CabinetOffice

Prime Minister's Strategy Unit

Marine Environment

Analytical paper produced to support the report *Net Benefits – a sustainable and profitable future for UK fishing.* Views reported in this paper **do not represent Government policy** and its findings are not necessarily endorsed or agreed by Government. This paper provides readers with the information and data used by Strategy Unit to arrive at its recommendations.

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Contents

1. Key messages

The UK's marine environment is degraded. We know that:

- The size of most fish stocks or the fishing pressure exerted upon them is outside safe biological limits;
- The genetics of some fish stocks have changed;
- Some non-target species have been fished out of some areas;
- The bycatch of marine mammals is serious and is an unacceptable risk to the viability of some populations;
- Damage to the seabed and to seabed communities is widespread which will adversely affect other species, including fish, dependent on these habitats and communities;
- Food webs have been disrupted;
- There is still uncertainty about some ecosystem processes.

Fishing is not the only cause of degradation, but

- Fishing is the most significant human activity causing change in the UK's marine environment;
- Fishing may reduce the resilience of marine environment to other pressures

A healthy marine environment provides many benefits. UK's seas should be able to provide and support:

- Lots of healthy fish which can be harvested regularly and profitably for food and still replenish;
- Healthy and viable populations of a diversity of marine wildlife other than commercial fish (both as food for fish and for appreciation by people);
- Healthy habitats for fish and other wildlife;
- Global processes such as atmospheric and climatic regulation, nutrient cycling, carbon sink and sources of sediment for coastal processes;
- A resource for learning, studying and understanding e.g. in monitoring climate change.

Future change is partly in our control

- The greatest risk beyond our control is of large-scale climate change;
- The effects of climate on fish stocks are obscured by the effects of fishing;
- We can choose to reduce the effects of fishing;
- If we act now, there is scope for recovery to a healthier and more productive state but recovery may take time to achieve. If we do not act now, the scope for recovery may diminish;
- The trends in other pressures on the marine environment are downwards, but we need to guard against shocks, such as the introduction of a deleterious marine species by ensuring resilience in fished ecosystems.

Key changes to give a chance for recovery

- Cut fishing effort;
- Be precautionary in our approach to fisheries and marine management;
- Take account of the influences of fisheries on the environment and vice versa;
- Apply environmental assessment procedures for existing and new fisheries;
- Find mechanisms to bring scientists and fishers together to improve common knowledge;
- Establish large areas of the seabed as sanctuaries from extractive uses and disturbance;
- Fund development (and introduction) of gear with improved selectivity and of appropriate fishing practices to avoid unwanted bycatch.

2. Background

This report sets out the results of the analysis by the Prime Minister's Strategy Unit on the effects of fishing on the marine environment around the UK. The report provides an overview of these effects, particularly those that are of long-term detriment both to fishers and the wider public. The report then identifies the changes needed to general fishery policy in order to minimise these impacts on the marine environment. The report does not cover the environmental effects of the UK fleet fishing outside Europe, those of foreign fleets supplying UK's consumers or of any associated industries. The report:

- describes effects of fishing on target and non-target species, and to the wider ecosystem, and some associated trends;
- examines the relationship of fishery values to other values of marine ecosystems, and compares fishery effects with other impacts on marine ecosystems;
- sets out the main environmental risks and trends that arise from current fishing practice and the challenges which therefore need to be addressed;
- establishes the need for recovery to a healthier state and better management of risk and uncertainty; and
- provides some key actions that fishery managers should take to integrate environmental values into decision-taking, in order to
    - help stimulate recovery and sustainability in fisheries,
    - minimise further environmental change,
    - aid integration of fisheries into broader marine management.

This work has been undertaken using established environmental concepts that need to be addressed in order to ensure that fishing can become environmentally sustainable. These concepts include sustainable use, the ecosystem (-based) approach and the precautionary approach to addressing risks in ecosystems that we do not fully understand.

In practical terms, these concepts can be translated into three requirements that cover individual social, economic and environmental objectives for the marine environment:

- Ensure current actions do not restrict the options of future generations (social, economic and environmental);
- Agree a balanced use (social, economic and environmental) of the sea; and
- Minimise the risk of irreversible change and long-term adverse effects to ecosystems.

Thus the bottom line for any exploitation of living resources is the conservation of the resource and the environment within which the resource exists. Humans are part of the ecosystem they shape and our activities are shaped by the natural system – in other words society and the environment are mutually dependent. Governance needs to ensure that social, economic and environmental aspects are correctly balanced for sustainable use.

From a practical perspective, this means managing fishing activities to ensure the long-term sustainability of fish stocks, and the integrity of their habitats both for fisheries and for nature conservation. Two principles of conservation for sustainable use, derived from the Convention on Conservation of Antarctic Marine Living Resources (CCAMLR), are relevant in this area:

- the maintenance of the ecological relationships between harvested, dependent and related populations of marine living resources and the restoration of depleted populations to the levels above those that ensure stable recruitment; and
- the prevention of changes or the minimisation of the risk of changes in the marine ecosystems and their wildlife that are not potentially reversible over two or three decades

The evidence presented in this report also needs to be considered within the context of many internationally agreed global and European targets that relate to fishing activity. These accept the need for changes in order to achieve a healthier and more sustainable situation and include:

- halting the decline of biodiversity across the European Union by 2010 (Gothenburg 2001);
- protecting and restoring the functioning of natural ecosystems (European Union's 6th Environmental Action Programme)
- seeking the conservation and, where relevant, restoration of ecosystems and populations of species in their natural surroundings (European Community Biodiversity Strategy, 1998);
- achieving sustainable exploitation of renewable marine resources of the seas (European Commission's draft strategy to protect and conserve the marine environment, 2002);
- encouraging the ecosystem approach in marine management by 2010; establishing representative marine protected area networks by 2012; and, where possible, restoring depleted fish stocks to maximum sustainable yields by 2015 (World Summit on Sustainable Development, Johannesburg, 2002); and
- requiring public participation in decision-making, and access to information (Århus Convention, 2001).

These existing targets now form part of the Government's approach to the marine environment and the meeting of its vision as set out in the Marine Stewardship report:

"*To provide for clean, healthy, safe, productive and biologically diverse oceans and seas*."

Underpinning this is now the development of strategic goals by the Government (Defra 2002) to guide their work on the marine environment. The most recent draft of these strategic goals included the following elements:

- to conserve and enhance the overall quality of our seas, its natural processes and its biodiversity;

- to use marine resources in a sustainable and ecologically sensitive manner in order to achieve maximum environmental, social and economic benefit from the marine environment;
- to develop proposals for an integrated and ecosystem approach to marine management;
- to sustain economic benefits and growth in the marine environment by enabling and encouraging environmentally sustainable employment;
- to increase our understanding of the marine environment, its natural processes and our cultural marine heritage; and
- to promote public awareness, understanding and appreciation of the marine environment and seek active public participation in the development of new policies.

Any recommendations on reforming fisheries activities should take these strategic goals into account.

3. Effects of fisheries on marine ecosystems

The primary effects of capture fisheries on the marine environment have been categorised into five broad areas by both the International Council for the Exploration of the Sea (ICES) and the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR):

- Removal of target species (including genetic effects)
- Mortality of non-target species
- Physical disturbance of the seabed
- Shifts in community structure
- Indirect effects on the food web

These are described in turn below. While examples are provided of destruction or substantial loss of habitats and species, the list is not exhaustive.

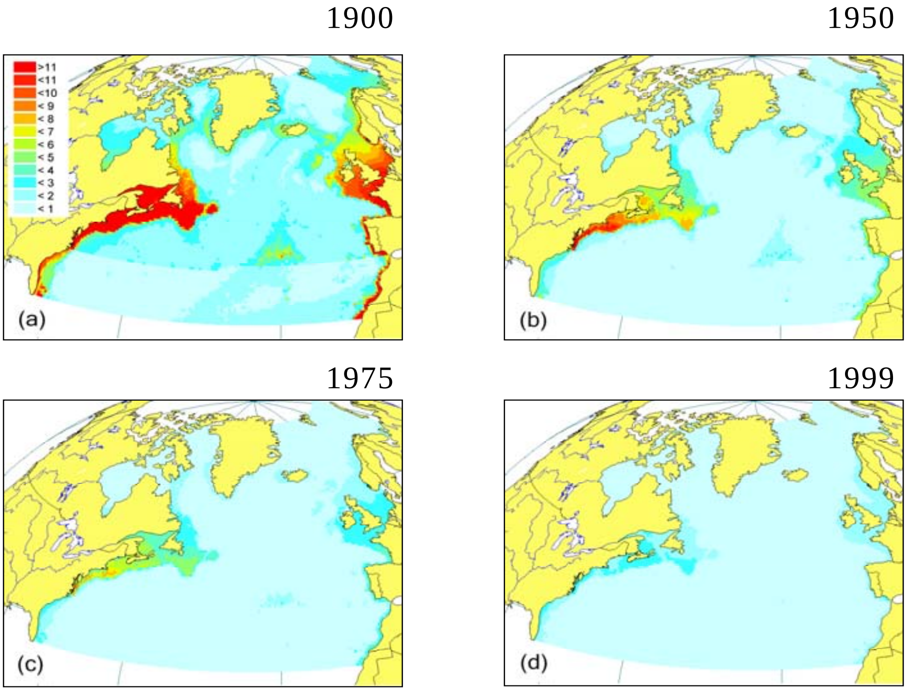
3.1 Removal of target species

The problems facing the UK fishing industry are part of a global problem. Most of the world's stocks of commercial species are now fully exploited or depleted. The Food and Agriculture Organisation of the United Nations (FAO) monitors the state of the world's fisheries and their report for 2002 shows that about 47% of the main stocks or species groups are fully exploited and are therefore producing catches that have reached, or are very close to, their maximum sustainable limits. Another 18% of stocks or species groups are reported as overexploited. An estimated 25% of the major marine fish stocks or species groups for which information is available are under-exploited or moderately exploited. The status of stocks in EU waters is similar and is outlined in the stock projections and management options report published with this report. The global situation is deteriorating and is part of a general trend observed over the years.

The most rapid depletion of fish stocks occurs early in the history of a fishery. A recent analysis (Myers and Worm 2003) shows that large predatory fish stocks are depleted by about 80% during the first 15 years of a fishery opening. Thereafter, rates of decline are slow. Although the methods and precise results of this analysis and controversial, the general message is not. Many fish stocks exploited for long-periods are now at a tenth or less of their pristine size and many are still declining. For most stocks of commercial species in European waters, this early loss of fish stocks occurred well before fishery records began.

The removal of the fish in the North Atlantic (Figure 1) that comprised a very large proportion of the vertebrate biomass of the oceans is the most substantial effect on the marine ecosystem caused by fishing. The earlier removal of the large whales from much of the north-east Atlantic would also have had a major effect on the marine ecosystem and its dynamics. It is important to remember that losses in the 20th century are in addition to greater losses of fish stocks towards the end of the 19th century in European waters. These were the result of the advent of steam trawling, combined with increased efficiencies due to the introduction of refrigeration and the railways that expanded market possibilities.

Figure 1. Biomass distributions in the North Atlantic for higher trophic level commercially exploited fish (tonnes/km2) (Christensen *et al* (2001, 2003) in Pauly and Maclean 2003)



As outlined in the stock projections report, the pressure of fishing continues to deplete stocks – the proportion of stocks inside 'safe biological limits' as assessed by ICES decreased from 26% to 16% between 1996 and 2001. "Outside safe biological limits" can mean either a spawning stock biomass below a certain level or fishing mortality above a certain rate (or both). An analysis of the scientific advice for groundfish stocks and stock complexes, for 2003 (Council of the European Union, 2003), illustrates the scale and complexity of problems affecting such species (Table 1).

If stock depletion continues unabated, then there will be an increasing risk of the collapse of these stocks. There is a growing body of evidence to show that recovery from stock collapse is not straightforward. In situations where collapse has occurred, such as off Newfoundland, recovery has mostly been absent or slow despite the closing areas of large areas of sea. Elsewhere, stocks that collapsed in the 1960s still have yet to show signs of recovery. Hutchings (2000) looked for evidence for recovery of 90 fish stocks after severe depletion. For the 25 stocks for which 15 years of post-decline data were available, only 12% made a full recovery after efforts to reduce fishing pressure, all of them clupeids (species including herring and sardines). Forty percent of species experienced no recovery at all after this period, and most others made little recovery. Recovery can fail for a number of reasons: Commonly, fishing mortality remains too high (either in directed catch or unaccounted bycatch); stock sizes have fallen below thresholds at which reproductive success declines rapidly; ecosystems have been altered in ways that make recovery difficult, such as habitat modification or loss of prey; or species interactions have changed such that recovery cannot occur, e.g. young fish are subject to high rates of predation. Experiments with closed areas in New Zealand have demonstrated that if extractive use pressures are removed completely, benefits occur early on but full recovery may take 25 years or more to achieve, as the population structures, including predatory fish, rebalance (Babcock *et al*. 1999; Roberts and Hawkins 2000). Changes are still being observed in these areas today. In other situations, such as off the east coast of America, where seabed areas have been closed to trawling to protect scallop populations, recovery has been more rapid (Murawski *et al*. 2000).

The lesson is that recovery is not guaranteed, and it is far better to take all measures to prevent collapse and to put a wide degree of precaution on exploitation when approaching such circumstances, rather than run the risk of closing off options for current and future generations, whether on a social, economic or environmental basis.

Table 1: The state of major North East Atlantic groundfish stocks or stock complexes for which the EU fixes a TAC or shares a multilateral/multi national TAC (Council of the European Union, 2003).

Species	Stock(s) below SSB	Status of juveniles	Fishing mortality (F)	Summary of major issues
Anglerfish[1]	Yes	At risk	Above F_{pa}	F far too high for several years while stock outside SBL. Juveniles subject to exploitation before reaching maturity.
Blue whiting	Yes		Above F_{pa}	F increased sharply recently. ICES fear stock abundance overestimated.
Cod[2]	Yes	At risk	Above F_{pa}	Majority of spawning stock in many instances composed of first-time spawners. Long term harvesting well above F_{pa}. Recruitment poor, suggesting juveniles at risk. Fishery relying on very young fish. Closure recommended by ICES and STECF for most stocks. Spawning and juvenile cod taken in fisheries for plaice, sole, *Nephrops*, rays. Lack of agreement on recovery plans.
Halibut	Yes		Above F_{pa}	Low recruitment.
Haddock[3]	Yes, except Faroe stock	At risk	Above F_{pa}	Caught in mixed demersal fishery; current North Sea stock very reliant on one good 1999 year class thus very high recent discard rates of smaller fish.
Hake	Yes		Above F_{pa}	Lack of agreement on recovery plan. Fishing above F_{pa}.
Plaice[4]	Yes, except Irish Sea		Above F_{pa}	Discarding is high and needs to decrease to enhance SSB. Low recruitment. Caught in mixed whitefish fisheries. Not well reflected in advice.

Nephrops[5]	Stable except Gulf of Cadiz, Cantabrian Sea, Galicia	At risk in some fisheries		Effort using multi-rig trawls (but with bigger mesh) increasing in many fisheries. Interaction with whitefish, cod in particular, a concern and not well reflected in ICES assessments or advice.
Saithe				Mixed fishery species
Sole[6]	Yes	At risk	Above F_{pa}	Caught in mixed fisheries and in *Nephrops* directed fisheries. This not well reflected in ICES assessment and advice.
Whiting[7]	Yes	At risk	Above F_{pa}	Low recruitment. Taken as mixed whitefish fisheries. Not well reflected in assessment or advice.

Notes
B_{pa} is the target biomass required to reduce the probability of hitting the biomass level below which recruitment is impaired.
F_{pa} is the fishing effort that will lead to B_{pa}
1. Anglerfish – Combined North Sea, Celtic Sea, Irish Sea, Bay of Biscay and Iberian region.
2. Cod – Combined north east Arctic, North Sea, Baltic, Kattegat, Skagerrak, Faeroe Bank, west Scotland, Rockall, Irish Sea and Celtic Sea.
3. Haddock – Combined North east Arctic, North Sea, Baltic, Kattegat, Skagerrak, Faeroe Bank, west Scotland, Rockall, Irish Sea and Celtic Sea.
4. Plaice – Combined North Sea, Baltic Sea, Irish Sea, Celtic Sea and English Channel.
5. Nephrops – Combined North Sea, Skagerrak, Kattegat, Moray and Clyde Firth, Irish Sea, Porcupine and Aran Bank.
6. Sole – Combined North Sea, Irish Sea, English Channel, Celtic Sea and Bay of Biscay.
7. Whiting- Combined North Sea, Skagerrak and Kattegat and NE Atlantic general

Nearly all species targeted in UK demersal fisheries have been depleted. Currently, over 60% of UK stocks are outside safe biological limits (cod, whiting, angler, haddock etc.) and 33% are of unknown status (includes some stocks of sole, halibut, pollock, flounder). For less than 10% of the whitefish stocks (for which there is information) is there confidence that they are currently being harvested within safe biological limits. Shellfish and crustacean stocks appear to be in a better state, however only *Nephrops* are subject to stock assessment. Invertebrate stocks often appear to thrive when whitefish stocks are at a low level, as illustrated by Georges Bank and the Grand Banks off eastern North America, possibly due to a reduction in predation by fish populations. However resilience in shellfish stocks may not be sustained in the medium to long term. Snow crab stocks off Canada appeared to increase in size after the cod collapse and initially showed good resilience to fishing, but the stocks have recently fallen, perhaps as a result of sustained fishing pressures or perhaps as a result of natural fluctuation.

While elasmobranchs (sharks, skates and rays) have always been less abundant than many of the major stocks, species such as the common skate (Brander 1981), angel shark (Rogers and Ellis 2000), and white skate (Dulvy *et al*. 2000) have been severely depleted in UK waters and extirpated from some areas such as the Irish Sea.

Stocks of pelagic fish, such as herring and mackerel, have also been reduced in size but, partly because they are caught often only in single species fisheries, most seem to be able to recover once fishing pressure is removed. Their ability to recover may also in part be due to 'trophic release' as stock of fish species that would prey on them are significantly reduced by fishing. Their resilience is also attributed to them generally being species with rapid population turnover rates.

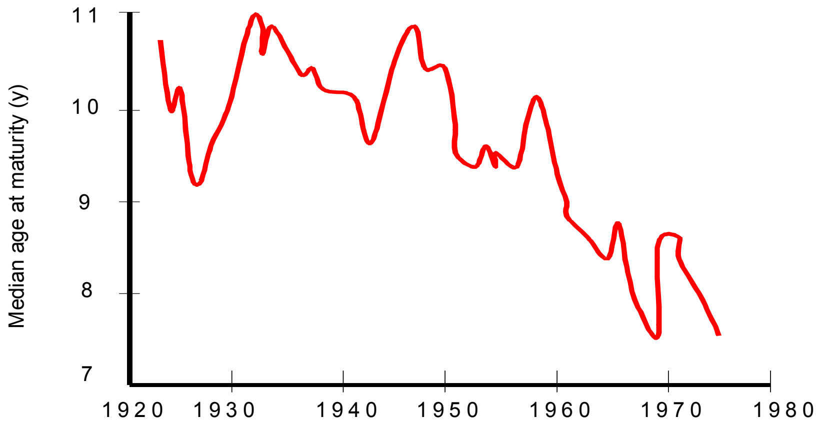
3.1.2 Genetic effects on fished stocks

Fishing pressure is also affecting the genetics of species, causing them to mature at an earlier age than they would otherwise have done. Figure 2 illustrates the effects that fishing pressure had on cod between 1920 and 1980. Spawning cod in the North Sea now mainly consists of first-time spawners, rather than having an age distribution with an emphasis of older, multiple-spawned individuals. This is important as first time, small spawners produce fewer eggs, and those eggs are less viable than those coming from larger, older fish. Consequently this genetic change makes the population less resilient to depletion. Effects are similar in other heavily exploited species.

Genetic effects are occurring because of the intensity of the fishing pressure. Fishing is now selecting particular traits in species, just as natural changes cause slow selection for traits in species over very long periods of time. Given that fishing mortality on post-larval stages is often two or three times greater than mortality from natural causes, the effects are occurring at dramatically accelerated rates. Experiments, copying the selective pressures of fishing, show that genetic effects resulting in significantly smaller fish, maturing early in life, can be manifested in a population within just four fish generations (Conover and Munsch, 2002). The strengths of selection on body size is large enough to be detected within single age classes of North Atlantic cod, as the fish grow and selective mortality takes place (Sinclair *et al*. 2002).

There is evidence that even if fishing pressure is completely removed from stocks; genetic changes may persist for centuries (Law 2003). There is therefore an urgent need for significant and immediate actions in the fisheries sector to prevent such genetic impacts being more widely expressed in populations. From an industry perspective, large fish are financially more valuable than minimum landing size individuals. Large fish in a population provide greater resilience and opportunities for sustainable exploitation. A sustainable fishing industry will require recovery towards healthier population structures. Undirected lowering of fishing mortality is unlikely to be an effective management measure alone as it will slow down genetic change but not prevent it. New approaches are needed such as directing fishing effort to certain size classes, life history stages or areas (Kenchington, 2003).

Figure 2. Median age-at-maturation (sexes combined) for cod (redrawn from Law 2000, after Jorgensen 1990).



3.2 Mortality of non-target species (fish, invertebrates, birds and marine mammals) through their incidental catch in fishing gear

Fishing kills many more fish than are landed and registered. Globally, the proportion of fish caught and discarded amounts to about 26% of the overall catch by weight (Alverson *et al*. 1994). However if industrial fisheries for reduction into fish-meal are removed from this (where all the catch is landed) the proportion rises to over 50% with some individual fisheries (e.g. shrimp and prawn fisheries), having discard rates of over 80% of the catch. In 1990, around 260,000 tonnes of roundfish, 300,000 tonnes of flatfish, 15,000 tonnes of rays, skates and dogfish and 150,000 tonnes of bottom-dwelling invertebrates were discarded in the North Sea alone. This amounted to about 22% of the declared landings by weight. This large-scale killing is an additional impact on the stocks of fish described above and on the environment.

While all fishing gears may be hazardous to marine animals, a few gears are particularly risky for specific species. Thus bottom-set gill netting particularly affects harbour porpoises, and some pelagic trawling practices affect dolphins. Figure 3 shows the trend for bycatch of harbour porpoise in UK fisheries in the North Sea (Defra 2003). Calculations indicate that if a population of harbour porpoises is to reach 80% of its carrying capacity at some point in the future, then bycatch should not exceed 1.7% of its population level. If 1.7% of the North Sea harbour porpoise population is divided pro-rata among those nations using bottom-set gillnets in the North Sea, the 1.7% level for the UK would be 500 animals. UK is still catching in excess of this internationally-agreed level (Figure 3). No-one wishes to catch any of these animals, so the ultimate target must be zero.

Figure 4 shows a marked increase in the stranding of cetaceans (majority being common dolphins) on beaches in the south west of England since the 1990s. Small cetacean bycatch in this region has been linked to pelagic trawling activity. The introduction of escape panels in the UK pelagic pair trawls fishing for bass is a good example of adaptive management to reduce this problem, though this type of measure will not be very effective in reducing overall catches of dolphins unless pelagic trawl fleets from other European Union member states operating in the area also employ similar mitigation measures.

Figure 3. Bycatch of harbour porpoise in North Sea bottom-set gill nets in UK fisheries (Defra 2003)

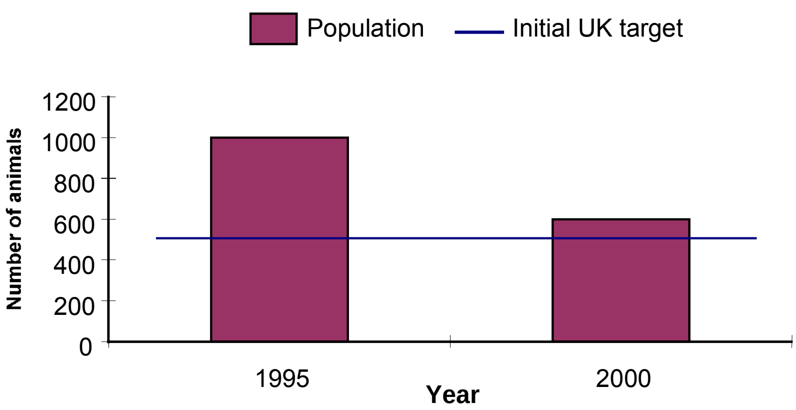
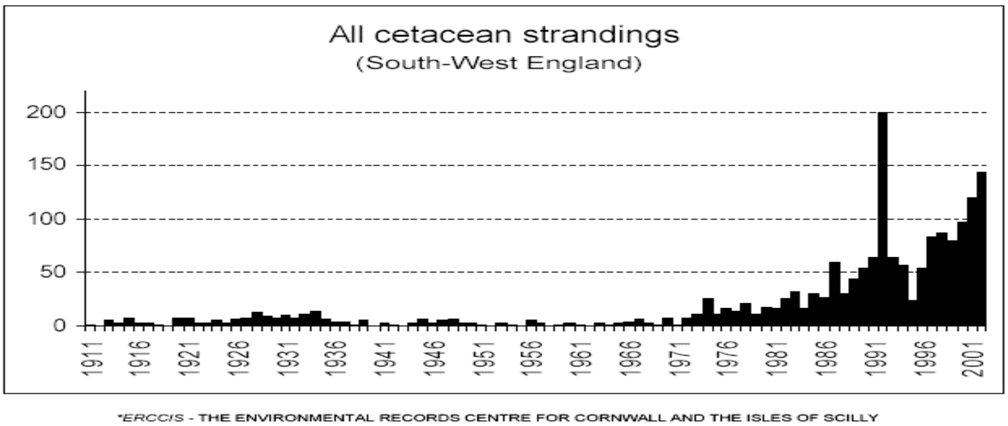


Figure 4. Stranding data for cetaceans in south-west England 1911 – 2001 (from the Environmental Records Centre for Cornwall and the Isles of Scilly)



The targeted capture of marine mammals in past centuries resulted in significant declines in their populations. With some exceptions in the north-east Atlantic waters (whaling off Norway, Iceland and the Faroes, and illegal killing of dolphins in Iberian waters), this targeted capture has now ceased. However, the bycatch of marine mammals in fishing nets has increased proportionately to the rise in the amount of certain fishing practices.

Bycatch also affects other species: lines of all sorts entangle turtles, and long-line hooks catch some seabirds and drift nets catch both birds and dolphins. There have been very few studies of bird bycatch in European waters; reviews in the 1980s indicated that some near-shore salmon nets were catching significant numbers of auks from nearby colonies around Scotland and Ireland; but most of these fisheries have now closed for salmon conservation reasons. There are reliable reports of auks being caught in both pelagic trawl gear and trawls for sandeels, but catches have not been quantified in either. There has been one study of catches in longline fisheries in waters to the north of the UK that showed a relatively high bycatch of northern fulmars (Dunn and Steel 2001). Mitigation measures are available for these longline fleets but there is no legal requirement to apply them.

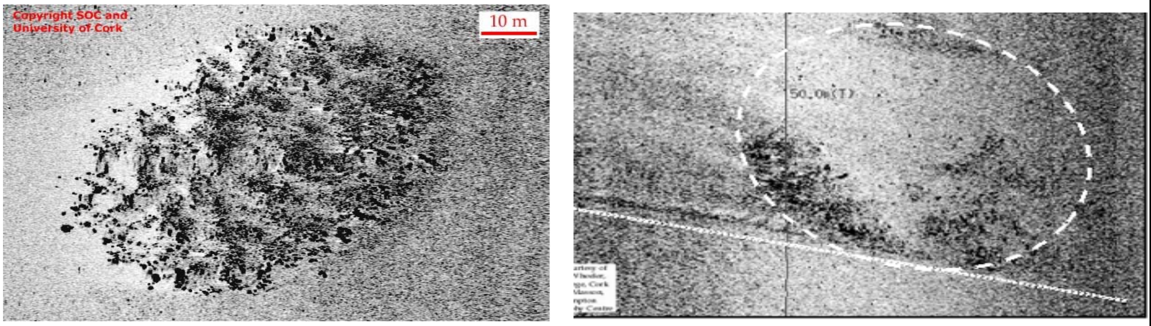
3.3 Physical disturbance of the sea bottom by fishing gear

There have been a number of studies documenting the effects of mobile gear on the seabed of inshore, continental shelf waters (e.g. De Groot and Lindeboom, 1994; Lindeboom and de Groot, 1998; Frid *et al*. 1999; Collie *et al*. 2000). Changes caused by trawling on the seabed and its habitats in the North and Irish Seas are widespread. Some habitats may be more resilient and recover faster than others. In most cases, the first pass of a trawl over an unfished benthic habitat will cause the greatest change. Thus in most areas of the continental shelf, damage is being inflicted on communities already substantially changed by fishing. The development of new gears and techniques for fishing over previously unfished grounds thus causes great damage to the marine environment. Examples in recent years include the development of rockhopper gear, the development of more powerful trawlers able to fish in deeper water and the development of accurate navigation and trawl handling gear enabling small patches of suitable habitat to be targeted.

These changes are liable to affect both commercially fished stocks and the rest of the marine ecosystem. Many fish species thrive better in a more natural environment that in a degraded one – in much the same way that natural woodlands and grasslands support many more species than ploughed agricultural land. The expansion in geographical extent of fishing pressure is reducing the area of relatively unimpacted environment acting as refuges for commercial stocks and wildlife alike.

Most of the data on the impact of fishing gear comes from comparatively shallow waters. There have been few studies in deep water, but the recent rediscovery of cold-water coral reefs in the north-east Atlantic waters has triggered a series of studies of these habitats and the impact of fishing upon them. In most cases, the first pass of trawl gear is sufficient to damage or destroy some areas permanently (Figure 5, Bett 2000). At least 25% of the known reef areas off Norway have been damaged. A recent study showed that a sample of cold-water coral from off west Scotland was at least 4550 years old (Hall-Spencer *et al*. 2002). Given that it is unclear how these reefs and the small sand volcanoes on which the coral sits were formed, such damage is permanent and should be avoided. These features increase three-dimensional habitat diversity and consequently have a high diversity of associated species.

Figure 5. Left – an intact Darwin Mound, Right – a Darwin Mound after the passage of a bottom trawl (Southampton Oceanography Centre/University of Cork)



Direct damage is not the only physical effect of trawling. The stirring of seabed sediments can alter the seabed habitat, as can the moving or removal of seabed features such as stones and boulders. Studies on communities of animals living in the sediments have concluded that the physical impacts arising from excessive fishing pressure change benthic community structure. Jennings *et al*. (2002a) document the effects of chronic trawling disturbance on the production of infaunal communities. In general, seabed communities in heavily trawled areas have changed from long-lived to more opportunistic species. Some shellfish species of potentially great longevity are thus displaced by bottom trawling, notably the clam *Arctica islandica* which regularly survives to 150 years in undisturbed Atlantic continental shelf conditions. Trawling causes a significantly reduced diversity and abundance of molluscs and other species living in the sediment, whilst encouraging a significant increase in rapidly reproducing species. It also benefits thaose species that scavenge on discards from fishing vessels or on moribund organisms damaged by the passage of fishing gear (Rumohr and Kujawski 2000). Some scavenging fish, such as gurnards will thrive in these disturbed areas, but many species will not.

Physical disturbance by fishing causes changes in nutrient cycling in marine ecosystems (Duplisea *et al*. 2001). This is important in avoiding eutrophication or anoxia in or near the seabed. Both of these effects can seriously reduce the numbers of fish or shellfish that an area can support. These changes in nutrient cycling are caused by the increased mortality of those species that dig deep into the seabed, such as *Nephrops* and the razor shell *Ensis* (Figure 6, Table 2).

Figure 6. Diagram illustrating the role of sediment bioturbating organisms in cycling nutrients into marine food chains (Plymouth Marine Laboratory/COST-IMPACT, 2003)

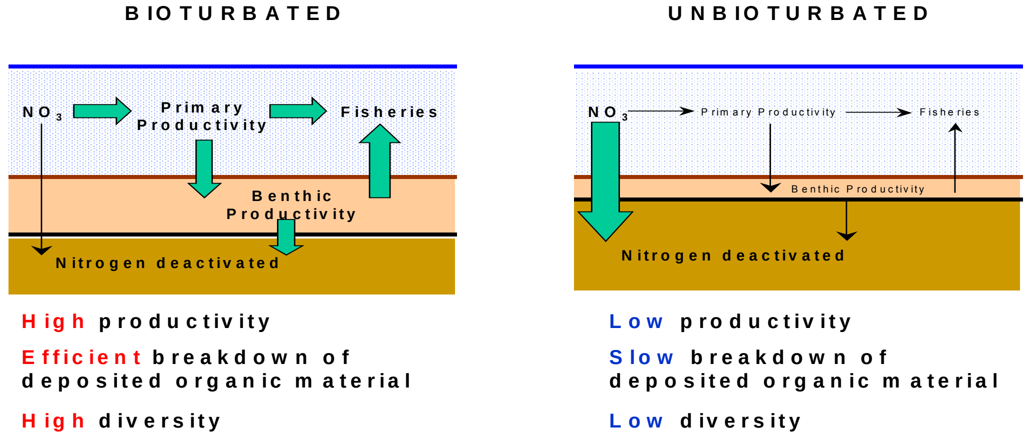


Table 2. Seabed wildlife involved in nutrient cycling through bioturbation activities (Plymouth Marine Laboratories/COST-IMPACT, 2003)

Very likely to be important for nutrient cycling	Of known importance for nutrient cycling
• Burrowing shrimps (Thalassinideans) • Burrowing urchins (e.g. *Brissopsis, Echinocardium*) • Small clams (bivalve molluscs) • Burrowing brittlestar (e.g. *Amphiura*) • Large motile and sedentary *worms (polychaetes e.g. Nereids, Capitella*; Echiurans e.g. *Maximallaria*)	• Norwegian lobster (*Nephrops*) • Razor shell (*Ensis*) • Large clams (e.g. *Arctica, Mya, Lutraria*) • Burrowing crabs (*Goneplax*, *Corystes*) • Burowing starfish (*Astropecten*) • Burrowing sea-cucumber (Synaptid Holothurians) • Peanut worms (sipunculids) • Burrowing fish (Hagfish, red bandfish)

In order, however, to understand how much habitat has been, and continues to be, changed, it is necessary to have relatively fine scale maps of habitat occurrence and trawling pressure (divided by gear). Neither of these is available for large areas yet, either inside EU waters or overseas. Considerable effort has gone into habitat mapping in some relatively restricted areas (e.g. near UK coasts, waters to the north and west of Scotland). These efforts might in due course be built upon to provide fine-scale maps over a relatively wide area. Fishing effort information could be collated from the satellite transponder signals, but these monitoring systems are only in place on larger vessels in EU waters at the moment, and the information is not available for use other than in enforcement.

3.3.2 Resilience and recoverability

Although benthic communities are impacted on a regular basis by mobile fishing gear, different habitats and species have differing resilience and recoverability, which can affect the longevity of any damage. Large, long-lived, slow-growing species will take a longer time to recover than small, short-lived, fast-growing species. Communities living in areas with a high level of natural disturbance can be more resilient to additional disturbance from fishing than in naturally undisturbed areas. Equally, effects of fishing may persist longer in relatively-undisturbed systems.

However, it is very hard to judge the real recovery time for seabeds that are trawled frequently, as the communities now present will have adapted to the disturbance. Highly-trawled areas will only support species that can persist in the face of this impact and, therefore, are likely to recover quickly from disturbance. Without protected areas of seabed, we are unable to judge the full extent of trawling impacts.

3.4. Shifts in community structure

Reductions in biomass of target species and the removal of larger individuals, often means that exploitation switches to other previously less favoured and/or unexploited species. Commercially exploited species of fish favoured for the table have usually been ones from towards the top of the food chain. The switch in emphasis to exploit a greater proportion of species that are removed from lower in the food chain has been termed 'fishing down the food chain'. This is a useful general concept to examine the broad-scale consequence of fishing although the concept masks issues such as the fact that species may feed at different levels in food chains depending on their age and size.

Figure 7 illustrates this phenomenon for the northeast Atlantic. Whether computer-based models or analysis using nitrogen stable isotope are used, all studies show a decline in the mean trophic level of landed fish. There is a strong correlation of this effect with fish size. For the North Sea the trend has been a decrease in the trophic level of demersal fish community between 1982 and 2000, consistent with the effects of fishing (Jennings *et al*. 2002b). In the Celtic Sea there was similarly a significant decline in the mean trophic level of survey catches from 1982 to 2000, as well as a decline in the trophic level of landings from 1946 to 1998 (Pinnegar *et al*. 2002). The switch in emphasis of exploitation can also be visualised in terms of overall changes in catch composition at a basin-wide scale (Figure 8), demonstrating the greater proportional contribution of lower level fish to overall catch composition and also the expansion in the relative contribution of invertebrate species, such as crustaceans.

Figure 7. Trend in mean trophic level of northeast Atlantic fisheries (redrawn from Pauly *et al* 1998).

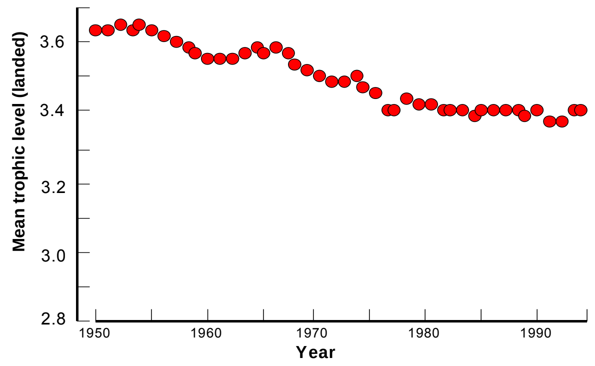
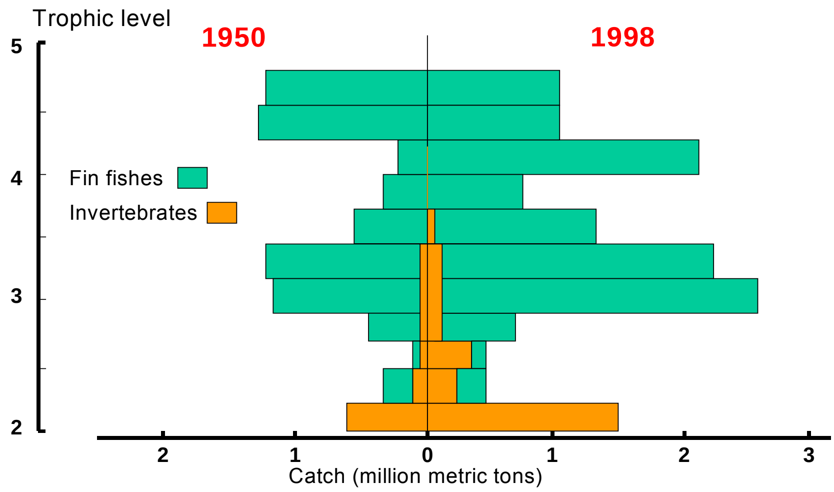


Figure 8. Catch composition for the northeast Atlantic, comparing 1950 with 1988 (redrawn from Pauly and Mclean, 2003)



Alongside such effects, there has been a reduction in the average size (and of age) of fish in the sea. Nets are designed to take the large fish and let small ones pass through the mesh resulting in a marked reduction in fish length. Figure 9 illustrates this for the North Sea by comparing sample trawl information for 1904 and 1991, reflecting an overall trend. For some heavily targeted species the effect has been dramatic with cod, on average, reducing from around 0.80 – 1 metre in length down to around 35 cm, and plaice now being an average of 25% smaller than they were a century ago. The metric of fish length is one indicator now being considered for assessing the impact of human activities on European seas (ICES 2003).

Figure 9. Size spectra southern North Sea (all fish species) comparing 1904 with 1991 data. (redrawn from Svelle *et al*. 1997)

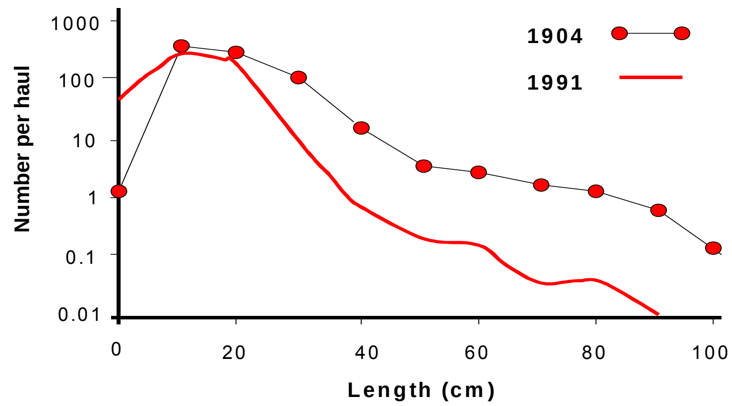


Table 3. Life characteristics of selected species of commercially exploited fish and non-target marine wildlife (source: MarLIN in litt; Froese and Pauly 2003).

Species	Sexual maturity (yrs)	Maximum reported life span (yrs)
Sandeel	1 – 2	10
Atlantic mackerel	2–3	17
Plaice	2–3	50
Cod	3–4	25
Blue whiting	3–5	20
Common skate	7–12	51
Orange roughy	5–12	149
Barnacle	1	5–10
Kelp	1–6	10–20
Egg wrack	5	10–25
Sea fan	?	20–100
Horse mussel	3–8	20–100
Maerl	?	20–700
Cold-water coral	?	4550

The removal of large individuals from fish populations has three main community effects that challenge the future sustainability of the fishing industry:

- *The loss of reproductive contribution to populations*: Large, 'old' individuals make the greatest reproductive contribution from a population, by producing many more eggs that are of an overall higher quality, than the fewer, lower quality eggs released from first time spawning fish. Many species caught in fisheries are long-lived with relatively late maturity (Table 3). Many of these species are caught before maturity and in several cases only the youngest reproductively active age classes remain in waters around Britain.

- *The loss of age class structure and resilience*: In the face of unfavourable environmental conditions or episodic events, populations consisting of a wider range of age classes including large individuals are more resilient than those consisting mainly of one age-class of small individuals. Dependence on a few reproductively active age classes to replenish populations can result in greater variability of recruitment into populations from year to year and therefore makes the stock resources even more difficult to evaluate and manage. Smaller, younger fish are also subject to more predation pressure thus raising overall natural mortality of populations.

- *The possible interruption of important behavioural characteristics*: Some scientists are now speculating that large individuals may provide migration 'knowledge' along with other instincts inherent in stock behaviour that enable effective completion of lifecycles. This theory may help explain why some stocks have not recovered from collapse, or at least not fully recover their former geographic spread, even though other conditions appear favourable (i.e. reduction or cessation of fishing).

This is reflected in a recent study that examined the changes in demersal fish populations at three locations around the UK, by comparing fishery research trawl data from 1901 – 1907 with survey catches for the same areas from 1989 – 1997. Whilst species diversity remained similar the composition of species changed. In general the proportion of small fish species not subject to commercial exploitation increased, larger fish decreased and a decline in large sharks, skates and rays was observed (Rogers and Ellis, 2000).

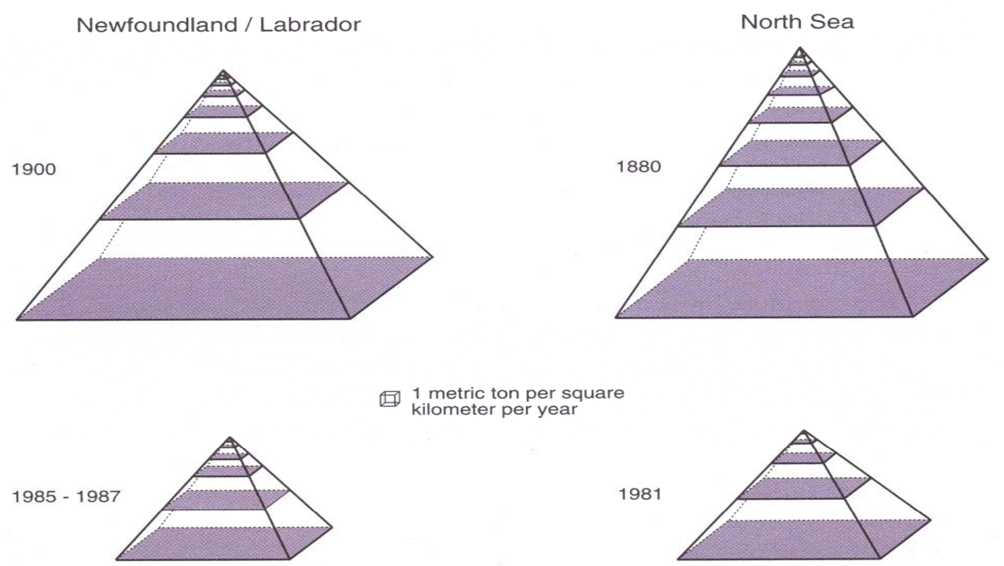
3.5 Indirect effects on the food web

The impacts of fishing on food webs and energy transfer between different trophic levels are much more difficult to determine, but may be as severe as the above physical and population level effects. They are difficult to study and assess given a lack of baseline information.

The marine environment around the UK in which fishing occurs was already altered by the time that fishing became industrialised. An example of the alterations that had occurred by this time was the severe depletion and in one case loss, of the great whales. Ecosystem change caused by fishing is compounding longer-term ecosystem imbalance, suggesting that recovery of fisheries will require longer timescales and more commitment than are presently being applied.

Recent studies of changes in ecosystem structure over the past 100 years for the North Sea and the Grand Banks have concluded that in both cases the food web has shrunk, that the amount of biomass that is transferred up the food web has declined dramatically and that there is insufficient food at higher (trophic) levels in the food chain (Figure 10). Thus the remnant stocks of predatory species of fish at the top end of the food chain may be forced to feed lower down the food chain. Shorter food webs expose top predators to greater environmentally driven fluctuations exhibited by plankton, that otherwise would have been dampened in webs with larger numbers of links (Pauly and Maclean 2003). Fishing has thus reduced the resilience of ecosystems to environmental changes caused for instance by climate change.

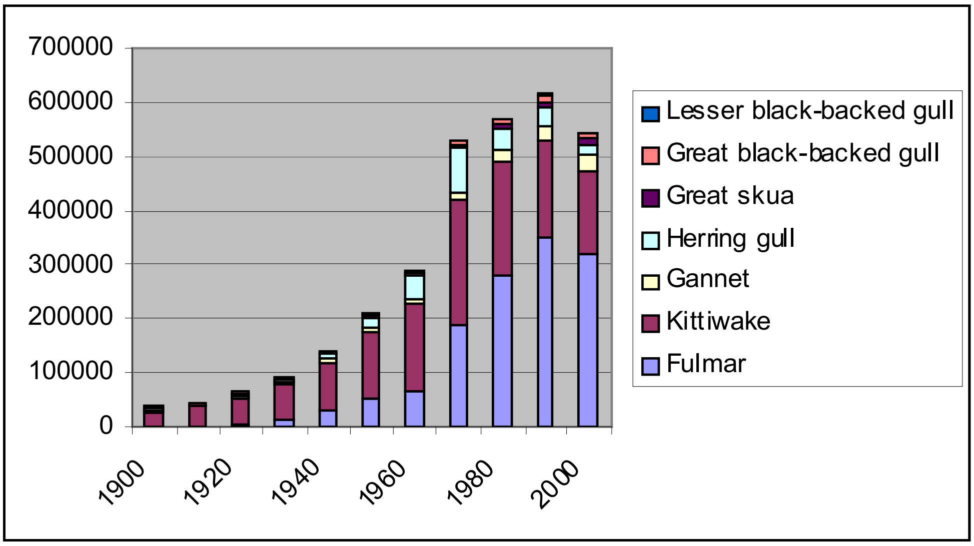
Figure 10. Representation of food webs for the North Sea (1880 and 1981), compared to Newfoundland/Labrador (1900 and 1985-1987). (Reproduced from Pauly and Maclean 2003: based on Bundy *et al.* 2000, Christensen 1995, Mackinson 2001, Pitcher *et al*. 2002).



The changes in the size profile of fish communities have also probably had great effects on the populations of fish-eating predators with those that consume small fish, such as common guillemots and seals increasing in numbers. This increase in both seals and guillemots is not only due to increased availability of food but also recovery from past persecution and exploitation – seabirds were intensively exploited for food in the 19th century. Also in the 19th Century, seals were killed for oil and latterly because they have damaged fishing gears or taken fish.

Fishing activities may directly support some scavenger species through the provision of fisheries waste as a gratuitous food supply. Populations of many species of scavenging seabird have increased in size over the past century (Figure 11). The relationship between scavenging seabirds and discards and offal is not entirely clear cut as some species such as herring gull reached their inflection point a few decades ago, but the general trend is clear. The decrease in populations since 2000 may well reflect the declining amount of offal and discards due to declining fish stocks.

Figure 11. Numbers of breeding pairs of scavenging seabirds in the north-west North Sea during the 20th century (Furness 1992, updated from results of Seabird 2000)



3.6 Effects of the environment on fisheries

The main effect of the environment on fisheries is through the natural processes affecting fish stock size. These may be looked at in the context of the life cycle of fish.

Spawning fish may require certain habitat or environmental features – for instance herring prefer well-oxygenated gravel banks, some skates and rays fix their egg cases to submarine vegetation, while others spawn broadly in areas where the sea temperature best suits them. The fecundity of individual fish depends on body condition and is related to size of fish and nutritional status; both of these will be affected by the amount of food in the environment. The viability of spawn is also dependant on these factors.

After hatching, fish larval growth and survival is highly dependant on environmental conditions. Growth is affected by temperature, salinity and the amount of planktonic food available. Some species of plankton are better than others for growth, and the mix of species is also environmentally-dependant. One effect of global warming and of acidification of surface waters has been a change in plankton communities in UK waters. Survival of plankton is a combination of the above growth factors and degree of predation pressure. The greatest predation at this stage is from other fish and fish larvae. A large planktivorous herring stock is likely to have a greater impact on survival of the larvae of many fish than a smaller one. During the larval stage, fish are largely at the whim of sea currents (though some vertical migration occurs). These currents may wash the larvae into suitable nursery areas for young fish or may not. Break-down in larval transport mechanisms has been cited as one of the factors behind the herring stock collapse in the 1970s (Corten 1986).

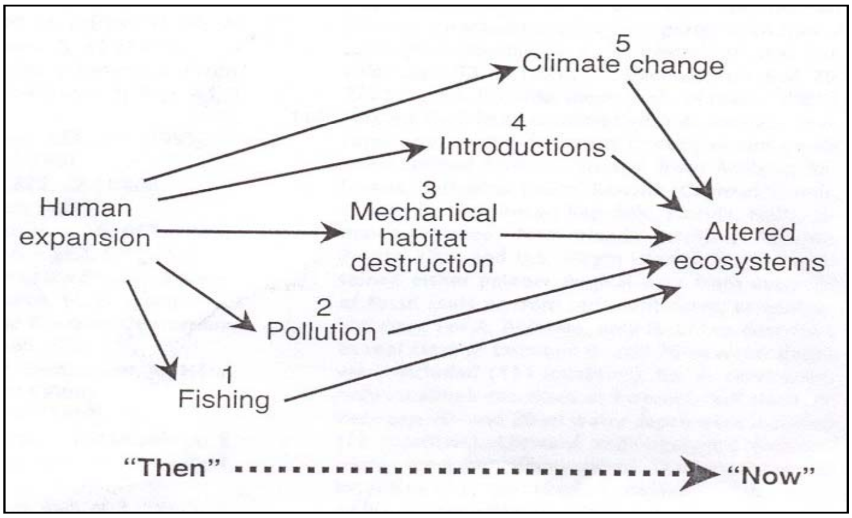
Once in nursery areas, fish continue to be affected by food and predation, although it likely that both food type and predator mix changes as the fish grows. Other fish remain the most important natural predator, with fisheries beginning to have a greater and greater effect for many species. At this stage, fish can start to propel themselves actively, and can actively seek prey or migrate to other areas. After a few years of growth, the fish become adult and may start to reproduce themselves.

4. Fishing impacts in the context of other uses

4.1 Introduction

Globally, overfishing of large vertebrates (fish and whales) and shellfish is the most pervasive impact that humans have had on marine ecosystems. Other impacts such as pollution, eutrophication, physical destruction of habitats, outbreaks of disease, invasions of introduced species, and human-induced climatic changes have all tended to come much later than overfishing in the sequence of historical events (Jackson *et al*. 2001) (Figure 12). In the UK, for example, records of concerns such as the effect of trawling, of the effects of small mesh size, and of the use of fish for animal feed rather than the table go back as early as 1376.

Figure 12. Historical sequence of human disturbance affecting coastal ecosystems. Fishing (step 1) always precedes other human disturbance in all cases examined, while subsequent steps 2 – 5 may vary in order and not occur in all examples (Jackson *et al*. 2001)



The consequence is that marine environment has been substantially altered over time as a result of human activities, principally fishing. The sheer variety of marine fisheries and gears employed and areas fished means that the footprint of the industry on the marine ecosystem is large. Expecting recovery of the ecosystem from its current state to occur within just a few years is unrealistic given this context. If management requires a return to healthier conditions, this may take time to achieve, and will be measured in decades, even if significant actions are taken today.

At a general level there is also a growing body of evidence indicating that overfishing may often be a precondition for eutrophication, outbreaks of disease, or species introductions to occur (Jackson *et al*. 2001). For example, despite greatly increased run-off as a result of the previous two centuries of land clearing around Chesapeake Bay in the USA, it was the decimation by mechanical harvesting of the oyster beds from the 1870s to the 1920s that resulted in the modern day problems with hypoxia and eutrophication in the Bay area (Cooper and Brush, 1993; Rothschild *et al*. 1994). Similar historical losses of native filter-feeding oyster populations and other bivalves in inshore waters and inlets in the UK may well have had similar effects, predisposing those areas to become more sensitive to nutrient loading. Mass removal of suspension feeders, grazers, and predators by fishing also leave marine ecosystems more vulnerable to disease and invasion (Lenihan, 1999; Stachowicz *et al*. 1999), in addition to altering community structure. Thus reducing the impact of fishing and promoting recovery to a healthier state will hold benefits for fisheries both directly and indirectly and for other sectors.

4.2 Fisheries values compared to values for other maritime sectors

Fisheries and their products are just one of many benefits that mankind gains both directly and indirectly from the marine environment. This section aims to identify the value of these benefits ("goods and services") and to set the value of fisheries within the context of the value of the marine environment as a whole. Many goods and services are mutually dependent upon each other, and their exploitation may have negative, positive or neutral impacts on the other goods and services. The inter-relationship of fisheries with other benefits provided by the marine environment is discussed in the following section.

Table 4 details a list of goods and services provided by the marine environment. Although this list is believed to be comprehensive, it should be recognised that the definition of goods and services is an ongoing process.

Where possible a monetary value has been assigned to each function. The monetary values are conservative estimates, as in many cases only a component of the total good or service has been valued for example, for non-use value only marine mammals are valued. They are, however, the best value estimates available, based on current knowledge, but it is advised that they are used only as very approximate estimates. A discussion of the derivation, and the associated assumptions and provisos, of these monetary values is provided in Annex 1. In some cases the good or service has not been valued in monetary terms but this does not indicate that it has a lesser (or greater) value; merely that research has not yet been carried out in this area. The valuations for the various goods and services cannot be summed to give an overall value, as the values are not directly comparable (see Annex 1). Also, as detailed above, almost half of the goods and services have not been valued in monetary terms, so to produce an aggregated value would be a significant underestimate. All monetary values are per annum, and are expressed in £UK 2002.

Table 4. Goods and services provided by the UK marine environment based on a framework from Groot et al. (2002) and Pearce and Turner (1990).

Good or service	**Value or description**
Monetary values available:	
Food provision	Fisheries – £800 to £1300 million
Recreation and tourism	Net output = £11,770 million. Consumer surplus ≈ £256 million to £504million
Disturbance prevention (Flood and storm protection)	Disturbance prevention by wetlands ≈ £2,616 million. No values available for other marine environments.
Nutrient cycling	Nitrogen and phosphorous recycling: £0.10 to £0.28 per m^3 No values available for other nutrients
Gas and climate regulation	£0.53 to £164 per tonne of carbon stored by the marine environment. No values available for other gas regulation
Bioremediation of waste	Sewage and waste treatment by wetlands ≈ £1096.81 to £1236.54 per acre. No values available for other marine environments.
Raw materials	Oil, gas and aggregates net output = £14,879 million No values available for other raw materials
Physical environment (a space to work in, e.g. shipping)	Net output = £11,000 million
Information service	The marine environment provides an insight into environmental resilience, stress, and a long term environmental record. Education, training and research funding = £83 million. Natural technologies can provide the key to improving our own, e.g. marine microbes can convert sugar into electricity, and may be a valuable method of producing batteries. No values available for natural technologies
Non–use value: bequest value and existence value	Annual non-use value of sea mammals ≈ £474 million to £1,149 million. No values available for other marine species.
No Monetary Values available:	
Genetic resources	Genetic diversity held in the marine environment holds significant value, e.g. to enable cross breeding and genetic engineering to improve existing commercial species and for medical purposes. Tropical rainforests have been valued at £0.01 to £19.38 per ha based on their genetic diversity.
Medicinal resources	There is much exploratory research being undertaken in this area, and the value is potentially huge, e.g. shark-derived material can be applied to inhibit cancerous tumour cells.
Ornamental resources	Some marine resources have value as ornamental goods, e.g. shells, driftwood, etc.

Spiritual and cultural values	There is value associated with the marine environment e.g. for religion, folk lore, painting etc.
Option use (the value associated with keeping one's options open)	There is value associated with maintaining a healthy marine environment, e.g. for every species we lose, we may lose a potential medical cure. Even though we may not use every marine species in the future, there is value in maintaining them, so that we have the option to use them
Habitat (refugium and nursery)	A healthy habitat is a pre-requisite for the provision of all goods and services, without this fundamental base the ecosystem would cease to function.
Biological control	Ecosystems have innate interactions and feedback mechanisms, leading to varying levels of stability within the community. Even small changes in the food web can significantly affect the resistance and resilience of an ecosystem to perturbations.
Glue value	The sum of the values of individual functions is likely to be less than the value of the entire environment, owing to the primary life support function, and the contribution of specific environmental assets to maintaining healthy and functional ecosystems.

It can be seen that fisheries are but one use of the marine environment and even though it is not possible to add other values together, the value of fisheries is relatively small compared with other values. In many cases, with a little compromise, the various activities can co-exist. In a few cases, activities interfere with each other leading to loss of value to some activities. These interactions have not been evaluated in a monetary sense.

4.3 Environmental impacts of fisheries compared to those of other sectors

A recent report by OSPAR on the status of the North Sea (OSPAR 2000) rated the impacts of fisheries as being the greatest of 32 human activities or 'pressures' (Table 5). The impacts of fisheries (emboldened in Table 5) nearly all fall within the top half of the table, and make up three of the six impacts of greatest significance. The depletion of fish stocks (removal of target species) was the only human pressure detectable at a basin wide-level. In summary, if the state of the marine environment is to be improved overall, the effects of fishing will have to be reduced.

Table 5. Priority classes of human pressures (OSPAR 2000)

Class*	Pressure	Score
A	**Fisheries removal of target species**	0.439
	Inputs from land: organic micro-pollutants	0.403
	Fisheries seabed disturbances	0.384
	Inputs from land: nutrient	0.341
	Fisheries effects of discards and mortality of non-target species	0.332
	Shipping: inputs of TBT and other anti-fouling substances	0.331
B	Offshore oil and gas industry: input of oil and PAHs	0.331
	Shipping: inputs of oil and PAHs	0.323
	Offshore oil and gas industry: input of other hazardous substances	0.295
	Inputs from land: heavy metals	0.279
	Input from land: oil and PAHs	0.267
	Shipping: introduction of alien species	0.234
	Shipping: input of other hazardous substances	0.233
	Mariculture: introduction of cultured specimen, alien species and diseases	0.228
	Inputs from land: microbiological pollution and organic material	0.224
C	**Fisheries: input of litter (ghost nets)**	0.223
	Offshore oil and gas industry: physical disturbance	0.217
	Shipping: input of litter	0.207
	Dredged material: dispersion of substances	0.176
	Military activities: (chemical) ammunition	0.175
	Engineering operations: constructions in the coastal zone	0.173
	Mariculture: input of chemicals	0.171
	Engineering operations: mineral extraction (sand, gravel)	0.167
	Mariculture: input of nutrients and organic material	0.162
	Dredged material: physical disturbance	0.156
	Inputs from land: radio-nuclides	0.152
D	Shipping: physical disturbance	0.150
	Recreation: input of litter	0.129
	Military activities: physical disturbance	0.129
	Recreation: physical disturbance	0.121
	Engineering operations: power cables and electromagnetic disturbances	0.115
	Dumping of inert material (wrecks, bottles)	0.110

*** Human pressures are ranked according to their relative impact on the Greater North Sea ecosystem, including sustainable use. While the division in the four classes A-D was established firmly, ranking within classes was not considered to be significant. Class A = highest impact; Class B = upper intermediate impact; Class C = lower intermediate impact; Class D = lowest impact.**

ICES (2002) compared the annual impact of two widespread activities, bottom trawling and marine aggregate extraction. This involved a comparison of the spatial extent and a quantification of the effects on population dynamics (in terms of total mortality and production) of the two activities. The approach did not address the longer-term consequences of habitat modification and removal by beam trawling or dredging.

An estimated 284 km^2 of the seabed in the southern North Sea is dredged each year. Dredging impact is not uniform and it is difficult to describe the precise nature of the impact caused by dredging. Some areas will be heavily impacted by several tens of hours of dredging, while other parts of the area dredged may only experience a single pass of a trailer dredger. There are estimates of immediate reductions in abundance of 72% and 94% in benthic fauna in and on a seabed uniformly dredged at average intensity.

There is similar variation in beam trawl spatial distribution and impact. Estimates based on the micro-distribution of the Dutch beam trawl fleet suggest that 4,160 km^2 are trawled more than five times per year, and 620 km^2 are trawled more than ten times per year. This underestimates the total impact by trawling in the southern North Sea as other fleets, particularly the UK and Belgian fleets, operate there, and there is also fishing by other towed gears such as otter trawls. Beam trawling activity is therefore more extensive than dredging activity.

ICES (2002) also concluded that the mortality rates caused by 10 or more passes of a beam trawl per year may, for many size classes of benthic fauna, be comparable to the effect of average levels of dredging activity reported above. Given that beam-trawling activity is more extensive than dredging, it is reasonable to assume that the overall effects of beam trawling on the benthic environment are greater than those of dredging.

5. Future trends and risks

5.1 Difficulties in setting realistic targets for sustainability

It is difficult to predict the future, but factors that may affect what happens may be split between those over which we have some control and those that are largely outside our control. All factors are to an extent inter-related. Before any change can occur, it is important to understand and agree on the desired state of the environment. Many might wish for a return towards a past "healthy" environment. The perception of such an environment though is coloured by experience inside the observer's lifetime. However, the state of the environment when today's generation was young was very unlikely to have been healthy, untouched or in balance. As an example, the Netherlands set targets for the state of the North Sea that reflected the condition in the 1930s – however even by this stage the large whale populations and many fish stocks were already heavily reduced in size and substantial parts of the southern North Sea had been converted into the dry land now forming the Netherlands. These changes will have profoundly affected the ecological balances in the North Sea. If we want sustainability of use of our seas and sustainability of the wildlife dependant on them, we need to be relatively explicit about what is wanted and probably to look further back into the past than our lifetimes.

It is also important to recognise that just stopping all activity adverse to the goals that we might wish to reach will not necessarily mean that the marine environment will return to the state prior to the start of those activities. Ecological change is not necessarily reversible. Human activities in the marine environment have often been sequential and consequent on previous changes. For example, it seems likely that sandeel stocks in the North Sea are elevated compared to the past due to the reduction of predation pressure from large fish such as mackerel and cod. These sandeel stocks are now being fished partly opportunistically in response to their skewed abundance relative to depleted stocks of the larger fish which prey on them. We do not fully know the effects of this fishing, but if fishing was removed on both the large fish and sandeel, there is no guarantee that either stock would return to a pristine state.

5.2 Trends and shocks

The main future trends in the marine environment are either related to climate change (over which there can be little short or medium term human control) or are related to manageable human activities.

Climate change will affect the oceanography of the world and therefore fish stocks. The greatest influence on UK seas is from the transatlantic flow of the Gulf Stream and North Atlantic Drift. It is unclear what climate change will do to this flow and various climate models have been attempting to predict the future. When these models are run with no human influences on climate, they show no long-term trend in this flow, although it is variable from decade-to-decade. When greenhouse gas concentrations are increased, the flow steadily decreases, declining by about 25% by 2100 and becomes more unstable. This decrease will reduce water temperatures coming from the Atlantic, but it is likely that in those parts of UK seas relatively unaffected by the Atlantic, warmer air temperatures will lead to warmer sea surface temperatures that may in turn heat the whole water column depending on the amount of turbulence in the area. Greenhouse gas increase is inevitable, but again the scale and speed of change is not predictable.

Changed sea temperatures will affect chemical balances and plankton communities, which will in turn affect food chains and fish populations. Other climate related changes will work directly on the physiology of organisms – the fecundity of many fish species is related to temperature, so as sea temperatures change, some fish may breed more successfully than others. However, most analyses indicate that the effects of climate change on adult fish stocks are much less than the effects of fishing. Thus, unless the effects of fishing on stocks are considerably reduced, it is unlikely that we will be able to detect the effects of climate on spawning stock biomass. Climate (through water temperature) has a greater effect on younger age classes – so any climate-caused reduction in fecundity and growth of younger fish may need to be allowed for in setting limits to spawning stock biomass and therefore harvesting.

The uncertainty of these mechanisms means that it is difficult to predict exact consequences but changes will occur and indeed some are already happening. In the western English Channel the mean annual sea surface temperature has increased by around one degree since the late 1980s (Genner *et al.* in press.), largely as a result of warmer winter temperatures. Analysis of long-term data has already shown changes in assemblages of plankton, demersal fish and intertidal macro-invertebrates (Southward *et al*. 1995; Beaugrand and Reid 2003). Onshore, the marine biodiversity climate change programme for Britain and Ireland (MarClim) has shown that a number of temperature-sensitive species close to the northern edge of their distribution have extended their range over the past two decades.

The increasing concentrations of greenhouse gases, particularly CO_2, in the atmosphere have affected and will continue to change oceanic chemistry. Several effects have been observed including changes in pH with consequential changes on the nature of metals, nutrients and carbonates in seawater. These changes can in turn affect the biology of the seas, particularly the nature of phytoplankton and marine bacterial communities. The eventual result of these changes is uncertain, but a decrease in productivity of the oceans, or a change in the nature of food supply for the higher parts of the food chain cannot be ruled out.

Trends in the main categories of human impacts on the marine ecosystem are mixed. As noted in Section 3, three of the top six human effects on the North Sea ecosystem relate to fishing (removal of target species, seabed disturbances, effects of discards and mortality of non-target species). In all cases, policy drivers are to reduce these effects, for instance recently in the CFP reforms of 2002, but there has been little overall success so far in UK waters. If fishing pressure continues at the present rate, then there is unlikely to be any change in the harmful trends outlined earlier in this paper.

Two of the other top six impacts relate to inputs from land (organic micro-pollutants and nutrients). This diffuse pollution from land is being addressed with some success. In EU waters, the Water Framework Directive (2000/60/EC), currently being implemented, should have a considerable effect in reducing the impact of the effects of these pollutants. This follows a succession of other EU initiatives and Directives, for example the 1991 Nitrates Directive (91/676/EEC), all designed to reduce unwanted effects of nutrients. The final impact in the top six relates to shipping inputs of TBT and other anti-fouling substances. TBT use is currently being phased out, so the trend in this problem is also one of reduction. Of the second highest category of impacts, six of the nine relate to inputs of oil and other hazardous substances from offshore industry, shipping and land. These are also being reduced, with the possible exception of landward sources, though these are also being addressed. Two relate to introductions of alien species – these are likely to continue despite efforts being made to tackle those that are transported in ballast water. Such introductions have had unpredictable but in some cases severe negative effects on marine environments globally.

There are a number of potential shocks, or major adverse changes, which could occur to UK's seas. The risk of these occurring may be reduced by appropriate management of human activities, and in all cases management needs to take account of these risks.

In relation to fisheries, possibly the most serious risk is that of the collapse of a major fish stock. Those stocks presently outside safe biological limits are at increased risk of collapse. Along with many other stocks, cod in the North Sea, Irish Sea and west of Scotland have been declining for a number of years despite warnings from ICES and recent advice recommending zero catches (ICES, 2003). Fish stock collapses have occurred in a number of areas globally and in most cases recovery has not occurred or is only occurring over a very long period. There is uncertainty around the reasons for this lack of recovery, but overall these cases illustrate the risk that changes are not necessarily reversible.

Another potential shock is that of a regime shift – the change of a marine ecosystem from being dominated by one species or group of species to another. Regime shifts have been noted in the North Pacific, and may be associated with oceanographic change (Ware and Thomson 1991; Baumgartner *et al*. 1992). In that ocean, the switch is between a system dominated by anchovy and the alternate of sardine. In European waters it is intriguing that gadoids (fish family including the cods and hakes) have done well during periods when herring were at a low stock size (the so called gadoid outburst) in the 1960s, while currently herring stocks are in good shape but gadoids at a low stock size. A similar situation occurs in the Baltic, probably linked to changes in the overall salinity and associated concentrations of oxygen on the seabed, but exacerbated by serious over-exploitation of the cod stock. It is also believed that herring and sprat consume cod eggs in the Baltic when these species are at higher stock sizes, thus contributing to the inhibition of any recovery in cod stocks.

Climate changes also appear to have affected the herring and pilchard balance off south-west England (Southward *et al*. 1988; Alheit and Hagen 1997). During periods of warmer oceans, pilchards dominate catches, while in cooler conditions, herring take over. This will only be of major fisheries consequence if there is a difference in market price between the two species. It is not known what other effects there may be on the ecology of the area.

Possibly one of the worst shocks to a sea occurred in the Black Sea in the 1980s; this nearly enclosed sea used to have a very large anchovy fishery that has all but disappeared now. The initial cause of this change was a progressive eutrophication of the sea due to excess inflows of nutrients causing plankton blooms at the surface. This in turn led to loss of oxygen from deeper waters due to decay of sinking organic material, causing the decline of bottom-living fish stocks. A type of comb jelly *Mnemiopsis leidyi* was introduced into this damaged system, probably through ballast water. The comb jelly multiplied rapidly and consumed most of the available plankton and fish eggs, including larval anchovy. There was a virtual collapse of the anchovy, scad and sprat fisheries and an increase in toxic red algal blooms. A further invasion by another comb jelly *Beroe ovata* has since occurred that consumes the original invader. The system has changed profoundly and rapidly, and it seems unlikely to return to its original state. Similar species have a strong influence on the prey of commercial fish in the northwest Atlantic.

More than 50 non-native species have been introduced to UK waters, but few of these have affected fisheries (Eno *et al*. 1997). The American razor-shell *Ensis americanus (*syn*. directus)* was first found in north Norfolk in 1989 and was thought to have come through larval drifts from populations established in mainland Europe. These European populations probably originated from larvae carried in ballast water from North America. The species occurs in very high densities and in the Wash is thought to have reduced the value of some shellfish fisheries. Further species introductions cannot be ruled out as future shocks to UK seas – these may come though a variety of vectors, such as in ballast water, as fouling on ships hulls or in association with species introduced for aquaculture purposes.

On a more local scale, a severe pollution incident such as an oil spill can cause severe short to medium term disruption to fisheries, especially if such incidents affect important nearshore fishing grounds. Regrettably there have been a number of such incidents in recent years in European waters, with those from the *Braer* and the *Sea Empress* affecting UK fisheries.

5.3 Risks

The above environmental factors and effects combine to pose a number of risks to the future of the fishing industry from the environment in its current state. These risks must be addressed in future fisheries management in order to minimise their potential effects.

The primary risk must be fish stock collapse. At present many demersal stocks are so heavily depleted that their reproduction is impaired – variously because only first-time breeders are left in the stock, the stock has been fished out of optimal habitat, or the latter has been degraded or destroyed by fishing activities. This puts these demersal stocks in a very precarious state, with little resilience to any further adverse influences, whether caused by man or natural environmental effects.

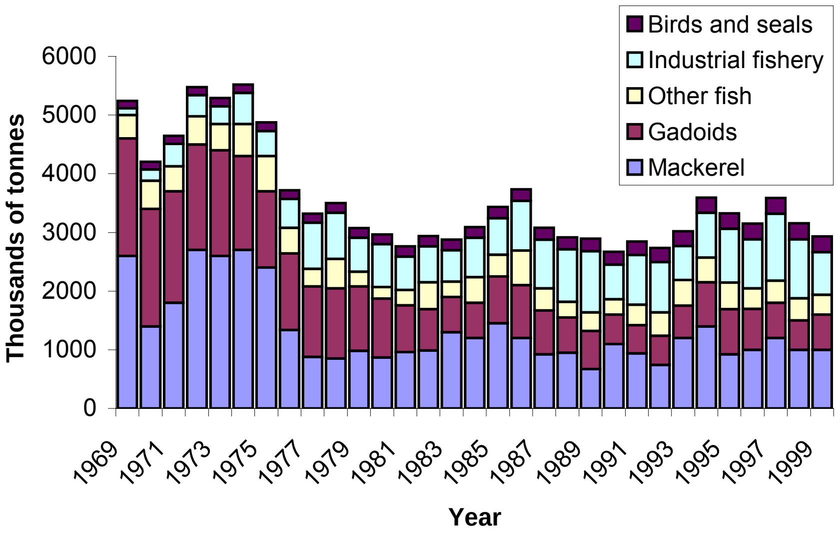
It may be that the over-fishing of predatory fish is also altering the ecosystem by allowing other predators on the prey of the predatory fish to expand. It seems likely that some seabird and marine mammal populations, including seals, have benefited from this effect of over fishing (and perhaps, in the case of seals, coupled with a reduction in culling). If this is the case, the risk here is that these alterations become fixed, thus preventing the predatory fish from returning easily to the ecological niche that they have been fished from.

Changes in the genetics of the main target species in UK waters have already occurred and are unlikely to be easily reversible. Further changes pose an increased risk of lower fecundity of the stock. Reduction in fishing pressure and a return to fish stocks more closely matching the original balanced age structure are necessary to reduce this risk.

Industrial fishing fleets are currently also targeting the small fish. The key target species are Norway pout, sandeel, capelin (all considered to be within safe biological limits), as well as sprat (status unknown), horse mackerel, blue whiting (several stocks outside safe biological limits at present). After rapid growth in the 1970s, the sandeel fishery is now by far the biggest fishery in the North Sea, with landings accounting for up to one-third of the total landing from all stocks. The few studies that have occurred in European waters have so far been unable to find any wide scale effects of these fisheries on other parts of the ecosystem (ICES 2003). Some effects may have occurred at more local scales off the east coast of Scotland and fisheries management has been adapted to reduce the risk of ecosystem level impacts.

Although studies have not found wide scale consequences, the effects of this industrial fishing cannot be fully anticipated – first there have been rather few studies (the sandeel fishery was very poorly monitored until comparatively recently) and secondly the depletion of larger fish predators might mean that no effects are discernible at present. This might change should stocks of the larger fish be given the opportunity to recover. Equally, overfishing of the smaller fish carries the risk of inhibiting the return of these larger predatory fish. A recent study of the interactions between fisheries and sandeel-dependent birds and seals in the North Sea (Figure 13), concluded that if mackerel or gadoid stocks recovered in future, they would be likely to severely compete with sandeel-dependent wildlife, as well as threatening the sustainability of the present industrial fishery (Furness, 2002). Taking the long-term view, choices need to be made about what sort of fishery is wanted in the North Sea as the system cannot accommodate and sustain all fisheries and dependent wildlife simultaneously.

Figure 13. Annual consumption of North Sea sandeels by major groups (based on Furness, 2002).



This issue of balance has been addressed elsewhere. Canada has drastically reduced industrial fishing activity in the Atlantic region. Mackerel fisheries are only allowed for human consumption and not for industrial purposes. In the USA, there are State-based policies to maintain sufficient quantities of forage fish for ecosystem needs including those of predatory fish.

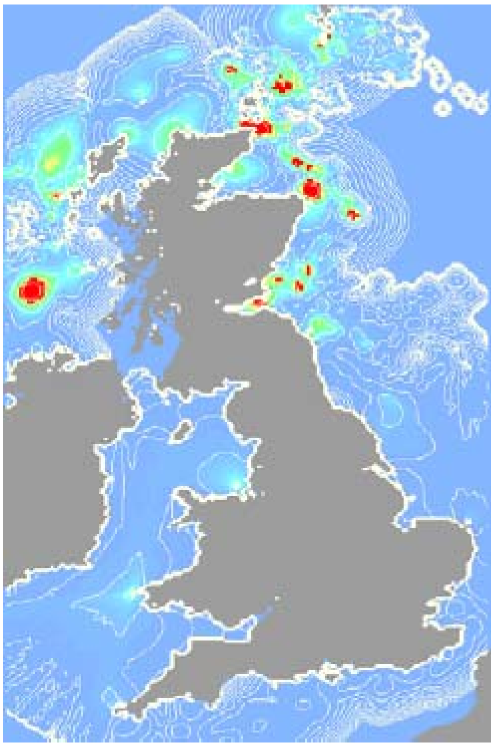
As noted above, fishing also damages the seabed habitat required for fish to breed. Further fishing may add to this damage, posing both a further risk to fish populations and to the habitats, which may also be of intrinsic interest. It is interesting to note that following the collapse of North Sea herring stocks in the 1970s, herring have not returned to spawn on all of the gravel banks previously used. It is not known whether this is caused by a loss of ‘genetic memory’, by elimination of sub-populations using those banks, or degradation of those banks as suitable habitat. The loss of features such as the Darwin Mounds to fishing will be permanent – we do not know what this loss of biodiversity might mean overall; but such losses should be avoided.

A concern that is frequently raised by fishers is that of the increasing seal population around the UK. This has led to calls in some quarters for the seal population to be reduced. The interaction of seals with fishers may be viewed at two scales – the localised and the general. At the local scale, seals damage nets, damage fish caught in nets and may deter fish from the area of nets, thus potentially reducing catches. The scale of this interaction and its economic consequence has not been fully assessed, though some useful work on the Clyde showed that all fishers in the area had personal experience of seals interfering with their fishing activities. 91% of towed gear users had caught seals in their gears occasionally. Seals were felt to generally target the larger fish in trawls and typically bit chunks out of these fish. The cost of seal damage to these gears was not great. Those using fixed gear experienced the biggest relative losses as seals bite through the rubber retaining bands on creel doors in order to steal bait. These traps are then useless until repaired. Fishers are permitted, under licence, to kill seals that are directly affecting their nets.

At a broader scale there is concern that seals are eating more and more fish, which might instead be available for fishers to catch. Fishers correctly point out that seal populations have been increasing steadily since the 1960s (when records began) and that their food requirements are high. Scientists note that the food requirement of a seal depends on its size and the oiliness of its prey. An average figure for a grey seal would be 7 kg of gadoid or 4 kg of sandeel per day (sandeels have particularly high oil content). The equivalent figures for the smaller harbour seals are 3-5 kg per day. Precisely which foods are eaten probably rely on relative availability of the prey in the foraging area. Discards from trawling operations may be consumed in some areas. An extremely simplistic (and misleading) calculation of multiplying the middle of these ranges of food consumption by days in a year and seal numbers would indicate that grey seals would eat in the order of 25,000 tonnes of prey per year, while common seals would consume 7,700 tonnes. This has led to calls for large scale culls.

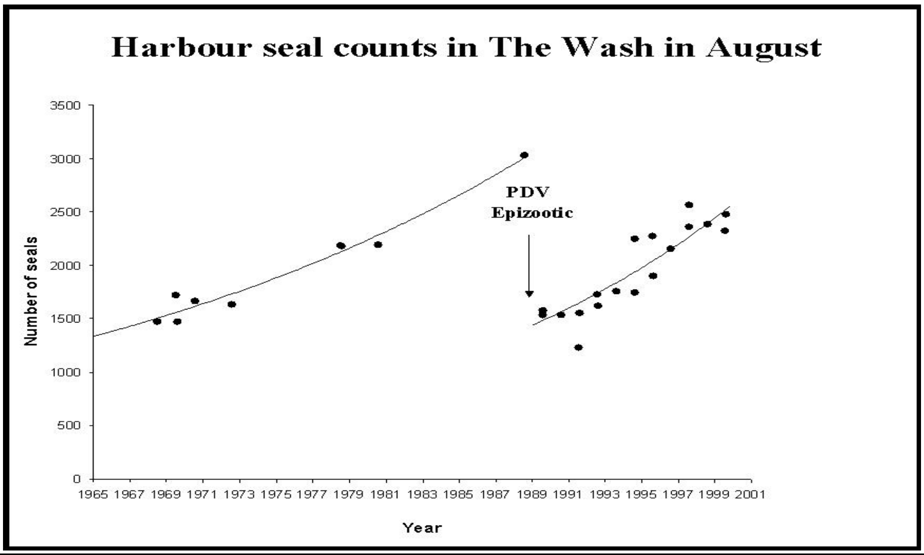
There are several reasons for believing that such a reduction in seal populations would not affect the stocks of fish that are targeted by fishermen. First, numerous studies of seal diet have shown it to be very variable both seasonally and geographically and to include large quantities of non-commercial species. Second, studies of the preferred seal foraging areas off the UK using satellite tags and modelling have found that seals feed in hot-spots (Figure 16) and not more generally in areas used for fishing. Many of these hot-spots are co-incident with sandbanks known to hold good populations of sandeels. The data underlying Figure 16 are based on seal movements from a limited number of colonies and it is likely that further hot-spots might be found if further seals were tagged.

Figure 16. Distribution of grey seal feeding areas modelled from satellite tag studies around Scotland. Core areas indicated by red. The data used for modelling come from seals tagged at some important colonies around Scotland. It is likely that further core feeding areas would be found with further satellite tag studies.



Thirdly, there have been two 'natural experiments' with seals in UK waters in recent years when the seal disease, phocine distemper dramatically reduced populations particularly in the southern North Sea (Figure 17). The first outbreak was in the late 1980s, when nearly half the seals in the Wash and adjacent areas died, with the second (on a similar scale) in winter 2002-03 (too recent to show in Figure 17, but the fall is likely to of a similar magnitude to that recorded in 1988, SMRU 2003). In neither of these cases has there been any sign of a subsequent improvement of fish stocks in the Wash or nearby areas. No increase in fish stocks was noted off nearby parts of continental Europe that were affected by the same outbreaks.

Figure 17. Counts of hauled-out harbour seals in the Wash in August 1965-2001. No counts have yet been published following the 2001 - 2002 epizootic, but it is thought that numbers will be below 1500 (SMRU 2003).



Finally, in the past there has been extensive hunting of seals off eastern Canada. Here seal numbers are far in excess of populations in Europe. Of the six species occurring in Canadian waters, the most prolific is the harp seal, with approximately 5 million along the Atlantic coast. Establishing clear links between the numbers of seals and the failure of fisheries resources to recover has been problematic. Canada has set a hunting ceiling of approximately 300,000 animals/year and it has now been suggested that seal exclusion zones be established with fishers able to shoot seals within such areas. Despite all the costs and public perception issues involved, no recovery of fisheries has occurred and in some instances there is a continued decline in cod stocks.

This is not to say that seals might not have an effect on fish stocks in the future in UK waters. There are signs that the grey seal population is beginning to level out after a long period of increase, but should it increase very substantially there may be measurable effects on stock sizes. In addition, seals might particularly affect any residual populations of a depleted fish stock to a greater degree than a healthy fish stock. As an example, there is some evidence off eastern Newfoundland that the remaining cod stocks are becoming more and more concentrated into small areas (this feature of stock concentration was one reason why the cod stock collapse was not noted until it was too late – fishers were still obtaining the same catch per unit effort, but from a smaller and smaller area). If seals target these residual stocks, then the fish may not reproduce enough to be able to recover. This 'predator hole' hypothesis has not been proven, but would be worthy of further study.

It is worth noting that the grey seal is one of the more uncommon seals at a global scale and is statutorily protected under European law for this reason. In general, the public in the UK are probably more in favour of seal conservation than seal culling. The adverse publicity to the fishing industry of such a cull occurring is likely to more than outweigh the unproven gains or costs to the fishing industry from reducing seal populations.

6 Management and policy options

6.1 Setting objectives for sustainability

There are many views on the state that our seas should be in. Some might want them turned over to maximising production of fish for the table, while others might wish to see large areas thronging with marine mammals and seabirds and untouched by human interference. The choices are of course only partly within human control – all that it is really possible to manage is human usage of our seas, while many biological factors are both beyond of our control and in many cases beyond our current level of understanding. What choices we do have should be taken at a societal level and not by any narrow interest group.

A common language that has been agreed at the wide societal level is that of sustainability. Sustainability involves essentially leaving the same options (or more) for future society as we have at present. Choices need to take account of sustaining use from social, economic and environmental perspectives. These perspectives are of course inter-related. This paper is about the environmental perspective and it is essential to realise that without environmental sustainability neither the economy nor the social structures of those fishing the sea are viable in the long term.

This paper has shown in many ways that current fisheries, not least in relation to stocks of commercially important fish, are not environmentally sustainable. In addition, the focus of fisheries management on fisheries income alone has disregarded many of the other uses of the environment and fish stocks that may also provide support for coastal communities. Securing the wise use of natural resources and identifying development choices that maximise benefits will require a more integrated, long-term, approach to environmental policy making from local, national and more global perspectives.

6.1.1 Reducing fishing effort

As outlined in the main report and other supporting reports, it is clear that excessive fishing pressure is causing problems both for fish stocks and the environment. If this pressure is not reduced then there is considerable risk to all aspects of sustainability. There have been several attempts to reduce fishing pressure through decommissioning but these have been largely unsuccessful due to 'latent' fishing capacity in fleets and to a continuing background of improving fish-catching technology (so called 'technical creep'). The means to reduce fishing pressure are discussed in other Strategy Unit reports and are not be duplicated here. Any reductions in fishing pressure need to be targeted at fish stocks or environmental features under greatest pressure and need to be effective.

6.2 Approaches to securing sustainable use of the environment

A range of approaches may be used at a number of geographical scales – international, national, regional or local, to ensure this wiser use. Key approaches and mechanisms to achieve this integration include:

- Adopting a precautionary approach for fisheries management;
- Progressively implementing the ecosystem approach to management;
- Improving a common knowledge base for decision-making;
- Carrying out strategic environmental assessments;
- Establishing a network of marine protected areas;
- Improving environmental performance of gear.

These are all mechanisms for bringing fisheries and environmental objectives into close alignment, as part of an overall approach to management of marine resources. They relate to the goals and objectives that the UK, along with other Member States and the European Union, has already signed-up to at national, regional and global levels. These approaches are considered in turn below:

6.2.1 Precautionary approach for fisheries management

In order to reduce risks it is necessary to manage fishing in such a way as to minimise effects that are likely to be serious or irreversible. Logically it is best to start with those aspects carrying the greatest risk or greatest adverse consequence. In many cases there is no certainty of cause and effect, or there is a low precision in either understanding of needs or in being sure that management will achieve its aims. In these circumstances, the appropriate response is to err on the side of caution – or take a precautionary approach. Scientific advice on some individual fish stocks now takes this approach into account, but there has been less implementation within decision-taking frameworks. The introduction in the fisheries management structure of other nations of 'harvest control rules' has formalised precautionary decision-making. Under these rules, there is agreement that if certain trigger conditions are reached, there is an automatic change in fishery controls. Examples in US fisheries include closing down of fisheries if stock sizes fall below certain levels or if the bycatch of a seabird exceeds a trigger level.

The precautionary approach however is not enough – as noted above there are both interactions between species that need to be allowed for, and in a wider sense, interaction with other parts of the environment or marine ecosystem. In order to address these interactions, including the interaction of humans, the ecosystem (-based) approach has been advocated.

6.2.2 Progressive implementation of the ecosystem approach to management

The ecosystem approach may be looked at in two ways. Firstly, by understanding the effect of parts of the ecosystem on fish stocks and on fisheries, it might be easier to manage fisheries more appropriately (of course, we can only manage fisheries and cannot manage the ecosystem). Second, by understanding the effect of fisheries on the ecosystem, it becomes easier to identify alternatives that reduce those effects, to the benefit of the environment itself and for fisheries. One difficulty faced is that we do not fully understand either set of effects and it will be some years, if ever, before we have a sufficiently good grasp of all interrelationships in the ecosystem. Nevertheless, this does not mean that we cannot embark now on progressive implementation of an ecosystem approach, as required by the reformed CFP (Council Regulation EC 2371/2002), and begin to implement those concepts and elements which are understood and tractable.

The broad objectives for the ecosystem that need to be achieved while managing human activities in the marine environment are:

- to ensure that ecological processes in the sea are not compromised by human activities;
- to ensure that management is conducted at spatial and temporal scales that maintain marine biological diversity;
- to maintain viable populations of all native marine species in functioning biological communities;
- to include within a spectrum of protected areas, representatives of all marine habitat types across their natural range of variation; and
- to accommodate human uses of the seas and the economic, social and cultural aspirations of people, within these constraints.

There are several ways in which fisheries management might take more account of environmental considerations, and thus allow fisheries to become more sustainable. These include:

- seeking to match overall effort, gear types and areas of activity with the long-term delivery of multiple benefits including the safe maintenance of fish stocks;
- using approaches that recognise the multi-species effects of most fisheries;
- setting management objectives for important non-target species and communities;
- establishing a monitoring regime against these objectives, coupled to relevant management action;
- using strategic environmental assessments of fisheries to assess impacts upon non-target species and habitats as well as target stocks (see below);
- developing environmental impact statements alongside existing advice on management options, so that in taking decisions managers are aware of the likely consequences of their actions;
- introducing environmental impact assessment before the introduction of new fishing gears or before a new fishery is opened;
- continuing the development and use of technical measures, with emphasis on the development of fishing practices and equipment that reduce bycatch and impact on the seabed;
- increasing the use of spatial fisheries management measures such as Marine Protected Areas (MPAs) to promote recovery and sustainable use of resources and to protect ecologically important areas;

- establishing Regional Advisory Councils so that they can guide ecosystem-based fisheries management at a regional scale;
- widening the use of economic tools, including market-based measures and grants for improved environmental measures, in order to foster stewardship of the marine resource;

6.2.3 Improved knowledge base for decision-making

Fisheries management is usually based on information gained from research vessel surveys. This is because studies have shown that much information coming from other sources, such as from catch landings, is unreliable or at least provides an incomplete picture. This is regrettable because if information could be gained in a reliable and scientifically consistent manner from fishers themselves, there could be considerably more data on which to base advice. It is also likely that further information on fish biology, environmental effects and the ecosystem in general might be available from the industry, which could in turn lead to more appropriate management.

Currently most international advice on fisheries is channelled through ICES. This organisation is dominated by traditional fisheries scientists and their methods, and there have been recent attempts to integrate environmental considerations into fisheries advice from ICES. This has generally not been very successful due apparently to the traditional nature of that organisation, and resistance within national marine laboratories to change. This lack of willingness to change and dominance by traditional fisheries science has inhibited many scientists from other relevant disciplines from contributing their knowledge, thus reducing the usefulness of the organisation. In addition, there is evidence that the advice from ICES is biased by senior scientists responding to political pressure and to avoid 'harming' national fishing fleets. Liberating ICES advice and structures from the dominance of national marine laboratories would probably go a long way towards solving these difficulties.

Beyond this integration of a wider set of disciplines into the advice of ICES, there is a need to take account of the knowledge of fishers. Regional Advisory Councils (RACs) may in future be able to bring some of this greater integration. These Councils will be primarily composed of fishing interests, but be joined and supported by both scientists and those with wider environmental interests. Whilst such bodies are still in early days of establishment they will represent a wider range of interests in fishery management decisions, working closely alongside each other, to identify common goals, to promote synergy and minimise opportunities for conflict. Such partnership working allows the development of trust, understanding, and an awareness of mutual responsibility.

6.2.4 Strategic environmental assessment and environmental impact assessment

There are formal EU mechanisms for assessing environmental impacts of industry and development but these are explicitly applied to only a few aspects of fishing policy or fishing activities. At present, responses to environmental damage caused by fisheries are reactive and place the burden of proof on those showing the damage. This is in contrast to mechanisms surrounding other industries, both marine and terrestrial. Strategic environmental assessments (SEA) are being applied to large areas of the UK continental shelf for both oil and gas licensing and for renewable energy sources (mostly wind power at present) as part of the UK's implementation of the EU SEA Directive (2001/42/EC).

The SEA process is in several stages all involving the users and other interested persons (stakeholders). The first stage is a description of the marine environment in which an activity is to occur or is occurring. Usually this is a large area of sea which in fisheries terms might be equivalent to a number of ICES sub-divisions. A description of the current activity then follows, accompanied by an assessment of the interactions between the activities and the environment. Any mitigation measures that are possible are also described. Possible future scenarios for activities are then identified and the risks to both the ecosystem and the activity are assessed. Once possible mitigation has been taken into account a residual list of effects is available for public debate and decision. The process, by being public, and usually carried out by the Government Regulator, encourages more democratic decision-making and greater ownership of environmental responsibilities.

Strategic environmental assessment could occur in the context of the regional seas envisaged for the RACs, or sub-divisions of such sea areas. SEAs could define the scale of fisheries at a point in time against which assessments of "new" fisheries could be made. SEAs could also be used to define aspects of fisheries impacts for prioritisation in mitigation. This prioritisation could in turn be used to direct funding for research or mitigation measures.

Plainly, if SEA is to be undertaken in several marine industries, it would be advantageous to fit these processes together in order to benefit from a common knowledge base and common understanding. Any necessary research to reduce uncertainty may be shared.

Environmental impact assessments (EIAs) apply at a smaller, individual development scale. The European Directive (Directive 85/337/EEC amended by 97/11/EC) does not apply explicitly to fisheries and there are some potential difficulties in applying it, particularly surrounding the question as to the definition of a new fishing operation. There are possibilities though. Fisheries for new species or on new grounds should be assessed before their commencement. A good example here would have been the proposals for management of deep-sea fisheries recently agreed at Council level. Future examples could include fisheries by those member states previously denied access to certain waters. New EU fisheries agreements with third countries should also be assessed.

Implementation of both EIAs and SEAs in fisheries would be a major step forward in implementing an ecosystem-based approach to fisheries management.

6.2.5 Marine Protected Areas

There are a number of definitions of Marine Protected Areas. OSPAR, in a wide context, has defined them as "an area…for which it is appropriate to institute… protective, conservation, restorative or precautionary measures". In a fisheries context, the term has been used to mean areas closed to fishing and therefore interchangeably with 'no-take zones'. The OSPAR definition obviously includes areas closed to fishing and is preferred in the context of this report as marine protected areas may have benefits beyond fisheries or may require management of activities other than fishing.

There have been many calls for the establishment of a network of Marine Protected Areas and in several contexts, commitments that these should be established in European and global seas. In most cases, this agreement relates to the conservation of biodiversity rather than as a fisheries measure – though of course benefits of marine protected areas may accrue beyond biodiversity conservation. In the case of marine protected areas for biodiversity, areas are selected for a specific purpose in mind with the boundaries and management measures within the area tuned with the purpose of achieving objectives for which the area has been established. Within the UK, it has proved very difficult to select suitable areas of sea for the conservation of wide-ranging marine species and so far none have been selected.

There have also been calls for the implementation on a large-scale (20-30% of sea area) of marine protected areas for marine biodiversity, with associated benefits for fisheries (e.g. Roberts and Hawkins 2003). Fishing would be banned in such areas with proposed benefits for fishing coming increases in yield outside such areas, an insurance against uncertainty, aiding in recovery of stocks and benefiting stock structure.

There is good evidence to support the biodiversity benefits of marine protected areas (see below), but the evidence for fisheries benefits is mixed. The abundance of fish and shellfish has been shown to increase within protected areas closed to fishing (e.g. Stokesbury 2002), but increase in fisheries yield will only occur if the fish (including eggs and larvae) leave the area closed to fishing in sufficient quantity to compensate for the loss of yield caused by closing the area. Insurance against uncertainty may occur through the protection of breeding fish if traditional fisheries management fails to do this outside the area, for instance due to poor management decisions or inadequate enforcement. The effectiveness of such insurance would depend on the configuration of the protected area and the dispersal characteristics of the fish species being protected. Similar factors would apply to the recovery of stocks, especially if the area can be shown to be of special importance for the stock requiring recovery. As outlined earlier in this paper, the only way to restore a more balanced population of fish would be to allow a population of large fish to become established and not be subject to fishing pressure.

Spatial and temporal closure of areas to fisheries is a commonly used tool in UK fisheries, however the majority of areas covered by such closures are relatively small and often nearshore (Rogers 1997). Closures may be for a variety of purposes, and might cover all gear or only a few types and/or target species. The most common purpose for fisheries management is to protect nearshore nursery grounds or to provide fixed gear reserves. These closures provide benefits to fisheries and often indirect benefits to wider environmental interests. In some parts of the world, fisheries closures have been much more extensive. Most of these, such as those in New Zealand, have been aimed at enhancing biodiversity generally, but specifically including stocks of fish and shellfish. Off the eastern USA, closures have been put in place to enhance recovery of fish stocks. In many cases, closures have been put in place partly for their benefits for nature as well as for fisheries.

Large scale, long-term closures have not yet been established off the UK, with the exception of some temporary closures for cod fishing introduced as part of early measures to enhance the recovery of cod in the Irish Sea. These proved largely ineffective for cod as they were too short in duration, allowed other fisheries to continue within them that had bycatch of cod and allowed substantial fishing effort to continue elsewhere and indeed may well have displaced excessive effort onto other fishing grounds. A similar situation occurred in the south-eastern North Sea (Rijnsdorp *et al*. 2001). Research has shown that marine protected areas are relatively ineffective for wide ranging fish stocks if there is not a reduction in overall fishing pressure on that stock. Where such effort reductions have occurred, there has not been a demonstration that wide-ranging stocks have benefited from closures above and beyond the effects that the effort reduction would have allowed. Natural variability in systems would though make this experiment difficult to conduct.

Marine protected areas do however have a number of benefits for biodiversity conservation, the scale of these benefits varying with the degree of protection and use that is allowed of the areas. Such benefits within the area may include:

- Protection (and allowing recovery) of biodiversity;
- Reduction/elimination of fishing gear impacts and bycatch;
- Provision of undisturbed spawning conditions, habitats, settling sites and migratory stepping stones;
- Provision of some fisheries management data including estimates of natural mortality;
- Provision of opportunities to enjoy relatively undisturbed/unmodified areas, and experience wilderness;
- Allowing the public to see and understand the effects humans can have, and the benefits of management;
- Provision of long term monitoring, benchmark, control areas, and places where research projects can be conducted with less influence from other human activities.

There is reasonable evidence from elsewhere in the world on the beneficial effects of marine protected areas for biodiversity within these areas. There have been few studies in European waters, but there is some evidence to suggest that such benefits would occur. This evidence includes increased densities of scallops in an experimental area off the Isle of Man, increased seabed life in an area only partially closed to fishing off the south Devon coast, and observations of increased fish stocks and marine life in the British Underwater Test and Evaluation Centre on the West Coast of Scotland.

The evidence is thus that marine protected areas are suitable for biodiversity conservation but that their benefits for fisheries have yet to be fully evaluated in European waters. There are likely to be benefits for biodiversity in general from closing areas for fisheries management purposes, but the inverse is not necessarily true. The most convincing case for the use of marine protected areas, especially no-take zones, in fisheries would be an unequivocal demonstration of an increase in yield outside the protected area. This would require careful experimental design and evaluation. Different sized marine protected areas would need to be established with replication and controls. Long-term surveillance and monitoring would be required, with pre-agreed criteria for evaluating success. Given that marine protected areas offer the possibilities of achieving gain for both fisheries and biodiversity, such experiments should be prioritised. Large-scale closures (whether as single closures or as a network) without such studies risk the loss of confidence by the fishing community in closures, and devaluing of a potentially useful fisheries management tool. Confidence will also be considerably enhanced if any marine protected areas are established in co-operation with the fishing community most likely to be affected (and most likely to gain any fisheries benefits). Given the difficulties in enforcing closed areas at sea, co-operation will be important in management of any protected area. A loss of confidence by the fishing community may affect the ability to establish and manage the networks of marine protected areas needed to meet international biodiversity conservation obligations.

Marine protected areas also have wider utility beyond biodiversity conservation. Marine reserves attract tourists and other recreational activities may be suitable in these areas, including scuba diving, sea angling and wildlife watching. These are all potential further sources of income to local communities. Any areas that are established experimentally should take account of such benefits when the results of the protection are evaluated.

6.2.6 Improved environmental performance of gear

Technical measures, such as the use of wider mesh nets and square mesh escape panels have been adopted in fisheries, both through regulation and voluntarily by fishers. Such measures are aimed at making fishing gear more selective and reducing unwanted bycatch. Such innovation should continue to be encouraged and its development financed. Selective fishing gear is also being trialled to reduce bycatch of dolphins in pelagic trawl nets. Although the trials of sorter grids and escape panels in these fisheries are being funded publicly, the initiative to start them came from fishers anxious to reduce their environmental impact.

Other measures can be introduced to reduce bycatches. There has been some testing of acoustic alarms on bottom-set gillnets to reduce harbour porpoise bycatch. When these alarms work, bycatch is reduced considerably. Further work is required to improve the reliability of the alarms, especially under commercial fishing conditions. Gear modification can be further enhanced by modifications of fishing practice, for instance seabird bycatch on long-lines can be reduced by setting baits underwater, by night, and on the opposite side of the ship from any offal discharge point. There are undoubtedly many other subtle means by which unwanted bycatch could be reduced. Fishers should be encouraged to experiment to find workable solutions. Once workable solutions are found, it is important that they are passed to others facing similar problems. Legislation can be a very blunt way of doing this, but more voluntary methods, such as the establishment of websites of information should be implemented.

6.2.7 Incentives to improve environmental performance

There is also scope for incentives (including payments, voluntary agreements and training) to fishers to adopt more environmentally sensitive practices, including selective fishing methods, perhaps especially in inshore waters which feature some of the most sensitive and vulnerable marine habitats. Such incentives should be part of a wider strategy, such as local management plans, for helping to achieve the sustainable development of inshore waters. Fishers are more likely to respond positively and comply if such concepts are closely integrated into their management regime rather than being bolted on to existing frameworks. This, in turn, reflects the need to 'improve a common knowledge base for decision-making (Section 6.2.3)' in that significant awareness-raising will be needed to facilitate and promote a growing sense of 'marine stewardship' in the producer sector.

6.3 Concluding thought

In concluding this analysis it is worth reflecting on events that unfolded in Canada and led to the demise of fish stocks and the social and economic problems now facing local populations - a situation to avoid in the UK and Europe. In April 2000 - Canadian Fisheries and Oceans Minister Herb Dhaliwal, had this to say:

'No one has nailed it down in detail, but we know the general picture. And I am not making excuses for my department when I say that environmental changes did some of the damage. We did the rest -- not just my department, but the whole fishing society. As a department, we knew less than we thought. On top of that, fishermen often provided false or incomplete catch information, and dumped or misreported fish. Too often everybody lobbied for higher quotas, and took whatever they could get. People fought for themselves; the fish lost; and we all paid the price. The codfish collapse wasn't just an Act of God or an Act of Parliament. It was the actions of people, in government, in industry, and in coastal communities, failing to work closely enough to protect the fish on which we all depend.'

After an 11-year fishing moratorium, the fishery shows no sign of recovery. In 2003, northern cod was added to Canada's list of endangered species.

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Annex 1 Method used to value goods and services

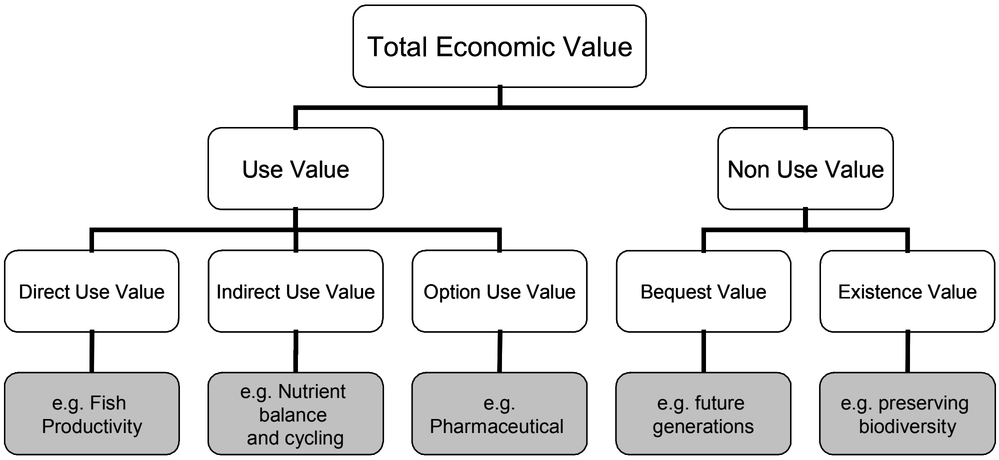
1. Assumptions and provisos

Describing natural environments in terms of the goods and services they provide is an increasingly common method of ensuring that we have a true understanding of exactly what we gaining and losing when we exploit the environment. In the past only environmental functions which are directly exploited by man have been included in the management process, neglecting many valuable aspects of the environment, and providing a result biased towards exploitation. The environment provides several different types of value to man, use and non-use, and these are defined by the Total Economic Value (TEV) framework. This framework is used in environmental economics to divide an environment into different components of value (Pearce and Turner 1990), as depicted in Figure 1. The Total Economic Value framework ensures that all aspects of value associated with the goods and services of the environment are captured.

Use values arise from humans actually using the environment, for example the coast for recreation, or a forest for timber. There are generally considered to be three types of use value:
Direct Use Values arise from the direct exploitation of the environment. The environmental functions listed under direct use are generally demand driven goods.
Indirect Use Values are benefits which are derived from the environment, without the intervention of man, for example climate regulation and waste degradation.
Option Use Value is the value associated with an individual's willingness to pay to safeguard the option to use a natural resource in the future, when such use is not currently planned. In other words, it is the value of being able to change one's minds, the value of keeping one's options open. Any *expected* future use is properly part of direct/indirect use value, not option value.

Non use values are representative of the value which humans bestow upon an environmental resource, despite the fact they may never use or even see it. Non use values are generally divided into two categories:
Bequest Value is the value an individual places on ensuring the availability of a natural resource to future generations.
Existence Value is the value placed on simply knowing that a natural resource is there, even if it is never experienced. An example of this is the fact that many individuals would be willing to pay some amount to ensure the continued survival of some species, say polar bears, which they will never see, simply because they derive value from the knowledge of their existence.

Figure 1: The Total Economic Value Framework, in the context of benthic biodiversity



Valuing all environmental goods and services enables the costs and benefits of exploitative activity to be evaluated, facilitating the management process. Valuing non-market goods and services is, however, still controversial and can be problematic. A variety of techniques are used in this review, and there are pros and cons to all the techniques. In many cases scientific concepts are used to break down the goods and services provided by the marine environment into components which can then be valued. There are several excellent reviews of the valuation techniques which may be applied (see for example Ledoux and Turner 2002), and as such only a brief overview of techniques is provided here.

- Stated preference: this generally involves the use of questionnaires to determine individuals preferences for environmental goods and services, for example by asking their willingness to pay, or willingness to accept, a specific change in the environment. This is the only method available for determining non-use values.
- Revealed preference: this method uses actual market data to determine a value for environmental functions which are not traded in markets. For example, the Travel Cost Method may be used to estimate how much people will spend to visit a free access site (e.g. a forest or beach), the journey expenditure can then be used to determine a value for the free access site. Hedonic pricing is another example of a revealed preference technique.
- Market-based methods: for example, fish harvests
- Cost-based techniques: this technique determines the costs to man in providing a proxy for the environmental function, for example, replacement costs, damage costs and preventative expenditure. This is not really a satisfactory measure of value as, for example, the cost of replacing a function is not the same concept as the value that the function provides.
- Opportunity cost: the cost in relation to contributions to pre-determined targets. This is not a true "valuation" but rather an approximation based on cost-effectiveness of achieving pre-determined targets.

There are a number of general points which must be made about the monetary data:

1. The values have been standardised as far as possible, but a comprehensive benefit transfer of the values has not been undertaken. The purpose of the figures is to provide a ball park, best estimate, of their magnitude, based on current knowledge. For example, it should be noted that there are very few valuation studies undertaken on the UK, or indeed the European, marine environment, and as a result the majority of the studies were undertaken in the U.S. and have been extrapolated to the U.K. The inaccuracies associated with this extrapolation are understood, but in the absence of U.K. studies, the U.S studies are believed to provide the best estimate available at the current time.

2. The monetary values cannot be aggregated to provide an overall value of the marine environment. This is because different methods have been used to calculate the values, and hence the values are not directly comparable. Several different methods are used to determine the values. Even if the same method is applied, a small change in the method can lead to a significant change in the value. For example, even if the same method is used the values will vary depending on the survey type, payment options, the respondent's characteristics, the current political climate, the discount rate applied etc.

Aggregating the values is also misleading as there are significant gaps in the valuation literature. This results in several of the goods and services not being quantified in monetary terms. This does not imply that they are not valuable, just that valuation work has not been undertaken in this area.

3. Some of the values are provided on a per area basis. These should not be multiplied up to a national scale for several reasons, the three most significant being: 1. environment types are not uniform, for example a wetland in Cornwall may be very different to a wetland in Renfrewshire; 2. the values do not take into account the fact that the per unit value may vary as the environment is exploited, for example as an environment or resource is diminished it's value may increase; 3. to multiply some of the values up would entail designating boundaries on the UK marine environment, and as many marine processes and organisms are mobile this will not be straightforward.

2. Details of the goods and services and determination of their values

i. Food provision and employment

Plants and animals which are neither cultivated or farmed, but taken directly from the wild, make up a significant part of the human diet. The capacity of the marine environment to provide a food source, and the accompanying employment, is clearly a significant function of the marine environment. Alongside, and intrinsically linked to, the provision of food and employment, is the support of cultural and spiritual traditions associated with fishing communities. The value of this will be discussed in detail in other reports, and hence is only mentioned here.

ii. Recreation and tourism

The net value of leisure and recreation was estimated as £11.77 billion by Pugh and Skinner (2002). This estimate can be broken down into several categories:

National Tourism:

Day Trips (i.e. a trip not undertaken on a regular basis and lasting 3hr+): In 1998 there were 81 million day trips to the seaside and the total spend on day trips to the seaside was £1.5billion. (StarUK 2003a).
Overnight tourism trips (i.e. trips away from home lasting one night or more): In 2001 there were 34 million trips to the seaside, and the total spend on trips to the seaside was £6 billion. (StarUK 2003b).
The value of UK tourism value is therefore £7.5 billion. This includes bird, cetacean and seal watching; aesthetic value, indirect value of tourism associated with commercial fishing activity. This does not include international visitors, regular recreation or consumer surplus (see below for definition).

International tourism:
No reliable estimate was available for this at the time of publishing.

Recreation:
A preliminary study suggests that UK sea anglers may spend at least £1 billion on their sport (SU estimate, 2003).
Other forms of marine based recreation are also very important, for example, water sports, diving, windsurfing and surfing, but values for these were not available for these at the time of publishing.

Consumer Surplus:
Definition of Consumer Surplus: The difference between the price actually paid for a good, and the maximum amount that an individual is willing to pay for it. For example, if the market price for a good is £1, but a person is willing to pay up to £3 for it, then the consumer surplus for that item is £2.

In addition to the actual spend is the consumer surplus. In the absence of a comprehensive study the focus here is on studies relating to beach use. As the majority of people visiting the sea side will benefit from the beach this is not unreasonable, but the estimate will be conservative. Three contingent valuation studies are used to determine the consumer surplus (Falk *et al*. 1994, King 1995, Silberman and Klock 1988), with values varying from £2.23 to £4.38 per person per visit. The values per visit are multiplied by the total number of visits, to give a total estimate of consumer surplus of £256 million to £504 million.

iii. Disturbance prevention
The marine environment provides considerable protection against storms and floods. Wetlands in particular act as a buffer against storm and flood damage. Farber and Costanza (1987) estimated the present value of a wetland, as wind protection, to be £10.09 per acre, using an 8% discount rate over 100years, using an avoided damage methodology. The damage costs are, however, linked to the Louisiana coast, making the transfer of this value to the U.K. somewhat tenuous. Brouwer *et al*. (1997) document a meta-analysis of contingent valuation studies on wetlands from around the world. This meta-analysis finds the largest mean willingness to pay by wetland function to be for flood control. This estimates the value of wetlands, in their function as storm and flood protection, to be £105.09 per household per year. The National Statistics Office estimates that there are 24,890,000 households in the UK in 2003. The value of disturbance prevention by wetlands is therefore estimated to be approximately £2.6 billion.

iv. Nutrient cycling

The cycling and maintenance of availability of essential nutrients, for example nitrogen, phosphorus, sulphur and metals, is crucial for life. Nutrient cycling encourages productivity by making the necessary nutrients available, and also results in the breakdown of nutrients and compounds, thus resulting in waste degradation and the maintenance of clean seawater. Nutrient cycling is undertaken in many components of the marine environment, in particular the marine benthic environment (i.e. the sea bed and mud flats) and salt marshes. The focus here is on nitrogen and phosphorous, as most research has been focused on these nutrients. Postel and Carpenter (1997) reported a replacement cost method for the valuation of the environment in its nutrient cycling capacity. The values which they propose are £0.10 to £0.28 per m^3. Estimates of the volume of the coastal water in the U.K. may be available, and hence it may be considered that this value could be multiplied up to provide a U.K. estimate. This is not advised for the reasons mentioned earlier in this annex.

v. Gas and Climate Regulation

Series of biogeochemical processes maintain the chemical composition of the atmosphere and ocean. In particular processes such as the regulation of the CO_2/O_2 balance, ozone, and SO_x, are essential for the maintenance of a healthy habitable planet, and breathable air. These gas regulation processes also play a critical role in climate regulation. In this case CO_2 is focussed upon as it is well researched, and is documented to have a significant impact on the environment. The marine environment plays a significant role in the regulation of carbon fluxes, in part due to its capacity to sequester CO_2 and act as a carbon sink. The capacity of the marine environment to act as a carbon sink will be affected by changes in the marine food webs, as changes in trophic dynamics will cause changes in the distribution of carbon throughout the marine environment.

Estimating the value of CO_2 is very complex and highly sensitive to assumptions, in particular about discount rates, so estimates are highly uncertain. Four different methods of calculating the value of carbon storage are presented here, each with their own advantages and disadvantages. The values calculated are not comparable as the methods used are different, but they can be used to provide a range of values.

1. Carbon Tax: In the Scandinavian countries a carbon tax of £108 to £164 per tonne of carbon is enforced (Xue and Tisdell 2001)
2. Afforestation: Forests can be used to absorb carbon. There are several different estimates of the costs of carbon storage, but here the study by Huang and Kronrad (2001) is applied. This research estimated that the average costs of sequestering a tonne of carbon varies from, £0.53 on unstocked land, to £130.86 on lands already intensively managed.
3. Abatement costs: Abatement cost estimates related to the marginal cost of achieving certain targets can be used, and this could justify values of £31.95 per tonne of carbon (COHERENCE 2000).
4. Damage costs: Fankhauser (1995) proposed that a rough benchmark of the marginal social costs of CO_2 emissions was £15.89 per tonne of carbon for emissions between 1991 and 2000. Damage per ton of emissions is, however, predicted to rise over time, and is estimated to be £22.25 per tonne of carbon in decade 2021-31.

The value of CO_2 regulation by the marine environment is estimated to be between £0.53 and £164 per tonne of carbon stored by the marine environment. Estimates of carbon stored by the marine environment are available, but are complex to extrapolate to the UK marine environment. This extrapolation was not considered viable, and hence has not been undertaken here.

vi. Bioremediation of Waste
The marine environment is where a significant amount of human waste (organic and inorganic waste) finally settles. It is washed off land, through rivers and estuaries, and then eventually sinking to the marine benthic environment where it is stored, diluted and recycled through assimilation and chemical re-composition. This de-toxification and purification process is of critical importance to the health of marine environment.

There are a number of studies which value the capacity of wetlands to process waste (Gren 1995, Bystrom 2000, Breaux *et al.* 1995). There are, however, no studies on any other marine environment with regard to waste bioremediation, and as a result the focus here is on wetlands. Breaux *et al.* (1995) estimate the value of the bioremediation function of wetlands in terms of potential savings over using more conventional waste water treatment. They determine the present value of wetlands, calculated over 30 years using a discount rate of 9%, to be £1096.81 - £1236.54 per acre in terms of savings. Estimates of the wetland area in the U.K. are available, and hence it may be considered that this value could be multiplied up to provide a U.K. estimate. This is not advised for the reasons mentioned earlier in this annex.

vii. Raw materials
A wide variety of raw materials are provided by the marine material, for a number of different uses. The most significant of these are oil and gas extraction and aggregate extraction. The net value of the oil and gas industry is £14.81bn, and the net value of the aggregate industry is £0.069bn (Pugh and Skinner 2002). The sum of these provides a conservative estimate of the value of the raw material provided by the marine environment.

viii. Physical Environment
The physical marine environment provides a space for various industries to work within. These industries are based in and around the marine environment, but rely only upon the physical nature of the marine environment. They do not benefit from the ecological functions. For example, shipping, dredging of channels, submarine telecommunications, marine equipment and construction, crossings and safety and salvage. The net value which these industries provide has been calculated to be £11billion (Pugh and Skinner 2002). This is anticipated to be an underestimate, as there are additional uses not included here, such as the generation of electricity, for example, from wind power.

ix. Information service
The marine environment can provide an insight into environmental resilience and stress, and provides a long term environmental record, revealing evolutionary tracks, which may provide an insight into how the environment has changed in the past, enabling us to determine how it may change in the future. This may be particular

relevant when studying climate change. There is significant value in education, training and university involvement in marine science, and this has been estimated at £82.8million (Pugh and Skinner 2002).

Through investigating natural technologies we are able to improve our own. For example, through the study of the natural mechanism behind the bivalve shell there is potential to provide an insight into new tougher, wear resistant ceramics for biomedical and structural engineering applications (Ross and Wyeth 1997). The study of microbes in marine sediments has resulted in the discovery that they are able to convert sugar into electricity, and may be a valuable method of producing batteries to provide economical electricity in remote places (Chaudhuri and Lovley 2003).

x. Non-Use Values: Bequest Value and Existence Value

Non-Use value can be divided into two components:
Bequest Value is the value an individual places on ensuring the availability of a natural resource to future generations. There is value associated with the marine benthic environment which does not concern our use of this environment, but is determined by our concern that future generations should have access to resources and opportunities. While the value to future generations of their own use of resources should be reflected through the use value categories (given a suitably lengthy time horizon and subject to the constraints of discounting), over and above this there may be utility to current generations from knowing that resources and opportunities are being passed to their descendants.

Existence Value is the value placed on simply knowing that a natural resource is there, even if it is never experienced. An example of this is the fact that many individuals would be willing to pay some amount to ensure the continued survival of some species, say polar bears, which they will never see, simply because that derive value from the knowledge of their existence. Existence values are not associated with any human use or option of human use, but simply reflect utility experienced from the knowledge that an environment exists in a certain state.

Existence and bequest values are difficult to determine accurately, and despite the considerable literature published in this area there is no comprehensive study of marine non-use values. Also, when values are determined, it is difficult to separate the existence value from the bequest value. As a result, in this review, only non-use values for sea mammals are provided.

Hageman (1985) and Loomis and White (1996) estimated that the average annual household willingness to pay to ensure the continued survival of various sea mammal species varied between £19.06 and £46.18, depending on the species. However, respondents of contingent valuation studies can tend towards multiple allocation of resources, that is they have 'x' amount of money which they will allocate repeatedly. We therefore will assume that the willingness to pay to maintain one sea mammal species is equivalent to the willingness to pay to maintain all sea mammal species. This will clearly result in a conservative estimate.

The National Statistics Office estimates that there are 24,890,000 households in the UK in 2003. It is therefore estimated that the non-use value of marine mammals varies between £474million and £1,149million. These values do not provide an estimate of the total non-use value of the UK marine environment, but do provide an insight to some potential values.

Not quantifiable in monetary terms at the present time, but have fundamental value, which should be recognised

xi. Biological control
Ecosystems have innate interactions and feedback mechanisms, leading to varying levels of stability within the community. Even small changes in the food web can significantly affect the resistance and resilience of an ecosystem to perturbations. Changes in marine food webs can influence the capacity to provide food resources, the distribution and sequestration of carbon, the cycling of nutrients, and waste storage and degradation. Marine organisms provide mobile and passive links between systems, transporting energy and nutrients.

xii. Habitat
The presence of healthy habitat is a pre-requisite for the provision of all goods and services, without this fundamental base the ecosystem would cease to function. The 'natural' marine habitat structure provides a refuge for plants and animals including surfaces for feeding and hiding places from predators. It also provides an essential breeding and nursery space for plants and animals; this is essential for the continued recruitment of commercial and/or subsistence species. The habitat thus plays a critical role in species interactions and regulation of population dynamics.

xiii. Genetic resources
The genetic resources available from the UK marine environment are not being utilised commercially at present, but it is expected that they may be of significant importance in the future, for uses such as cross breeding or genetic engineering to improve existing commercial species for fish farming. For example, tropical rainforests have been valued at £0.01- £ 19.38 per ha based on their genetic diversity, and their resultant potential to yield successful pharmaceutical products. In the same way it is possible that the genetic diversity held in the marine communities may provide valuable information for future medicines (Simpson *et al.* 1996).

xiv. Medicinal resources
Medicinal resources do overlap to some extent with genetic resources, but there are fundamental differences, not all medicinal resources are genetics based, and vice versa, hence the separate classification of these functions. As a result care should be taken to avoid double counting when considering these two functions. At present much exploratory research being undertaken in this area, and it is expected there will be use in the future. For example, recent research on the sea mouse, *Aprodite sp.*, has discovered that its spines have a remarkable capacity for reflecting light. This capacity may provide important information for use in the field of photonic engineering, and potentially in the development of new communication technologies and medical (Parker *et al*.2001).

Cone shells (Conidae) are harvested for their shells, but it is now becoming apparent that the toxins they produce for immobilising their prey have great medical application (Chivian *et al*. 2003). Dr. Carl Luer of the Mote Marine Laboratory is currently collaborating with the Moffitt Cancer Research Institute undertaking research on how shark-derived material can be applied to inhibit tumour cells.

These findings and researches indicate the importance of maintaining a healthy marine environment, as if we lose species, we may lose potential cures to diseases such as cancer.

xv. Ornamental resources
Some marine resources have value as ornamental goods e.g. shells, driftwood etc.

xvi. Spiritual and cultural values
There is value associated with the marine environment e.g. for religion, folk lore, painting etc.

xvii. Option use value
Option Use Value is the value associated with an individual's willingness to pay to safeguard the option to use a natural resource in the future, when such use is not currently planned. As detailed above there are a wide variety of potential uses of the marine environment that have been recently discovered. Option value is the value we put upon the fact that there may be more of these discoveries in the future, which we may or may not exploit. It is the value associated keeping one's options open. Any *expected* future use is not option value.

For every species we lose, we may lose a potential cure, and as such even though we may not use every species in the future, there is value in maintaining them, so that we have the option to use them. This value is expected to be very significant, considering what the marine environment has provided to date.

Other potential uses of the marine environment include:

- Food provision and employment
- Underwater space for living
- Marine archaeology
- Museum exhibits and collections

xviii. Glue value
Glue Value relates to the fact that the sum of the values of individual functions is likely to be less than the (anthropogenic) value of the entire environment, owing to the primary life support function, the contribution of specific environmental assets to maintaining healthy and functional ecosystems. This is sometimes described as primary value, "glue" value, or infrastructure value (Pearce and Moran 1994). It arises because individual functions can provide additional value when examined in the context of the other functions with which they coexist at wider scales (spatial or temporal) than the scale of investigation. Thus, although this classification breaks the environment down into specific components, the inter-dependency of these components, and overall value of the environment, should be recognised, although at present this is unlikely to be in monetary terms. Estimation of "glue" values is complicated by lack of scientific knowledge about the true interrelationships of

ecosystem functions within and across ecosystems; this context of fundamental uncertainty takes analysis beyond the proper realm of environmental valuation, and into that of precaution and avoidance of irreversible calamities.

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