State of the environment: the coastal and marine environment






Chief Scientist's Group report

January 2023

We are the Environment Agency. We protect and improve the environment.

We help people and wildlife adapt to climate change and reduce its impacts, including flooding, drought, sea level rise and coastal erosion.

We improve the quality of our water, land and air by tackling pollution. We work with businesses to help them comply with environmental regulations. A healthy and diverse environment enhances people's lives and contributes to economic growth.

We can't do this alone. We work as part of the Defra group (Department for Environment, Food & Rural Affairs), with the rest of government, local councils, businesses, civil society groups and local communities to create a better place for people and wildlife.

Published by:

Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH

www.gov.uk/environment-agency

Further copies of this report are available from our publications catalogue: www.gov.uk/government/publications or our National Customer Contact Centre: 03708 506 506

Email: research@environment-agency.gov.uk

Please cite this report as: Environment Agency, Chief Scientist's Group. (2023). State of the environment: the coastal and marine environment. Available from: https://www.gov.uk/government/publications/state-of-the-environment

Research at the Environment Agency

Scientific research and analysis underpins everything the Environment Agency does. It helps us to understand and manage the environment effectively. Our own experts work with leading scientific organisations, universities, and other parts of the Defra group to bring the best knowledge to bear on the environmental problems that we face now and in the future. Our scientific work is published as summaries and reports, freely available to all.

This report is the result of research commissioned by the Environment Agency's Chief Scientist's Group.

You can find out more about our current science programmes at https://www.gov.uk/government/organisations/environment-agency/about/research

If you have any comments or questions about this report or the Environment Agency's other scientific work, please contact research@environment-agency.gov.uk.

Dr Robert Bradburne
Chief Scientist

Contents

Chair’s foreword

England’s green and pleasant land is largely bordered by its blue and fragile coast, much coveted and heavily populated in places. Whether it boils in anger or sparkles like glass, people seek the sea simply to enjoy the sights and to breathe the air. Many who live on the coast were drawn by employment in fishing, international trade, energy production and defence. Yet, coastal towns are now among the most deprived in the country. Long term prosperity on the coast is a priority; preserving England’s precious natural resources is also a priority.

A healthy marine environment provides flood and coastal protection, nutrient absorption, enhanced biodiversity, improved water quality, recreation, improved health and wellbeing, tourism and delicious seafood. The challenge of protecting the environment and coastal economies requires agreement between multiple interests. Our updated River Basin Management and Flood Risk Management Plans, launched in 2022, include the local actions that government, regulators, the water sector, and other partners need to deliver to protect and enhance the estuarine and coastal environment over the next five years. We cannot do this alone and collaboration through partnership is key.

An estimated 85% of salt marsh has been lost since the 1800s, yet that which remains provides over £1 billion in flood resilience benefits and stores the carbon equivalent to nearly 40 million people’s annual domestic emissions. We can’t afford to lose those benefits. The Environment Agency is leading a partnership initiative, Restoring Meadow Marsh and Reef, to restore at least 15 percent of priority estuarine and coastal habitats by 2043. This will build on the existing investment of £120 million in the next five years to compensate for habitat loss due to coastal squeeze and the development of sea defences.

This State of the Environment Report, produced by the Environment Agency’s Chief Scientists Group, raises some concerning issues about chemical pollution and the impact of storm overflows along the coast. These impacts must not be underplayed but we shouldn’t throw the bathing out with the bathwater. Bathing water quality at beaches and resorts has shown enormous improvements in recent decades. The latest bathing water results for England show 97.1% of bathing waters passed water quality standards following testing at over 400 designated sites. I would encourage people to check bathing water quality on the Environment Agency’s Swimfo website before going swimming, particularly during or after it rains, when slurry from agricultural land and sewage can be washed into rivers and out to sea.

Climate change is affecting the ocean globally, changing water temperature, acidity, salinity and sea level. By the end of the 21st century, once-a-century sea level events are expected to become annual events. The National Flood and Coastal Erosion Risk Management Strategy sets out how we (alongside risk management authorities, partners and communities) will work towards the ambition of climate resilient coastal communities. Shoreline Management Plans will help to increase resilience and offer a framework for adapting to climate change through this century.

We need a concerted effort to enhance the marine environment while providing good jobs for coastal communities. We are investing £200m in our Flood and Coastal Innovation Programme which includes eight local authority coastal projects. We are also investing £1.8m in Championing Coastal Coordination from the Water Environment Improvement Fund over the next three years with 20 projects receiving funding in 22/23.

These innovative projects mix citizen science, local on-the-ground restoration and large-scale work to bring a more coordinated approach to coastal management. We hope what we learn from this innovation will help others join us and invest in scaling up projects and programmes that champion coastal resilience. In a country where nearly two thirds of people live within 15km of the sea and over a third live within 5km, that seems like something everyone should support.

Alan Lovell
Chair of the Environment Agency

Headline messages

- Estuarine, coastal and marine ecosystems provide many essential services to people, including flood and coastal defence benefits, carbon sequestration, nutrient absorption, provision of nursery sites and supporting fisheries, enhanced biodiversity and improved water quality, as well as socio-economic benefits relating to recreation, tourism and improved health and well-being.

- Over the long term, human activities from both land-based and marine sources have degraded estuarine, coastal and marine ecosystems. This, in turn, has impacted human health, prosperity and wellbeing.

- Multiple pressures from human activities act in combination and interact in complex ways that can be difficult to predict and measure. Climate change along with continued overfishing and habitat loss are amongst the main threats to coastal and marine ecosystems.

- Tipping points, where irreversible environmental changes occur, are likely to be reached as the climate changes. The likelihood of individual tipping points occurring will depend on the extent to which climate change can be limited. Reductions in carbon emissions are urgently needed to avert the risks of catastrophic impacts to marine life and the oceans regulatory functions.

- Phytoplankton are the foundation of ocean food chains, as well as capturing carbon and adding oxygen to the atmosphere. Coastal phytoplankton communities are changing. The consequences of these changes could be far reaching and are not well understood.

- We rely upon marine sediments to store carbon and they are the largest carbon store on earth. These sediments are disturbed by dredging and trawling.

- Coastal flooding and erosion are projected to increase significantly as climate change and locked-in sea level rise continue posing a major risk to the coastal environment and communities.

- Some pollutants from rivers to coastal waters, such as phosphorus, heavy metals and polychlorinated biphenyls (PCBs), have reduced since the 1990s. Historical and potentially emerging sources of substances that accumulate and persist in the environment continue to threaten coastal and marine ecosystems. New chemicals are being produced globally at a growing rate. Global chemical production has almost doubled since 2000 and is anticipated to continue growing.

- Plastic pollution is widespread across the coastal and marine environment and is a potential major threat to marine wildlife.

- Improved waste-water treatment has increased the quality of bathing waters during the bathing season, but these environmental gains are threatened by climate and population pressures. People are increasingly using these and other waters outside of the official bathing season with a consequent expectation that standards will be maintained year-round.

- Habitats and species have undergone huge changes and declines over long-term timescales with a consequent loss of ecosystem services to society. In some cases, there are tentative signs of recovery, for example saltmarsh that has been restored and some species of fish are recovering from over exploitation. Other wildlife, such as cetaceans, continue to suffer from the legacy of historical chemicals in the environment and many seabirds are of high conservation concern.

- To secure a more resilient, healthy and prosperous future for people and wildlife a step change is urgently needed for the protection, recovery and restoration of the estuarine, coastal and marine environment, embracing a system wide approach. It is clear from recent successes that a shared ownership of the risks and a recognition of the need for increased capacity in the collaboration of private, public and non-governmental sectors can bring about the changes that are needed to realise these benefits in the future.

1. Introduction

Engagement with and appreciation of coastal and marine habitats and wildlife, including those in estuaries, benefits human health and wellbeing and has enriched England's culture and economy for thousands of years.[1] Approximately 36% of people in the UK live within 5km of the coast, and 63% live within 15km.[2] Each year people make approximately 270 million recreational visits to the English coast.[3] There is growing evidence to show that living or spending time at the coast has a range of health and wellbeing benefits.[4] England's interlinking coastal and estuarine habitats form distinctive seascapes around the coast. These include sea cliffs, sand dunes, shingle beaches, intertidal mudflats, intertidal salt marshes, seagrass beds, native oyster beds and coastal lagoons. These habitats are vitally important for many species. For example, many estuaries provide important nursery areas for fish, and are internationally important sites for birds. The East of England wetlands, from the Humber to the Thames host over one million over-wintering birds on the East Atlantic flyway every year.[5] Estuaries are among the most productive ecosystems in the world.

The coastal and marine wildlife of England is ecologically important and has great intrinsic value. Some species are also commercially valuable. Many are of huge cultural significance. Iconic species from puffins and mackerel to shore crabs, native oysters, and common starfish are as much symbols of the English seaside as lighthouses, fishing boats and beach huts. They are a cherished part of how we experience our coast and seas.

Multiple pressures affect the health and resilience of coastal and marine ecosystems. These include climate change, pollution, physical loss and disturbance of habitats, unsustainable fishing and invasive non-native species. Many of these pressures are increasing, leading to rapid and extensive environmental change. How we understand, value and use these environments is also changing. There is a growing evidence base and wider understanding of the vast range of services provided by coastal and marine ecosystems.

This report begins by looking at the ecosystem services provided by coastal and marine environments globally and nationally, and the pressures they are experiencing. It then looks at state and trends predominantly related to England's coastal environment. Offshore waters are also included where relevant. The report ends with a discussion of some of the challenges and opportunities on the horizon, and highlights some of the ways that they can be addressed.

2. Coastal and marine ecosystem services

Coastal and marine habitats are increasingly understood to have great benefits to humans in a multitude of ways. These ‘ecosystem services’ include improved water quality, sequestration of carbon, provision of seafood and other products, recreation, flood and erosion risk reduction, health and wellbeing benefits, and cultural services. Estuaries are complex ecosystems, and when allowed to function naturally without excessive pollution or physical modification, they will process and remove nutrients and other pollutants from the water.[6] An increasing amount of the world’s medicines, materials and energy are derived from the ocean.

Globally, the ocean plays a crucial role in regulating earth systems, through oxygen production, temperature regulation, carbon sequestration, climate regulation and water and nutrient cycling.[7] The movement of massive ocean currents regulates weather and climate systems by transferring heat from the tropics to the poles. The ocean has absorbed most of the heat energy produced by climate change since the 19th century.[8] The ocean mitigates human-driven climate change, its waters directly absorbing at least one quarter of the CO_2 emitted annually by human activities.[9]

Marine phytoplankton, small drifting organisms that capture energy from the sun, like plants do on land, are at the base of ocean food chains. They are the food source for zooplankton, microscopic animals that are important food sources for a wide range of marine life, including fish larvae. Marine phytoplankton produce at least 50% of all oxygen produced on earth.[10] In addition, they take up CO_2 during photosynthesis. When these phytoplankton die, a small but significant proportion are transported to deep ocean sediments and the carbon they have taken up is stored there for thousands to millions of years.

The carbon sequestered in coastal, estuarine and marine habitats alone are substantial.[11] Marine sediments are the largest carbon store on earth.[12] Carbon taken up and stored by these habitats, particularly salt marsh and seagrass beds, is sometimes called ‘blue carbon’. Blue carbon habitats in UK waters hold 136 megatonnes (Mt) of carbon, 119Mt of which is stored in sediments (Figure 1). Blue carbon habitats in the UK take up and store an additional 620,000 tonnes of carbon every year.[11]

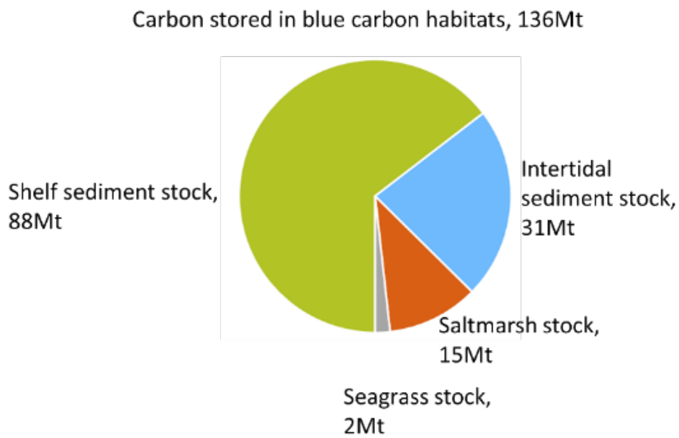


Figure 1: Blue carbon stored by habitats in UK waters. Data source: Parker et al. 2021.[11]

The ecosystem services provided by the UK coastal and marine environment were valued at £211 billion in 2018 (Figure 2). This is an underestimate, because not all benefits could be quantified or valued. For example, the value of remediation of wastewater was included, but the value of remediation of agricultural run-off was not.[13] A separate study of the water quality benefits of coastal and marine habitats in the Solent alone, has found that the combined value of nitrogen and phosphorus removal by these habitats, through absorption into sediments, atmospheric loss, and incorporation into structures such as oyster shells, is worth around £1.1 billion every year.[14] There is relatively low confidence around current estimates of carbon sequestration for UK coastal and marine habitats, representing an important knowledge gap.[11]

All of these services are interconnected and depend on healthy, resilient coastal and marine ecosystems. It can be argued that essentially, coastal and marine ecosystem services are priceless, in that humanity is dependent on them for health, wellbeing and prosperity. Any value derived is therefore an underestimate, but important for enabling decisions to be made about the management of these systems.[15]

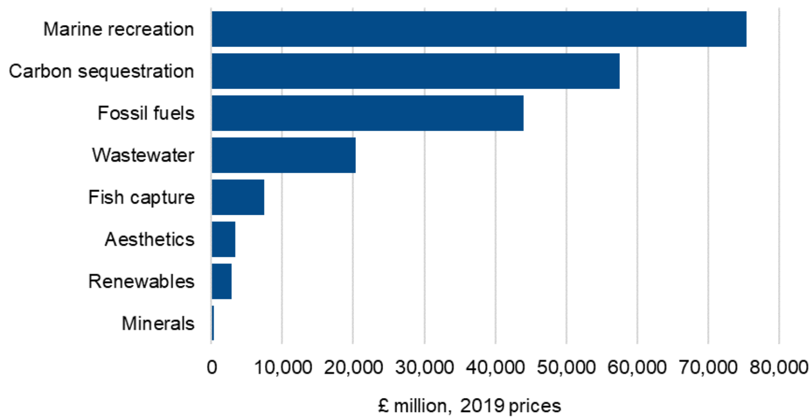


Figure 2: Asset value of assessed coastal and marine ecosystem services in the UK, 2018. Source: ONS marine natural capital accounts.[13]

Case study: Fishing in North Shields: history, culture and economy

Fishing, particularly in inshore coastal waters, is an important part of England's cultural heritage. Fishing brings a unique sense of place and identity to many coastal communities, as well as providing other social, cultural and economic benefits. It can play a significant role in bringing tourism to an area.[16]

Despite the decline in UK fishing since 1972, the strong cultural and social benefits of fishing have ensured that the North Shields fishing industry has continued. The fishing grounds near North Shields have a long history of fishing, but the number of fish landed at the port has declined, reflecting the impacts of past overfishing on fish stocks.[17,18] In 2021, the total catch was 1,511 tonnes[19]. The catch of herrings alone in 1909 was 20,000 tonnes.[20] A 2005 study found that only 10% of the landings in North Shields was attributable to local fleet, which was thought to have around 70 active fishers.[21] There were 668 fishers registered to North Shields in 2021[19] but many of them operate out of other places for much of the year.[22]

The local authority has received a grant of £5.5 million to regenerate the fishing industry and for other economic diversification projects. The 'Fish Quay Regeneration Strategy' (FQRS) intends to transform the local industry from a supply to a demand service by creating a premium North Shields brand of high-quality fish and fish products. The FQRS also created a Regional Business Cluster team of fish processors and helped to fund a national fish filleting school.[21] The Fish Quay area is evolving to be a fashionable place to eat the local catch, with prawns being a popular choice, reflecting the fact that 55% of the total prawn catch in England is landed here.[19]

3. Coastal and marine environmental change: drivers, activities, pressures, and impacts

3.1 Drivers of coastal and marine environmental change

Unsustainable levels of resource consumption in wealthy countries such as the UK, along with population and economic growth are major drivers of environmental change.[23] These and other drivers create and exacerbate a wide range of pressures, which, in turn, negatively affect the state of the environment. This section will describe some of the pressures on England's coastal and marine environment, using UK data where specific information for England is not available.

3.2 Activities affecting the coastal and marine environment

Activities that can create pressures on marine and coastal environments include shipping and port activities, dredging and aggregate extraction, fisheries and aquaculture, and offshore industrial infrastructure (Figure 3). Leisure and tourism, and flood and erosion defences can also have impacts. The housing, infrastructure and agricultural production needed to support England's population also have direct and indirect impacts on the coastal and marine environment. Some activities, such as agriculture, that affect the quality of coastal and marine water bodies are land-based, sometimes taking place far upstream in river catchments.[24] The way that these activities are managed and regulated can help to balance trade-offs between impacts and benefits.

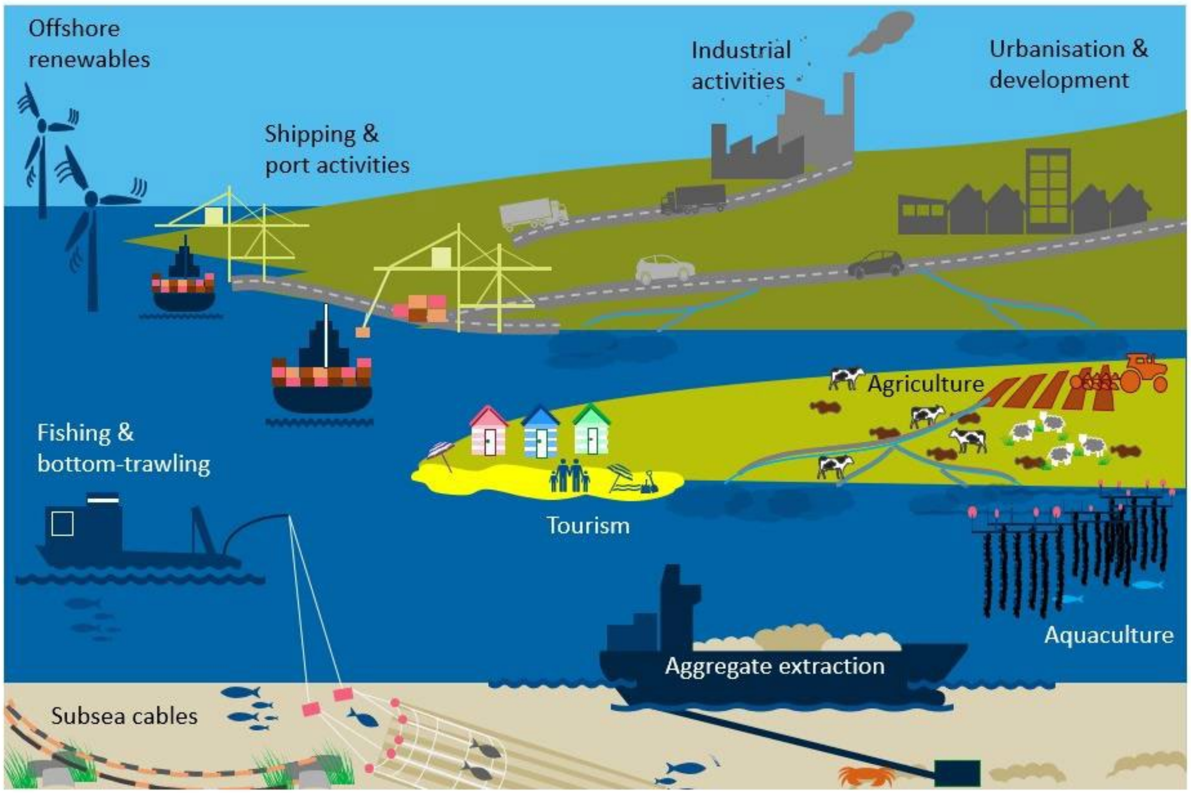


Figure 3: Activities affecting the coastal and marine environment.

Dredging and extraction

Around 15 to 20 million tonnes of marine aggregate are extracted annually from Britain's seabed. In England and Wales 88% of extracted aggregate is used by the construction industry. Demand is predicted to increase up to 29 million tonnes per year by 2030.[25] Dredging is also carried out to maintain navigation routes, and for coastal flood and erosion protection projects that use sand or sediments to protect the coast, and is essential for economic activity reliant on ports and shipping. Most dredging in the UK occurs around the south-east coast.[26] Impacts of dredging and aggregate extraction will vary with local environmental conditions and management, but can include:[27,28]

- habitat and biodiversity loss and degradation
- resuspension of organic matter, nutrients and chemical pollutants from sediments
- noise and light pollution
- disruption to the stability and structure of the seabed
- morphological changes to nearby areas

Dredging and extraction activity is likely to increase as the population continues to grow and infrastructure projects increase in number and size.[29] Dredged sediments can be used beneficially to reshape shorelines and to protect and restore coastal and estuarine habitats such as mudflat and salt marsh. Less than 1% is used in this way.[30]

Shipping and port activities

Ports are vital to the UK economy, with 95% (by volume) of all imports and exports transported by sea.[31] The main environmental impacts of shipping relate to emissions to air, water discharges and physical impacts.[32]

Shipping fuels produce significant quantities of air pollutants, including sulphur oxides and particulate matter, reducing the air quality in coastal areas.[33] These substances have negative effects on human health. The emissions to air can be reduced by using cleaner fuels, or by installing cleaning systems known as 'scrubbers'. Most systems are open loop and discharge this toxic mixture of pollutants to seawater. Other, closed loop systems store the contaminated material for disposal at port. At least 10 gigatonnes of polluted scrubber water are discharged annually around the world, almost as much as the 11 gigatonnes of cargo carried by ships every year.[34]

Other discharges to water from shipping that have a negative environmental impact can contain antifouling paints, plastic litter, oil and cargo from discharges and shipping accidents, wastewater and invasive non-native species. Physical impacts can include noise, light, erosion, wildlife collisions and resuspension of sediments.[32]

The international shipping sector is also a source of greenhouse gas (GHG) emissions, contributing 3% of global emissions.[35] Without additional measures, carbon emissions from shipping activity are predicted to increase by up to 50% globally by 2050 compared with 2018.[36]

Fisheries

Fisheries constituted 0.03% of UK economic output between 2018 and 2020. Although a relatively small part of national output, it is an important part of local economies. In 2021, 10,724 fishers were employed in the UK, 13.5% of these were registered in the 2 ports of Newlyn and North Shields alone. The main species of fish landed in the UK are cod, haddock, mackerel and herring. Shellfish make up 20% of all landings. The main shellfish species landed are crabs, *Nephrops* (also known as scampi or langoustine) and scallops.[37]

Historically, rapid growth of the industry along with technological changes transformed the fishing industry from the 19th century onward.[38] Bigger, more efficient vessels initially meant larger catches, along with lower employment.[39] However, catches of many global and UK fish stocks declined during the 20th century, primarily driven by overfishing.[40,38,207] Overfishing affects the size, structure and sometimes the viability of fish populations, and in turn, other species throughout the wider food web.

Effects of fishing on the environment can include:

- damage to seabed ecosystems and fish nursery grounds and release of carbon stored in sediments, through activities such as bottom trawling[41, 42]
- bycatch of non-target animals in active fishing gear and entanglement in abandoned, lost or discarded fishing gear,[43] both of which trap and kill large numbers of animals every year[44]
- noise pollution

Offshore infrastructure and industrial activities

UK waters contain large numbers of cables and pipelines for electricity, oil, gas and telecommunications, as well as wind, wave and tidal energy installations and oil and gas extraction and storage sites. The offshore wind project pipeline, which includes wind farms in the planning and construction stages, increased by 60% in 2021/22. In 2019, the industry employed 7,200 full-time equivalent employees.[45]

Impacts of offshore wind activities, including the laying of cables[46] can include:

- damage and destruction of seabed habitats
- noise pollution
- risk of contact with fuel or chemicals
- possible effects on movement and behaviour of some species from electromagnetic fields emitted by cables[47,48]

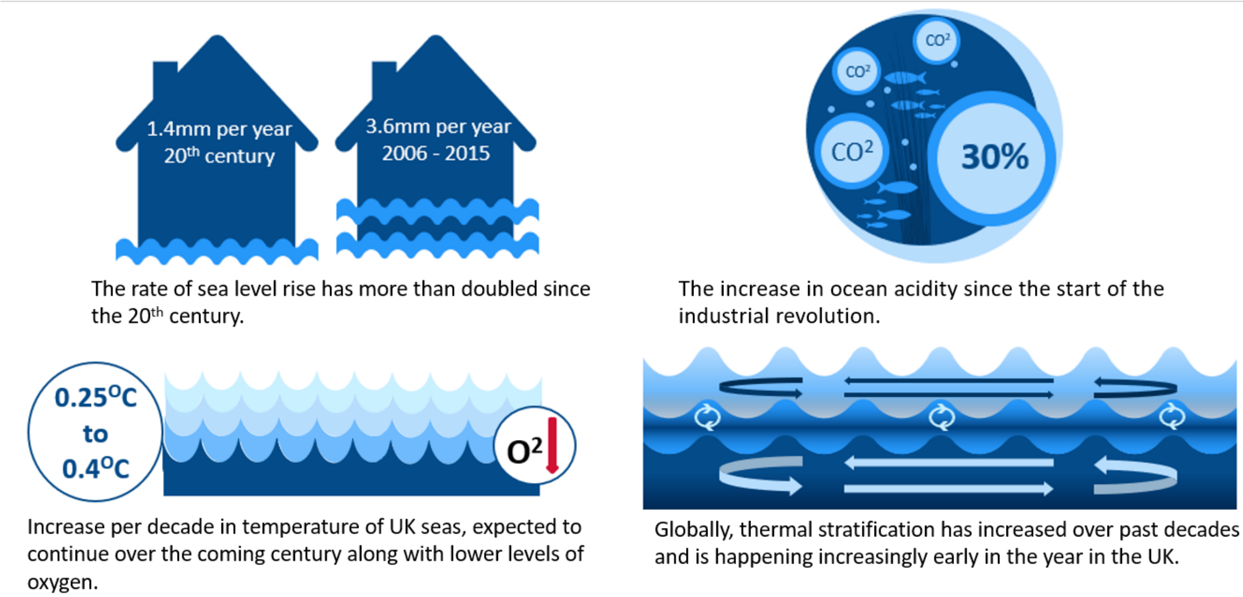
An impact analysis for North Sea offshore wind activities identified a range of bird, mammal and fish species affected, including sandeels, harbour porpoise, guillemot and haddock.[49] Offshore wind farms may also create habitat and nursery grounds for some species.[50]

Offshore oil and gas activity is declining across Europe but is still an important part of the maritime economy. Fossil fuels accounted for 32% of the assessed asset value of UK coastal and marine ecosystem services in 2018.[13] The impacts of oil and gas extraction include damage to the seabed and its ecosystems, and death or injury of marine animals through collisions with equipment.[43]

Tidal power is an emerging infrastructure sector in the nearshore area and has the potential to affect sediment pathways and volumes, and the movement and migration of fish and other wildlife.

3.3 Pressures on the coastal and marine environment

Climate change



Infographic 1: Physical impacts of climate change on the ocean

The 2022 Intergovernmental Panel on Climate Change (IPCC) report makes clear the threat posed by climate change, stating "The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all."[51] The effects of climate change on ocean ecosystems and processes are a large part of the risk, and far-reaching changes are already happening.

Climate change is affecting the physical characteristics of the ocean globally and in the UK. The effects are stronger in some places than others as a result of factors such as weather patterns and ocean currents. The main physical changes include:

- water temperature and thermal stratification
- acidification (decreasing pH)

- sea level
- salinity

There is also evidence to suggest that flow patterns in rivers will be affected, potentially affecting water quality in estuaries. Increased frequency of heavy rainfall events and storms may also increase flushing of nutrients and other pollutants into estuaries and coastal waters.[52] Climate change is affecting the distribution of species, ecological community structure, and the functioning of ecosystems, and therefore also the services they provide. The degree to which climate change can be limited will make a huge difference to the impacts felt.[53]

Warming waters

The world's ocean temperatures are increasing, and in 2021 were the highest ever recorded.[54] UK seas are also following a warming trend, with increases expected to continue over the coming century by between 0.25°C and 0.4°C every decade.[55]

Coastal and marine species and ecosystems around the UK are already being affected. Species distributions are shifting in a range of habitats, including rocky shores, shallow and shelf sea habitats and deeper waters. Native species are moving northwards, and species from more southern areas are being observed more often. There is evidence that the timing of some life-cycle events is also being altered.[56] A global analysis of the risk posed by warming waters to marine species found that with continued high emissions, 87% of species will be at high risk of negative impacts by 2100.[57]

Phytoplankton can be very sensitive to temperature and salinity change as well as changes in concentrations of nutrients in the water.[53] Changes to the timing of phytoplankton blooms, also sometimes known as 'algal blooms', alongside altered distribution of other species would have significant impacts on species throughout food webs.[53] Some phytoplankton species can produce natural toxins and when they develop into large blooms are called 'harmful algal blooms (HABs)'. Shellfish can take up these algal species and their toxins, causing economic impacts to aquaculture businesses through closures or product recalls undertaken to protect human health.[58] There is evidence to suggest that HABs are changing in their occurrence patterns in UK waters, as a result of climate change.[59]

Warmer waters have lower levels of dissolved oxygen. Inputs of nutrients to estuaries and coastal areas can cause eutrophication, problematic levels of algal growth, which can further lower oxygen levels.[60] Measurements taken in the North Sea between 1990 and 2010 show decreasing oxygen concentrations, reflecting global declines, which have been measured over longer periods.[61] In addition, abrupt hypoxic events are increasing globally in frequency and intensity, and may have even more severe impacts on marine ecosystems than acidification and warming.[62]

Combined impacts of warmer temperatures and decreased oxygen include altered growth rates and sizes of some fish species, with larger bodied animals unable to survive at all as oxygen levels decrease. Projections suggest that by the end of the century, dissolved oxygen concentrations may decline globally by up to 4%, and by up to 11.5% in UK regional seas, including the North Sea.[61] It is difficult to predict what the impacts of this will be for the UK, but global assessments suggest that wide ranging effects will occur, potentially altering species abundance and distribution, including in important fisheries, changes to food webs, and disturbance to global carbon cycling.[60]

The long-term temperature increase has also increased the frequency of 'marine heatwaves'. These events, combined with a range of other pressures from human activities, are threatening species at the edges of their thermal tolerance ranges. The North Sea has been identified as a region where this is having a significant impact.[63]

Temperature changes are also very likely to affect the Atlantic Heat Conveyor or Atlantic Meridional Overturning Circulation (AMOC). This important ocean current is projected to weaken during this century as a result of climate change. Changes are already happening but the causes of these are unclear. The AMOC is a major factor in maintaining the climate and marine environment of the UK.[64]

Acidification

CO_2 from the atmosphere is absorbed into the ocean, lowering its pH. Since the start of the Industrial Revolution, there has been an approximate 30% increase in global ocean surface acidity, from pH 8.2 to 8.1.[65] The UK is projected to see a continued increase over the rest of the century.[66] One of the main impacts of this is on species which build their skeletons or other structures from calcium carbonate, because it is harder to construct and dissolves more easily as acidity increases. This then has impacts on wider ecosystems and the services they provide, including the capture and transport of carbon to the seabed by some types of plankton.[67] Other impacts in UK waters may include:

- changes to the composition of intertidal communities
- increased mortality rates of some fish larvae such as Atlantic cod
- reduced productivity of shellfish aquaculture leading to significant economic losses

Sea level rise and extreme weather events

Sea levels are rising around the world because of melting glaciers and ice sheets, as well as thermal expansion of the water as it warms. The rate has more than doubled, from 1.4 millimetres (mm) per year over the 20th century, to 3.6 mm per year between 2006 and 2015.[68]

UK mean sea levels have risen by about 12 to 16 centimetres (cm) since 1900 and will continue to rise.[69] The Climate Change Committee state that a mean one metre (m) rise is now inevitable at some point in the future.[70] Exact levels will vary around the country. Southern England will see the highest rises, because the land is still sinking after the last ice age. In London for example, levels are projected to rise by between 29cm and 70cm (with 90% confidence) by 2100, even if actions are taken to limit climate change to 1.6°C. Worst-case scenario projections show a rise of between 53cm and 115cm by 2100. [71]

Larger rises of up to 2.3 m global mean rise by 2100 (relative to the period 1995 to 2014) are considered possible due to potential marine ice sheet instabilities, but assessing their likelihood is almost impossible.[72] Some polar ice sheets, such as the massive Thwaites Glacier, are breaking up faster than previously expected.[73] The likelihood of such tipping points occurring and the timescales over which they happen will depend on the degree to which temperature increases can be constrained.

Changes in extreme weather such as storms, and wave heights, are more difficult to attribute to climate change because of gaps in understanding some of the processes involved, and difficulties distinguishing true effects from natural variation.

Whether storm frequency or intensity around the UK increases or not, any storms that do reach UK coasts will have higher impacts when combined with sea level rise. Higher sea levels mean that more wave energy reaches the coast during storms, increasing coastal flood and erosion risk, and damaging coastal defences, with significant social, economic and ecological impacts.[74]

Some of the environmental impacts of sea level rise highlighted as major risks by the most recent UK climate risk assessment (CCRA3) include:

- localised, and over time, more widespread loss of coastal habitats, such as seagrass and salt marsh, that provide flood protection and carbon storage as well as critical wildlife habitats and fish nurseries[53]
- risk to marine environments from erosion exposing old landfill sites[75]
- risks to aquifers and agricultural land from saline intrusion[53]
- loss of some heritage sites[76]

Thermal stratification

Warming of surface waters in the ocean affects the amount of mixing between the surface and deeper layers. Salinity can also be a factor. Measurements taken between 1970 and 2017 show a global increase in stratification during that period.[77] In the UK, stratification does not show any consistent long-term trends, but is happening increasingly earlier in the year.

The strength and timing of stratification in UK shelf seas is projected to change. Stratification is projected to typically start one week earlier by 2100. [78] Effects of increased stratification include reduced transport of nutrients to the upper ocean layers, reducing growth of important primary producers such as phytoplankton.[79] Reduced phytoplankton productivity in the upper ocean would reduce the amount of carbon captured and transported down to the ocean floor. This could, in turn, reduce the abundance of life in these deep-sea ecosystems and affect broader ocean food web structures.[77] In some waters closer to the coast, stratification as a result of higher rainfall and run-off may increase eutrophication.[79]

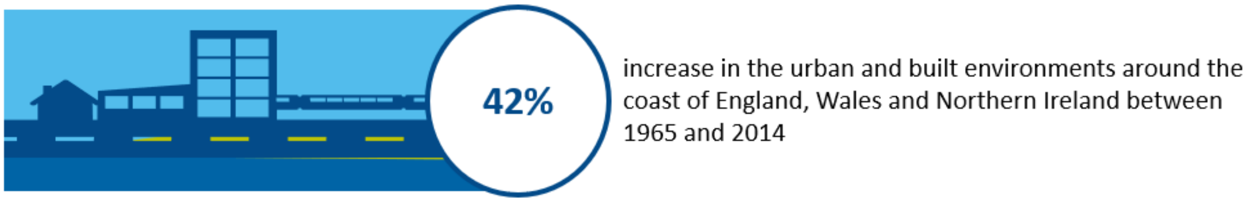
Salinity

Climate-related changes in rainfall, evaporation and ocean currents can all affect the ocean's salinity. [80] Salinity in UK coastal waters has not decreased to date, but evidence suggests that they will become significantly less saline over the rest of this century.[81] Changes in salinity affect the location and strength of ocean currents, seawater density, and may alter important processes carried out by marine organisms.[80] Salinity has decreased sharply in the eastern North Atlantic, west of the UK, in recent years.[82] This may be a factor in the decline of Atlantic salmon, which is already under pressure in the freshwater part of its lifecycle from a range of sources. [53] Combined effects of lower salinity, increasing temperatures, and more frequent heatwaves are also likely to increase the risk of shellfish being infected with Vibrio bacteria, which can then infect people who consume them.[53]

River flows from catchment to coast

Winter river flows have increased over the past few decades, and this is projected to continue, along with increased frequency of high flows, intense rainfall events, and flooding. Projected lower flows in summer may cause nutrients and pathogens to become trapped in estuaries for longer periods.[83] It is difficult to predict the potential effects of these changes on estuaries and coastal waters. Such projections need more detailed studies, including modelling, of the interaction of catchments at the land sea interface. Increased frequency of storms may increase the transport of pollutants and untreated waste-water into coastal waters, from run-off and storm overflows. Such events could also wash accumulated trapped nutrients and pathogens from estuaries out into coastal waters, possibly affecting their quality.[84]

Land use change at the coast



Infographic 2: Increase in urban and built environments around the coast, 1965 to 2014

Coastal habitats provide a range of valuable ecosystem services to society. These include reducing flood and erosion risk, carbon sequestration, nutrient absorption, provision of nursery sites and supporting fisheries, enhanced biodiversity and improved water quality. They also provide socio-economic benefits relating to recreation, tourism and improved health and wellbeing. It is estimated for example that salt marshes provide flood protection to around 24,000 properties in suburban areas and 17,000 properties in urban areas in the UK.[13] Large areas of coastal habitats have been destroyed, degraded and fragmented over time as population growth and the associated need for homes, amenities, industry, infrastructure and food, has taken up land. The National Trust estimate that between 1965 and 2014, urban and built environments around the coast of England, Wales and Northern Ireland increased by 42%. Industrial use of land increased by 39%. About 74% of the coast remained undeveloped.[85]

The construction of hard defences around parts of England's coast has provided coastal communities, farmland and infrastructure with valuable protection from flooding and erosion. These structures often disrupt natural processes of erosion and replenishment of the coastline and prevent nearshore, coastal and nearby terrestrial habitats from interacting and evolving. Protecting one place can mean increasing the risk somewhere else along the same coast. Hard defences or development combined with sea level rise also causes habitat loss through 'coastal squeeze'.[86]

Pollution

Microplastics are found throughout the marine environment and have entered the food chain.

Chemical pollution continues to threaten coastal and marine ecosystems.

Light and noise pollution are increasing issues for coastal and marine environments and have negative effects on a range of marine life.

Direct discharges of untreated sewage along with run-off from agricultural land and from towns and cities into coastal waters can result in contamination by faecal organisms, bacteria and viruses causing problems in areas used for bathing or shellfish production.

Infographic 3: Highlighted pollutants affecting coastal and marine environments

Pollutants from a range of sources create pressures on the coastal and marine environment. It is thought that around 80% of marine pollution comes from land-based sources.[87] Point source and diffuse pollution enter directly into estuaries and coastal waters from towns, cities, transport, agriculture and other sources.

Activities inland also affect the coastal and marine environment. Pollution entering rivers and streams from agricultural practices, storm overflows, waste-water treatment, industrial discharges and road run-off is transported downstream into estuaries and coastal waters, with a range of impacts on ecosystems and wildlife.

There is growing recognition and understanding of the threats posed by chemical pollution to coastal and marine environments. A vast range of chemicals, including pharmaceuticals, heavy metals and pesticides enter the coastal and marine environment. Many are now found worldwide, often far from where they were produced or used. Despite decreasing inputs of some pollutants, issues remain with many substances.

Some substances have been identified as posing risks as a result of their toxicity, ability to accumulate in plants and animals, and persistence in the environment for long periods. These 'persistent, bioaccumulative and toxic' (PBT) chemicals can be present at elevated levels in the environment for decades after inputs have stopped. Where PBT substances are widespread globally as a result of historical use, they are termed 'ubiquitous, persistent, bioaccumulative and toxic' (UPBT).

Some pollutants have been in use for a long time but understanding of their environmental presence, persistence and impacts is still emerging. For example, perfluoroalkyl and polyfluoroalkyl substances (PFAS) are a group of industrial chemicals with a wide range of applications, including in everyday products from food packaging, toiletries and non-stick cookware to clothing and carpets. PFAS have been in common use since the 1950s and since then the number of different substances has increased enormously. Evidence has shown that some PFAS are toxic, but the complexity of the group and lack of definitive evidence for individual substances means that there are evidence gaps around the risk posed by the vast majority. Most of these substances are known to be persistent, and some have been shown to bioaccumulate. This raises the level of concern about their potential risk to the environment and human health.[88]

Since 1950, more than 140,000 new chemicals have been synthesised globally.[89] Global chemical production has almost doubled since 2000 and is anticipated to continue growing.[90] Inherent risks associated with new types of pollutant such as nanoparticles, and biodegradable polymers, need to be better understood, together with potential exposure routes to ensure that potential impacts are prevented or managed.

Estuaries and coastal waters provide an essential service to society by receiving 37% of England's treated sewage discharges. Discharges of untreated sewage into coastal waters by water companies have been the focus of much media attention in recent years. These direct discharges by water companies take place when high rainfall events threaten to overwhelm sewers and water treatment systems. This, along with run-off from agricultural land, and from towns and cities, can result in contamination of water bodies with faecal organisms, bacteria and viruses that can cause problems in areas used for bathing or shellfish production.

Agricultural run-off and treated wastewater can cause excessive nutrient inputs to estuaries and coastal waters.[91] This can lead to problem levels of growth of macroalgae in some locations. There can be wider ecological effects because of impacts on inshore phytoplankton abundance and community structure.

Wet wipes and other items incorrectly flushed down the toilet cause significant problems in some estuaries, and cost millions of pounds in blocked sewage networks each year. In the tidal Thames they occur in large numbers, binding areas of sediment together, altering the structure of the shore. One such mound in Barnes, south London, has been observed to have grown in height by 1.4 m since 2014 and covers 1,000 square metres (m^2).[92]

Plastics originate from both land-based sources such as tyre wear and littering, and from marine activities such as fishing. Plastics are found on the surface, in the water column, and in seabed sediment, [93] affecting wildlife through ingestion, smothering and entanglement.

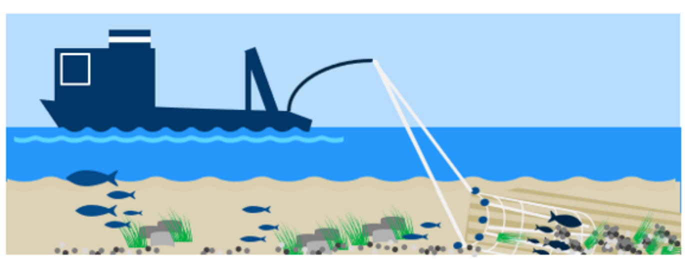
Light and noise pollution are increasing issues for coastal and marine environments. Noise from activities such as shipping and offshore construction has negative effects on a range of marine life. These impacts have implications at the individual, population and ecosystem levels. Impacts of noise on marine life include: [94]

- increased stress levels, affecting physiological functions
- impaired ability to find mates and evade predators
- impaired communication
- altered foraging behaviour

Light pollution reaches coastal waters from nearby urban areas. Areas further out to sea are affected by shipping and offshore industry and exploration as well as light from the land, scattered in the atmosphere and reflected back down. The effects of light on marine life are less well understood than noise. However, research over the past 35 years has shown impacts of light pollution on marine organisms, including birds, coral, fish and mammals at a range of spatial scales.[95] Recorded impacts of light pollution include:

- disruption to cellular and physiological processes
- reduced reproductive ability
- alterations to ecosystem composition and structure

Overfishing



Of the 57 fish stocks of UK interest, 26% have been assessed as being fished unsustainably. The percentage of fish stocks known to be fished sustainably increased from 9% in 1990 to 51% in 2019.

Infographic 4: Fish stocks

Overfishing has been identified as one of the two biggest threat to marine ecosystems.[96] The percentage of fish stocks of UK interest that are fished sustainably increased from 9% in 1990 to 51% in 2019. 26% were assessed as being fished at unsustainable levels.

It was not possible to assess the remaining 23% because of a lack of data, representing a significant evidence gap.[97]

Overfishing affects fish populations directly, preventing stocks from recovering. Such population and species losses can be permanent. Overfishing also affects the size distribution within fish populations, which become dominated by smaller individuals that mature earlier and grow faster. This then affects other species throughout the food web.[98]

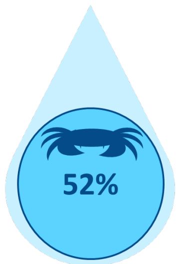
Case study: The Marine Stewardship Council (MSC) blue label

Infographic 5: MSC label

Reducing overfishing and bycatch protects coastal and marine ecosystems as well as supporting the continuation of fishing as a livelihood and way of life.

Everyone can play a part in making sure fisheries are sustainable. The Marine Stewardship Council (MSC) awards its ‘blue label’ certification to fisheries that meet sustainability criteria. This allows retailers and consumers to be confident in their choices when buying fish and seafood. The MSC supports fisheries to work towards sustainability, using its Pathway to Sustainability programme. However, even with the work carried out since the MSC was founded in 1997, only 15% of global marine catch is yet certified sustainable.[99] Consumer spend in the UK and Ireland on MSC certified fish and seafood has grown more than tenfold between 2009 and 2019 and was valued at £1.26 billion in 2021.[100]

Invasive non-native species



invasive non-native species likely to cause deterioration are present in 52% of England's assessed coastal and water bodies and 48% of estuaries.

Infographic 6: Invasive non-native species

Coastal and marine environments are particularly vulnerable to invasive non-native species (INNS), because of high levels of shipping activity, creating a major pathway of introduction.

INNS likely to cause deterioration in ecological status are present in 52% of all of England's assessed coastal water bodies and 48% of estuaries. 71% of estuaries are at risk of deterioration from current or future invasions (with a high level of confidence). 100% are at risk with a lower level of confidence. 56% of coastal water bodies are at risk of deterioration in ecological status from INNS with a high level of confidence, 72% with a lower level of confidence.[101]

INNS can outcompete or predate on native species, causing localised or more widespread extinctions. This can also affect commercial aquaculture and fisheries.[102] The number of marine INNS established across 10% or more of coastline in Great Britain has increased from 15 in 1960 to 1969, to 37 in 2021.[103] There is a high risk that the continued warming of UK seas will result in the introduction of additional INNS.[102]

Multiple pressures, combined impacts and tipping points

Pressures affect the environment in multiple ways, and are often interlinked and interact with each other, in ways that can be complex and difficult to predict and measure. Combined impacts of multiple pressures reduce the resilience of coastal and marine ecosystems. Coastal areas experience greater combined effects than areas further offshore because they are more influenced by pressures from activities on land as well as at sea. [104]

There are many examples of combined effects, because all pressures interact with others to some extent. One example is the combined effect of changing rainfall patterns and human activities on land, including changes in land use. These pressures can combine to cause run-off of large pulses of soil and sediment into coastal waters. One of the impacts of this is the darkening of coastal waters around the world, with major potential impacts on the structure of marine food webs and the ecosystem services they provide.[105,106]

When pressures are too great, thresholds or tipping points can be passed where the recovery of the original physical, chemical or biological state is extremely difficult, or no longer possible.[107] One study found that by 2100 under a high emissions climate scenario, changes to ocean circulation patterns could reduce or even stop the transfer of water from the North Atlantic into the North Sea, with greatly reduced circulation in the North Sea, making its condition more influenced by inputs from rivers, like an enclosed estuary.[108] If this tipping point were to be reached, it would have significant impacts on species survival, and ecosystem service provision, particularly if eutrophication and pollution continue or increase.[53] Globally, 70% to 90% of tropical coral reefs are notably now projected with high confidence to pass a tipping point beyond which recovery will be impossible, even if climate change is limited to 1.5°C.[109]

Most tipping points are thought to occur when gradual change reaches a certain point, but it is highly likely that increased frequency of some types of extreme event such as sudden changes in salinity or oxygen levels will trigger irreversible changes including extinctions at species level or larger scales.[53]

4. State and trends

4.1 Current and future flood and erosion risks

Coastal flooding and erosion is an environmental process that has an impact on people, property and the environment. Management of flood and erosion risk to people and property has, in turn, had a significant impact on the inland and coastal environment.

Coastal floods are among the biggest risks England faces.[72] The need to manage these risks has led to extensive construction of hard defences such as sea walls around the coast. These structures can cause disruptions to natural coastal processes that, in combination with sea level rise and storm surges, threaten coastal habitats such as sand dunes and salt marshes. Changes already being observed include steepening, whereby beaches and coastal habitats are being lost as sea level rises and disruption to sediments reduce natural replenishment. A 2004 analysis found steepening was occurring at 61% of coastal locations in England and Wales.[110] Coastal squeeze, preventing inland migration of habitats as sea levels rise, is expected to prevent up to three-quarters of coastal habitats from adapting to future sea level rise.[70] Areas to replace protected habitats being lost in this way can usually keep pace with this process for now, but this will become increasingly challenging over time.

Recent years have seen widespread damage to coastal defences, properties and infrastructure during severe storm events. 102,000 people in England were calculated to be at significant risk from coastal flooding in 2020.[74] Valuable coastal infrastructure assets are also at risk. For example in 2018 it was estimated that nearly 9% of the best quality (Grade 1 and Grade 2) agricultural land was at high risk of coastal flooding (1:200 or greater risk).[111] The most productive agricultural land in England is often on land historically claimed from coastal wetlands that, due to soil erosion, is often close to or even below sea level now.

Exposure and vulnerability to flood risk is not equally distributed across society. Deprived communities face higher flood risk exposure from all sources, and this inequality is greater in coastal communities.[112] Social vulnerability to flooding is a measure which describes a reduced ability to prepare for, respond to, and recover from flooding, as a result of a range of social factors. Of the 8% of neighbourhoods in England with high social flood vulnerability, 38% are within 2 kilometres (km) of the coast.[113]

It is difficult to confidently predict future coastal flood risk, because doing so has to take into account uncertainties around future social, political and environmental change. Projections are usually made by considering a range of scenarios covering different levels of climate change, population growth and other relevant factors. Despite the uncertainties all future scenarios project that there will be large increases in the number of people in England and other UK countries who will be at significant risk from coastal flooding in the coming decades. If climate change is limited to 2°C, there is likely to still be a more than 200% increase in the number of people at significant risk by the 2050s, and over 300% by the 2080s (Figure 4).

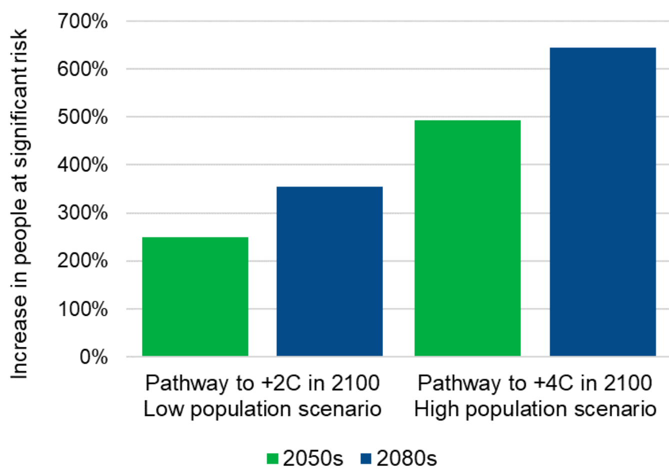


Figure 4: Projected change in numbers of people in the UK at significant risk of coastal flooding in 2050 and 2080. Data presented for scenarios of 2°C and 4°C warming by 2100. Data source: Sayers et al.[74]

There are risks to major industry and infrastructure. The UK Climate Change Committee estimate that approximately 1,600 km of major roads, 650 km of railway, and 92 railway stations in England are likely to be at risk of coastal flooding or erosion by 2100.[70] A study using Environment Agency data has projected that by 2025, without intervention, 79 historic coastal landfills will begin to erode into coastal waters. By 2055 and 2105 respectively, this will increase to 122 and 144.[114] Estimates using a high population growth and 4°C warming scenario, are that total annual damages from coastal flooding will more than double from £361 million in 2020 to £1 billion by the 2080s.[74]

Coastal flooding and erosion are natural processes that have and will always happen at the coast, but these risks are further increased by sea level rise. Around 17% of the mainland UK coastline is being affected by coastal erosion, particularly in the east and south of England.[115]

Continuing sea level rise and ongoing coastal processes mean that the number of residential properties at risk from coastal erosion in England is estimated to increase from approximately 270 between 2010 and 2030 to between approximately 1,980 and 4,150 by 2110, assuming current risk management ambitions are achieved.[116] Around 550 hectares (ha) of higher quality (Grade 1,2 and 3) agricultural land is projected to be at risk from coastal erosion by 2100.[117]

England has extensive coastal flood defences, without which the current risk and past damages would be much higher. However, as the risk increases, 'holding the line' by building and maintaining hard defences will become unrealistic in some locations because of prohibitive costs, resulting in serious safety implications.[76] Sea level rise in some parts of the country is already leading to coastal changes that pose a serious risk to the viability, both physical and economic, of some coastal communities.[76] This poses questions of how these communities might be supported in managing the transition between their current and future positions.[118] Local authorities in some parts of England where the scale and pace of change is already very significant are now working with Defra and the Environment Agency to assist affected communities and plan for the future.[119]

Photo 1: waves overtopping a sea wall

4.2 Coastal and estuarine water quality

Ecological status

Coastal and estuarine waters up to one nautical mile from the coast are assessed to see whether they are at good ecological status (GES). This measures how close the water body is to an 'undisturbed' ecological reference state. Elements assessed include nutrient pollutants, levels of dissolved oxygen, degree of physical modification such as hard defences, and biological measures such as diversity of fish, algae and invertebrates. Of all assessed coastal waters, 45% were at GES in 2021. This indicates no change in coastal water quality overall since 2016. In 2021, only 19% of assessed estuaries were at GES. [120] This figure obscures high levels of variation in water quality among different estuaries. This is caused by differences in their physical conditions, and in the type and degree of pressures on each estuary and its wider catchment. Nitrogen levels, as well as the effects of physical modification in heavily modified water bodies, are the primary reasons for estuarine and coastal water bodies not achieving good ecological status.

Nutrient pollution: state and trends

Nitrogen pollution is a major cause of poor ecological conditions in coastal and estuarine waters. Nitrogen standards are set to protect estuaries and coastal waters from eutrophication. The main source of nitrogen to the water environment in England is agriculture, comprising 69% of inputs. The second largest source is waste-water, which contributes close to 25%.[121]

Of monitored estuarine and coastal water bodies, 93% and 47% respectively exceeded nitrogen standards set for good ecological status in 2019. This is causing issues, including excessive growth of macroalgae in shallow harbours.[121] The spatial extent of eutrophic areas in UK waters decreased over the period between 2006 and 2014.[122] Problem areas remain in several locations (Figure 5).

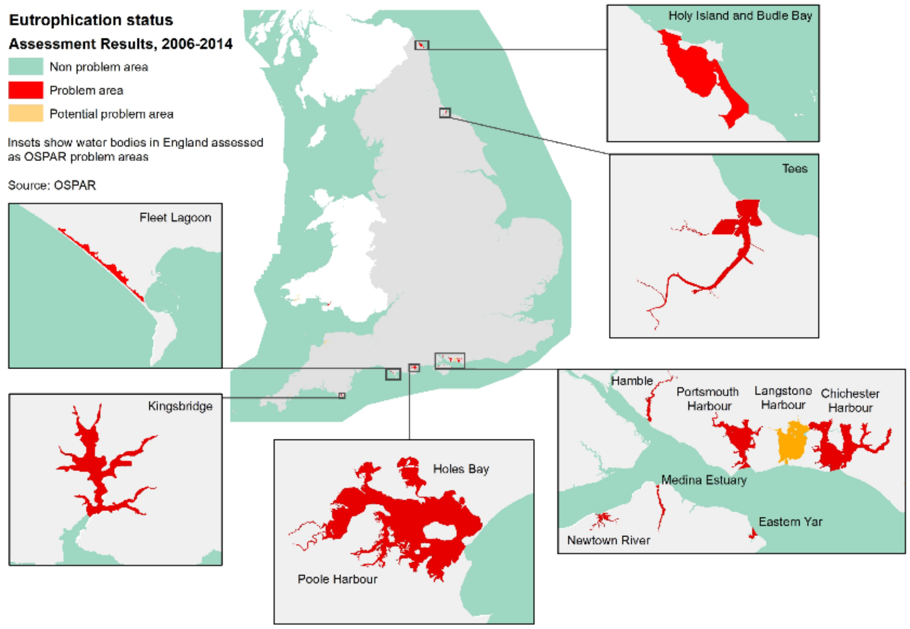


Figure 5: Water bodies in England assessed as problem areas for eutrophication. Data source: OSPAR 2017.[123]

Case study: Nitrogen in Poole harbour

Poole Harbour is designated as a Special Protection Area (SPA), Site of Special Scientific Interest (SSSI) and a Ramsar site for its estuarine habitats, including salt marshes, mudflats and subtidal communities. The site and its habitats support many species, including breeding and wintering birds, lichens and rare invertebrates.

The amount of nitrogen entering the harbour has doubled in the past 50 years.[124] Consequently, the mudflats in the harbour are covered in green algae which has smothered sea grass and salt marsh, affecting wetland birds and other wildlife. Agriculture is the main source of nitrogen, and also contributes a significant amount of phosphorus, to the catchment. Some local farmers are taking ownership of nitrogen targets and aim to be among the most nitrogen efficient farmers in the UK. This follows new limits on nutrient losses for catchments, set by the Environment Agency. The Environment Agency is working with farmers to help them meet their targets, by providing new tools to calculate nutrient loss. Farms are not the only source of nitrogen to Poole Harbour. The Environment Agency is also working with local industries, Wessex Water, local authorities and the general public to help reduce nutrient inputs. Similar approaches with industry in the Solent have led to major improvements. Nutrient loads to Solent waterbodies are now much lower than 20 years ago, for example in Langstone Harbour the nitrogen load has been halved, and the phosphorous load reduced by over two thirds. All Solent water bodies affected by eutrophication have experienced decreases in nutrient input and macroalgae.[125]

Inputs of nutrients from rivers to tidal waters

Data for the UK show a clear reduction in phosphorus inputs from rivers to coastal waters since 1990, but a variable picture for nitrogen, which tends to fluctuate more with rainfall conditions (Figure 6). Phosphorus inputs have reduced mainly as a result of improvements in sewage treatment.[126] Climate change-related increases in winter rainfall and run-off, along with agricultural intensification, will create additional pressures. Without extensive additional measures around agricultural practices this will mean higher losses of nitrogen and phosphorus to the water environment.[127,121]

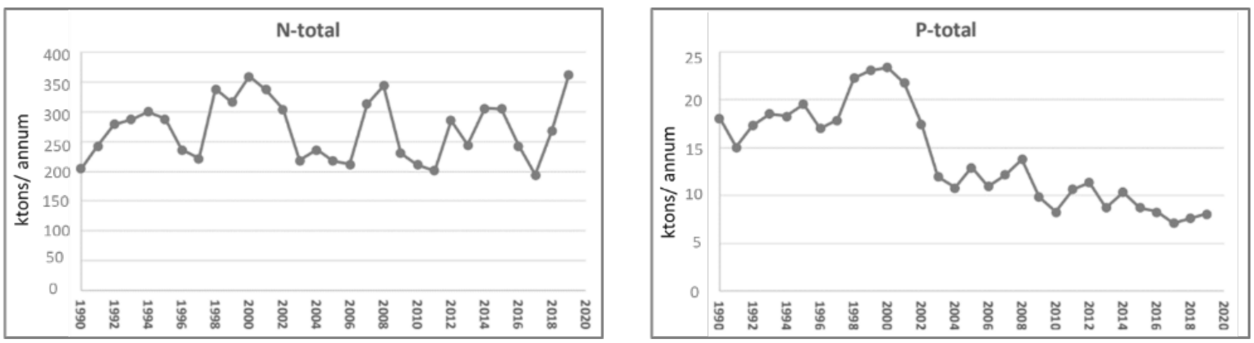


Figure 6: Riverine inputs (ktons per annum) of nutrients (nitrogen and phosphorus) from the United Kingdom to maritime areas. Data source: OSPAR 2021.[126]

Chemical pollutants: state and trends

Chemical status

Over 50 chemicals are designated as priority substances and are monitored to assess compliance with environmental quality standards (EQSs). EQSs may be expressed as concentrations in either water or aquatic organisms. This assessment is used to classify the chemical status of coastal and estuarine waters under Water Framework Regulations.

All assessed water bodies failed to achieve good chemical status in 2019. The failures are mostly related to revised and improved assessment methodologies, which resulted in a more comprehensive assessment of the prevalence of PBT chemicals in the environment. It is these substances which are causing the widespread failures. They account for a relatively small number of the 52 chemicals assessed in surface waters, and there is little underlying change in chemical status for the others.

UPBTs are already banned or have very tightly controlled uses. Their levels reflect their persistence in the environment, and bioaccumulation in wildlife may be due to discharges of these so-called legacy chemicals over many years.

The main sources of chemicals in the global coastal and marine environment include:

- the chemicals industry
- other industries that use chemicals, including agriculture and transport
- public use such as domestic, veterinary and medical use
- legacy chemicals – those used historically but still in existence
- accidents
- waste management and incorrect disposal

Chemical pollution affects ecosystems at all levels, from individual species, to the ecosystem services that sustain human life.[128] Toxic effects of chemicals on coastal and marine life can be acute, or chronic because of long-term exposure to lower levels of a substance. For example, high levels of polychlorinated biphenyls (PCBs), UPBT chemicals which were once used widely as an electrical coolant, have accumulated in the tissues of whales, dolphins and porpoises found in UK waters. PCB levels known to have toxic reproductive effects have been found in a range of species and are thought to be linked to observed population declines and reproductive failures.[129] Mercury, another PBT chemical, accumulates in fish at the top of marine food chains. Health organisations warn against consuming large amounts of these species, because of harmful health effects.[130] PBT and UPBT chemicals can have environmental impacts decades after their use is discontinued.

Persistent chemicals from past industrial use remain in marine sediments and some can accumulate up food chains, even long after they are banned from production and use. They can then be remobilised if the sediment is disturbed, either by human activity, climate changes or natural processes such as storms that affect sediment movement. Some pollutants that were disposed of into landfill many years ago are now making their way into coastal and marine environments as coastal flooding and erosion is exposing old, closed landfills to the sea. There are significant evidence gaps in terms of knowing what substances are being released, and what impacts they may have.[114]

Many new chemical substances are produced and used each year. Assessments are made on their hazards and risk, but it takes time to build up evidence. In addition, most chemicals degrade over time, and information on the by-products of this degradation is not always available. This presents a continuing challenge for government and regulators.

Population growth and societal behaviour change is predicted to increase the pressure from chemicals on the water environment as the market for chemicals grows and changes. Climate change is likely to alter both how and what chemicals are used and how they behave in the environment, making some chemicals more toxic or more mobile.

Climate change impacts are linked to increased or changed release of hazardous chemicals, for example, increased frequency and intensity of rainfall events, washing more chemicals into water bodies from sewers and land. More extreme weather events such as storms, flooding and drought are expected to increase levels of re-release of chemicals stored in sediments, and eroding soils, which are then washed into water bodies.[131,132]

Heavy metal inputs from rivers to coastal and marine waters

Heavy metals are toxic to fish and other animals. The main pathways of these metals into the marine environment are inputs of legacy metals from rivers and point sources, and through atmospheric deposition. The largest overall source of metals to coastal waters is abandoned metal mines.[133] Mercury is an exception to this, with the main sources being natural, industrial and agricultural processes. Heavy metals are deposited from the atmosphere into marine environments, as well as via riverine inputs.[134]

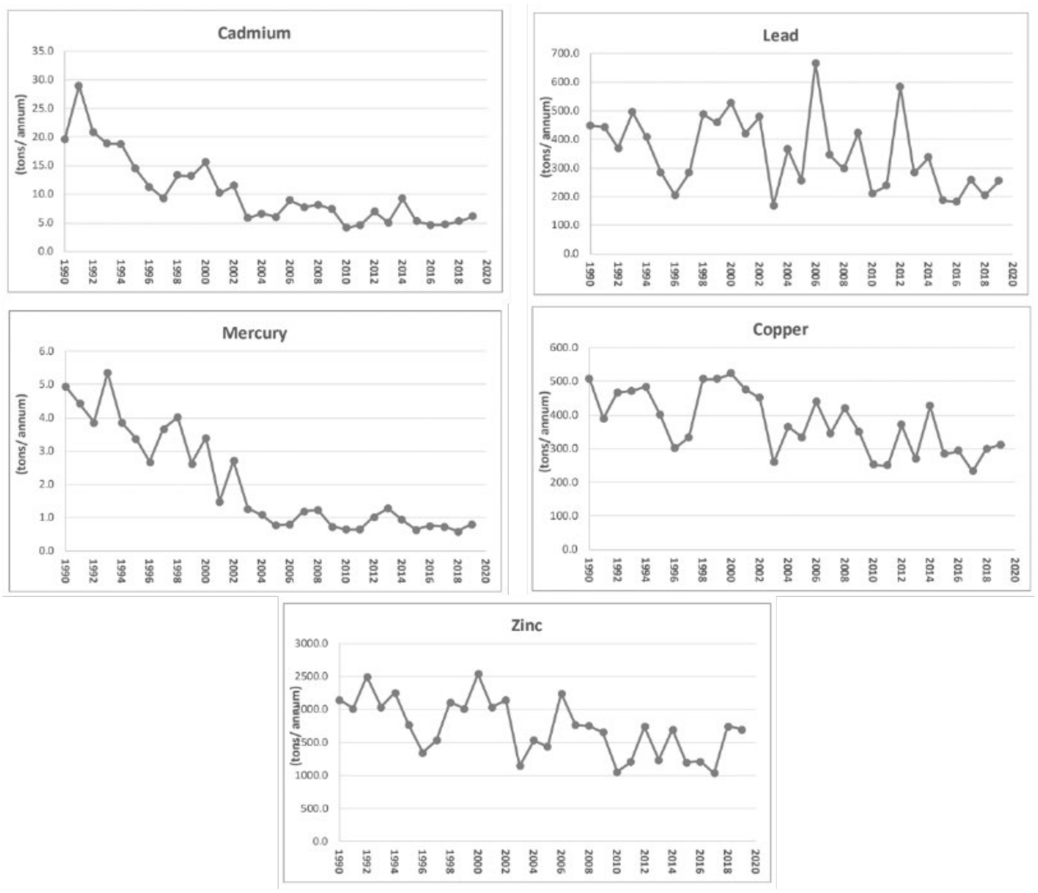


Figure 7: Inputs (tons per year) of selected metal pollutants from UK rivers to maritime areas 1990 to 2019. Data source: OSPAR 2021.[126]

Heavy metal inputs from the UK to coastal and estuarine waters have decreased considerably since 1990, although further improvements since 2012 are not evident (Figure 7).[135] Large reductions were seen when legislative changes prevented or restricted the use and discharge of some metals, although there have been large fluctuations between years. Methodological changes mean that reductions are impossible to determine accurately, but it is known that levels have greatly reduced.[126] As with the inputs of nutrients, rainfall driven fluctuations in river flows are a major influence on between year variations in annual inputs of metals to the marine environment. There are knowledge gaps around what happens to heavy metals when they reach estuaries, and therefore what proportion reaches the marine environment.[136]

PCB inputs from rivers to coastal and marine waters

PCB inputs from UK rivers to coastal and marine waters have reduced from around 2,000 kg in 1990 to less than 250 kg in 2019 (Figure 8). This reflects the ban on PCB production and restrictions on use in the UK. In addition, significant progress has been made in phasing out PCB contaminated equipment. PCBs are still present in coastal and marine sediments around the UK, although levels are declining in most regions.[137]

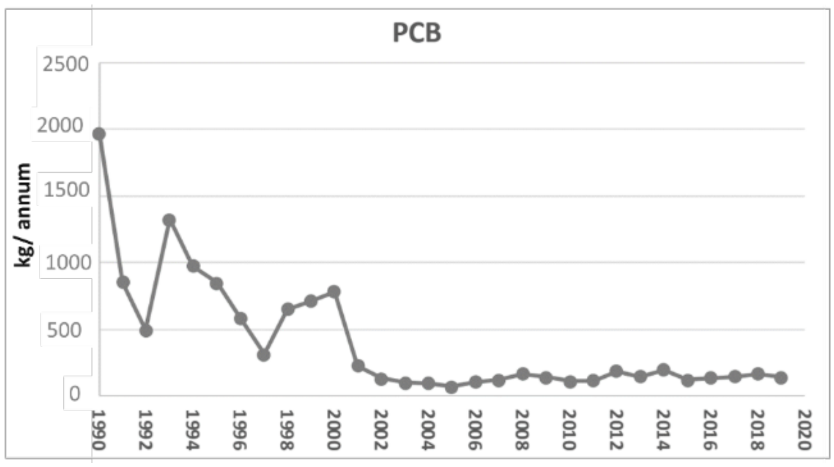


Figure 8: Annual riverine inputs of PCBs (kg per year) from UK rivers to maritime areas, 1990 to 2019. Data source: OSPAR 2021.[126]

Chemicals in coastal and marine sediments: state and trends

Coastal and marine sediments around the UK are monitored for the toxic heavy metals lead, cadmium and mercury to assess progress towards environmental targets. Assessment of UK sediments in 2018 found that in some locations, lead, cadmium and mercury were at levels above the threshold where toxic effects on marine life are likely to occur (Figure 9). All 3 were found to be at broadly similar levels to those measured in 2012. There is low confidence in this assessment, because of limitations in available data and methodology.[138] A recent study looking at 31 years of data from hundreds of UK sites has found widespread increases in sediment concentrations of copper, nickel and iron over this time period, with potential implications for marine life. There is emerging evidence that products such as antifouling paints and emissions scrubbers used in shipping are an increasing source of some of these toxic metals.[139]

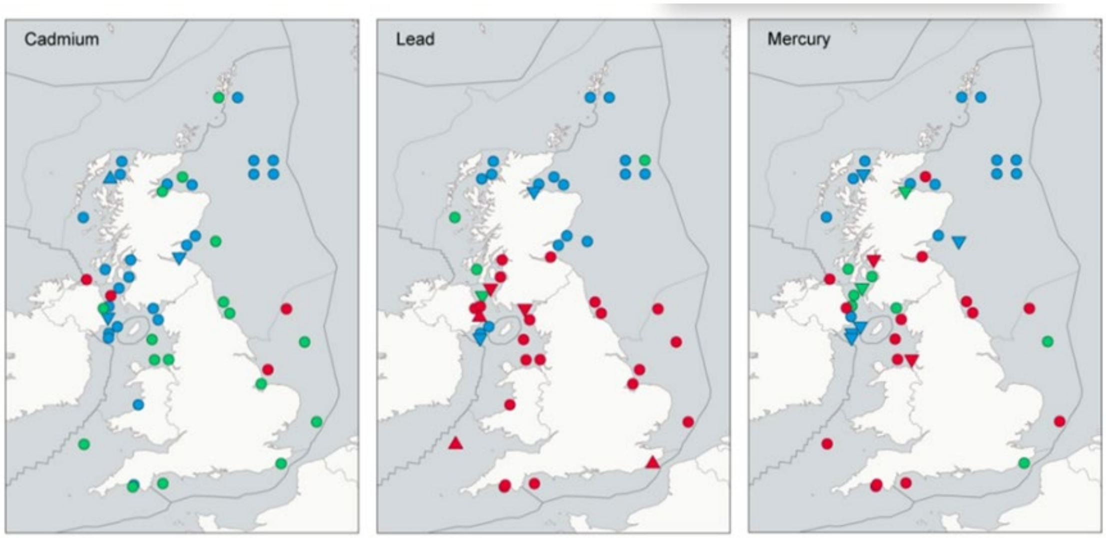


Figure 9: Levels of cadmium, lead and mercury in sampled coastal and marine sediments around the UK. Green = concentration significantly below the likely toxic effects threshold for marine life; blue = concentration significantly below background level; red = concentration at or above the likely toxic effects threshold for marine life. Circle = no change; Upward triangle = significant increase in concentration; Downward triangle = significant decrease in concentration. Data source: Manuel Nicolaus et al. 2018. Reproduced under the Open Government Licence v3.0.

Chemicals in wildlife: state and trends

Some additional initial assessments of levels of 4 PBT chemicals in blue mussels, harbour porpoise and dab were carried out in 2019 to develop an indicator of marine wildlife exposure. This indicator was created to support assessments of progress towards goals set out in the government's 25-Year Environment Plan. The chemicals assessed are representative of the 3 groups highlighted in the plan as being of particular concern: PBT chemicals, heavy metals, and pesticides and biocides. Results so far show that where assessment was possible, levels exceeded toxic effect thresholds in almost all species for all 4 substances. Exceptions were perfluorooctanesulfonic acid (PFOS) in dab and polybrominated diphenyl ethers (PBDEs) in blue mussels. Exceedances were most widespread for mercury in dab and blue mussel but were not assessed for harbour porpoise. None of the substances was increasing in any of the sampled species.[140]

Bathing waters: state and trends

Sewage, and animal faeces entering the sea can both contain microorganisms that pose human health risks. The main sources are agricultural run-off, sewage related pollution and urban diffuse pollution including contamination from dogs and birds.[141]

The Environment Agency monitors coastal waters that are designated for bathing, regularly throughout the bathing season (15 May to 30 September) to assess levels of faecal indicator bacteria in the water. Bathing waters have improved significantly since 1995 when this monitoring began. Just over 97% of bathing waters in England passed the minimum standard in 2022, just under 2% lower than in 2021, but the same level as in 2015. Just over 72% achieved excellent standard. More than 70% of bathing waters have achieved the Excellent standard for the past 4 years (Figure 10). Growing numbers of people are using bathing waters outside of the monitoring season, giving rise to questions of whether monitoring, and pollution warnings such as water company sewage alerts, should be implemented year-round.

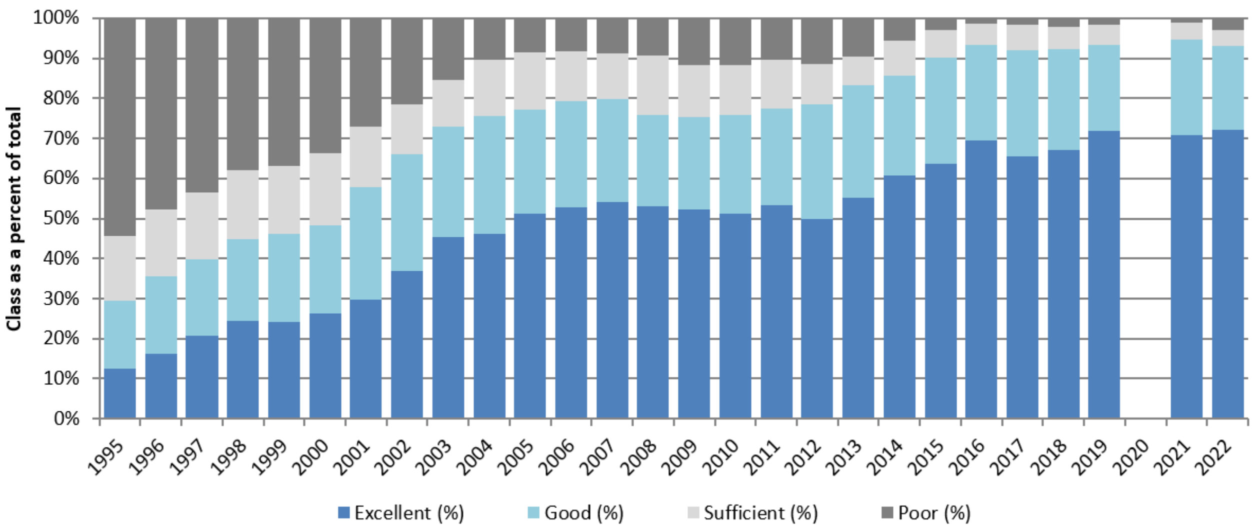


Figure 10: Designated bathing water quality in England, 1995 to 2022. No status assigned in 2020 as a result of limited sampling during the Covid-19 pandemic. Data source: Environment Agency.

Shellfish waters: state and trends

Some coastal waters are designated as protected areas for shellfish. Most of these are in estuaries. Shellfish waters are protected by both environmental and food hygiene legislation. These waters are monitored for faecal bacteria, to check that they meet regulatory standards.

In 2021, 75% of shellfish waters failed to meet aspirational standards set for environmental protection.[120] This rate of compliance has been broadly static over recent years (Figure 11). This reflects the ongoing water quality challenges posed by high rainfall, flooding, storm overflows and diffuse pollution from agricultural land.[142] The rate of compliance is lower compared to bathing waters because shellfish are filter feeders that feed on faecal bacteria, and because the regulatory standards are more stringent.[141] Policy changes affecting where water companies target their investments are expected to improve compliance levels at some sites in coming years.

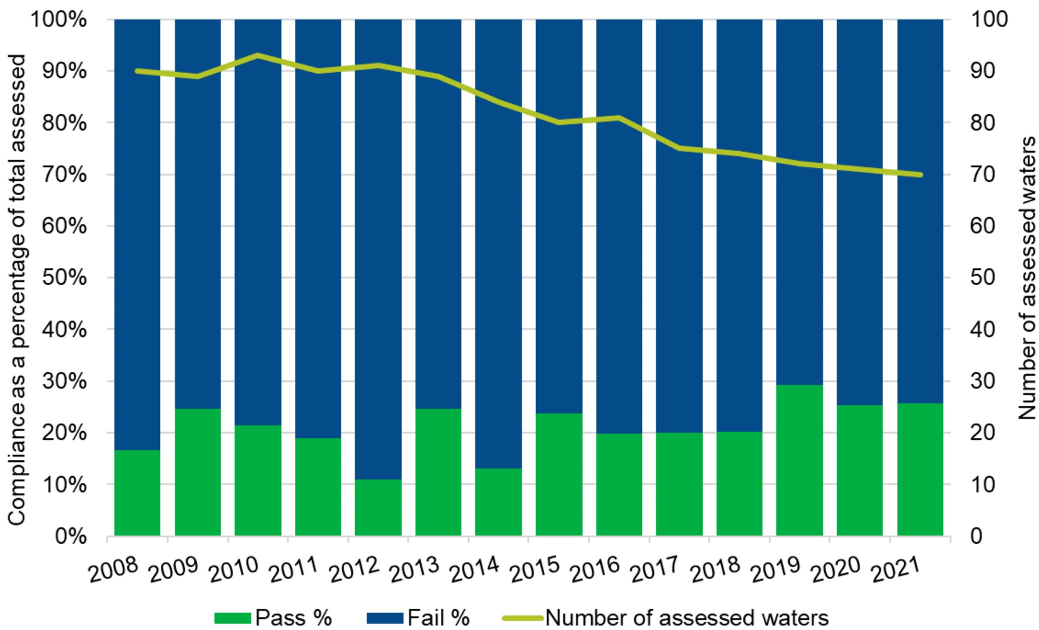


Figure 11: Percentage of assessed English shellfish waters compliant with environmental standards for faecal indicator bacteria, 2008 to 2021. Data source: Environment Agency.

Plastic pollution: state and trends

Plastic pollution has been a focus of media attention in recent years. Plastic pollution of coastal and marine environments takes a range of forms, including:

- plastic litter blown off land or carried down rivers and into the sea
- microplastic fibres from clothes that end up in wastewater
- plastics, including wet wipes, incorrectly flushed down toilets
- discarded or lost fishing nets, lines, and their microplastic breakdown products
- nurdles, small plastic pellets lost during manufacture and shipping

A global study estimated that about 4.8 to 12.7 million metric tons of plastic entered the ocean in 2010 alone.[143]

Photo 2: Plastics on the strandline at Watergate Bay, Cornwall.

Plastics are now considered to be a major threat to marine wildlife.[144] A review of 747 studies found that marine plastic debris affected 914 species through entanglement and/or ingestion.[145] Grey seals, a protected UK species, are known to be affected, mainly by entanglement in fishing gear.[146] Fishing-related marine litter is also affecting sensitive UK habitats.[147]

A review of the effects of microplastic pollution on marine phytoplankton and zooplankton found that it reduced growth, reproduction and rates of photosynthesis and carbon uptake in a range of species. The risk posed to carbon sequestration by these effects is not yet understood, but is of concern given the key role of phytoplankton in carbon uptake, and the widespread nature of ocean microplastic pollution.[148]

A recent global assessment of the impacts of marine plastic pollution found that it reduces the benefits derived from marine ecosystem services by at least US$500 billion to US$2,500 billion each year, not including broader social and economic losses.[149]

The most recent assessments of beach litter cover the period between 2008 and 2015. These show that the amount of plastic litter on beaches varies around the UK. Assessments suggest that the Celtic sea region has larger amounts of beach litter than the Greater North Sea region. Plastic litter remains a common problem for UK beaches and did not decrease during this period (Figure 12).[150] More recent survey findings from beach cleans suggest a decrease in overall items per 100 metres (m) of beach in both 2020 and 2021, and a decrease in plastic bags between 2013 and 2021, driven at least partly by single use plastics bans and charges.[151]

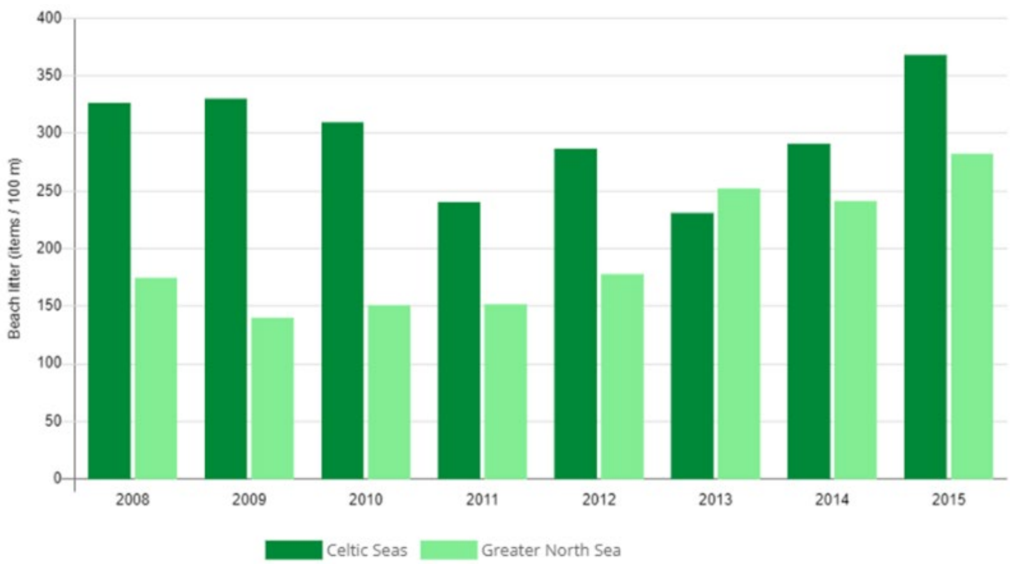


Figure 12: Items of litter per 100m of beach, UK, 2008 to 2015. Data source: Marine Conservation Society and OSPAR.

Fulmar stomachs analysed for ingested plastic found that 60% of birds in the greater North Sea region, between 2004 and 2014, had more than 0.1 grams (g) of plastics in their stomachs. This is a good indicator of the levels of floating plastic litter in their environment. There has been a small but not statistically significant decrease in this indicator over the assessed period.[152] A 25-year survey of seafloor litter around the UK found that a range of plastic litter types, including fishing-related plastics and plastic sheeting litter both increased significantly between 1992 and 2017. Plastic bags were the only category to see a significant decrease.[153]

Microplastics have been less well studied, particularly in sediments. A Natural England and Environment Agency study of sediment samples from inshore Marine Protected

Areas in England found microplastics at all 22 sites.[93] Another study found microplastics in all water samples and all mussels collected from 8 locations around the UK coast, and in all samples of mussels bought from 8 different UK supermarkets.[154]

4.3 Habitats and biodiversity

This section presents trend data for some of England's main coastal and marine habitats. Overexploitation and other human activities over long-term timescales have depleted populations and destroyed and degraded habitats. In England, as elsewhere around the world, historical land use change has resulted in large losses of intertidal habitats such as salt marshes and mudflats.[155] Past overfishing and changes to fishing practices depleted fish populations and destroyed seabed habits. In addition, many estuaries and coastal water bodies are heavily modified by structures built to aid navigation and flood defence, such as channels and sea walls. This has resulted in habitat loss as well as altering the natural form and function of water bodies and their remaining habitats. In 2021, 56% of estuarine and coastal water bodies were assessed as 'heavily modified'. Physical modification was the reason for failure to achieve good status in 44% of all assessed estuarine and coastal water bodies in 2019.[156]

It is difficult to know exactly how much has been lost. Historical evidence tells us that the seas around the UK once teemed with life. The annual arrival of the vast herring school, and the associated mass of sharks, whales, dolphins and porpoises feeding on them off the east coast was considered one of the greatest wildlife spectacles on earth. It is now estimated that fish in seas across Europe probably represent less than 5% of those prior to exploitation.[157] Losses are often perceived as smaller than they really are, because of the often poor quality or absence of historical data for comparison. This is known as 'shifting baseline syndrome'. There are still major knowledge gaps in assessing the current status and distribution of some species and habitats, notably for those on the seabed.[158]

In addition, many species are now experiencing major shifts in their geographical ranges, mostly as a result of climate change.[159] This can have cascading effects on other species through changes in ecosystem dynamics.

Some species may recover as areas of habitat are created, protected and restored. Others may continue to decline, as a result of continuing pressures. Some UK coastal and marine ecosystems could be lost in some places if projected changes to winter storm patterns combine with ongoing sea level rise. For example, seagrass beds may not have time to recover in between damaging storms if storm frequency increases.[53] Some habitats are considered irreplaceable because of their age, location, ecology, or the ability to recreate them should they be destroyed.

Habitats: state and trends

There are some gaps in the evidence on the state and trends of England's coastal habitats. However, it is known that large areas have been lost over long-term timescales, to development, land use change and the installation of coastal defences. Much of England's existing coastal habitat is now protected under some form of legislation, requiring avoidance of damage and, in the case of internationally protected sites, the restoration of coastal habitats where this damage does occur unavoidably. Sites designated as part of the National Nature Recovery Network will complement the existing site network and help it remain resilient to future change.

Dunes

Sand dunes are important habitats for a diverse range of species. Many are designated as protected sites because of this, and because they are home to rare and critically endangered species such as natterjack toads, and sand lizards. Beach and dune habitats are inherently linked and together protect the coast from storms and other extreme weather events, and provide recreation and leisure opportunities for people.

Human activities have altered sand dune habitats for hundreds of years.[160] In particular, the construction of hard coastal defences is widespread and prevents natural replenishment of sand dunes by reducing or severing connectivity with the beach, leading to habitat degradation and loss over time through erosion. Sea level rise and increasingly frequent severe storms, combined with coastal development are also a threat to dunes.[161]

It is thought that the UK has lost around 30% of its sand dune habitats since 1900. The rate of loss slowed from the 1970s onwards. The area of sand dune in England was estimated at around 12,000 ha in 2000.[162] The largest remaining areas are predominantly around the west coast, but smaller systems in the east are also of significant importance for flood protection.[163]

Losses are predicted to continue, with one study predicting a further loss in England of 1,071 ha between 2010 and 2060.[164] One study estimated that across Europe, the loss of beaches and sand dunes from erosion would cost 3.6 billion euros annually in lost ecosystem services by 2100.[165]

Evidence suggests that dune wetland habitats in England are drying out due to changes in hydrological conditions that may be linked to climate change. There has been a 30% reduction in their extent in the largest protected sites between 1990 and 2012. Remaining sites show a shift from wetter to drier plant communities.[166]

Intertidal and subtidal sediments

Seabed sediment habitats such as sand and mud can be broadly divided into intertidal and subtidal habitat types.[158] Intertidal refers to the area of the shore that lies between the high-water mark and the low water mark. Subtidal habitats are those that lie below the low water mark and are always underwater. A wealth of species live in or on the surface of seabed sediments, including crabs, sea urchins, burrowing worms and other invertebrates, shellfish such as oysters and scallops, and flatfish.[167] Intertidal habitats such as seagrass and salt marshes provide structure on seabed sediments and act as nursery grounds and refuges for many fish species. The habitats and species associated with intertidal sediments are better understood than those inhabiting subtidal seabed sediments.

Marine sediments take up and sequester excess nutrients from the water and are also important carbon stores.[168] One study assessed the total carbon in water, sediments and coastal habitats of the north-west European shelf seas, estimating that the sediments held between 71% and 87% of the total.[169] This stored carbon can be released by habitat loss, seabed disturbance and climate effects. Work is ongoing to assess the potential scale of these threats.[170] It is generally accepted that the main pressure on subtidal seabed habitats is bottom trawling.[171] Globally, bottom trawling is estimated to release around 590 to 1,470Mt of CO2 into the water column every year. Despite there being significant uncertainties about how much carbon is released back to the atmosphere from subtidal sediments, the protection of these important carbon stocks is a sensible precautionary policy.[172] Research is ongoing into how much of this ends up back in the atmosphere.[173] One study has estimated that preventing bottom trawling in the parts of the UK's waters with the highest 5% of sediment carbon content would reduce the disturbance of organic carbon by over 18%, even if all fishing disturbance was displaced to other areas within the study region.[41] Evidence on the extent and nature of subtidal seabed sediments is currently patchy. Research is ongoing into mapping and understanding these habitats.[174]

Photo 3: seabed habitat, courtesy of Paul Naylor.

Salt marsh

Salt marshes are intertidal habitats that grow on sediments in estuaries and sheltered parts of the coast. Salt marshes provide a large range of ecosystem services and are vital habitats for many species, including fish and migratory and wading birds. Their carbon uptake and storage capacity is among the highest of any habitat.[175] They can also help reduce wave heights and reduce coastal flooding and erosion by providing tidal storage. If 15% of England's current salt marsh extent was re-established or created, this could store an additional estimated 2.25 million tonnes of carbon once the habitat is fully established. It could also increase sequestration by an annual estimate of 8,250 tonnes.[11] It is important to manage these sites well. Mismanagement of salt marsh wetlands can lead to emissions of CO_2 rather than them acting as a carbon sink. Salt marsh at sites with lower salinity can also emit methane, and so site selection is also an important factor in salt marsh creation.[176]

The latest mapped extent of salt marsh in England is just over 35,500 ha. This is an overall increase of 7% compared with figures from 2006 to 2009. Habitat creation and restoration as part of flood management schemes account for 37% of the increase.[177] Over the longer term the extent of salt marshes in the UK has declined. Long-term assessments suggest an estimated 85% of England's salt marsh has been lost since the mid-19th century, [178] mainly as a result of land conversion for agriculture or development.[177] Comparisons of salt marsh maps and data dating back to 1888, with more recent maps and surveys, show a similar pattern for the tidal Thames (Figure 13).[92] Reliance on historical maps and information means that there is greater uncertainty around exact past extents than those measured more recently.

Salt marshes are now predominantly threatened by sea level rise and coastal development. Disruption to the supply of sediment, mainly caused by man-made structures, affects the ability of salt marshes to keep pace with sea level rise, and hard defences or other built environments prevent them from migrating inland.[86] One study has predicted that nearly all tidal salt marshes in Great Britain are expected to be in retreat as a result of sea level rise by 2100, under a worst-case, high emissions climate scenario. Under a low emissions scenario, the study found a high probability of retreat on the south-east and east coasts, but not in the north-west, over the next 2 centuries.[179] Another study predicts a loss of almost 3,780 ha of salt marsh in England between 2010 and 2060.[164]

An indicator measuring the ecological quality of UK salt marsh habitats based on data from 2015 found that quality thresholds were being met in the northern North Sea, Western Channel and Celtic Seas regions but not in the southern North Sea and eastern English Channel. The main reasons for failure to meet thresholds are not yet fully understood but may be related to the effects of physical modification.[180]

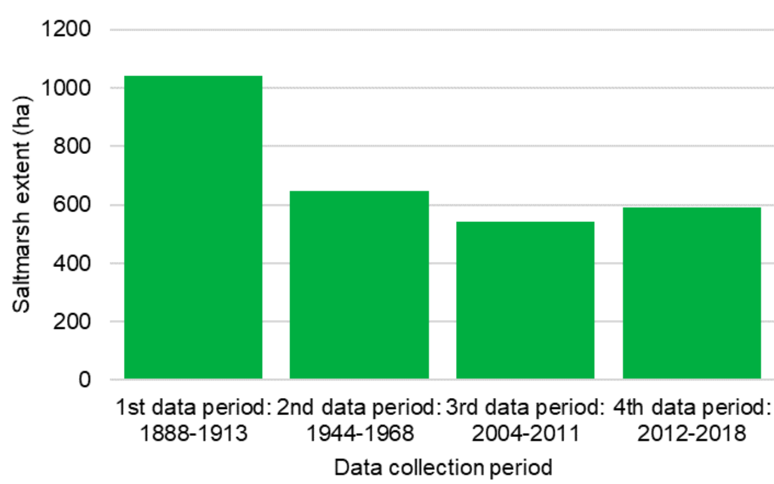


Figure 13: Salt marsh extent in the tidal Thames, 1883 to 2018. Source: Zoological Society of London, State of the Thames 2021.

Case study: Steart Marshes

The Environment Agency and Wildfowl and Wetlands Trust have created 180 ha of salt marsh as part of the UK's biggest ever coastal realignment scheme at Steart in Somerset.[177]

The now completed salt marsh scheme absorbs wave energy naturally via the low gradient and coarse vegetation.[181] This will help to protect local homes, businesses and infrastructure from storm surges and protect the newly constructed flood banks from erosion so that they last longer.

Additional benefits of the restoration include increased biodiversity, and carbon sequestration and storage. It is estimated that around 30,000 tonnes of carbon have been buried at Steart Marshes since the restoration from agricultural land.

Photo 4: aerial view of Steart Marshes, courtesy of Wildfowl and Wetland Trust

Seagrass

Seagrass beds grow on both subtidal and intertidal sediments.[182] Seagrass habitats sequester and store carbon, reduce coastal flood risk, and provide habitat and nursery grounds for marine fish and invertebrates. The current area of seagrass in England is estimated to be over 3,300ha. This is almost certainly an underestimate.[183] With high certainty, the UK has lost 44% of its seagrass since 1936. Over longer timescales, between 84% and 92% may have been lost. There is more uncertainty around these calculations, because of a lack of historical data.[184] The main reason for UK seagrass declines are physical loss and degradation of habitats through fishing and coastal development, and reduced water quality.[185] An indicator measuring the ecological quality of UK seagrass habitats based on data from 2015 found that quality thresholds were being met in all assessed regional seas.[186]

Globally, temperate seagrass meadows are declining and are predicted with high confidence to continue to retreat as a result of intensified extreme temperatures and a limited ability to disperse.[77]

Native oyster habitat

Native oysters, and the habitats they create, provide a range of ecosystem services, including shelter and nursery grounds for fish and invertebrates.[187] Oysters are able to remove excess nutrients and organic matter from the water, improving water quality.[168] One adult oyster can filter 200 litres of water in a single day. The physical structures of oyster reefs and beds help reduce wave heights and stabilise seabed sediments, preventing erosion.[188]

Habitats created by native oysters were historically widespread and a major feature of Europe's coastal and offshore waters.[189] Native oyster populations have declined by 95% in the UK since the mid 19th century. Losses resulted from overfishing, combined with habitat loss, disease, pollution, predators, pathogens and invasive non-native species.[189] A series of unusually cold winters in the 1930s and 1940s also contributed to the declines.[190] There were large offshore areas of oyster habitat in the English Channel and the southern North Sea in the 18th and 19th centuries. These declined significantly during the 20th century.[43] The deeper water southern North Sea populations were extinct by the end of the 20th century.[191]

Native oyster landings in English and Welsh waters decreased from around 3,500 tonnes in 1887 to less than 500 tonnes in 1947 (Figure 14).[190] Native oysters are now functionally extinct in UK waters, but there are efforts to restore populations in some remaining strongholds such as the Essex estuaries.[192]

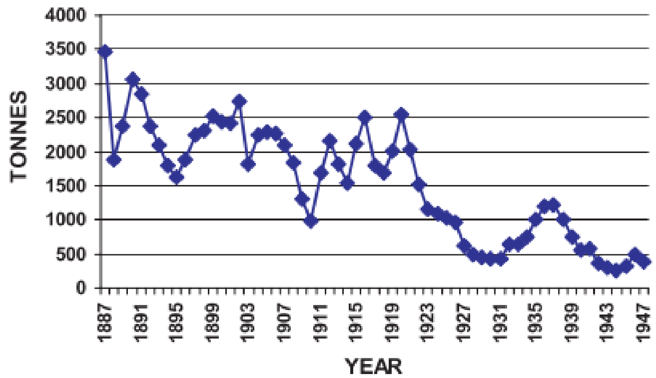


Figure 14: Native oyster landings (tonnes) in England and Wales, 1887 to 1947. Source: Laing et al 2006.[190]

Photo 5: Native oyster with blue mussels, courtesy of Paul Naylor

Case study: The Essex Native Oyster Restoration initiative

The Essex Native Oyster Restoration Initiative (ENORI) is a collaboration with oystermen, government, conservationists and academia, including the Environment Agency. ENORI's mission is to restore and create self-sustaining populations of native oysters that provide ecosystem services, increased biodiversity and sustainable fisheries, while recognising their cultural importance. The Essex estuaries hold the largest remaining populations of native oysters in England, leading to the designation of a Marine Conservation Zone in 2013.[187] So far ENORI has used a multi-disciplined approached by using traditional models, local knowledge, and new innovative restoration methods to recover native oysters. It has established the UK's first network for the restoration of native oysters and secured a marine licence for restoration activities that recognise the role played by traditional aquaculture in the survival of native oysters.[193] The Environment Agency is leading the cross-Defra 'Restoring Meadows, Marsh and Reef' or ReMeMaRe (pronounced re-memory) initiative, which supports this restoration. The initiative aims to restore 15% of the current extent of salt marshes, seagrass beds, native oyster reefs and other marine habitats by 2043, the end of the government's 25-Year Environment Plan.[194]

Kelp

Kelp forests are among the habitats with the highest levels of primary productivity, and therefore take up significant quantities of carbon from the atmosphere.[195] Subtidal kelp forests occur along >12,000 miles of UK coastline. It has been conservatively estimated that kelp accounts for around 45% of all primary production in UK coastal waters; this almost certainly being an underestimate.[196] There is a lot of uncertainty around how much of the captured carbon ends up in long-term sediment stores and how much is re-released into the water column.[169]

Kelps act as 'ecosystem engineers', shaping their environment by creating habitat, nursery grounds and food sources, including for commercially important species such as lobster and Atlantic cod. They also alter the physical conditions around them, including light, nutrient levels and water motion. Kelp forests also contribute to coastal defence against flooding and erosion by absorbing wave energy.

Kelp forests across Europe are experiencing pressure from nutrient and sediment inputs from land use change and urbanisation, which reduce light availability. Other factors causing negative impacts include water temperature change, increased storm frequency leading to physical damage, and some fishing practices.[1] Of the 7 kelp species found around the UK, 4 are predicted to decrease, and 3 to increase in abundance or range with continued environmental change. One of those increasing is a non-native species, first recorded in 1994 on the south coast of England[197] and now dominant in some places such as Plymouth Sound. The impacts of changes to the identity, abundance or productivity of kelp species could have far-reaching consequences for wider ecosystem structure and functioning, the nature of which represent a major knowledge gap.[1]

Case study: Sussex kelp restoration project

Kelp forests once stretched 40km along the Sussex coastline but since 1987 96% has been destroyed by trawling, storm damage and other human pressures.[198] As part of the drive to fund private investment the Environment Agency and Defra have invested £79,000 in the Sussex Kelp Restoration Project (SKRP), which aims to restore the 4 km natural kelp forest in the Sussex Bay, with the possibility of restoring kelp forests across the remaining county coastline.[199]

The introduction of a 2021 Trawling Bylaw made trawling illegal in a 300km^2 area of Sussex coastal waters.[200] Studies of the seabed habitat in the 6 months after the bylaw was introduced have provided a baseline to show how the seabed recovers and changes. Findings of the SKRP predict that the kelp population will begin to recover its previous extent in 5 to 10 years.[201] Adur and Worthing Councils are set to become the first local authorities in the UK to lease the seabed off their coast from the Crown Estate in a pioneering project to invest in climate change measures and restore marine habitat. The plan is to create a Sussex Bay Marine Park, protecting marine life and providing eco-tourism opportunities.[202]

Marine plankton: state and trends

Marine plankton is a term that encompasses drifting marine organisms, including bacteria, algae and microscopic animals, as well as larger animals such as jellyfish. Marine plankton as a group are hugely diverse and have pivotal roles supporting food webs, cycling nutrients and carbon, and capturing solar energy.

Plankton communities are a good indicator of change in marine ecosystems, because they respond rapidly to environmental changes. However, it is often difficult to disentangle the different pressures behind observed changes. Many of the pressures on the coastal and marine environment may affect these communities in fundamental ways, altering the balance of different species and how they process and cycle nutrients. For example, high levels of nutrients entering estuaries and inshore coastal waters from rivers can promote excessive growth of phytoplankton. Moreover, this can change the balance of different species, with effects cascading up the food chain and on the ecosystem services they support. Climate change may also be affecting productivity and community structure of inshore phytoplankton, but the effects of nutrients around our coasts are currently larger and preventing detection of climate effects. Climate impacts are easier to detect further offshore where there is a lesser impact from nutrient inputs.

In most areas of the Celtic Seas and the Greater North Sea, phytoplankton biomass increased between the periods 2004 to 2008 and 2009 to 2014. This assessment identified increases in phytoplankton biomass and both increases and decreases in zooplankton abundance in different locations. This may have implications for the structure and functioning of the whole marine ecosystem. It was not possible to determine whether good environmental status (GEnS) had been achieved. [203]

Phytoplankton community composition in inshore waters of the Celtic Sea and Greater North Sea has changed significantly in recent decades.[203] Analysis of data from 2006 to 2020 has found that of the 12 individual estuaries and 7 coastal water bodies with enough data to assess them confidently, all but one, Great Ouse, are showing significant levels of community change.[204] This is likely to be due to changes in nutrient levels (especially the ratio between nitrogen and phosphorus). These findings suggest that it is unlikely that these waters are in GEnS.[205]

Fish: state and trends

Centuries of overfishing, alongside other pressures such as pollution, has had a lasting impact on all parts of the marine fish community.[206] An analysis of government data found that since bottom trawl catch records began in UK waters in the late 1880s, fish numbers declined so steeply that by 2007, 17 times the fishing effort was required to catch the same number of fish. This suggests that availability of bottom living fish fell by 94% during this period.[207] Historical records suggest that declines were just as steep before official catch records began, with an estimated 66% decline between 1867 and 1892.[208]

Some UK fish populations are now beginning to recover from past overfishing. However, indicators assessing the recovery of fish populations, using measures of average and maximum size and community composition show that even in places where declines have been halted or some recovery has been seen, it may take decades for some populations to meet recovery targets unless current pressure levels are reduced.[209] A lack of historical data means that it is difficult to know what the true, pre-exploitation baseline would look like.[210]

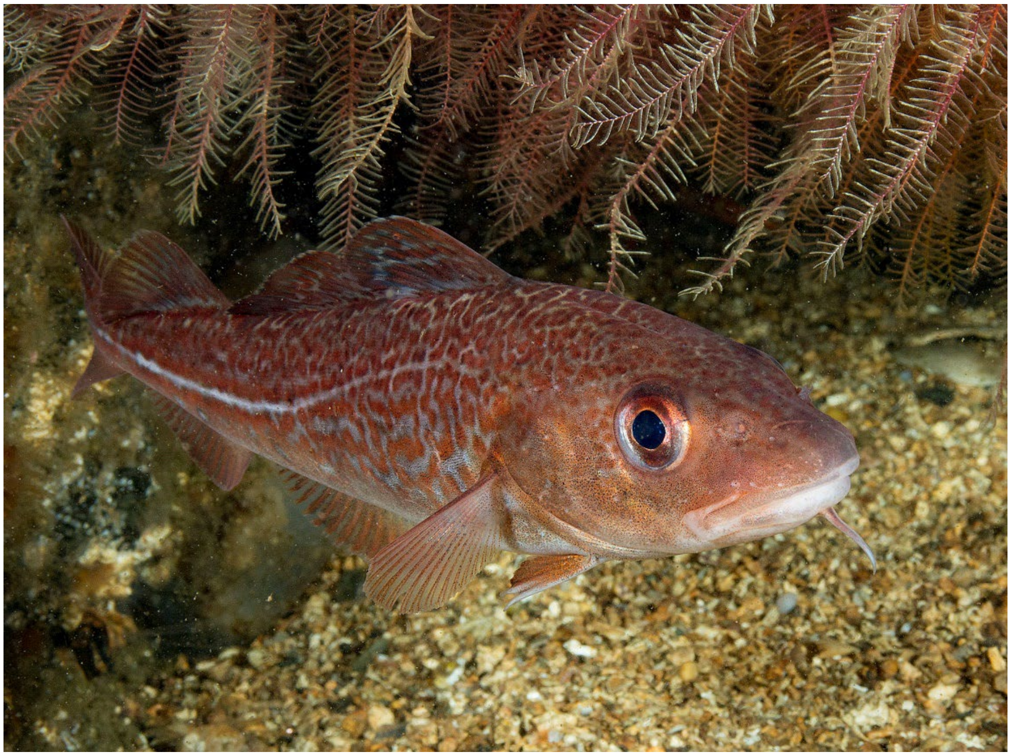


Photo 6: young cod fish, courtesy of Paul Naylor

The ‘typical length’ indicator measures the size of fish in the pelagic (open water feeding) and demersal (bottom feeding) communities. Typical length decreases under high fishing pressure.[211] A decline in this indicator has occurred for demersal fish communities in recent decades in the central and southern North Sea. Other regions show improvements, or no change over the same period. Pelagic fish communities show no long-term changes in typical length in most of the North Sea and Celtic Sea areas. Increases and decreases have been recorded in some areas within these broader regions (Figure 15).[212]

The ‘mean maximum length’ indicator reflects changes in the species composition of the fish community. If the indicator shows an increase, this means that the community is healthier and less vulnerable to additional (often fishing-related) mortality.[213] Both demersal and pelagic fish communities in the central and southern North Sea had a decreased mean maximum length in 2015 and 2016 relative to the 1980s, (Figure 16). The health of fish communities is showing signs of improvement in parts of the Celtic Seas region, and in the English Channel.[214]

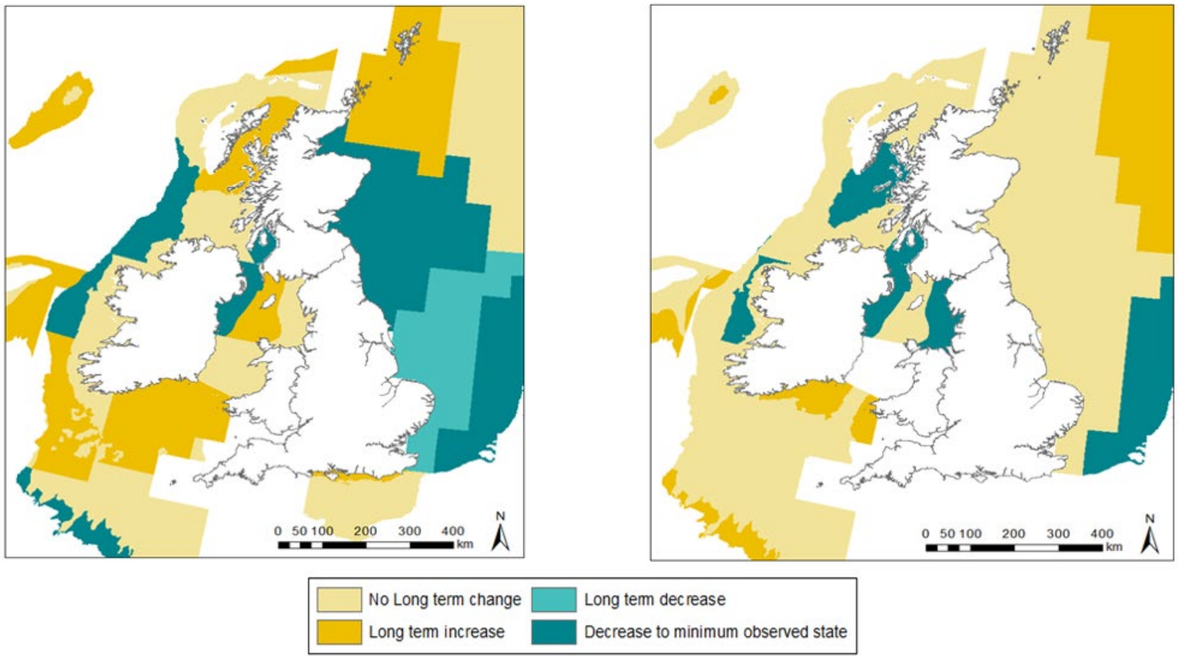


Figure 15: Long-term changes in the typical length of demersal (left) and pelagic (right) fish communities in UK waters and surrounding areas, 1980 or 1990 to 2015 or 2016. Source: Centre for Environment, Fisheries & Aquaculture Science; International Council for Exploration of the Sea; Marine Scotland.

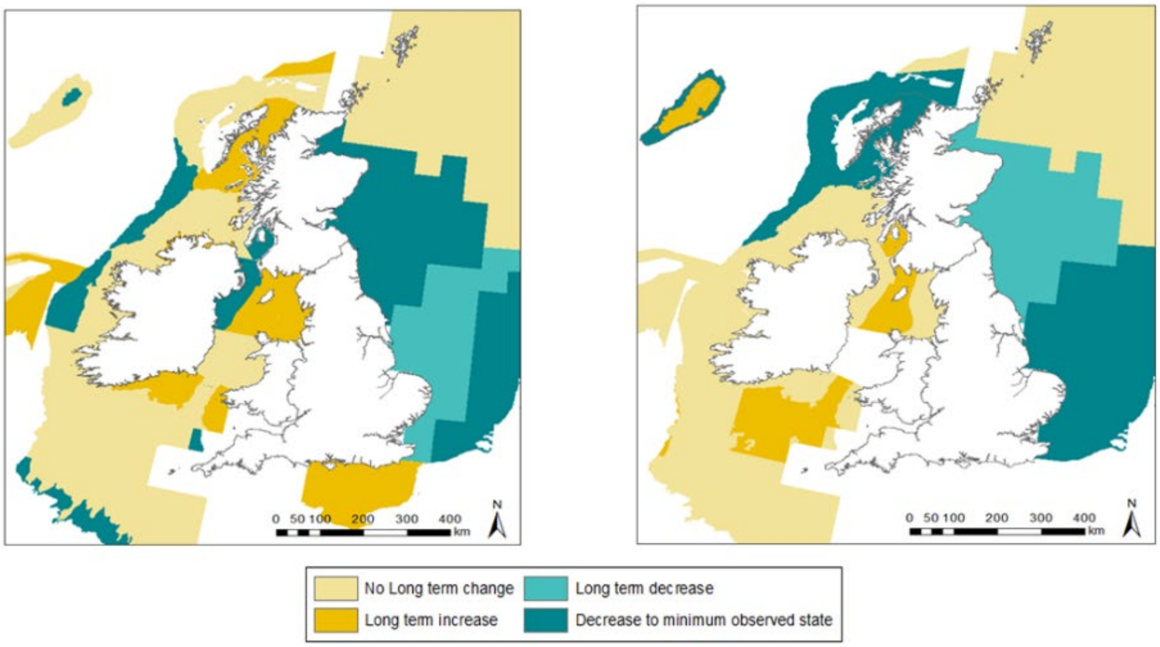


Figure 16: Long-term changes in the mean maximum length of demersal (left) and pelagic (right) fish communities in UK waters and surrounding areas, 1980 or 1990 to 2015 or 2016. Source: Centre for Environment, Fisheries & Aquaculture Science; International Council for Exploration of the Sea; Marine Scotland.

Salmon and sea trout, migratory fish species with marine life stages, have declined in England over the past 5 decades. Many English rivers recorded their lowest ever salmon numbers in 2021. Salmon are at serious risk of being lost completely from a number of river catchments.[215] Reduced marine survival is a major factor in the declines, but little is known about the relative importance of pressures experienced during this life stage. Climate change, probably combined with cyclical changes to ocean currents, has reduced feeding opportunities for salmon as waters have warmed, and the composition of zooplankton communities has changed. Problems locating food, avoiding predators, and following migration routes as acidification alters their sense of smell, are also thought to be important factors. Other influential factors are thought to include tidal barrages, artificial light at night, impingement in power station cooling waters and thermal discharges, pile-driving noise pollution, invasive non-native species, electromagnetic fields, salmon mariculture and tidal lagoons.[216]

Seabirds: state and trends

The UK is home to 25 species of breeding seabirds, including globally important populations of puffins, razorbills and kittiwakes. Even though some species have seen population increases, [217] overall, the picture for UK seabirds has deteriorated over past decades. Out of Britain and Ireland's 25 breeding seabird species, 24 have now been listed as red or amber.[218] Non-breeding waterbirds in the Greater North Sea have achieved GEnS under marine regulatory assessments, but this is not the case in the Celtic Sea. Breeding seabirds are not at GEnS in either sub-region. The percentage of species meeting abundance targets has declined significantly for all seabird categories in all assessed regions over the long and medium term, defined as from the early 1990s to mid-2010s, and from the early 2000s to mid-2010s respectively (Figure 17). There has been little or no change in percentages meeting targets for abundance for all seabird categories over the short term, measured between the late 2000s and the mid-2010s, apart from wintering waterbirds in the Celtic Seas region, which have declined.[219]

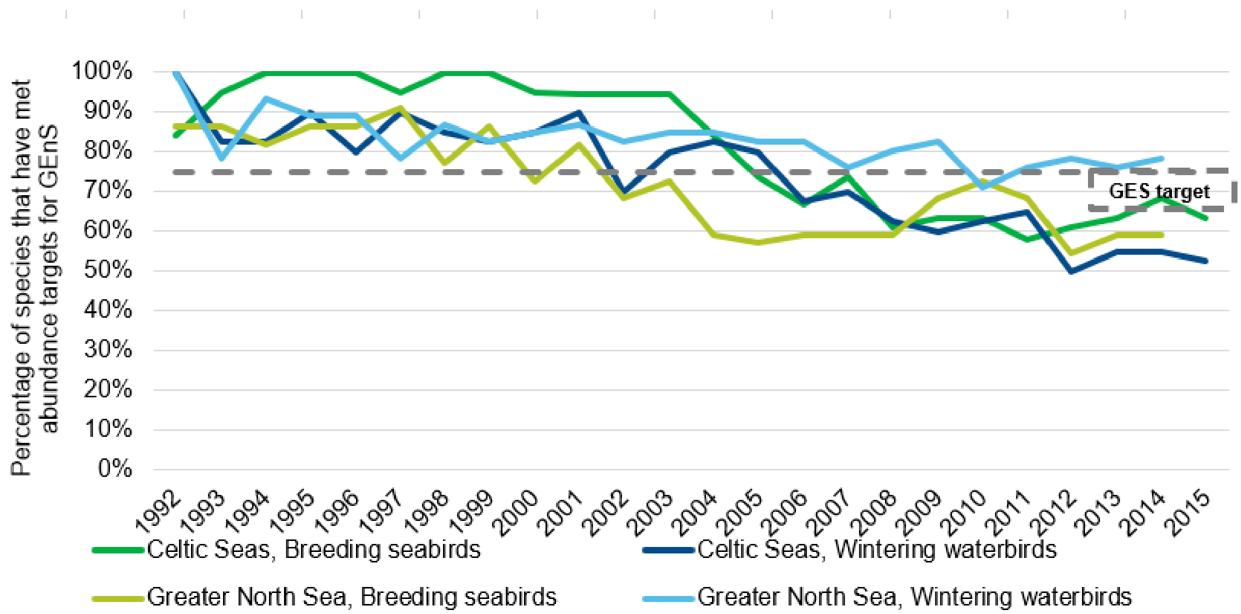


Figure 17: Percentage of seabirds at GEnS for abundance, Greater North Sea and Celtic Seas, 1992 to 2015. Data source: Department of Agriculture, Environment and Rural Affairs; Joint Nature Conservation Committee; Natural England; Natural Resources Wales; Scottish Natural Heritage.

In 2018, the breeding seabird index in the UK was 28% lower than in 1986. This is the second lowest point recorded, with the lowest point being in 2013 (at 29% lower).[220]

The causes of declines are not fully understood, but it is known that climate change is having a significant impact on some species through reductions in availability of small fish and changes to the areas the birds are choosing to feed in. There have also been large numbers of seabird deaths from avian flu in recent years. If climate change pressures continue as predicted, some seabird species, such as the great skua, may become extinct in the UK by 2100, while others will have reduced distributions.[53]

Marine mammals: state and trends

There are 37 mammal species recorded from UK seas.[221] Many species population trends are uncertain. It is difficult to assess changes in many marine mammals because, as a result of their migration routes they can cover very large areas and are affected by factors outside of surveyed areas.[222] Seals appear to be increasing in some places, but the state and trends for some whale and dolphin species are less well understood. Distributions of some species are also changing.

Cetaceans

Globally, some large cetacean species are starting to recover from past exploitation. Several pressures continue to affect numbers, including fishing bycatch, ship strikes, legacy chemicals, marine litter, and climate change. Strandings data suggest that chemicals and bycatch are major pressures on UK cetaceans.[223]

The state and trends in cetaceans in England's waters are not well understood for most species. Bottlenose dolphin and minke whale populations are considered to be consistent with GEnS in the Greater North Sea, but status is unknown for other areas, and for other cetacean species.[224] Some species of large whale, such as fin and humpback whales, are appearing more often in the southern North Sea, including UK waters, as their distributions shift.[225] Distributional changes have also been recorded in the harbour porpoise, which has shifted the centre of its range southward from northern parts of the North Sea.[226]

Seals

Seals are considered to be a good indicator of overall ecosystem health as they are near the top of food chains. However, it is not known what the undisturbed state of seal populations in the UK would look like.

The status of harbour seals in the Celtic Seas region is uncertain. They are not considered to be at GEnS in the Greater North Sea region, mainly because of declines in Scottish populations. The causes of these declines are unknown, but under investigation.[227] English populations in the north-east and south-east have increased overall since 1990, as they recover from historical hunting, pollution and overfishing pressures, although they then appeared to level off and decline between 2015 and 2021.[219] Harbour seals and, to a lesser extent, Atlantic grey seals, were also affected by the Phocine distemper virus in 1988 and again in 2002, with significant numbers lost during both outbreaks.[228]

Atlantic grey seals in both the Celtic Seas and the Greater North Sea region are at GEnS, having increased in abundance since 1990 and in the shorter-term period between 2012 and 2019.[229] Pup production, an indicator of population condition, has also increased (Figure 18).[219]

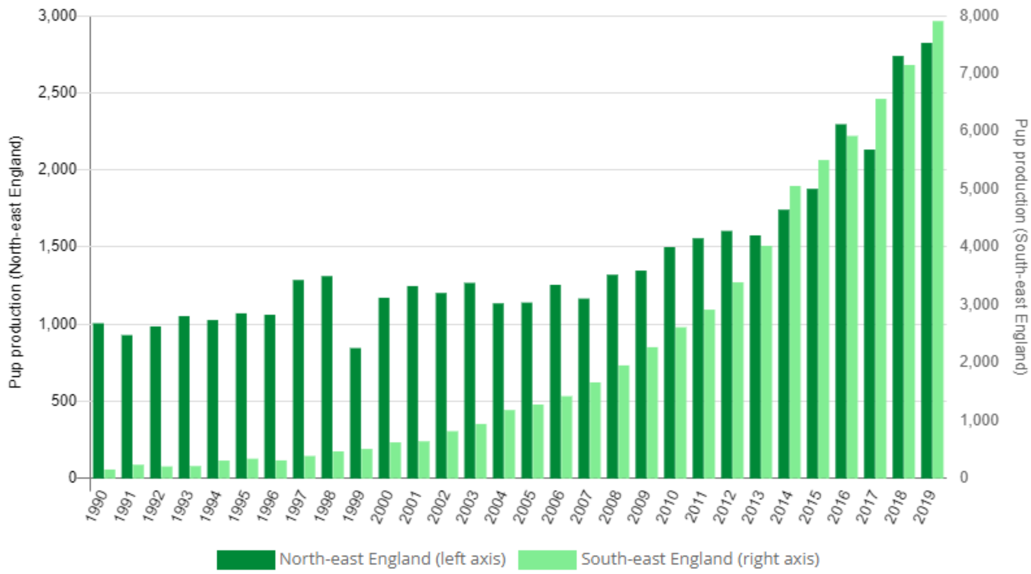


Figure 18: Atlantic grey seal pup production, 1990 to 2019. Data source: Joint Nature Conservation Committee; Seal Mammal Research Unit.

5. Emerging challenges and opportunities

5.1 Industrial expansion and net zero

The way the coastal and marine environment is used is undergoing rapid changes both globally and across the UK. Globally, increased demand for food, energy and mineral resources is leading to increased development of industries extracting these resources from offshore waters. Shipping, leisure and tourism, and desalination are among the activities that have seen rapid global acceleration over past decades.[230] Development and urbanisation of coastal areas is adding to existing pressures on these environments. In the UK, aquaculture and offshore renewable energy production are 2 sectors with the potential for rapid growth. While these industries could boost local economies, the benefits of new coastal industries do not always automatically flow down to local communities.[231] A just transition, ensuring that social or environmental inequalities or harms are not exacerbated or created, will be a vital part of efforts to reduce emissions.

Aquaculture

Global demand for fish products is increasing as the population grows and per capita consumption rises. Expansion of aquaculture will meet some of the extra demand.[232] England's aquaculture sector produced around 8,000 tonnes in 2020, including salmon and trout farming. This is less than one-tenth of the tonnage of wild caught fish landed in England by UK vessels in 2021.[19] One third of production volume is shellfish worth approximately £26 million a year. The aquaculture sector is aiming to diversify, and to increase production volume by 10 times to approximately 90,000 tonnes by 2040, compared with 2020 figures. Species dominating the proposed expansion, other than salmon and trout, include mussels, oysters and seaweeds.[233]

The environmental impacts of aquaculture are mainly but not exclusively related to fish farming. Impacts can include spreading of diseases and parasites to wild populations, pollution of the sea bed by faecal material affecting biodiversity, and release of nutrients and pharmaceuticals, affecting phytoplankton and other wildlife.[234]

Seaweed cultivation currently takes place on a very small scale, but could expand as its uses, including in food, supplements, fibres and even bioplastics and fuels, are increasingly recognised. [235] More research is needed to assess the potential environmental impacts and risks of large-scale seaweed farming, including spreading of diseases to-, and changes to the genetic make-up of, surrounding seaweed populations.[236] Potential benefits include carbon sequestration, and creation of nursery habitat for fish.

The expansion of marine aquaculture in England will depend, at least in part, on good land management practices, as its viability is sensitive to pollution from land into coastal and estuarine waters.[237]

Renewable energy and carbon capture, usage and storage (CCUS)

Renewable energy industries, particularly offshore wind, will grow over the coming decades, as efforts to reduce carbon emissions continue. The UK government has ambitions to greatly expand the offshore wind industry, aiming to generate up to 50 gigawatts (GW) by 2030.[238] Other renewables industries such as wave and tidal power are less developed but could have positive and negative environmental impacts. For example, their effect on waves can affect the feeding of fish and coastal bird species.[239] Positive impacts can include the creation of new habitats, and protection of sensitive habitats from bottom trawling activity.

Decarbonising existing industries is also crucial for achieving net zero targets. The government plans to facilitate CCUS in 4 of England's industrial regions, Teeside, Humberside, Southampton, and Merseyside, capturing up to 10Mt of carbon per year. Environmental impacts on estuarine, coastal and marine environments could include habitat loss from onshore and offshore infrastructure, and noise pollution and disturbance of sediments during construction and laying of pipelines. The availability of CCUS in these regions may also attract further industrial development, bringing additional associated pressures.

5.2 Adapting to current and future coastal change

Climate change is causing rapid physical changes to the coastline, with sea level rise and increased flood and erosion risk threatening coastal habitats, ecosystems and communities. Decisions will need to be made by a wide range of stakeholders and interested parties about where coastal land, habitats and communities can and should be protected, and where a more adaptive approach is needed, working with natural processes as the coastline adjusts to the changing climate and its impacts.

Nature-based solutions, such as making space for water away from vulnerable properties or infrastructure, beach replenishment, and creating or restoring coastal habitats such as salt marsh to reduce the impact of storm surges will play an important role in coastal flood risk management.[119] Restoring connectivity between habitats in the seascape will be vital in maximising the benefits of such approaches. For example, efforts to restore natural beach and dune connectivity as part of dune restoration will improve climate resilience, as well as dune biodiversity.[240] Nature-based solutions will not be feasible in some places because of previous land-use decisions, such as where historic landfill sites are at risk of eroding into the sea if they are not defended.

Understanding how climate change will affect the coastline, and how this might vary from place to place, is essential for preparing for and adapting to future conditions. Locating coastal erosion hotspots will help in planning adaptive measures with affected coastal communities. There is also evidence that sea level rise is affecting tidal ranges, with both increases and decreases occurring in different locations. These changes and their impacts are only beginning to be understood. As knowledge increases, this will alter current projections of coastal and estuarine habitat change and affect plans for how communities adapt to future conditions.[241]

Case study: Sandscaping to protect Bacton Gas Terminal

The coast of north Norfolk has been eroding naturally for thousands of years but climate change, leading to more extreme weather events and sea level rise, has accelerated the process. Flooding and erosion have affected local homes and businesses. Bacton Gas Terminal had become close to the cliff edge, threatening its viability, as had the villages of Bacton and Walcott nearby.

In 2019, the Environment Agency worked with North Norfolk District Council and other partners to place around 1.8 million cubic metres of sand in front of the terminal which, through natural longshore sediment drift, would protect not only the terminal itself but also a 6 km section of the coast from erosion.[242] This was the first time this approach had been used at such a scale in the UK, and subsequent changes to the foreshore have been monitored over a 3-year period, since construction. During this time there have been a few severe storms, during which, without the additional sand, the waves would have reached the cliffs.

The Environment Agency contributed £5 million towards the total cost of £20 million for this project, while the majority of the remainder came from the gas terminal’s operator, because of the risk to the terminal. It is estimated that this sandscape scheme will last for around 15 years, enabling the gas terminal to operate for its current design life, and the nearby villages to better prepare for future adaptation to coastal change.[243] Funding, among other factors, will determine whether similar approaches are used at other sites.

Photo 7: The Bacton to Walcott sandscaping scheme in progress. Photo credit: Chris Taylor/North Norfolk District Council.

5.3 Benefits of coastal and marine recovery

A cleaner, healthier coastal and marine environment, with restored ecosystem structure and function, would increase provision of ecosystem services, benefitting human health, wellbeing and prosperity. Restored and resilient coastal and marine ecosystems also contribute to global goals for biodiversity enhancement and carbon reduction. The UK leads the Global Ocean Alliance of 73 countries committed to marine conservation actions, including the 30 by 30 target of protecting 30% of the world's ocean by 2030.[244] The UK government has set a range of national targets relating to coastal and marine ecosystems, in its 25-Year Environment Plan. These include commitments to reversing biodiversity loss, bringing fish stocks back to sustainable levels, and reducing pollution from chemicals and harmful bacteria.[245] New pressures, including emerging pollutants, and the increasing use of the coastal and marine environment for net zero solutions including renewables and carbon capture, utilisation and storage (CCUS) increase the complexity of these challenges.

There are significant opportunities in coastal areas to use nature-based solutions to help address the joint nature and climate crises, by protecting, creating and restoring habitats that sequester and store blue carbon. Although this will be a small part of the overall picture of emissions reductions and carbon removal needed to prevent catastrophic climate change, the multiple benefits gained from these habitats mean that they are an important and valuable part of the solution.[246] For example, protecting seabed habitats by creating well managed and regulated Marine Protected Areas (MPAs) also benefits many fish stocks, helping coastal communities thrive.[247] The fishing industry must be managed sustainably, and adapt to climate change impacts such as acidification and storms. Healthy fish stocks also give wildlife, such as seabirds that rely on fish, a better chance of coping with multiple pressures. Ocean recovery has been described in one study as a 'grand challenge for science and society', achievable over coming decades, but only if action is taken without delay. The study estimated that the economic return from the actions needed would be around US$10 for every US$1 invested, and that over one million new jobs would be created.[248]

At the national level, one study modelled the economic benefits of investing in greater coastal and marine habitat restoration, protecting a third of UK seas, supporting net zero climate actions, and improving the sustainability of fisheries. Results of the models showed benefits to the economy of at least £50 billion by 2050 compared with a 'business as usual' scenario, and the creation of over 100,000 full-time jobs.[249]

Photo 8: Atlantic grey seal among underwater kelp.

5.4 Creating change, working together

The challenges of protecting and restoring coastal and marine ecosystems are complex and difficult to address. Much can be achieved, however, by working together, with the right targets and legislation in place, and engagement and commitment at all levels. Public participation is an important part of government decision-making for marine spatial planning and river basin management plans.

Marine spatial planning is a method to allocate human activities in marine areas to balance development with the need to protect the environment in a coordinated and open way. River basin management plans describe the challenges that threaten the water environment and how these challenges can be better managed through measures to achieve good water status. In recognition of the complex challenges facing England's coastal and marine environments, the Environment Agency, the Marine Management Organisation, Natural England and the Inshore Fisheries and Conservation Authorities have set up the 'Championing Coastal Coordination' initiative. The initiative aims to enhance and progress coordination for coastal sustainability and resilience in England, including inputs from both public and private sector interests.[250]

Other initiatives such as designating areas as national or international reserves and parks increase public understanding and allow greater engagement in environmental management and protection. For example, the North Devon UNESCO biosphere reserve is a successful partnership, bringing residents, landowners, businesses and a range of other stakeholder groups together to participate in improving and protecting their environment, including coastal and marine areas. The North Devon UNESCO biosphere was part of a programme of projects (which also included the Suffolk Coast and Heaths Area of Outstanding Natural Beauty), known as the Defra Marine pioneer.[251] The Pioneer projects provided a framework to improve knowledge of the marine system, including social and economic aspects, and to link up policy with local planning and delivery as well as highlighting the need for strong governance. This knowledge was then fed back into updating and tracking progress on the government's 25-Year Environment Plan.[245] The Marine pioneer was supported nationally by the Marine Management Organisation and implemented locally by the Marine Pioneer Steering Group.

Projects included:

- assessment of the current extent and state of natural assets and the ecosystem services they provide
- creation of fisheries research and management plans
- trialling of an autonomous plastic waste collecting robot ('wasteshark') that also maps and records marine data

- study of existing and potential salt marsh sites, to maximise the wider benefits gained from habitat creation
- using the natural capital approach to support decision-making on natural flood defence

National Marine Parks are another way to link ecologically important and protected seascapes with human culture, increasing public engagement and improving co-ordinated management. The first in the UK, in Plymouth, was created in 2019 by Plymouth City Council and over 70 other groups. The park covers an area of 400 square km. Local residents are involved in shaping the park's future and understanding marine protection through education, exploration and employment. A programme of events took place in 2022 to encourage local people to get in, on and under the water. A 'Digital Park in the Sea' combines innovation labs and webcams for an on land immersive experience and offers a space for ideas, testing and creativity. The Blue Marine foundation, a non-governmental organisation (NGO), has set out a vision of creating 10 National Marine Parks over the next 10 years.[252] Plymouth Sound National Marine Park is a pioneering example of how these could succeed.

6. Conclusions

Human activity over centuries has degraded England's coastal and marine environment. The combined impact of climate change, land use change, growing population and continuing development pressure all threaten the status and recovery of these ecosystems and the services they provide. Overexploitation of fish stocks has depleted populations, only some of which are now beginning to recover, and some of which are still unsustainably fished. This has had ongoing impacts on other species through the coastal and marine food web. Climate change is creating new risks and continues to exacerbate existing pressures. The threat posed by climate change to ocean regulatory functions, including the increasing risk of crossing major tipping points, should not be underestimated. A timely and proportionate response in reducing greenhouse gas (GHG) emissions will reduce some of the risks.

Strong regulation of industrial discharges, and improvements in waste-water treatment over past decades have, in many respects, meant cleaner, safer coastal waters. However with the growing pressures of climate change and population growth, it is becoming more challenging to maintain some achievements, and some gains are at risk of being reversed. Improvements are needed in land-based activities such as agriculture to address increasing pressures from upstream areas of catchments.

There has been destruction and degradation of coastal habitats, and widespread physical modification of estuaries from construction of infrastructure and flood defences. This has delivered great value to society but in turn has damaged the ability of the coast to protect people and communities, infrastructure and the environment from the effects of flooding and erosion. In the future pressures must be managed using a systems approach, whereby combined impacts and interdependencies are taken into account. As part of this, trade-offs between different beneficiaries need to be understood and communicated. This approach supports sustainable management that maximises the benefits of our marine environment to all users. It considers connections between inland environments and the wider catchments and habitats in the seascape. The increase in salt marsh area seen in recent years, some of which was created as part of flood management schemes, demonstrates what can be achieved by working collaboratively with a range of users of the water environment. Habitat protection, restoration and recovery efforts such as this have clearly demonstrated the multiple benefits that flow from working with nature.

Chemical pollution is increasingly understood to be affecting coastal and marine life, with repercussions for entire ecosystems. The growing global market for chemicals, and accelerating production of new substances is an enormous challenge for governments and regulators. Individuals can make a difference, including through choices about what and how much they buy and use. Better consumer information on chemicals in products, and how to dispose of them, will enable these decisions.

Plastic pollution is an increasing issue for coastal and marine water quality and affects wildlife, as well as blocking sewers and increasing the risk of sewage spills. Individuals can help improve the water environment by implementing and sharing their knowledge about plastic pollution and ‘unflushables’ such as wet wipes.[253]

There is much to be gained from recognising the importance of the coast and ocean for human wellbeing and prosperity. Cleaner, more biodiverse coasts, estuaries and seas are more productive and more resilient, supporting and protecting communities. It is clear from this report that the environment of our estuaries, coasts and seas are diminished. Improvements are still within reach but require strong governance and action at all levels of civil, private and public sectors to honour commitments made, and to turn the situation around.

Glossary

Bottom trawling

A fishing technique that uses a cone-like net with a closed end that holds the catch. These nets are towed by one or two boats and are designed to catch fish living deep or on the bottom of the sea.

Carbon capture, usage and storage (CCUS)

The process of capturing carbon dioxide before it enters the atmosphere. The captured carbon dioxide is then used, and any unused carbon is stored.

Carbon sequestration

The capture of CO_2 from the atmosphere into biological or geological carbon sinks, such as forests, soils or the ocean.

Coastal squeeze

The deterioration of quality or loss of natural habitats on the seaward side of man-made structures, preventing the otherwise naturally occurring landward movement of habitats in response to sea level rise.

Continental shelf

The shallow submerged edge of a continental landmass and extending to depths of around 100 to 200 metres.

Cetaceans

All species of dolphins, porpoises and whales.

Ecosystem services

Ecological functions or processes that provide valuable services to people. These can be classified as supporting, provisioning, regulating or cultural services. Examples are biodiversity maintenance, food, climate regulation and aesthetic appreciation.

Eutrophication

Nutrient over-enrichment of water, such as by nitrogen or phosphorus, causing a decline in water quality and problematic levels of algal growth. Hypoxia (or oxygen depletion) and harmful algal blooms are 2 of the most acute potential symptoms.

Functionally extinct

Species can be considered functionally extinct when their populations get so small that they are either unable to fulfil their previous role in the ecosystem or are expected to be unable to sustain the population's reproductive viability.

Good ecological status (GES)

Ecological status of water bodies is assigned by various water, habitat and biological tests. Using a 'one-out, all-out' rule means that if any of the individual tests fail, then the whole water body fails.

Good environmental status (GEnS)

A set of descriptors under the UK Marine Strategy Regulations, that set out the environmental conditions that would need to be met to protect and preserve the marine environment, prevent its deterioration or, where practicable, restore marine ecosystems in areas where they have been adversely affected; and to prevent and reduce inputs in the marine environment, with a view to phasing out pollution, so as to ensure that there are no significant impacts on, or risks to, marine biodiversity, marine ecosystems, human health or legitimate uses of the sea.

Hard defences

Coastal protection schemes, such as sea walls and groynes.

Hypoxia, or hypoxic events

A low level of oxygen, primarily a problem for estuaries and coastal waters.

Inshore

Inshore waters are those extending up to 12 nautical miles (nm) from the coast.

Intertidal

Refers to the zone of the shore that lies between the high-water mark and the low water mark.

Legacy chemicals/metals

Legacy chemicals, including metals, are those that have been tightly controlled for many years, but which remain at high levels in the environment.

Macroalgae

Algae species that are visible without a microscope, including seaweeds.

Mariculture

The farming of marine organisms for food and other products such as pharmaceuticals, food additives, either in the natural marine environment, or in land- or sea-based enclosures.

Marine Protected Area (MPA)

Geographical areas of the marine environment established and managed to achieve long-term nature conservation and sustainable use Part of the UK’s commitment to protecting its seas and associated benefits to society for future generations.

Maximum sustainable yield

Fishing at the maximum sustainable yield (MSY) level aims to catch the maximum quantity of fish that can safely be removed from the stock, while maintaining its capacity to produce sustainable yields in the long term.

Natural capital

The elements of nature that directly or indirectly produce value, including ecosystems, species, freshwater, land, minerals, the air and ocean, as well as natural processes and functions.

Natural capital approach

Applying the concept of natural capital to inform decision-making.

Offshore

Away from the shoreline. Refers largely to the expanse of submerged continental shelf on the ocean side of the shoreline, but may also refer to areas nearer the ocean edge of the shelf.

Pathogen

An organism such as a virus or bacterium that causes disease to its host.

Phytoplankton

Single-celled algae that inhabit the water column. They are primary producers, harvesting light energy from the Sun to produce food which gets passed up through the marine food web.

Pelagic

The pelagic zone consists of the entire water column of the open ocean.

Priority substance

Chemicals identified under Water Framework Directive regulations as those posing the greatest risk to people and wildlife.

Ramsar

Ramsar Sites are wetlands of international importance that have been designated under the criteria of the Ramsar Convention on Wetlands for containing representative, rare or unique wetland types or for their importance in conserving biological diversity.

Seascape

Mosaics of connected and interacting coastal and marine habitats, including both intertidal and subtidal habitats.

Shelf seas

Relatively shallow water covering the shelf of continents or around islands. The limit of shelf seas is conventionally considered as 200m water depth at the continental shelf edge, where there is usually a steep slope to the deep ocean floor.

Stratification

Stratification is a term used to describe 2 distinct layers occupying the vertical water column in the sea: the near-surface layer is less dense than the near-bed layer. This can be because of differences in temperature, salinity, or both.

Subtidal

Subtidal relates to the region below the level of low tide, that is always underwater.

Vibrio bacteria

Vibrio bacteria naturally live in certain coastal waters and are present in higher concentrations between May and October when water temperatures are warmer.

Zooplankton

Zooplankton are small, aquatic microorganisms in the water column. The zooplankton community is composed of both primary consumers, which eat free-floating phytoplankton, and secondary consumers, which feed on other zooplankton.

References

[1] Smale, D. A. et al. (2013). Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. Ecology and Evolution 3: 4016-4038 https://doi.org/10.1002/ece3.774 [Accessed 8 December 2022].

[2]European Commission. 2013. Coastal regions: population statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Coastal_regions_-_population_statistics

[3] Elliott, L.R. et al. 2018. Recreational visits to marine and coastal environments in England: Where, what, who, why, and when? Marine Policy 97: 305-314 https://doi.org/10.1016/j.marpol.2018.03.013 [Accessed 8 December 2022].

[4] Environment Agency. 2021. State of the environment: health, people and the environment. Available from: https://www.gov.uk/government/publications/state-of-the-environment/state-of-the-environment-health-people-and-the-environment [Accessed 8 December 2022].

[5] RSPB. 2022. A bid to make the UK's wild bird superhighway a new World Heritage Site. A bid to make the UK's wild bird superhighway a new World Heritage site - RSPB England - Our work - The RSPB Community [Accessed 3 January 2023].

[6] Thornton, D. C. O. et al. 2007. Sediment–water inorganic nutrient exchange and nitrogen budgets in the Colne Estuary, UK. Marine Ecology Progress Series 337:63-77 https://www.int-res.com/abstracts/meps/v337/p63-77/ [Accessed 8 December 2022].

[7] Laffoley, D. et al. 2020. Evolving the narrative for protecting a rapidly changing ocean, post-COVID-19. Aquatic Conservation 31:1512-1534. https://doi.org/10.1002/aqc.3512 [Accessed 8 December 2022].

[8] Zanna, L. et al. 2019. Global reconstruction of historical ocean heat storage and transport. PNAS 116:1126-1131 https://doi.org/10.1073/pnas.1808838115 [Accessed 8 December 2022].

[9] Watson, A.J. et al. 2020. Revised estimates of ocean-atmosphere CO_2 flux are consistent with ocean carbon inventory. *Nature Communications* 11, 4422. https://doi.org/10.1038/s41467-020-18203-3 [Accessed 8 December 2022].

[10] NOAA. [online]. How much oxygen comes from the ocean. https://oceanservice.noaa.gov/facts/ocean-oxygen.html [Accessed 8 December 2022].

[11] Parker, R. et al. 2021. Carbon stocks and accumulation analysis for Secretary of State (SoS) region, Cefas Report for Defra project ME5439. Available from: https://randd.defra.gov.uk/ProjectDetails?ProjectId=20754 [Accessed 8 December 2022].

[12] Atwood, T. B. et al. 2020. Global patterns in marine sediment carbon stocks. Frontiers in Marine Science https://www.frontiersin.org/articles/10.3389/fmars.2020.00165 [Accessed 8 December 2022].

[13] ONS. 2021. Marine accounts, natural capital, UK, 2021. Section 2. Marine habitats. https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/marineaccountsnaturalcapitaluk/2021 [Accessed 8 December 2022].

[14] Watson, S. C. L. et al. 2020. Assessing the natural capital value of water quality and climate regulation in temperate marine systems using a EUNIS biotope classification approach. Science of The Total Environment 744: 140688. https://doi.org/10.1016/j.scitotenv.2020.140688 [Accessed 8 December 2022].

[15] Bateman, I. J. et al. 2011. Economic values from ecosystems. In: UK National Ecosystem Assessment Understanding nature's value to society. UK National Ecosystem Assessment. http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=zeBWV7obaV0%3d&tabid=82

[16] Reed, M. et al. 2011. The social impacts of England's inshore fishing industry: final report. DEFRA, London. https://eprints.glos.ac.uk/2630/ [Accessed 8 December 2022].

[17] Simmonds, E. J. 2007. Comparison of two periods of North Sea herring stock management: success, failure, and monetary value, ICES Journal of Marine Science, Volume 64, Issue 4, May 2007, Pages 686–692, https://doi.org/10.1093/icesjms/fsm045 [Accessed 8 December 2022].

[18] Cook, R., et al. 1997. Potential collapse of North Sea cod stocks. Nature 385: 521–522 https://doi.org/10.1038/385521a0 [Accessed 8 December 2022].

[19] Marine Management Organisation. 2021. National statistics, UK sea fisheries annual statistics report. https://www.gov.uk/government/statistics/uk-sea-fisheries-annual-statistics-report-2021 [Accessed 10 Oct 2022]

[20] Rowland, T.H. 1994. cited in: Christy, D. et al. 2021. Fishing against the odds: fishers' motivations to carry on fishing in the wake of the hindering EU Common Fishery Policy - a case study in North Shields, UK. Maritime Studies 20:175–187 https://doi.org/10.1007/s40152-021-00227-0 [Accessed 8 December 2022].

[21] Brookfield, K et al. 2005. The concept of fisheries-dependent communities: A comparative analysis of four UK case studies: Shetland, Peterhead, North Shields and Lowestoft. https://doi.org/10.1016/j.fishres.2004.10.010 [Accessed 13 Sep 2022]

[22] Christy, D. et al. 2021. Fishing against the odds: fishers' motivations to carry on fishing in the wake of the hindering EU Common Fishery Policy—a case study in North Shields, UK. Maritime Studies 20:175–187 https://doi.org/10.1007/s40152-021-00227-0 [Accessed 8 December 2022].

[23] IPBES. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, et al. (eds.). IPBES secretariat, Bonn, Germany. 56 pages. ipbes_global_assessment_report_summary_for_policymakers_en.pdf

[24] Nedwell, D. B. et al. 2002. Variations of the Nutrients Loads to the Mainland U.K. Estuaries: Correlation with Catchment Areas, Urbanization and Coastal Eutrophication. Estuarine, Coastal and Shelf Science 54:951-970 https://doi.org/10.1006/ecss.2001.0867 [Accessed 8 December 2022].

[25] The Crown Estate. 2021. Marine aggregates capability and portfolio 2021. Available from: https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/minerals-dredging/ [Accessed 8 December 2022].

[26] Tillin, H. M. et al. in Todd, Todd, V. L. G. et al. 2015. A review of impacts of marine dredging activities on marine mammals. ICES Journal of Marine Science 72: 328–340, https://doi.org/10.1093/icesjms/fsu187 [Accessed 8 December 2022].

[27] CEFAS. Date unknown. ME1101 Development of Approaches, Tools and Guidelines for the Assessment of the Environmental Impact of Navigational Dredging in Estuaries and Coastal Waters: Literature Review of Dredging Activities: Impacts, Monitoring and Mitigation. http://randd.defra.gov.uk/ http://randd.defra.gov.uk/Document.aspx?Document=10507_Literaturereviewofenvironmentalimpactsofnavigationaldredgingfinal.docx [Accessed 8 December 2022].

[28] Atterby, A. et al. 2021. Natural England and JNCC guidance on key sensitivities of habitats and Marine Protected Areas in English waters to aggregate resource extraction. JNCC report no. 694. https://data.jncc.gov.uk/data/6e02f22c-846f-400b-80a4-38f549e52c00/JNCC-Report-694-FINAL-WEB.pdf [Accessed 8 December 2022].

[29] Todd, V. L. G. et al. 2015. A review of impacts of marine dredging activities on marine mammals. ICES Journal of Marine Science 72: 328–340, https://doi.org/10.1093/icesjms/fsu187 [Accessed 8 December 2022].

[30] Manning, W.D., Scott, C.R and Leegwater. E. (eds). 2021. Restoring Estuarine and Coastal Habitats with Dredged Sediment: A Handbook. Environment Agency, Bristol, UK. https://catchmentbasedapproach.org/wp-content/uploads/2021/10/Restoring-Estuarine-and-Coastal-Habitats-with-Dredged-Sediment.pdf [Accessed 8 December 2022].

[31] Department for Transport. 2021. National statistics: Port freight annual statistics: 2020. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1014546/port-freight-annual-statistics-2020.pdf [Accessed 8 December 2022].

[32] Jägerbrand, A. K. et al. 2019. A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. Science of The Total Environment 695:133637. https://doi.org/10.1016/j.scitotenv.2019.133637 [Accessed 8 December 2022].

[33] Air Quality Expert Group. 2017. Impacts of shipping on UK air quality. London: Department for Environment, Food and Rural Affairs. Available from: https://uk-air.defra.gov.uk/library/index [Accessed 8 December 2022].

[34] The International Council on Clean Transportation. 2021. Global scrubber washwater discharges under IMOs 2020 fuel sulfur limit. https://theicct.org/wp-content/uploads/2021/06/scrubber-discharges-Apr2021.pdf [Accessed 8 December 2022].

[35] UK Parliamentary Office of Science and Technology. 2022. POSTnote: International shipping and emissions. https://post.parliament.uk/research-briefings/post-pn-0665/ [Accessed 8 December 2022].

[36] International Maritime Organization. 2021. Fourth IMO Greenhouse Gas Study. Available from: https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx [Accessed 8 December 2022].

[37] House of Commons library. 2022. Research briefing: UK fisheries statistics. https://commonslibrary.parliament.uk/research-briefings/sn02788/ [Accessed 8 December 2022].

[38] Roberts, C. 2012. Ocean of life. London: Penguin books. ISBN 9780241950708

[39] Juniper, T. 2015. What nature does for Britain. London: Profile books. ISBN 9781781253281

[40] FAO. 2022. The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. https://doi.org/10.4060/cc0461en [Accessed 8 December 2022].

[41] Epstein, G. and Roberts, C.M. 2022. Identifying priority areas to manage mobile bottom fishing on seabed carbon in the UK. PLOS Clim 1:e0000059. https://doi.org/10.1371/journal.pclm.0000059 [Accessed 8 December 2022].

[42] Hiddink, J. G. 2017. Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. PNAS 114:8301-8306 https://doi.org/10.1073/pnas.1618858114 [Accessed 8 December 2022].

[43] EEA. 2017. State of Europe's seas. https://www.eea.europa.eu/publications/state-of-europes-seas https://www.eea.europa.eu/publications/state-of-europes-seas [Accessed 8 December 2022].

[44] Richardson, K. et al. 2019. Building evidence around ghost gear: Global trends and analysis for sustainable solutions at scale. Marine Pollution Bulletin 138: 222-229 https://doi.org/10.1016/j.marpolbul.2018.11.031 [Accessed 8 December 2022].

[45] ONS. 2021. Wind energy in the UK: June 2021. https://www.ons.gov.uk/economy/environmentalaccounts/articles/windenergyintheuk/june2021 [Accessed 8 December 2022].

[46] NOAA. 2009. Guidelines on Best Environmental Practice (BEP) in Cable Laying and Operation. http://www.gc.noaa.gov/documents/2017/12-02e_agreement_cables_guidelines.pdf [Accessed 8 December 2022].

[47] Taormina, B. et al. 2018. A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions. Renewable and Sustainable Energy Reviews 96:380-391 https://doi.org/10.1016/j.rser.2018.07.026 [Accessed 8 December 2022].

[48] Klimley, A. P. et al. 2021. A call to assess the impacts of electromagnetic fields from subsea cables on the movement ecology of marine migrants. Conservation science and practice 3: e436 https://doi.org/10.1111/csp2.436 [Accessed 8 December 2022].

[49] Gușatu, L.F. et al. 2021. Spatial and temporal analysis of cumulative environmental effects of offshore wind farms in the North Sea basin. Sci Rep 11:10125 https://doi.org/10.1038/s41598-021-89537-1 [Accessed 8 December 2022].

[50] Hooper, T. et al. 2017. The implications of energy systems for ecosystem services: A detailed case study of offshore wind. Renewable and Sustainable Energy Reviews 70: 230-241 https://doi.org/10.1016/j.rser.2016.11.248 [Accessed 8 December 2022].

[51] IPCC. 2022. Summary for Policymakers [Pörtner, H.-O. et al. (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Pörtner, H.-O. et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. https://www.ipcc.ch/report/ar6/wg2/ [Accessed 8 December 2022].

[52] Watts, G. and Anderson M (eds). 2016. Water Climate Change Impacts Report Card 2016 edition. Living With Environmental Change. https://www.ukri.org/wp-content/uploads/2021/12/091221-NERC-LWEC-WaterClimateChangeImpacts-ReportCard2016.pdf [Accessed 8 December 2022].

[53] Berry, P. and Brown, I. 2021. Chapter 3: Natural Environment and Assets. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London. CCRA3-Chapter-3-FINAL.pdf (ukclimaterisk.org) [Accessed 8 December 2022].

[54] Cheng, L. et al. 2022. Another Record: Ocean Warming Continues through 2021 despite La Niña Conditions. Adv. Atmos. Sci. https://doi.org/10.1007/s00376-022-1461-3 [Accessed 8 December 2022].

[55] MCCIP. [Online]. Report card: temperature. Marine Climate Change Impacts Partnership. https://www.mccip.org.uk/temperature [Accessed 8 December 2022].

[56] MCCIP. [Online]. Ecosystem change. https://www.mccip.org.uk/all-uk/uk-impacts/hub/ecosystem-change [Accessed 8 December 2022].

[57] Boyce, D.G. et al. 2022. A climate risk index for marine life. Nature Climate Change. https://doi.org/10.1038/s41558-022-01437-y [Accessed 8 December 2022].

[58] Brown, A. R. et al. 2022. Harmful Algal Blooms and their impacts on shellfish mariculture follow regionally distinct patterns of water circulation in the western English Channel during the 2018 heatwave. Harmful Algae 111:102166 https://doi.org/10.1016/j.hal.2021.102166 [Accessed 8 December 2022].

[59] Bresnan, E. et al. 2020. Impacts of climate change on human health, HABs and bathing waters, relevant to the coastal and marine environment around the UK. MCCIP Science Review 2020, 521–545 https://www.mccip.org.uk/harmful-species

[60] Laffoley, D. and Baxter, J. M. (Eds.). 2019. Ocean deoxygenation: Everyone's problem - Causes, impacts, consequences and solutions. Full report. Gland, Switzerland: IUCN. Available from: https://portals.iucn.org/library/search/node/deoxygenation [Accessed 8 December 2022].

[61] MCCIP. [Online]. Report card: oxygen. https://www.mccip.org.uk/oxygen [Accessed 8 December 2022].

[62] Sampaio, E. et al. 2021. Impacts of hypoxic events surpass those of future ocean warming and acidification. Nature Ecology & Evolution 5:311-321. https://doi.org/10.1038/s41559-020-01370-3 [Accessed 8 December 2022].

[63] Smale, D.A. et al. 2019. Marine heatwaves threaten global biodiversity and the provision of ecosystem services. Nature Climate Change 9: 306–312. https://doi.org/10.1038/s41558-019-0412-1 [Accessed 8 December 2022].

[64] McCarthy, G. D. et al. 2020. Effects of climate change on the Atlantic Heat Conveyor relevant to the UK. MCCIP Science Review 2020, 190–207. Available from: https://www.mccip.org.uk/atlantic-meridional-overturning-circulation-amoc [Accessed 8 December 2022].

[65] EEA. [online]. Ocean acidification. https://www.eea.europa.eu/ims/ocean-acidification [Accessed 8 December 2022].

[66] CEFAS. [Online]. pH and ocean acidification. UK Marine Online Assessment Tool, available at: https://moat.cefas.co.uk/ocean-processes-and-climate/ocean-acidification/ [Accessed 8 December 2022].

[67] Humphreys, M.P. et al. 2020 Air–sea CO_2 exchange and ocean acidification in UK seas and adjacent waters. MCCIP Science Review 2020, 54–75. Available from: https://www.mccip.org.uk/ocean-acidification [Accessed 8 December 2022].

[68] IPCC. 2019. Technical Summary [Pörtner, H.-O. et al. (eds.)]. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [Pörtner, H.-O. et al. (eds.)]. In press. https://www.ipcc.ch/srocc/chapter/technical-summary/ [Accessed 8 December 2022].

[69] MCCIP. [Online]. Report card: sea level rise. https://www.mccip.org.uk/sea-level-rise [Accessed 8 December 2022].

[70] Committee on Climate Change. (2018). Managing the coast in a changing climate. https://www.theccc.org.uk/publication/managing-the-coast-in-a-changing-climate/ [Accessed 8 December 2022].

[71] Horsburgh, K. et al. 2020. Impacts of climate change on sea-level rise relevant to the coastal and marine environment around the UK. MCCIP Science review 2020, 116-131. Available from: https://www.mccip.org.uk/key-challenges-and-emerging-issues/key-challenges-and-emerging-issues-2020 [Accessed 8 December 2022].

[72] Haigh, I.D., Nicholls, R.J., Penning-Roswell, E. and Sayers, P. (2020) Impacts of climate change on coastal flooding, relevant to the coastal and marine environment around the UK. MCCIP Science Review 2020, 546–565. https://www.mccip.org.uk/coastal-flooding [Accessed 8 December 2022].

[73] Science. 2021. Ice shelf holding back keystone Antarctic glacier within years of failure. https://www.science.org/content/article/ice-shelf-holding-back-keystone-antarctic-glacier-within-years-failure [Accessed 8 December 2022].

[74] Sayers, P.B. et al. 2020. Third UK Climate Change Risk Assessment (CCRA3): Future flood risk. Research undertaken by Sayers and Partners for the Committee on Climate Change. Published by Committee on Climate Change, London. Supporting document CCRA3 – Flooding results summary. Available from:

https://www.ukclimaterisk.org/independent-assessment-ccra3/research-supporting-analysis/ [Accessed 8 December 2022].

[75] Jaroszweski, D., Wood, R., and Chapman, L. (2021) Infrastructure. In: The Third UK Climate Change Risk Assessment Technical Report. [Betts, R.A., Haward, A.B., Pearson, K.V. (eds)] Prepared for the Climate Change Committee, London. https://www.ukclimaterisk.org/wp-content/uploads/2021/06/CCRA3-Chapter-4-FINAL.pdf Page 20. [Accessed 8 December 2022].

[76] Kovats, S. and Brisley, R. 2021. Health, Communities and the Built Environment. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B., Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London. https://www.ukclimaterisk.org/wp-content/uploads/2021/06/CCRA3-Chapter-5-FINAL.pdf [Accessed 8 December 2022].

[77] Bindoff, N.L. et al. 2019. Changing Ocean, Marine Ecosystems, and Dependent Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, et al. (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 447-587. https://doi.org/10.1017/9781009157964.007 [Accessed 8 December 2022]

[78] MCCIP. [Online]. Report card: stratification. https://www.mccip.org.uk/stratification [Accessed 8 December 2022]

[79] Sharples, J. et al. 2022. Climate change impacts on stratification relevant to the UK and Ireland. MCCIP Science Review. Available from: https://www.mccip.org.uk/stratification [Accessed 8 December 2022]

[80] Scottish Government. 2020. Scotland's Marine Assessment 2020: Salinity. http://marine.gov.scot/sma/assessment/salinity [Accessed 8 December 2022]

[81] Dye, S.et al. 2020. Climate change and salinity of the coastal and marine environment around the UK. MCCIP Science Review 2020, 76–102. Available from: https://www.mccip.org.uk/salinity [Accessed 8 December 2022]

[82] MCCIP. [Online]. Report card: salinity https://www.mccip.org.uk/salinity [Accessed 8 December 2022]

[83] Robins, P. E. et al. 2016. Impact of climate change on UK estuaries: A review of past trends and potential projections. Estuarine, Coastal and Shelf Science 169: 119-135. https://doi.org/10.1016/j.ecss.2015.12.016 [Accessed 8 December 2022]

[84] Robins, P. E. et al. 2018. Improving estuary models by reducing uncertainties associated with river flows. Estuarine, Coastal and Shelf Science 207:63-73. https://doi.org/10.1016/j.ecss.2018.02.015 [Accessed 8 December 2022]

[85] National Trust. 2015. Mapping our shores: 50 years of land use change at the coast. Available from: http://web.archive.org/web/20220619133910/https:/www.nationaltrust.org.uk/news/fifty-years-of-land-use-change-at-the-coast [Accessed 8 December 2022]

[86] Environment Agency. 2021. What is coastal squeeze? Available from: https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/what-is-coastal-squeeze [Accessed 8 December 2022]

[87] UNEP. 2006. Annual report. https://www.unep.org/resources/annual-report/unep-2006-annual-report [Accessed 8 December 2022]

[88] Environment Agency. 2021. Poly- and perfluoroalkyl substances (PFAS): sources, pathways and environmental data. Chief Scientists Group Report. Poly- and perfluoroalkyl substances (PFAS): sources, pathways and environmental data - report (publishing.service.gov.uk) [Accessed 13 December 2022]

[89] Landrigan, P. J. et al. (2018). The Lancet commission on pollution and health. The Lancet 391:462-512. https://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(17)32345-0.pdf [Accessed 8 December 2022]

[90] UNEP. 2019. Global Chemicals Outlook II. Nairobi: United Nations Environment Programme. Available from: https://www.unep.org/explore-topics/chemicals-waste/what-we-do/policy-and-governance/global-chemicals-outlook [Accessed 8 December 2022]

[91] Malone, T. C. and Newton, A. 2020. The Globalization of Cultural Eutrophication in the Coastal Ocean: Causes and Consequences. Front. Mar. Sci., 17 August 2020. https://doi.org/10.3389/fmars.2020.00670 [Accessed 8 December 2022]

[92] ZSL. 2021. The State of the Thames 2021. https://www.zsl.org/sites/default/files/ZSL_TheStateoftheThamesReport_Mar2022%20%281%29.pdf [Accessed 8 December 2022]

[93] Green, B. C. and Johnson, C. E. 2020. Characterisation of microplastic contamination in sediment of England's inshore waters. Marine Pollution Bulletin 151:110788 https://doi.org/10.1016/j.marpolbul.2019.110788 [Accessed 8 December 2022]

[94] R. Williams et al. 2015. Impacts of anthropogenic noise on marine life: Publication patterns, new discoveries, and future directions in research and management. Ocean & Coastal Management, Volume 115: 17-24, https://doi.org/10.1016/j.ocecoaman.2015.05.021 [Accessed 8 December 2022]

[95] Tidau, S. 2021. Marine artificial light at night: An empirical and technical guide. Methods in Ecology and Evolution 4th June 2021. https://doi.org/10.1111/2041-210X.13653 [Accessed 8 December 2022]

[96] Government Office for Science. 2017. Foresight Future of the Sea: A Report from the Government Chief Scientific Adviser. https://www.gov.uk/government/publications/future-of-the-sea--2 [Accessed 8 December 2022]

[97] Defra 25-Year Environment Plan indicators. 2021. C10a (interim) Marine fish (quota) stocks of UK interest harvested sustainably. https://oifdata.defra.gov.uk/3-10-1/ [Accessed 8 December 2022]

[98] Lynam, C.P. et al. 2018. Size composition in fish communities (Typical Length). UK Marine Online Assessment Tool, available at: https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/fish/size-composition/ [Accessed 8 December 2022]

[99] MSC website [online]. https://www.msc.org/ [Accessed 8 December 2022]

[100] MSC. UK and Ireland Market Report 2021. https://www.msc.org/docs/default-source/uk-files/uk-and-ireland-market-report-2021.pdf?Status=Master&sfvrsn=52a488d2_10 [Accessed 8 December 2022]

[101] EA. 2019. 2021 river basin management plans. Invasive non-native species challenge. https://prdldnrbm-data-sharing.s3.eu-west-2.amazonaws.com/Challenge+narratives/INNS+challenge+RBMP+2021.pdf [Accessed 8 December 2022]

[102] Genner, M.J., et al. 2017. Future of the Sea: Biological Responses to Ocean Warming. Foresight evidence review. Available from:

https://www.gov.uk/government/publications/future-of-the-sea-biological-responses-to-ocean-warming [Accessed 8 December 2022]

[103] JNCC. 2021. Biodiversity indicator B6 – Pressure from invasive species. Data available from: https://hub.jncc.gov.uk/assets/647caed5-93d0-4dc0-92bf-13d231a37dda [Accessed 8 December 2022]

[104] EEA. 2020. Briefing no. 18. Multiple pressures and their combined effects in Europe's seas. https://www.eea.europa.eu/publications/multiple-pressures-and-their-combined [Accessed 8 December 2022]

[105] Mustaffa, N. I. H. et al. 2020. Coastal Ocean Darkening Effects via Terrigenous DOM Addition on Plankton: An Indoor Mesocosm Experiment. Frontiers in Marine Science 7 https://doi.org/10.3389/fmars.2020.547829 [Accessed 8 December 2022]

[106] Blain, C. O. et al. 2021. Coastal darkening substantially limits the contribution of kelp to coastal carbon cycles. Global change biology 27:5547-5563 https://doi.org/10.1111/gcb.15837 [Accessed 8 December 2022]

[107] Heinze, C. et al. 2021. The quiet crossing of ocean tipping points. PNAS 118: e2008478118 https://doi.org/10.1073/pnas.2008478118 [Accessed 8 December 2022]

[108] Holt, J. et al. 2018) Climate-Driven Change in the North Atlantic and Arctic Oceans Can Greatly Reduce the Circulation of the North Sea. Geophysical Research Letters, 45: 11,827 - 11,836. https://doi.org/10.1029/2018GL078878 [Accessed 8 December 2022]

[109] O. Hoegh-Guldberg et al. 2018. 'Impacts of 1.5 °C global warming on natural and human systems' in Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty, V. Masson-Delmotte et al., Eds. (Intergovernmental Panel on Climate Change, 2018). https://www.ipcc.ch/site/assets/uploads/2018/11/sr15_chapter3.pdf [Accessed 8 December 2022]

[110] Taylor, J. A. et al. 2004. A macroscale analysis of coastal steepening around the coast of England and Wales. The Geographical Journal 170: 179-188 https://doi.org/10.1111/j.0016-7398.2004.00119.x [Accessed 8 December 2022]

[111] Jacobs. 2018. Research to Assess the Economics of Coastal Change Management in England and to Determine Potential Pathways for a Sample of Exposed Communities. Report for the Committee on Climate Change. https://www.theccc.org.uk/wp-content/uploads/2018/12/Economics-of-coastal-change-management-in-England-Jacobs.pdf [Accessed 13 December 2022]

[112] Environment Agency. 2020. Social deprivation and the likelihood of flooding. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1072781/Social_deprivation_and_the_likelihood_of_flooding_-_report_2.1.pdf [Accessed 8 December 2022]

[113] Lindley, S. et al. 2011. Climate change, justice and vulnerability. Joseph Rowntree Foundation Report. Available from: https://www.jrf.org.uk/report/climate-change-justice-and-vulnerability [Accessed 8 December 2022]

[114] Brand, J. H. et al. 2018. Potential pollution risks of historic landfills on low-lying coasts and estuaries. WIREs water 5:e1264. https://doi.org/10.1002/wat2.1264 [Accessed 8 December 2022]

[115] Masselink, G. et al. 2020. Impacts of climate change on coastal geomorphology and coastal erosion relevant to the coastal and marine environment around the UK. MCCIP Science Review 2020, 158–189. https://www.mccip.org.uk/coastal-geomorphology [Accessed 8 December 2022]

[116] Environment Agency analysis of National Coastal Erosion Risk Mapping data. Data available from: https://www.data.gov.uk/dataset/7564fcf7-2dd2-4878-bfb9-11c5cf971cf9/national-coastal-erosion-risk-mapping-ncerm-national-2018-2021 [Accessed 8 December 2022]

[117] Jacobs, 2018. In: CCC. 2018. Managing the coast in a changing climate. https://www.theccc.org.uk/publication/managing-the-coast-in-a-changing-climate/ [Accessed 8 December 2022]

[118] Sayers, P. et al. 2022. Responding to climate change around England's coast - The scale of the transformational challenge. Ocean & Coastal Management 225: 106187 https://doi.org/10.1016/j.ocecoaman.2022.106187 [Accessed 8 December 2022]

[119] Environment Agency. 2020. National Flood and Coastal Erosion Risk Management Strategy for England. Available from: https://www.gov.uk/government/publications/national-flood-and-coastal-erosion-risk-

management-strategy-for-england--2#full-publication-update-history [Accessed 8 December 2022]

[120] Environment Agency. 2021. State of the water environment indicator B3: supporting evidence. https://www.gov.uk/government/publications/state-of-the-water-environment-indicator-b3-supporting-evidence/state-of-the-water-environment-indicator-b3-supporting-evidence [Accessed 8 December 2022]

[121] Environment Agency. 2019. Nitrate pressure narrative: 2021 river basin management plans. Available in links document from the Challenges and Choices consultation summary report. https://prdldnrbm-data-sharing.s3.eu-west-2.amazonaws.com/Challenges+and+choices+2020+links.pdf [Accessed 8 December 2022]

[122] OSPAR. 2017. Third Integrated Report on the Eutrophication Status of the OSPAR Maritime Area. Available from: https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/pressures-human-activities/eutrophication/third-comp-summary-eutrophication/ [Accessed 8 December 2022]

[123] OSPAR. 2017. IA2017 Eutrophication status in areas assessed in Arctic Waters, the Greater North Sea, Celtic Seas, and the Bay of Biscay, 2006–2014. https://odims.ospar.org/en/submissions/ospar_eut_status_2017_06/ [Accessed 8 December 2022]

[124] Environment Agency. 2022. Press release: Farmers take ownership of nitrogen targets in Dorset's Poole Harbour. https://www.gov.uk/government/news/farmers-take-ownership-of-nitrogen-targets-in-dorset-s-poole-harbour. [Accessed 01 Aug 2022].

[125] Environment Agency analysis. Summarised here: http://www.solentforum.org/services/Member_Services/css/Nutrients/ [Accessed 8 December 2022]

[126] OSPAR. 2021. Comprehensive Study and assessment of Riverine Inputs and Direct Discharges (RID) – 2019 data report. Publication number: 800/2021. Available from https://www.ospar.org/about/publications [Accessed 8 December 2022]

[127] Environment Agency. 2019. Phosphorus pressure narrative: 2021 river basin management plans. Available in links document from the Challenges and Choices consultation summary report. https://prdldnrbm-data-sharing.s3.eu-west-

2.amazonaws.com/Challenges+and+choices+2020+links.pdf [Accessed 8 December 2022]

[128] Back to Blue Initiative. 2022. The invisible wave: getting to zero chemical pollution. https://backtoblueinitiative.com/the-invisible-wave-getting-to-zero-chemical-pollution-whitepaper/# [Accessed 8 December 2022]

[129] Jepson, P., Deaville, R., Barber, J. et al. PCB pollution continues to impact populations of orcas and other dolphins in European waters. Sci Rep 6, 18573 (2016). https://doi.org/10.1038/srep18573 [Accessed 8 December 2022]

[130] For example Harvard Medical School. [online]. What to do about mercury in fish. https://www.health.harvard.edu/staying-healthy/what-to-do-about-mercury-in-fish [Accessed 8 December 2022]

[131] Environment Agency. 2019. Chemicals in the water environment pressure narrative: 2021 river basin management plans. Available in links document from the Challenges and Choices consultation summary report. https://prdldnrbm-data-sharing.s3.eu-west-2.amazonaws.com/Challenges+and+choices+2020+links.pdf [Accessed 8 December 2022]

[132] UN Environment Programme. 2021. Chemicals, Wastes and Climate Change: Interlinkages and Potential for Coordinated Action. Report produced by the UN secretariats of the Basel, Minamata, Rotterdam and Stockholm conventions. https://mercuryconvention.org/Portals/11/documents/Climate_Change_Interlinkages.pdf [Accessed 8 December 2022]

[133] Mayes, W.M. et al. 2013. Riverine Flux of Metals from Historically Mined Orefields in England and Wales. Water Air Soil Pollut 224: 1425 https://doi.org/10.1007/s11270-012-1425-9 [Accessed 8 December 2022]

[134] OSPAR. 2017. Intermediate assessment. Inputs of Mercury, Cadmium and Lead via Water and Air to the Greater North Sea: D8 – concentrations of contaminants. https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/pressures-human-activities/contaminants/heavy-metal-inputs/ [Accessed 8 December 2022]

[135] CEFAS. 2018. Marine Online assessment Tool (MOAT). Inputs of mercury, cadmium and lead via water and air. https://moat.cefas.co.uk/pressures-from-human-activities/contaminants/metal-inputs/ [Accessed 8 December 2022]

[136] OSPAR. 2017. Intermediate assessment: Inputs of Mercury, Cadmium and Lead via Water and Air to the Greater North Sea. https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/pressures-human-activities/contaminants/heavy-metal-inputs/ [Accessed 8 December 2022]

[137] Maes, T. et al. 2018. Trends and status of Polychlorinated biphenyls in UK sediments. UK Marine Online Assessment Tool, available at: https://moat.cefas.co.uk/pressures-from-human-activities/contaminants/pcbs-in-sediment/ [Accessed 8 December 2022]

[138] Manuel Nicolaus, E. E. et al. 2018. Status and trend of cadmium, lead and mercury in sediments. UK Marine Online Assessment Tool, available at: https://moat.cefas.co.uk/pressures-from-human-activities/contaminants/metals-in-sediment/ [Accessed 8 December 2022]

[139] Richir, J. et al. 2021. Three decades of trace element sediment contamination: The mining of governmental databases and the need to address hidden sources for clean and healthy seas. Environment International 149 https://doi.org/10.1016/j.envint.2020.106362 [Accessed 8 December 2022]

[140] Defra 25-Year Environment Plan indicators. 2021. Indicator H4: Exposure and adverse effects of chemicals on wildlife and the environment. Interim. https://oifdata.defra.gov.uk/8-4-1 [Accessed 8 December 2022]

[141] Environment Agency. 2019. Faecal contamination pressure narrative: 2021 river basin management plans. Available in links document from the Challenges and Choices consultation summary report. https://prdldnrbm-data-sharing.s3.eu-west-2.amazonaws.com/Challenges+and+choices+2020+links.pdf [Accessed 8 December 2022]

[142] Brown, A. R. et al. 2020. Stakeholder perspectives on the importance of water quality and other constraints for sustainable mariculture. Environmental Science & Policy 114:506-518 https://doi.org/10.1016/j.envsci.2020.09.018 [Accessed 8 December 2022]

[143] Jambeck, J. R. et al. 2015. Plastic waste inputs from land into the ocean. Science 347: 768-771. https://doi.org/10.1126/science.1260352 [Accessed 8 December 2022]

[144] Gall, S.C. and Thompson, R.C. 2015. The impact of debris on marine life. Marine Pollution Bulletin 92:170-179 https://doi.org/10.1016/j.marpolbul.2014.12.041 [Accessed 8 December 2022]

[145] Kühn, S. and van Franeker, J. A. 2020. Quantitative overview of marine debris ingested by marine megafauna. Marine Pollution Bulletin 151 https://doi.org/10.1016/j.marpolbul.2019.110858 [Accessed 8 December 2022]

[146] Allen, R. 2012. Entanglement of grey seals *Halichoerus grypus* at a haul out site in Cornwall, UK. Marine Pollution Bulletin 64: 2815-2819 https://doi.org/10.1016/j.marpolbul.2012.09.005 [Accessed 8 December 2022]

[147] Rapid assessment of evidence collation on Abandoned, Lost or otherwise Discarded Fishing Gear (ALDFG). Centre for Environment Fisheries and Aquaculture Science Ref: SAR-369. Project ME5232. Final Report. Available from: https://randd.defra.gov.uk/ProjectDetails?ProjectId=20483 [Accessed 8 December 2022]

[148] Shen, M. et al. 2020. Can microplastics pose a threat to ocean carbon sequestration? Marine Pollution Bulletin 150: 110712 https://doi.org/10.1016/j.marpolbul.2019.110712 [Accessed 8 December 2022]

[149] Beaumont, N. J. et al. 2019. Global ecological, social and economic impacts of marine plastic. Marine Pollution Bulletin 142:189-195 https://doi.org/10.1016/j.marpolbul.2019.03.022 [Accessed 8 December 2022]

[150] CEFAS. [online]. Marine online assessment tool. Trends in UK beach litter from 2008 to 2015. https://moat.cefas.co.uk/pressures-from-human-activities/marine-litter/beach-litter/ [Accessed 8 December 2022]

[151] MCS. 2021. Great British Beach Clean results. https://www.mcsuk.org/what-you-can-do/join-a-beach-clean/great-british-beach-clean/great-british-beach-clean-2021-results/ [Accessed 8 December 2022]

[152] Defra 25-Year Environment Plan indicators. 2021. Indicator C1b. Fulmars. https://oifdata.defra.gov.uk/3-1-1/ [Accessed 8 December 2022]

[153] Maes, T. et al. 2018. Below the surface: Twenty-five years of seafloor litter monitoring in coastal seas of North West Europe (1992–2017). Science of The Total

Environment 630:790-798 https://doi.org/10.1016/j.scitotenv.2018.02.245. [Accessed 8 December 2022]

154 Li, J. et al. 2018. Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. Environmental Pollution 241:35-44. https://doi.org/10.1016/j.envpol.2018.05.038 [Accessed 8 December 2022]

155 Mc Mellor, S. and Underwood, G. J. C. 2014. Water policy effectiveness: 30 Years of change in the hypernutrified Colne estuary, England. Marine Pollution Bulletin 81: 200-209. https://doi.org/10.1016/j.marpolbul.2014.01.018 [Accessed 8 December 2022]

156 Environment Agency. 2019. Physical modification challenge: 2021 river basin management plans. Available in links document from the Challenges and Choices consultation summary report. https://prdldnrbm-data-sharing.s3.eu-west-2.amazonaws.com/Challenges+and+choices+2020+links.pdf [Accessed 8 December 2022]

157 Roberts, C. 2007. The unnatural history of the sea. London: Octopus publishing group.

158 CEFAS. [online]. Marine online assessment tool. Benthic habitats. https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/benthic-habitats/ [Accessed 8 December 2022]

159 Küpper, F.C. and Kamenos, N.A. 2017. Future of the sea: The future of marine biodiversity and marine ecosystem functioning in UK coastal and territorial waters (including UK Overseas Territories). Available from: https://www.gov.uk/government/publications/future-of-the-sea-the-future-of-marine-biodiversity [Accessed 8 December 2022]

160 Provoost, S. et al. 2011. Changes in landscape and vegetation of coastal dunes in northwest Europe: a review. J. Coast. Conerv. 15:207-226 https://doi.org/10.1007/s11852-009-0068-5 [Accessed 8 December 2022]

161 Jordan, P. and Fröhle, P. 2022. Bridging the gap between coastal engineering and nature conservation? J Coast Conserv 26:4 https://doi.org/10.1007/s11852-021-00848-x [Accessed 8 December 2022]

162 Jones, L. et al. 2011. Coastal Margins. In: UK National Ecosystem Assessment Understanding nature's value to society. UK National Ecosystem Assessment.

http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=KLy76Rak0WQ%3d&tabid=82 [Accessed 8 December 2022]

[163] Defra and Environment Agency. 2007. Sand dune processes and management for flood and coastal defence. Part 4: Techniques for sand dune management. R&D Technical Report FD1302/TR. https://assets.publishing.service.gov.uk/media/6026632d8fa8f5037f5d846a/Part_4_Techniques_for_sand_dune_management_technical_report.pdf [Accessed 8 December 2022]

[164] Beaumont, N.J. et al. 2014. The value of carbon sequestration and storage in coastal habitats. Estuarine, Coastal and Shelf Science 137:32-40 https://doi.org/10.1016/j.ecss.2013.11.022 [Accessed 8 December 2022]

[165] Paprotny, D. et al. 2021. Future losses of ecosystem services due to coastal erosion in Europe, Science of The Total Environment 760:144310 https://doi.org/10.1016/j.scitotenv.2020.144310 [Accessed 8 December 2022]

[166] Burden, A. et al. 2020. Impacts of climate change on coastal habitats relevant to the coastal and marine environment around the UK. MCCIP Science Review 2020, 228–255. Available from: https://www.mccip.org.uk/coastal-habitats [Accessed 8 December 2022]

[167] Jennings, S. et al. 2002. Trawling disturbance can modify benthic production processes. Journal of Animal Ecology 70:3 https://doi.org/10.1046/j.1365-2656.2001.00504.x [Accessed 8 December 2022]

[168] Watson, S. C. L. et al. 2022. Inclusion of condition in natural capital assessments is critical to the implementation of marine nature-based solutions. Science of the Total Environment 838:156026 http://dx.doi.org/10.1016/j.scitotenv.2022.156026 [Accessed 8 December 2022]

[169] Legge, O. et al. 2020. Carbon on the Northwest European Shelf: Contemporary Budget and Future Influences. Frontiers in Marine Science https://www.frontiersin.org/articles/10.3389/fmars.2020.00143 [Accessed 8 December 2022]

[170] Kröger S, et al. (Eds.) 2018. Shelf Seas: The Engine of Productivity, Policy Report on NERC-Defra Shelf Sea Biogeochemistry programme. Cefas, Lowestoft. https://www.uk-ssb.org/shelf_seas_report.pdf [Accessed 8 December 2022]

[171] CEFAS. [online]. Marine online assessment tool. Condition of benthic communities: subtidal habitats of the Southern North Sea. https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/benthic-habitats/subtidal-habitats/ [Accessed 8 December 2022]

[172] Epstein, G. and Roberts, C. M. 2022. Identifying priority areas to manage mobile bottom fishing on seabed carbon in the UK. PLoS Climate 1:e0000059 https://doi.org/10.1371/journal.pclm.0000059 [Accessed 8 December 2022]

[173] Sala, E., Mayorga, J., Bradley, D. et al. 2021. Protecting the global ocean for biodiversity, food and climate. Nature 592, 397–402. https://doi.org/10.1038/s41586-021-03371-z [Accessed 8 December 2022]

[174] NERC marine ecosystems research programme. [online]. https://www.marine-ecosystems.org.uk/Research_outcomes/Natural_Capital [Accessed 8 December 2022]

[175] McLeod, E. et al. 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. Frontiers in Ecology and the Environment 9:552-560 https://doi.org/10.1890/110004 [Accessed 8 December 2022]

[176] Environment Agency. 2021. Salt marsh restoration handbook. https://catchmentbasedapproach.org/learn/saltmarsh-restoration-handbook/ [Accessed 8 December 2022]

[177] Environment Agency. 2022. The extent and zonation of saltmarsh in England 2016-2019. https://www.gov.uk/government/publications/the-extent-and-zonation-of-saltmarsh-in-england-2016-2019 [Accessed 8 December 2022]

[178] Environment Agency analysis, 2019.

[179] Horton, B.P. et al. 2018. Predicting marsh vulnerability to sea-level rise using Holocene relative sea-level data. Nat Commun 9: 2687 https://doi.org/10.1038/s41467-018-05080-0 [Accessed 8 December 2022]

[180] CEFAS. [online]. Marine online assessment tool. Condition of intertidal saltmarsh communities in coastal waters determined using Water Framework Directive methods. https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/benthic-habitats/intertidal-saltmarsh/ [Accessed 8 December 2022]

[181] Environment Agency. 2014. Press release: biggest coastal flood management scheme completed. https://www.gov.uk/government/news/biggest-coastal-flood-management-scheme-completed [Accessed 8 December 2022]

[182] NEA. 2011. Chapter 12: Marine. In: UK National Ecosystem Assessment Understanding nature's value to society. UK National Ecosystem Assessment. http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=HCNDuZ4ikto%3d&tabid=82 [Accessed 8 December 2022]

[183] Environment Agency analysis of map data. Data available from: https://www.data.gov.uk/dataset/aa1787a7-71fb-4c44-bf27-7825f9c5ee64/national-seagrass-layer-england [Accessed 8 December 2022]

[184] Green, A., et al. 2021. Historical Analysis Exposes Catastrophic Seagrass Loss for the United Kingdom. Frontiers in Plant Science. https://www.frontiersin.org/articles/10.3389/fpls.2021.629962/full#h5 [Accessed 8 December 2022]

[185] Environment Agency. 2021. Seagrass Restoration Handbook. https://catchmentbasedapproach.org/learn/seagrass-restoration-handbook/ [Accessed 8 December 2022]

[186]Defra 25-Year Environment Plan indicators. 2021. Indicator C4: Diverse seas: condition of seafloor habitats https://oifdata.defra.gov.uk/3-4-1/ [Accessed 8 December 2022]

[187] Lown, A. E. et al. 2021. European native oysters and associated species richness in the presence of non-native species in a southern North Sea estuary complex. Conservation Science and Practice 3:e361. https://doi.org/10.1111/csp2.361 [Accessed 8 December 2022

[188] Jordan, P. and Fröhle, P. 2022. Bridging the gap between coastal engineering and nature conservation? J Coast Conserv 26:4 https://doi.org/10.1007/s11852-021-00848-x [Accessed 8 December 2022

[189] European Native Oyster Habitat Restoration Monitoring Handbook. 2021. https://catchmentbasedapproach.org/learn/european-native-oyster-restoration-handbook/ [Accessed 8 December 2022

[190] Laing, A. et al. 2006. Return of the native – is European oyster (Ostrea edulis) stock restoration in the UK feasible? Aquatic Living Resources 19:283-287. https://doi.org/10.1051/alr:2006029 [Accessed 8 December 2022

[191] Benthem Jutting, T. van (1943). Mollusca. Lamellibranchia. In: Boschma, H. (Ed). Fauna van Nederland. Sijthoff, Leiden. In: OSPAR. 2018. Case Reports for the OSPAR List of threatened and/or declining species and habitats. https://qsr2010.ospar.org/media/assessments/p00358_case_reports_species_and_habitats_2008.pdf [Accessed 8 December 2022

[192] Allison, S. et al. 2019. Strongholds of Ostrea edulis populations in estuaries in Essex, SE England and their association with traditional oyster aquaculture: evidence to support a MPA designation. Journal of the Marine Biological Association of the United Kingdom, 100: 27-36 https://www.cambridge.org/core/journals/journal-of-the-marine-biological-association-of-the-united-kingdom/article/strongholds-of-ostrea-edulis-populations-in-estuaries-in-essex-se-england-and-their-association-with-traditional-oyster-aquaculture-evidence-to-support-a-mpa-designation/E40EAAC369DC06BC1D4390793B07C8B5 [Accessed 8 December 2022

[193] The Wild Oysters Project. [online]. https://wild-oysters.org/ [Accessed 8 December 2022

[194] Environment Agency. 2021. Briefing note: Blue Recovery – estuary and coast ecosystem resilience through collaborative partnerships. https://ecsa.international/sites/default/files/docs-reach/20201208_Blue Recovery Fund_Feb2021.pdf [Accessed 01 Aug 2022].

[195] Mann, K. H. 1973. Seaweeds: Their Productivity and Strategy for Growth. Science 182: 4116. https://doi.org/10.1126/science.182.4116.975 [Accessed 8 December 2022

[196] Mann, K. H. 2000. In Smale, D. A. et al. (2013). Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. Ecology and Evolution 3: 4016-4038 https://doi.org/10.1002/ece3.774 [Accessed 8 December 2022

[197] Fletcher, R. L. and Manfredi, C, 1995. In Smale, D. A. et al. (2013). Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. Ecology and Evolution 3: 4016-4038 https://doi.org/10.1002/ece3.774 [Accessed 8 December 2022

[198] Rewilding Britain. 2019. Sussex kelp restoration project. https://www.rewildingbritain.org.uk/rewilding-projects/sussex-kelp-restoration-project. [Accessed 8 December 2022

[199] Defra. 2021. Press release: Innovative nature projects awarded funding to drive private investment. https://www.gov.uk/government/news/innovative-nature-projects-awarded-funding-to-drive-private-investment [Accessed 8 December 2022

[200] Sussex Wildlife Trust. 2022. News: Sussex Kelp Anniversary. https://sussexwildlifetrust.org.uk/news/sussex-kelp-anniversary [Accessed 8 December 2022

[201] Sussex Kelp Restoration Project. 2021. Sussex Kelp Restoration Project Science Film (youtube). https://www.youtube.com/watch?v=WCu0zXEDhAc . [Accessed 8 December 2022]

[202] Adur & Worthing Councils. Joint Strategic Committee. 2021. Sussex Bay: Restoring our marine and estuarine habitats, supporting our coastal communities. https://democracy.adur-worthing.gov.uk/documents/s5308/Item%206%20-%20Sussex%20Bay.pdf https://www.adur-worthing.gov.uk/news/archive/pr21-106.html [Accessed 12 Dec 2022].

[203] Defra 25-Year Environment Plan indicators. 2021. Indicator C5: Diverse seas: condition of pelagic habitats. https://oifdata.defra.gov.uk/3-5-1/ [Accessed 8 December 2022]

[204] Graves, C. A. et al. *In prep.*

[205] Environment Agency assessment.

[206] Defra. 2019. Marine strategy part one: UK updated assessment and Good Environmental Status. https://www.gov.uk/government/publications/marine-strategy-part-one-uk-updated-assessment-and-good-environmental-status [Accessed 8 December 2022]

[207] Thurstan, R., Brockington, S. & Roberts, C. 2010. The effects of 118 years of industrial fishing on UK bottom trawl fisheries. Nat Commun 1, 15. https://doi.org/10.1038/ncomms1013 [Accessed 8 December 2022]

[208] Thurstan, R. et al. 2010. Origins of the bottom trawling controversy in the British Isles: 19th century witness testimonies reveal evidence of early fishery declines. Fish and fisheries 15:506-522 https://doi.org/10.1111/faf.12034 [Accessed 8 December 2022]

[209] CEFAS. [Online]. Marine online assessment tool. Fish. https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/fish/ [Accessed 8 December 2022]

[210] Greenstreet, S.P.R. et al. 2018. Proportion of large fish (Large Fish Index). UK Marine Online Assessment Tool, available at: https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/fish/large-fish-index/ [Accessed 8 December 2022] [Accessed 8 December 2022]

[211] OSPAR. [online]. Size composition in fish communities. Available from: https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/fish-and-food-webs/ [Accessed 8 December 2022]

[212] Defra 25-Year Environment Plan indicators. 2021. Indicator C7: Healthy seas: fish and shellfish populations. Typical length. https://oifdata.defra.gov.uk/3-7-1/ [Accessed 8 December 2022]

[213] OSPAR. [online]. Pilot assessment of mean maximum length of fish. Available from: https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/fish-and-food-webs/ [Accessed 8 December 2022]

[214] Defra 25-Year Environment Plan indicators. 2021. Indicator C7: Healthy seas: fish and shellfish populations https://oifdata.defra.gov.uk/3-7-1/ [Accessed 8 December 2022]

[215] CEFAS, Environment Agency and Natural Resources Wales. 2022. Assessment of Salmon Stocks and Fisheries in England and Wales in 2021. https://www.gov.uk/government/publications/assessment-of-salmon-stocks-and-fisheries-in-england-and-wales-in-2021 [Accessed 8 December 2022]

[216] Gillson, J. P. et al. 2021. A review of marine stressors impacting Atlantic salmon *Salmo salar*, with an assessment of the major threats to English stocks. Rev. Fish. Biol. Fisheries. https://doi.org/10.1007/s11160-022-09714-x [Accessed 8 December 2022]

[217] JNCC. 2020. Seabird Population Trends and Causes of Change: 1986-2018 Report https://jncc.gov.uk/media/3617/smp-annual-report_1986-2018.pdf Joint Nature Conservation Committee. [Accessed 8 December 2022]

[218] RSPB. 2021. UK birds of conservation concern. https://www.rspb.org.uk/globalassets/downloads/bocc5/bocc5-report.pdf [Accessed 8 December 2022]

[219] Defra 25-Year Environment Plan indicators. 2021. C3: Diverse seas: status of marine mammals and marine birds (interim) https://oifdata.defra.gov.uk/3-3-1/ [Accessed 8 December 2022]

[220] Natural Capital Committee. 2020. State of Natural Capital Annual Report 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/858739/ncc-annual-report-2020.pdf [Accessed 8 December 2022]

[221] Mammal Society. [online]. Full Species List. https://www.mammal.org.uk/species-hub/uk-mammal-list/ [Accessed 8 December 2022]

[222] Pinn, E. et al. 2018. Cetacean abundance and distribution: wide-ranging cetaceans. UK Marine Online Assessment Tool, available at: https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/cetaceans/abundance-and-distribution-of-cetaceans-other-than-coastal-bottlenose-dolphins/ [Accessed 8 December 2022]

[223] ZSL. [online]. UK cetacean strandings investigation programme (CSIP). https://www.zsl.org/conservation/get-involved/uk-cetacean-strandings-investigation-programme-csip [Accessed 8 December 2022]

[224] CEFAS. [online]. Marine online assessment tool. Cetaceans. https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/cetaceans/ [Accessed 8 December 2022]

[225] Berrow, S. and Whooley, P. 2022. Managing a Dynamic North Sea in the light of its ecological dynamics: Increasing occurrence of large baleen whales in the southern North Sea. Journal of Sea Research 182: 102186. https://doi.org/10.1016/j.seares.2022.102186 [Accessed 8 December 2022]

[226] CEFAS. [online]. Marine online assessment tool. Cetaceans other than bottlenose dolphins https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-

areas/cetaceans/abundance-and-distribution-of-cetaceans-other-than-coastal-bottlenose-dolphins/ [Accessed 8 December 2022]

227 OSPAR. 2017. Seal Abundance and Distribution. https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/marine-mammals/seal-abundance-and-distribution/ [Accessed 8 December 2022]

228 Harding, K. C. et al. 2002. The 2002 European seal plague: epidemiology and population consequences. Ecology Letters 5:727-732 https://doi.org/10.1046/j.1461-0248.2002.00390.x [Accessed 8 December 2022]

229 Defra. 2019. Marine Strategy part one. UK updated assessment and Good Environmental Status. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/921262/marine-strategy-part1-october19.pdf [Accessed 8 December 2022]

230 Jouffrey, J-B. et al. 2020. The Blue Acceleration: The Trajectory of Human Expansion into the Ocean. One Earth. https://doi.org/10.1016/j.oneear.2019.12.016 [Accessed 8 December 2022]

231 Morrissey, 2017, cited in Government Office for Science. 2018. Future of the sea: health and wellbeing of coastal communities. https://www.gov.uk/government/publications/future-of-the-sea-health-and-wellbeing-of-coastal-communities [Accessed 8 December 2022]

232 Merino, G. et al. 2012. Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate? Global Environmental Change 22: 795-806. https://doi.org/10.1016/j.gloenvcha.2012.03.003 [Accessed 8 December 2022]

233 Seafish. 2020. Seafood 2040 – English aquaculture strategy. Available from: https://www.seafish.org/about-us/working-locally-in-the-uk/working-with-the-seafood-industry-in-england/seafood-2040/english-aquaculture-strategy-from-seafood-2040/ [Accessed 8 December 2022]

234 Black, K. and Hughes, A. 2017. Future of the Sea: Trends in Aquaculture. Foresight evidence review https://www.gov.uk/government/publications/future-of-the-sea-trends-in-aquaculture [Accessed 8 December 2022]

[235] Capuzzo, E. and McKie, T. 2016. Seaweed in the UK and abroad – status, products, limitations, gaps and Cefas role. https://www.gov.uk/government/publications/the-seaweed-industry-in-the-uk-and-abroad [Accessed 8 December 2022]

[236] Campbell, I. et al. 2019. The Environmental Risks Associated with the Development of Seaweed Farming in Europe – Prioritizing Key Knowledge Gaps. Frontiers in Marine Science. https://doi.org/10.3389/fmars.2019.00107 [Accessed 8 December 2022]

[237] Webber, J. L. 2021. Impacts of land use on water quality and the viability of bivalve shellfish mariculture in the UK: A case study and review for SW England. Environmental Science & Policy 126:122-131 https://doi.org/10.1016/j.envsci.2021.09.027 [Accessed 8 December 2022]

[238] UK Government. 2022. British energy security strategy. https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy [Accessed 8 December 2022]

[239] Frid, C., et al. 2012. The environmental interactions of tidal and wave energy generation devices. Environmental Impact Assessment Review 32:133–139. https://doi.org/10.1016/j.eiar.2011.06.002 [Accessed 8 December 2022]

[240] Jones, L., Rooney, P., Rhymes. J. and Dynamic Dunescapes partners. 2021. The Sand Dune Managers Handbook. Version 1, June 2021. Produced for the Dynamic Dunescapes (DuneLIFE) project: LIFE17 NAT/UK/000570; HG-16-086436 https://dynamicdunescapes.co.uk/wp-content/uploads/2021/10/The-Dynamic-Dunescapes-Sand-Dune-Managers-Handbook-June-2021_Oct-Update.pdf [Accessed 8 December 2022]

[241] Haigh, I. D. et al. 2019. The Tides They Are A-Changin': A Comprehensive Review of Past and Future Nonastronomical Changes in Tides, Their Driving Mechanisms, and Future Implications. Reviews of Geophysics 58: e2018RG000636 https://doi.org/10.1029/2018RG000636 [Accessed 8 December 2022]

[242] North Norfolk District Council. [online]. Bacton to Walcott Coastal Management. https://www.north-norfolk.gov.uk/sandscaping [Accessed 8 December 2022]

[243] BBC News. 2021. Norfolk sand: Has a colossal experiment worked? https://www.bbc.co.uk/news/science-environment-58919791 [Accessed 8 December 2022]

[244] UK Government. [Online]. Global Ocean Alliance: 30 by 30 initiative. https://www.gov.uk/government/topical-events/global-ocean-alliance-30by30-initiative/about [Accessed 8 December 2022]

[245] Defra. 2018. 25-Year Environment Plan. London: Department for Environment, Food and Rural Affairs. https://www.gov.uk/government/publications/25-year-environment-plan [Accessed 8 December 2022]

[246] Williamson, P. and Gattuso, J-P. 2022. Carbon Removal Using Coastal Blue Carbon Ecosystems Is Uncertain and Unreliable, With Questionable Climatic Cost-Effectiveness. Front. Clim. 4:853666 https://doi.org/10.3389/fclim.2022.853666 [Accessed 8 December 2022]

[247] Grorud-Colvert, K. et al. 2021. The MPA guide: A framework to achieve global goals for the ocean. Science 373: 6560 https://doi.org/10.1126/science.abf0861 [Accessed 8 December 2022]

[248] Duarte, C.M. et al. Rebuilding marine life. Nature 580, 39–51 (2020). https://doi.org/10.1038/s41586-020-2146-7 [Accessed 8 December 2022]

[249] Analysis by New Economics Foundation for WWF. In: WWF and Sky ocean rescue. 2021. The value of restored UK seas. WWF2009-01 Value of restored UK seas report v6 (002).pdf [Accessed 8 December 2022]

[250] Environment Agency. 2022. [online]. Expression of interest: championing coastal coordination. https://consult.environment-agency.gov.uk/fcrm/championing-coastal-coordination-3c-s/ [Accessed 8 December 2022]

[251] Marine Pioneer Programme (2017 – 2020): Testing delivery of the 25-Year Environment Plan. https://zenodo.org/record/4564011#.Y3ZVF3bP1QA [Accessed 8 December 2022]

[252] Blue Marine Foundation. 2021. National Marine Parks: A Vision for British Seas. https://www.bluemarinefoundation.com/wp-content/uploads/2021/04/National-Marine-Parks-Vision.pdf [Accessed 8 December 2022]

[253] Interreg. [online]. Plastic Free Bingo. https://preventingplasticpollution.com/resources/plastic-free-bingo/, South West Water. [online]. Love your loo. https://www.southwestwater.co.uk/services/your-wastewater/love-your-loo [Accessed 8 December 2022]