Chapter 12:
Marine

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Key Findings*

The diversity of organisms in Marine habitats provide a range of ecosystem services and benefits of significant value to UK society[1]. The benefits include food (fish, shellfish); reduction of climate stress (carbon and other biogas regulation); genetic resources (for aquaculture); blue biotechnology (e.g. biocatalysts, natural medicines); fertiliser (seaweed); coastal protection; waste detoxification and removal and disease and pest control; tourism, leisure and recreation opportunities; a focus for engagement with the natural environment; physical and mental health benefits; and cultural heritage and learning experiences. Energy from waves and tides and biofuels from macro- and microalgae are likely to be provided in the near future. Many of the benefits are accrued directly by coastal dwellers and visitors, but also indirectly by much of the UK's society[1,a].

[1] *well established*
[a] *virtually certain*

Changes in sea temperature are likely to be affecting most Marine ecosystem services. These changes are already affecting food production, wildlife populations, such as seabirds, and possibly human health through the increase in optimum environmental conditions for outbreaks of pathogens[c]. Yet at the same time, climate change could bring increased benefits for the marine leisure and recreation industries because of the potential for warmer summers. Some of the effects of increases in sea temperature and those of heavy fisheries exploitation are difficult to distinguish from each other and are likely to have synergistic effects[c].

[c] *likely*

Climate change is changing species distribution. This is particularly evident in coastal intertidal species, plankton and fish, where long-term data is richest. Comparison of historic (since the 1950s) and present distribution and abundance of over 60 indicator species in the UK has shown some of the fastest changes in the abundance, range and population structures of species in the world. These changes have been related to recent, rapid climatic warming. In particular, several southern species of warm water intertidal invertebrates and macroalgae have considerably extended their ranges northwards along the Welsh and Scottish coastlines, and eastwards along the English Channel. Northern cold water species have shown a modest contraction in range and significant declines in abundance at sites close to their southern limits. These species-specific rates of change are driving alterations of community structure and function[1,a].

[1] *well established*
[a] *virtually certain*

Human activities that affect the seafloor damage regulating and supporting services. Human activities that have a physical impact on the seafloor (e.g. trawl fishing, building offshore windfarms, aggregate extraction, coastal defences, ports and coastal developments) damage the benthic biota (species which live on the seabed) and their communities, and affect the regulating and supporting services that they provide. Usually the impacts are quite localised, but seabed trawl fishing activity, the most widespread of these activities, has the greatest impact[1,a].

[1] *well established*
[a] *virtually certain*

Increasing activity in several economic sectors in the Marine environment is putting extra pressure on all sea shelf, coastal and estuarine habitats[1,c]. These sectors include marine renewable energy development, expansion in recreation and leisure activities, and port activities. Their impacts vary in spatial extent and importance, but are compounded by climate change. Human contamination of marine waters with a range of hazardous substances has been reduced through reductions in industrial effluent and improvements in sewage treatment infrastructure[1,a]; however, there are now concerns about more recently introduced chemicals, such as nanoparticles and pharmaceuticals, which pass through sewage treatment plants[c].

[1] *well established*
[a] *virtually certain*
[c] *likely*

* Each Key Finding has been assigned a level of scientific certainty, based on a 4-box model and complemented, where possible, with a likelihood scale. Superscript numbers and letters indicate the uncertainty term assigned to each finding. Full details of each term and how they were assigned are presented in Appendix 12.1.

The quantity of wild fish caught in UK waters is insufficient to meet the UK demand for this food. Landings into UK ports of fish and other seafood declined steadily from 1.2 million tonnes wet weight in 1948 to 0.5 million tonnes in 2000, but have remained steady since then. Since 1945, there has been an increased demand for fish in the human diet leading to the rise of aquaculture, particularly of finfish in Scottish waters and shellfish in English, Welsh and Northern Irish waters. There has also been a 46% increase in the volume of fish imported from overseas between 1998 and 2008[1,a].

[1] *well established*
[a] *virtually certain*

The sustainability of food provision from Marine Habitats is threatened by overexploitation of fisheries; fishing is also damaging other Marine ecosystem services. Over the last 50 years, fishing activity has put significant pressure on living resources and habitats. Several fish stocks in the North Sea and Irish Sea are overexploited and are subject to recovery plans. Out of 18 indicator finfish stocks in UK waters, only 50% were considered to have full reproductive capacity and to be harvested sustainably in 2008, but this is an improvement from 10% or less in the early 1990s[1,a].

[1] *well established*
[a] *virtually certain*

Water purification and breakdown of waste by ecosystems appears to be keeping pace with inputs in open shelf waters, although localised contamination and some eutrophication problems persist[1,a]. The waste processing and purification services widely provided by Marine habitats generally ensure that food provided by the sea is safe to eat and the water is clean enough to use for recreation, such as swimming, angling, scuba diving, and surfing[c]. In some coastal waters, such as estuaries, local contamination by diffuse pollution (e.g. agricultural fertiliser, urban runoff and synthetic chemicals) still exceeds the capacity of the ecosystem to remediate or assimilate it[c].

[1] *well established*
[a] *virtually certain*
[c] *likely*

The UK's seas are important to people's quality of life but are less well protected than terrestrial environments[a]. The UK population has a strong affinity for the sea and has always derived inspiration from it. More people are using the sea for leisure and recreation, education, research and health benefits. Despite this, protection of the Marine environment falls short of that on land. For example, there are only 81 marine Special Areas of Conservation (SACs) out of a total of 621 designated under the Habitats Directive, and very few marine Sites of Special Scientific Interest (SSSIs). The Marine and Coastal Access Act (2009) signals an increasing awareness of how important Marine Habitats are to UK culture and society and will foster greater biodiversity protection[a].

[a] *virtually certain*

Marine microbial organisms play a key role in cycling nutrients that are essential for other marine organisms and the services and benefits they provide[1,a]. Microbial processing of nutrients in the sediment depends on invertebrates disturbing and irrigating the sediment[2]. Without this recycling, most nutrients would be lost from the ecosystem to the seabed as they would sink from the water column and then be buried[a]. In open water, planktonic coccolithophores make a major contribution to the global carbon sink[a]. Climate change may affect internal nutrient cycling by changing nutrient exchange processes between the open waters and the open ocean and altering water stratification, but the likely direction and extent of these changes is still poorly understood[c].

[1] *well established*
[2] *established but incomplete evidence*
[a] *virtually certain*
[c] *likely*

Many organisms create living habitats such as reefs and seagrass meadows. These can provide essential feeding, breeding and nursery space that can be particularly important for commercial fish species[1,c]. Such habitats play a critical role in species interactions and the regulation of population dynamics, and are a prerequisite for the provision of many goods and services[c]. Fishing at the seabed with trawl nets and dredging fishing gears severely damages living reefs and deep-sea corals, which are very slow-growing and, consequently, take a long time to recover[a]. Boat anchoring, propeller scarring and channel dredging can damage shallow water and intertidal habitats[c]. However, building coastal defences and offshore structures, such as wind turbines, oil platforms and reefs, provides artificial habitats which can have positive impacts, particularly for species usually associated with rocky environments[b].

[1] *well established*
[a] *virtually certain*
[b] *very likely*
[c] *likely*

Marine ecosystem services are strongly interlinked[2,c]. Very similar ecosystem functions and biological activity underpin waste regulation, climate regulation and nutrient cycling. These functions also underpin cultural services, such as leisure and recreation, which depend on clean, functioning seas. Attractive seascapes, inshore fishing boats, and the local seafood provide enhanced local tourism and cultural services. Yet fishing also affects other components of the ecosystem, damaging food webs and seabed habitats. Hence, the provisioning service of fishing can negatively affect delivery of other services. For instance, seabirds and mammals are important for tourism and recreation, but compete with humans for fish as food or are trapped in fishing nets; this indicates a trade-off between food provision, cultural services and conservation[a].

[2] *established but incomplete evidence*
[a] *virtually certain*
[c] *likely*

Farmland food production and urban waste disposal may conflict with the delivery of ecosystem services and benefits in estuarine and coastal waters[2,c]. Fertiliser use can increase food production, but excess nutrients run off the land into estuarine and coastal waters. These waters also receive significant amounts of other agrochemicals (e.g. pesticides, artificial growth hormones), microorganisms and urban surface waste water, thereby providing a cleansing regulating service for farmlands and urban habitats. However, excessive enrichment of water by nutrients can reduce the flow of oxygen and nutrients to the seabed, with a deleterious effect on the water quality and other organisms. The major pressures occur in the east, south and north-west of England. Here, some estuarine areas are nutrient-enriched and are at risk from, or currently affected by, eutrophication. Nevertheless, UK marine waters as a whole do not suffer from eutrophication[1,a].

[1] *well established*
[2] *established but incomplete evidence*
[a] *virtually certain*
[c] *likely*

The development of Marine Plans and designation of Marine Conservation Zones will incorporate the explicit objectives of sustaining and increasing ecosystem services and managing the use of marine resources sustainably. It is imperative that these plans consider the components of Marine habitats not only in terms of biodiversity and habitats, but also with regards to ecosystem functioning and the provision of ecosystem services and benefits. The use of monetary and non-monetary valuation of ecosystem services will aid the process of considering the impacts and benefits of development on Marine habitats[a].

[a] *virtually certain*

The characteristics and biodiversity of a large proportion of UK subtidal Marine habitats is still unknown and not mapped; Marine ecosystem services are poorly quantified. We need to understand and measure the links between Marine biodiversity, ecosystem function and provision of ecosystem goods and services, and the effects of human impacts on these links. Although recent national assessments (e.g. Charting Progress 2, State of Scotland's Seas) have gathered a lot of evidence, extensive data gaps remain. Such knowledge would support more effective marine planning and licensing of activity in UK waters for the sustainable use of Marine habitats and the maintenance of clean, healthy, productive and biologically diverse seas[a].

[a] *virtually certain*

12.1 Introduction[1]

"How inappropriate to call this planet Earth, when it is quite clearly Ocean." Arthur C. Clarke

The broad marine habitat covers all UK areas that are either permanently immersed in seawater or are inundated with saline water at some stage in the tidal cycle. This includes estuaries, beaches, coasts and all subtidal habitats out to the limit of the UK's marine area (**Figure 12.1**). The seas of the UK extend to some 867,400 km^2, which is more than three and a half times the land area. Mainland Britain has over 17,820 km of coastline (based on ordnance survey digital measurements of 1:10,000 maps using the high water line, www.ordnancesurvey.co.uk/; **Table 12.1**) and the widest range of marine habitats of any European country with an Atlantic border (Hiscock 1996). These habitats support a high diversity of animals and plants, and are ranked as one of the highest in Europe (Defra 2005) with approximately 8,500 marine species (Hiscock & Smirthwaite 2004). This number only refers to multi-cellular species, however, and molecular techniques are now enabling documentation of the vast diversity of microbes that are naturally present in the oceans. One drop (one millilitre) of seawater can contain 10 million viruses, 1 million bacteria and about 1,000 small protozoans and algae (Heip *et al.* 2009). Estimates of marine biodiversity for the UK will, therefore, continue to be revised upward as the diversity of the microbial component is elucidated.

At phyletic levels marine diversity is higher than diversity on land or in freshwater. There are 14 exclusively marine phyla and only one exclusively terrestrial phylum. Recorded multi-cellular species diversity is lower in the marine environment than it is on land and in freshwater.

12.1.1 Charting Progress

The underlying data on the description of marine habitats and species and their current status and recent trends (Sections 12.1.2, 12.1.3, 12.2) draws heavily on the information collated for the Charting Progress (CP) reports prepared by the UK Marine Monitoring and Assessment Strategy (UKMMAS) Community for the UK Government and the Devolved Administrations (Scottish Government, Welsh Assembly Government, and the Department of the Environment, Northern Ireland). These reports show the extent of progress towards the UK Government and Devolved Administrations vision of "clean, safe, healthy, productive and biologically diverse oceans and seas". The first report was published in 2005 (Defra 2005) and the latest report, Charting Progress 2, was published in July 2010 (UKMMAS 2010). Charting Progress 2 (CP2) focuses on the state of components of the

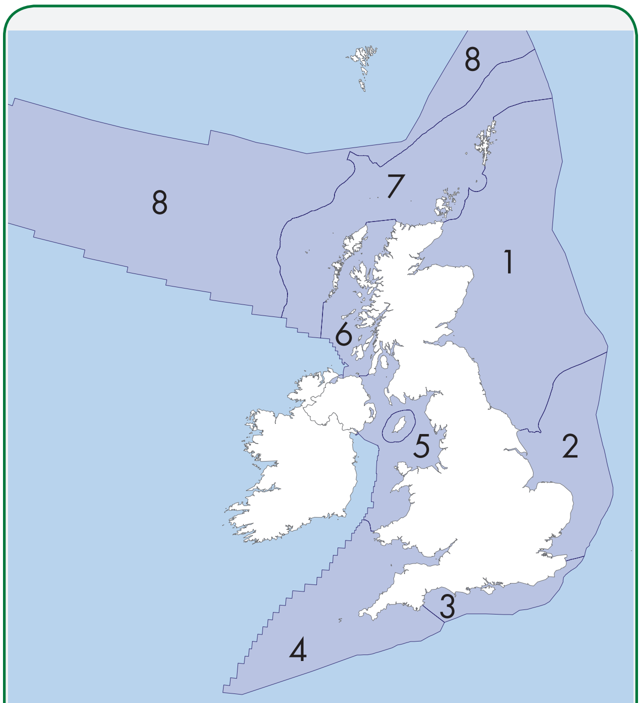

Figure 12.1 UK Regional Seas and boundaries. 1) Northern North Sea; 2) Southern North Sea; 3) Eastern Channel; 4) Western Channel and Celtic Sea; 5) Irish Sea; 6) Minches and Western Scotland; 7) Scottish Continental Shelf; 8) Atlantic North-West Approaches, Rockall Trough and Faeroe/Shetland Channel. Source: map based on UKMMAS (2010). Coastline: World Vector Shoreline@National – Geospatial Intelligence Agency. Source: NOASS, NGDC.

Table 12.1 Length of coastline for Great Britain and Northern Ireland*. Lengths given with and without principal islands and derived from 1:10,000 Ordnance Survey maps. Source: adapted from Frost (2010), where GB data is derived from the British Cartography Society (www.cartography.org.uk/default.asp?contentID=749) and Northern Ireland data is provided by the Agri-Food & Biosciences Institute AFBI.

Coastline	Approximate Length (km)
England	8,982
England + Principal Islands (Isle of Wight, Lundy, Scilly Isles)	10,077
Scotland	6,718
Scotland + Principal Islands (Arran, Islay and Jura, Shetland and Orkney, Western Isles)	18,588
Wales	2,120
Wales + Principal Islands (Anglesey and Holyhead)	2,740
Northern Ireland	686
Northern Ireland + Principal Islands (Rathlin)	718
Total Mainland GB	**17,820**
Total GB + Principal Islands	**31,368**
Total UK (GB + Northern Ireland + Principal Islands)	**32,086**

* Coastline length is highly dependent on the scale of the data from which it is measured. Therefore the length of coastline presented in this table differs from that in Chapter 11 due to the different techniques and sources on which these measurements are based.

1 Section 12.1 has been reproduced (with minor modifications) with permission from Frost (2010).

marine environment including marine habitats and ranging from microbes through to higher trophic levels such as seals, cetaceans and turtles. It also provides information on trends in these components, along with the pressures and drivers of change. This chapter includes a summary of the relevant sections of CP2 and the supporting Feeder Reports (see Sections 12.1.2, 12.1.3, 12.2). For more information please visit the CP2 website: http://chartingprogress.defra.gov.uk

12.1.2 Marine Habitats[2]

The UK marine seabed was categorised into six component habitat types (**Figure 12.2**) for the CP2 assessment (Benjamins *et al.*, 2010). These categories (**Table 12.2**) have also been used in this and other assessments such as the Marine Climate Change Impacts Partnership (MCCIP) report card.

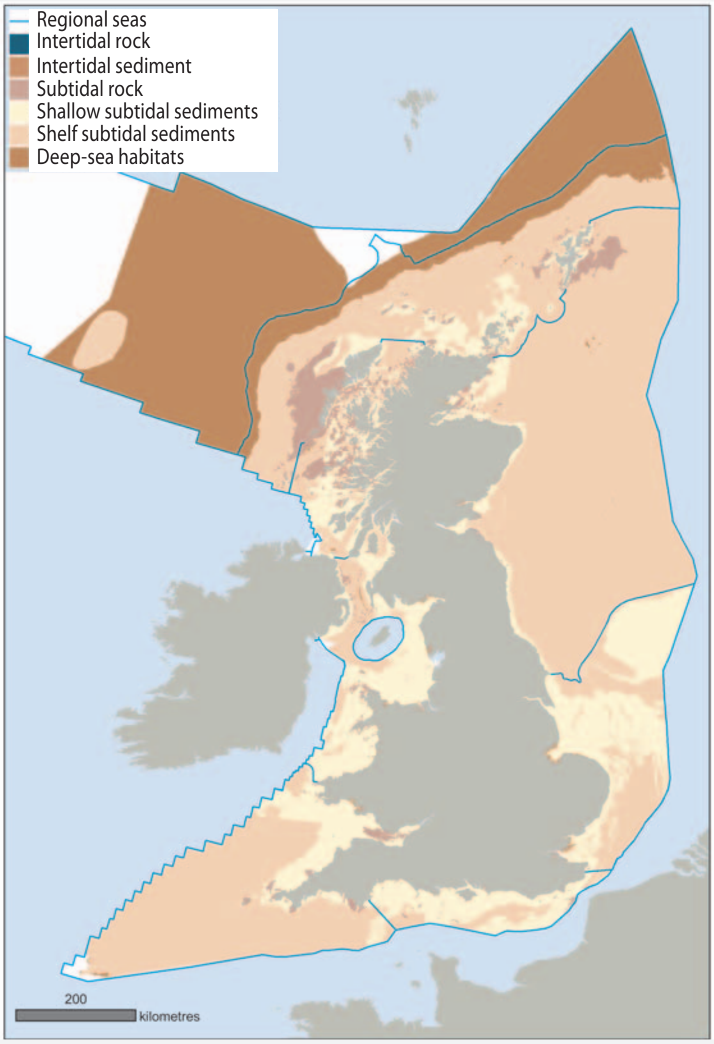

Figure 12.2 Distribution of six component habitat types found throughout UK marine waters. Subtidal and deep-sea habitat types are derived from modelling; intertidal habitat types are derived from survey data. Any white space in the map indicates where there are insufficient data to model the habitats. Source: data from JNCC and reprinted with permission from UKMMAS (2010). Map © JNCC 2010. World Vector Shoreline © US Defense Mapping Agency. Seabed habitats derived from UKSeaMap 2010 predictive map and survey data © JNCC and UKSeaMap funding partners and © MESH 2010, respectively.

Intertidal Rocky habitats are widespread throughout the UK, with the exception of the south-eastern and north-western coasts of England where they are almost completely absent and the intertidal zone is dominated by sandy beaches or intertidal mudflats. Intertidal Sediment habitats are most common in England and Wales, making up large stretches of coastline, as opposed to Scotland where lengths of Intertidal Sediment coastlines are interrupted by rocky promontories and headlands. Nearly 25% of all Intertidal Sediments occur within estuaries (Wyn *et al.* 2006) where muddy sediments are particularly prevalent. Saltmarshes also typically occur within estuaries, usually landward of intertidal muds.

In the subtidal zone, sedimentary habitats, such as sand, gravel, muds and mixed sediments, cover almost all of the continental shelf around the UK as well as coastal habitats such as sea lochs and lagoons. Shallow Subtidal Sediment habitats, which can be regularly disturbed by surface waves, are widespread in the Irish Sea, the Eastern Channel and the Southern North Sea; they also occur in coastal lagoons, particularly in southern England and western Scotland. Shelf Subtidal Sediment habitats are only rarely disturbed by surface waves because of their greater water depth and, therefore, support more stable communities. They occur throughout offshore areas of most regional seas, but also much closer to coasts where the water deepens rapidly such as around most of Scotland, Northern Ireland and Cornwall.

Subtidal Rock habitats are relatively uncommon. The largest expanses occur in Scotland (particularly to the west of the Hebrides and around Shetland) and in south-west England and Wales where there are significant offshore reefs. Biogenic reefs are included in this category and can be quite extensive, such as beds of horse mussels (*Modiolus modiolus*), or small and isolated, such as reefs of the tubeworm (*Serpula vermicularis*), both of which have a northern distribution in the UK. The ross worm (*Sabellaria spinulosa*) is very widespread and common, especially in the south-east of England, but occurs mostly as crusts or isolated individuals, only rarely forming low-lying reefs.

Deep-sea habitats occur below 200 m, beyond the edge of the continental shelf. Within UK waters they mainly occur to the north and west of Scotland and west of Rockall islet, although there are also small areas in the extreme south-western Celtic Sea. Most of these are sediment habitats, with rocky habitats and reefs largely confined to seamounts and similar structures.

In addition, the marine environment has a pelagic component which is the water overlying the seabed. Additional physical factors influence marine habitats and the organisms that live in them including: temperature, tidal flows, wind-induced wave exposure and stratification. These physical factors are influenced by the structure of the coastline. For example, headlands entrain high tidal current flows. The degree of wave exposure of coastlines is dependent on the predominant wind direction and the amount of fetch. Marine organisms are also affected by the degree of light penetration and turbidity and salinity of the water in which they live—the latter of which depends on the freshwater inflow as in estuaries, for example see Section 12.1.4.

2 Section 12.1.2 has been reproduced (with some minor modification) with permission from Benjamins (2010).

Table 12.2 Component and sub-component habitats assessed in the Charting Progress 2 report. Each component habitat corresponds to one or more high-level European Nature Information System (EUNIS) habitat codes. This includes a diversity of underlying, more specific, EUNIS habitat sub-component categories which are also included in the component habitat type, except where indicated.

Component Habitat	Definition	Sub-component Habitat
Intertidal Rock	All rocky habitats and biogenic reefs between Highest Astronomical Tide mark and Lowest Astronomical Tide mark	Intertidal rock
		Intertidal biogenic reefs
Intertidal Sediment	All sediment habitats (muds, sands, gravels and mixed sediments) between Highest Astronomical Tide mark and Lowest Astronomical Tide mark	Saltmarshes
		Intertidal muds
		Intertidal sands and muddy sands
		Intertidal coarse and mixed sediment
		Intertidal seagrass beds
Subtidal Rock	All rocky habitats and biogenic reefs from Lowest Astronomical Tide mark outward to 200 m depth (typically the edge of the continental shelf)	Infralittoral rock
		Circalittoral rock
		Subtidal biogenic reefs
Shallow subtidal Sediment	All sediment habitats (muds, sands, gravels and mixed sediments) from Lowest Astronomical Tide mark down to the wave-base depth (between 50–70 m depth around much of the UK)	Shallow muds
		Shallow sands and muddy sands
		Shallow coarse and mixed sediment
		Macrophyte-dominated sediment (seagrasses, maerl, seaweeds)
Shelf Subtidal Sediment	All sedimentary habitats (muds, sands, gravels and mixed sediments) from the wave-base depth outward to 200 m depth (typically the edge of the continental shelf)	Shelf muds
		Shelf sands and muddy sands
		Shelf coarse and mixed sediment
Deep-sea Habitats	All habitats occurring in waters deeper than 200 m depth (typically beyond the edge of the continental shelf)	Deep-sea rock
		Deep-sea bioherms
		Deep-sea sediments

12.1.3 Marine Fauna

Charting Progress 2 focused on the indicators of change affecting the major and/or more distinctive taxonomic marine groups (thus reflecting important changes to the marine environment) where there is a significant amount of data or the species or groups have conservation status. These include plankton, fish, seals, cetaceans, birds, and turtles. The invertebrate fauna which dominate the biomass within sediments are useful as indicators of change, but are not systematically monitored in either time or space in UK waters. However, in CP2 a variety of studies were used to determine the status of intertidal, subtidal and deep-sea sediment habitats (see Benjamins *et al.* 2010).

The plankton component of the UK marine ecosystem includes bacteria, archaea, viruses and many protists (microbes). The CP2 assessment highlights the importance of microbes for the functioning of the oceans; for example, viruses help to sustain the balance and diversity of life because of their involvement in nutrient cycling (Schroeder 2010). However, there is not enough information to be able to provide any assessment of status or trend for the UK's microbial community (Schroeder 2010). Photosynthesis by phytoplankton makes up at least 50% of primary production in UK marine waters, and plankton, along with the smaller microbial community, are the basis of the food supply for all higher trophic levels (Reid *et al.* 2010).

More than 330 fish species inhabit the shelf seas surrounding the British Isles, ranging from species commonly found in coastal waters or in estuaries, to those present in deep-sea and offshore oceanic waters (Pinnegar *et al.* 2010). Fish represent an important link in marine food webs, both as predators (sometimes 'top predators') and as prey for marine mammals and seabirds, as well as sustaining important commercial fisheries.

Two species of seal are found in the UK: grey seals (*Halichoerus grypus*) and harbour (or common) seals (*Phoca vitulina*) (Duck 2010), each of which makes up 36% and 4% of the world's population of these species, respectively. Grey seals are found all around the UK, however 90% of the UK's population is found in Scotland. Eighty percent of harbour seals are also found in Scotland. Harbour seals are also found in the south and south-west of England but here they are very sparse (Duck 2010).

In UK waters there are 28 species of cetacean (whales, dolphins and porpoises), of which, 11 appear regularly (Pinn 2010). The greatest diversity occurs off the continental shelf, particularly in waters to the north and west of Scotland and in the south-west towards the Bay of Biscay. Cetaceans are mobile and wide-ranging, so most of the animals found in UK waters are part of much larger and more widespread biological populations (Pinn 2010). The five species most abundant in UK waters are considered to have a favourable conservation status assessment. The status of a further six species is unknown due to a lack of suitable abundance estimates. The remaining 17 species are considered rare or vagrant and their conservation status in UK waters cannot be assessed (Pinn 2010).

The UK's marine environment supports internationally important numbers of birds. More than 100 species regularly use the marine areas of the UK. The majority of these species are waterbirds, such as waders, herons, egrets, ducks, geese, swans, divers and grebes, and seabirds, such as petrels, gannets, cormorants, skuas, gulls, terns and auks (Mitchell 2010). Most of the evidence of status and trends in birds is collected near to land, that is in estuaries and coastal areas. Less is known about bird populations that do not live in the intertidal zone or close inshore due to difficulties in gathering data in offshore areas (Mitchell 2010).

The leatherback turtle (*Dermochelys coriacea*) is the most common of the four turtles occasionally reported in UK waters (Marubini 2010). It is a wide-ranging species, migrating throughout the Atlantic; UK waters represent a small peripheral part of its summer foraging habitat (Marubini 2010). There is currently not enough evidence to be able to assess population trends.

12.1.4 Linkages with Other UK National Ecosystem Assessment Habitats

Specific marine habitats occur at the interface with freshwater (river) and coastal habitats. In these marine habitats, usually estuaries, sea lochs or sometimes lagoons, the salinity of the water can be reduced and spatially or temporally variable depending on the amount of freshwater inflow, the physical structure of the terrestrial boundary, and the extent of tidal inflow from the sea.

The marine ecosystem, especially coastal estuarine, sea loch and coastal shelf habitats, directly interacts with terrestrial habitats, particularly Coastal Margins (Chapter 11), coastal and estuarine urban habitats and freshwater (through runoff into estuaries and coasts). The division between Coastal Margin habitats and Marine habitats is usually rather indistinct. For example, many Coastal Margin habitats are inundated with saline water during extreme weather events.

There is also a freshwater catchment to coast connection between all of the terrestrial habitats that are further inland and the marine habitat, via the freshwater flows that link them.

12.2 Trends and Changes in Marine Habitats

This section includes a discussion of the trends and changes in component habitats (extent and status) included in this assessment and their associated fauna. The major drivers of change are also identified.

12.2.1 Intertidal Rock[3]

Although Intertidal Rock habitats are generally in good condition, the harvesting of edible shellfish and the occurrence of non-native species are adversely affecting some local communities. In addition, species composition of intertidal rocky communities in the Channel and Celtic Seas is already impacted by warmer waters. Recorded occurrences of non-native species are increasing around the UK coastline, but the impacts on native communities are still poorly understood. The pressures on this habitat have increased over the last ten years (**Box 12.1**).

12.2.2 Intertidal Sediments

Human pressures have adversely affected moderate to large areas of Intertidal Sediment habitats, notably mudflats and saltmarshes, in most of the UK's seas apart from northern and western Scotland. Historical land-claim from the sea and the construction of coastal defences and other structures have caused widespread habitat loss, particularly in England. Such structures also affect these habitats by changing water current patterns and sediment distribution. In the Southern North Sea and Eastern Channel, the spread of non-native species, such as common cordgrass (*Spartina anglica*), has led to changes in saltmarshes and mudflats. Although water quality levels have improved overall, there are still some small inshore areas (particularly within the North Sea and Irish Sea) where pollution and nutrient enrichment are a problem. Beach litter levels remain high and have been increasing in almost all areas except the eastern English Channel. The pressure on this habitat has increased over the last ten years.

12.2.3 Subtidal Rock and Other Hard Substrata

Overall, only limited areas of subtidal rocky habitat appear to be directly impacted by human activity. Some have, however, been permanently damaged by mobile fishing gear such as bottom trawling. This has had a particular impact on fragile biogenic reefs such as horse mussel beds. Locally, particularly near some large ports around England and Wales, subtidal rocky habitat has also been lost because of construction, coastal infrastructure or the disposal of dredged materials. The pressure on this habitat has not changed over the last ten years.

12.2.4 Shallow and Shelf Subtidal Sediments

In most regions, large areas of subtidal sediments have been adversely affected by mobile fishing gears, such as bottom trawls and dredges, but there have been less severe impacts on the Scottish Continental Shelf and the Eastern Channel. Locally, the extraction of aggregates has altered the seabed in the Eastern Channel, Southern North Sea, Bristol Channel and Irish Sea. While there is increasing demand for marine aggregate, the area impacted is relatively small, and is likely to remain so. There is also pressure from windfarm developments, particularly on shallow sandbanks, which is likely to increase in the future. Some estuaries and subtidal coastal habitats along the south coast of England and in the Irish Sea continue to experience nutrient enrichment and hazardous substances pollution. In most regions, non-native species are spreading in the subtidal coastal areas. The picture on pressures for these habitats over the last

3 Sections 12.2.1–12.2.5 have been reproduced (with some minor modification) with permission from Benjamins (2010).

Box 12.1 Intertidal rocky shore change: the MarClim Project (an excerpt from Charting Progress 2).

Comparison of historic and present distribution and abundance of over 60 indicator species has provided evidence of some of the fastest changes in the abundance, range and population structures of species globally, and related these changes to recent rapid climatic warming. In particular, several southern species of warm water intertidal invertebrates and macroalgae have considerably extended their range northward along the Welsh and Scottish coastlines, and eastward along the English Channel. Northern cold water species, meanwhile, have shown a modest contraction in range, and significant declines in abundance, at sites close to their southern limits during the same period (Mieszkowska *et al.* 2006, Hawkins *et al.* 2008). Contractions and expansions of geographic range edges due to global environmental change are resulting in species both being lost from, and introduced to, assemblages. Such changes are initially being recorded at the periphery of the geographic ranges in Britain where organisms are often already experiencing temperatures close to their thermal limits. However, MarClim data has also identified local and regional heterogeneity within the geographic range of several species, as evidenced by environmental hotspots or physical/hydrographic barriers occurring inside the distributional limits of sessile invertebrates.

Laboratory and field experiments have shown that many of the changes in the southern species have occurred as a result of increased reproductive output and juvenile survival close to northern range edges in response to increased warming, particularly shorter, milder winters (Mieszkowska *et al.* 2006, 2007; Herbert *et al.* 2007). This data has also highlighted the role of the North Atlantic Oscillation (NAO)—an index describing large-scale climatic changes—in larval transport and subsequent recruitment success. Dispersal of intertidal invertebrate larvae is primarily influenced by NAO-induced variability in oceanic circulation, whereas recruitment is mainly impacted by atmospheric effects (Broitman *et al.* 2008). Annual monitoring at approximately 150 key sites around the British coastline has continued since the completion of the MarClim report. The time-series data shows continued temperature-induced changes in intertidal rocky communities (an example of which is displayed in **Figure 1**), including increased abundance of non-native species, such as the Pacific oyster (*Crassostrea gigas*), the increase in which has resulted in declines in local biodiversity in regions where it has established natural populations. In addition, the role of artificial hard structures (e.g. for coastal defence) as stepping stones allowing the expansion of species linked to rock habitats has been highlighted (Moschella *et al.* 2005; Herbert *et al.* 2007). All of these factors influence the outcomes of species' interactions including competition, facilitation and predation, ultimately altering the structure of communities and ecosystem processes within British intertidal ecosystems (Coleman *et al.* 2006; Poloczanska *et al.* 2008; Burrows *et al.* 2009).

Figure 1 Lower shore at Mothecombe. *Photo courtesy of Nova Mieszkowska, Marine Biological Association.*

ten years is different across the regions; in general, there has been improvement in the southern North Sea, but for most other regions, there has been no change or there is not enough evidence to assign a trend.

12.2.5 Deep-sea Habitats

Deep-sea habitats are similar to other subtidal habitats in their vulnerability to the impacts of some types of mobile fishing gears. Although this represents the main pressure on these habitats, their current status varies by region, with large areas of habitat impacted in the Scottish Continental Shelf area and only limited areas known to be impacted further offshore. The fishing pressure on this habitat has increased over the last ten years.

12.2.6 Plankton[4]

Over the past two decades, there has been a large increase in phytoplankton biomass in offshore waters around, and to the west of, the British Isles. There have been large changes (a 'regime shift') in the plankton community in UK waters particularly in the North Sea. In recent studies, climatic variability and water transparency have been shown to be more important than nutrient concentration to phytoplankton production at offshore regional scales, at least for the North Sea. Warming water has caused many phytoplankton taxa to change their seasonality (i.e. spring blooms are occurring earlier), resulting in their availability as seasonal food for zooplankton and fish larvae being out of synchrony (**Figure 12.3**). Since the 1950s, the abundance of total copepods has reduced considerably in UK waters with implications for the fish that feed on them. There has also been a marked shift from a cold boreal community dominated by plankton that spend all their time in the water column, to one characterised by warm temperate species. Since the mid-1980s, there has been a large increase in the abundance of planktonic larvae of benthic animals in the North Sea, but the causes are not clear.

Over the last 50 years, there has been a progressive shift northward in warmer water zooplankton and a retreat to the north of colder water species. The relative proportions of the cold water indicator copepod (*Calanus finmarchicus*) and its warmer water sister species (*C.helgolandicus*), which is said to have lower nutritional value, have shown a similar northward movement. The increasing sea temperature since the 1980s is the key driver linked to these changes.

12.2.7 Fish[5]

The CP2 report provides an integrated assessment of the status of fish populations over the last 20 years, with a specific focus on the past five years, using a range of data

4 Section 12.2.6 has been reproduced (with some minor modification) with permission from Reid & Edwards (2010).
5 Section 12.2.7 has been reproduced (with some minor modification) with permission from Pinnegar *et al.* (2010).

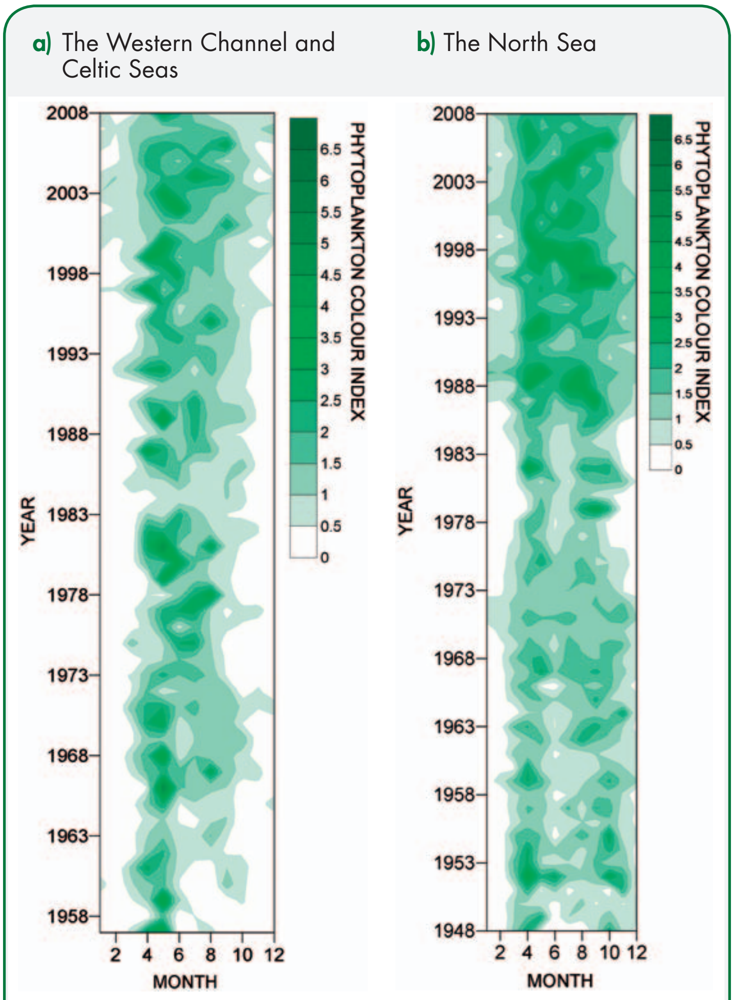

Figure 12.3 Plankton greenness determined from Continuous Plankton Recorder data in a) the Western Channel and Celtic Seas, and b) the North Sea. Source: data provided by David Johns, Sir Alister Hardy Foundation for Ocean Science (SAHFOS) (2010).

sources from non-commercial monitoring programmes. It has shown improvements since the first Charting Progress report (Defra 2005). It is more challenging to compare current state and trends with respect to historical conditions (fish communities and populations from 50, or 100 to 120 years ago, before the onset of industrialised steam trawling) as only piecemeal data exists.

The diversity and overall abundance of demersal (bottom-dwelling) fish have improved around the UK during the past five years. This probably reflects a decrease in fishing, although life-history traits, such as average size and age-at-maturity, typically show little or no change and seem to respond more slowly to reductions in human pressures. This reduction in fisheries pressure has been largely associated with a combination of EU controls on Total Allowable Catches and the large-scale decommissioning of fishing vessels in the UK.

However, demersal fish populations are, today, severely depleted when compared with those of 50 or 100 years ago, and there has been a long-term trend in overexploitation impacting fish communities as a whole. Interpretation of the limited data that exists for earlier periods suggests that, although fish are smaller on average than previously reported, species diversity may have increased in some areas of the UK compared to historic data. The Southern North Sea, the Western Channel and Celtic Sea are considered to have shown the most deterioration from historic data (1880 to 1900) due to the impact of fishing. All other areas of the UK have shown a less severe deterioration, but fishing is still acting as the main pressure and driver of change. Surveys throughout the UK have revealed a gradual increase in estuarine fish diversity and overall numbers, probably linked to the fact that many estuaries have become significantly cleaner in recent years. The numbers of adult salmon (*Salmo salar*) and sea trout (*Salmo trutta*) returning to rivers have increased on many rivers, though there have also been declines in a number of rivers. The number of eel (*Anguilla anguilla*) juveniles has fallen in many areas, reflecting an Atlantic-wide downturn in the numbers of elvers returning to rivers. Causes of this decline are unclear, but suggestions include changes in oceanic conditions, overexploitation, freshwater habitat destruction, contaminants and the introduction of the parasite *Anguillicola crassus* from Asia.

Although the general situation for most estuarine and marine fish communities seems to have improved in recent years, certain vulnerable fish have continued to deteriorate. This includes many deep-water fish species, sharks, rays and skates, and transitional/diadromous species that move between fresh- and saltwater, such as the European eel and sturgeon.

Commercial fisheries continue to exert a significant pressure on target and non-target fish populations, but there are improvements in the proportion of stocks being harvested sustainably. However, as the seas become busier, other anthropogenic pressures are also becoming increasingly apparent. These include the impact of new on- and offshore infrastructure such as: the release of endocrine-disrupting substances from sewage works; pesticides and plastics manufacturing; the extraction of sand and gravel; the loss of coastal habitats; and the extraction of water from, or alteration of river flows in, estuaries. Climate change is also beginning to have a detectable impact on fish populations, with marked changes in distribution, the timing of migration, overall reproductive output (recruitment) and growth rates.

12.2.8 Seals[6]

After decades of increase, total grey seal pup production now appears to be levelling off in the UK and is rising at only a small number of colonies. This reduction in the rate of increase is probably because of density dependent factors affecting the population as a whole, for example, competition for space and food. In contrast, harbour seal numbers have dramatically declined by more than 50% in Shetland, Orkney and the east coast of Scotland since 2001. There has been a smaller decline in the Outer Hebrides, but numbers on the west coast of Scotland have remained relatively stable. The causes of these declines are not yet known. Contributing factors could be either natural, anthropogenic, or both, and include: competition with grey seals, predation by killer whales (in the Northern Isles), unregulated shooting (in local

6 Section 12.2.8 has been reproduced (with some minor modification) with permission from Duck (2010).

areas), declines in important prey species (such as sand eels) and disease (Phocine Distemper Virus outbreaks). As a charismatic species, harbour seals are often highly valued, for example, by the local tourist industry. Therefore, even when populations are very small such as in the southern part of England, pressure on these individuals is considered significant.

12.2.9 Cetaceans[7]

Abundance estimates exist for a few cetacean species over a large geographic and temporal scale, whilst for other species the information is restricted to a more local, limited geographic scale. Harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), white-beaked dolphin (*Lagenorhynchus albirostris*), minke whale (*Balaenoptera acutorostrata*) and fin whale (*Balaenoptera physalus*) are the five most abundant cetacean species in UK waters. Their abundance in North Sea and adjacent waters has not changed and they, therefore, have a favourable conservation status assessment. The status of white-sided dolphin (*Lagenorhynchus acutus*), Risso's dolphin (*Grampus griseus*), short-beaked common dolphin (*Delphinus delphis*), killer whale (*Orcinus orca*), sperm whale (*Physeter macrocephalus*) and long-finned pilot whale (*Globicephala melas*) is unknown due to a lack of suitable abundance estimates. Other species in UK waters are considered to be rare or vagrant, so their conservation status in UK waters cannot be assessed.

12.2.10 Birds[8]

Seabird and waterbird populations in the UK have increased in size over the last century as a direct result of increased protection from hunting and persecution in the UK. But since around the mid-1990s, declines in numbers of both wintering waterbirds and breeding seabirds indicate that pressure is once again being exerted on marine bird populations.

12.2.10.1 Seabirds

The number of seabirds breeding in the UK increased from around 4.5 million in the late 1960s to 7 million by the end of the 1990s. Between 2000 and 2008, the total number of breeding seabirds decreased by around 9%, although changes in breeding numbers have varied greatly between individual species (JNCC 2009). Of the seabird species breeding in the UK, only northern gannet (*Morus bassanus*) and great skua (*Stercorarius skua*) sustained a positive trend in population size since 1969 when comprehensive monitoring of breeding numbers began. Conversely, herring gull (*Larus argentatus*) and roseate tern (*Sterna dougallii*) numbers have declined the most since 1969: by approximately 70% and 90% respectively. In 2004, 2005 and 2007, the mean breeding success of a sample of 21 seabird species was at its lowest levels since monitoring began in the mid-1980s. These falls in breeding success have been most acute in black-legged kittiwakes (*Rissa tridactyla*) and other species, such as common guillemot (*Uria aalge*), that rely on sandeels. There is strong evidence that climate-driven changes in the food chain have had acute negative impacts on seabird breeding success, particularly on Britain's North Sea coast. However, it is important to note that, although the impact of climate change on seabirds is considered to be high, much of the evidence for this is correlative rather than demonstrably causal. Other impacts affecting seabirds include fisheries reducing sandeel and other key prey species availability and quality, and reducing their discards, which is potentially linked to the reduced abundance of scavenging species such as great skua and northern fulmar (*Fulmarus glacialis*). The introduction of non-indigenous species (e.g. brown rats and mink on offshore islands that prey on ground-nesting seabirds such as storm-petrels and Atlantic puffins) has caused considerable damage to colonies in the past. However, more recent control measures have led to increases in numbers and breeding success at some seabird colonies, and to the complete recovery of others (e.g. Craik 1997, 1998).

Due to difficulties in gathering data in offshore areas, less is known about seabird populations outside the breeding season when they spend the majority of their time offshore and are not tied to particular intertidal or inshore coastal locations.

12.2.10.2 Waterbirds

Average numbers of waterbirds wintering in, or migrating through, marine areas in the UK doubled between the mid-1970s and the mid-1990s (Chapter 9). Since then, average numbers have declined slightly, but in the winter of 2006–2007, they were still 85% higher than in the mid-1970s when coordinated monitoring began. However, some species of diving duck and estuarine wader have recently declined more substantially: in 2006–2007 there were 43% fewer goldeneye (*Bucephala clangula*), 54% fewer dunlin (*Calidris alpina*) and 28% fewer bar-tailed godwit (*Limosa lapponica*) than in 1975–1976.

Five pressures were identified as being the most significant for UK waterbird populations: contamination by hazardous substances (waterbirds such as seaduck, divers and grebes have a low resistance to the effects of contamination by surface pollutants like oil); removal of species (leading to reduced food availability); habitat damage; habitat loss; and climate change. Climate change may already be contributing to recent declines in numbers of some species, including bar-tailed godwit, grey plover (*Pluvialis squatarola*), dunlin and ringed plover (*Charadrius hiaticula*), by encouraging a north-eastwards shift in their distribution. As a result, more birds are now wintering on the east coast of Britain and fewer birds are wintering in the south-west. Total numbers of waders wintering in the UK may be starting to decline as more birds move east and spend winter along the coasts of mainland Europe. The other impacts described are also thought to be contributing to changes in numbers and distributions of waterbirds. Visual disturbance from offshore renewable energy development could lead to the loss of foraging habitat for inshore feeders, such as terns, and is likely to increase in the future as the UK and Devolved Governments strive to meet their targets for renewable energy production (Mitchell 2010).

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8 Section 12.2.10 has been reproduced (with some minor modification) with permission from Mitchell (2010).

12.2.11 Summary of Pressures Causing Change in Marine Habitats and their Biodiversity

Climate change is rapidly altering species distribution, a fact which is becoming particularly evident in those marine communities and populations where long-term data is available: coastal rocky intertidal species, plankton and fish. These changes have been related to recent rapid climatic warming, with southern species extending their range northward and northern cold water species undergoing a modest contraction in range, and significant declines in abundance, at sites close to their southern limits. Climate change will also facilitate outbreaks of non-native species in the future and different species-specific rates of change are already driving alterations of community structure and function.

Human activities that have a physical impact on the seafloor (e.g. trawl fisheries, aggregate extraction, construction of offshore windfarm developments, coastal defences, ports and coastal developments) adversely affect the species and communities (benthos) which live on the seabed. Usually the impacts are quite localised, but seabed trawl fishing activity is the most widespread activity and has the greatest impact of all human activities.

There is an increase and diversification of human activity in the marine environment which is creating additional pressures on all shelf sea, coastal and estuarine habitats. These include marine renewable energy development, expansion in recreation and leisure activities, port activities and aggregate extraction, as well as land reclamation and urban development at the coast. Human contamination of marine waters with hazardous substances has been reduced through improvements in sewage treatment infrastructure and reductions in industrial effluent, but there are now concerns about emerging environmental contaminants and chemicals, such as nano-particles and pharmaceuticals, which pass through sewage treatment (Readman 2006; Guitart & Readman 2010).

12.3 Ecosystem Goods and Services Provided by Marine Habitats for Human Well-being

Marine habitats and their diversity of organisms provide a wide range of ecosystem goods, services and benefits of significant value to the UK's society (**Figure 12.4**). These benefits include: food such as fish and shellfish, the reduction of climate stress by regulating carbon and other biogases; genetic resources for aquaculture; industrial inputs for blue biotechnology such as biocatalysts, natural medicines; fertiliser (seaweed); coastal protection; waste breakdown and detoxification leading to pollution control, waste removal and waste degradation; disease and pest control; tourism, leisure and recreation opportunities; a focus for engagement with the natural environment; physical and mental health benefits; and cultural heritage and learning experiences. Energy provision is likely to be an increasingly important marine ecosystem service. The technology for energy extraction from the physical component of marine habitats, such as wave and tidal power, is being developed and biofuels from macro and microalgae are likely to be provided by their biomass in the near future. The benefits accrue directly to coastal dwellers and visitors, and also

Figure 12.4 Examples of the goods, services and benefits from Marine habitats provided to human well-being. Source: adapted from Hiscock *et al.* (2006) and Beaumont *et al.* (2006); drawings by Jack Sewell and Tim Holleyman.

indirectly to much of the UK's society. The following sections explore each of these services, and the benefits that society obtains from them, both within the UK and overseas.

12.3.1 Provisioning Services

The provisioning services provided by UK seas, such as finfish and shellfish stocks, seaweed and other raw materials, benefit people both within the UK and abroad. The benefits include: fish and shellfish for consumption both from wild capture and aquaculture; fishmeal and fish oil as inputs for aquaculture and food supplements; algae and seaweed as inputs into pharmaceuticals and biofuels; and bait used during sea angling. Although the industry built around the provisioning of fish is declining in importance in terms of its contribution to Gross Domestic Product, it still remains an important socio-economic activity in coastal regions. This is especially so in remote coastal communities in Scotland, Wales and south-west England where it provides employment through fishing, aquaculture farms, fish processing, and associated industries such as boat building and maintenance, gear supply, markets and transportation. This section focuses on trends in production and consumption of fisheries resources from the UK's marine habitats.

Official statistics for catch landings by UK and foreign vessels into the UK are used as a proxy for the volume and value of the provision of fish for consumption. It is important to note that, although these statistics are incomplete estimates of the total provisioning services provided by marine habitats in UK waters, alternative technology now available, may improve future estimates (**Box 12.2**).

Not all fishing vessels registered in the UK are obliged to land all their UK catch in the UK, and similarly vessels registered in other countries can land some of their non-UK catch in the UK should they choose to do so. The Sea Around Us project estimates that more than 75% of the volume of fish caught in UK seas in 2006 was captured by non-UK vessels, notably by French, Danish, Norwegian and Dutch fishing fleets. It is also difficult to relate specific landings to the actual location where they were caught. Currently, technology allows catches to be attributed to areas of the oceans, usually referred to as ICES (International Council for the Exploration of the Sea) rectangles (0.5° Latitude x 1° Longitude), but this has not always been the case and many of the rectangles include both UK and non-UK waters. For example, UK vessels catch fish from the west of Scotland, Irish Sea, Norwegian Coast, Bear Island and Spitzbergen, Faroe Islands, North Sea, Rockall, Barents Sea, south and west of Ireland, English Channel, Bristol Channel, Bay of Biscay, east and west of Greenland, and Labrador, amongst other areas. The most important areas are the west of Scotland, Irish Sea, North Sea, south and west of Ireland, Celtic Sea and the English Channel. Finally, there is no defined relationship between landings of fish by UK boats and consumption of fish by UK citizens, so the benefits obtained from fish consumption caught by UK and foreign vessels landing into UK waters must be assumed to be obtained both within the UK and by the UK's export markets (e.g. Netherlands, France and Russia).

The remainder of this section draws on historical data collated from the UK Sea Fisheries Statistics. Unfortunately, it is difficult to attribute this data in a strict sense to marine ecosystems that lie within the boundaries of the UK, but it is currently the best data available, for the time period covered by the UK National Ecosystem Assessment (UK NEA).

Box 12.2 Using position data and catch value to illustrate spatial dimension of catch value. An alternative approach to quantifying and valuing food provisioning from UK seas is to use spatial effort data based on satellite-derived Vessel Monitoring System (VMS) position data of vessels over 15 m, and plot this together with catch value as shown in **Figure 1** (Saunders *et al.* 2010). At present, this data is only available for 2004 to 2007 and does not distinguish between species caught. Nevertheless, it provides a highly resolved spatial dimension to catch data and demonstrates the patchy nature of catch value by area. It also illustrates the importance of coastal areas around the mainland and offshore islands; these areas tend to have the highest value, reflecting the dominance of shellfisheries for lobster, crabs, nephrops (scampi or langoustine) and scallops. Other areas of value include the shelf-edge of northern Scotland and the northern half of the North Sea; demersal species are particularly important targets for the Scottish fleet in these areas, as are nephrops.

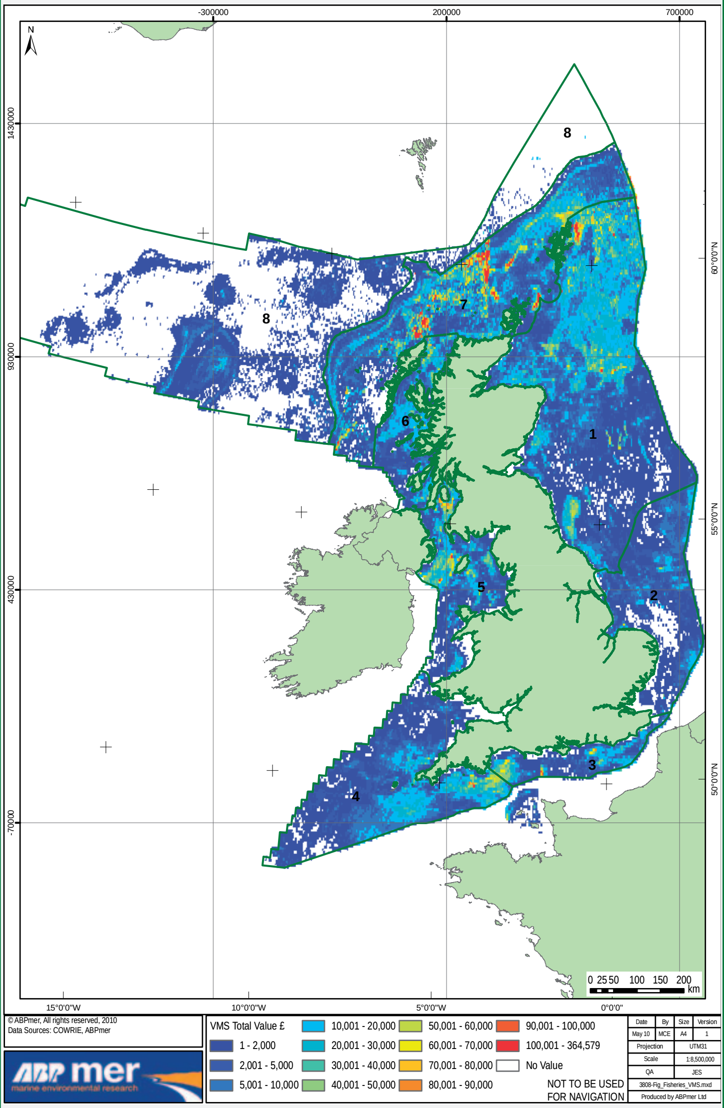

Figure 1 Spatial distribution of the annual mean value of all UK fish landings in 2004–2007 based on VMS position data and ICES rectangle data on catch value for VMS vessels. Source: map reproduced with permission from Dunstone (2008).

12.3.1.1 Production

Finfish and shellfish from marine ecosystems. Landings of fish are divided into three separate fisheries statistics categories: 1) demersal fish species which live on or near the seabed including cod, haddock, plaice, whiting, pollack, and soles; 2) pelagic fish species, such as herring and mackerel, which are typically found in mid and upper waters; and 3) shellfish including scallops, oysters, mussels, cockles, octopus, squid, cuttlefish, prawns, crabs, and lobsters.

Total landings of demersal, pelagic and shellfish species combined into the UK increased from 1.1 million tonnes per year in 1938 to 1.2 million tonnes per year in 1948, after which they declined steadily to 0.5 million tonnes in 2000 (MMO 2010). Thereafter, total landings have remained stable (**Figure 12.5**). The value of total landings on the other hand, increased rapidly from around £17 million in 1938 to £464 million in 1990, and has shown a gradual increase since then. However, if these figures are adjusted using the Retail Price Index (RPI) to be equivalent to 2008 values (**Figure 12.5**), the total value of the fish catch shows a similar decline to that of volume caught. The decline in landings has not been consistent across all landing categories. Landings of demersal and pelagic species have declined over time, while landings for shellfish increased from 34,090 tonnes in 1966 to 144,986 tonnes in 2008 (**Figure 12.6a**). Landings of shellfish have now overtaken both demersal and pelagic species in terms of value (**Figure 12.6b**), but they remain the smallest in terms of volume. Demersal species still constitute the largest proportion of total landings, but they are much reduced since the Second World War (WWII) as a result of declining stock sizes, reduced quotas and imposed fishing effort reductions in the North Sea, eastern English Channel, west of Scotland and Irish Sea.

From 1956 to 2008 there have been declines in landings of demersal and pelagic finfish and shellfish in all regions of the UK (**Figure 12.7a**), but declines have been most dramatic in England and Wales. Pelagic landings have shown instability across the countries throughout the whole of this period (**Figure 12.7b**), while shellfish landings have increased for all (**Figure 12.7c**).

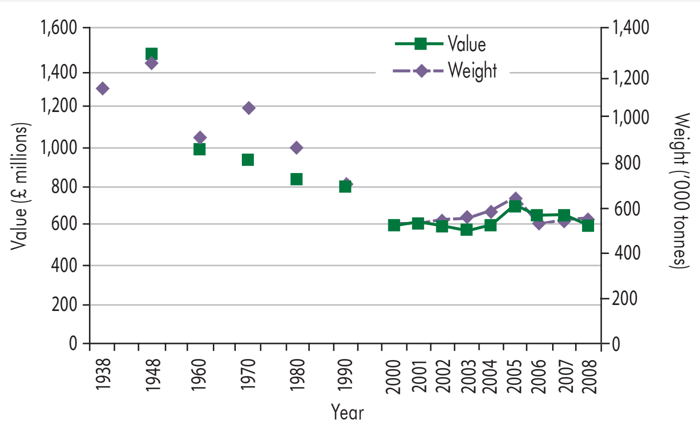

Figure 12.5 Landings into the UK by UK and foreign vessels: 1938 to 2008 adjusted to 2008 prices using the Retail Price Index. Source: data extracted from MMO (2010).

The trends in demersal and pelagic finfish landings can be attributed to a number of factors including: declining fish stocks due to fishing and environmental change; catch quotas; restrictions on the number of days allowed at sea; a shift to shellfish harvesting; and latterly, decommissioning schemes that have seen reductions in the size of the overall fishing fleet.

For certain species, such as cod and herring, there have been substantial declines in landings during this period following stock crashes. Reporting on the mackerel fishery in the English Channel and Celtic Sea, Lockwood and Johnson (1976) state that between 1926 and 1966 mackerel catch fluctuated between 12,000 and 40,000 tonnes; by 1970 this had increased to 60,000 tonnes, and in 1975 it was more than 300,000 tonnes. They report that similar increases were seen in the North Sea. The mackerel catch has since declined and, in 2008, approximately 90,000 tonnes were harvested (MMO 2010). The North Sea herring fishery has also had mixed fortunes; overfishing since WWII led to a stock collapse and a complete moratorium on herring fishing between 1978 and

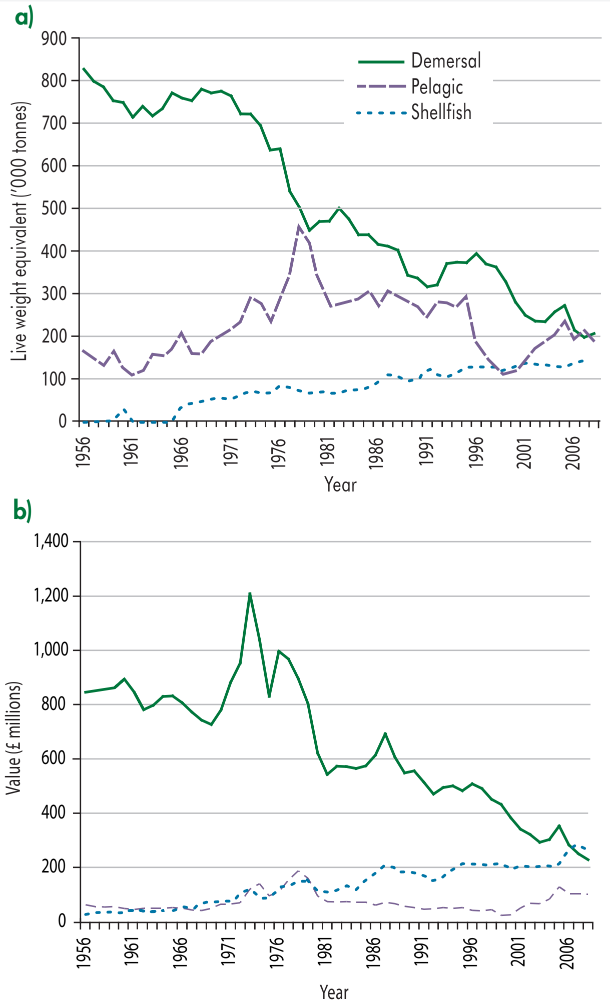

Figure 12.6 Landings into the UK by UK and foreign vessels from 1956 to 2008 by a) live weight equivalent, and b) value, of three categories of landings: demersal, pelagic and shellfish. Values were adjusted to 2008 prices using the Retail Price Index. Source: data extracted from MMO (2010).

1982. Herring biomass has subsequently recovered and the fishery is now considered to be within safe biological limits (Pinnegar *et al.* 2006).

Shellfish landings, especially of scallops and Norway lobster (*Nephrops* species), have increased since 1966. The increase in scallop fishing is partly due to stringent quotas being placed on demersal and pelagic fish species, but also the ease by which boats fitted for demersal trawling can be converted to activities such as scallop dredging. In addition, most shellfish species are not under quota restrictions (quotas are only in place for *Nephrops* species and the northern prawn *Pandalus borealis*).

The recorded declines in landings do not necessarily reflect the size of the fish stocks in UK waters. Out of 18 indicator finfish stocks in UK waters, the proportion of stocks being harvested sustainably rose from 5–15% in the early 1990s to around 50% in 2008 (Armstrong & Holmes 2010). The proportion of stocks with full reproductive capacity (when spawning stock biomass is at, or above, the ICES-defined precautionary reference point at the start of each year) declined until the late 1990s, but since 2000, has started to increase again. However, the majority of stocks continue to be fished at rates well above the values expected to provide the highest long-term yield (Saunders 2010).

To fully understand the importance of food provisioning services from the marine environment, it is necessary to consider the effort expended in catching the fish and other secondary services associated with marine fishing. In 1948, there were 39,380 regular fishermen in the UK, by 2008, this number had fallen to 10,242 (**Figure 12.8**). England and Wales have constantly had the highest number of regular fishermen compared to Scotland and Northern Ireland. The capacity of the Scottish fleet, however, is much greater than that of the English, Welsh and Northern Irish fleets (**Table 12.3**), reflecting the greater proportion of boats over 10 m-long in the Scottish fleet.

In recent years, there has been a decline in fishing effort in the demersal whitefish fleet in the cod recovery zones. The

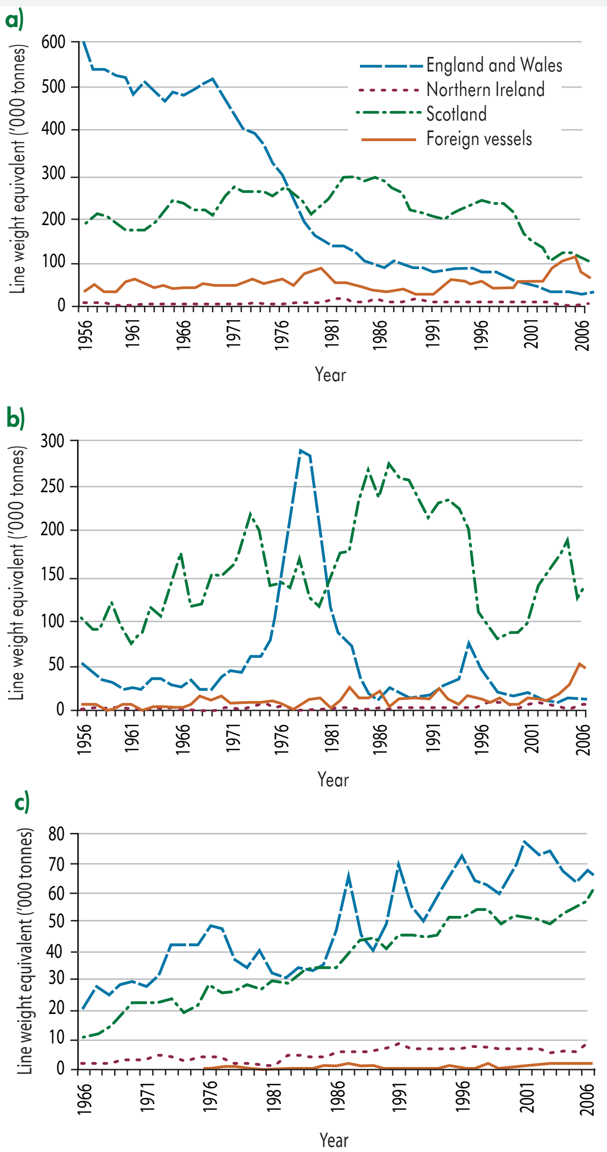

Figure 12.7 Landings (live weight equivalent in tonnes) of a) demersals (1956 to 2008), b) pelagics (1956 to 2008), and c) shellfish (1966 to 2008) into England and Wales, Scotland and Northern Ireland by UK vessels and by foreign vessels into the UK. Source: data extracted from MMO (2010).

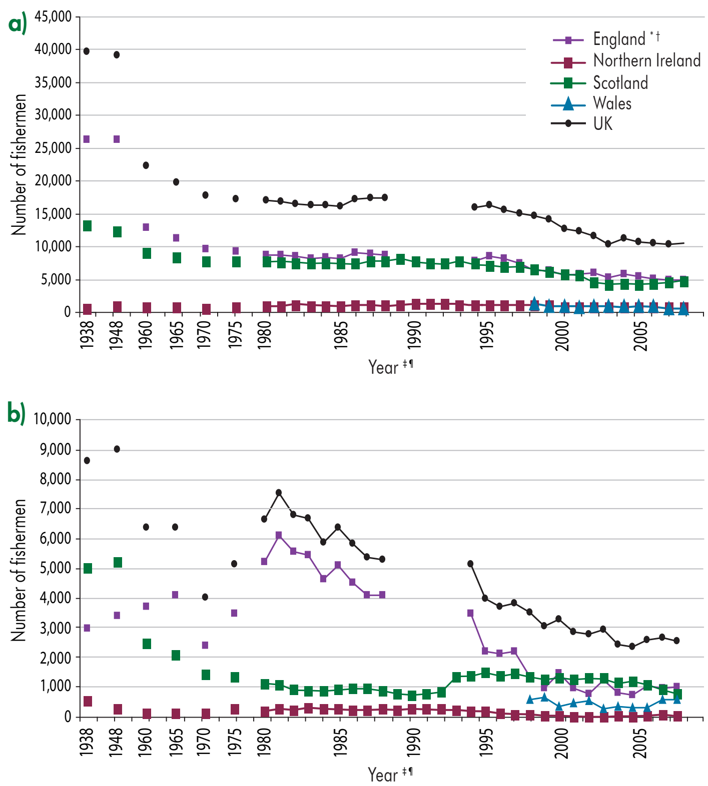

Figure 12.8 Changes in total number of a) regular and b) part-time fishermen for each nation of the UK. No data is available for England and Wales between the years 1989 to 1993. *Prior to 1952 figures were based on information supplied by the Registrar General of Shipping and Seamen. Since 1952 figures have been supplied by the District Fishery Officers of Defra. †From 1966 these figures exclude 'hobby' fishermen, i.e. fishermen who do not fish commercially. The corresponding figures for Scotland and Northern Ireland have never included 'hobby' fishermen. ‡1987 figures include those from 1986 for Newlyn and Plymouth. ¶The apparent increase in fisherman in Scotland 1993 reflected the licensing of 10 m and under vessels, when more information became available on the numbers of such active vessels. Source: data extracted from MMO (2010).

Table 12.3 Fleet capacity in 2008 by country. Source: data extracted from MMO (2010).

Country	Number of Vessels	Capacity (gross tonnage)	Engine power (kilo watts)
England	3,200	59,974	306,450
Northern Ireland	351	12,734	52,828
Scotland	2,213	126,794	419,984
Wales	470	5,606	32,803

UK fleet has been heavily altered by both decommissioning and vessels switching from demersal fish to *Nephrops* fishing. Restrictions on the number of days allowed at sea, introduced by the Scottish Parliament in 2003 for the North Sea and Irish Sea and west of Scotland cod recovery zones, are also limiting the number of fishing days of certain segments of the UK fleet. In addition, decommissioning schemes run between 1997 and 2007 have led to a reduction in fleet size which has resulted in a 12% decrease in fish landed. As a consequence of fleet contraction, the Scottish demersal fleet is now considered to be in line with catch opportunity (Baxter *et al.* 2008).

A number of secondary services are also supported by the provision of fish, both up and down the supply chain. The fishing industry is dependent upon boat builders and repairers, gear merchants, and suppliers of boxes and ice, amongst other items. At the same time, the industry supplies numerous fish processors and food industries, and the UK has around 480 fish processing sites that employ around 15,000 people (Seafish 2009). Furthermore, the seafood service sector covers a range of outlets including fish and chips shops, and hotels and restaurants, and hence, is beneficial to millions of workers and consumers. There are also around 280 ports, harbours and creeks around the UK where finfish and shellfish are landed. The major fishing ports in the UK in terms of value of fish landed are Peterhead, Fraserburgh and Lerwick (all in Scotland). In 2005, the combined employment level in the catching, processing and aquaculture sector in the UK was 31,633 people, representing 3.5% of the total employment in all maritime industries in the UK, including leisure and recreation (Pugh 2008).

Fishing impacts on the marine environment. The removal of fish from marine environments has a number of impacts on marine ecosystems which may affect the delivery of other ecosystem services. Food web changes occur when the abundance of a species is severely reduced. Physical impacts are also common, especially from the use of bottom-trawls and dredging methods. The impacts of beam and demersal trawls on benthic communities are well understood. They are known to affect the biomass and production of benthic invertebrate communities (Jennings & Kaiser 1998) which are an important food source of many commercially exploited fish species. Disturbance of these benthic communities may also interfere with supporting ecosystem services such as nutrient cycling (Widdicombe *et al.* 2004).

Aquaculture. Aquaculture is the farming or culturing of aquatic organisms (fish, molluscs, crustaceans and algae) using techniques designed to increase the production of the organisms in question, for example, through regular stocking, feeding and protection from predators (ONS 2007). The majority of marine aquaculture in the UK is related to salmon and shellfish (including mussels, oysters, clams and scallops) farming. Farming of seaweed is a growing part of this sector although there is very little information about its likely future importance or impact.

As catches of wild fish have declined over time, so the demand for farmed fish has increased. The aquaculture sector in the UK has increased dramatically: the economic contribution from fish and shellfish farming increased by 132% over the period 2000 to 2006 (CEFAS 2008). In 2007, Scottish production of marine finfish represented over 99% of UK cultured marine finfish, producing approximately 130,000 tonnes (FRS 2009). Production was dominated by Atlantic salmon (*Salmo salar*), making Scotland the largest salmon producer in the EU and the third largest globally after Norway and Chile (Baxter *et al.* 2008). In 2007, turnover from finfish farming in the UK was £327 million, while shellfish farming generated £23 million (CEFAS 2008).

Trends in Scottish salmon production show a nine-fold increase from 17,952 tonnes in 1988 to 169,736 tonnes in 2003 (**Figure 12.9**). Between 2002 and 2005, salmon production varied, but since then, it has remained stable. At the same time, employment in the salmon aquaculture farms has decreased from 1,309 total staff in 1998 to 949 staff in 2008 (FRS 2009; **Figure 12.10**). Mean productivity per person, however, has been increasing; for Atlantic salmon it increased from 132.4 tonnes per person in 2005 to 151.4 tonnes per person in 2006 (Baxter *et al.* 2008).

In England and Wales, there were 518 registered fish and shellfish farms in 2008, of which, 197 were trout and other finfish farms (marine and freshwater fish are not separated) and 128 were shellfish farms; the remainder were coarse fish farms. Shellfish farm production in England and Wales has been gradually rising (**Figure 12.11**). A total of 15,686 tonnes were produced in 2008 comprised primarily of mussels (15,025 tonnes) and oysters (642 tonnes). In England it was worth £4.5 million in 2007, and was mainly mussels with small quantities of Pacific oyster (*Crassostrea gigas*) and native oyster (*Ostrea edulis*), and very small quantities of clam and cockle (Saunders 2010). In Wales, shellfish production was almost entirely mussels and was worth £7.5 million. In Northern Ireland there were 84 licensed fish farms in 2007 (CEFAS 2009) which were dominated by mussels, with some oyster and clam production. It was estimated to be worth £5.8 million in 2007 (Saunders 2010). Shellfish production in Scotland in 2007 involved 170 shellfish production companies operating on 336 sites and was worth £5.1 million. Total production in 2007 was 5,053 tonnes, and was dominated by mussels (4,806 tonnes), followed by Pacific oysters (208 tonnes), native oysters (22 tonnes), queen scallops *Aequipecten opercularis* (15 tonnes) and scallops *Pecten maximus* (2 tonnes) (FRS 2008).

Marine aquaculture contributes 21.4% of the finfish and shellfish supplied to the fish processing sector (Seafish 2009). Provisional data for 2007, released by the Office for

National Statistics, shows that total sales (turnover) by the UK fish processing sector were £2,567 million, compared with total inputs of £2,077 million, resulting in a GVA (Gross Value Added) of £490 million. Based on the proportion of aquaculture product supplied to the fish processing sector, it is estimated that £105 million of the GVA was related to aquaculture.

Aquaculture impacts on the marine environment. The CP2 Productive Seas Evidence Group Feeder Report (Saunders 2010) describes a number of impacts of both finfish and shellfish aquaculture on the marine environment. Finfish production often has a greater environmental footprint due to:

- The dependence on wild species as fish feed (e.g. sandeeels, herring and anchovy), the removal of which may impact on seabird breeding success.
- The organic enrichment of areas beneath fish cages leading to the deoxygenation of seabed sediments.
- Increased inputs of nitrogen and phosphorus from fish faeces which may contribute to phytoplankton growth and eutrophication.
- Introductions of non-indigenous species and interbreeding of escaped farm species with the wild population.
- Increased densities of larval sea lice which can be transferred from farmed fish to wild fish.
- Contamination by synthetic compounds (e.g. disinfectant antibiotics) and non-synthetic compounds (e.g. heavy metals).
- The introduction of microbial pathogens.
- Changes in habitat structure, water flow and wave exposure due to the presence of infrastructure both underwater and around the aquaculture site.
- Management of other species, such as seals, that may impact on aquaculture.

Shellfish aquaculture is often considered relatively sustainable, especially where spat collection results as a consequence of natural settlement (as is the case of many mussel farms) and where harvesting is based on hand-collection or raking. Where bottom cultivation is used and harvesting (including spat collection) is undertaken by dredging (e.g. for mussels and oysters), there are concerns over the impacts of physical damage to the environment. Other concerns over shellfish aquaculture include localised depletion of phytoplankton where overstocking has occurred and the introduction of non-indigenous species.

Fishmeal and fish oil. Fishmeal is produced almost exclusively from small, bony species of pelagic fish which generally live in the surface waters or middle depths of the sea, and for which there is a limited market for human consumption, for example, sandeel, herring, capelin and sprat (**Figure 12.12**). Fishmeal production also provides a major outlet for recycling trimmings from the food-fish processing sector, which would otherwise be dumped at extra cost to the environment and the consumer. The UK imports around four times as much fishmeal as it produces (FAO 2008).

Seaweed (macroalgae). Seaweeds play a wide and varied role in modern life as they are increasingly being exploited as a food resource and a source of industrial

Figure 12.9 Annual production of Atlantic salmon (live weight equivalent in tonnes) from the Scottish aquaculture sector between 1988 and 2008. Source: data extracted from FRS (2009).

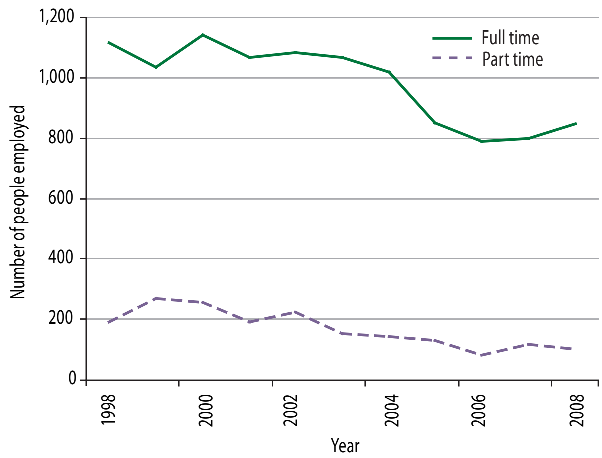

Figure 12.10 Number of people employed in Scottish salmon farms between 1988 and 2008. Source: data extracted from FRS (2009).

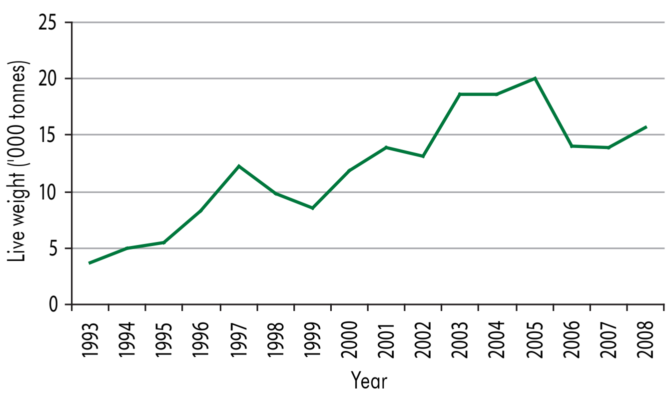

Figure 12.11 Farmed shellfish production (live weight equivalent in tonnes) in England and Wales from 1993 to 1998, including the production of oysters, mussels, clams, cockles and scallops Source: data extracted from CEFAS (2009).

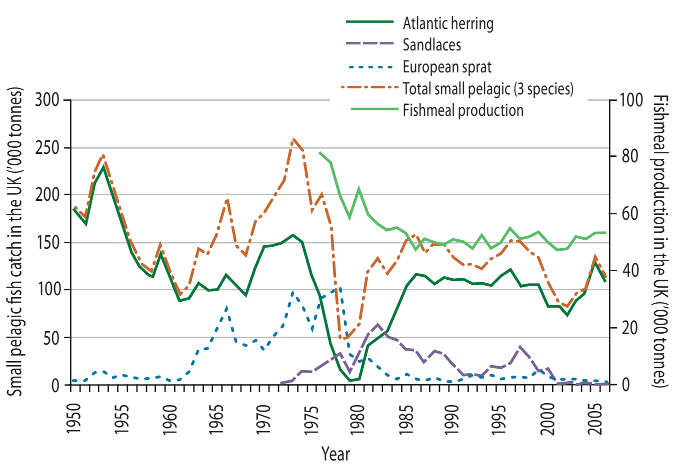

Figure 12.12 Yearly small pelagic fisheries and fishmeal production in the UK. The species used to produce fishmeal are herring, sprat, sandeels and capelin (following the International Fishmeal and Fish Oil Organization). Source: data from the Food and Agriculture Organization (FAO) FishStat statistical collections for fish production in the UK (FAO 2008).

and pharmaceutical chemicals. Gelatinous extracts include alginate, agar and carrageenan, which are used as food additives. Seaweeds are marketed for consumption as sea vegetables, beauty and health products, and land fertilisers. The UK coastline harbours a large array of seaweeds, a small number of which are exploited for commercial gain. Around 3,000–4,000 tonnes (wet weight) per year of *Ascophyllum* are harvested in Scotlands' Uist Islands (see The Minch Project; www.cne-siar.gov.uk/minch/seaweed/seaweed.htm), along with *Laminaria* species, principally *L. hyperborea*, cast ashore during the winter months; some 35 people are involved in its collection. In 2006, three commercial seaweed harvesting companies were identified in Northern Ireland, although small-scale collection is also seasonally customary (McLaughlin *et al.* 2006). Twelve species of seaweed were commercially harvested as fresh vegetation or drift, beach-cast seaweed. Collection was carried out largely by non-mechanical means: harvesters use boats for shore access, vehicles for the transportation of the harvest, and diving and cutting equipment. The international seaweed industry value exceeds US $6 billion annually (McLaughlin *et al.* 2006; equivalent to approximately £3.6 billion), which is an important driving factor for the UK seaweed industry.

Bait. Estimates of sea angling in the UK currently suggest that at least 1,000 tonnes of bait worms are used every year (Fowler 1999). Bait collection or provision activity is rarely recorded or declared, but market surveys indicate that some 500–700 tonnes of bait worms are dug for personal use and 300–500 tonnes of worms from commercial (including 'black economy') sources enter the retail trade. Bait worms entering the retail market are derived from wild-dug and farmed sources in the UK. The commercial value of the main bait species (e.g. ragworms (*Neanthes* (*Nereis*) *virens, Hediste* (*Nereis*) *diversicolor, Nephtys* species), lugworms (*Arenicola marina*, *A. defodiens*) and peeler crabs (*Carcinus maenus*)) in the UK is between £25–£30 million per annum (Fowler 1999).

12.3.1.2 Consumption

Supplies of seafood to the UK can be divided into four categories: landings by UK and foreign vessels, aquaculture, and imports. In 2008, consumers in the UK bought over 385,000 tonnes of fresh, frozen and canned seafood at retail outlets, together worth over £2.73 billion (Seafish 2009). The UK consumes an average of 23.6kg of fish products per person per year, and predictions have suggested that this is set to rise (Pinnegar *et al.* 2010). The UK human population is anticipated to rise from 61 million to 77 million by the year 2051 (Office for National Statistics 2010). This equates to a total UK demand for fish products of 1.8 million tonnes, suggesting that indigenous and global fish resources will come under increasing pressure in the future.

UK exports of fish and shellfish rose from 377,000 tonnes (£355 million) in 1998 to 480,000 tonnes (£891 million) in 2003 (Saunders *et al.* 2010). Exports subsequently declined in weight to 431,000 tonnes in 2007, although the value increased to £944 million in 2006 before declining to £909 million in 2007. Exports are mainly the pelagic fish mackerel and herring, as well as salmon.

The UK is becoming increasingly reliant on imports. Import volumes have increased by 46% between 1998 and 2008. In 1998, 533,000 tonnes (£1,066 million) were imported, rising to 754,000 tonnes (£1,922 million) in 2006 (MFA 2008), making the UK a net importer of fish. The main species imported are cod, haddock, tuna, shrimps and prawns. For some key demersal species, such as cod and haddock, imports currently are well in excess of exports. Whereas in the pelagic fishing sector, exports of herring and mackerel are larger than imports. Most imports in 2007 were from European countries. These figures are part of the total landings into the UK.

12.3.1.3 Pressures

The provision of fish and other ecosystem services are being impacted through non-sustainable rates of fishing mortality (related to fishing effort and fishing gear selectivity) leading to changes in age structure, spawning stock biomass, species compositions and distribution of fish stocks. In addition, some fishing practices, such as trawling and dredging, have a negative impact on the marine environment which, in turn, reduces the environment's ability to provide food. Climatic factors have been shown to alter fish community structure through changes in distribution, migration, recruitment and growth (Pinnegar *et al.* 2010; Pinnegar & Heath 2010).

Profitability of fishing operations has also varied widely due to factors such as increases in fuel prices, quota trading, and first-sale prices following the introduction of buyers and sellers regulations in 2006. For instance, the demersal fisheries in the North Sea, west of Scotland and Irish Sea have experienced a shift away from offshore fishing for finfish species, towards valuable fisheries for Norway lobster and other shellfish, along with mixed demersal species in inshore waters (Saunders *et al.* 2010). The shift away from offshore demersal finfish has resulted partly from long-term declines in many stocks and associated fishing restrictions, particularly those aimed at cod recovery, and partly from the perceived economic opportunities in other fisheries.

The Common Fisheries Policy (CFP) has been the dominant regulatory influence on the behaviour of fishermen.

The restrictive influences of this policy have intensified in recent years with a combination of catch quotas, gear restrictions and limits on days at sea all seeking to reduce fishing effort and catches to more sustainable levels. The fishing industry has also continued to innovate, and there have been marked technological developments to increase catch efficiency. However, Thurstan *et al.* (2010) propose that the landings of fish (in tonnes) per unit of fishing power may have declined by 94% over the last 118 years (1889 to 2007). It seems obvious that declining stocks of many fish have resulted in reduced catches. Climate change is also a factor and is to be included alongside fishing pressure in the current ongoing review of the CFP to cover the two main drivers of fish stocks in the north-east Atlantic.

12.3.2 Regulating Services

12.3.2.1 Waste breakdown and detoxification

There is a long history of the use of rivers, estuaries and coastal water for disposal of various types of waste materials by humans. The waste results from industrialisation and the need to dispose of toxic and non-toxic materials, and urbanisation requiring the need to remove human waste products through sewerage systems. This use of the water system solved immediate health problems for humans, but created environmental problems. Yet the environment has a natural capacity to detoxify some substances and to degrade others to less toxic forms (although sometimes more toxic forms are produced). Marine ecosystems that receive human waste materials are, therefore, providing a waste breakdown and detoxification service. The capacity of the marine environment to cope with such loads has been overwhelmed at times, resulting in pollution.

The development of sewerage systems resulted from the need to dispose of human waste away from populations to allow improvements in human health and hygiene; with relatively low population levels at the time, this proved successful. The subsequent growth in population resulted in a gross overloading of many estuarine and coastal waters, and led to the introduction of different levels of technical treatment over time. Primary treatment, involving the settling of solid material and its subsequent disposal to agricultural land as soil conditioner and fertiliser, or the disposal of solid material to designated coastal sites, was effective for many years. However, this resulted in many waters being contaminated with faecal bacteria and caused local changes to the ecosystem at designated sites. After WWII (during which the sewerage infrastructure had been severely damaged in many places), the needs of the developing population were met by no, or only primary, treatment of solid material prior to its discharge to coastal waters. By the end of the 1980s, however, it was apparent that there was a need for change, and the EC Urban Waste Water Treatment Directive came into force requiring a minimum of secondary treatment generally using aerobic biological processes to degrade the biological content of the sewage (derived from, for example human waste, food waste, soaps and detergent) before discharge. Hence, the pressure on the environment's capacity to process the sewage effluent reduced. Although the human population continues to grow, technical treatment has reduced our need to make use of the capacity of the ecosystem to degrade sewage waste. There still remain local issues, however, where the presence of human faecal bacteria and pathogens is affecting other uses of the coastal seas.

The deleterious effects of recently introduced and less well studied environmental contaminants and chemicals, such as nano-particles and pharmaceuticals, which pass through sewage treatment plants is of concern, and the capacity of ecosystems to breakdown and detoxify these products is largely unknown (Readman 2006; Celiz *et al.* 2009).

Sewage contains significant quantities of the nutrients nitrogen and phosphorous. Add to this the significant use of compounds of nitrogen and phosphorus in agriculture as fertilisers, manures and slurries and there is considerable risk of eutrophication, especially in estuaries and coastal waters, if nutrient enrichment leads to an increase in the growth of algae and other plant life and subsequently causes an undesirable disturbance to the balance of organisms and water quality. To prevent this happening, many discharges of sewage to freshwaters are now given further treatment to remove nitrogen and phosphorus. In England and Wales, for example, secondary treatment was applied to the waste from 63 million population equivalents (a measure of the load from sewage and industrial waste expressed in human population terms) in 2009, which is about 99.4% of the total; of this, 16 million population equivalents were subject to tertiary treatment including the reduction of nutrient concentration (Environment Agency pers. comm.). As a result of such treatments, eutrophication has become a localised problem. The fact that the seas around the UK are dynamic and well-oxygenated—a requirement of the bacteria that help to breakdown the organic materials in sewage—also means that further treatment of sewage is often not necessary. Wetlands, particularly around estuaries, can be very effective at absorbing nutrients and further reducing the load on the sea. This capacity is under threat from construction for flood and coastal protection and, though mostly in the past, through land reclamation. Some of this capacity is being redeveloped as part of managed realignment schemes improving natural flood defences, but it requires careful management to deliver the service (Andrews *et al.* 2006; Shepherd *et al.* 2007; Chapter 11).

Since WWII there has been a rapid growth in chemical industries and industries that make use of a wide range of chemicals. This has resulted in the discharge of substantial quantities of substances to the seas which have caused various degrees of pollution; now, all significant industrial discharges are subject to permits designed to protect the environment. However, there still is a legacy today of certain substances that are persistent, toxic and liable to bio-accumulate, and these materials will be present in the environment for some time. To some extent, and for some substances, burial in sediments and dispersion will reduce the threat that these substances pose—providing a service of storage and removal from the environment. In some circumstances, activities that disturb sediments, such as bottom trawling or dredging and disposal operations in ports, can interfere with this service.

We use the environment to degrade all contaminants on a shorter or longer timescale by bacterial action, hydrolysis, photolytic degradation and metabolism within animals. Anything which is readily biodegradable or which hydrolyses rapidly would take a shorter time to degrade (e.g. organophosphate insecticides); anything that is persistent (e.g. polychlorinated biphenyl's (PCBs), particularly CB138, CB153 and CB180) would take longer to degrade. But over varying periods of time, the majority are eventually transformed to less toxic compounds. There can be problems with this service, for example, alkylphenol ethoxylates are readily degraded, but to alkylphenols which are both more persistent and more toxic. While it may be desirable to ensure that discharges of hazardous substances to the sea are as low as we can reasonably achieve, we should also aim to avoid damaging the plants and animals in the sea—making appropriate use of the capacity of the sea to degrade and detoxify will help us to achieve this.

Some of the most high profile, and often accidental, discharges are those of oil (hydrocarbons) into the sea. The oil and shipping industries release small quantities of oil during routine operations which, together with natural oil seeps on the seabed, provide a background level of hydrocarbons in the seas. Populations of bacteria which can degrade hydrocarbons are present in the sea. Therefore, there is an effective natural cleansing service in the seas for hydrocarbons, except in the case of large spills from shipping accidents. Even in the case of large spills, the oil is eventually degraded, although it can take some time to return to pre-existing levels due to a combination of factors; more often than not, it takes the oil too long to degrade to prevent disruption to other ecosystem services.

Growth of organisms on structures and vessels in the sea is known as fouling and can be a serious problem reducing the performance and strength of these economically important maritime appliances. The widespread use of Tributyltin (TBT) as an anti-foulant on ships and structures during the 1970s and 1980s dealt with the problem very effectively. However, a well-documented side-effect of TBT is the severe impact it has on certain molluscs (Gibbs *et al.* 1991; Vos *et al.* 2000). Following restrictions on the use of TBT due to its detrimental effects on marine life, and coupled with the fact that TBT does degrade in the seabed as a result of bacterial activity, there is good evidence that the problems it causes will disappear after a few years. Since the ban on the use of TBT, several new synthetic anti-foulants have been brought onto the market. Some, including Irgarol, are compounds which have been shown to have deleterious impacts on non-target benthic organisms living in the vicinity of marinas, ports and harbours (Hall *et al.* 1999; Chesworth *et al.* 2004).

12.3.2.2 Climate regulation

The chemical composition of the atmosphere and ocean is maintained through a series of biogeochemical processes regulated by living marine organisms. The maintenance of a healthy, habitable planet is dependent on processes such as the regulation of the volatile organic halides, ozone, oxygen and dimethyl sulphide, and the exchange and regulation of carbon, by marine organisms. For example, marine organisms play a significant role in climate control through their regulation of carbon fluxes, by acting as a reserve or sink for carbon dioxide in living tissue, and by facilitating burial of carbon in seabed sediments. Of all the carbon dioxide captured in the world by photosynthesis and stored as living or dead material of biological origin, over half (55%) is captured by living marine organisms (Nellemann *et al.* 2009). However, there is no readily available data for the UK that quantifies total living biomass in marine and estuarine sediments or the water column.

Shelf sea systems make a significant contribution to the carbon budget (Nellemann 2009), and marine phytoplankton productivity in UK ocean, shelf and coastal waters has been used as an indicator of the climate regulation service (Beaumont *et al.* 2008). Large-scale marine primary production can be determined by remote sensing methods to quantify the concentration of photosynthetic pigments (Joint & Groom 2000). Production can then be calculated using the photosynthesis model of Smyth *et al.* (2005). This model was applied to earth observation data collected between 1998 and 2009 (www.neodaas.ac.uk) to calculate planktonic primary productivity for an area slightly larger than UK territorial waters (47°–63°N; 15°W–9°E). The average annual primary production (carbon sequestered by phytoplankton) was 0.371 ±0.020 billion tonnes of carbon per year (Gt C/yr ±95% confidence interval; Smyth unpublished). This is about 0.75% of the widely accepted value of around 50 Gt C/yr for global marine production based on global primary production models (Behrenfeld & Falkowski, 1997; Field *et al.* 1998; Carr *et al.* 2006). Values for the 12-year period are quite variable with no clear patterns evident (**Figure 12.13a**). These surface water figures are an underestimate for total primary production. They do not include primary production from the significant quantities of macroalgae on the intertidal seashore and the shallow subtidal rocks, nor from the significant levels of benthic micro-algal production on intertidal sand and mudflats, especially within estuaries. They also do not indicate how much of the fixed carbon is then subsequently sequestered either by removal offshore sinking into deep water and sediments, or by burial in shallow water sediments.

Another approach that is being developed by various research projects (e.g. Natural Environment Research Council (NERC) Oceans 2025, EU Marine Ecosystem Evolution in a Changing Environment (MEECE)) is coupled, hydrodynamic ecosystem modelling of the last 50 years in the north-east Atlantic and north-west European shelf seas. A 3D simulation model hindcast (ERSEM-POLCOMS and developments (Allen *et al.* 2001; Holt *et al.* 2005)) forced by the ECMWF-ERA (climate) re-analysis produces estimates of annual biomass of carbon in the pelagic components of bacteria, phytoplankton and zooplankton (Butenschön unpublished, **Figure 12.13b**). Similar to the 12-year phytoplankton production time-series, there is considerable annual variation in the modelled biomass outputs and no signal of a clear trend in change over the period from 1960 to 2004.

Changes in marine biodiversity influence the biogeochemical cycling of carbon and nutrients within seabed sediments, in the overlying water column, and at the interfaces between sediment and water. This can ultimately result in changes in the capacity of the marine environment

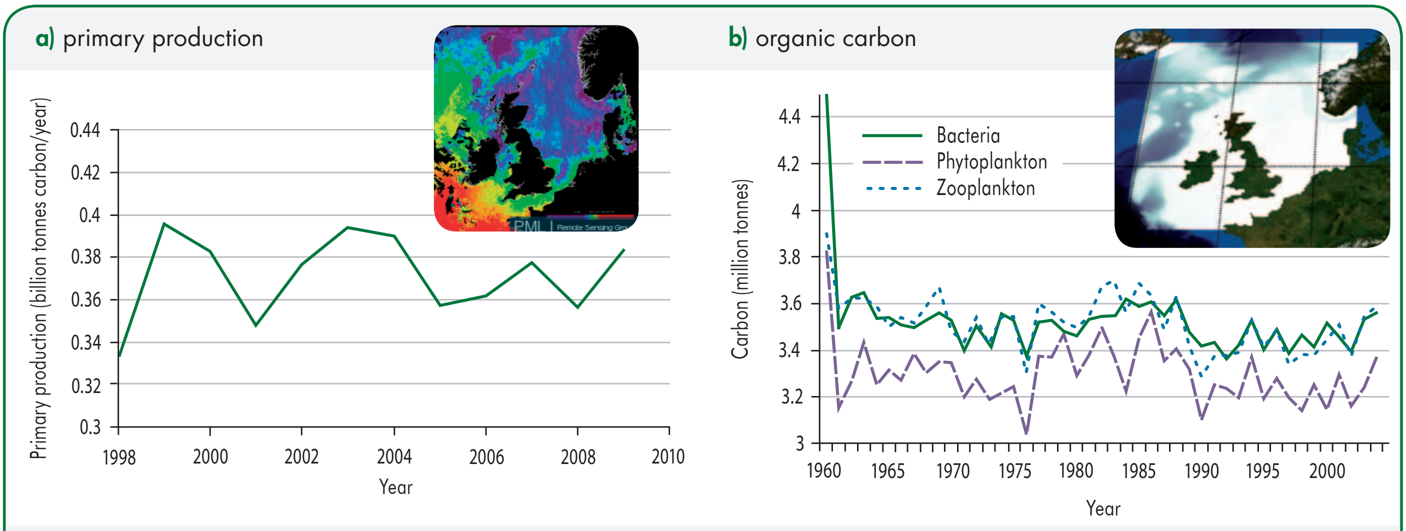

Figure 12.13 Carbon regulation in UK waters: a) using the indicator of annual marine phytoplankton productivity in ocean, shelf and coastal waters for an area slightly larger than UK territorial waters (47°–63°N; 15°W–09°E). Large-scale marine primary production was determined by applying remote sensing methods for data collected between 1998 and 2009 (www.neodaas.ac.uk) to quantify the concentration of photosynthetic pigments (Joint & Groom 2000) and then calculating primary production using the photosynthesis model of Smyth *et al.* (2005); **b)** using hindcast ecosystem modelling (ERSEM-POLCOMS and developments (Allen *et al.* 2001; Holt *et al.* 2005)) forced by the ECMWF-ERA (climate) re-analysis of annual biomass of carbon in the pelagic components of bacteria, phytoplankton and zooplankton (Butenschön unpublished). Map insets show domain area which is used to generate data.

to act as a carbon sink and has a strong feedback on the atmosphere and the climate (Legendre & Rivkin 2005). The surface water primary production of carbon by phytoplankton that is exported as organic and inorganic carbon to the deeper ocean waters is termed the 'biological carbon pump'. The global ocean has taken up approximately one third of accumulated emissions of the greenhouse gas carbon dioxide since the industrial revolution (Sabine *et al.* 2004; Sabine & Feeley 2007). This has had the benefit of slowing the rate of build-up in the atmosphere, but the accumulation in the ocean reduces seawater pH making it more acidic. This high rate of reduction of pH, known as ocean acidification, may lead to ecosystem damage and functional changes in the future (Widdicombe *et al.* 2009; Hopkins *et al.* 2010) with possible impacts on ecosystem services including changes in shellfish yields and fish productivity, changes in wildlife resources, such as deep-water corals and genetic resources for biotechnology, and negative feedbacks on climate regulation. Research is underway to assess the impacts of ocean acidification.

12.3.2.3 Flood, storm and coastal protection

Living marine flora and fauna can play a valuable role in the defence of coastal regions by dampening environmental disturbances (Beaumont *et al.* 2007, 2008; Chapter 11). A diverse range of species bind and stabilise sediments and create natural sea defences, for example biogenic reefs, seagrass beds, mudflats and saltmarshes. The presence of these organisms in the front line of sea defence can dissipate energy and, therefore, dampen and prevent the impact of tidal surges, waves, storms and floods (Brampton 1992; Möller *et al* 1999; Widdows & Brinsley 2002). This is a critical service, particularly as the risk of flooding, both in terms of severity and frequency, has been accentuated in recent years by the onset of climate change. The impacts of global sea level rise (Boorman 2003) climate related changes in shoreline erosion, and human influence on shoreline structure are causing a loss of saltmarsh in the UK of 2% per year (Nottage & Robertson 2005). This loss of wetland has contributed to an increase in flood risk and subsequent investment in flood defence (Dixon *et al.* 1998).

Many types of flora can contribute to the reduction in wave energy in UK coastal zones. Seagrasses (Fonseca & Cahalan 1992) and halophytic (salt tolerant) reeds (Coops *et al.* 1996) play a minor role in the UK due to their small spatial scale; the major contribution to disturbance prevention is from saltmarshes (Paramor & Hughes 2004). With respect to alleviating flood risk to coastal communities, estuarine and coastal wetlands not only attenuate wave energy, but also play a role in reducing erosion of the coastline. Mudflats dissipate tidal and wave energy to a level low enough to permit net sediment deposition and this allows colonisation by saltmarsh or reedbed vegetation on the upper intertidal zone (Nottage & Robertson 2005). This coupled system is maintained through sediment exchange aided by the alternating dominance of bio-stabilisers and bio-destabilisers, controlled by climatic factors (Widdows & Brinsley 2002). Although saltmarshes are often inundated with marine water, especially during high spring tides, their role in disturbance prevention is addressed in detail in Chapter 11.

Subtidal and intertidal biogenic reefs are habitats that are under threat (Section 12.2.3). They are also likely to dampen energy in waves and tidal surges but the contribution that they make to disturbance prevention has not been quantified.

12.3.3 Cultural Services

The population of the UK is often cited as having a strong affinity for the sea, as much of our heritage is linked to maritime activities. Reminders of this maritime heritage are still in existence today: fishing villages, fish and chips, the large navy, lighthouses and museums, and literature on smuggling. In a UK-wide poll undertaken by The Wildlife Trusts in 2007, 78% of respondents stated that the UK's seas are important to their personal quality of life (The Wildlife Trusts 2007). While the majority of the UK population no longer obtains its livelihood from the sea, the fact that many people consider the sea to be important for their quality of life suggests that they obtain other benefits from it that include cultural ones.

It is difficult, however, to disentangle the cultural benefits society derives from the marine environment from those it obtains from the coastal terrestrial fringes as it is from the coast that most people experience the sea (Chapter 11 & 16). Few people, other than divers, ever interact with the underwater seascapes around the UK. Fishermen, who are dependent upon the sea for their livelihoods, and commercial and recreational boat users do not experience the underwater world in the same way as one would a terrestrial environment. The sense of place associated with sites on land is rarely experienced for sub-marine sites (Rose *et al.* 2008). Furthermore, while the coast is often thought of as a place of beauty and with a sense of nostalgia, the sea and undersea are considered quite differently, often in negative terms such as barren, cold and dark (KSBR Brand Futures 2008).

The relationship with the marine environment is also distinct because of the way property rights are defined. The Crown Estate owns the seabed out to the 12 nautical mile (nm) territorial limit, but they do not own the water column or the rights for navigation or for fishing. In some cases, fishing rights are heritable (for example, some coastal salmon fisheries in Scotland are owned by the operators as heritable titles) or informal agreements exist between fishermen (for example, crab potting areas are allocated to particular boats), but in general, marine waters are open access; the sense of ownership is, therefore, missing.

12.3.3.1 Environmental settings: education, research and development opportunities

The marine environment presents a number of educational opportunities; school trips to the beach and/or aquaria are common particularly in coastal communities, although people living some distance away from the coast are also able to learn about marine life through visits to aquaria and sealife centres throughout the UK (e.g. Birmingham and Alton Towers) (**Figure 12.14**). A number of environmental non-governmental organisations (NGOs) and environmental education businesses also offer educational facilities to schools. For example, the Marine Conservation Society (MCS), through its Cool Seas programme, has visited more than 400 schools in the UK, reaching over 120,000 school children since its inception in 2006. Surfers Against Sewage also have a schools programme, as do many aquaria: for example, the National Marine Aquarium (NMA) in Plymouth received 27,166 educational visitors during 2008–2009. Recognising their educational potential, the NMA offers a number of educational experiences linked to the national curriculum. The Marine Biological Association runs both The Shore Thing, a climate change shore project linked to the national curriculum, and educational events at beaches designated as part of the BBC Breathing Places national educational programme. The Aggregates Levy Sustainability Fund has also supported an outreach programme, Explore the Sea Floor, which reached over 500 schools between 2005 and 2008, and has distributed more than 9,000 interactive educational CD-ROMs, amongst other activities (Murphy 2008).

In recent years, the development of new technologies (such as remotely operated underwater vehicles, deep-sea sampling equipment, remote sensing and improved diving equipment) and investment in marine research have led to greater understanding of the marine environment. An indication of how marine research and development in the UK has changed is given by Pugh & Skinner (2002). Between surveys in 1988–1989, 1994–1995 and 1999–2000 they report an approximate 10% increase in public sector research funding (e.g. NERC, Department for the Environment, Food and Rural Affairs (Defra), university), with researcher numbers fluctuating around 2,000. Some funding levied from marine industries, such as aggregate extraction, is used to support a broad range of marine research (**Box 12.3**). The top four marine-related university course disciplines in 1999–2000 were marine biology, physical and chemical ocean environment, the coastal zone and ship design. The proportion of research that is focused entirely on UK seas is unknown.

The private sector, particularly pharmaceuticals and 'blue' biotechnology industries, are growth areas that are also known to invest substantial sums into marine-related research and development. For example, Aquapharm Biodiscovery Ltd, Oban, secured £4 million in 2007 to support its work on anti-infective drug discovery and the development of novel ingredients for food additives and cosmetics such as anti-ageing creams (www.aquapharm.co.uk/news_archive.html); it has subsequently obtained a further £4.2 million in 2010 to continue this work (www.aquapharm.co.uk/news.html). Other centres of blue biotechnology strength include the Marine Biodiscovery

Figure 12.14 Educational trips to the seashore are becoming increasingly popular amongst schools, especially those located near the coast. Gara rocks near East Prawle in South Devon. *Photo courtesy of MarLIN.*

Centre, Aberdeen; Plymouth Marine Laboratory; Glycomar, based together with Aquapharm within the European Centre for Marine Biotechnology, Oban; and the University of Newcastle's School of Marine Technology and Science. Detailed statistics that disaggregate the marine related component are not available to assess how these industries have changed over time.

12.3.3.2 Environmental settings: leisure and recreation

The most obvious cultural benefit that society receives from the marine environment is the opportunity for leisure and recreational activities. The UK Leisure Day Visits Survey (2002–2003[9]) reports 267 million visits to the seaside during that year, approximately 5% of all UK leisure day visits. This is an increase from previous surveys: in 1994, seaside visits accounted for only 3.5% of all UK day leisure visits (although this figure varies across England, Scotland and Wales: in 2002–2003 4% of day visits in England were to the seaside, compared to 9% in Scotland and 12% in Wales). Expenditure at the seaside as a proportion of all expenditure on leisure day visits has remained more or less constant at around 4% between 1994 and 2002–2003, although the actual amount has increased over this period from £2.2 billion to £3.2 billion.

It is difficult to account for the contribution of the marine environment to these figures, but the draw of the sea must be assumed to play a part, especially given the opportunity it provides for water-based recreational activities and wildlife-watching. Anecdotal evidence suggests that wildlife-watching is an increasingly popular activity at the coast, yet the sector has still to be documented quantitatively (Curtin & Wilkes 2005) and only a small number of focused studies currently exist. The 2002 UK Tourism Survey data suggests that of all UK tourism trips (trips away from home lasting one night or more), 17.1% involved wildlife-watching/nature study; up from 14.8% in 2000 and 15.4% in 2001 (these statistics have not been collected in subsequent years). It is unclear what proportion of these are marine wildlife-watching activities, but there appears to be a growing number of tour operators offering trips to see whales, sharks, dolphins, seals and seabird colonies around the UK coast. In Scotland, all forms of wildlife-watching tourism have been estimated to generate £156 million in income and 7,446 jobs (Scottish Government Social research 2010). Of this, £36 million and 1,705 jobs (Full Time Employment (FTE) equivalent) are attributable to marine wildlife tourism, and £56 million and 2,681 jobs are generated by coastal wildlife tourism. In a like-minded study, the Royal Society for the Protection of Birds (RSPB 2010) has attempted to estimate the value of seabird colonies through the analysis of visitor expenditure across four case study sites: Bempton

Box 12.3 Marine aggregate extraction support for marine research.

Support for marine research comes from a diverse range of sources, for example, the Aggregates Levy Sustainability Fund (ALSF) which is a research levy imposed on the industry (MALSF 2010). By March 2011, the Marine ALSF will have provided about £25 million to marine research associated with aggregate extraction (MEPF Secretariat 2010). While much of the research it funds focuses on environmental and ecosystem impacts of aggregate extraction (**Figure 1**) and the recovery of extraction sites, some £7 million is dedicated to the characterisation of the seabed environment (for example, Regional Environmental Characterisation (REC) projects to enable broad-scale characterisation of the seabed habitats, their biological communities and potential historic environment assets within the regions); development of techniques for locating seabed historic objects, their management and conservation (**Figure 2**); and knowledge transfer. One such example is the Historic Seascape Characterisation programme supported jointly through the ALSF and English Heritage. The programme is developing an approach for mapping the historic seascapes of England's waters in an attempt to better understand the historical and cultural development of the present marine, intertidal and coastal areas.

Figure 1 Operational trailer suction hopper dredger. *Photo courtesy of HR Wallingford.*

Figure 2 Divers photograph the wooden hull structure of the 'Mystery Wreck', Eastern Solent. *Photo courtesy of Hampshire & Wight Trust for Maritime Archaeology and D. McElvogue.*

9 More recent statistics are available from the 2005 survey, but the surveys were carried out independently for each country within the UK and the method of data collection changed making comparison difficult.

Cliffs nature reserve, East Yorkshire; South Stack Cliffs nature reserve, Anglesey; Mull of Galloway nature reserve, Dumfries and Galloway; and Rathlin Island, County Antrim. They estimate that between 3–9% of day-tripper spend and 5–16% of holidaymaker spend (those staying overnight) is attributable to seabirds in the four locations. In 2009, this equated to £754,190 from Bempton; £222,822 from South Stack; £114,848 from the Mull of Galloway; and £115,629 from Rathlin. Given the isolated nature of these locations, the reserves make an important contribution to the local economies. The RSPB has also calculated that certain iconic bird species make substantial contributions to local economies through the attraction of visitors (Dickie *et al.* 2006). For example, white-tailed eagles (*Haliaeetus albicilla*) bring between £1.4 million and £1.6 million annually to the Isle of Mull, and the small family of choughs (*Pyrrhocorax pyrrhocorax*) on the Lizard, Cornwall, brought £118,000 in 2004.

Statistical evidence is available for water-based recreational activities for 2005 to 2008 from a consortium of the British Marine Federation (BMF), Maritime and Coastguard Agency (MCA), Royal National Lifeboat Institution (RNLI) and Royal Yachting Association (RYA) (BMF *et al.* 2005–2008). They estimate that more than 50% of all small sail boat activities, wind surfing, use of personal water craft, motor boats/cruising, yacht cruising, power-boating, yacht racing, surfing, kite surfing, angling from a boat, outdoor swimming, and sub-aqua activities in the UK occur at the coast where they are dependent on the marine environment. In many instances, over 75% of activities occur at the coast (e.g. yacht cruising and racing, power-boating and the use of personal water craft), with this figure rising to 94% for kite surfing and 100% for surfing. In 2005, water-based activities accounted for 36.7 million coastal visits[10] (52.2% of all water-based visits), rising to 47.1 million coastal visits in 2007 (55.2%). In 2008, like all water based activities, coastal visits fell to 35.6 million although as a proportion of total water-based activities they rose to 60%. Since the survey began distinguishing between coastal and inland waters (2005), participation in most activities has remained quite consistent. Only angling from boats and sub-aqua diving have shown any real change, with a large increase in participants in the last two years.

Recreational sea angling is a popular and relatively well-studied activity. It is comparatively well-quantified in terms of number of participants, their expenditure and the jobs associated with this leisure industry (**Box 12.4**).

12.3.3.3 Environmental settings: health goods (mental and physical)

Angling and many other activities that occur at sea bring with them extra cultural benefits, in addition to the activity itself. For example, drawing from an internet survey of the social and community benefits of angling, Stolk (2009) reports high levels of club membership by anglers (49% for sea anglers). Respondents stated that club membership brings a number of benefits including connecting people, building relational networks, enabling intergenerational socialisation and providing routes into volunteering. Almost a quarter of respondents also reported involvement in environmental or aquatic habitat conservation projects, helping to engage local communities and raise awareness of conservation issues.

In addition, spending time by the sea and coast has long been recognised for its benefits for health and well-being. For example, Victorian doctors often prescribed visits to the coast to hasten recovery after long illnesses. It is only recently, however, that the links between the environment

Box 12.4 Recreational sea angling.

In Scotland, 125,188 adults and 23,445 children participated in sea angling in 2008, equating to 1,540,206 sea angling days and a total expenditure of approximately £141 million (Radford *et al.* 2009). The industry is thought to directly support 3,148 jobs (FTE), supporting a Scottish household income of approximately £70 million through wages, self-employment income, rents and profits.

The most recent Defra figures for England and Wales indicate that, in 2003, 1.1 million households in England and Wales contained one or more members who partook in sea angling and the mean number of sea angling days per year was 11.3 (Crabtree *et al.* 2004). The industry was estimated to have a value of £538 million per year and to support 18,889 jobs (FTE). Estimates from the South West alone suggest that 240,000 residents participate in sea angling, plus an additional 750,000 angling days are engaged in by visitors (Cappell & Lawrence 2005). The value of the industry is estimated at £165 million and supports more than 3,000 jobs.

All of these studies found that the majority of anglers fished within 50 miles of their homes. Visiting anglers, however, make a considerable contribution to the total angling expenditure. Crabtree *et al.* (2004) estimated this as £192 million per year or 35% of the total for 2002. This equates to 1% of all tourism spend in 2002 for England and Wales (UK Tourism Survey 2002).

Although exact figures are unavailable, the evidence suggests that the population of sea anglers has either stabilised or shown a small increase since the early 1990s. The mean number of days spent angling, however, has decreased from 36 days per year in the 1970s, to 12 days per year in 1992 (Dunn & Potten 1994) and to 11.3 days per year in 2002 (Crabtree *et al.* 2004). These figures hide the fact that shore anglers (**Figure 1**) are much more active than those fishing from a charter boat: 13.6 days per year compared to 4.96 days per year respectively (Crabtree *et al.* 2004).

Figure 1 An angler watches waves in Whitby, North Yorkshire. *Photo © ronfromyork, 2011. Used under license from Shutterstock.com*

10 These figures do not include those for cliff-climbing, coastal walking and general leisure time at the beach.

and health and well-being have been medically documented. This has mainly occurred for the green environment (Bird 2007) and has demonstrated how interaction with nature can help reduce stress, increase physical activity and create stronger communities. Effort is now turning to the blue environment, and in 2009 the Blue Gym project was initiated by the Peninsula Medical School[11] (Universities of Exeter and Plymouth) to examine the health benefits that can be gained by spending time in coastal environments (Depledge & Bird 2009).

12.3.3.4 Environmental settings: heritage goods

Aesthetic and inspirational properties. Even though much of the marine environment is hidden from view, it has captured the imagination of many over the centuries leading to a wealth of literature, for example Coleridge's *The Rime of the Ancient Mariner*, Wordsworth's *By the Sea*, John Masefield's *Sea Fever* and Neil Gunn's *The Silver Darlings*; works of art, such as Pocock's sea battles and Turner's coastal views; and schools of artists, including The Newlyn and St. Ives Schools. The sea continues to be drawn upon as a source of inspiration with any number of craft fairs and galleries exhibiting art work using driftwood, shells and other marine themes. In addition, it inspires underwater documentaries, such as 'The Blue Planet', and has always permeated through children's cartoons, for example 'Popeye' and 'Captain Pugwash', the incidence of which has increased in the last five to ten years with films like 'Finding Nemo', 'Shark Tale' and 'SpongeBob SquarePants'.

Cultural heritage. Advancements in understanding the marine environment have led to a corresponding increase in public interest about underwater heritage resources (Kaoru & Hoagland 1994) and wider marine issues. To date, no assessment of the heritage value of the marine environment in UK waters has been undertaken, but a growing number of marine sites are receiving protected status because of their importance to UK history. Protection is offered for a number of reasons including the presence of ancient monuments, important wrecks and war graves (through the Protection of Wrecks Act, 1973; the Protection of Military Remains Act, 1986; and the Ancient Monuments and Archaeological Areas Act, 1979). Approximately 93 marine sites have been protected (MCA 2010), but this represents only a small proportion of the 44,000 wrecks that have been mapped and catalogued by Shipwrecks UK (www.shipwrecks.uk.com/info1_2.htm) around the coast of Great Britain and Ireland (the number which is growing as more wrecks are discovered). The level of protection for such sites has increased since 2002 when English Heritage, Cadw, Historic Scotland and Northern Ireland Environment Agency took over responsibility for marine archaeology in UK waters.

Currently, protection of the marine environment falls short of that on land. For example, there are only 83 inshore and nine offshore Special Areas of Conservation (SACs) out of a total of 621 designated under the Habitat's Directive in the UK. And there are only 107 Special Protection Areas (SPAs) designated under the Bird's Directive (out of 262 across the UK) in coastal areas, of which, only three are entirely marine (Bae Caerfyrddin/Carmarthen Bay, the Outer Thames Estuary and Liverpool Bay; www.jncc.gov.uk/page-1414); some of these sites are also protected under the OSPAR Convention. Although there are a small number of Sites/Areas of Special Scientific Interest (SSSIs/ASSIs)[12] below the low water mark (mean low spring water in Scotland), such as The Wash and Morecombe Bay, many coastal SSSIs/ASSIs do not offer protection to subtidal marine life (JNCC 2010). Furthermore, there are only two marine nature reserves (Skomer Island and Strangford Lough) and they are considered limited in their scope; although a former marine nature reserve has recently been made into the first Marine Conservation Zone (MCZ) designated under the Marine and Coastal Access Act (2009). This relative absence of protection of marine habitats results from the land-based focus of much existing conservation legislation and a probable lack of understanding of the value of marine ecosystems. For example, the Wildlife and Countryside Act, 1981, through which SSSIs are designated, made no provision for SSSIs in the marine environment (Defra 2009); SACs can only be selected according to the presence of four marine habitats (sandbanks always slightly covered with water, reefs, submarine structures with leaking gases, submerged or partially submerged sea cave); only four marine species appear in Annex II of the Habitats Directive (common and grey seals, bottlenose dolphin and harbour porpoise[13]).

It is also important to note that not all protected areas are protected by statutory designations. The RSPB, for example, owns a number of nature reserves around the UK coast which provide protection for important seabird colonies (e.g. Ramsey Island, Noup Cliffs, Rathlin); The Wildlife Trusts also own a number of coastal nature reserves. Neither of these organisations has dedicated marine reserves, however, largely because of the inability to purchase the seabed and designate it as a reserve.

Protection of the marine environment, however, will see a number of changes in the near future due to requirements written into the UK Marine and Coastal Access Act (2009) and the Marine (Scotland) Act 2010 (Section 12.5).

Enfranchisement and neighbourhood development. Concern over marine issues unites people in a number of ways, contributing to social and environmental citizenship and neighbourhood development. For example, the NGO Surfers Against Sewage originally formed in 1990 and has grown into an organisation with 10,000 members (Surfers Against Sewage 2010). They campaign on a number of issues, particularly those relating to the health of recreational water users and rights of access. They are also involved in beach litter picks, in association with MCS's Adopt-a-Beach programme, and in outreach activities within schools in Cornwall. The MCS initiated its beach clean and litter survey activities through its Beachwatch programme in 1993. In

11 Recently renamed as the Peninsula College of Medicine and Dentistry.
12 SSSI is a conservation designation denoting a protected area in GB. ASSI is a conservation designation denoting a protected area in Northern Ireland.
13 Although other species listed in Annex II of the Habitats Directive do occur in UK waters, it is unlikely that areas away from the coast can be identified as essential to their life and reproduction.

1994, Beachwatch involved 2,062 volunteers and covered 173 beaches, equating to 204 km of coast. By 2008, these numbers had grown to 374 beaches and 5,219 volunteers, but with a slight reduction in coastal length surveyed to 175.1 km. The increase in interest in beach-cleaning led MCS to develop the Adopt-a-Beach programme in 1999 to help its members to carry out more regular beach cleans and litter surveys.

12.3.4 Supporting Services

12.3.4.1 Nutrient cycling

There is substantial input of nutrients into UK marine waters through exchange with offshore waters (North Atlantic, English Channel inflow), rivers, groundwater and atmospheric inputs (Jickells 1998). However, the storage, cycling and maintenance of this supply of nutrients and micronutrients, for example, carbon, nitrogen, phosphorus, sulphur and metals, is essential for living marine organisms and supports all of the other marine ecosystem services.

Nutrient cycling encourages productivity, including fisheries productivity, by making the necessary nutrients available to all levels of food chains and webs. Nutrient cycling is undertaken in many components of the marine environment: within seabed sediments, particularly intertidal and subtidal muds, where bacterial processing of nutrients (e.g. nitrification and denitrification) is facilitated by the physical feeding, burrowing and irrigation activity, known as 'bioturbation', of invertebrates (Covich *et al.* 2004; Olsgard *et al.* 2008); within the water column where bacterial nutrient cycling is facilitated via food web links with phytoplankton and zooplankton and also fish (Proctor *et al.* 2003; Blackford 1997); between trophic levels and in the course of bacterial breakdown of detritus (mainly dead algal and plant material) in macroalgal beds and in saltmarshes. Without recycling at the sediment-water interface, most nutrients would be lost from the ecosystem, sinking and becoming buried in the sediments that cover much of the seabed.

Nutrient concentrations are seasonally and annually variable (Butler 1979; Jordan & Joint 1997; Gowen & Stewart 2005). For example, water column nitrate and phosphate concentrations measured at an English Channel station between 1923 and 1987 show a wide range in the nitrate:phosphate ratio (Jordan & Joint 1998). Since the late 1950s and early 1960s, enrichment of the Irish Sea with anthropogenic nutrients has increased winter levels of dissolved inorganic nitrogen and phosphorus (Gowen & Stewart 2005).

Climate change may alter nutrient exchange processes between the open waters and the open ocean, and also alter water stratification, therefore affecting internal nutrient cycling, but the likely direction and extent of changes are still poorly understood (MCCIP 2008). Threats to nutrient cycling in the estuarine and saltmarsh areas principally arise from increasing loss of saltmarshes and intertidal mudflats due to land reclamation. A further threat has been excess nutrient loading through river runoff exceeding capacity for storage and recycling, although, as stated in Section 12.3.2.1 this threat is diminishing.

12.3.4.2 Biologically mediated habitat

Many organisms provide structured space or living habitat for other organisms through their normal growth, for example, reef-forming invertebrates, meadow-forming seagrass beds, marine algae forests and networks of burrows and holes in the sediment (Beaumont *et al.* 2007). These 'natural' marine habitats can provide essential feeding, breeding (spawning grounds) and nursery space for other plants and animals, which can be particularly important for the continued recruitment of commercial and/or subsistence fish and shellfish species. Such habitat can also provide a refuge for plants and animals including places to hide from predators. Living habitat plays a critical role in species' interactions and regulation of population dynamics, and is a pre-requisite for the provision of many goods and services. In the UK, examples of living habitat include kelp and seagrass beds, maerl grounds (calcified red seaweed), mussel patches and cold water coral reefs.

Maerl grounds are predominantly found on the west coasts, but are also patchily distributed around the UK. They support a large number of species (Jackson *et al.* 2004) through their provision of refuge and food for juvenile life stages of commercially important shellfish, such as the queen scallop (*Aequipecten opercularis*) (Kamenos *et al.* 2004), and juvenile gadoid fish such as Atlantic cod (*Gadus morhua*), saithe (*Pollachius virens*) and pollack (*Pollachius pollachius*) (Hall-Spencer *et al.* 2003). Seagrass has only a patchy distribution in the UK, but provides both refuge and nursery habitat for a number of commercial fish species (Murphy *et al.* 2000) including Atlantic cod, halibut (*Hippoglossus hippoglossus*), flounder (*Platichthys flesus*) and plaice (*Pleuronectes platessa*) (Gotceitas *et al.* 1997), and also commercial shellfish (Davidson & Hughes 1998). Kelp and many other species of marine macrophytes are widely distributed in UK coastal waters (Birkett *et al.* 1998), support a diverse range of species (Orth *et al.* 1984; Norderhaug *et al.* 2002) and provide refuge for fish species such as juvenile Atlantic cod (Cote *et al.* 2002).

Mussel patches, both living and dead shells, can be used as substratum for colonisation by some species and provide refuge from predation for others (Gutiérrez *et al.* 2003). Intertidal mussel beds reduce the harsh effects of temperature, wave action and light, providing favourable conditions for a wide range of associated fauna (Seed & Suchanek 1992; Lintas & Seed 1994).

Cold water corals can occur in deep water, for example, *Lophelia pertusa* is found off the UK coast from north of the Shetland Islands into the north-east Atlantic (Wilson 1979). This species, and several others, can form colonies which aggregate over time into reef structures. Cold-water reefs, like their tropical counterparts, provide habitats for various species of invertebrate (Bett 2001; Gage 2001). Fish are present in significantly higher densities in cold water coral reefs than the background environment (Bett & Jacobs 2000).

Seabed fishing with trawl nets and dredging fishing gears is particularly destructive to living reefs which take a long time to recover since deep-sea corals can be particularly slow-growing. In 2003, evidence that trawl fishing was damaging cold water coral reefs in the deep-sea Darwin Mounds off the west coast of Scotland resulted in legislation under the Common Fisheries Policy to protect them. Shallow water and intertidal living habitats are vulnerable to invasive macroalage species (Milneur *et al.* 2008) as well as smothering by opportunistic algae, such as *Ulva* species, particularly in nutrient enriched areas (Fletcher 1996); at a more local level they can be damaged by boat anchoring, propeller scarring, and channel dredging.

12.3.5 Wild Species Diversity

12.3.5.1 Flagship species

Flagship species are "popular charismatic species that serve as symbols and rallying points to stimulate conservation awareness and action" (Leader-Williams & Dublin 2000). Walpole & Williams (2002) state that to be a flagship species "they need only operate in the public relations and fundraising spheres". Marine flagship species are mainly the large megafauna, such as turtles, seals and cetaceans (whales, dolphins and porpoises), as well as smaller species such as seabirds and seahorses.

Scientists and conservationists will often consider a wide range of species and habitats as having flagship status as they are considered to be health indicators for the marine environment. For example, WWF lists 16 marine flagship species/habitats for UK waters: harbour porpoise; leatherback turtle; Atlantic salmon; Atlantic cod; long-snouted seahorse; basking shark; common skate; fan mussel; native oyster; pink seafan; saltmarsh; seagrass beds; maerl beds; horse mussel beds; deep-water mud habitats and deep-water reefs (Hiscock *et al.* 2005).

The significance of flagship species is that their importance goes beyond their ecological function and is related primarily to their appeal to the wider public. For example, relatively small populations of harbour seals on the south and west coasts of England and Wales (in some cases less than 10 individuals) may not have a huge impact from an ecological perspective. However, the populations are well known to locals and popular with tourists, thus providing a significant boost to the local economy. Even single individuals, such as straying migratory whales, can generate media interest and a short-term boost in tourism activity. In Looe, south-east Cornwall, a single grey seal (named Nelson due to only having one eye) was such a popular draw for locals and tourists that when it died in 2003, after 20 years of inhabiting the local area, a statue was erected in its honour (www.bbc.co.uk/cornwall/content/articles/2008/01/23/aboutcornwall_nelsontheseal_feature.shtml).

On a larger scale, the economic benefits of well-established populations of flagship species are derived from a wide range of activities linked to their presence including diving and snorkelling, rock-pooling, boat trips (e.g. whale- and dolphin-watching, shark-spotting and visits to seal colonies) and aquarium visits. Seabirds are also hugely popular and a major factor in encouraging wildlife tourism. Spectacular seabird 'cities' and particular species, such as the Atlantic puffin (*Fratercula arctica*), draw many visitors and are important sources of income for local economies (RSPB 2010; Mitchell *et al.* 2010).

Flagship species can also play a part in encouraging membership of societies that promote marine conservation. Many organisations promoting a scientific or conservation interest in the sea (e.g. NGOs, conservation agencies and learned societies) adopt a 'charismatic species' as a logo. The value of UK wildlife is partially reflected in membership of marine wildlife-related charities. There are at least 10 in the UK that are either entirely, or strongly, focused on marine life, with some specifically related to whales, dolphins, seabirds, seals and seahorses. A significant example is the RSPB which plays an important role in championing marine conservation; of its 200 reserves, 53 can be classified as being in habitat category 'Cliffs, beaches and estuary' providing protection for a number of important seabird colonies.

12.3.5.2 Sentinels of human health

Wild species can act as important sentinels of human health for chemicals (**Box 12.5a**), pathogens and harmful algal blooms (**Box 12.5b**). Consumption of microbe or biotoxin contaminated shellfish has the potential for significant impacts on individual and population human health. Recent studies have highlighted the relatively high disease and hospitalisation risk of consuming seafood. Between 1996 and 2000, the estimated annual impact of seafood-borne illness in England and Wales was approximately 116,000 cases, 77,000 of which were associated with the consumption of shellfish. These shellfish cases led to approximately 13,000 visits to General Practitioners, 3,600 hospital days and 16 deaths (Adak *et al.* 2005). The total cost of indigenous food-borne illness in 2008 was estimated by the Food Standards Agency for England and Wales at approximately £1.48 billion (using the 'value of fatality prevention index'). Only a small proportion of this would be attributable to contaminated shellfish consumption. While little historic evidence is available for incidence of shellfish-associated food-borne illness, it is assumed that monitoring of UK shellfish harvesting sites using the approach outlined (**Box 12.5a,b**) has led to a reduction in food-borne illnesses associated directly with shellfish consumption. However, specific data to substantiate this assumption is not available.

12.3.5.3 Blue biotechnology

Since the 1960s, many pharmaceutical compounds have been produced from a diverse range of marine bacteria. Marine micro-organisms continue to be a productive and successful focus for natural products research. Emerging products include new medicines, enzymes, and chemicals with applications in human health and manufacturing, as well as new additives and colourants for the food industry. The marine environment is viewed as an increasingly important source of novel antimicrobial metabolites. For example, marine biotechnology forms a significant part of research activities in the European Centre for Marine Biotechnology at the Scottish Association for Marine Science (SAMS), in the newly opened Marine Biodiscovery Centre at Aberdeen University, and at PML within its trading subsidiary PML Applications. At these research centres, scientists are exploiting their expertise in the biology and chemistry of a wide variety of marine organisms to produce novel pharmaceutical products, biomedical research tools, anti-foulants, catalysts, high-value extracts for nutritional

Box 12.5

Box 12.5a Wild species as sentinels of the environmental impact of chemicals on human health and well-being.

Several so-called 'biological effects markers' are widely measured in sentinel marine animals, such as fish, to measure exposure to, and effect of, man-made chemical pollutants. In this instance, the sentinels are employed to indicate potential effects of similar exposures of human populations to water and products arising from polluted areas. In the UK, liver cancer is measured in sentinel marine and estuarine flatfish to indicate exposure to carcinogenic chemicals (**Figure 1**). The prevalence of these cancers differs between sites and ranges from baseline (less than 1%) to high (more than 20%) at given locations. Due to the migratory behaviour of fish (many species move between feeding and breeding grounds) and the slow formation of cancers (over a year or more), it has been somewhat problematic to link cancer prevalence directly with man-made chemical pollutants, particularly at offshore sites. However, strong evidence exists for this relationship in other heavily polluted waterways of the world, and the pattern of prevalence is very repeatable in UK waters, suggesting a clear basis for cause (Stentiford *et al.* 2009).

Other markers utilised in UK waters include the measurement of the egg yolk protein vitellogenin (VTG) in the blood of male fish. This protein is known to occur in male fish exposed to endocrine disrupting chemicals (EDCs) and is elevated in some UK estuaries (Kirby *et al.* 2004) and even offshore (Scott *et al.* 2007). In both areas, elevated VTG has been associated with the occurrence of so-called 'intersex' fish at these sites. In these cases, the male testis is partially replaced with a female ovary which most likely indicates an exposure to EDCs during crucial early life stages (Stentiford *et al.* 2003, 2005). The linkage between freshwater and estuarine inputs of EDCs and the effects seen in the marine environment is currently unstudied.

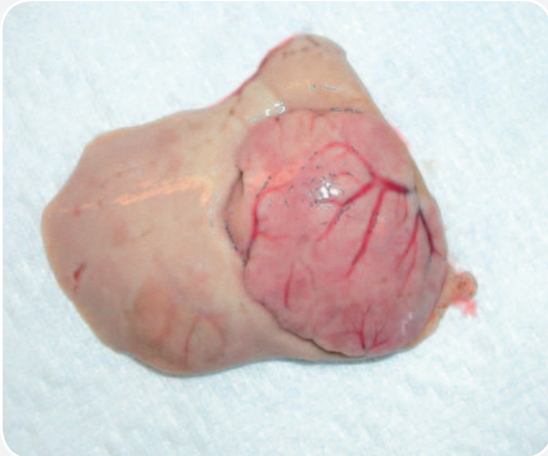

Figure 1 Liver cancer (on right of picture) in marine flatfish from UK waters. *Photo Crown Copyright 2010, reproduced with permission from CEFAS.*

Box 12.5b Wild species as sentinels of the environmental impacts of pathogens and harmful algal blooms on human health and well-being.

Pathogenic microbial contamination and the presence of harmful algal blooms are important issues in waters used for potable water supplies, recreation and for the protection and propagation of fish, shellfish and wildlife. Pathogenic microbes are present in faecal inputs into terrestrial, freshwater and marine environments, and include viruses, bacteria and parasites. Sources are broad-ranging and include farmed and wild mammalian and avian faecal matter, and human faecal matter in various states of treatment. The traceability of these sources has been highlighted as a problem (Simpson *et al.* 2002; Baker-Austin *et al.* 2009). Pathogens of concern to human health can remain viable and in large quantities in the environment for long periods of time (e.g. *Escherichia coli* O157:H7). Filter-feeding shellfish, such as clams and mussels (**Figure 2**), may concentrate bacteria and viruses from their growing waters. Because they are frequently consumed raw or only lightly cooked, shellfish contaminated with these pathogens have the potential to cause human disease.

In the UK, considerable effort is expended in the direct and indirect monitoring of pathogenic microbes from faecal sources, mainly through detection and quantification in farmed and fished molluscan shellfish. These pathogens are monitored under a framework of EU food health regulations, and so, exceeding agreed levels of contamination can lead to cessation of the harvest of shellfish in affected zones. Thus, in very specific circumstances, the presence of microbial biodiversity can be viewed as an antagonistic problem, reducing the marine food provisioning service. The measurement of microbial contaminants in water and in sentinel shellfish provides a direct indicator of health risk to human consumers and demonstrates the complex association of terrestrial, freshwater and marine habitats in governing this level of risk in specific geographic locations.

Harmful Algal Blooms (HABs) are caused by massive and prolonged overgrowth of algae and other plant-like organisms such as dinoflagellates, diatoms and cyanobacteria. Natural links have been made between the occurrence of HABs and eutrophication in riverine, estuarine and coastal waters, and the management of nutrient inputs to the watershed can lead to significant reductions in HABs (Heisler *et al.* 2008). The issues surrounding the presence of HABs, and the toxins associated with them, in the marine environment are broadly similar in scope and effect to those described for the microbial contaminants of bivalve molluscs and controls are included in the same regulatory framework on food hygiene across Europe. Essentially, these toxins can bioaccumulate, particularly within filter-feeding molluscan shellfish, and can cause harm to human consumers. Due to perceived increases in HAB occurrence and severity, and the known acute and chronic toxicity to animals, plants and humans, HABs, and their associated effects, have emerged as a worldwide concern.

The measurement of toxins associated with the formation of HABs in sentinel shellfish provides a direct indicator of health risk to human consumers and, as described for microbial contaminants of shellfish, particularly demonstrates the complex interactions between terrestrial, freshwater and marine habitats that govern the level of risk in specific geographic marine locations.

Figure 2 Mussel beds in Exmouth. *Photo courtesy of Rob Ellis, Plymouth Marine Laboratory.*

supplements and personal care products. In its current manifestation, blue biotechnology development makes use of only very small amounts of sampled material, with further development for products being predominantly laboratory based.

12.3.6 Delivery of Marine Ecosystem Services by Different Components of the Marine Habitat and Associated Fauna

We considered the delivery of services and benefits from each of the six CP2 habitats: Intertidal Sediment, Intertidal Rock, Shallow Subtidal Sediment, Subtidal Rock, Shelf Subtidal Sediment, and Deep-sea habitats; as well as additional habitats which could be considered to have distinct biodiversity and biogeochemical properties that might affect provision of ecosystem services: estuarine (transitional) waters, pelagic mixed water column and pelagic stratified water column and shelf subtidal rock. The same services tend to be delivered by different habitat types (i.e. sediment, rock or pelagic) regardless of where they are (i.e. intertidal, coastal shelf, transitional waters, deep-sea). The organisms and their biological activity and functions differ between these habitats and locations, but most marine environments deliver most marine ecosystem services. The ecosystem processes and intermediate services that underpin benefits are similar for provisioning (Chapter 15), regulating (Chapter 14) and cultural services (Chapter 16). However, the amount of service, and hence the benefit derived, will vary according to the habitat/location. This is the key point for quantifying ecosystem service delivery, but most of the ecosystem service and benefit data is not available at the disaggregated level of marine habitat/location type in the UK.

Consideration of three key marine communities—pelagic microbial communities (including phytoplankton and zooplankton), benthic bioturbators (organisms living in seabed sediments whose physical activities, such as feeding, burrowing and irrigation, disturb the sediment), and fish—suggests that the number of final benefits delivered by a community or assemblage is not always equivalent to their contribution in terms of underpinning intermediate and final ecosystem services (**Figure 12.15**). For example, this encapsulates the concerns about future ocean acidification impacts since there is building evidence that these are likely to affect pelagic microbial communities and benthic organisms in particular (Widdicombe *et al.* 2009; Turley *et al.* 2010). Potentially, although we get fewer direct benefits from these organisms, all of the underpinning ecosystem processes and functions, and intermediate services they provide, could be impacted, with catastrophic effects. The impacts on fish may also be large, but the ecosystem impacts might not be so catastrophic.

12.3.7 Ecosystem Service Interactions with other UK NEA Broad Habitats

The ecosystem services and benefits of the Coastal Margins (Chapter 11) are largely shared with, and often derived from, the access and proximity to marine habitats. Examples include: bathing waters adjacent to sand dunes and sandy beaches; marine wildlife-watching (seabirds

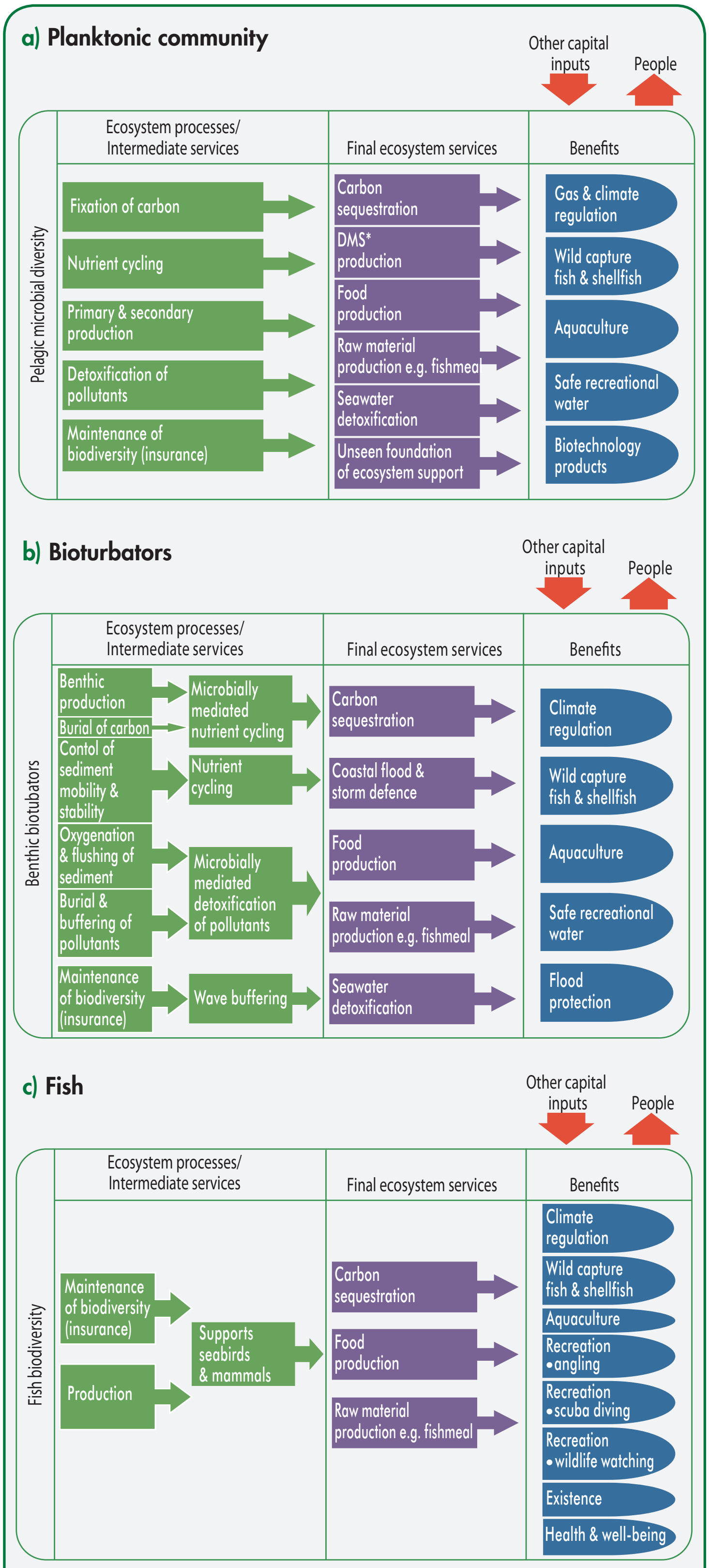

Figure 12.15 Schematic diagram of a selection of ecosystem processes and/or intermediate ecosystem services from three key marine communities to illustrate how ecosystem processes are linked to final ecosystem services and the benefits they generate for people: a) pelagic planktonic community; b) benthic bioturbators; and c) fish. Schematic follows the philosophy of the UK NEA Conceptual Framework (Chapter 2), and is adapted from Fisher *et al.* (2008). *DMS is dimethyl sulphide which is a climate regulating gas (Charlson *et al.* 1987; Liss *et al.* 1997).

and mammals); boating; and habitat and food provision for seabirds in intertidal areas (e.g. beaches and saltmarshes) inundated with seawater. Similarly, coastal urban habitats enjoy many of these benefits through access and proximity to marine ecosystems. Part of the cultural value of these terrestrial habitats is derived from locally caught food of marine origin.

In turn, marine ecosystems receive much of the diffuse waste from terrestrial and freshwater habitats, for example, via river runoff, treated sewage effluent, urban stormwater overflow, and excess nutrient runoff from farmland and air pollution in coastal cities. Therefore, they provide an important, but largely unquantified, regulating service for these habitats of waste removal and degradation.

Another linkage is that the aquatic medium acts as a carrier for economically important eels and salmon which migrate between oceans, coasts and rivers in different phases of their lifecycle. As juveniles, eels migrate from the oceans via coastal waters into rivers, where they grow to adulthood, and then migrate back to the sea to reproduce again. In contrast, salmon reproduce in rivers and migrate as juveniles to the sea, where they grow to adulthood, returning to the rivers where they spawned to reproduce again themselves.

12.4 Trade-offs and Synergies Among Marine Ecosystem Goods and Services

Delivery of many marine ecosystem services is strongly interlinked and synergistic, as would be expected when considering ecosystem services in such a large and interconnected habitat as the UK's estuarine, coastal, shelf and deep-sea waters. The biological activity and ecosystem functions of the same, or very similar, organisms underpin waste regulation and detoxification, climate regulation, and nutrient cycling in the water column or in the sediment seabed (Section 12.3.6). In turn, cultural services, such as leisure and recreation, are dependent on clean, functioning seas, so the functions of these organisms also underpin cultural services. Similarly, the habitats that prevent disturbance by mitigating the hazards of flooding and wave damage also provide supporting habitat for other species, and are constituent parts of habitats for leisure and recreation. Generally, the flagship wild species are those which underpin wildlife-watching activities and pertain to marine cultural benefits. Regionally based fisheries providing food also support local tourism and, therefore, cultural services.

Yet excessive fish extraction is unsustainable and impacts on other components of the ecosystem by affecting trophic (food web) structure and damaging seabed habitats. Hence, excessive fishing potentially negatively affects delivery of the other services. Trade-offs occur, to a greater or lesser extent, between many marine ecosystem services and food provision by fisheries. For example, birdwatching is a popular leisure activity and public engagement with seabirds and mammals is evident (Section 12.3.5), but there has been a conflict with fisheries overexploitation. Commercial fisheries for small fish species, such as sandeels, may reduce food availability for seabirds (Frederiksen *et al.* 2004; Frederiksen *et al.* 2007; Wanless *et al.* 2005), marine mammals and predatory fishes (MacLeod *et al.* 2007). Poor breeding success at many seabird colonies has been related to a lack of sandeel prey resources, although it is likely that climate change is also contributing to a reduction in the number and quality of prey fish (Mitchell *et al.* 2010).

In the waters off south-east Scotland, a sandeel fishery that operated in the 1990s significantly depressed adult survival and breeding success of black-legged kittiwakes at adjacent colonies compared with years prior to the fishery opening and after it was closed. Since 2000 there has been a ban on sandeel fishing off eastern Scotland and north-east England. If fishing is resumed to levels that significantly reduce local sandeel stock, it would potentially exacerbate reductions in breeding success and survival that are probably now being caused by increases in sea surface temperature as a result of climate change (Mitchell *et al.* 2010).

At the same time, fisheries were benefiting some seabirds by providing them with food as discharged offal and discarded undersize fish, and thus, supported populations of scavenging species (e.g. great skua, northern fulmar) above levels that natural food sources could sustain. However, overfishing and the introduction of measures to conserve fish stocks have reduced the amount of discards which may have contributed to a population downturn of northern fulmars and other offshore surface-feeders since the mid-1990s (Mitchell *et al.* 2010).

Bottom trawling fisheries and some shellfisheries cause habitat damage and hence substantial changes to marine ecosystems including the disturbance of the seafloor leading to mortality of benthic organisms, changes in benthic community composition and re-working of sediment (Frid *et al.* 1999; Kaiser *et al.* 2006). This changes the levels of supporting services, such as nutrient cycling and habitat provision (Percival *et al.* 2005; Bremner *et al.* 2005; Olsgard *et al.* 2008; Cesar & Frid 2009), and there is evidence that these changes have taken place over the last 60 years (Frid *et al.* 2000). Changes in marine benthic communities can lead to a reduction in the food available to waterbirds, which has probably resulted in changes in numbers and distribution of seaducks, divers and waders (Mitchell *et al.* 2010).

Seals and cetaceans, such as dolphins, are popular with wildlife-watchers, making an important contribution to cultural services, as well as being flagship wild species. However, they are viewed by fishermen as competitors for fish stocks for human consumption, and can be trapped and damaged by nets. Similarly, recreational angling is sometimes viewed as competing for resource with commercial fisheries for food provision. Some recreational fishermen consider that overexploitation by commercial fisheries has reduced the overall size of trophy fish that they target.

Marine habitats are strongly linked to inland and coastal habitats including farmland, coastal urban cities and freshwater (Section 12.1.4). Application of fertilisers and livestock manure on farmland promotes increased terrestrial food provision, but excess nutrients and also nutrient-rich effluent from the storage of silage are conveyed, via freshwater runoff, into estuarine and coastal areas. For example, on an annual basis freshwaters contribute about 50% of the total external supply of dissolved inorganic nitrogen to the Irish Sea (Gowen *et al.* 2005). The enrichment of marine water by nutrients causes accelerated growth of macroalgae and microalgae. In shallow coastal and intertidal waters, the macroalgae can smother the soft sediments, impeding the flow of oxygen and nutrients to and from the sediment, and affecting marine life living within the sediment. When the microalgae and macroalgae die, their decomposition by microbial communities can further deplete oxygen in the sediment and overlying water, causing hypoxia and even anoxia, which have a deleterious effect on the water quality.

Eutrophication is one of the major threats to the health of estuarine, coastal and marine ecosystems around the world. The major pressures in the UK occur in the east, south and north-west of England where inputs of nutrients of anthropogenic origin (notably nitrate and phosphate from agriculture, but also urban wastewater sources) have resulted in nutrient enrichment of coastal waters (Chapter 4 in UKMMAS 2010). UK marine waters as a whole do not suffer from eutrophication problems, but some estuarine areas are nutrient enriched and are at risk from, or currently affected by, eutrophication.

Eutrophication can reduce and change marine biodiversity through the mortality of fish, shellfish and invertebrates, which will impact on most marine ecosystem services. It also encourages macro and micro algal blooms, which may be visually unattractive and reduce leisure and recreation benefits. Eutrophication can potentially increase blooms of harmful toxin-producing algae (harmful algal blooms; HABs), which can accumulate in filter-feeding shellfish or humans through consumption of contaminated shellfish, thus impacting on the human health benefits of marine food provision (see **Box 12.5a,b**). However, recent studies (Gowen *et al.* 2009) indicate that the abundance of HAB species that occur in the UK and Irish coastal waters is not related to anthropogenic nutrient enrichment. If poisoned shellfish are consumed, either because of a screening failure or unregulated harvesting, the human consequences can be severe, ranging from diarrhoea, to memory loss, paralysis and death. Harmful algal blooms may harm fish through food chain effects: fish may consume contaminated algae either directly or indirectly by eating prey that have consumed contaminated algae. This can impact food provision through reduced catches in the case of direct kills (e.g. fish and shellfish) or through closure of wild and aquaculture shell-fisheries when accumulated toxins have rendered the harvested shellfish unfit for human consumption.

The use of the marine ecosystem for waste disposal and detoxification services can also impact on food provision when it leads to bioaccumulation of pollutants, such as heavy metals and organic compounds, through the food chain. This impacts on sealife but also potentially on human health when fish and shellfish are consumed.

12.5 Options for Sustainable Management

A common paradigm amongst scientists discussing marine management has been that we do not manage marine ecosystems; rather we manage human activities within them. However, fundamentally we rarely understand the biodiversity or ecosystem implications of management decisions, let alone the impacts on ecosystems services. It is arguable whether, with the exception of fisheries, we manage any activity in the marine environment with respect to the provision of ecosystem services and their benefits. In the case of fisheries, it is only very recently that our management strategies are showing even slight signs of success.

The biodiversity and habitats of 80–90% of the UK's marine seabed remains unmapped and is known only via interpolation from the sites that have been surveyed and sampled: we do not know in detail what the characteristics of the seabed are in terms of sediment or rock habitat, what organisms live there, or how they change temporally. We need a much more comprehensive evidence base to properly quantify ecosystem services in a meaningful way that supports policy and new marine legislation.

12.5.1 Policy and Legislation

Currently, this is a time of massive change in EU and UK legislation with respect to marine ecosystems due to the recent introduction and forthcoming implementation of the EU Marine Strategy Framework Directive (MSFD), the UK Marine and Coastal Access Act (2009) and the Marine (Scotland) Act. The MSFD seeks to put in place measures to achieve good environmental status in EU waters by 2020. The EU and national legislation recognise that there are increasing commercial and leisure uses of marine ecosystems, for example, a growth in shipping for transport, marine renewable energy production, gas pipe and cable-laying, recreational boating, fishing, scuba diving and wildlife-watching, as well as traditional activities such as fishing (**Figure 12.16**). UK marine waters are viewed as

Figure 12.16 The marine environment is becoming increasingly busy, sometimes causing conflict in the use of space. Plymouth Sound. *Photo courtesy of Trevor Burrows Photography, Plymouth Marine Labratory.*

becoming increasingly crowded, but unlike on land, there are few, if any, defined property rights regarding the water column and the seabed beyond 12 nm, so management has only recently become spatially oriented. Within the new legislation the ecosystem and its biodiversity is viewed as being of sufficient importance that it must be considered equally with economic and social issues to be managed (as embodied by the ecosystem approach).

12.5.2 Conservation, Protected Areas and Fisheries Management

Protection within the marine environment around the UK will see dramatic change in the near future. The Marine and Coastal Access Act (2009) and the Marine (Scotland) Act 2010 (and the forthcoming Northern Ireland Marine Bill) require the designation of an ecologically coherent network of (MCZs), or Marine Protected Areas (MPAs) in Scotland, by 2012. This is also a requirement under the EU Marine Strategy Framework Directive. The MCZs will protect nationally important marine wildlife, habitats, geology and geomorphology, and will focus on all marine wildlife, not just threatened species; while the Scottish MPAs will focus on marine biodiversity and nationally important marine historic assets.

There are also calls from some scientists and NGOs to implement closed area networks to fulfil the same function for fish stocks. The EU Common Fisheries Policy is about to be revised and it is hoped that it will become more harmonious with the aspirations of the MSFD. Important progress is being made in UK fisheries management to improve the status of commercial fish stocks; for example, real-time closures, such as the voluntary closures in the North Sea to avoid areas of high cod abundance (www.scotland.gov.uk/Topics/marine/Sea-Fisheries/17681/closures), and changes to gear, such as the use of square-meshed escape panels in nets to help non-target species escape.

Some inshore areas around the UK are now closed to towed gear through fisheries bylaws. For example, no fishing is allowed out to three nautical miles at Whitby, north-east England and some sea lochs in Scotland are closed to benthic trawls to protect deep mud sediments. Other areas that are closed through conservation designations to protect slow-growing features include a SAC designated near Arisaig, western Scotland to protect mearl beds, and 60 nm^2 of Lyme Bay in south-west England which has been closed to benthic trawls and scallop dredging to protect fragile reefs.

It is not yet known whether these measures will lead to significant reductions in the levels of physical disturbance to seabed habitats. It is unlikely that the status of impacted benthic habitats will improve without further directed management measures to protect the seabed, particularly where they support long-lived, fragile and/or functionally important species.

The UK has direct control of inshore fisheries (within 6 nm of the coast) that mainly utilise small vessels of less than 15 m in length. New Global Positioning System (GPS) tracking technologies to monitor fishing vessel effort (see **Box 12.2**) should be implemented widely on these vessels with a view to strengthening management strategies and measures.

12.5.3 Management of Human Activities and Future Environmental Change

The development of marine planning, as proposed in the Marine and Coastal Access Act (2009) and the Marine (Scotland) Act, should be an important mechanism to help maintain or improve the quality of marine habitats, integrating the needs for sustainable use by industry with environmental protection objectives. They should enable proactive management of marine ecosystems. It is imperative that such plans consider not only the components of marine ecosystems in terms of biodiversity and habitats, but also in terms of ecosystem functioning and the provision of ecosystem services. The use of monetary and non-monetary techniques for the valuation of ecosystem services will aid the process of considering the impacts on, and also benefits for, ecosystems of marine development within marine plans.

With the extent of human activity in the marine environment increasing, it is likely that stronger governance will be needed including increased stakeholder involvement, improved enforcement of legislation and possibly reconsideration of property rights.

The marine environment is a dynamic and changing habitat, not least because of the rapid impacts of climate change and the anticipated onset of the impacts of ocean acidification. It is also highly interconnected. Planning will need to consider not only the current spatial impacts of different human uses of, and activities in, the marine environment, but also the future implications. This is particularly important with respect to deciding on the locations of protected or conservation areas, and of permanent structures such as wind turbines and other renewable energy devices. Spatially resolved modelling tools are likely to be able to assist in this process.

Links between deep-sea, shelf, coastal, estuarine, freshwater and terrestrial systems must be considered in these plans. A further complication is that most relevant legislation divides the UK marine area into inshore and offshore parts. This is because international and EU law usually places different rights and obligations on states in respect of their territorial waters (0–12 nm). There is a need to re-invigorate integrated coastal zone management in the light of the new marine legislation so that coastal management and marine management are fully aligned.

12.6 Future Research and Monitoring Gaps

Although recent National reports (Charting Progress 2 in 2010, State of Scotland's Seas in 2011) have gathered a lot of evidence, the characteristics and biodiversity of many UK marine habitats, particularly those which are subtidal, are still unknown and unmapped, and marine ecosystem services are poorly quantified. We need to understand and quantify the ecological links between marine biodiversity, ecosystem function and provision of ecosystem goods and services, and to understand the effects of human impacts on these links. Such knowledge would support more effective marine planning and licensing of activity in UK waters, encouraging the sustainable use of marine habitats and the maintenance of clean, healthy, productive and biologically diverse seas.

A list of gaps in knowledge was prepared by Austen *et al.* (2008) and many of the issues are still relevant, particularly with respect to the need to support marine spatial planning for sustainable management:

- ***Spatial and temporal ecology of marine systems***—information is needed on the scales at which underlying marine ecosystem processes occur, how these relate to the scales at which services are delivered, and what the linkages are between them. Marine landscape ecology still needs considerable research effort if it is to reach the level of understanding we have for terrestrial ecosystems.
- ***Improved understanding of non-coastal and sub-tidal marine ecosystems***—empirically derived theory concerning the nature of marine biodiversity-ecosystem functioning relationships needs to be tested under natural conditions and in a wide variety of marine habitats, particularly non-coastal and subtidal.
- ***Relationship between function (and/or biodiversity), process and provision of services***—a diversity of ecological processes underpin the provision of marine ecosystem services, but the relationships between them needs to be quantified and the key processes and elements of biodiversity determined.
- ***Development of modelling and predictive tools to link biodiversity to function, provision of service and value***—a predictive capacity to anticipate the impacts of human activity on the provision of marine ecosystem services and benefits is required to support policy and management. Models of marine systems exist but they need to better incorporate biodiversity and ecosystem services, and they need to be made operational.
- ***The role of biodiversity in providing resilience in the provision of ecosystem services***—the extent to which marine biodiversity facilitates resistance to change in the delivery of marine ecosystem services, as well as the ability of marine biodiversity to recover and restore delivery of services, needs to be understood.
- ***Limitations ('tipping points') of marine biodiversity***—there may be a uniform relationship between biodiversity and the provision of marine ecosystem services or there may be crucial non-linearities and tipping points at which delivery is no longer possible. These relationships, and the limits at which marine biodiversity can still provide a service, need to be defined.
- ***Defining the best mechanisms to afford the protection of goods and services***—the species, habitats and functions that are critical to maintain and enhance the delivery of marine ecosystem services need to be identified. This will help to define and prioritise management mechanisms and policy strategies for their protection and restoration. Knowledge that can inform such management priorities is particularly limited in subtidal zones.
- ***Development and application of technology to support research***—some underwater technology is already available but has not been fully utilised. For example, there are technologies to support underwater habitat-mapping where data is remotely collected, yet much of the seabed remains unmapped. Consequently, we do not know what the characteristics of the seabed are or what organisms live there.
- ***Building environmental accounts for the services associated with marine systems***—to support policy and management we need to clearly describe and quantify the processes that impact upon marine ecosystem services, the benefits they generate and their value.

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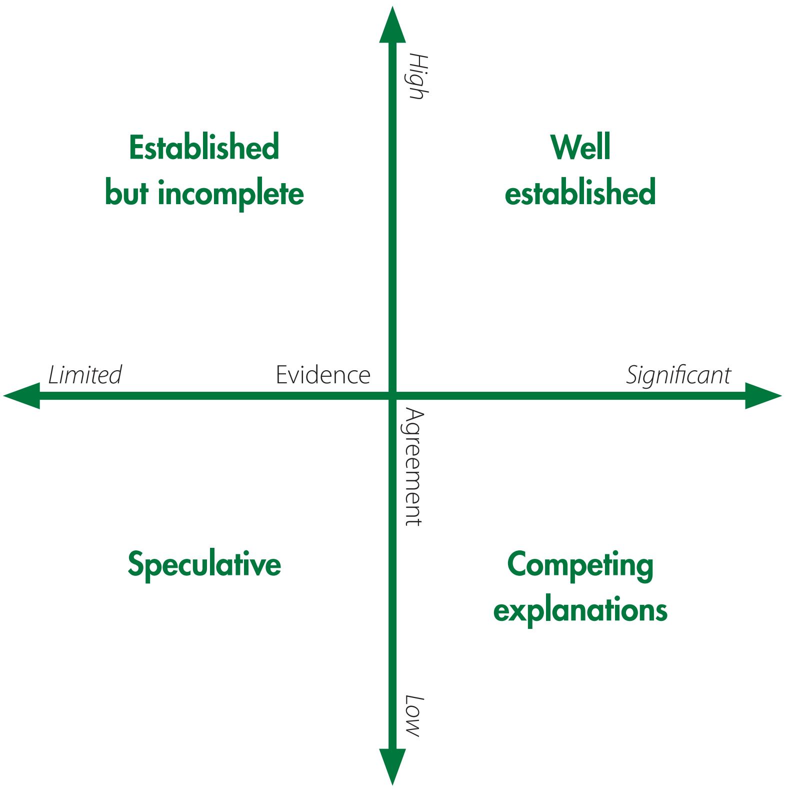
Appendix 12.1 Approach Used to Assign Certainty Terms to Chapter Key Findings

This chapter began with a set of Key Findings. Adopting the approach and terminology used by the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Assessment (MA), these Key Findings also include an indication of the level of scientific certainty. The 'uncertainty approach' of the UK NEA consists of a set of qualitative uncertainty terms derived from a 4-box model and complemented, where possible, with a likelihood scale (see below). Estimates of certainty are derived from the collective judgement of authors, observational evidence, modelling results and/or theory examined for this assessment.

Throughout the Key Findings presented at the start of this chapter, superscript numbers and letters indicate the estimated level of certainty for a particular key finding:

1.	*Well established:*	high agreement based on significant evidence
2.	*Established but incomplete evidence:*	high agreement based on limited evidence
3.	*Competing explanations:*	low agreement, albeit with significant evidence
4.	*Speculative:*	low agreement based on limited evidence



a.	*Virtually certain:*	>99% probability of occurrence
b.	*Very likely:*	>90% probability
c.	*Likely:*	>66% probability
d.	*About as likely as not:*	>33–66% probability
e.	*Unlikely:*	<33% probability
f.	*Very unlikely:*	<10% probability
g.	*Exceptionally unlikely:*	<1% probability

Certainty terms 1 to 4 constitute the 4-box model, while *a* to *g* constitute the likelihood scale.