been mapped to the level of detail that modern technology allows. It is this high-resolution imagery that would allow us to identify small features, such as coral and wreckages, an issue that hampered the search for the missing Malaysia Airline Flight 370.

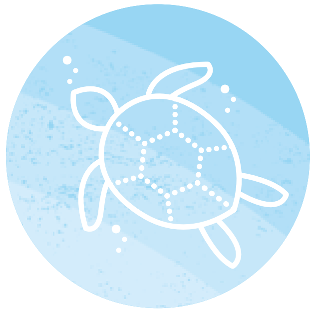
The deep sea is the least studied habitat on Earth.[21] Marine autonomous vehicles offer an opportunity to address this uncertainty. Improving our understanding of the marine environment has a range of benefits. In shallower waters, the UKHO is working with Small Island Developing States to produce the first modern charts of their waters, connecting them to global shipping networks.

FIGURE 2
Ocean Zones



Introduction

The Government Office for Science developed the Future of the Sea project in consultation with colleagues across Government. Its purpose is to inform Government's long-term approach to the sea, and provide evidence and strategic thinking to inform relevant activities by all sectors. To achieve this, it considers three questions:



Why does the sea matter to the UK?

How are the UK's marine interests expected to change?

What are the implications of these changes?

The project has sought to fully answer these questions, and therefore considered the UK's relationship with the sea in the broadest possible sense. As a result, the report summarises evidence on social, technological, environmental, economic and political changes, and is the product of combined expertise from science, industry and policy. Its recommendations are intended to inform future activity.

1.1 Why Does the Sea[i] Matter to the UK?

UK marine and maritime[ii] interests can be divided into three categories: economic, environmental and governance.[iii] These groupings are inter-connected: the marine environment underpins the economy and economic activity is a major determiner of the environmental health (see Figure 3). Effective and stable governance is a key enabler for both and for optimising economic benefit and sustainable ecosystem services (which are co-dependent). As a result, while this report dedicates individual chapters to considering the implications for the Future of the Sea separately in these categories, we have applied the widest range of experience and evidence to each. Information and knowledge mainly derived from science also cuts across all of these categories and it is a key enabler for innovation.

i The terms 'sea' and 'ocean' are often used interchangeably (e.g. sea level rise, ocean acidification) and their definitions can vary. For the purposes of this report we use the word 'sea', apart from in the cases where 'ocean' is used specifically as an accepted term (e.g. ocean warming).

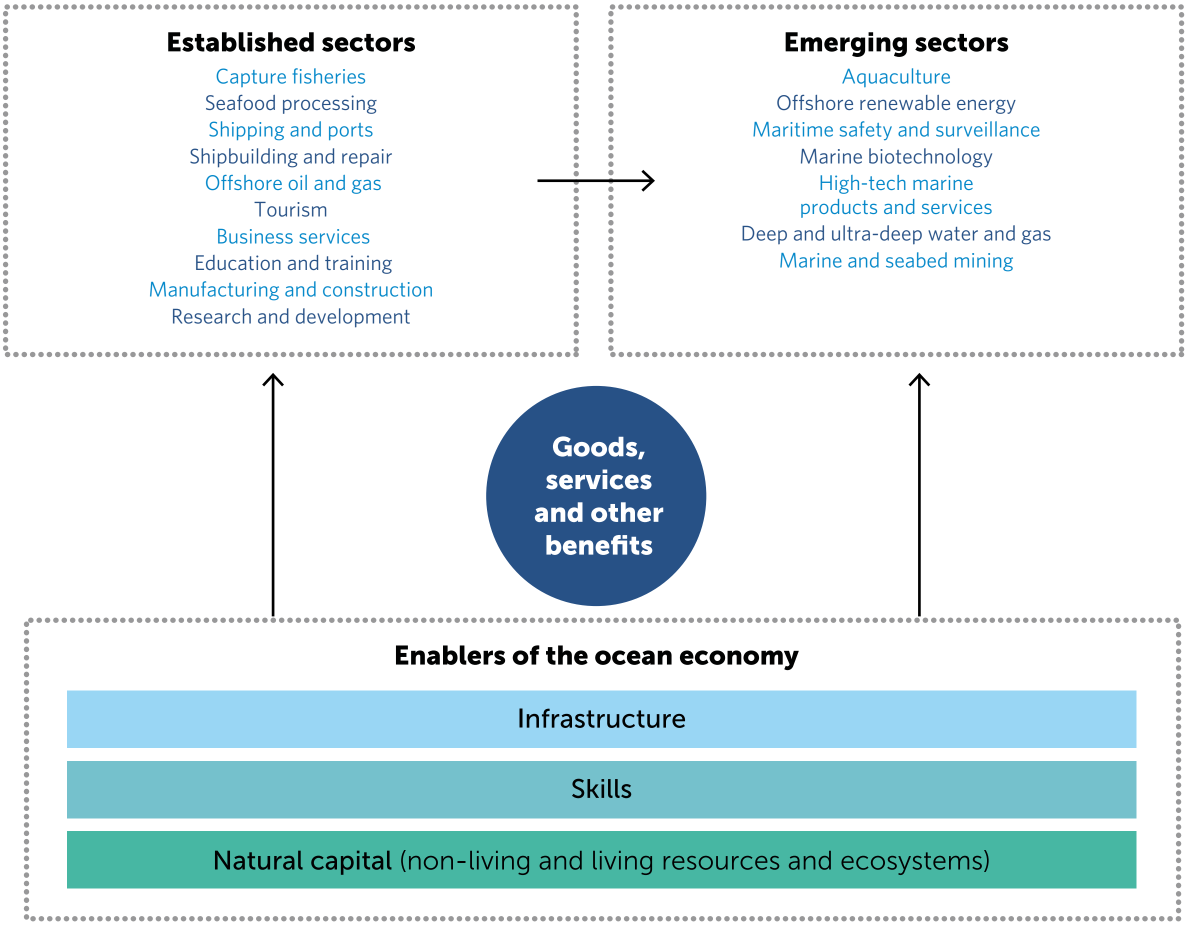
ii The distinction between 'marine' and 'maritime' is not always clear. A general rule is that 'marine' refers to the seas in general, and anything happening in the water, whereas 'maritime' refers more specifically to transportation, shipping and other activities that happen on the water. For the purposes of consistency, this report uses 'marine' as a catch-all term.

iii This report also contains some references to the critical role that the sea plays in domestic and international security but, with a very broad project scope, GO-Science has chosen to exclude some elements of security from this report.

1.1.1 The Economy

- **Directly valuable sectors**. Many sectors depend on the sea. It is difficult to accurately measure this. However based on a simple calculation of the broad range of relevant sectors (including fishing, all maritime activity, and offshore oil and gas), it can be estimated to contribute around £47 billion GVA and employ more than 500,000 people.[22] For comparison, the total value of the pharmaceutical, aerospace and road freight industries was £29.5 billion in 2013.[23] This valuation is based on the combined contribution of exclusively marine sectors (so goes beyond valuations made specifically to maritime), but may be a conservative estimate given there is likely to be a large amount of sea-dependent activity in sectors such as tourism.[iv] Different parts of the UK have their own strengths, for example Scotland is a world leader in aquaculture.

FIGURE 3
The inter-connected nature of the marine economy



iv Reaching an accurate estimate for the value of the marine sectors to the UK is difficult. There have been various estimates previously published. For example, in 2017 Maritime UK published research suggesting that, under their definition of the sector ('the individual shipping, ports, marine and maritime business services industries' – excludes some sectors in the GO-Science calculation, particularly offshore oil and gas) it was worth an estimated £14.5 billion direct GVA and £37.4 billion indirect GVA, in 2015. The Crown Estate estimates that in 2005/06 marine activities generated £46 billion in GDP, and Cefas and the MMO both use an estimate of £38.5 billion for the marine economy in their annual reports (2016/17 and 2014/15 respectively). The different attempts at valuation demonstrate the challenge of fully capturing the value of economic activity that directly relates to the sea. GO-Science has calculated its estimate by totalling published estimations of contributions to UK GVA of the main 'ocean economy' sectors based on the definition used by the OECD (see Figure 7). We will refer to this as the UK's 'marine economy'. See Figure 7 for data sources.

- **Indirect value to the wider economy**. The indirect contribution of the sea is much more fundamental – 95 per cent of UK trade is seaborne,[23] with 48 per cent of food consumed in the UK imported[24].
- **Importance to communities**. Direct economic reliance on the sea varies significantly across the country. Coastal communities are more likely to rely on the sea, but other places in the UK have ocean industries. For example, in 2015 maritime business services contributed £2 billion in UK GVA[25].

1.1.2 The Environment

- **Fundamental to life**. The sea regulates global temperature, is the largest store of carbon dioxide[26] – having absorbed 30 per cent of emitted anthropogenic CO_2 emissions[27] – and produces half of our oxygen.[28] Taken together, the marine environment underpins all life on Earth, as well as the viability of many industries.
- **Biodiversity**. A hugely significant proportion of the sea remains unexplored (see ‘Discussion: Understanding the sea’, page 16). The sea is home to huge biodiversity, with an estimated 91 per cent of the ~2.2 million marine species still undescribed.[29] The UK leads the world in designating and managing Marine Protected Areas (MPAs), with 23 per cent of UK waters protected[30] (more than double the UN’s global target[31]).
- **Ecosystem services**. Marine ecosystems provide a range of important services, from biological assets such as fisheries, to environmental protection and carbon absorption. For example, salt marshes around the UK provide £~1 billion worth of coastal flood defences.[32] These services are an important example of where environmental health directly impacts upon wider UK interests.
- **Health and wellbeing**. There is an important link between human health and wellbeing and the sea. The sea is a key source of nutrition, and fish provide essential protein, oils and minerals.[4] There are also hazards, ranging from physical threats to coastal communities from sea level rise, to risk of ill-health from invasive pathogens and pollution. Some positive benefits to physical and mental health have also been observed from living by the sea.[33]

1.1.3 Governance[v]

- **Law and enforcement**. Domestic and international law is crucial for delivering the UK’s marine and maritime interests. At an expert stakeholder workshop held at Chatham House, there was strong agreement that without effective, strong and up-to-date laws and governing mechanisms, all other activities are compromised.
- **International treaties and organisations**. The UK has an active role in many of the organisations and treaties that underpin global marine governance. The UK is party to the UN Convention on the Law of the Sea, and has observer status on the Arctic Council. The International Maritime Organization is also based in London. The outcome of international legal agreements will be critical to the nature of future resource use.

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v A significant amount of marine policy is devolved. Although this report’s primary purpose is to inform the UK government, we recognise the importance of collaboration with the devolved administrations to deliver many of its recommendations.

- **Domestic governance**. Domestically, the diversity of UK marine interests means that responsibility lies across many different government bodies.
- **Security and defence**. The sea is an important arena in defence. A number of global maritime limits are currently disputed. Appropriately policed sea lanes are necessary to ensure the delivery of legal trade (e.g. energy) and the effective interdiction of illegal activity (e.g. drugs).

1.2 How are the UK's Marine Interests Expected to Change?

This wide range of marine interests is facing an era of potentially unprecedented change, bringing with it major challenges (primarily environmental) and opportunities (primarily economic). GO-Science has worked closely with colleagues in Government, academia and industry to identify the key changes affecting UK interests.

1.2.1 Social

The global population is projected to grow to 9.8 billion by 2050.[1] As a result, demand for energy will nearly double, while food and water demand will increase by over 50 per cent.[2] It is also estimated that by 2050 the demand for minerals may increase by 25 per cent.[34]

Other trends include the following.

- ***An ageing population***.[vi] The number of people aged 60 years and above in the UK is projected to grow from 14.9 million in 2014 to 21.9 million in 2039.[35] This has implications for the UK workforce and vulnerability to climate change, particularly in coastal communities (where people are on average older than in the rest of the UK[6]).
- ***Global migration towards the coast***. Average population density is three times higher by the coast,[36] and growing[37] as a result of urbanisation (large cities tend to be coastal). Twelve of the world's 16 largest cities are within 100 km of the sea.[37] This is likely to increase pollution, fishing levels and vulnerability to sea level rise.[38] The combination could have implications for environmentally sustainability and potentially knock-on effects for the UK through displacement of people.

1.2.2 Technological

Advances in autonomy and other technologies are expected to fundamentally change employment in some marine sectors, and create new opportunities to safely and efficiently explore, monitor and work at sea.[20] This function is supported by technology developments in robotics and artificial intelligence. Other trends include the following.

- ***Increasing reliance on satellites and data sharing***. New opportunities from autonomy are likely to increase our reliance on satellite technology at sea, and create a growing market for data-sharing infrastructure.[20]

vi GO-Science has produced an in-depth report into the implications of the UK's ageing population. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/535187/gs-16-10-future-of-an-ageing-population.pdf

- ***Opportunities from biotechnology***. New research and technological innovation is enabling greater innovations in biotechnology. The potential benefits include growing opportunities to use genetic resources in cosmetics and pharmaceuticals.
- ***Increasing cyber security exposure and risks***. This area is not excluded from the overall trend for increasing global cyber security risk, with threats particularly linked to the growing reliance on digital and autonomous systems.[39]
- ***Alternative fuels for shipping***. In the absence of new technologies to reduce emissions, global shipping could be responsible for up to 17 per cent of carbon emissions by 2050.[40] Industry has identified a growing demand for cleaner fuels and a subsequent search for alternative fuels as one of the major trends affecting sea transportation. [20]

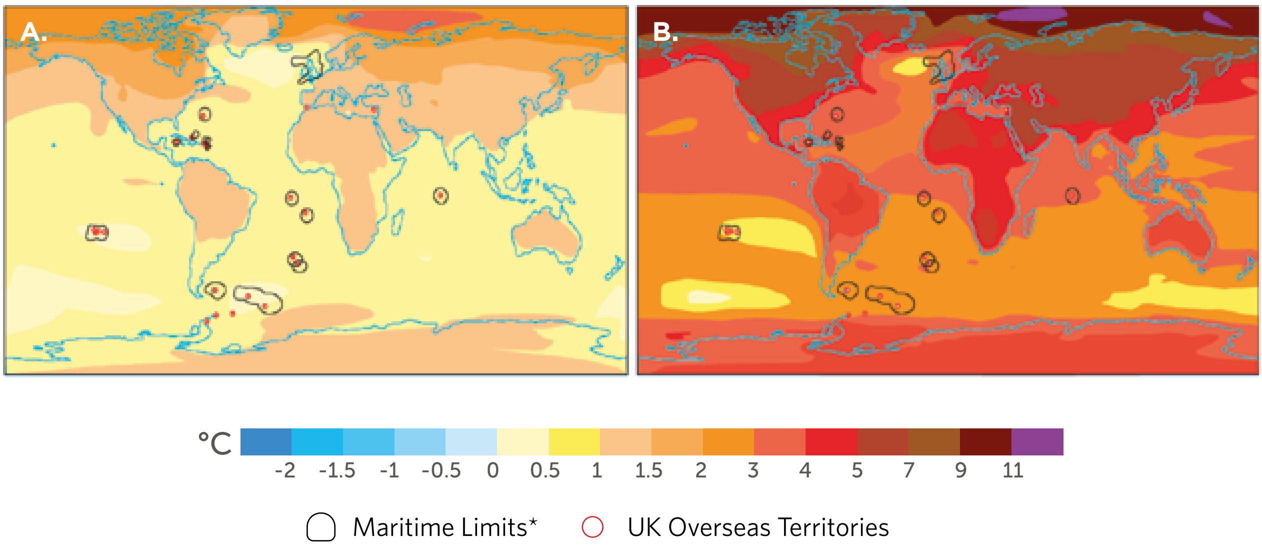
1.2.3 Environmental

Direct human activity (particularly over-exploitation) and, under all IPCC projections, climate change linked to anthropogenic carbon dioxide (CO_2) emissions are changing the marine environment, threatening biodiversity, human health and the marine economy. Specific trends include the following.

- ***Pressure on fish stocks***. Over 31 per cent of global fish stocks are currently fished to biologically unsustainable levels.[41] A growing demand for resources will create challenges for the sustainable management of capture fisheries and increasing aquaculture production, which is growing by 8 per cent globally year on year.[42]
- ***Ocean warming***. Global sea surface temperatures have risen by 0.7°C since pre-industrial times. A further increase of 1.2°C to 3.2°C, depending on emissions, is projected by 2100. Ocean warming has been linked with a high degree of confidence to coral bleaching, species migration and decline in cold-water species.[9]
- ***Rising sea levels***. A combination of melting polar ice and, more significantly, water expansion due to warming led to a global sea level rise of around 20 cm between 1901 and 2010. This is projected to continue rising. Current estimates suggest a further rise of 0.25–1 m by 2100 depending on emissions.
- ***Ocean acidification***. The sea has absorbed very large amounts of CO_2. This decreases the pH levels of sea water, making it less alkaline, threatening the biological processes of many marine species including reef-forming corals. Uptake of CO_2 has decreased ocean pH by 0.1 units over the last 100 years (corresponding to a 26 per cent increase in acidity[27]). By 2100, under medium emissions scenarios, ocean pH is projected to decrease by a further 0.2 pH units.[43] Shellfish, whose ability to form shells is reduced by acidification, are particularly vulnerable.[43]
- ***De-oxygenation***. A combination of nutrient-rich pollutants entering the sea, and rising sea temperatures is increasing the prevalence of excessive blooms of algae that can both smother intertidal habitats and also deplete underwater oxygen levels.[44,45] This can have severe consequences for marine biodiversity and fisheries, causing population declines, reduced reproduction and reduction of suitable habitat.[44,45]

- ***Plastics***. Around 70 per cent of all litter in the sea is plastic, which not only accumulates on beaches and strandlines but also clogs the digestive tracks of birds and fish. Across the globe, we produce more than 300 million tonnes of plastic per annum, and projections suggest that the amount of plastic in the sea will treble between 2015 and 2025. Plastic breaks down into ever smaller pieces, rather than decomposing.[10]
- ***Chemical pollution***. The marine environment continues to be polluted by a number of persistent, bioaccumulative and toxic chemicals (PBTs).[46] An example is polychlorinated biphenyls, once widely used as coolant in electrical goods, which despite a series of bans on their use since the 1970s,[47] are still today found at very high levels in marine mammals such as killer whales.[11]

FIGURE 4
Change in average surface temperature (1986-2005 to 2081-2100) for RCP 2.6 (a) and RCP 8.5 (b), overlaid with a map of the British Overseas Territories



Source: *IPCC, Climate Change 2014: Synthesis Report – Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team: R.K. Pachauri and L.A. Meyer, eds), Geneva: IPCC (2014)*

1.2.4 Economic

The GVA of the global 'ocean economy' (as defined by the OECD) is projected to double to $3 trillion by 2030.[5] This will include significant growth in industries that are UK strengths, for example offshore wind power.[5] Other trends include the following.

- ***Declining employment in some industries***. UK employment rates in some key industries have recently declined. For example, industry estimated that total employment in the UK offshore oil and gas sector would have declined from 440,900 in 2013 to 302,000 in 2017.[48] There is a significant regional disparity to the relevant employment trends in coastal communities.
- ***More trade***. Global trade, which is primarily maritime, is projected to double by 2031.[5] This will lead to busier sea routes and challenge marine spatial planning, especially in parts of the sea with multiple usages.
- ***Emerging sectors***. We are witnessing the potential emergence of completely new sectors, such as deep-sea mining, and the rapid growth of others, such as aquaculture and offshore renewable energy.

1.2.5 Political

Leaving the European Union is likely to have an important effect on the UK's marine interests. A significant proportion of relevant legislation is linked to EU membership, for example the Common Fisheries Policy. Looking forward, the UK is therefore in a position to redevelop a large amount of its policy in this area, should it choose to, and set leading global standards. Other trends include the following.

- ***The growing value of marine space***. Growing demand for marine resources, combined with new technologies enabling greater exploration and resource extraction is likely to increase the value of marine space. The political implications for this are uncertain, but could include increasing marine policy initiatives and growing competition between countries over marine territory.
- ***Global Britain***. The UK's significant marine strengths and interests provide a natural platform for international engagement, at a time when the sea is projected to become a higher priority issue.

The rest of this report considers the implications of these changes.

Discussion: UK Overseas Territories

The UK has specific constitutional and legal responsibility for 14 Overseas Territories (OTs) including ensuring their security and good governance. With the exception of Antarctica, they are all islands or groups of islands. They are extremely diverse, including wealthy communities in Bermuda and the world's most remote population on Tristan da Cunha. There is less evidence on some of the OTs than there is for the mainland UK. Where possible, this report considers the OTs in our overall analysis of the UK (and makes clear where they differ).

Anguilla
This territory in the eastern Caribbean consists of the main inhabited island and a number of smaller uninhabited islands, with a total land area of 91 sq. km. Following the 2001 census the population was 11,430.[49] The tourism and service sectors represent a large portion of Anguilla's GDP.[50]

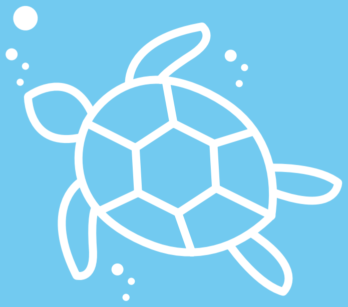
Bermuda
With a population of 64,237 in 2010[51] and having been self-governing since 1620, Bermuda is the most populated and oldest of the OTs. International business activity, and real estate and renting accounted for about 45 per cent of total GDP, which was $5.9 billion in 2015.[52]

British Antarctic Territory
This 1,709,400 sq. km region of Antarctica is six times the size of the UK mainland. There are no permanent residents, with the British presence comprising of three research stations run by the British Antarctic Survey, and a historical base at Port Lockroy.

British Indian Ocean Territory (BIOT)
This region covers an area of 640,000 sq. km of ocean. Within this area there are around 55 small islands, the largest of which is Diego Garcia, used by the UK and US militaries. In 2010, the UK established the BIOT as an MPA, at the time the world's largest.

Cayman Islands
Comprising three islands in the Caribbean Sea, the islands have a total land area of 264 sq. km and a population of 55,456 based on the 2010 census.[53] GDP in 2016 was $2.7 billion,[54] with tourism and finance services accounting for a large proportion of GDP.[55]

The Falkland Islands
These are situated in the Southern Atlantic, with a population of 3,398 recorded during the 2016 census.[56] GDP in 2012 was $282 million, with oil and gas exploration, and fishing underlying the bulk of economic activity.[57]



Gibraltar

This territory is located at the point where the Mediterranean Sea meets the North Atlantic. A total of 32,194 people resided in the 6.5 sq. km of Gibraltar in 2012.[58] GDP in 2014 was around $2 billion,[59] with finance, tourism, and shipping making up the bulk of economic activity.[60]

Montserrat

This is an island in the Caribbean Sea. The population in the 2012 census was 4,992.[61] Following a volcanic eruption in 1995, 73 per cent of island inhabitants left leaving a residual population of only 3,000 in 1998.[62] Volcanic activity continues, with the last eruption in 2003.

Pitcairn Islands

Officially, Pitcairn, Henderson, Ducie and Oeno, these four islands are spread across the southern Pacific between New Zealand and Peru. Only Pitcairn Island is inhabited, with an estimated population of 54 in 2016. The population is sustained by fishing and subsistence farming. Henderson Island was recently found to have the highest density of man-made debris (99.8 per cent of which was plastic) recorded anywhere in the world.[63]

Saint Helena, Ascension and Tristan da Cunha

These islands are spread across the South Atlantic. The 2016 population of all of three was 5,901, with 4,802 living on Saint Helena.[64] Tristan da Cunha is 1,500 miles from the nearest continental land (South Africa).

South Georgia and the South Sandwich Islands

These islands are located in the far south Atlantic Ocean. There are no permanent inhabitants, although the British Antarctic Survey maintains research stations on South Georgia.

Sovereign Base areas of Akrotiri and Dhekelia on Cyprus

Following the independence of Cyprus in 1960, the UK retained sovereignty of Akrotiri and Dhekelia, comprising 157 sq. km.

Turks and Caicos Islands

The Turks and Caicos are two island groups in the Caribbean with a total land area of 311 sq. km.[65] Of the 30 islands, eight are inhabited, with a total population in 2012 of 31,458.[66] GDP in 2013 was around $545 million with the bulk of the economy relying on tourism ($208 million) and financial services ($62 million[67]).

Implications for the Economy

Key findings

This chapter considers the major effects of projected social, technological, environmental, economic, and political change for the UK's major marine economic interests, and the cross-cutting implications of them.

Issue

A growing population, increased demand for resources and technological and environmental change will have profound effects on the marine economy, increasing the UK's reliance on the sea and potentially providing substantial economic growth. This is true for both emerging and established sectors. The UK has many economic strengths; however the changing nature of the marine economy will affect what is needed to retain and capitalise on these competitive advantages in the future. This report also identifies a number of key decision points around how the UK and the rest of the world approaches new industries and technologies, requiring action either now or in the near future.

Response

The UK is well placed to take advantage of the opportunities brought by a growing global ocean economy if it creates the right environment, builds on its research and development strengths, and has a long-term strategy.

In order to capitalise on these opportunities and secure a world-leading position, the UK needs to address issues including a lack of coordination between different stakeholders, economic and environmental uncertainties, the long-term supply of skills and infrastructure, and environmental sustainability. By enabling the UK to respond proactively, we can minimise the risk of missing out on new opportunities and ensure that its businesses can grow and thrive.

The Government recently published its Industrial Strategy, a long-term plan to boost the productivity and earning power of the people throughout the UK."

Recommendations for the UK

2. ***Identify and work with key sectors to create a long-term platform for UK businesses to capitalise on growing global opportunities*** for goods and services. These include maritime business services, high-value manufacturing, autonomy and robotics, satellite communication, marine science, and hydrographic surveying and mapping.

3. ***Capitalise on the significant potential of the offshore renewable energy sector***, building on and learning from the UK's experience in offshore wind. Promote innovation and growth in the sector to generate economic growth, build a UK supply chain, reduce emissions to meet UK climate change ambitions, and support local communities.

4. ***Support mechanisms to address insufficient join up*** between the diverse sectors of the marine economy around common research, infrastructure and skills needs. This includes encouraging a collaborative approach to find technological responses to shared needs and to develop shared uses for space and infrastructure.

5. ***Address local issues in coastal communities*** that could limit the potential of the marine economy, particularly meeting changing skills needs in communities that are on average older,[6] and addressing digital and physical connectivity challenges.[7]

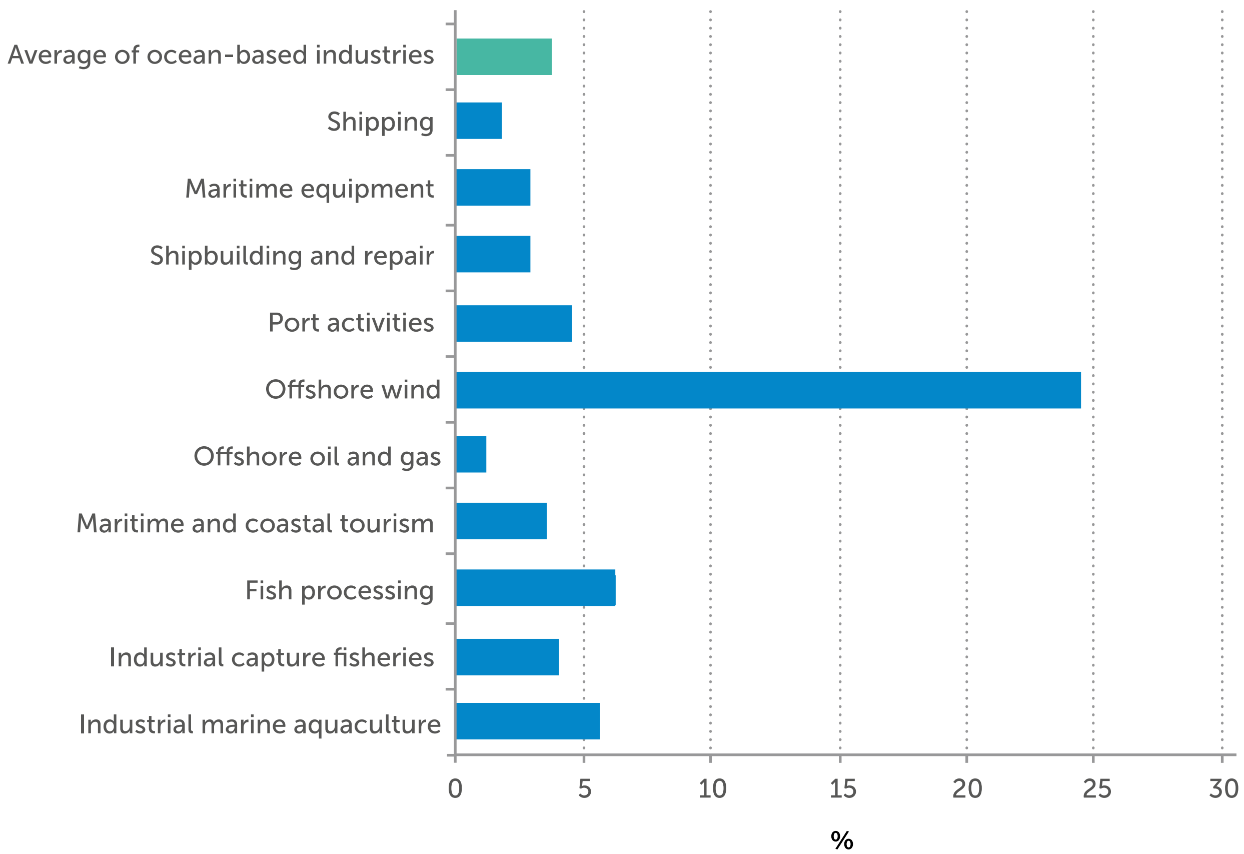
6. ***Better capitalise on the UK's science, technology and engineering base*** to ensure the strengths are effectively translated into innovation and growth in the marine economy.

2.1 Cross-cutting Issues for the Marine Economy

2.1.1 UK Economic Strengths and Opportunities

The UK has the opportunity to capitalise on the fundamental changes that are occurring in the marine economy. By 2030, driven by growing global resource demand, new technologies and other trends described above, many marine industries will have the potential to outperform the growth of the global economy as a whole. Under a business as usual scenario, the OECD projects that the 'ocean economy' will reach US$3 trillion by 2030 (~2.7 per cent of world GDP in 2030), more than double its 2010 contribution to global GVA. This will be driven by particular growth in aquaculture, offshore wind, fish processing, and port activities[5] (see Figure 5).

FIGURE 5
Estimated global industry-specific growth rates in value added, 2010-2030



***Source**: Organisation for Economic Co-operation and Development (OECD), The Ocean Economy in 2030 (2016)*

GO-Science analysis suggests that new opportunities will emerge for the UK to compete globally, export its goods and services, replace jobs lost in certain sectors (e.g. oil and gas, which is re-adjusting to changing market conditions and new technology), meet domestic resource demand and set the regulatory framework for emerging industries. The UK is facing the future marine economy with a number of significant strengths. This includes leadership in strategically important sectors.

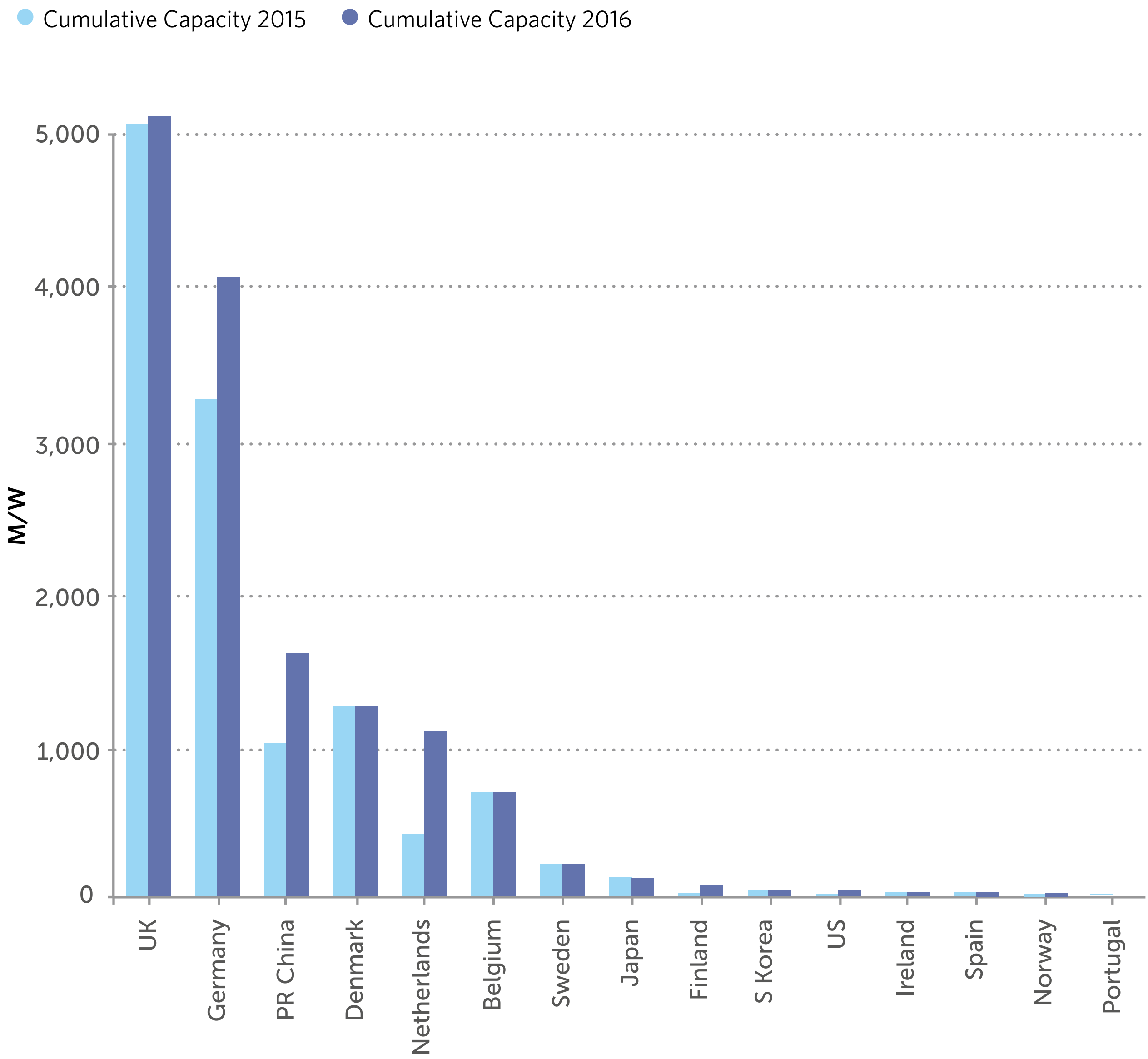
- **Offshore wind** is predicted to be one of the biggest areas of growth globally from 2010 to 2030, both in terms of GVA to the global 'ocean economy' (<1 per cent to 8 per cent) and employment (+1257 per cent).[5] The growth in industrial scale offshore wind farms started in the UK,[68] which has the largest installed offshore wind capacity of any country in the world (36 per cent of global capacity in 2016[69]). Specific opportunities lie in exporting the UK's expertise, for example in operation and maintenance,[70] to growing overseas markets.
- The UK is the global centre for **maritime business services**. In 2013, 26 per cent of maritime insurance policies were written through London.[23] Industry-commissioned analysis suggests that the maritime business services sector directly contributed £2 billion to UK GVA in 2015.[25] British law is the global industry standard and the UK has significant legal and judicial expertise on shipping, insurance and international trade matters, with 25 per cent of maritime legal partners practising in the UK.[71] This puts the UK at the forefront of growing opportunities, particularly in legal and regulatory innovation, for example relating to marine autonomous vehicles.
- The UK shipbuilding industry retains global leadership in **high-value manufacturing**, including defence, research and luxury vessels. Industry expects that the innovations required by environmental regulation may offer new opportunities for the UK's specialised shipbuilding,[20] and Department for Transport has identified the design and manufacture of superyachts, high-end powerboats and sailing yachts as a major opportunity. The UK is also a global leader in **subsea engineering**, a sector the industry values at £8.9 billion a year,[72] with significant export potential and wide-ranging applications.
- The growth in **marine autonomy and robotics** is expected to be the most significant technological development for the marine economy,[20] transforming the majority of marine industries and sectors, notably monitoring and mapping, maintenance of offshore infrastructure, and shipping.[18] The UK has significant relevant research strengths,[73,74] and has a large number of innovative marine autonomy small and medium enterprises

- (SMEs[75]). Industry predicts a global market of $136 billion over the next 15 years with a 10 per cent UK market share,[76] and there are likely to be wider benefits across the economy, and to marine research.[19]
- **Satellite communication** will be a critical enabler for autonomy, and associated expected growth in autonomous shipping and big data collection at sea.[20,77] Satellites are also the major tool for monitoring illegal activity at sea (see page 91). Industry expects a growing focus on improving data transfer between autonomous vehicles and satellites in the next few years.[20] The Satellite Applications Catapult is already capitalising on the UK's strengths in this sector, working with the Pew Charitable Trusts in Chile to monitor illegal fishing off its coastline.
- **Hydrography**. There remains a high amount of uncertainty about the topography of the seabed (see 'Discussion: Understanding the sea', page 16). A significant proportion of the UK's domestic exclusive economic zone (EEZ) is unmapped at high resolution for hydrographic purposes.[78] Almost all activity in the marine environment is at least partly supported by seabed mapping,[78] which provides information on safe shipping routes, marine ecosystems, seabed morphology and movement and marine spatial planning including the safe positioning of offshore infrastructure. Growing economic activity, and growing demand for marine resources, is likely to increase the need for mapping. The UK is a global leader in this field, with the UK Hydrographic Office having primary charting responsibility for 71 countries around the world. This means that the UK has the technical expertise and the global relationships to lead this increasingly important and, due to advances in autonomy, technically feasible activity.

The UK has extensive marine science and research capabilities;[79] it ranked first in Europe and third in world (behind the US and China) for the number of scientific publications in marine science 2010–2014.[80] The growing economic importance of the sea, coupled with significant uncertainty about changes to its environment, is likely to make this increasingly valuable. In 2016, G7 Science Ministers agreed to work together to deliver shared marine research priorities, recognising the importance of international collaboration in this field.[81] Chapter 5 sets out the specific priorities for marine sciences (see page 99).

The UK and the Overseas Territories' large marine area provides a number of long-term opportunities. The large size of many of these regions and their diversity creates new opportunities for scientific research, for environmental protection, and for capitalising on our growing ability to extract resources from the sea, including marine genetic resources, and renewable energy.

FIGURE 6
Global cumulative offshore wind capacity in 2016



***Source**: Adapted from Global Wind Energy Council (GWEC), Global Wind Report 2016,*

2.1.2 Bringing Together Different Sectors

The marine economy is extremely diverse. Many sectors rely on the sea, and new technologies are creating emerging sectors, such as deep-sea mining. These individual sectors have historically struggled[vii] to understand their shared value and make joint representations on mutually important issues.[20] Although the diversity of the individual sectors means that full coordination may be neither desirable nor achievable, they do share a number of common interests.

- **Physical challenges of the sea**. The sea is a large and hostile environment to work in. Imaginative engineering solutions are needed to overcome the large distances, and physical damage from biofouling, waves and tides, and corrosive salt water present when operating in the marine environment. For example, the large distances create unique communication challenges that are not experienced by land-based industries. As a result the offshore wind farm Greater Gabbard, which is 23 km off the Suffolk coast, requires three 45 km long export cables to bring power onshore.[82] There are also concerns that the increased risk of testing technology in the sea can increase costs.[83]
- **Shared technological solutions**. Different marine sectors rely on many of the same technologies; at a basic level, these relate to shipping and navigation. Moving forward, the growing potential from autonomous vehicles means that data transfer, battery, sensing and communication technology are all going to be of growing importance across the marine economy, particularly as the parts of the economy with easier communication are transformed by the Internet of Things.[84]
- **Historic slow technological adoption**. Industry acknowledges that there has been a tendency across the marine economy to be slow in adopting new technologies.[20]
- **Shared environmental risks**. The different sectors are all, in some way, threatened by changes to the marine environment. High uncertainty can also lead to precautionary regulation which can increase costs and reduce the probability of success. Industry is also a key player in ensuring the future health and stability of the marine environment, e.g. in emissions and in the exploitation of biological resources.
- **Skills and infrastructure in coastal communities**. See 'Discussion: Place-based issues for the future of the sea', page 58.

The growing value and importance of the marine economy suggest that, as far as possible, these common needs should be addressed and managed strategically, building on existing initiatives, for example the Maritime Growth Study.[viii] This applies both for industry to capitalise on potential economies of scale, innovate collectively and address common needs, and for Government in developing skills, infrastructure and export strategies.

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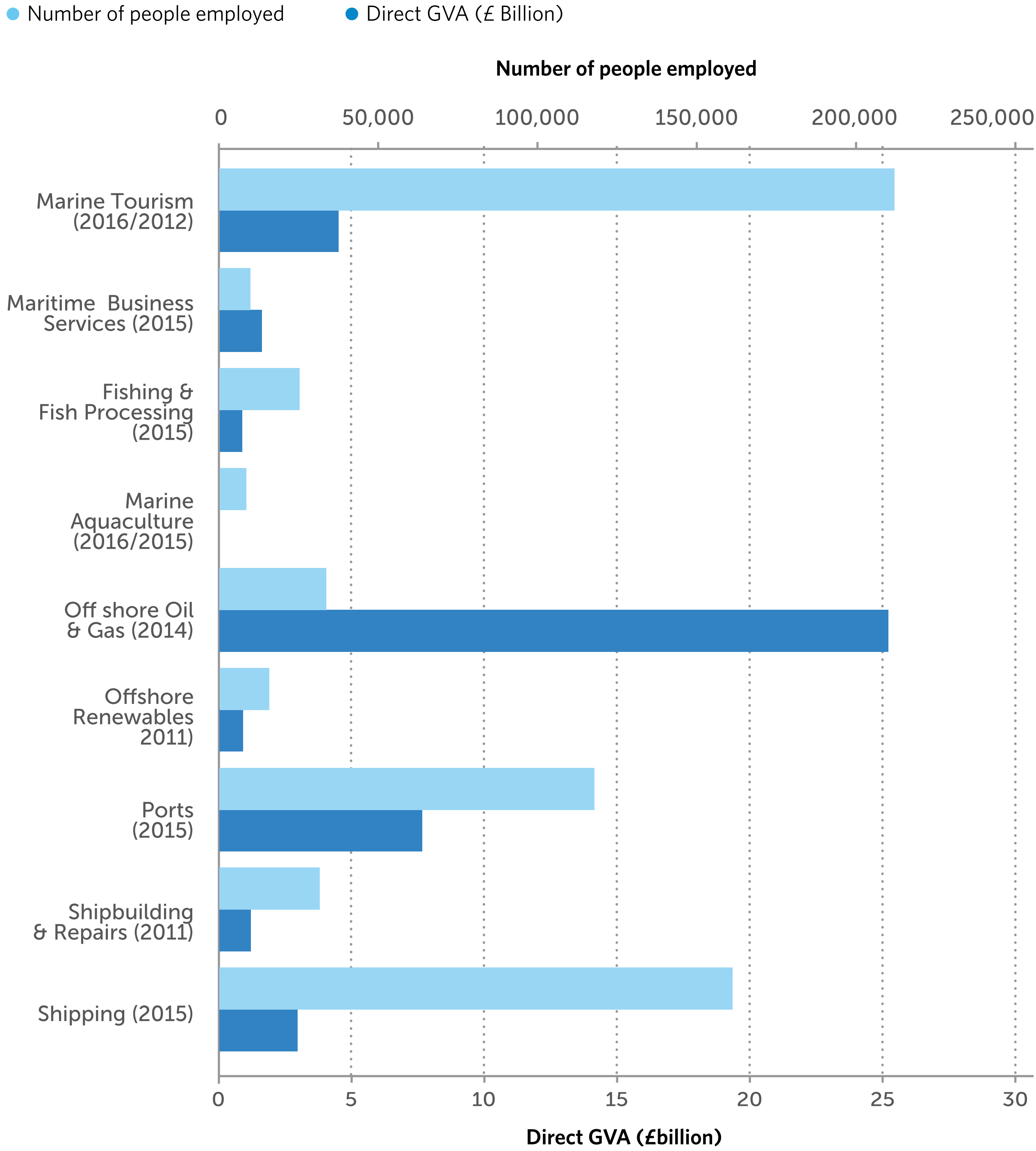
vii There are a number of trade bodies representing different components of the marine economy, including Maritime UK, which was set up to represent the combined sectors following the Maritime Growth Study in 2015.

viii Published in 2015, the study contains recommendations to keep the UK's maritime sector competitive in a global market. In particular, it considers actions relating to sector leadership by Government and industry, skills and domestic and international marketing.

FIGURE 7

Estimated number of people employed and GVA from different UK marine industries[ix]



Sources: *Marine Tourism: GVA: Coastal Communities Fund Annual Progress Report 2016; Employment: Beatty, C., Fothergill, S. and Gore, T., Seaside Towns in the Age of Austerity (Sheffield Hallam University, 2014); Maritime Business Services: Centre for Economics and Business Research for Maritime UK: The Economic Contribution of the UK Maritime Business Services Industry (2017); Fishing and Fish Processing: GVA: ONS, UK Non-Financial Business Economy (Annual Business Survey) (2017); Employment: Seafish, UK Seafood Industry Overview (2017); Marine Aquaculture: GVA: ONS, UK Non-Financial Business Economy (Annual Business Survey) (2017); Employment: Seafish, Seafish Guide to Aquaculture (2016); Offshore Oil & Gas: Oil & Gas UK, Economic Report 2015; Offshore Renewables: Oxford Economics, The Economic Impact of the Marine and Maritime Sector on the UK in 2011/12 (2013); Ports: Centre for Economics and Business Research for Maritime UK, The Economic Contribution of the UK Ports Industry (2017); Shipbuilding and Repairs: Department for Business, Innovation and Skills, Industrial Strategy: UK Sector Analysis (2012); Shipping: Centre for Economics and Business Research for Maritime UK, The Economic Contribution of the UK Shipping Industry (2017)*

ix As discussed above, there is a significant challenge in determining exact figures for individual marine industries. This in part is due to marine-specific activities, for example manufacturing, often being recorded as part of wider activity.

2.1.3 Technological Innovation

New technologies can help to sustainably meet the long-term challenges associated with growing resource demand. For example, marine biotechnology has the potential to provide solutions to food production, cleaner fuel, and the development of new pharmaceuticals[18] and could even be used to genetically engineer coral to be more resilient to bleaching.[85]

The UK has considerable relevant expertise in marine science and technology (see page 99). However, industry reports that the UK struggles to turn these strengths into economic growth, skilled UK jobs and new manufacturing demand.[20] Levels of innovation in general in marine science are also often weak in comparison with other sectors.[20] In some sectors, where the UK leads in terms of expertise and capability (such as autonomy), we are still behind the leading countries in attracting inward investment.[20]

For the UK to retain its current strengths, and lead in the future, it is therefore important that it encourages innovation in marine technology. GO-Science interviewed representatives from a range of marine sectors, who suggested that increased collaboration, the introduction of new funding streams for innovation and designated marine testing zones could all help further promote innovation across the sectors.[20] A collaborative approach to innovation appears particularly important given the opportunities to create the technological response to shared needs and to develop shared infrastructure – for example, floating multi-use offshore platforms, which could allow offshore energy generation to be integrated with aquaculture and leisure facilities.[86,87]

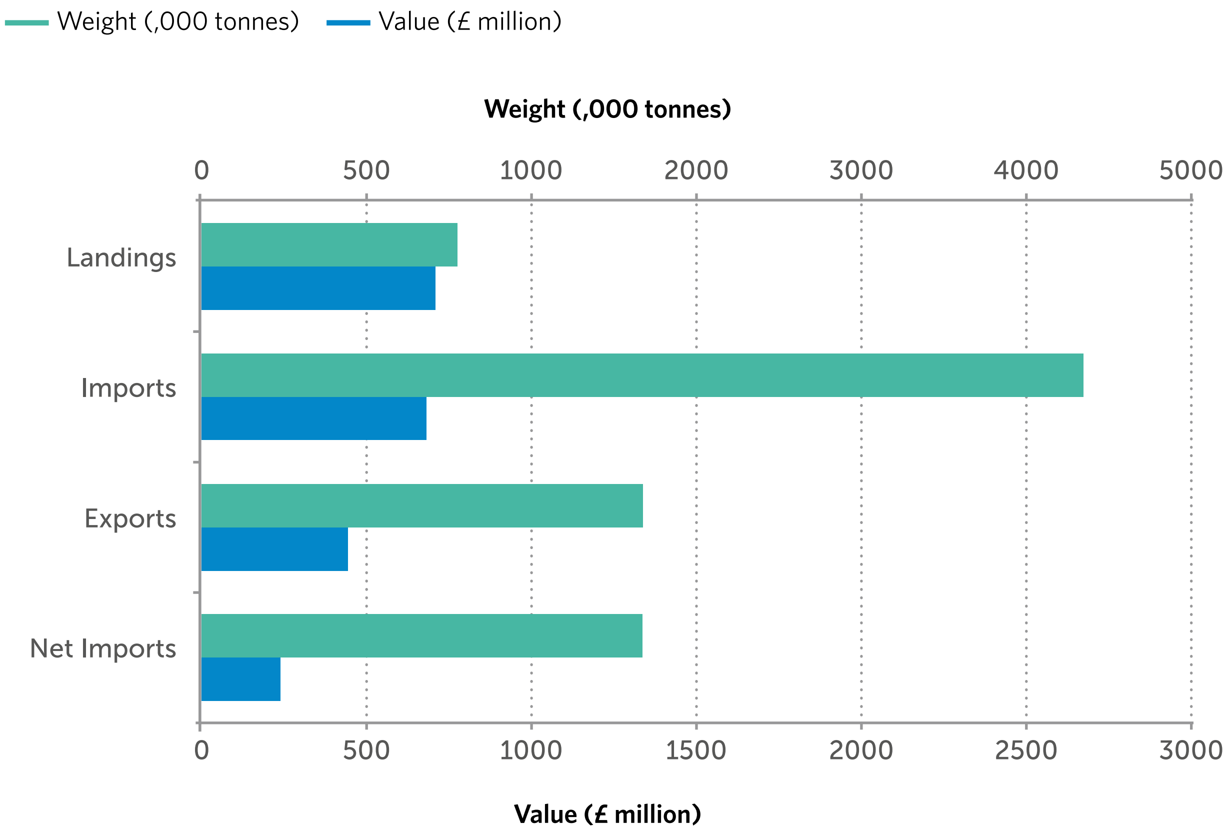
The rest of this chapter explores the evidence for the long-term challenges and opportunities from the perspective of established and emerging sectors.

2.2 Implications for Established Sectors

2.2.1 Fisheries

Fisheries employ around 12,000 fishermen in the UK and the fishing fleet is the second largest in Europe in terms of gross tonnage.[88] Landings into the UK by the home fleet in 2015 were valued at £775 million.[89] Despite increases in fleet fishing revenues in 2016, employment in the fisheries sector has fallen by 6 per cent since 2005 and the amount of fish landed declined by 7 per cent from 2014 to 2015.[90] The UK also has a significant fish processing sector, which contributed £594 million in GVA in 2015[91] and supports 13,554 jobs. Sixty per cent of full time employment in the seafood processing sector is located within Humberside and the Grampian region of Scotland.[92]

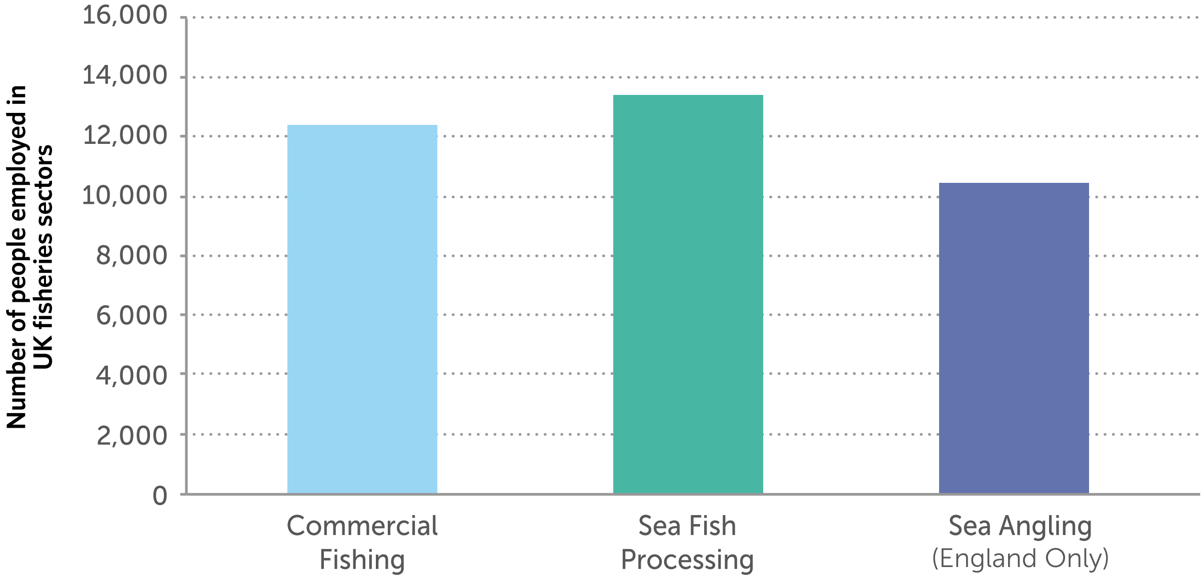
FIGURE 8
Fish landings, imports and exports in 2015; NB, Fish landings are by the UK fishing fleet into UK and abroad



Source: *Dempsey, N., Rutherford, T. and Allen, G., UK Sea Fisheries Statistics, Briefing Paper 2788, House of Commons Library (2016)*

ix Published in 2015, the study contains recommendations to keep the UK's maritime sector competitive in a global market. In particular, it considers actions relating to sector leadership by Government and industry, skills and domestic and international marketing.

FIGURE 9
UK full time employment for fisheries sectors (2015; 2016; 2012 respectively)



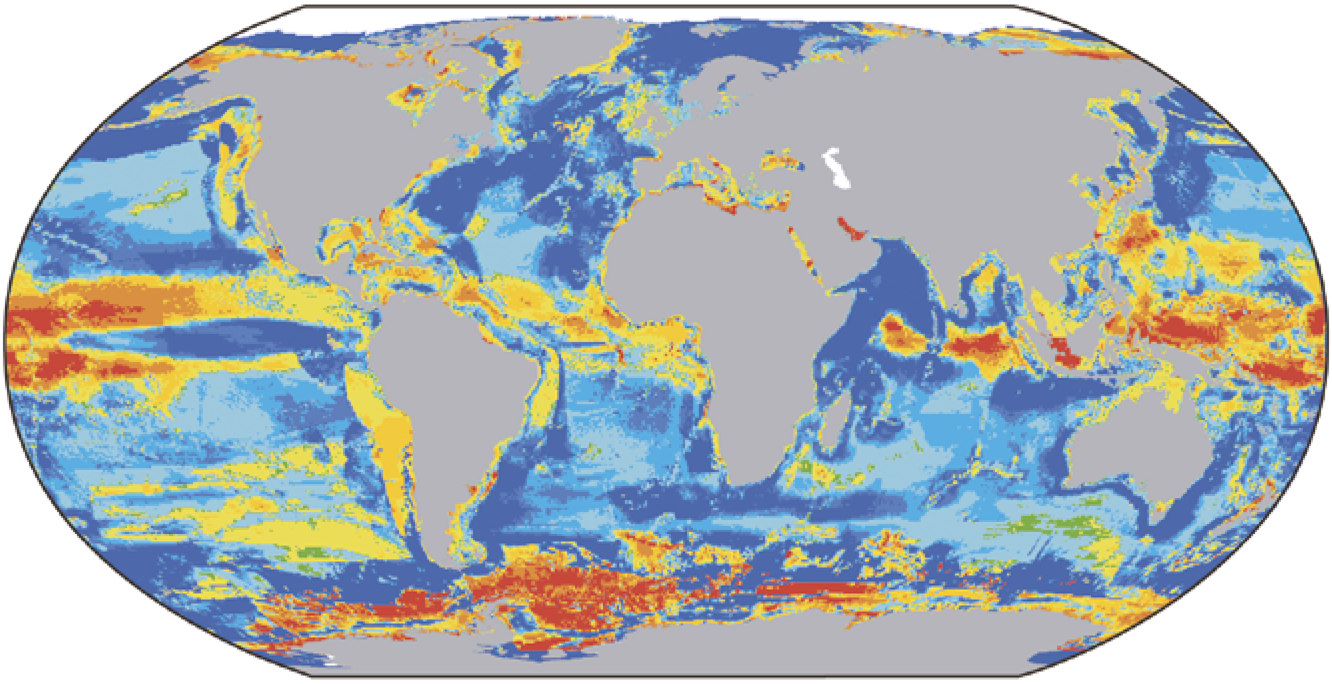
***Sources**: Marine Management Organisation, UK Sea Fisheries Statistics (2015); Seafish, Seafood Processing Industry Report (2016); Armstrong, M., Brown, A., Hargreaves, J., Hyder, K. et al., Sea Angling (2012): A Survey of Recreational Sea Angling Activity and Economic Value in England, DEFRA (2013)*

People in the UK consume on average 20.8 kg of fish per capita per year. This is mostly salmon, tuna, cod and haddock.[93,94] The supply to UK consumers is heavily reliant on imports (see Figure 8); the UK is a net importer of fish and in 2015 imported fish was valued at £2,673 million.[90] China and Iceland are the biggest sources of fish exported to the UK, while the UK exports the largest amounts to France, the Netherlands and Ireland.[90] Commercial and subsistence fisheries also play an important role in the economies and food security of many British Overseas Territories, including the Turks and Caicos Islands, St Helena, and Anguilla. Turks and Caicos for example, rely on fishing of lobster and conch for export to the US; it is the third most important economic sector after tourism and finance.[95]

Several global issues challenge the future productivity and sustainability of fisheries. Overfishing degrades marine biodiversity and ecosystems and affects the sustainability of stocks for future generations. Climate change will increasingly affect fisheries.[96] Ocean warming will lead to alterations in fish species abundances and distributions with potential consequences for productivity and fish availability.[9] Based on the IPCC's projections (Figure 10) the water around the British Isles will be relatively unaffected when it comes to the change in maximum catch potential. However, fisheries in tropical countries, including the Overseas Territories, will be particularly threatened, with a reduction in the abundance of catch highly likely.[97] Small-scale fishermen in those places will also be less able to adapt as fish distributions change in response to climate change, as they are less able to follow the catch due to limited mobility.[98] This also has implications for international development (see page 94).

FIGURE 10

Climate change risks for fisheries: projected global redistribution of maximum catch potential of ~1000 exploited marine fish and invertebrate species; projections compare the 10-year averages 2001–2010 and 2051–2060 using ocean conditions based on a single climate model under a moderate to high warming scenario, without analysis of potential impacts of overfishing or ocean acidification



Change in maximum catch potential (2051-2060 compared to 2001-2010, SRES A1B)

<-50% | -21 to -50% | -61 to -20% | -1 to -5% | no data | 0 to 4% | 5 to 19% | 20 to 49% | 50 to 100% | >100%

Source*: IPCC, Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team: R.K. Pachauri and L.A. Meyer, eds), Geneva: IPCC (2014), Figure SPM.9 (a): 15*

In the UK, new fishing opportunities could arise due to increased abundances of warm-water species (e.g. red mullet),[9] while cold adapted species (e.g. cod) may move northward or decline in their abundance within UK waters.[9] Ocean acidification could also damage shellfish stocks[43] – by 2050, the combined effects of warming and acidification could create losses of ~£87 million per annum for the UK fishing industry.[99] Decreasing and changing fish stocks could also affect the recreational sea angling sector, which contributed £360 million in GVA in England in 2012.[100]

New technology is also likely to affect the industry. For example, the UK has been the testing ground for Inshore Vehicle Monitoring Systems (IVMS), and will soon apply it to large sections of its fishing fleet. IVMS will allow digital management and monitoring of fishing activities, and there is the potential to combine it with marine data loggers, enabling vessels to collect oceanographic data as they fish, with applications for marine science and MPA management. There are wider issues relating to marine data (see page 102).

2.2.2 Offshore Oil and Gas

Fossil fuels currently dominate the global energy landscape. However, increased demand, awareness of fossil fuel emissions' contribution to climate change, and UK Government policy are driving the search for alternative and renewable energy sources.[101] The UK has a large potential renewable energy capacity offshore. In 2015, UK energy supply was predominantly made up of gas (29 per cent), coal (21 per cent), nuclear (19 per cent) and renewables (23 per cent[102]) (Figure 11.a). Of the renewable energy sector, 20.8 per cent of supply was generated through wind power and 3.2 per cent came from hydro, wave and tidal[103] (Figure 11.b).

The oil and gas sector is expected to experience small global growth up to 2030 but this would represent a decline in its relative contribution to the global 'ocean economy' GVA from 34 per cent to 21 per cent.[5] Total offshore crude oil production is predicted to rise relatively slowly from around 25 million barrels of oil-equivalent per day in 2010 to 28 million by 2030, with a similar trend in offshore gas.[5] A downturn in the oil price has led to declining jobs in the UK oil and gas sector (see Figure 12), which poses challenges for communities that rely on the sector. This is an important issue for Scotland – Aberdeenshire is home to 27 per cent of the total UK offshore oil and gas workforce.[104] However there are likely to be significant opportunities for other emerging offshore energy industries to harness the UK expertise in oil and gas.

There are opportunities to access new fuel deposits in the deep sea – 37 per cent of proven oil reserves are offshore and one third of these are in deep water.[5] New technology and exploration using seismic surveys supported by deep-water drilling is uncovering more deposits.[5, 105] However using these deposits would potentially have implications for the UK's climate targets.

FIGURE 11.A
UK 2015 Renewable Energy Supply Mix

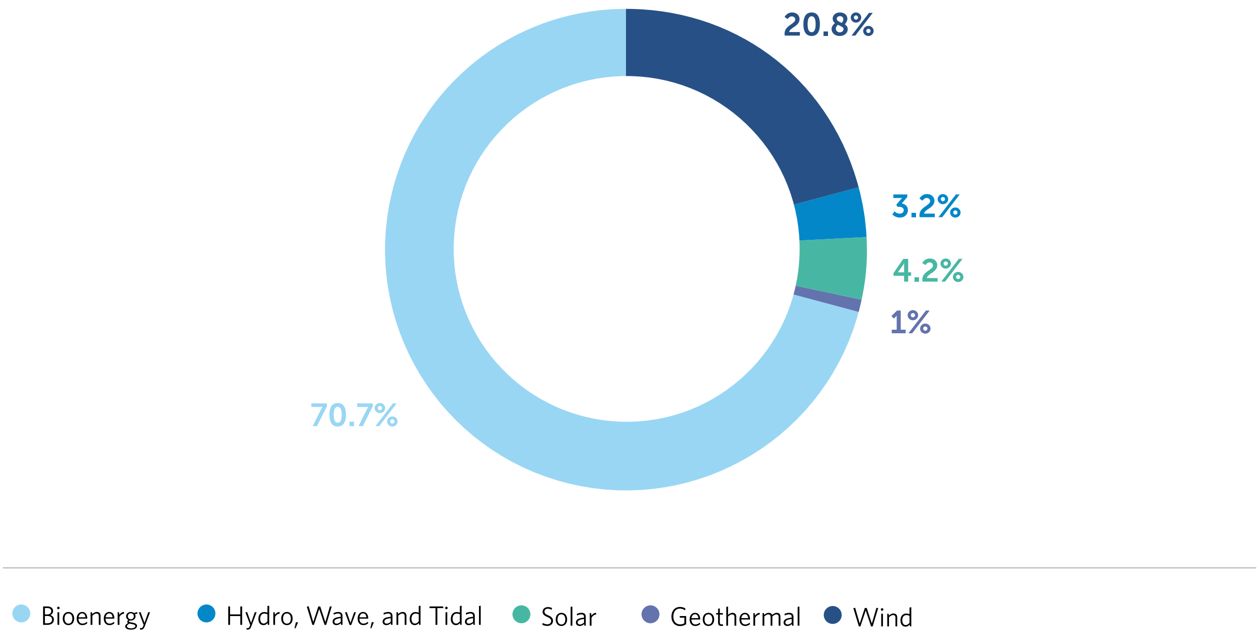
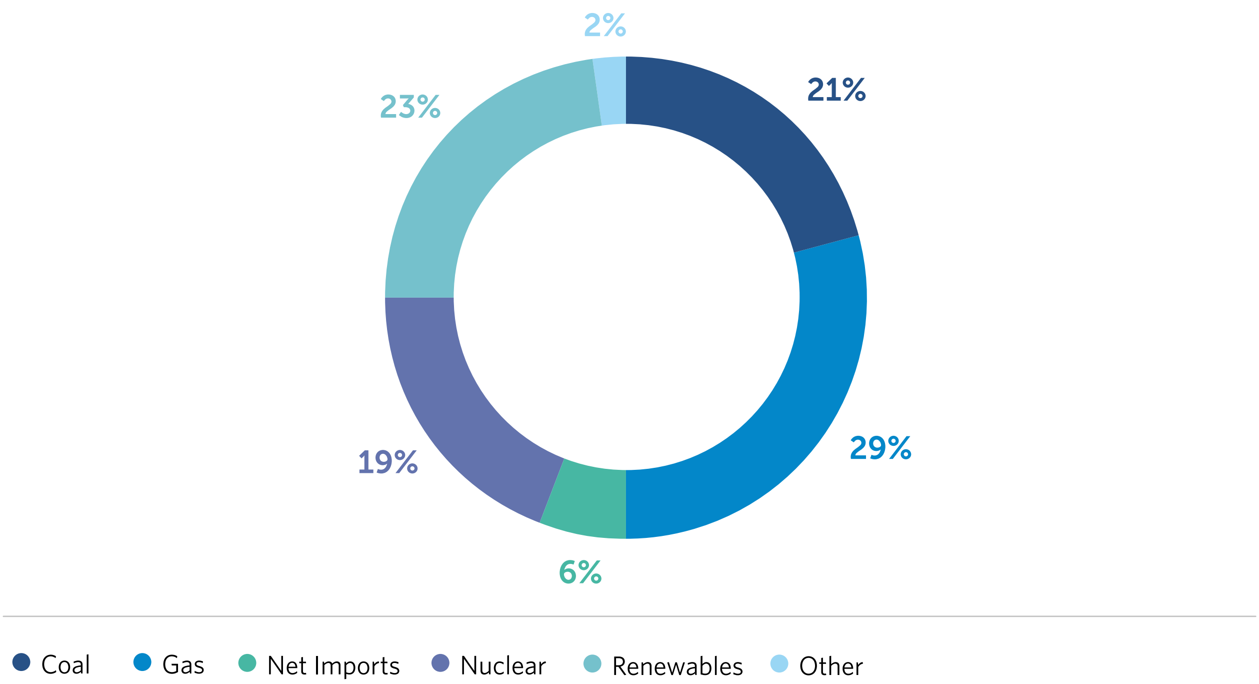


FIGURE 11.B
UK 2015 Energy Supply Mix



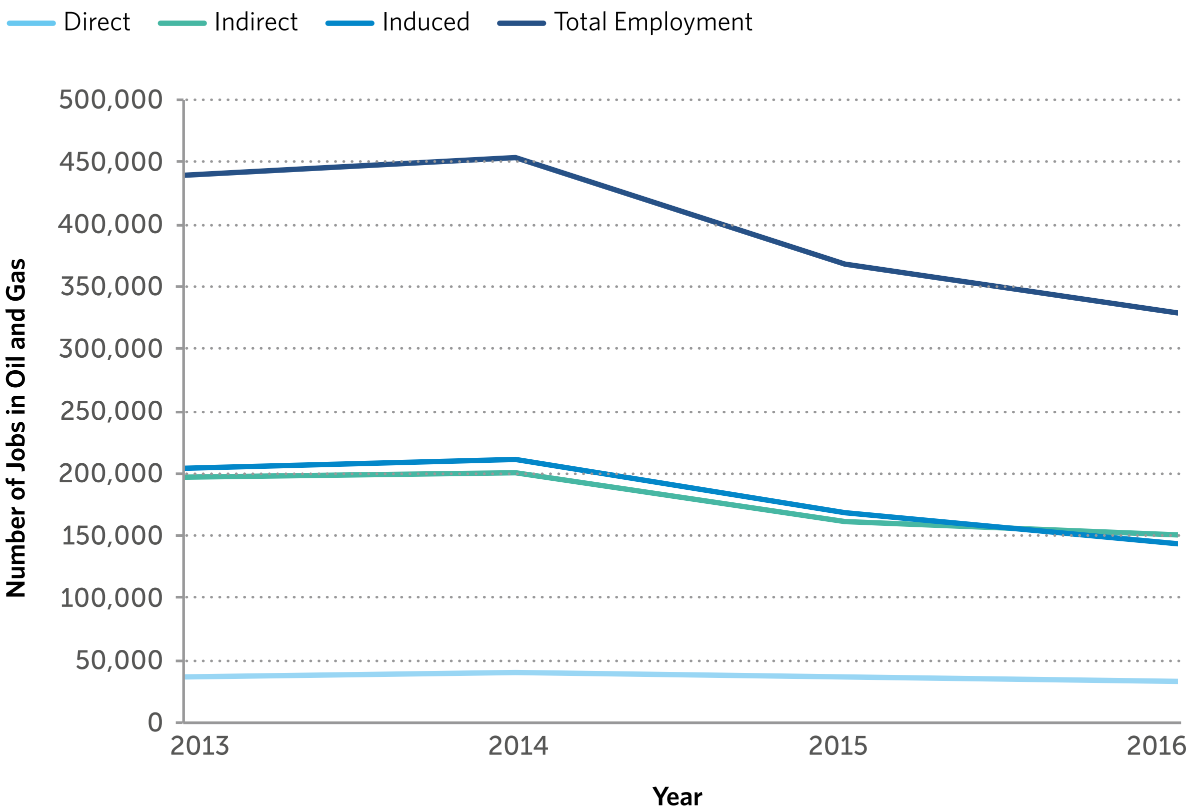
***Data Sources**: a) The Office of Gas and Electricity Markets (Ofgem), Infographic: Promoting a Sustainable Energy Future (2017), b) Department for Business, Energy & Industrial Strategy, Digest of United Kingdom Energy Statistics 2016: 158*

Decommissioning of offshore infrastructure

As offshore oil and gas reserves in the North Sea decline, the oil and gas infrastructure is being decommissioned. Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) Decision 98/3 on the Disposal of Disused Offshore Installations views re-use, recycling, or disposal on land as the preferred courses of action, while stating that in some cases leaving structures in place may be appropriate.[106] The industry sponsored 'INSITE' (INfluence of Structures In The Ecosystem) programme is investigating whether man-made structures affect the North Sea ecosystem, such as in their potential effects on species distribution, food webs or migration.[107]

While there is uncertainty about the cost to the tax payer of decommissioning, the market is growing, and an estimated £17.6 billion is forecast to be spent on decommissioning on the UK continental shelf between 2016 and 2025.[108] Although there are uncertainties around the economic and environmental implications of large-scale decommissioning,[108, 109] this potentially presents the UK with an opportunity to use its expertise in offshore oil and gas to develop world-leading capability.[108] A UK supply chain could offer highly skilled employment, especially to those who previously worked in oil and gas extraction, and the opportunity to export goods and services to the growing global decommissioning market.[108] Other North Sea countries, including the Netherlands, have significant marine salvage capability and are likely to take the lead in removing the structures. Opportunities for the UK are particularly likely to be in processing these structures on land.

FIGURE 12
UK jobs in oil and gas (2013–2016)



***Source**: Oil & Gas UK (2016)*

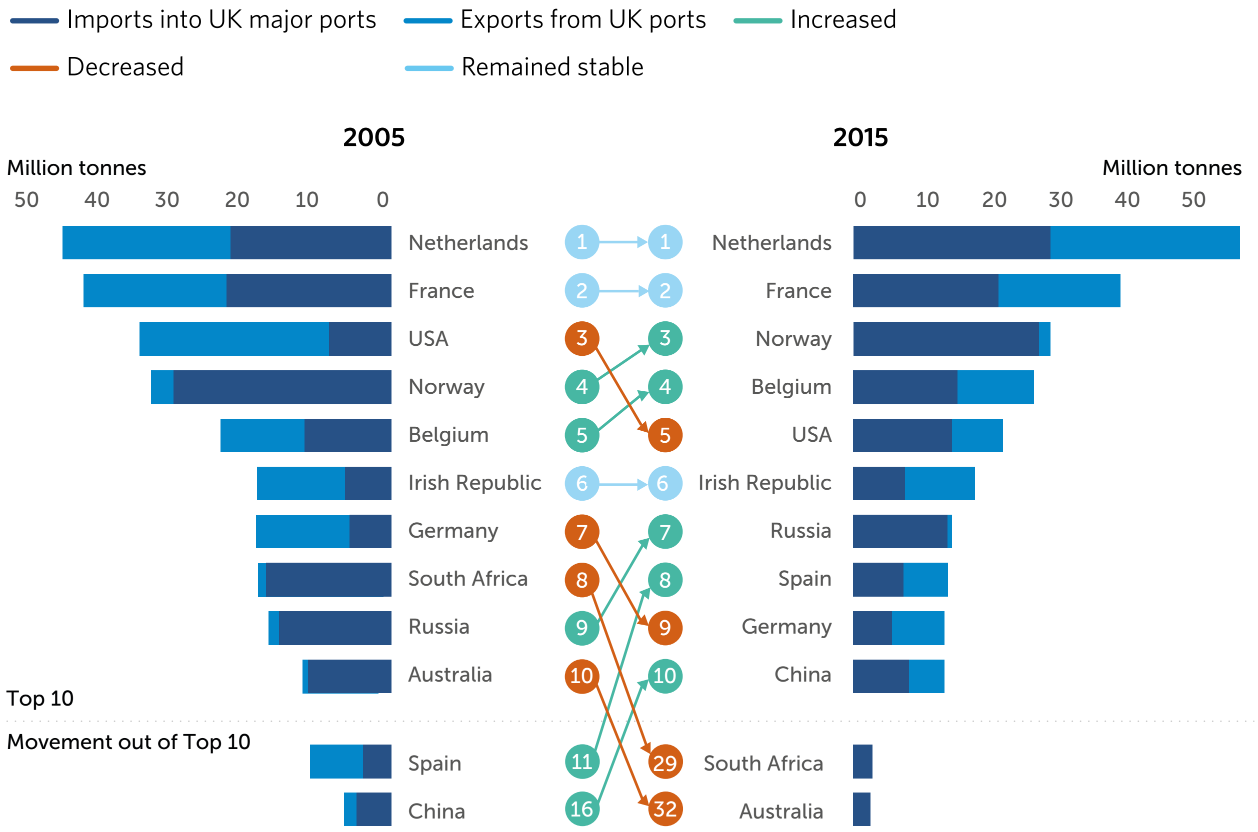
2.2.3 Shipping and Trade

The shipping industry is a vital part of the UK economy, with 95 per cent of imports and exports carried by sea. In 2015, the UK processed 497 million tonnes of seaborne trade, contributing to about 5 per cent of the total global volume.[111] The UK maritime sector (shipping, ports and business services) is the largest in Europe, worth an estimated £14.5 billion GVA.[25] Six of the UK's top-ten trading partners by volume are EU countries (Netherlands, France, Belgium, Ireland, Germany and Spain)[110].

Future patterns in trade, which will drive the shipping industry, are driven largely by demand. This makes the sector susceptible to shifts in global production and consumption. Growing population and development will increase the demand for the transport of goods and the drive to mitigate against climate change will put pressure on the shipping industry to lower CO_2 emissions. As climate change progresses, new cross-Arctic shipping routes will open. New technologies will enable the UK to respond to these changes, but will also present legislative challenges, which the UK is well placed to address. This sub-section considers these issues in order.

Changing trade flows

FIGURE 13
Top 10 (by volume) country trade routes with the UK



***Source**: Department for Transport*

Changing global demographics and trade flows are important factors in the demand for shipping. An increase in world population, UK population, urbanisation and increased national income will lead to an increased demand for imported consumer goods and therefore a growing demand for sea transport.[112] As a result, the OECD estimates that global freight trade could more than triple by 2050.[5] In particular, wealth and production in Asia will expand, making it an even more prominent global shipping hub.[106]

Developed economies like the UK are moving towards being service-sector led, meaning they will tend to import more goods by sea than they export.[112] Where these imported products are of critical importance to the UK, the impact of delays or failure on shipping routes or ports (e.g. due to weather or cyber threats) could have serious consequences. Therefore, the risks to trade routes as part of supply chain vulnerability need to be considered and mitigated against.

Changing demands for products have a knock-on effect for the ships that carry them. For example, shifting patterns of demand in energy will influence the volumes of oil and gas transported at sea. On a global scale, the OECD predicts that in the short-to-medium term, growth in the volume of oil transport will continue to increase, particularly in Asia where economic growth is the largest.[5] However, since 2000 the UK has seen a decline in the volume of liquid bulk (e.g. liquefied gas and oil) transported to and from the UK by sea, while imports and exports of containerised cargo have been increasing.[112] In the long term, the decarbonisation of the energy sector and increase in the use of renewable energy is expected to significantly reduce the amount of oil and gas transported by sea, changing shipping needs.[113] In the UK, it is predicted that this will have the added benefit of reducing CO_2 emissions to help meet climate change targets, with some projections estimating that the changing demand can reduce the CO_2 emissions from the shipping of fuel by 2050 between 81 per cent and 62 per cent.[114]

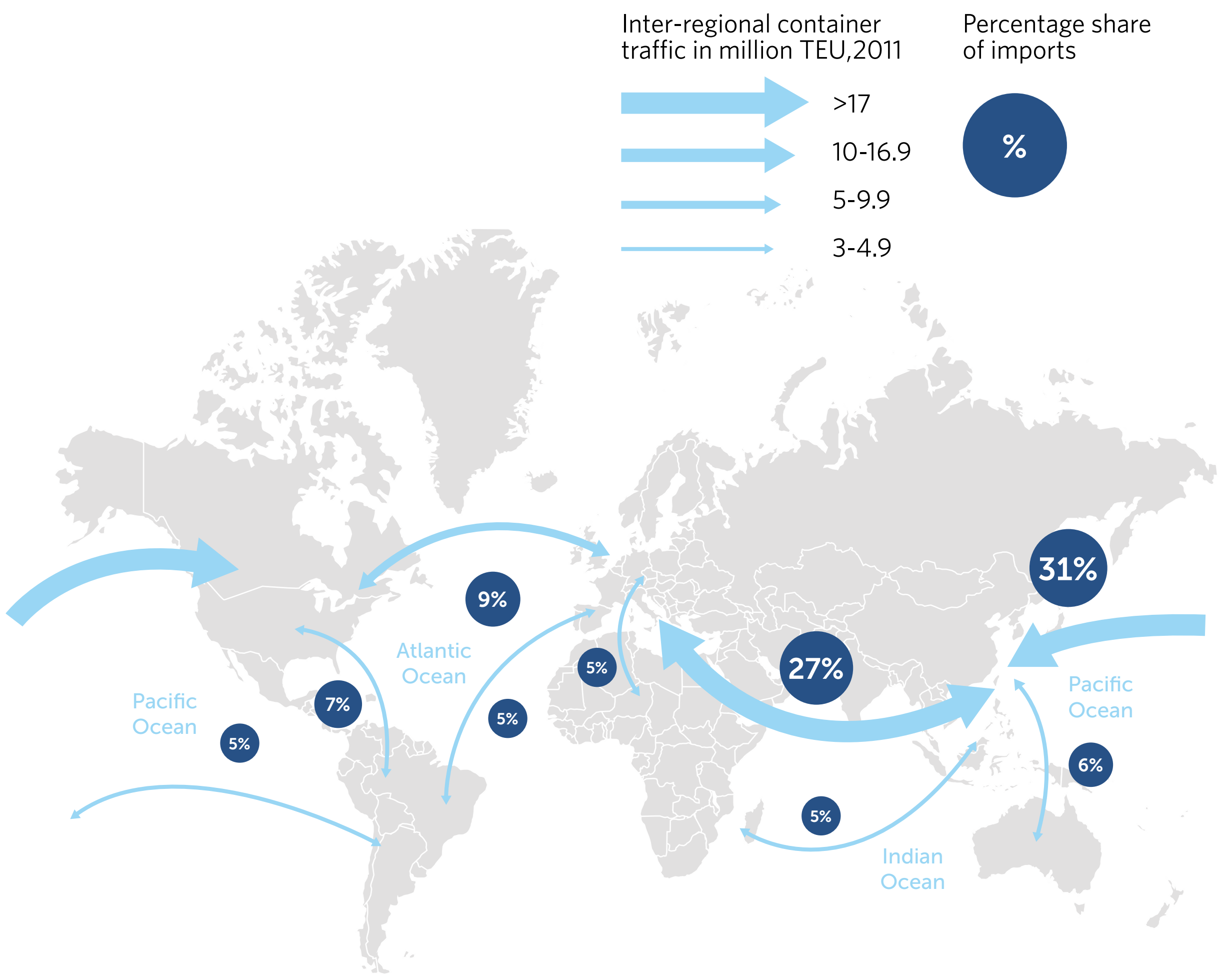
Climate change

Climate change is likely to have a significant impact on the shipping industry, particularly through increasing pressure to reduce emissions. By 2050 the UK's shipping emissions could account for up to 11 per cent of the total permitted under the Climate Change Act.[114] Industry recognises the growing need to 'go green',[20] and is making efforts to reduce greenhouse gas emissions.[113] The UK has set out its ambition in this area.[115] It is important that this continues to be part of the global initiative to cut down emissions.

Measures include the implementation of emissions control areas, some already in place, and a drive towards enhanced fuel efficiency and alternative energy sources.[20, 113] Hydrogen fuel has been proposed as one possible long-term solution.[20] In order to ensure widespread adoption of low-carbon shipping by the industry, these technologies and initiatives must be cost effective and easy to implement.[116] Existing infrastructure linked to the shipping industry will also need to be resilient to the effects of climate change, particularly sea level rise (see page 7).

FIGURE 14

Inter-continental container shipping (as a percentage share of imports)



***Source**: Adapted from Humpert, M. The Future of Arctic Shipping: A New Silk Road for China? The Arctic Institute (2013)*

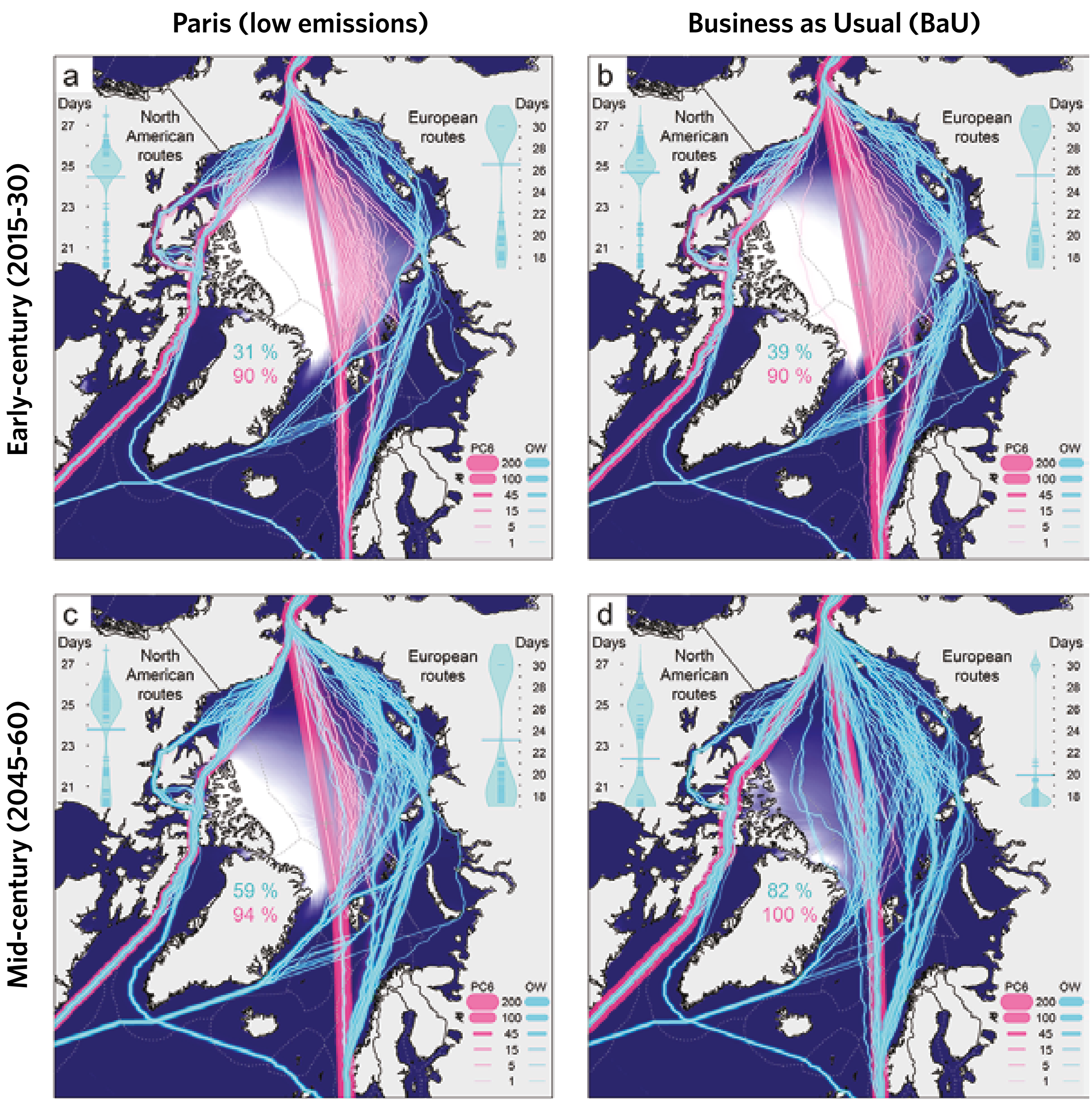
Arctic shipping

Since 1970, the Arctic has been losing around 3000 cubic km of ice per decade,[117] and this decline is projected to continue beyond 2050. Among its many impacts, the loss of sea ice may create shorter shipping routes, seasonally, between East Asia and the UK. By the mid-century this could supplement traditional canal routes, saving 10–12 days and 2000 nautical miles in the case of the Suez Canal, as well as minimising transit through territorial waters.[20]

Arctic shipping could serve four key sectors: mineral resources, fisheries, logistics and tourism, all of which could generate $100 billion in investment over the next decade.[118] Although there are potential benefits from shorter global routes, destinations for resource extraction and tourism, this may be offset by the inherent risks posed by a challenging environment, requiring specialist knowledge and the need for flexibility.

FIGURE 15

Fastest available September trans-Arctic routes from calibrated future climate simulations for Paris style scenario (a, c) and a BaU world (b, d); cyan lines represent open water (OW) vessels, and pink lines represent Polar Class 6 vessels (PC6, capable of navigating in sea ice 1.2 m thick); line weights indicate the number of transits using the same route; percentages are the probability that Arctic routes are open for the respective vessel class.



Source: *Adapted from Melia, N., Haines, K. and Hawkins, E., Sea Ice Decline and 21st century Trans-Arctic Shipping Routes, Geophysical Research Letters 43 (18) (2016), 9720–9728*

Shipping also presents a challenge to the sensitive Arctic environment itself, with potential impacts including emissions of 'black carbon' (caused by soot), transport of alien species (some of which can become invasive) and chemical contamination[119]. However, these risks can be at least partly mitigated by mandatory legislation and voluntary guidelines, many of which are developed and supported by the UK.[72]

If environmentally, socially and economically feasible, the UK is well positioned geographically, geopolitically and commercially to benefit from Arctic shipping. The UK can benefit from increased Arctic trade; it has good trading links with Arctic Council States (including the US, Canada and Russia), and has specialist shipbuilding capability valuable when building new Arctic-going ships (Cammell Laird are building the new Arctic research ship RRS Sir David Attenborough in Birkenhead). Eastern ports (Aberdeen for example) could also take advantage of increased traffic through the Arctic Circle if they can adapt their capability accordingly.[72]

Finally, the UK's active role in many international organisations means it is well placed to ensure that increased activity in the Arctic is accomplished in line with established UN and International Maritime Organization (IMO) conventions, many of which were written with significant UK contributions.[72]

Future ships[x]

The design and operation of the ships that carry trade are likely to be significantly affected by the changes described elsewhere in this report, and by technological innovation. In particular, 'smart shipping' will be facilitated by the growing use of sensors and satellites, which will provide the industry with data to improve efficiency, navigation and onboard safety, and reduce costs.[18, 20, 113] Data-collection advances on ships can help facilitate the UK in meeting demands for the reduction of emissions.

Industry estimates that fully autonomous unmanned ships, capable of transporting cargo without a crew could be in operation as early as 2035.[20] This could revolutionise the shipping industry, allowing ships to become smaller and more efficient by removing the need to have an onboard crew.[20,113] This is particularly likely to apply to short sea and coastal routes, as larger ships are used on long routes for efficiency as well as crew reasons. To date, Scandinavian countries (specifically Norway and Finland) have led the development of autonomous shipping.

x The government is doing relevant activity in this space. A National Shipbuilding Strategy was announced in the 2015 Strategic Defence and Security Review. Sir John Parker was asked to produce an Independent Report to inform the National Shipbuilding Strategy, and this was published in November 2016. The National Shipbuilding Strategy builds on Sir John's recommendations and sets out the way forward for naval shipbuilding in the UK. It explains out how government will transform how it procures naval ships and grows the fleet. It will re-energise industry to further develop a globally competitive shipbuilding and maritime engineering industry, capable of winning business in the military and commercial markets, both at home and overseas. Warships will be built in the UK after a competitive process, and UK yards are encouraged to partner with foreign firms where they meet our national security requirements. All other naval ships will be subject to open competition; however integration of sensitive UK-specific systems will be done in the UK. In addition, the Governments Industrial Strategy sets out Grand Challenges to put the UK at the forefront of the industries of the future, ensuring that the UK takes advantage of major global changes, improving people's lives and the country's productivity. One of the Grand Challenges focuses on the future of mobility, recognising that we are on the cusp of a profound change in how we move people, goods and services.

However the UK has significant capability in the development of autonomous technology, and specialist ship building. There are therefore opportunities to take a leading role in developing this industry, with the UK already active in addressing some of the legislative issues that autonomous shipping may bring.[113]

The rise of automation and smart shipping also highlights the need to consider connectivity in the sea. Industry has identified challenges around data transfer as a particular priority, and there is likely to be growing demand to improve communication at sea.[20] The UK has leading capability to develop and capitalise on in the satellite industry, which will underpin this connectivity. Advances in communication, improved sensing, and intelligent and autonomous control systems will also present new challenges for cyber security, making ships and related infrastructure vulnerable to cyberattacks. This means that measures to mitigate this threat will be vital, especially in ships' navigation systems.[39]

In the longer term, additive manufacturing (3D and 4D printing) and modular manufacturing (shipping semi-finished products rather than smaller parts and components) are also expected to affect future shipping, potentially reducing the need to ship certain products and therefore impacting the weight, volume and cost of shipping products.[113] These could also allow future ships to act as 'floating factories' able to process and customise products on board, to respond to changing demands for goods.

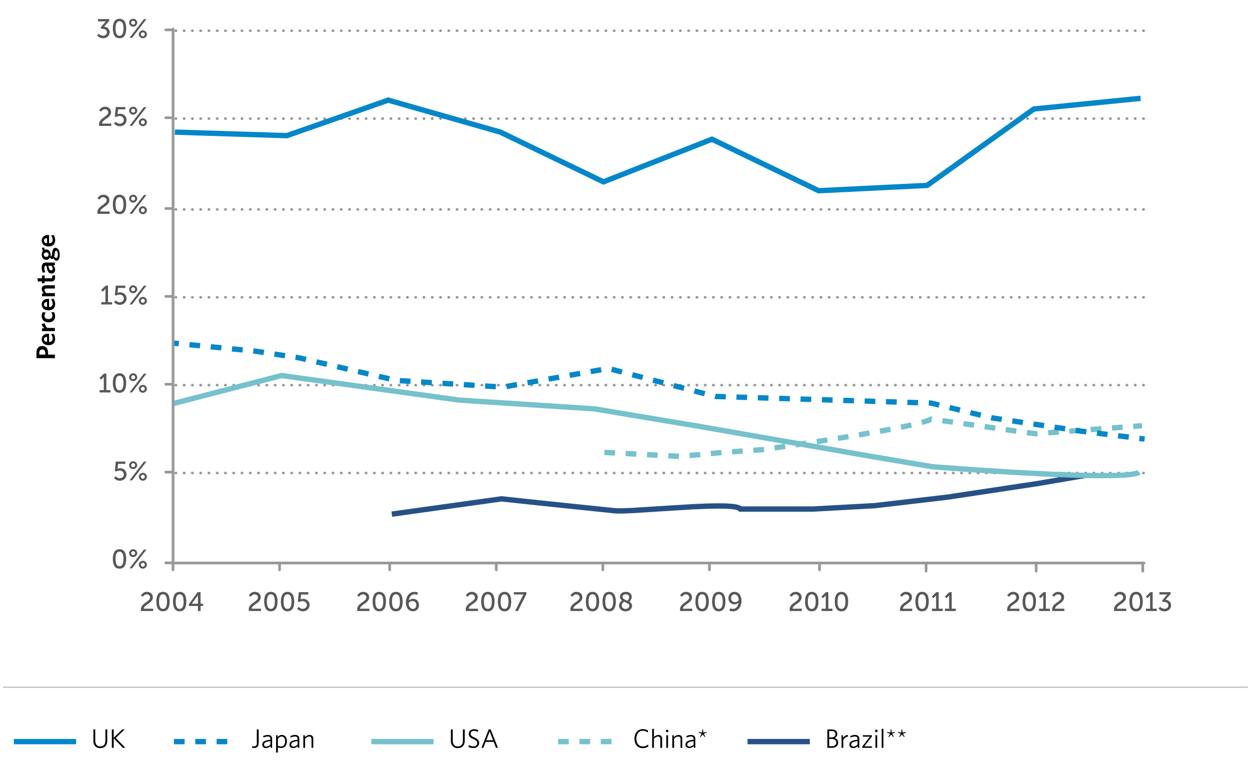
Security

Piracy and armed robbery at sea can threaten the security of trade routes. It costs the international economy an estimated US$7 to $12 billion annually.[120] There are three main hotspots within which the majority of piracy related activity occurs – Horn of Africa/West Indian Ocean, the Gulf of Guinea off the coast of West Africa, and the Malacca and Singapore straits and Sulu and Celebes Seas in Southeast Asia. These areas all contain some of the busiest shipping trade routes. Although incidences of piracy had been declining, there was an increase in such activity in the first half of 2017 off the coast of Somalia; piracy/armed robbery continues to be a major concern in the Gulf of Guinea and the situation in the Sulu and Celebes Seas is being closely monitored. The UK plays a lead role in combating piracy and armed robbery at sea, including the support of maritime security capacity building projects in key affected areas. Beyond piracy, there are additional risks to the security of maritime trade – such as recent attacks on shipping in the Bab al Mandeb. More broadly, there are a large number of maritime security concerns that centre on smuggling (of people, drugs, and counterfeit goods among other things).

2.2.4 Maritime Services

The UK has a world-leading maritime business services sector, with the largest share of maritime insurance premiums (26 per cent)[23] and shipbroking (26 per cent) in the world[72] (see Figure 16). The UK is the second to the US (18.1 per cent) in worldwide earnings from services and income as a proportion of world exports with 7.4 per cent, compared with Germany at 7 per cent and France at 5.3 per cent.[121] The strength of its service sector makes the UK potentially well placed to take a leading role on regulatory innovation in response to the above changes in the shipping sector. This would allow it to continue its status as a maritime services hub.

FIGURE 16
Share of maritime insurance premia (top five countries) Source: Department for Transport, Maritime Growth Study (2015)



Note: * No data is available for China prior to 2008
** No data is available for Brazil prior to 2006

Source: *IUMI - International Union of Marine Insurance*

2.2.5 Ports

The UK's ports are critical for linking the marine economy and trade to the wider economy. This is due in part to a reliance on seaborne trade to facilitate some of its most critical imports, including 40 per cent of food (by value).[122] The UK's port sector is the second largest in the European Union,[123] handling around 5 per cent of the world's total maritime freight traffic volume at some point in its journey.[112] The UK's 53 major ports (those that handle more than 1 million tonnes annually) handled 486 million tonnes in 2015 and over 100 others handle a further 11 million tonnes.

Ports and the surrounding infrastructure play a crucial role in transferring goods to their final destination, relying on a network of critical transport, including road and rail. Port capacity will therefore be important for the future of the whole UK economy. For some emerging activities, such as the import and export of large-scale manufacturing of components for offshore wind, deep-water capability will be particularly important.[124]

Autonomy could improve port efficiency.[113] It will also have implications for how ports operate, and create the need to facilitate autonomous shipping. However an increased dependence on technology will also make port operations more vulnerable to cyberattacks.[39] As with the shipping industry, changes in trade and product flows will impact UK ports, as they will have to adapt to the type of freight being transported.

UK ports will be exposed to increasing risk from sea level rise. That this is likely to exceed 50 cm by 2080 has been highlighted as a concern for the flooding of UK ports,[8] which can disrupt port operations and damage infrastructure.[125] Immingham, near Grimsby, for example, which specialises in petrochemicals and biomass fuel, ceased operations for a number of days after flooding in December 2013. The IPCC predicts there is up to a 1-in-6 chance of sea level rise exceeding 55 cm under the lowest sea level rise scenario (RCP2.6) and at least a 5-in-6 chance of exceeding 45 cm under the highest scenario (RCP8.5) by 2090. While port flood events are decreasing due to improved defences and forecasting, financial losses are likely to arise from pre-emptive closures.[8]

Ports, due to their coastal location, are also affected by challenges around skills shortages in coastal communities (see page 58). However, within these communities, ports do have the potential to act as hubs for collaboration between different sectors, potentially creating opportunities for clustering for industry and innovation.

The fundamental role that port infrastructure plays in the economy should be reflected in policy decisions that prioritise their resilience to climate change and developing the necessary skills to adapt to the changing marine economy. As with many issues relating to the future of the sea, there is a strong global element to this. For effective trade, secure and efficient ports are needed in all parts of the trading route[112] and the UK will need to continue working with the IMO to ensure these standards are met globally.

2.3 Implications for Emerging Sectors

There are a number of emerging, potentially transformative, sectors in the marine economy. For some, there will be important decisions to be taken about how the UK and the international communities define, regulate and support these industries. These decision points are one of the justifications for the project's first and overriding recommendation (see page 9).

2.3.1 Aquaculture

Aquaculture is the fastest growing food supply sector in the world and now provides more fish for human consumption than wild capture fisheries.[41] In the past three decades, global aquaculture production expanded by an annual average rate of 8 per cent,[42] and by 2030 the industry is projected to provide over 60 per cent of fish destined for direct human consumption.[42] Aquaculture in the sea represents around 36 per cent of total global production.[41] Asia has a major dominance, with China alone producing 60 per cent of all global aquaculture products.[41] Given growing global demand for food, it is likely that aquaculture will become increasingly important for global food security.

Aquaculture has become a significant component of the UK seafood sector – the industry was valued at almost £800 million in 2014.[126] The majority of current production occurs in Scotland because of its sheltered coastlines and other environmental factors that provide favourable conditions for production.[3] Production in England, Wales and Northern Ireland has declined or remained stable in recent years owing to more exposed coastal areas and thus fewer opportunities to develop fish farms.[3] UK production centres on a few key species, with Atlantic salmon forming a major component and valued at £519 million in 2012.[3] Scottish aquaculture is regarded as world leading, allowing premium prices to be applied to its salmon.[3] As with other sectors, such as offshore wind, there is significant overseas investment in the UK aquaculture industry.[127]

Growing consumer demands for Atlantic salmon from countries such as China, Japan and North America[3] mean that the UK has opportunity to further position itself as a competitive supplier to these markets, through which new technologies can play a role in helping to increase production. UK expertise within the aquaculture sector and marine sciences can also be exported to help inform rapidly growing aquaculture industries in other areas of the world, such as Southeast Asia,[128, 42] to encourage best and sustainable practice. Despite unsuitable coastlines, the emergence of offshore and on-land production technologies may create opportunities for the aquaculture industry outside of Scotland.[3] There are also opportunities for aquaculture to co-locate with other offshore infrastructure, e.g. renewable energy generators.[129]

Aquaculture has similar climate change risks to fisheries. Although ocean warming may create some opportunities, e.g. to farm new species such as sea bass,[3] generally there are expected to be increasing risks. Ocean warming may increase the prevalence of parasites and pathogens,[9] and affect productivity – it is estimated that a 1°C increase in temperature could lead to a 50 per cent reduction in the productivity of mussel aquaculture in the UK.[3] The vulnerability of shellfish to acidification could affect commercial species such as mussels and oysters, although the exact impacts are uncertain.[3,43] Changes in extreme weather brought about through climate change could result in storm damage to fish farm infrastructure.[3]

The availability of the raw materials that constitute aquaculture feed may be a contributing factor to the long-term sustainability of the industry. In 2009, 81 per cent of the global fish oil supply was absorbed by the aquaculture industry.[130] Fish oils are derived from marine capture fisheries, so their supply is tied to the sustainability of that industry.[131] Raw materials are also becoming increasingly expensive, with fish oil likely to increase by over 70 per cent in real terms, while fishmeal is expected to double in price by 2030.[42] Since aquaculture feeds typically represent 50–60 per cent of the operating costs of a finfish production business,[3] rising costs are a key challenge. There are already several alternate sources of lipids and proteins that have the potential to mature into economically viable replacements. Oil seed crops are able to deliver both vegetable oils and protein meals, meaning that they are likely to become important components of aquaculture feed in the future.[3]

2.3.2 Offshore Wind

Offshore wind is an area of significant opportunity for the UK. The UK is ahead of much of the world in certain subsectors, such as operation and maintenance,[132] and has the largest installed offshore wind capacity of anywhere in the world (36 per cent of global capacity in 2016).[70] The industry is going through a period of rapid growth and change which is driving down costs, largely due to technological innovation and continued Government support.[132] The cost of electricity generated by offshore wind has recently dropped steeply – in the 2017 Contract for Difference auctions, the lowest strike price agreed for offshore wind projects was £57.50/MWh. This is approximately half the price previously agreed at the 2015 auction.[133] There are 13,000 direct and indirect jobs in the UK supported by offshore wind, and this is predicted to increase to 44,000 by 2023.[134] Offshore Renewable Catapult predicts that, with continued support, the UK offshore wind industry could be worth £2.9 billion to the UK economy by 2030.[132]

The growth in industrial scale of offshore wind farms began in the UK, giving companies a first-mover advantage in some parts of the supply chain[69] and the opportunity to export our goods and services. The area with the largest UK opportunity is the operation, maintenance and service sector of offshore wind,[69] which currently hosts a large number of UK SMEs.[132] This will, in part, interact with growing automation across the marine sector. Offshore Renewable Catapult projects that 65 per cent of the estimated value of supply chains within UK offshore wind projects will be from UK suppliers by 2030 (it is currently 32 per cent), including 75 per cent of the turbine supply chain, and 53 per cent of installation.[132]

While there are opportunities here, the relatively small percentage of the supply chain that is supplied by UK businesses could be seen as a missed opportunity. This report's conclusion considers the potential for a more strategic position being used to identify and develop targets for capitalising on such opportunities in the future (see page 105).

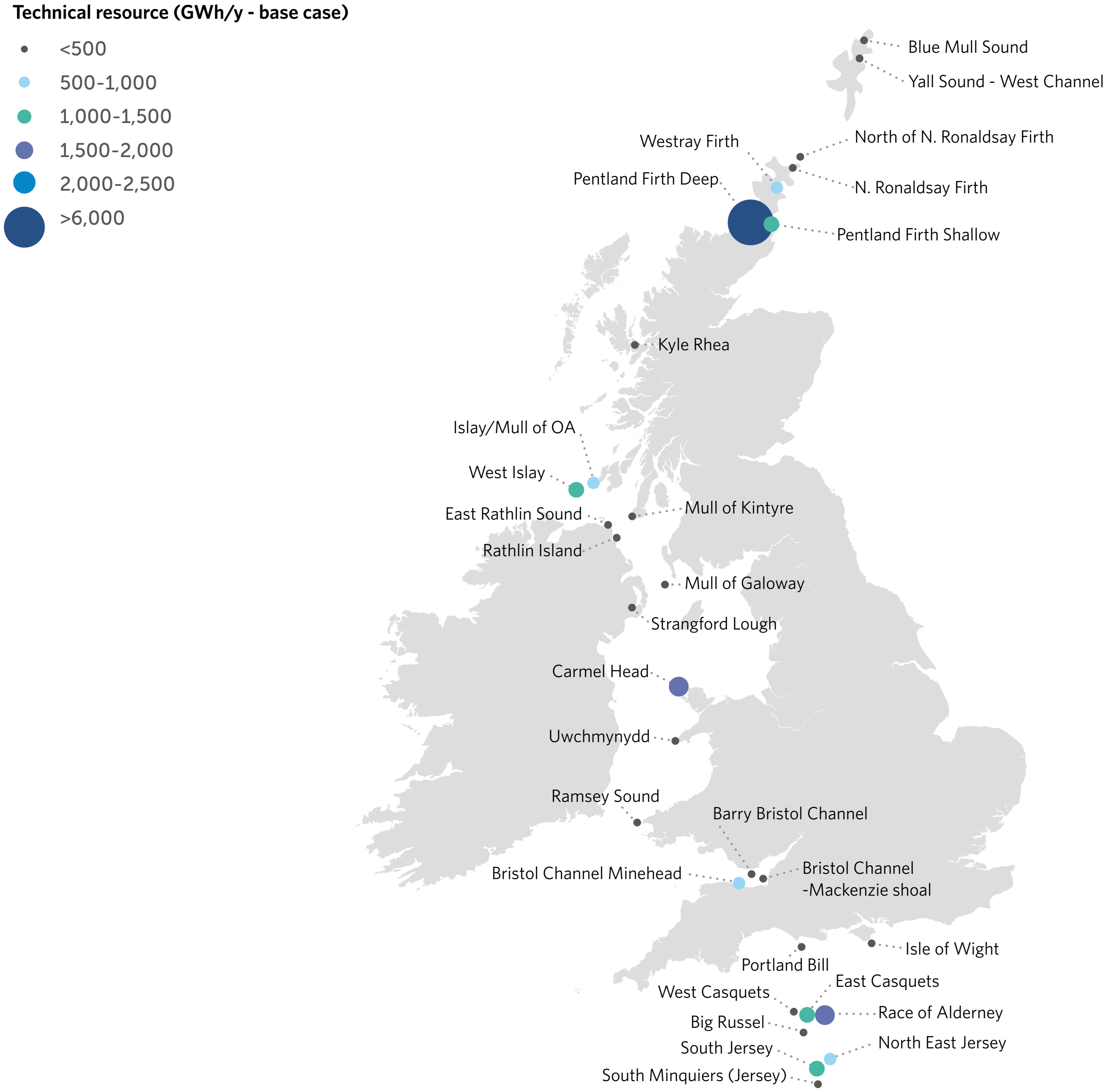
2.3.3 Other Offshore Renewable Energy Sources

UK waters have the potential to provide energy in other ways, including through waves, tidal, ocean currents and temperature and salinity gradients.[106, 135] Mainland UK waters are among the best in the world for wave and tidal energy resource,[136] holding 50 per cent of Europe's tidal resource. Wave and tidal energy has the potential to meet up to 20 per cent of the UK's current electricity demand.[137] The industry is still emerging, but the UK is currently leading the development of related technology and there are presently around 1,700 people employed in the sector in the UK.[136]

The most technologically developed method for harnessing the power of the sea is to exploit areas with high tidal ranges, using barrages across estuaries or by the construction of lagoons, although there are only a few such projects in operation around the world, all of which are barrages.[138] Theoretically, tidal lagoons could generate the equivalent of 8 per cent of the total electricity that the UK has used in recent years.[139] However there is ongoing uncertainty about the cost-effectiveness of tidal lagoons as an energy source.

Tidal stream energy, which harnesses the energy of current flows during tide changes, remains in its infancy, and designing blades that are durable in such an environment is challenging.[140] However, progress is being made: the MeyGen tidal energy project in the Pentland Firth set a monthly world record for tidal stream power generation in August 2017, of more than 700 MWh.[141] Estimates of the total UK tidal stream potential range from the conservative 17 TWh/year up to values of 197 TWh/year.[139] Progress in using wave energy has been slow, and from 2008 to 2015 this contributed only 8 per cent relative to the amount of electricity provided to the UK grid by tidal systems.[142]

FIGURE 17
Practical tidal resource sites in the UK; the size of the circles represents practical annual energy potential



***Source**: Carbon Trust, Accelerating Marine Energy (2011)*

If the above challenges can be overcome, there are opportunities to grow the sector and export UK products and expertise. Similar to other emerging sectors, there is therefore an opportunity for the UK to define its strategy towards these energy sources. Industry says that marine energy could create 20,000 skilled jobs in the next decade and the sector could contribute around £4 billion to UK GDP by 2050.[136] Beyond reducing carbon emissions,[143] one of the main benefits of tidal and wave energy is the predictability and reliability of the resource. There is also some evidence that tidal lagoons can both help reduce flood risk due to sea level rise,[8] and in other places increase it.[144] Although there is a clear environmental benefit to the implementation of marine renewables, potential environmental impacts, such as loss of intertidal habitats, must also be considered in their installation.[145, 146]

2.3.4 Carbon Capture and Storage

Under the UK Climate Change Act, the UK is committed to reducing its CO_2 emissions to 80 per cent of 1990 levels by 2050.[147] Carbon capture and storage (CCS) is seen as a potential way to reduce CO_2 emissions. CCS involves the capture of CO_2 from emissions, which is then injected either into the deep sea, depleted oil and gas fields or layers of rock.[148] The UK has a significant CCS research community. However there are a range of technical and commercial challenges to fully realising the technology's potential. The technology is still in early development and the enabling infrastructure and regulatory environment is yet to be developed across the different sectors of the energy economy that would be involved in CCS.[149] There is also currently little economic value in the deployment of CCS without government support.[150]

There are concerns over the environmental impacts of deep-sea storage and so geological storage (such as depleted oil and gas reservoirs) is currently seen as the most viable option.[151] CCS has the potential to store 40 per cent of UK CO_2 emissions by 2050.[150] Exhausted North Sea oil and gas fields could also present an opportunity to re-commission existing offshore structures and support jobs that were previously reliant on the offshore oil and gas sectors.[149, 150] However, there is some evidence of the potential for leakage of stored carbon during the first few hundred years after capture.[152,153]

2.3.5 Deep-Sea Mining[xi]

Significant deposits of metals are known to exist on the seafloor, potentially offering new opportunities to meet growing global resource demand. For example, ferromanganese crusts in the Pacific are estimated to contain about seven times more cobalt, widely used in batteries, than land-based reserves.[154] Industry is currently exploring the feasibility of mining these resources. This is likely to increase in the near future due to advances in technology and a developing international legal framework.[154]

Terrestrial mining is increasingly relying on lower-grade and deeper deposits,[155] which cause greater environmental damage.[156] At the same time, the development and popularity of new technologies that require specific metals, such as some of the rare earth elements has

xi This report's conclusions on deep-sea mining and marine genetic resources draw heavily from "Future ocean resources: Metal-rich minerals and genetics", a report by the Royal Society based on a policy briefing that was originally developed with the Future of the Sea project.

FIGURE 18
Global permissive areas for polymetallic nodules and ferromanganese crusts; permissive areas are here defined as those with conditions appropriate to allow high-grade deposits and neither guarantee economically viable deposits nor cover all possible deposit sites

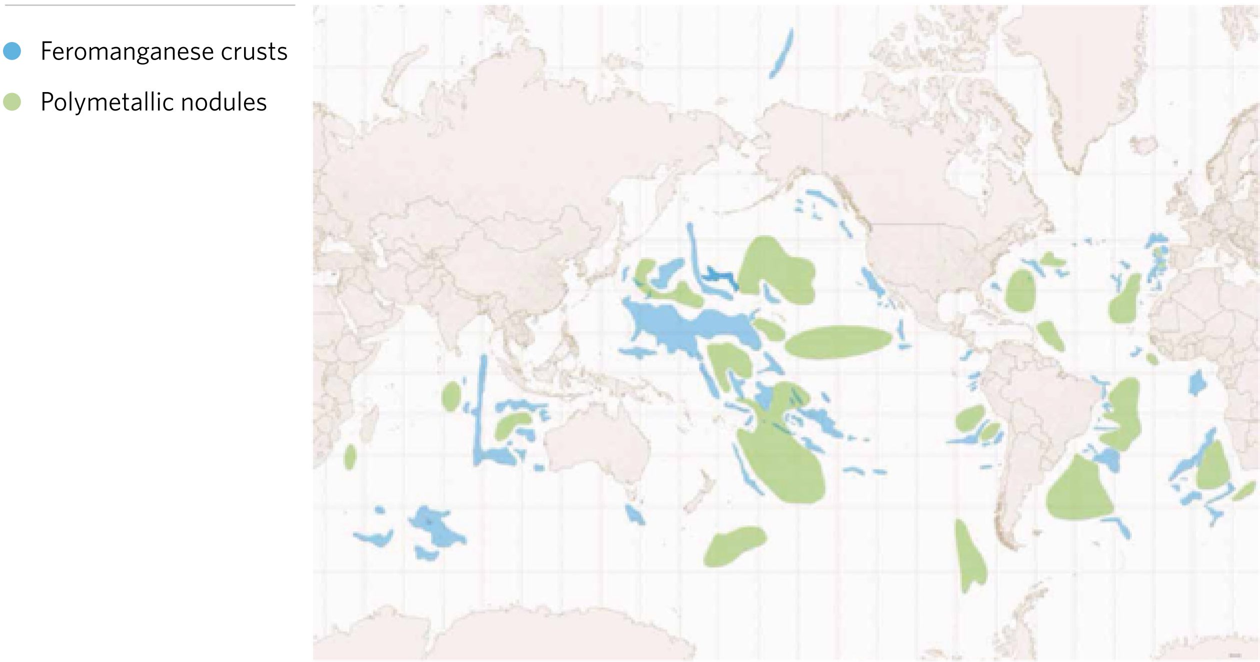
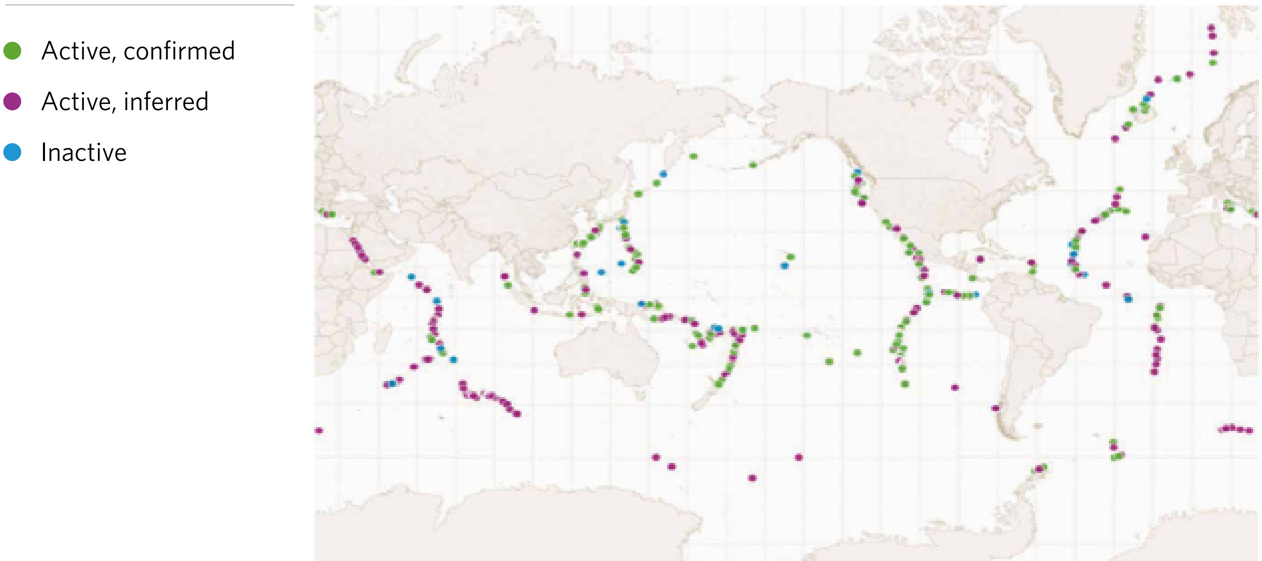


FIGURE 19
Sites of known active and inactive hydrothermal vents on the mid-ocean ridges; these are often sites of potential mineral resources and specific marine ecosystems; in many areas, lack of vents on the map reflects lack of exploration rather than their physical absence, though active vents are expected to be found in areas of active volcanism



Source: *Royal Society, Future Ocean Resources: Metal-Rich Minerals and Genetics – Evidence Pack (2017)* driven increasing demand for these metals. For example, the number of global smartphone subscriptions is projected to rise from 3.9 billion in 2016 to reach 6.8 billion by 2022.[157] This has heightened interest in deep-seabed mining, which was first identified as potentially feasible in the 1950s.

There are three deposits of interest:[156] polymetallic nodules on deep abyssal plains, seafloor massive sulphides (SMS) deposits around active and extinct hydrothermal vents and cobalt-rich ferromanganese crusts on seamounts (Figure 19). A full assessment of the potential scale of these resources[156], and the environmental impact of mining them,[155,158] is not possible due to a lack of data.[155] However, it is known the nodules and crusts are large resources, while SMS deposits are likely to be small and more localised, but potentially high value.[156]

It is unknown whether the UK's EEZ contains sufficient mineral deposits to attract commercial seabed mining operations.[156] This is because the potential resource is uncertain in most areas and the fluctuation of metal prices means that the economic viability of resources is not consistent.[155] Polymetallic sulphide deposits are known to exist in EEZs of UK Overseas Territories on the Mid-Atlantic Ridge (e.g. Ascension Islands),[155] but greater understanding of their geological setting is needed to understand their resource potential.[155]

Seabed mining could still be worth £40 billion to the UK over the next 30 years.[159] The economic opportunities for the UK are more likely to lie in resources in the Area Beyond National Jurisdiction. The UK has sponsored contracts for exploration in the main area of economic interest for nodules – the Clarion-Clipperton Zone in the north-east Pacific. As a party to the United Nations Convention on the Law of the Sea (UNCLOS), the UK is well placed to access minerals on the seabed beyond national jurisdiction. Industry suggests that the UK could take a lead in the industry, due to its relative skills and experience in deep-water oil and gas extraction, which also offers export opportunities for the UK's supply chain.[20]

However, we know relatively little about the deep sea and its biology. Mining affects ecosystems that are difficult to access, are poorly understood and are likely to be very slow to recover from disturbance.[158] The impacts include creating sediment plumes that smother or have toxic effects on organisms, removing key habitats, and disrupting the dispersal of species.[156] This means that the environmental impacts of mining are not fully understood.[155, 156]

Growing technological capability and resource demand are furthering the development of the deep-sea mining industry. The International Seabed Authority[xii] is leading on the development of the regulations for deep-sea mining, and published draft regulations for consultation in August 2017, which include environmental regulations. The regulations will need to be agreed by the Member States of the International Seabed Authority. The UK is well placed to help address the many environmental uncertainties that still remain and ensure that international legislation continues to be designed and implemented to maximise economic sustainability and environmental protection. A better understanding of the baseline biodiversity of deep-sea zones may be key in guiding decisions on future legislation. Recent initiatives to map deep-sea regions have seen the Abyssal Baseline (ABYSSLINE) project carry out explorative surveys of megafauna biodiversity within the 'UK-1' region of the eastern Clarion-Clipperton Zone. This has led to the discovery of numerous new deep-sea species, helping to further understanding of the region's biodiversity.[160]

xii An intergovernmental body formed in 1994 with a principal function to regulate deep-sea mining. See page 89 for a summary of key international organisations and agreements.

2.3.6 Marine Genetic Resources

Marine genetic resources (MGR) is an umbrella term for chemicals derived directly from marine life such as genes, and for substances that they produce, such as antibiotics. MGRs have a range of uses, particularly in the pharmaceutical and cosmetic industries.[155]

The MGR market could have high value, but its potential is difficult to assess, as it depends on what types of resource are discovered. Extreme environments such as the deep and polar seas have been highlighted as being likely candidates for MGR discovery, due to the adaptations that organisms have in such hostile conditions.[161] Available information suggests that annual global sales of marine biotechnology products are upwards of US$1 billion,[155] and there are 4900 patents associated with the genes of marine organisms, a figure that is growing by 12 per cent per year.[162] The anti-cancer drug Halaven (developed from the marine sponge Halichondria okadai) has global annual sales between US$300 and $350 million,[155] suggesting that biotechnological applications of marine resources are a growing source of economic opportunity.[162]

DNA sequencing and molecular synthesis means that the exploitation of MGR chemicals is unlikely to have a significant environmental impact, although some complex chemical compounds which cannot be synthesised may only be available from purified extracts of organisms and require repeated collection of an organism, particularly if that compound is only produced in small quantities and cannot be synthesised.[163] Some products rely on continued harvesting of natural resources. For example, the octocoral Antillogorgia elisabethae, which is used in skincare products, is regularly harvested by fishermen in the Bahamas.[155]

Analysis by the Royal Society suggests that the value of current MGRs could be assessed by the creation of a repository which records their extent and commercial uses. This may also help to attract further investment in this exploration-based industry (a potential synergy with deep-sea mining). There is also evidence that more help is needed getting compounds to market, which is currently slow and expensive. Although advances in synthetic biology are expected to accelerate this process in future,[155] MGR is potentially one of several examples in this report of an emerging industry that would benefit from long-term support if it was identified as a major priority.

Emerging technologies, particularly marine autonomous systems and big data analytics, are likely to improve our access to and understanding of MGRs.[155] The UK is also developing and patenting some of the most advanced genetic screening methods (e.g. Oxford Nanopore Technologies). These technologies are readily available, comparatively cheap, and allow the screening of large numbers of genetic sequences,[164] thereby increasing the likelihood of MGR discovery.

Access to MGR and benefit sharing where resources are found in national waters, currently rests with national governments. The United Nations General Assembly will consider a recommendation to launch a new Implementing Agreement, under UNCLOS, on the conservation and sustainable use of marine biodiversity beyond national jurisdiction. This will consider the possibility of a benefit-sharing regime related to the use of MGRs in this space.[165] The Antarctic Treaty governs the collection of MGRs from Antarctica.

Discussion: Place-based issues for the future of the sea

UK[xiii] coastal communities are an important consideration when assessing the future of the sea. The furthest place from the coast on the mainland UK is only about 117 km inland.[166]

Economic issues

Though many of the diverse sectors that make up the marine economy are not coastal (for example the maritime services hub in London), many are. For example, the ports of Portsmouth and Southampton contribute to 20.5 per cent GVA of the Solent's economy.[113]

Coastal communities vary considerably, ranging from industrial centres to fishing ports, and tourist towns. This diversity is reflected in large disparities in their prosperity. For example, while Blackpool is the 24th most deprived local authority area in the country, Bognor Regis ranks 279th out of a total of 354.[7] This diversity makes it difficult to develop inclusive strategies for coastal communities. However it is possible to identify some common themes.

Poor transport infrastructure (e.g. inadequate roads, limited public transport options) and access to services are a particular problem for many coastal communities, which can be geographically isolated and far from major settlements.[167] Poor connectivity can reduce employment opportunities and market access, and act as a barrier to attracting individuals and business investment.[168]

On average, rates of employment are lower in coastal communities than elsewhere, and opportunities for young people in particular are limited.[6, 169] Tourism continues to be of significant economic importance for many coastal towns. In some communities almost 60 per cent of local employment is in the tourism sector.[169] Evidence suggests that a dependence on tourism for employment can result in low-skilled, seasonal, poorly paid work. Coastal populations also have a generally lower proportion of workers with level 4/5 qualifications[xiv] (17 per cent compared to the UK national average of 21 per cent in 2008).[170]

Although there are issues with dependence on tourism, it is an important part of the economy. Marine tourism is estimated to be worth between £4 billion and £5 billion (0.24 per cent of total UK GVA). There are opportunities for further growth[171] which are often linked to the quality of the wider marine environment.[172] For example, dolphin watching in the Moray Firth in Scotland generates at least £4 million for the local economy each year.[173] If coastal communities are to continue to rely on the tourism industry, protecting the marine environment, and better understanding its value (see page 81) will be important.

xiii The Overseas Territories will each have unique challenges and opportunities, given their diversity (see page 26).

xiv According to government defined levels, a Level 4 qualification is "Specialist and appropriate for technical jobs e.g. certificate of higher education", a Level 5 qualification is "High level of expertise and competence e.g. diploma of higher education". In context, Level 3 represents two or more A Levels and Level 6 represents an honours degree.

FIGURE 20
Number of residential properties exposed to flooding more frequently than 1:75 years in the present day.

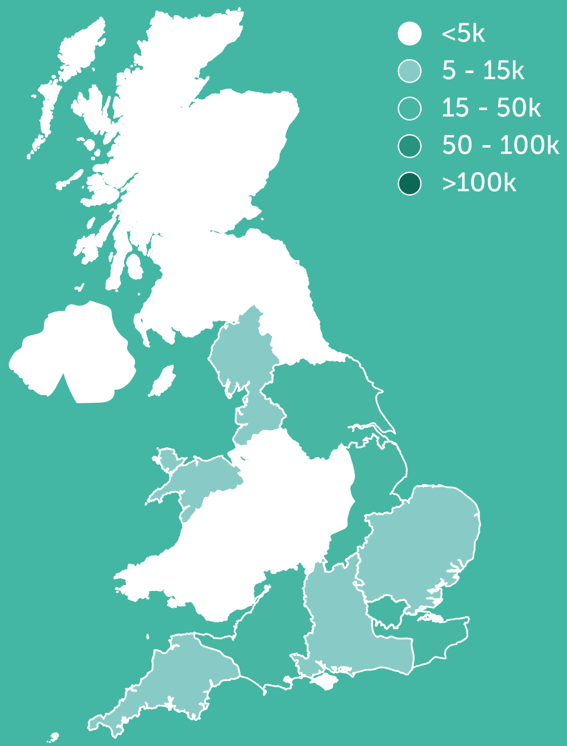
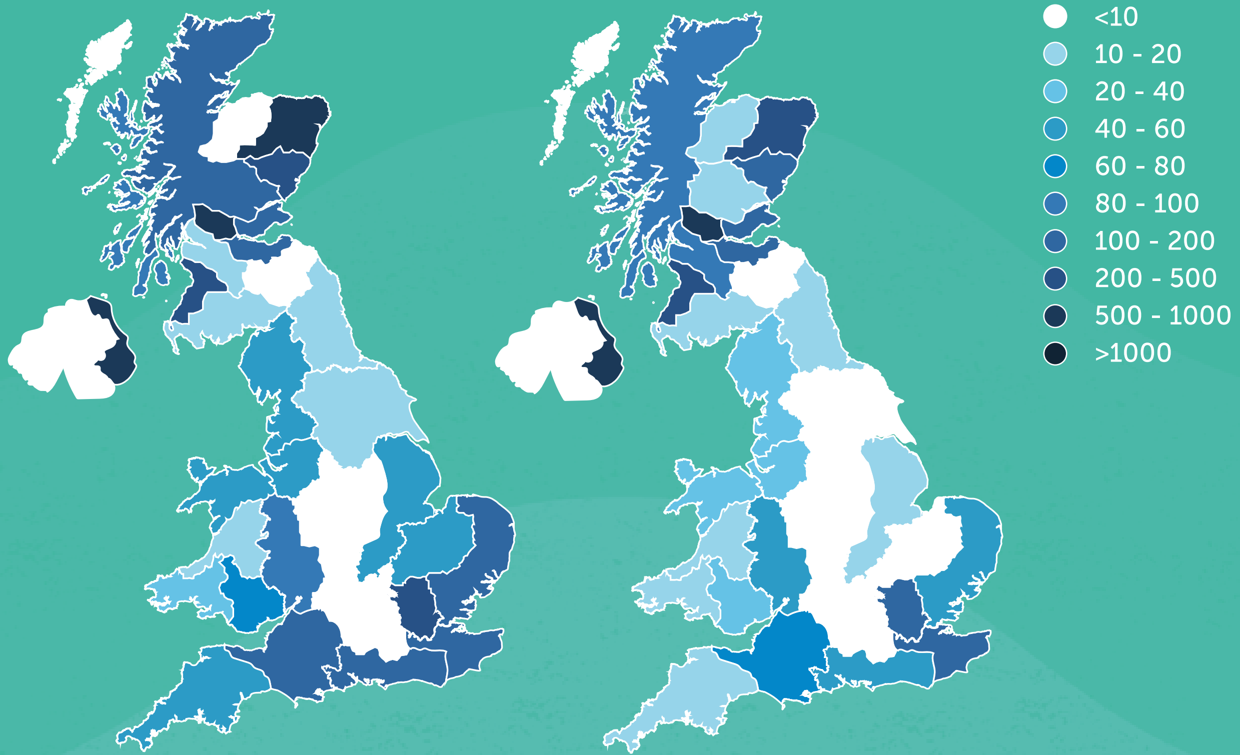


FIGURE 21
Percentage increase in properties for (left) Current Adaptation and (right) Enhanced Adaptation levels under Low–Medium sea level scenario and low population growth.



Source*: Sayers, P.B., Horritt, M., Penning-Rowsell, E., McKenzie, A. and Thompson, D. (eds) The Analysis of Future Flood Risk in the UK using the Future Flood Explorer, FLOODrisk (2016), Figure 6-16*

Demographic issues

Another common feature is an older-than-average population. Coastal communities have a higher proportion of residents over 65 years than those inland (in England and Wales,[xv] 20 per cent on average in coastal areas, compared to 16 per cent overall for the two countries[6]). This ageing is a result of emigration by younger people, and selective immigration of older people[168] when they retire.

In coastal communities, local services face challenges because older residents have often moved away from their family support networks, and can have difficulty accessing centralised health care due to poor transport links.[7] Ageing also poses an additional challenge in the context of a changing marine economy, and skills shortages in coastal communities. Older people are less likely to participate in learning activity.[174] A 2012 survey found that over 40 per cent of people aged 55–64 had done no learning since leaving school.[175] The residents of coastal communities are older, and therefore less likely to retrain, suggesting that they may face acute challenges in adapting their skills to meet changing employment demands in the marine economy.

Demographic issues can be exacerbated by a lack of good quality affordable housing. In coastal communities, 6.1 per cent of household spaces were unoccupied by 'usual residents' (i.e. these properties are second homes or holiday lets), compared to 4.4 per cent for non-coastal England and Wales.[6] This can drive up prices and exclude locals from the housing market.[33] Inadequate supply can inadvertently support the viability of poor quality rental properties.[33] Roughly half of housing stock in coastal resorts (coastal towns where tourism is the dominant industry) is of poor quality, compared to 33 per cent elsewhere.[7] The lack of affordable housing may be a key factor in causing young people to leave coastal areas.[7]

Environmental change also has a direct implication for the economies of coastal communities. One of the greatest threats is the increase of coastal flood risk presented by sea level rise.[176] The Environment Agency estimates that major flood events could occur once every three years by 2080, compared to historical occurrences of once every 100 years, placing 1 million people in coastal communities and £120 billion of coastal infrastructure at risk.[7] The associated challenges described above are likely to exacerbate the risk from flooding for older populations in coastal communities.[177]

Coastal erosion is an associated risk of sea level rise. Approximately 17 per cent of the mainland UK coastline is affected by coastal erosion, with the east, south-east and south of England most vulnerable.[178] It is currently estimated to pose a risk to 122,000 properties (residential and commercial) and 5000 hectares of agricultural land in England and Wales, worth £7.7 billion.[178]

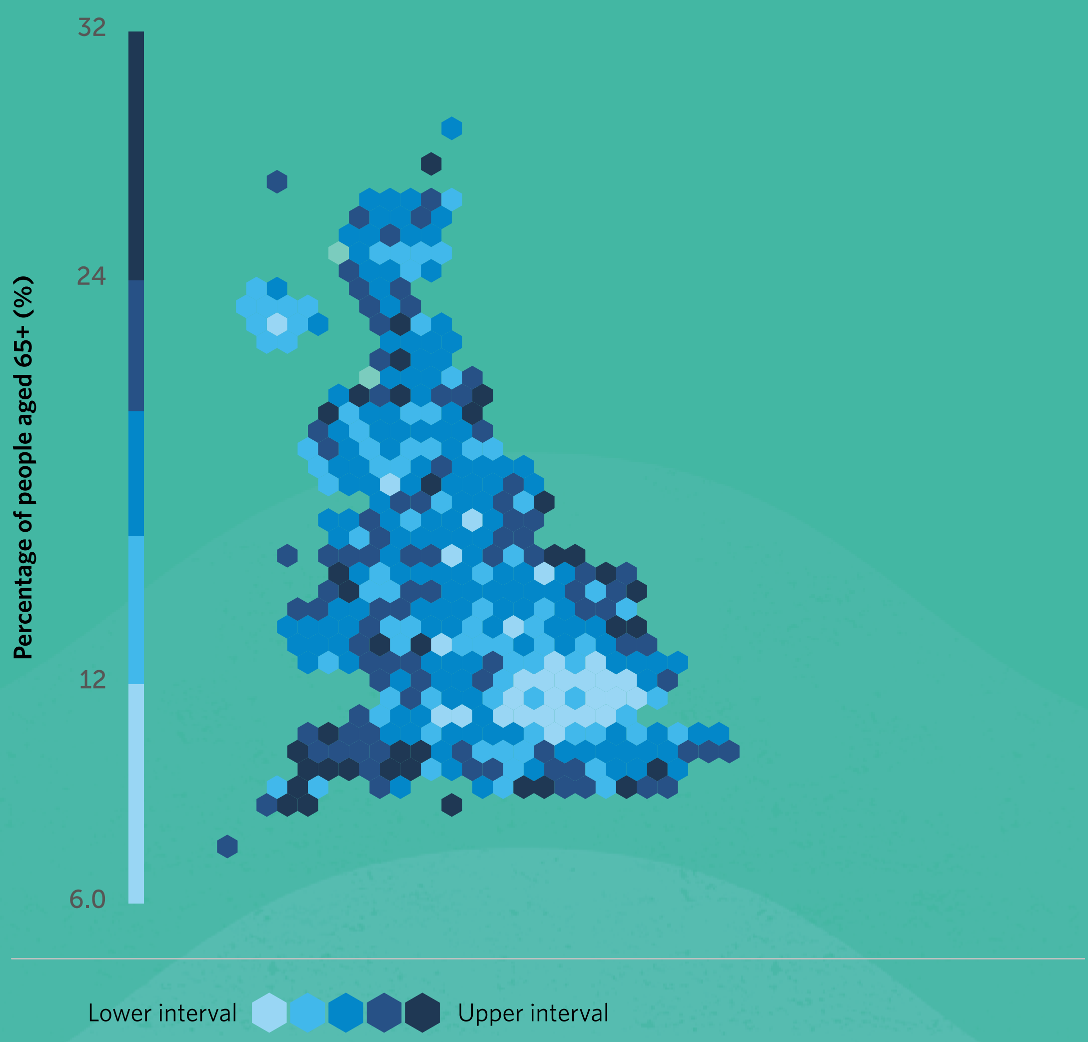
Significant additional investment is likely to be required to maintain current coastal defences or to retreat defence lines to more suitable locations, with implications for infrastructure assets in coastal areas. It has been estimated that the annual cost of maintenance of coastal defence infrastructure will increase by 150 to 400 per cent.[27] This is particularly the case for mid-west Wales and south-east England: by the 2080s, under Low–Medium (~30 cm global sea level

xv Only England and Wales are used here in this section due availability of data for these regions.

rise from 1990 to 2100) sea level rise, a vertical wall with 1:100 years (e.g. a 1 per cent chance of the wall being exceeded in a year) protection decreases to 1:5 (20 per cent) and 1:8 years (12.5 per cent) for the two regions respectively.[8]

It is possible that in some areas it may not be viable (due to engineering limits or cost) to provide coastal defences, and that retreating to historic coastlines, even in developed areas, will be the only sustainable option.[7] Some shoreline management plans, for example on the North Norfolk coast, already include plans for managed realignment. This involves moving shoreline defences further inland allowing previously protected land (including agricultural land) to undergo natural processes, creating natural flood protection through new intertidal habitats.[179] The economic uncertainty created by sea level rise was identified as an important challenge at GO-Science's coastal communities' workshops.

FIGURE 22
Proportion of population aged 65 and over, by local authority (ONS)



***Source**: Office for National Statistics*

Coastal communities' workshops

GO-Science ran a series of workshops in coastal communities, bringing together academics, business leaders and local government to consider what the future of the sea means for different parts of the UK.

Humber

The Humber region has a significant relationship with the sea, particularly through its history as a deep-sea fishing port. Today it has one of the largest port complexes in the UK, supporting 33,000 jobs and handling more than 65 million tonnes of cargo.[180]

There is great diversity within the region; for example the challenges and opportunities for Hull, the largest town in the region, are different to Grimsby. There are also a large variety of economic uses of the sea, with offshore renewable energy increasingly important to the economy. Economic activity in Yorkshire and the Humber due to offshore wind development, including the Siemens wind turbine manufacturing plant, is estimated to be worth £4–10 billion in GVA to the local economy, offering 8,000–15,000 jobs by 2020.[182] This industry is expected to continue to be an important part of its future economy.

However, attendees at the workshop noted that the Humber region's reliance on the sea is declining. The local economy is now more service-based, rather than manufacturing, involving jobs which tend to be lower quality and poorly paid.[181, 182] In order to make the most of future economic opportunities, many of which are linked to the sea, priorities for the region include better connectivity and improved transport links to maintain a young workforce, and better links between the Humber and the rest of Northern England; investment in deep-water port capabilities to provide for growth in offshore salvage and decommissioning associated with removal of marine infrastructure from the oil and gas industry; and improvement of skills to encourage local supply chains.

Sea level rise and coastal erosion are major challenges for the Humber region, particularly due to the vulnerability of Spurn Head, a spit at the mouth of the estuary. Projections predict that a serious storm surge, driven by a 0.3 m rise in sea levels, will occur in the Humber within the next 50 years, potentially causing £10 billion of damage.[183] Around 90,000 hectares of land, home to 400,000 people, are at risk of being flooded[184] and the Local Enterprise Partnership reports a lack of investment in the region due to the uncertainties associated with sea level rise.

North Wales

North Wales has a strong relationship with the coast. Marine and coastal activities, including tourism and fisheries, are crucial for the economy. There is a long history of marine science off the North Wales coast[185] and Wales has a large number of universities. Attendees also argued that there is a strong cultural link to the sea that should be celebrated and protected.

The coast has new economic relevance as the potential and technical feasibility of offshore renewable energy and other emerging industries grow. This is combined with fishing and aquaculture industries, and an important tourism sector to create significant and diverse opportunities for the region. One of the major opportunities identified was tidal energy. (North Wales is one of the few places where tidal range energy could be generated, and is a key development area for tidal stream energy with a significant resource and proximity to grid connection.) These potentially have wider benefits (e.g. tidal lagoons to tourism and the environment).

One of the critical issues was the challenges around capitalising on the future opportunities that North Wales has; Wales is the poorest nation in the UK.[186] Attendees identified three major issues for capitalising on future economic opportunities: skills, infrastructure, and ensuring that local communities benefit. They also commented that a lack of long-term planning and coordination has historically affected marine and coastal activities in the region.

In order to increase the chances of capitalising on these opportunities, attendees recommended the development of a mechanism for bringing marine and coastal stakeholders together. They also identified the importance of learning the lessons of what they saw as previous missed opportunities, and in integrating where possible natural solutions when planning economic activity.

East Anglia

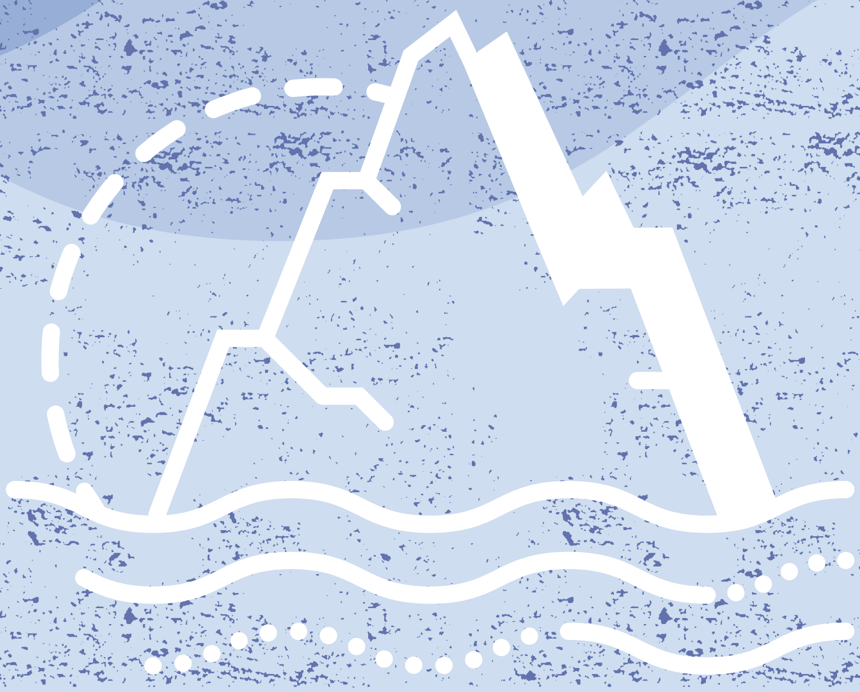
East Anglia has considerable expertise in fisheries, offshore wind, oil and gas and marine technology and a large number of local jobs and supply chains rely on these sectors. The region has been involved in the offshore energy sector since it began in the 1960s and today the combined offshore wind industry of Norfolk and Suffolk is worth £994 million per year, employing 8,000 people.[187,188]

Attendees considered the region's diversity and expertise in the marine economy to be one of its greatest strengths and saw opportunities to export this. They also identified opportunities to take advantage of advances in marine autonomy and CCS, through 'Offshore Enterprise Zones' with designated testing areas for new technology development.

Challenges highlighted by attendees included a need to improve road and rail infrastructure, especially to the ports and to Great Yarmouth harbour, to allow for better transportation of goods in and out of the region. In particular, they argued for further investment on the roads to support the expansion of trade at Felixstowe port, which handles 40 per cent of the UK's container traffic.[189] Existing infrastructure in the region must also be protected from the growing threat of sea level rise and coastal erosion; major trunk roads including the A47 and A12 have been identified as at high risk of flooding.[190] Lowestoft's flood defence scheme was identified as enabling increased investment in the area, compared to other places that have greater uncertainty about flooding.

The marine economy can bring jobs to the region but industry struggles to recruit locally due to skills shortages. East Anglia's working-age population has fewer qualifications than the England average. In 2012, 29.8 per cent of people were qualified to degree level or above (compared to 34.2 per cent national average).[189] Attendees identified that investment in seafaring and engineering skills, and better links between local schools, colleges and universities to develop a skilled local workforce should be priorities.

Implications for the Environment



Key findings

This chapter considers environmental change through the lenses of its implications – for biodiversity, human health and wellbeing, and the ecosystem goods and services that the environment provides.

Issue

The marine environment supports a diverse range of species and habitats and has a critical role in the geochemical cycles that underpin life on Earth. Advances in science and engineering have allowed us to increasingly understand the critical role the sea plays, and the many changes affecting the marine environment. Some of these changes occur naturally; however, many are a result of human activities. The marine environment and the vital goods and services it provides are increasingly threatened by over-exploitation, pollution, and increased CO_2 in the atmosphere, which is leading to warming and acidification of the ocean. Coastal regions are particularly stressed because of the concentration of human activity. Without action to understand and mitigate these threats, there is a significant risk of irreversible damage to the marine environment. This would lead to the loss of key ecosystem goods and services, and increase the risk to human health and wellbeing.

Response

The UK has a large opportunity to draw on its marine science strengths, which are already allowing us to measure and understand more about the sea than ever before. We can also build on early successes in MPAs and sustainable fisheries management in the face of growing pressures. However the challenges facing the marine environment are profoundly global – they are shared across the globe and domestic action is not enough to protect countries' own waters.[xvi] Turning the tide will require internationally coordinated research and policy efforts. The UK is well placed to take a leading role, and is already taking significant action towards marine environmental protection.

Recommendations for the UK

7. ***Address the key threats to biodiversity*** and protect marine ecosystems to preserve the long-term sustainability of the sea. This will require an internationally targeted effort, focused on improved monitoring and fisheries management, and addressing activities on land as well as at sea. It includes supporting public awareness campaigns about marine protection – addressing the out of sight, out of mind challenge.

xvi A helpful illustration of how marine pollution travels from its point of origin can be found at plasticadrift.org, which shows how plastics travel across the world's seas over a decade.

8. ***Reduce plastic pollution in the sea***, which is projected to treble in a decade without further intervention. The major response is likely to lie in preventing it from entering the sea, introducing new biodegradable plastics, and potentially public awareness campaigns about marine protection – again addressing the out of sight, out of mind challenge.

9. ***Develop accurate and useful valuations of the marine environment*** through the goods and services it provides (including food, capturing carbon, mitigating flooding, and supporting human health) so that environmental externalities can be made clear and their value incorporated into decision making.

10. ***Ensure the Overseas Territories are resilient to growing environmental risks linked to climate change***. The risk to the Overseas Territories was further exposed by the 2017 Atlantic hurricanes, and the nature of their economies and locations makes them more vulnerable than much of the UK mainland.

3.1 Implications for Marine Biodiversity

FIGURE 23
Average plastic abundance in a Fulmar stomach (left of tweezers) and the equivalent amount of plastic at human stomach scale (right of tweezers)

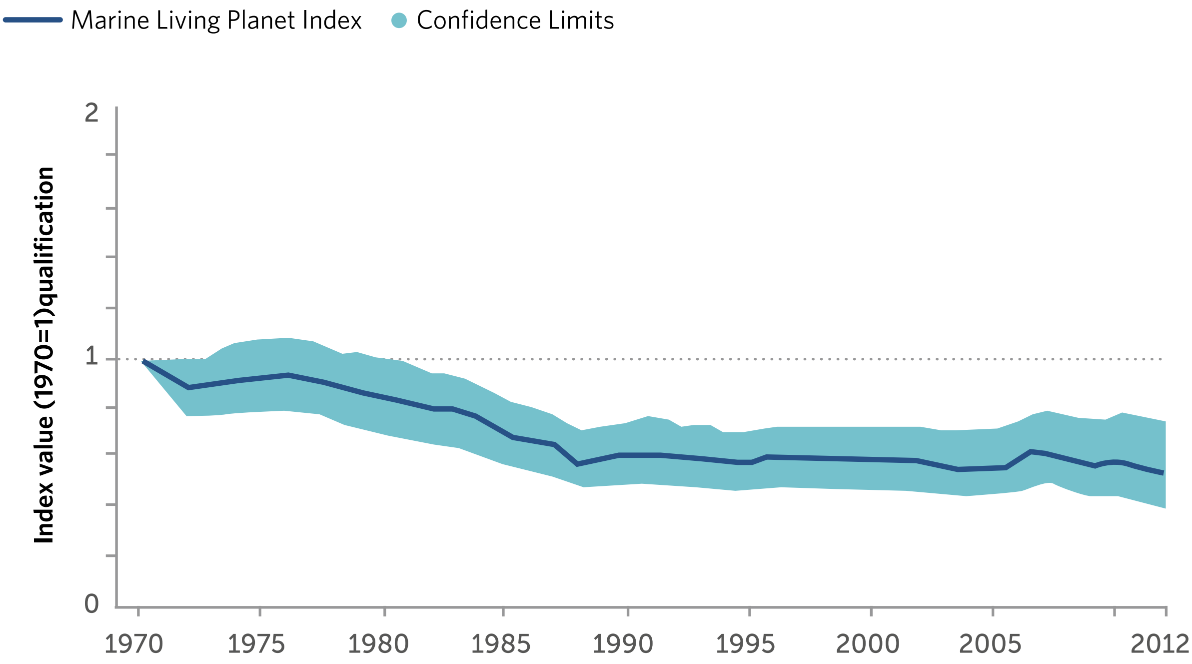
Source*: Jan van Franeker – IMARES, in Foresight Evidence Review: Plastic Pollution (2017)*

The UK and global seas are home to a diverse range of species vital for underpinning marine ecosystem health.[5,191,192,193] The Overseas Territories support many important populations of rare, migratory and threatened species,[196] and large expanses of undisturbed habitats with international conservation significance.[196, 197] This biodiversity is crucial to the successful future of the sea because it provides many important services that underpin human welfare and economic prosperity.[5,191,192,193] These range from the provision of food and medicine, to climate regulation and waste detoxification.[198] These services and the challenges for valuing them are discussed in more detail below.

Over the last 100 years human activities in our seas, such as plastic pollution (see Figure 23), have intensified dramatically leading to increased pressure on marine biodiversity.[5, 32, 194] It has been estimated[xvii] that there has been a 49 per cent decline in marine vertebrate populations between 1970 and 2012[194] (see Figure 24), although there is also evidence that in some areas new policy measures (e.g. better fisheries management) have led to signs of recovery for some species. Understanding and managing these pressures is essential to safeguarding the benefits that our sea provides.

xvii It is difficult to develop indices that do not show declining trends through time. This is because the indices depend on consistently measuring the same variable over long periods – something which is rarely achieved – and ensuring that they are not biased because of changes in the structure of marine communities so that the index becomes progressively less representative through time. There is a tendency to start these time series by measuring abundant species at time=0 but because of the changing dynamics of communities they might not be abundant species later in the time series. Consequently, there is an in-built tendency for the time series to show downward trends. It is often, therefore, hard to distinguish the effects of variability from the effects of directional change.

FIGURE 24
The global marine LPI shows a decline of 49 per cent between 1970 and 2012; this is based on trends in 5829 populations of 1234 vertebrate species



***Source**: WWF, Living Blue Planet Report: Species, Habitats and Human Well-being (Tanzer, J., Phua, C., Lawrence, A., Gonzales et al., eds), Gland, Switzerland: WWF and Zoological Society of London, (© 2015 WWF, all rights reserved)*

The main causes of marine biodiversity loss are interacting with the wider variability of the marine environment (e.g. weather cycles, biological variability in fish stocks) to place increased stress on ecosystems. These changes are not isolated threats – they are happening concurrently, and have combined effects. The UK is leading many activities to address these issues[xviii] – establishing MPAs in the UK's domestic and global EEZs (see page 75), the UK Marine Strategy which contains measures to contribute towards Good Environmental Status in the UK sea,[195,199] and developing a 25 Year Plan for the whole environment. Greater opportunities for join up lie in ensuring that economic activity and UK international engagement are fully considered and, where possible, reflect these ambitions.

The threats to biodiversity described below are subject to many uncertainties. While there remain many unknowns about the future of marine biodiversity, and the resulting impact on people, our ability to monitor and understand these changes is growing (see Chapter 5, 'Science').

xviii The UK Government recognises the importance of minimising and halting marine biodiversity losses and is invested in addressing anthropogenic threats that contribute to marine biodiversity losses. Some recent successful interventions include the designation of 298 marine protected areas in UK waters. In English waters there are currently; 50 Marine Conservation Zones protecting 20,000 sq. km, 44 SPA for seabirds and 39 marine Special Areas of Conservation; more MPAs are due for designation in the forthcoming years. Management of MPAs has seen the introduction of fisheries management such as the prohibition of bottom-towed gear over vulnerable features such as rocky reef systems (an issue highlighted in section 3.1.1). The UK government has also delivered a policy which sees microbeads banned in cosmetics and personal care products, and a levy on plastic bags (the impact of which is highlighted in section 3.1.4).

3.1.1 Overfishing and Habitat Loss

The biggest threat to marine biodiversity and therefore all the goods and services that it provides continue to be from overfishing and habitat loss. Due to progress by European countries, the number of fish stocks within safe biological limits in the North-East Atlantic is at its highest level since the 1980s.[200] Illegal, unreported and unregulated (IUU) fishing practices also damage fish stocks, with estimates suggesting that illegal fish imports in the EU are worth 1.1 billion[201].

However, over 31 per cent of global commercial fish stocks for which assessments exist are currently fished to biologically unsustainable levels.[41] Over 50 per cent of the UK's commercial fish stock is not exploited sustainably. The proportion of fish stock for which assessments are not available and are overfished is probably much greater. This threatens the functionality of many marine food webs and ecosystems, especially in coastal regions.[192] The latest assessment by OSPAR however has indicated that fisheries management policy in the North-East Atlantic is having some positive impacts, suggesting that 'deterioration has been halted and, in some areas, that fish communities are showing signs of recovery'.[202]

Unsustainable fishing, in the UK and elsewhere, can also cause a decline of populations of non-target species which are caught accidentally.[203,204] For example, it has been estimated that between 160,000 and 320,000 seabirds have been killed annually in longline fisheries across the world.[205] One of the biggest threats to corals and other benthic habitats is from fishing practices such as bottom trawling, which can damage or destroy corals and habitats.[206, 207, 208, 209] Fisheries are expanding to deeper waters due to decreased resources in coastal areas, which risks putting greater pressure on these habitats and exploiting fish species that are very vulnerable to over-exploitation.[209]

The sustainability of fish stocks is critical to global food security, and wider stability. Many of the world's poorest countries rely on seafood for protein (see Chapter 4, 'Implications for Global Engagement', section 4.2). Sustainable fishing practices could help reduce wider biodiversity loss and the risk of damage to deep-sea habitats and ecosystem function.[210]

3.1.2 Ocean Warming and Acidification

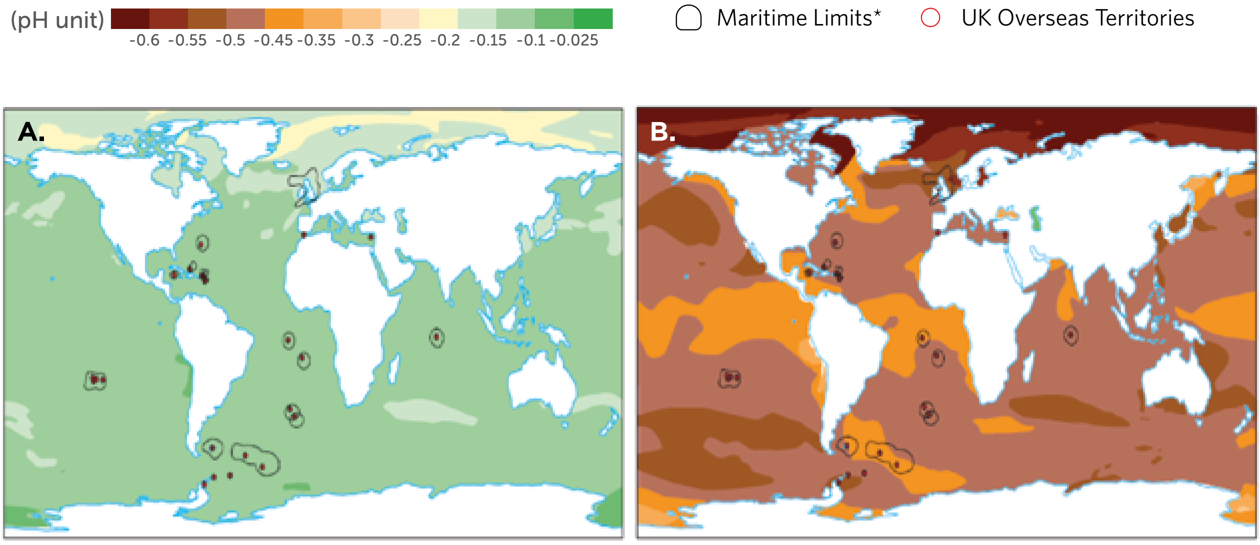
One of the main causes of future biodiversity loss will be ocean warming.[9] Increased temperatures cause physiological stress, threatening the abundance and productivity of many marine species.[9] Warming is also expected to cause large geographical shifts of species, with an increase in warm-water species as they replace cold-water species, potentially resulting in localised extinctions and arrival of invasive species.[9, 211]

Coral reef systems are especially vulnerable to increases in sea temperature. They support over 25 per cent of all marine species, and are of economic importance to many of the Overseas Territories where they support regional fisheries and eco-tourism,[197] and can provide coastal defences.[212] Increases in temperature can cause coral bleaching,[9,213] which has recently occurred at record levels in the Great Barrier Reef[214]. This involves the expulsion of food-providing algae from the coral, causing disease and death. Currently, coral is declining at an annual rate of 1–2 per cent,[215] with projections estimating that tropical coral bleaching may occur on average every two years by 2050.[214] This will reduce the opportunity for reefs to recover and threaten the species and livelihoods that they support.[216]

Another impact of carbon absorption, ocean acidification, affects important calcifying species such as mussels and coral.[43] Around 85 per cent of known deep-sea cold-water coral reefs in the UK will be potentially exposed to corrosive waters by 2060.[217] The effects of ocean warming, in particular, overlap with acidification to have damaging effects on biodiversity, including commercially important species.[43]

FIGURE 25

Change in ocean surface pH (1986-2005 to 2081-2100) for RCP 2.6 (a) and RCP 8.5 (b), overlaid with a map of the British Overseas Territories



Source: *Adapted from IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovern mental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.*

3.1.3 Invasive Species

There is projected to be an increase in introduced alien species entering UK waters,[xix, 9,218, 219] mainly transported by vessels. Some of these can become invasive by increasingly rapidly in abundance and out-competing local endemic species, but most become integrated into the faunal communities. Invasive species can outcompete or predate on indigenous species, and can cause localised extinctions.[9] Several species are predicted to colonise UK waters in the next few decades and this could result in structural change within planktonic, pelagic and benthic communities resulting in changes for commercial fisheries and aquaculture species[9,219] (see page 36) For example, there has been an increase in jellyfish blooms in the North-East Atlantic.[220] Jellyfish can predate commercial fisheries and aquaculture species, sting recreational swimmers and clog fishing nets. They can also clog the seawater intake screens of power and desalination plants, causing power reductions and possible shutdowns.[221]

xix The IMO's Ballast Water Management Convention, in response to this issue, was adopted in 2004 but has not yet come into effect.

In 2011, a jellyfish blockage at Torness nuclear power station in Scotland caused both nuclear reactors to be shut down for several days.[222] Once established, invasive species are difficult to eradicate. However measures to prevent the introduction of invasive species through shipping[xx] and fisheries will help reduce the risks.[223] Non-native species detection has been integrated into the UK's statutory biodiversity programme since 2016.

3.1.4 Pollution

Pollution has an important effect on marine biodiversity. Plastic pollution is an increasingly high-profile issue.[224] Over 70 per cent of marine litter is plastic and there is extensive evidence that entanglement in, or ingestion of, plastics can cause injury and death to a wide range of marine organisms, including commercially important fish and shellfish.[10] It is predicted that there will be a 3-fold increase in the amount of plastic in the sea between 2015 and 2025,[10] with the full implications still unknown[10] (although there may be some for human health – see page 76).

While plastic is a high-profile issue, it is not necessarily the greatest threat. Other types of pollution including pharmaceuticals in sewage and agricultural runoff, radioactive waste, noise and light pollution are also thought to pose threats to the health of marine creatures.[47] For example, polychlorinated biphenols, a group of industrial chemicals, have been found to accumulate in the tissues of whales, dolphins and porpoises in very high concentrations in UK and European waters and are likely to be toxic to the animals, causing population declines.[225, 47]

There are concerns about the potential impacts of brominated flame retardants on the development and reproduction of marine creatures.[226] Other potential dangers to marine life include toxins released from algal blooms;[227, 228, 229] exposure to toxic pesticide run-offs; and metal pollution – harbour dredging can cause cadmium and other harmful metals to be taken up by shellfish, for example.[230] Levels of some toxic metals, such as lead, are declining in marine fish.[231] There was also an 80 per cent reduction of inputs of hazardous organochlorine pesticides such as lindane into the North-East Atlantic between 1990 and 2008.[47]

Light and noise pollution are also areas of current focus. Although there is little information on the impacts of light pollution on marine ecosystems,[47] an estimated 54 per cent of Europe's coastline is affected by artificial light pollution,[232] which could potentially affect the behaviour of marine organisms.[233, 234] Similarly, there is evidence that noise pollution (from shipping, sonar, construction, etc.) can have negative effects on a variety of marine animals.[235]

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xx The IMO's Ballast Water Management Convention, in response to this issue, was adopted in 2004 but has not yet come into effect.

An increase in the use of chemical fertilisers has resulted in increased nutrient pollution to coastal waters.[236] It is projected that by 2030 global nitrogen input into the sea will have increased by 14 per cent from 1995 levels.[237] Nitrogen fertiliser can increase the biomass and growth rate of algae, and increasing rates of hypoxia, or areas of low oxygen, are a growing concern for biodiversity and ecosystem functioning.[44] These algal blooms can also have harmful effects on human health, as they can have direct toxic effects on fish and shellfish,[238] which when eaten can have severe impacts on human health and even be fatal.[239]

The result of the latest research into the excessive enrichment of water with nutrients (eutrophication) indicates that this occurs in the OSPAR maritime area (see Figure 26), particularly in areas sensitive to nutrient inputs, such as estuaries.[240] This is despite the reduced input of nutrients and lower concentrations of nutrients observed in this area. Although the extent of eutrophication in the OSPAR maritime area has continued to improve since 1990, concerns about atmospheric and riverine inputs of nutrients identified in the 2010 OSPAR quality status report still remain.

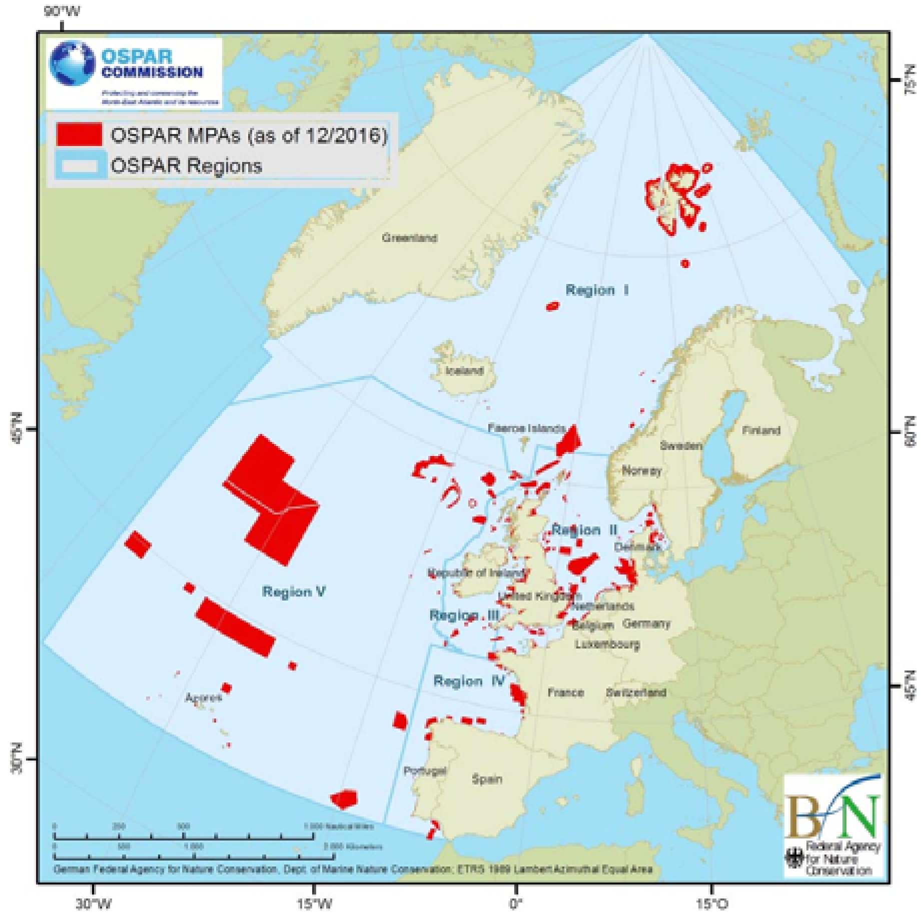
3.1.5 Marine Conservation

Evidence shows that losing marine species and habitats will have significant, potentially irreversible, consequences for the health of the sea [192, 194] – weakening its ability to sustain life, provide food, regulate our climate, and maintain water quality.[199] There are many measures which can be taken to help protect marine biodiversity, including climate change mitigation, reducing pollution and creating sustainable fisheries. However, protection measures will need to account for the multiple stressors facing the marine environment if they are to be effective. For example, sustainable fisheries management plans will need to consider range shifts and other climate change effects to ensure the long-term health of stocks, and the associated habitats and food webs.[241]

Marine Protected Areas are an important tool for protecting marine habitats. SDG 14 states that 10 per cent of the sea should be protected by 2030, while OSPAR set the goal of establishing a network of MPAs across the North-East Atlantic[xxi] (see Figure 26). MPAs can be important biodiversity reservoirs, providing habitats for species at risk from overfishing, and acting as buffers for climate-related stress.[242] While currently only approximately 3 per cent of global seas are protected,[243] the UK has taken a leading role: 23 per cent of UK waters are protected.[30] The UK Overseas Territories make a significant contribution to this, with large MPAs established around the Pitcairn, South Georgia & the South Sandwich Islands, and the British Indian Ocean Territory. Evidence suggests that the conservation benefits of MPAs increase if they are no-fishing zones, larger than 100 sq. km, older than 10 years old and well enforced.[244]

xxi Since 2010, 289 MPAs have been added to the network, bringing the total number to 448. They now cover 5.9 per cent of the OSPAR area compared with a total coverage of 1.1 percent in 2010.

FIGURE 26
Distribution of OSPAR MPAs across OSPAR Regions (as of 1 October 2016)



__Source__: German Federal Agency for Nature Conservation, Dept of Marine Nature Conservation (1989)

There are several long-term challenges facing the use of MPAs. Enforcing many of them, particularly outside of the mainland UK's EEZ, is inherently difficult due to their size and distance from human population, but good enforcement is necessary to prevent illegal fishing or destructive practices.[244] This is part of a wider issue around enforcement at sea (see page 91). To be effective, MPAs must be able to adapt to ocean-warming-related species migration changes. This may mean moving them depending on the season, or providing protected 'corridors' to allow species to move easily from one protected area to another.[245, 246, 247] It is also important that baseline data of the biodiversity in an area is established before an MPA is designated, along with continual assessment and ongoing monitoring to evaluate and ensure the effectiveness of protection measures.[245, 248, 249]

Importantly, MPAs do not protect against the other threats to marine biodiversity.[250] Many threats, including pollution, warming and acidification, do harm far away from where their causes originate.[199] This is a further indication that global as well as localised action is required.

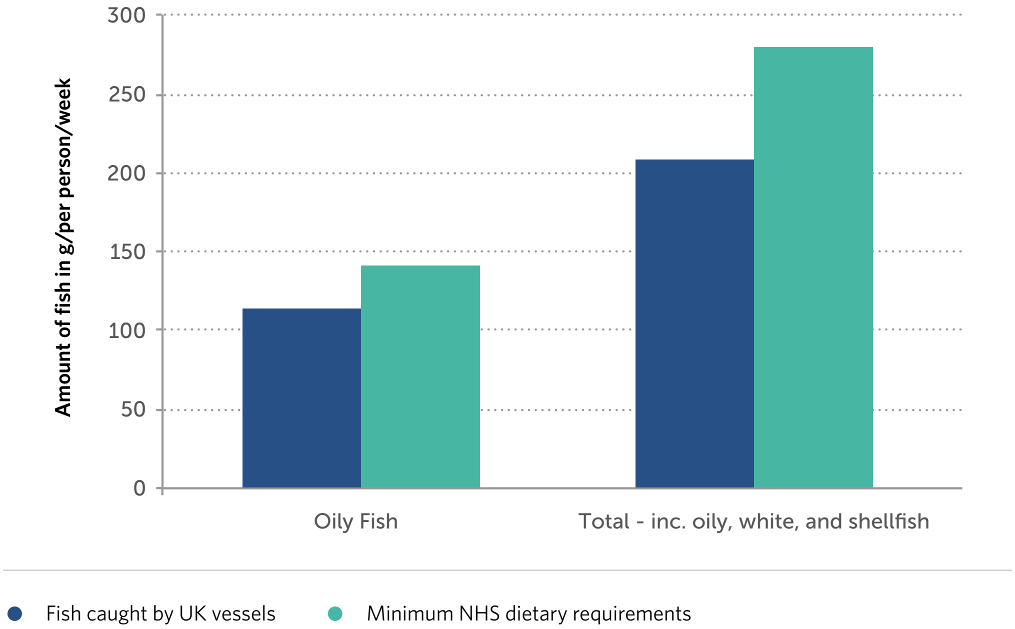
At a national level, there is room for greater education about the importance of the sea, and the impact of human behaviour upon it. This is an element of the 'sea blindness' referred to throughout this report. Evidence suggests that understanding the environmental implications affects people's behaviour.[251, 252] A recent survey found a lack of public knowledge about marine biodiversity in UK waters.[253] Given the significant threat posed by increased marine litter, initiatives to increase public awareness of the sea, and the threats it faces, should be supported.

3.2 Implications for Human Health and Wellbeing

There is an important link between the marine environment and human health and wellbeing. Over a third of the UK population lives within 5 km of the coast,[8] and coastal communities may prove especially vulnerable to some of the risks described in this chapter (see 'Discussion: Understanding the sea', page 16).

Although many of the changes described in this chapter will have direct implications for health and wellbeing, they may also have indirect implications through seafood. There is evidence that consumption of oily fish, such as mackerel and sardines, decreases the risk of cardiovascular disease (due to their high levels of omega-3[254]). As a result of this, Government guidelines recommend that 'a healthy diet should include at least two portions of fish a week, including one of oily fish'.[255] As it stands, UK vessels currently catch a smaller amount of fish each week than is required to meet these requirements nationally (see Figure 27). This demonstrates that, even if the majority population of the UK that does not rely on fish for protein (as some of the Overseas Territories do), the future of fisheries and levels of pollution in seafood (see page 73) could affect our health.

FIGURE 27
Total amount of fish caught in the UK per week and the minimum weekly requirement of fish suggested by the NHS (both in grams per person). Shown for oily fish and all types of fish.



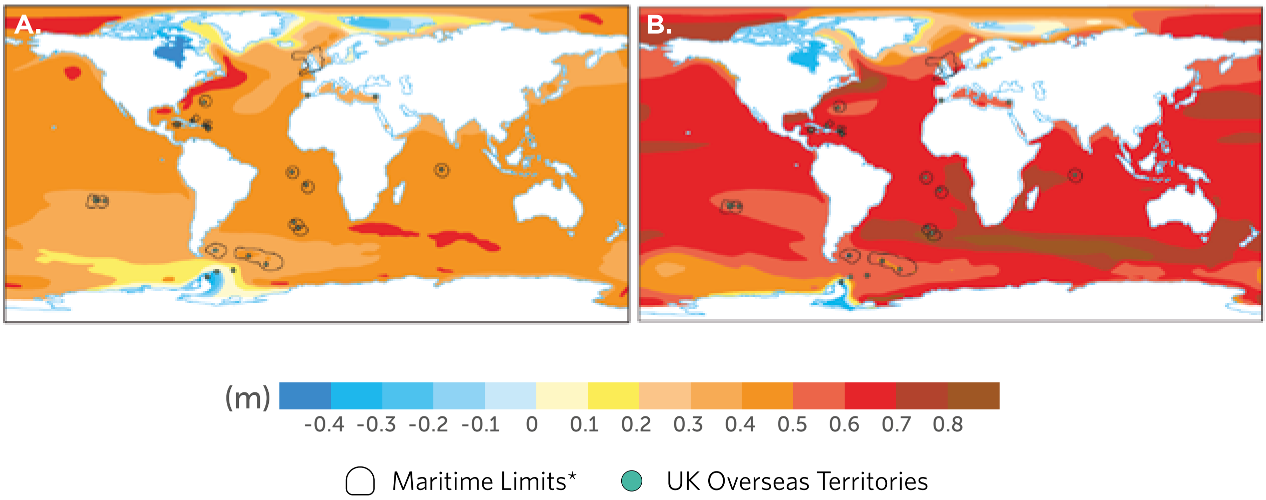
Source: *NHS and the Marine Management Organisation*

While the marine environment may pose a greater risk to health and wellbeing in the future, there are also health benefits to be valued and protected. Research is increasingly unravelling the complexity of the relationship between the sea and human health and wellbeing. There is evidence that it is possible to promote good public health by ensuring access to high quality marine and coastal environments.[33] Overall, coastal communities report better health than inland communities with similar age and socio-economic population profiles.[256, 257] There is also evidence to suggest that the same individuals show fewer symptoms of depression and anxiety when living close to the coast than they do when living further inland.[258]

3.2.1 Sea Level Rise

Sea level rise is projected to increase the frequency and severity of coastal flooding.[259] Flooding caused by storm surges affects vital services, which are generally under-provided in coastal communities (see page 58). It is estimated that 42 emergency services, five hospitals and 77 GP surgeries are currently at significant risk of coastal flooding.[260, 261] Studies also show that flooding can exacerbate or provoke mental health problems,[262] and that the associated economic difficulties can cause anxiety and depression.[263]

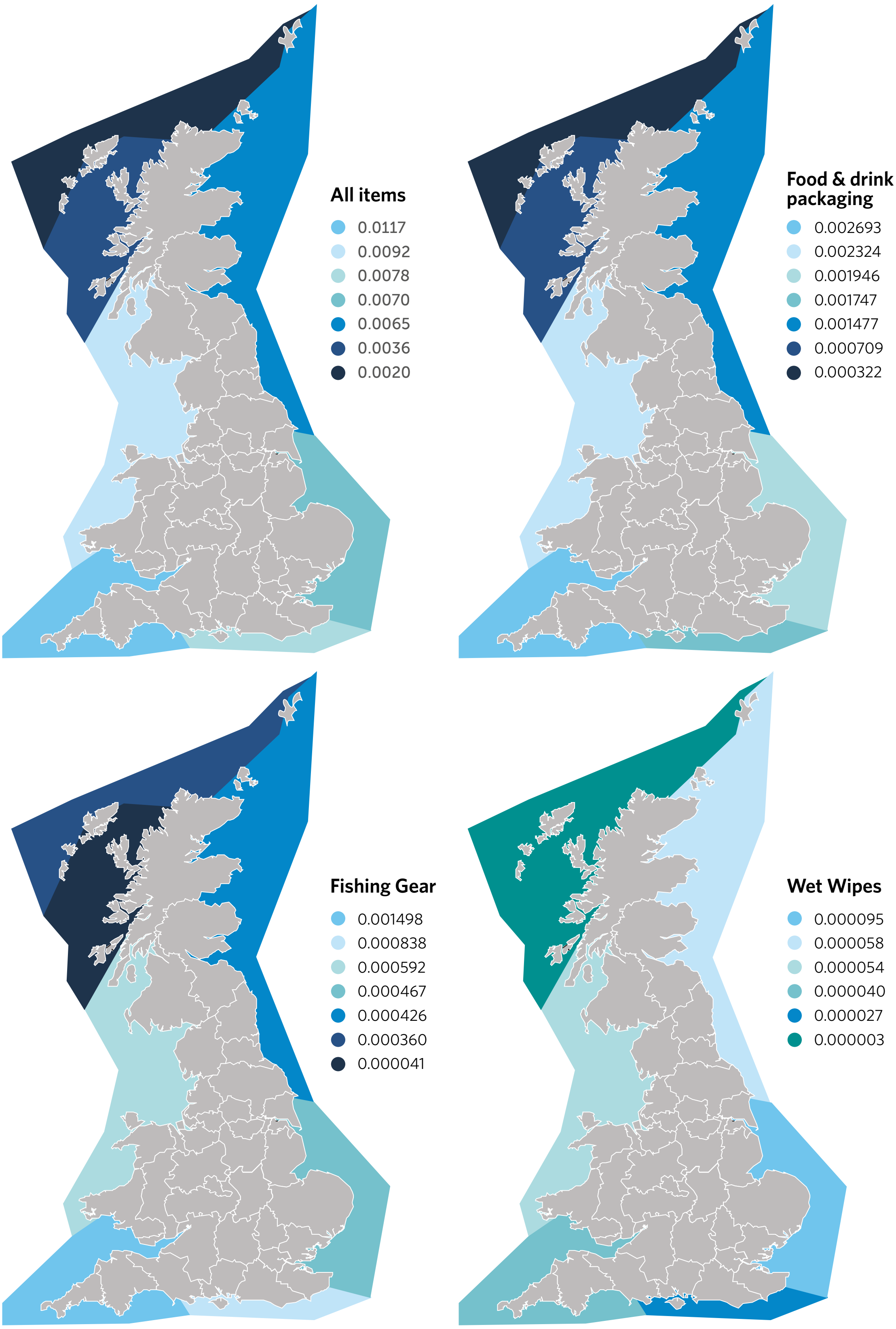
FIGURE 28
Change in average sea level (1986-2005 to 2081-2100) for RCP 2.6 (a) and RCP 8.5 (b), overlaid with a map of the British Overseas Territories



***Source**: IPCC, Climate Change 2014: Synthesis Report – Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team: R.K. Pachauri and L.A. Meyer, eds), Geneva: IPCC (2014)*

FIGURE 29

Distribution maps of regional mean number of items per metre, per minute, per person, by litter type (colour relates to the number of items)



***Source**: Adapted from Nelms, S.E., Coombes, C., Foster, L.C., Galloway, T.S. et al., Marine Anthropogenic Litter on British Beaches: A 10-year Nationwide Assessment using Citizen Science Data, Science of the Total Environment 579 (2017): 1399–1409*

3.2.2 Pollution

High levels of plastic pollution can affect health and wellbeing in several ways. Litter left or washed up on the coast can impact upon residents' quality of life by reducing recreational opportunities, and can deter coastal visitors. This reduces their access to the health benefits associated with outdoor activity,[33] as well as potentially affecting the tourism industry.[264] A recent EU-wide survey demonstrated that over 70 per cent of visitors noticed litter on either most or every visit to the coast. In the UK during 2010 around 40 per cent of local authorities undertook beach cleaning with annual costs in the region of £15.5 million.[10] The uninhabited Henderson Island, one of the Pitcairn Islands, was recently found to have the highest density of man-made debris of anywhere in the world, with 99.8 per cent of it plastic.[64] Coastal plastic litter can also increase the risk of bacterial pathogens such as *E. coli*.[265] However there is currently no evidence that microplastics in seafood pose a threat to human health.[266]

Other kinds of pollution pose direct and indirect, via seafood, risks to human health. Marine pollution may also have direct effects on human health, with the consumption of seafood potentially leading to ingestion of hazardous chemicals that have accumulated in the food chain.[47] Indeed, in addition to the Government guidelines for the recommended consumption of oily fish for a healthy diet, there are also guidelines for the maximum level of fish consumption due to the risks posed by pollutants.[258] Persistent, bioaccumulative and toxic chemicals (PBTs) are of concern due to their potential impacts on human health.[47]

Metal pollution of the sea also has implications for human health. For example, UK exports of crab to China have been affected by cadmium contamination,[267, 268] with excessive cadmium consumption affecting kidney function and bone mineralisation later in life.[268]

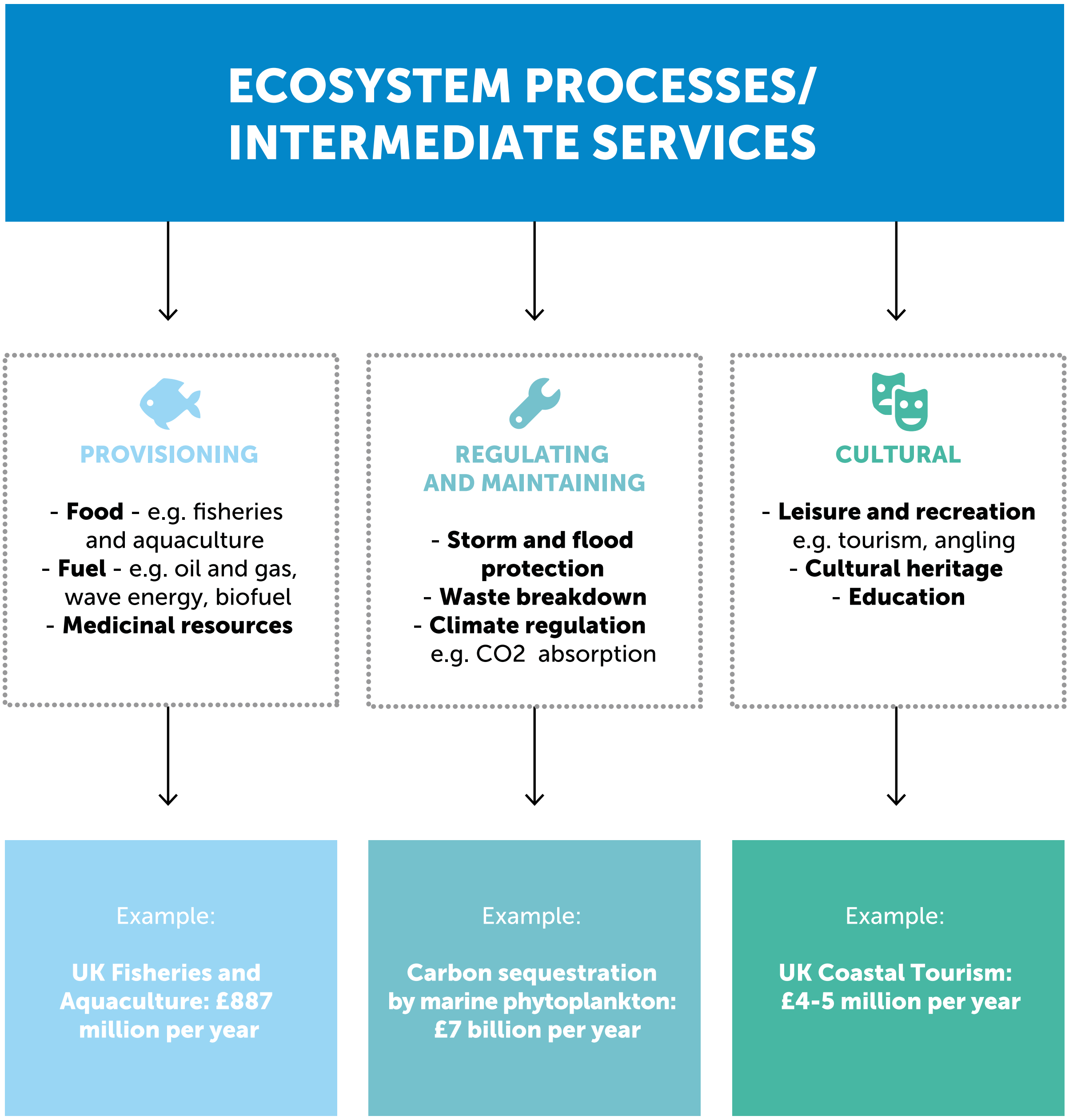
Some perfluorinated compounds (PFCs), which are used in a range of commercial and industrial applications, are listed as persistent organic pollutants (POPs) by the Stockholm Convention on Persistent Organic Pollutants.[12] These compounds are thought to cause adverse human health effects, such as hormonal disruption[269] and have long elimination half-lives in humans;[270] seafood consumption is a major source of PFCs in human diets.[271]

Pharmaceutical pollution may also pose a serious risk to human health by contributing to anti-microbial resistance (AMR), a major global threat. Pharmaceuticals are regularly discharged into coastal environments via sewage effluent, leaching from coastal landfills, and runoff from agricultural land. To date, 113 pharmaceuticals have been detected in coastal waters globally, and the maximum concentrations of 69 of these exceeded the European Medicines Agency threshold for predicted environmental concentrations.[272] Micro-organisms exposed to sub-lethal levels of antibiotics can result in antibiotic resistance, and widespread examples of this have been reported in fish, seabirds and marine mammals living in coastal waters.[273]

There have been reports showing that human Vibrio bacterial infections are increasing worldwide, including fatal diseases such as cholera, gastroenteritis and septicaemia.[274] Many scientists believe this increase may be associated with rising sea temperatures (global sea surface temperatures having risen by 0.7°C over the past century),[177] as warmer water promotes Vibrio growth and persistence in the aquatic environment. Ongoing warming of coastal regions is expected to support the spread of these bacteria, particularly in northern latitudes,[275, 276] posing a direct threat to human health.

3.3 Valuing Ecosystem Services

FIGURE 30
Ecosystem services derived from marine and coastal ecosystems and example ecosystem valuations; ecosystem processes, also known as intermediate services, underpin and support wider services for society; examples of specific services are listed but are not exhaustive



The marine natural environment provides many valuable goods and services upon which society depends (see Figure 81). One of the major implications of environmental change is on the provision of these goods and services. However we currently struggle to adequately value these,[xxii] meaning that the cost and full implications of changes to them are not easily understood or reflected in decision making.

Some goods and services are easier to value than others. Seafood, like other ecosystem services that directly provide provisions, is reasonably easy to value (UK fisheries landings in 2015 were worth £775 million[277]) and can therefore be accurately considered in decision making. However many other ecosystem services are more difficult to measure, and their value is often shared across sectors or between an entire community. For example, the sea captures around one third of all carbon dioxide emissions.[278] This essential service helps to regulate the climate and slow the rate of build-up of carbon dioxide in the atmosphere,[279] but is threatened by biodiversity loss and climate change.[278,280] It is possible to identify specific habitats that have an important role in this process, and to attempt to value their contribution – UK coastal habitats such as sand dunes and salt marshes are estimated to be worth £1 billion from 2000 to 2060 for their role in carbon sequestration.[32] However, because the value of this service in moderating climate change is shared across society, there is a lack of individual stakeholders adequately motivated to respond to the societal loss of value (estimated to be 25 per cent[32]) from expected habitat losses.

xxii Another concept used to value the environment is natural capital. This refers to the standing value of the environment itself, e.g. the price of land. In the marine context, natural capital is often not a good measure of value. This is because the marine environment can often have low standing value but provide high-value services as described above.

FIGURE 31
Examples of different ecosystem services and their estimated values

Ecosystem service	Estimated GVA per year NB. Not all value is directly from the sea	Source
Aquaculture, fisheries and processing Total of GVA from UK seafood landings, seafood processing sector and aquaculture production	£1.1 billion	ONS(205)
Marine tourism and recreation Estimate of GVA from commercial marine industry, marine recreation and tourism (e.g. sailing, wildlife watching SCUBA diving)	£4–£5 billion	Coastal Communities Fund (2016)
Climate regulation/CO_2 sequestration (coastal shelf) Estimated using alternative costs of potential non-natural alternatives	£7 billion	UK NEA (2014)
Coastal protection (intertidal habitats) Estimated using alternative costs of potential non-natural alternatives	£3.1– £33.2 billion	UK NEA (2011)

Collecting more evidence about the value and functioning of ecosystem services is one of the priorities for the future of the marine environment. Improving our ability to value and therefore accurately consider ecosystem services in policy and other decisions has two clear benefits.

1. Avoiding long-term damage for short-term gain. The difficulty in measuring the value of the natural environment, and an associated lack of incentive for decision makers, risks creating situations where we unknowingly do long-term harm to the UK by prioritising short-term benefits that are easier to value.
2. Finding alternatives to artificial solutions. Protecting and sustaining the natural environment can provide cost-effective ways to deliver services that would otherwise require man-made solutions. For example salt marshes can reduce the cost and required height of sea wall defences – an 80 m width of salt marsh could save £2600–£4600 per metre of sea wall.[281]

Although better evidence will help, it also requires support from decision makers. Government is well placed to lead on the incorporation of cross-society benefits from ecosystem services, such as carbon sequestration, into decision making.

3.4 Resilience of the Overseas Territories

The UK Overseas Territories (see page 26) are primarily islands or groups of islands and, as such, their inhabitants are particularly vulnerable to the effects of marine climate change. There is no evidence that the 2017 Atlantic hurricanes, which caused significant damage to Anguilla, Turks and Caicos, and the British Virgin Islands, were caused by anthropogenic climate change. However, their impact does demonstrate the vulnerability that some Overseas Territories have compared to mainland UK. Given the growing risk that this report identifies to human health and economic activity, it is important that measures are taken to ensure all the Overseas Territories have the necessary measures in place to ensure their ongoing resilience to climate change.

Canada

The priorities for other nations depend on their trading relationships and geography. Understanding these is important for defining the future opportunities and threats to UK maritime interests. This is demonstrated using three countries with different geographic and economic profiles: Canada, Chile and Indonesia.

The first country, Canada, has the longest coastline in the world, totalling 244,000 km and bordering three different oceans. As a result, Canada has a diverse marine economy, which contributes Can$27.7 billion (~1.7 per cent of GDP) annually to its GDP.[282] The Canadian Prime Minister recently announced a Can$1.5 billion national Oceans Protection Plan that outlines measures for marine safety, cleaner shipping, economic development, and marine protection.[283]

Engagement opportunities

Polar research

The UK and Canada share a strong interest in the poles and polar science. The Arctic includes over 40 per cent of Canada's landmass and is home to more than 100,000 Canadians.[284] The Arctic also offers opportunities and challenges as a result of climate change and growing resource exploration, some of which have important international dimensions. In 2014, the UK was third in the world for the number of published articles on the Arctic,[285] and the RRS David Attenborough, which is planned for completion in 2019, is a good example of the UK's strength in manufacturing the high-specification vessels required for polar exploration.

Aquaculture

Canada has significant expertise in aquaculture and the industry there has increased in value by 63 per cent over the last decade. Canada aims to build on this success by improving fisheries and aquaculture management as well as enabling access to export markets.[286] The UK is one of the leading aquaculture producers in Europe, producing a value of over £590 million at first sale (sales by producers to distributors and vendors).[287]

Tidal energy

Canada has shown increasing investment in tidal energy, with the Can$50.7 million Bay of Fundy project, which began to generate electricity on 7th November 2016.[288] It is hoped that this project will increase Canadian expertise in the deployment and service of grid-integrated tidal turbines as the world market opens to the technology.[289] The UK also has significant strengths in tidal stream technology and the Hendry review recently published its findings into the feasibility and practicality of tidal lagoons.[290]

Implications for Global Engagement

Key findings

How we engage with the rest of the world is a key question throughout this report. This chapter specifically considers UK global engagement through two crucial lenses – our approach to global governance, and to international development.

Issue

The UK is directly and indirectly affected by the economy, environment and security of the sea around the world. Stable and effective governance is critical for the future success of UK interests. There is a challenge to ensure that, where necessary, marine governance is evolving to fit the developing economic, social and technical opportunities presented by the sea. These range from existing challenges around maximising opportunities while minimising environmental impacts, and enforcement against illegal activity, to long-term threats from climate change. This manifests itself in a number of important upcoming decision points for the international community – for example, around the regulations for deep-sea mining.

International development is another crucial part of how the UK engages internationally around the sea. The UN's SDG 14 is to: "Conserve and sustainably use the oceans, seas and marine resources for sustainable development". There are a number of issues discussed in this report that are linked to international development and could present long-term global challenges. For example, many developing nations are at increased risk from declines in the fish stock that they rely upon for food and income.

Response

The UK has the expertise and experience to continue showing global leadership, whether through international diplomacy or development, with clear opportunities emerging to do more. The inherently global nature of the sea means that doing this will have direct and indirect benefits for the UK. However, to do this effectively, in the face of a changing marine environment and economy, there is a strong case for the UK determining its strategic approach overall. This recommendation is particularly timely as leaving the European Union offers the UK the opportunity to re-determine its approach, and its role in global governance of the sea – in particular how it engages with international organisations in the future.

Recommendations for the UK

11. ***Promote, support and enforce stable and effective global governance***. UK interests are directly affected by the economy, environment and security of seas around the world. Good governance at global and country levels is therefore critical. The UK is actively engaged in this already but, in line with this report's overall recommendation, would benefit from ensuring a strategic approach in this area that delivers on national priorities.

12. ***Ensure that, when the UK leaves the EU, any new regulation is robust for the long-term challenges and opportunities in the sea.*** Some of the UK's marine interests are currently subject to EU regulation. As the UK leaves the EU, it had the opportunity to reassess its marine priorities and create replacement legislation that reflects this.

13. ***Lead the development of new regulation for emerging industries and technologies*** such as autonomous vehicles and deep-sea mining. This will help to ensure that the UK's economic and environmental priorities are reflected in international law.

14. ***Use UK expertise and technology strengths to build marine capacity in developing countries***. Effective fisheries management in tropical developing countries will be especially important, as a reduction in catch is highly likely,[14] but there are also opportunities from climate mitigation, hydrography and sustainable coastal and marine management practices.

15. ***Ensure international development activities and UK marine priorities are aligned***. The UK is directly affected by what happens in other countries' seas. In the developing world 60 per cent of people obtain more than 30 per cent of their protein supply from fish,[15] and the projected drop in catch abundance has the potential to lead to political insecurity.[16, 17]

4.1 Implications for International Governance

The success of our response to many of the challenges and opportunities described in this report will be determined by international collaboration. Cooperation through international agreements, treaties and bodies is therefore a critical issue.

The UK plays a leading role across this international governance regime, either as an independent country or through its membership of the European Union (EU). The issues they cover are extremely broad (see Figure 32). The changes described in this report will strengthen the need for some of these arrangements and challenge the viability of others. This chapter considers some of the most relevant changes, and their general implications for global governance and the UK's approach to it.

FIGURE 32
Summary of key international organisations and agreements relating to the sea

Organisations	
International Maritime Organization	Specialised agency of the United Nations setting global standards for the safety, security and environmental performance of international shipping.
Intergovernmental Panel on Climate Change	The international body, established by the United Nations, for assessing the science related to climate change (not exclusively marine). The IPCC has published five assessment reports (latest in 2014) of the latest evidence of climate change.
Arctic Council	An intergovernmental forum promoting cooperation, coordination and interaction among Arctic States, indigenous communities, and other Arctic inhabitants. The UK has 'observer status' on the Council.
International Seabed Authority	An autonomous international organisation, established under the 1982 United Nations Convention on the Law of the Sea to act as a custodian of resources on the high seas. One of its principal functions is to regulate deep-seabed mining.
International Whaling Commission	Commission set up in 1946, with a legally binding 'Schedule' that sets specific measures to regulate whaling and conserve whale stocks.
Agreements	
The United Nations Convention on the Law of the Sea	Treaty defining the rights and responsibilities of nations with respect to their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources. Most other international agreements exist within this convention.
International Convention for the Prevention of Pollution from Ships	International convention developed by the IMO to eliminate pollution of the oceans and seas.

4.1.1 Climate Change and Environmental Protection

The changes described in Chapter 3 (Implications for the Environment) will have three consequences for governance. First, the need for effective mechanisms for reducing and mitigating the effects environmental changes will increase. The UK has had a leading role in developing global legal agreements to protect the marine environment. This continues. For example, the IMO is working to secure a global framework to address greenhouse gas emissions from shipping.

Second, it is also likely that activity to fulfil existing targets and goals will become more complicated.[291] For example, the UK is a party to two UN agreements, SDG 14 and the Convention on Biological Diversity, which recommend and oblige respectively the implementation of MPAs. Adapting and improving existing responses will be crucial for ensuring that this and other commitments are met, and the marine environment is adequately protected.

Third, environmental changes have the potential to disrupt the basis for current governance regimes. Coastlines serve a vital function in establishing the baselines from which marine territory is defined and upheld. As such, existing regimes are potentially threatened by shifting coastlines as a consequence of climate change. For example, a 90 cm sea level rise (within IPCC projections for year 2100, based on ongoing high carbon emissions) would flood 85 per cent of the Maldives capital Male.[292] Any uncertainty about the legal implications of this could lead to uncertainty over navigation, as well as sovereignty rights to resources, particularly where it transpires that previously declared areas are potentially violating international law.[293]

4.1.2 Policing and Enforcement

There is a significant amount of illegal activity at sea, such as smuggling, trafficking and unregulated fishing. For example, the majority of cocaine destined for the UK is transported across the Atlantic Ocean.[294] There are two challenges here – identifying illegal activity at sea, and responding to it.

Policing large spaces is inherently problematic. At sea, the projected doubling of trade by 2030,[5] alongside growing demand for marine resources and a diversification of marine activity, is likely to further complicate policing.

Technology provides some opportunities to improve the monitoring of illegal activity. For example, the UK is a global leader in satellite technology and has already developed a near-real-time satellite monitoring system, which helps enforcement to detect and respond to illegal fishing activity across the world significantly faster than the otherwise manual system, and is being deployed off the coast of Chile.[295] Improvements in drone, satellite and data technology all offer some opportunity to collect evidence on illegal activity. However, while making activity easier, satellites and other surveillance technology do not necessarily determine illegal activity, and remain dependent on having the necessary enforcement mechanism in place.

Robust laws have effective mechanisms for enforcing them. While illegal activity is often committed by stateless vessels, sovereign states have been found to have breached international law. On the high seas, there is a particularly acute challenge in enforcing illegal activity by nation states; for example, in the South China Sea, China, Vietnam, the Philippines, Taiwan, Malaysia and Brunei are all contesting claims to marine territories. In 2016, China was found to have breached UNCLOS in its development of artificial islands in the South China Sea. This raises questions about the enforcement of international law and highlights the need for governance in terms of integrated and comprehensive legal frameworks.

The international community is currently developing an Implementing Agreement to provide greater detail on the obligations set out in UNCLOS regarding the conservation and sustainable use of biodiversity in areas beyond national jurisdiction. Given the growing pressures described elsewhere in this report, and the scale of the marine environment beyond national jurisdiction, it is crucial that governance is robust. Resilient, enforceable regulations will be essential to ensure future biodiversity conservation targets are met.[296, 155]

Chile

The second country, Chile, has over 6,000 km of coastline and at the UN Ocean Conference committed to protecting 1 million sq. km of sea with MPAs, making it a world leader in marine conservation.[297] It is showing a growing interest and leadership on many marine issues including marine research, sustainable fisheries and security, and is currently developing a national ocean policy. Chile is also looking to the sea to provide solutions to challenges around the operational costs and vast amounts of water needed for its large mining industry.

Engagement opportunities

Protecting MPAs from illegal fishing

The UK has the opportunity to build on recent initiatives using satellite technology to monitor illegal fishing in the waters surrounding Easter Island[298] and work with Chile to effectively monitor the wider MPA network in the waters around it, including the UK's MPA in the Pitcairn Islands. There are also strong links between the Royal Navy and the Armada de Chile, the Chilean navy, responsible for coastal protection.

Sustainable economic development in the sea

Chile has recently announced the creation of a new Ocean Policy Council to focus on challenges facing marine sustainability. The UK can work with Chile and others to promote sustainable development in line with UN SDG 14. The key priorities for Chile in this area that overlap with the UK's strengths are the development of coastal infrastructure, improving the sustainability of aquaculture and coordinating research to address uncertainties associated with climate change and El Niño, to which Chile is especially vulnerable.[299]

Offshore energy

In the long term, Chile may depend upon the installation of marine renewables to help meet the energy demands of its mining industry. Chile's wave energy resource is estimated at 240 GW, which is among the highest capacity in the world,[300] although not all of this is necessarily exploitable. The UK has considerable expertise in the early development and installation of these technologies.

4.1.3 Industry and Technology

International engagement is also used to develop global industries and support the UK's position within them. This is because the global nature of economic activity at sea means that many sectors are significantly shaped by international law and agreements.

In some cases, an industry requires coordinated international effort to become operational. Perhaps the most relevant example is deep-sea mining (see page 54), for which the International Seabed Authority is in the process of developing regulations. Even established industries, such as shipping and fishing, are also shaped and developed by ongoing international negotiation in response to new challenges and opportunities. For example, the UK has co-sponsored a paper at the IMO which has approved a regulatory scoping exercise to identify regulations affected by or potentially prohibitive to autonomous operations.[301] This is expected to provide the basis of changes to permit the widespread uptake of autonomy in the shipping industry and beyond.

The changes that this report anticipates indicate a number of future decision points at an international level on the global approach to marine industries. There is an opportunity for the UK to capitalise on its advantageous position to develop the regulatory environment within the IMO and the International Seabed Authority for emerging technologies and industries, and a potential advantage to doing so.

More broadly, international governance can shape the global response to the disruptive implications of other new technologies, such as artificial islands. The UK is already active in the global response to emerging technology and industries. This should continue. In common with this report's primary recommendation, there is an opportunity to assess our strategic approach to this activity, to ensure enough is being done through this channel to support our economic and environmental priorities.

4.1.4 Exiting the European Union

The UK's marine interests are currently subject to many EU regulations, including fishing, ports and customs, and marine environmental protection. These are currently integral to the UK law. As the UK leaves the EU, it has the opportunity to reassess its marine priorities and create replacement legislation that reflects this. Where it is part of an international organisation or agreement through the EU, the UK will also need to consider whether and how it continues to engage on these, and where to form replacement relationships. The evidence presented in this report suggests that any replacement legislation or wider activities must be robust to long-term environmental challenges, capitalise on economic opportunities, and help to deliver effective domestic and international governance. This could be incorporated as part of wider UK activity to develop a strategy for its marine interests and engagement around them.

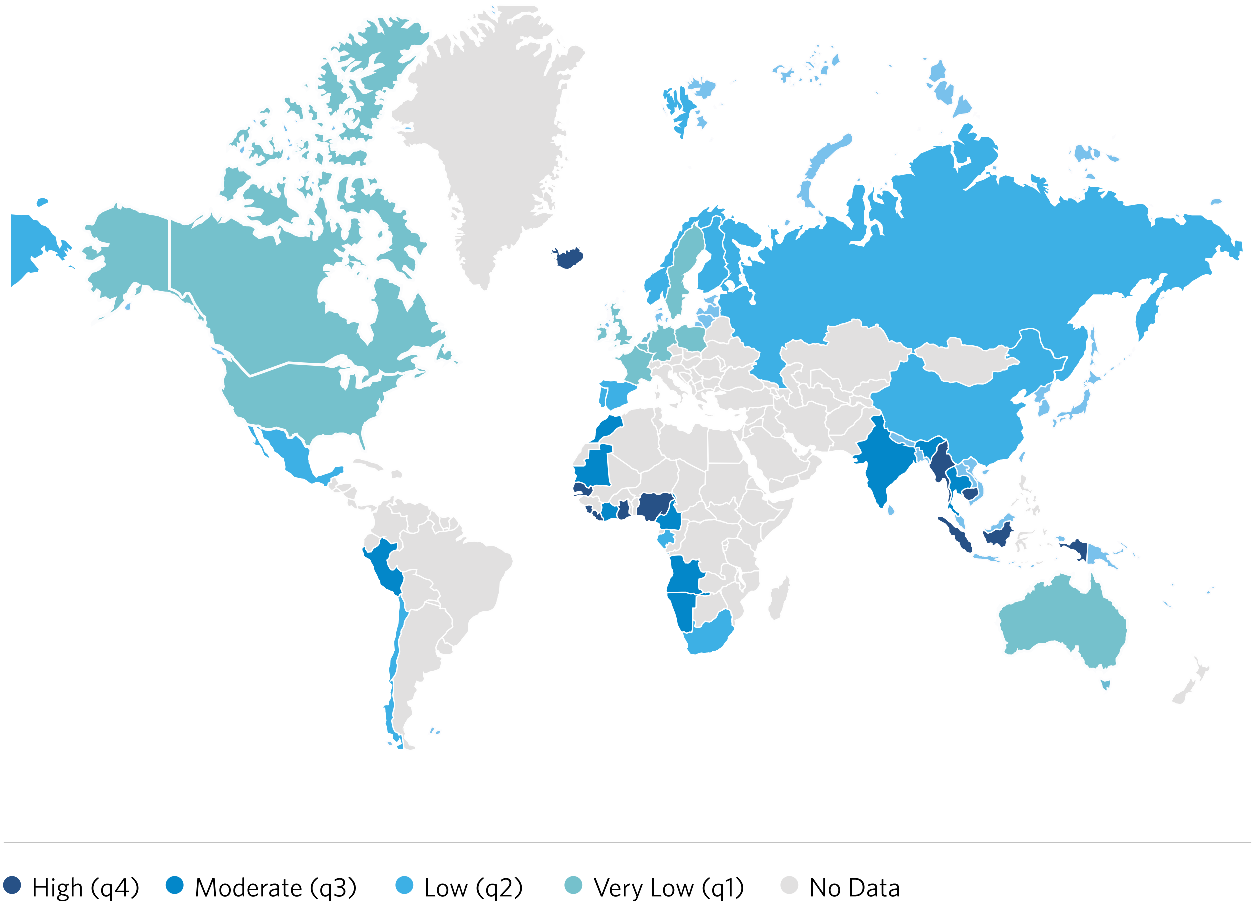
4.2 Implications for International Development

The UK has a significant aid budget, and global development presence. In 2015, the UK provided £12.1 billion of aid to developing countries, in line with the United Nations' target of 0.7 per cent of gross national income.[302] The sea is an important theatre for international development. The UN's SDGs have a strong marine focus. SDG 14 specifically covers the sea, but others have a strong relevance, including SDGs 2, 7, 9 and 13.

Many developing countries rely on the sea, particularly for its fish (see Figure 33). This means that the health of the marine environment is a development issue. At the same time, there are significant capacity building opportunities, which can address other issues at sea, particularly piracy (see page 48) and modern slavery. Examples included in this report where the UK has the opportunity to build capacity include sustainable fisheries, good governance and hydrography (see 'Discussion: Understanding the sea', page 16).

4.2.1 Sustainable Fisheries

FIGURE 33
Overall national dependency on fish and fisheries (in the regions considered) by quartile. A country's dependence score was determined from global fisheries statistics using three indicators measuring the contribution that fisheries make to the national diet, to employment and to gross domestic product.



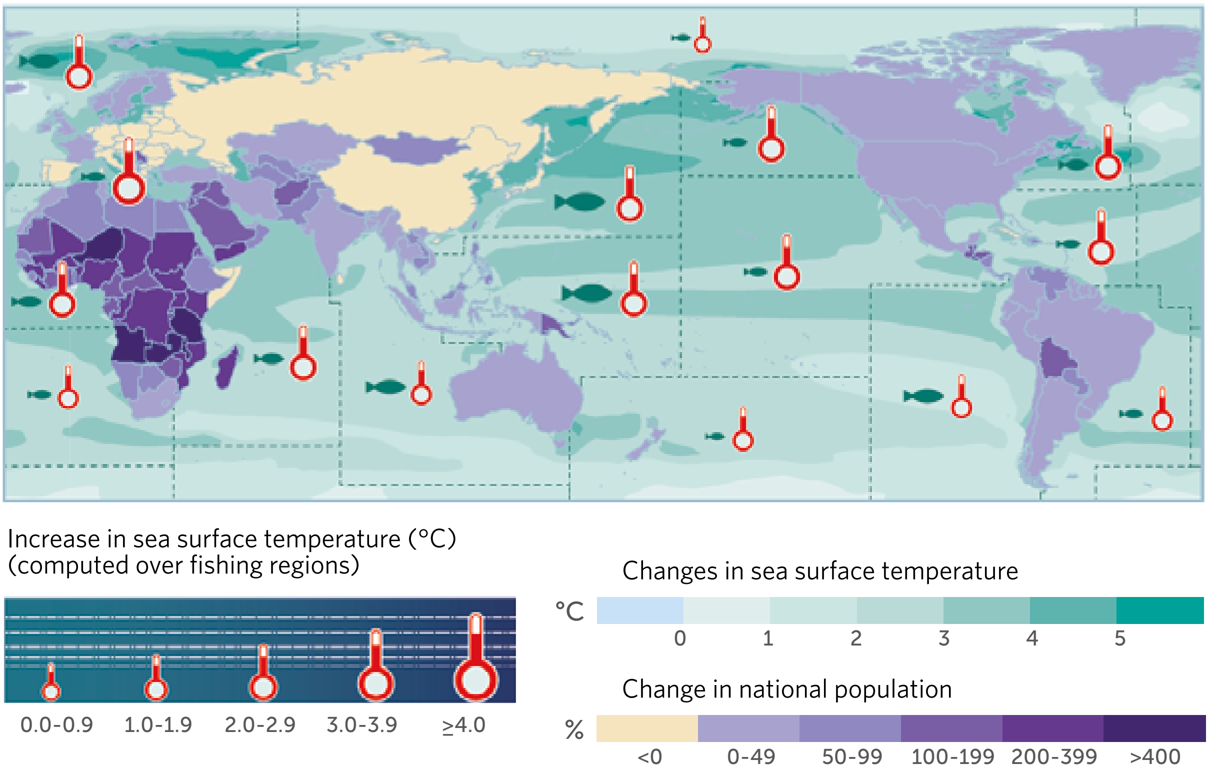
Source: *Barange, M., Merino, G., Blanchard, J. L., Scholtens, J. et al., Impacts of Climate Change on Marine Ecosystem Production in Societies Dependent on Fisheries, Nature Climate Change 4 (3) (2014): 211*

Unsustainable fishing practices threaten long-term global food security, especially in the developing world where 60 per cent of people obtain more than 30 per cent of their protein supply from fish.[15] In 2013, fish accounted for 17 per cent of the world's protein intake.[41] Demand is due to increase as projected population growth dictates the need for an estimated additional 40 million tonnes of seafood by 2030.[5]

Developing nations are particularly reliant on fisheries to provide employment and nutrition. Ninety per cent of people employed in the fisheries sector work in small-scale fisheries and almost all (97 per cent) of those workers live in developing countries.[41] Fish is also an important dietary component in many developing countries, providing a source of essential protein, fats, minerals and vitamins to communities that would otherwise be malnourished.[4] Effective management in tropical developing countries will be especially important, as fisheries are at high risk from climate change and highly likely to face a reduction in abundance of catch.[99]

Global fish stocks remain overfished beyond sustainable limits.[41] Restoration of over-exploited stocks and expansion of sustainably managed fisheries and aquaculture will help ensure long-term global food security, support livelihoods, and promote economic development, especially in Small Island Developing States.[303] The UK, through the Marine Stewardship Council and other institutions, has expertise in the research and implementation of sustainable fisheries management plans. By building on many initiatives already in place,[304] the UK is well placed to lead the global response.

FIGURE 34
Future change in sea surface temperature and population change by country.



Over the sea the change in both the spatial pattern and the regional average of sea surface temperature is shown, along with present day catch, as shown on the central map. Also shown on this map is the projected change in population by country.

***Source**: The Met Office*

4.2.2 Illegal Activities

The development of many countries can be undermined by illegal activities at sea. Issues such as illegal fishing and trafficking of goods and people directly affect the UK. By supporting international efforts to police the sea, the UK can help to address development challenges including food security, modern slavery and smuggling.

The control of illegal fishing is a growing global priority. It has been estimated that the annual cost to the global economy of illegal, unreported and unregulated (IUU) fishing is between $10 billion and $23.5 billion, and illegally caught fish are thought to comprise approximately 15 per cent of total catch.[305] IUU fishing endangers the sustainability of fish stocks and threatens long-term food security. IUU and food security are of particular concern in many parts of the developing world, especially in West Africa where 40 per cent of fish is caught illegally.[306] This can be difficult to police and requires international cooperation; however, new technologies in satellite applications may offer part of the solution. The UK has already established innovative initiatives in Chile and the western Pacific island, Palau, using satellite technology to monitor, detect and respond to illegal fishing activity.[296] There is the opportunity to build on this to lead the global effort to combat the illegal fishing industry and prevent illegally caught fish from entering domestic and international markets.

The policing of illegal fishing offers the UK and international partners the opportunity to address another global development priority, modern slavery. Fishing industries across the Asia Pacific region, predominantly in Thailand, have been identified as using the forced labour of trafficked foreign nationals, particularly when operating illegally.[307, 308] In addition to human trafficking and migrant smuggling, sea routes are often used to transport illegal drugs to the UK.[309] In 2009, $2 billion worth of cocaine, most of which was destined for UK markets was smuggled through West Africa, predominantly through the sea.[310]

As vessels operate far from shore and across multiple national jurisdictions,[308] satellite technology and international coordination will be required to monitor effectively. By working with developing nations for more effective enforcement of marine space, the UK can help address many of these issues.

Indonesia

The third country, Indonesia, comprises over 17,400 islands, covering 5.8 million sq. km of marine territory. This inherent relationship to the sea strongly links Indonesia's prosperity to the success of its maritime management. As such, the country's priorities include plans to manage marine resources and develop marine infrastructure, inter-island connectivity, diplomacy and defence.[311]

Engagement opportunities

Resources

Indonesia is aiming to develop its fishing industry to reduce reliance on food imports. The Centre for Environment, Fisheries and Aquaculture Science (Cefas) are collaborating with the Indonesian Government on a package of marine and fisheries initiatives.[312] However, environmentally unsustainable fishing, including IUU fishing, harms the environment, introduces security challenges and costs the Indonesian Government up to $20 billion a year.[313] The UK has expertise in technology and has already developed a satellite monitoring system to detect illegal activities such as IUU fishing, piracy and pollution.[296] Indonesia signed in April 2016 a Memorandum of Understanding with the UK on Regulation of Marine and Fisheries Cooperation,[314] reflecting the attractiveness of UK legislation models internationally.

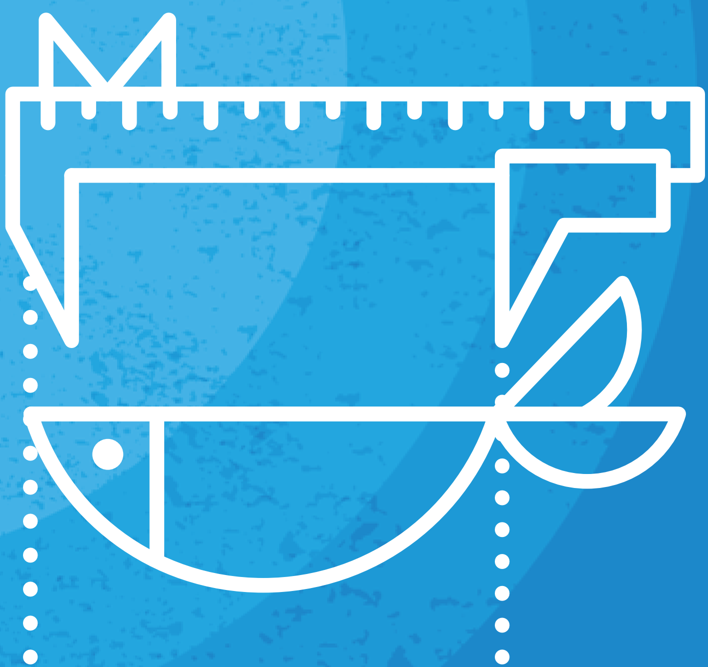
Security

Indonesia's military modernisation agenda aims to build strong naval capabilities as a pre-emptive and preventative strategy,[315] in particular concerning escalation in the South China Sea as well as the vulnerability of the Strait of Malacca. Indonesia's spending on defence totalled over $14 billion in 2016.[316] This will entail a substantial amount of international investment and sharing of technical capabilities.

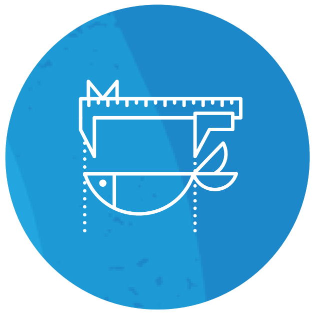
Infrastructure and inter-island connectivity

90 per cent of global trade is seaborne, with 40 per cent of that passing through Indonesian waters.[317] Indonesia recognises the need to capitalise on this by upgrading national infrastructure and enhancing inter-island connectivity.[316] The Japanese Government has already committed to developing marine infrastructure, and Indonesia is looking for similar arrangements from other key supplier countries.[316] The UK has expertise in the design, manufacture and installation of marine renewable energy, as well as capabilities in ship building, including fishing and transport vessels.

Science



This chapter considers the growing importance of marine science, in its broadest sense.



Issue

Interdisciplinary marine science will be critical to furthering our understanding of the sea, its value, and the impact of climate change and human activities on the marine environment. Key to doing this successfully will be continued and expanded ocean observations, facilitated by new technologies, particularly around autonomy. Science and innovation are key to a successful marine economy, and can provide a fundamental basis upon which to develop policy and governance arrangements.

Response

Joined-up scientific activity at a global scale will be crucial for strengthening our understanding. With its significant marine science strengths, the UK is well placed to lead the large-scale and long-term global effort to understand the changing sea and in turn build resilient coastal and marine environments, and make the most of its new economic opportunities. However, to fully service the needs of society, mechanisms should be found to ensure that marine science and policy are more closely integrated.[xxiii]

Recommendations for the UK

16. ***Ensure scientific activity is joined up and positions itself to deliver UK priorities.*** UK interdisciplinary expertise across the natural, physical, social and health sciences is likely to be critical for global capacity building, sustainably managing marine resources, addressing key uncertainties relating to the climate and marine environment, and developing the technologies needed for the future marine economy. Science has a key role to play in developing policy and industry. The interfaces between science and policy, and science and industry, should therefore be strengthened.

xxiii The Marine Science Co-ordination Committee is a body with cross-government (including Scottish, Welsh and Northern Irish) membership and academic non-executive members. Its role is to identify opportunities to align marine science and policy decisions. The latest version of the Marine Science Strategy, setting out opportunities to achieve this, is under development at the time of writing and has been informed by the priorities identified in this report.

17. *Prioritise key research needs*:

- Improved modelling of sea level rise and coastal flooding to inform planning of infrastructure and reduce uncertainty for coastal communities
- Technologies to enable modern communication at sea, and improve data transfer and battery power
- The interactions between different stressors, e.g. ocean warming and ocean acidification, and their cumulative impact on the marine environment
- The 'tipping points' at which marine ecosystems will be unable to recover from projected damage

18. *Ensure international scientific collaboration.* The shared, global nature of many issues affecting the future of the sea means that there are likely to be significant benefits to UK science from working in collaboration with international partners and multilateral organisations on shared future issues.

19. *Enable big data to be a driver of innovation,* including ensuring that the UK has the necessary storage capacity, analytical skills, and coordination between sectors and within Government.

20. *Improve our understanding of the sea* through UK contributions to systematic, globally coordinated and sustained global ocean observations and seabed mapping. Collecting more information will allow for greater investigation of fundamental long-term and large-scale processes, provide baselines upon which interventions and investments can be grounded, information for sustainable exploitation of natural resources, and improve our understanding of climate change and its impact.

5.1 Priority Knowledge Gaps

Although there is sufficient evidence to prove beyond reasonable doubt the existence of the long-term changes described elsewhere in this report, there remains a high degree of uncertainty about their exact nature and impact. The UK is in a strong position to lead the global effort to address these uncertainties and, in doing so, to underpin the development of policy to mitigate and adapt to them.

The IPCC climate change scenarios reflect this uncertainty. Here there are two issues at play. The first is the uncertainty related to the output from climate models (e.g. projections for global sea level rise under one emissions scenario (RCP 2.6) range between 22.5 cm and 47.5 cm). The second is the uncertainty related to international policy action to reduce greenhouse gas emissions. Global governments are in a position to address both, supporting initiatives to improve climate models and by agreeing and delivering policies to reduce emissions.

This uncertainty affects our ability to mitigate and respond to the threats from climate change. For example, there is uncertainty about the extent of sea level rise, potentially the marine environment change with the greatest implications for the UK. This is primarily linked to uncertainties about the severity of global warming, and a lack of understanding of how ice sheets are affected by global temperature rise.[8] This has significant implications when ensuring the resilience of critical coastal infrastructure. Nuclear power stations, for example, are required to have defences that protect them from 1:10,000 year flooding events, but our certainty about the frequency of these events changes over time.[8]

In the waters surrounding the UK and its Overseas Territories, there are still many questions about the current state of biodiversity, for example the location of seabed habitats.[21, 32] This makes it difficult to track how marine biodiversity is impacted by environmental changes. The extent to which we rely on ecosystems for goods and services is also poorly quantified[15] (see 'Valuing Ecosystem Services' section 3.3, page 81).

While impacts of many of the stressors on the marine environment have been studied individually, little attention has been given to the way they interact.[43] There is a possibility that some marine ecosystems will reach a threshold of irreversible change, although what these 'tipping points' look like is currently unknown.[15]

Finally, there is uncertainty about the potential impact of new economic activity in the shelf and deep seas, for example deep-sea mining (see page 54) and large-scale extraction of offshore energy.[15] Given the growing demand for marine resources, which makes it likely that these industries will develop, it is crucial that policy makers and industry are empowered to make the best possible decisions about them.

5.2 International Collaboration

Internationally coordinated research is required to address a range of uncertainties around changes to the marine environment and the implications of new economic activity.[249, 318] Strengthened and integrated scientific observations of the ongoing physical, chemical and biological changes in the sea will be necessary in order to provide large-scale, long-term evidence of trends and impacts to guide policy and protect the marine environment.[319] New technologies such as autonomous systems, floats and sensors will greatly assist the capturing of this data. The UK's extensive marine science and technology expertise and world-leading research institutions make it well placed to play a leading role in global marine research efforts.[15, 80]

The G7 Science Ministers, at a meeting in Japan in 2016, recommended global action to improve ocean monitoring and observations, with upgraded infrastructure and data-sharing policies. It is hoped that these efforts will help facilitate effective marine spatial planning, environmental protection, MPA monitoring, hazards warning and sustainable resource extraction.[318, 320] The UK's marine science and research expertise is allowing it to play a major coordinating role in this initiative.

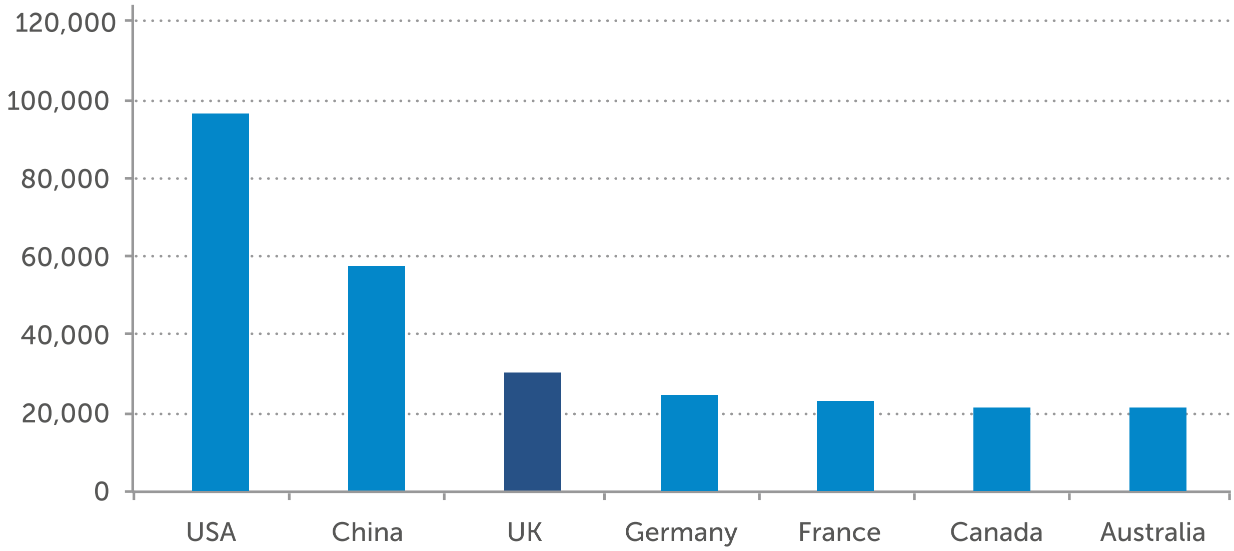
5.3 Data and Data Collection

The 'big data' revolution – industry projects a 4300 per cent total increase in data collected annually from 2015 to 2020[18] – is likely to have major consequences for how we use and understand the sea. Significant amounts of scientific (oceanographic and meteorological), spatial (seabed mapping, geological surveying), and shipping (traffic and performance) data is collected in the UK.[321, 322, 323] The wider big data trend is supplemented in the sea by the growing potential to use new technology to collect data more efficiently and cheaply in hostile marine environments.[324] The potential benefits are significant. A lack of data is a major cause of the uncertainties described above. More data can also improve enforcement, drive efficiencies in trade and shipping,[18] and reduce uncertainty around the impact of emerging industries.[319] More research and integration of the social sciences can help support the use of this data, helping to predict societal responses and adaptation to the changing marine economy and environment.

Marine autonomy will have versatile marine science applications, and allow data to be collected from areas previously unexplored by science, such as deep hydrothermal vents, and beneath polar ice sheets.[19] It will also be able to provide high-resolution seafloor mapping data, unable to be provided by surface vessels, which will have a range of scientific, economic and planning applications. The UK is a leading developer of this technology and so has the capacity to apply and demonstrate the benefits at home, as well as export it, and to lead internationally coordinated data collection.

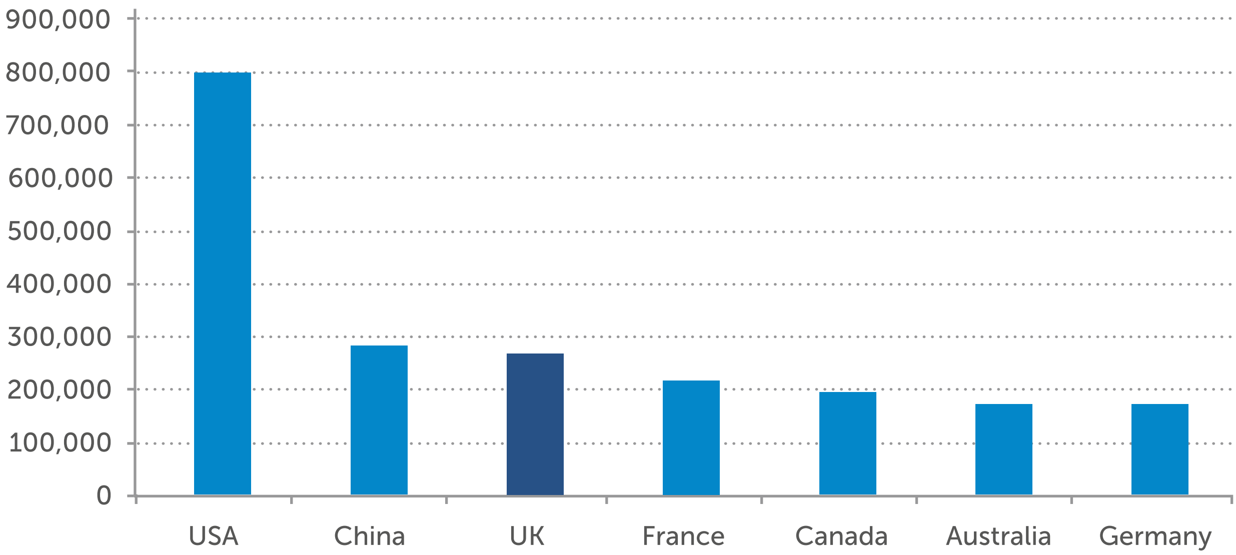
In order to capitalise on these opportunities, it is important for the UK to ensure that it has the necessary storage capacity, analytical skills and cross-sector coordination. GO-Science has spoken to colleagues in industry, academia and Government to assess some of the challenges associated with capitalising on the big data revolution. Chief among them were the need to ensure that there is the necessary processing and storage capacity to make best use of the increased amount of data collected. Other challenges identified include ensuring data is shared where possible, ideally between different sectors, but particularly between appropriate Government agencies to avoid duplication of effort and allow for greater insight to be gained from a larger data set. In order to achieve this, other challenges around common data formats need to be addressed. As with so much in this report, there are significant benefits to international collaboration too.

FIGURE 35
Ocean science publications by top countries represented by number of publications.



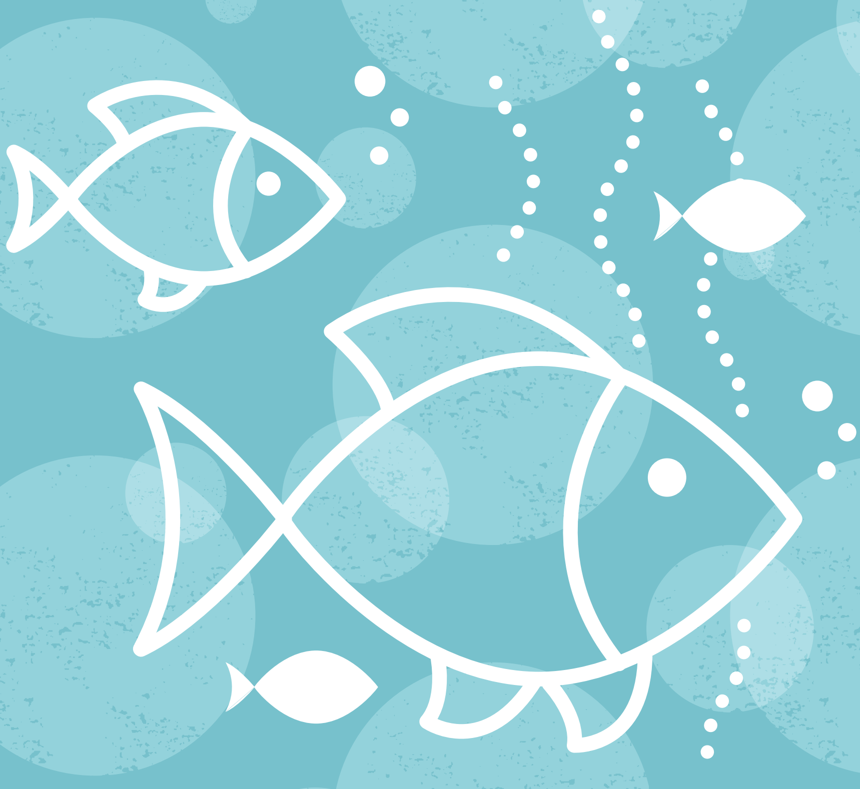
Source: *UNESCO, Global Ocean Science Report: The Current Status of Ocean Science around the World (L. Valdés et al., eds). Paris: UNESCO Publishing*

FIGURE 36
Ocean science publications by top countries represented by number of citations.



Source: *UNESCO, Global Ocean Science Report: The Current Status of Ocean Science around the World (L. Valdés et al., eds). Paris: UNESCO Publishing*

Conclusion: The Case for Coordination



Recommendation 1

The UK should develop a more strategic position, with clear priorities, with regards to its marine interests. This would underpin all the other recommendations made in this report.

This report began with an assessment that 'business as usual' is not an option for the UK. The Government has many recent and ongoing initiatives that are improving the future of the sea. However, without additional action, this report's findings suggest a risk of significant environmental degradation, instability, and a failure to capitalise on or retain some of our global strengths. While the future of the sea offers many positives to the UK, there is therefore an opportunity to improve our approach and, in doing so, increase the likelihood of success.

There are 20 recommendations. Regarding these, this report's extensive evidence base and the input from colleagues in academia, industry and policy shows that the need for a more strategic approach is the most critical. That is why it is recommended here that the UK **develops a clear, joined-up strategy for our marine interests.** Getting cross-cutting agreement on what the UK should be aiming to achieve in the medium- to long-term future in marine would create a common framework to act upon and capitalise on the strengths of the UK's individual marine interests. It would support the delivery of all the other recommendations in the report.

Such an approach would address the current lack of coordination, which broadly manifests itself in four ways.

Within Government
Figure 37 demonstrates how, as a result of its broad scope, responsibility and interest for marine issues are shared across departments and within the devolved administrations. This creates a significant risk of siloed thinking that is currently not addressed through any overriding strategy.

Within Industry
The different sectors that make up the marine economy are extremely diverse, making full coordination both impossible and undesirable. 'Maritime' industries in particular have some join up; however shared issues around skills, infrastructure, legislation and technological innovation go beyond those industries, and the join up appears to be significantly less in general than it is for comparable sectors.

Within Science
The UK has a Marine Science Co-ordination Committee which facilitates significant join up within the sector. However, the sheer breadth of relevant disciplines means that opportunities

for joint research and to inform policy are not necessarily capitalised on.

Between Government, Industry and Science.
All three actors have common interests, and can work together to share data and other evidence. There is also an important communication aspect to this. Government has a role in signalling its priorities and needs, while better join up with science and industry can make the case to Government for policy action.

This is a good time to develop a strategic position. This report has described many long-term challenges and opportunities with major potential implications, as well as approaching decision points (e.g. around deep-sea mining), where the UK must commit to following a certain path. Other nations have shown a more pro-active, cross-cutting approach to developing their marine interests in recent years and, based on this report's findings, the UK would benefit from doing the same; in so doing, it could capitalise on many opportunities to show global leadership. As we leave the EU, this provides the opportunity to put the sea at the heart of the new 'Global Britain' agenda, and signal our intentions to the rest of the world.

The breadth of the UK's marine interests may mean that all its domestic and international concerns cannot be considered in a single strategy. In particular, although they should be guided by common principles, the management and use of UK waters (including around the Overseas Territories) may be a separate question to the UK's strategic global priorities that inform its international engagement. Nevertheless, the evidence presented in this report is clear that, if more can be done, there is a significant prize up for grabs. There is global opportunity for the UK.

FIGURE 37
Departments' responsibilities and interests in different marine issues (self-identified). As well as the departments listed, others such as HMRC and DfID have some responsibility for the issues described in this report. A significant proportion of marine policy responsibility is devolved, so the full picture is even more complex.

● Responsible for
○ Interested in

	BEIS	▲ OGA	MHCLG	DEFRA	▲ JNCC	▲ CEFAS	▲ EA	▲ MMO	DfT	▲ MCA	DIT	FCO	MOD	▲ UKHO
Biodiversity				●	●	○	●	○				●		
Border security/defence									●	●	○		●	
Coastal communities			●	●		○	○	○	○					
Coastal tourism	○		○					○	○	○		●		
Communications			○					○	○	○	○	○	●	●
International law	○			●	○		○	○	●	●	○	●	○	●
Fishing and acquaculture	○		○	●	○	●	●	○		○	○	●		○
Mapping		●	○	●	○			○	○	●	○	○	●	●
Marine science	○			●	○						○	●		●
Marine spatial planning	○	○	○	●	○		○	●	○	●		○		○
Maritime manufacturing	●		○					○	○	○	●		○	
Maritime trade	○		○	○	●			○	●	○	●	○	○	●
Maritime business services	●		○	○				○			○		○	●
Offshore renewables	●	○	○	●	●	○	○		○	○	○	○		●
Mining	●	○	○	●	○		●				○	●		○
Natural capital	○	○		●	○	○		○				○		○
Naval capability				○							○	○	●	●
Oil and gas	○	●	○	○	●		●	○			○	○		○
Overseas territories and crown	○			●	●				○	○	○	●	○	●
Polar regions	○	○		○	●				○			●	○	●
Ports and infrastructure	○	○	○	●		○		●	●	○	○	○	○	
Safety/security at sea				○					●	●	○	●	○	
UK & Global climate change	●		○	●	○			○	○			○		

Glossary of Terms

Ocean economy	All economic activities within the marine and coastal industries.
Sustainable Development Goals	A set of 17 goals set out by the United Nations which focus on ending poverty, environmental protection, and ensuring global prosperity.
Hydrography	The measurement and description of the physical features of the seabed.
Additive manufacturing	A manufacturing process, also referred to as 3D printing, in which objects are created layer-by-layer using computer-guided machinery.
Persistent, bioaccumulative and toxic chemicals	A class of high-toxicity manufactured compounds that do not biodegrade.
Exclusive Economic Zone	An area of the sea over which a specific state or country has special rights regarding the use of marine resources.
Carbon sequestration	The process by which carbon is captured and prepared for long-term storage to reduce atmospheric or marine accumulation of greenhouse gases.
Illegal, unreported and unregulated (IUU) fishing	Fishing activities that are in breach of national, regional or international laws governing fishing.
Autonomous vehicles	A vehicle that is capable of sensing its environment and navigating without human input.

Evidence Base and References

The Foresight Future of the Sea team considered a wide range of evidence and commissioned 11 peer-reviewed evidence reviews (see below). The evidence review topics were chosen with guidance from the project's expert advisory group.

The project team conducted a series of 11 interviews with leading marine businesses about the implications of emerging technologies for their sectors, available here: https://www.gov.uk/government/publications/future-of-the-sea-industry-perspectives-on-emerging-technology

The team also co-hosted workshops with the Transport Systems Catapult on marine autonomous systems and with Chatham House on the future of ocean governance. Workshops were also held in Hull, Great Yarmouth and Bangor (north Wales).

Evidence Reviews

Birchenough, S., Williamson, P. and Turley, C., Ocean Acidification (2017)

Black, K. and Hughes, A., Trends in Aquaculture (2017)

Depledge, M., Lovell, R., Wheeler, B., Morrissey, K., White, M. and Fleming, L., Health and Wellbeing of Coastal Communities (2017)

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Hutchinson, T., Marine Pollution: Hazardous Chemicals and Physical Contaminants in the Marine Environment (2017)

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Mangan, J., Trends in the Transport of Goods by Sea (2017)

Melia, N., Haines, K. and Hawkins E., Implications from Opening Arctic Sea Routes (2017)

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Thompson, R.C., Plastic Pollution (2017)

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