Final Report

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A study on the consequences of technological innovation in the capture fishing industry and the likely effects upon environmental impacts

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1 Executive summary

Commercial fishing is known to result in the incidental injury and death of many non-target fish, invertebrates, mammals, birds and reptiles. It may also damage vulnerable habitats and disrupt ecosystems. The severity and type of environmental impacts varies greatly between fisheries and the fishing techniques used. Technological advancements in the fish capture industry can also affect the environmental impacts of fishing operations. Generally, '*profit increasing*' technology results in increased environmental impact, whereas '*impact mitigation*' technology reduces environmental impact, although there are some exceptions to this rule.

Profit increasing technologies. The fish capture industry is undergoing a continual incremental process of technological advancement, which increases efficiency and profitability. Such technologies usually achieve one or more of the following:

- Reduction in costs
- Increase in the catching efficiency of the fishing gear
- Increase in the encounter rate with the target species
- Value added to the catch through onboard processing

Historically, many of these 'profit increasing' technologies have been industry-led and widely adopted, but they have traditionally been developed with little consideration of environmental impact. The technologies have precipitated expansions in fishing effort, both spatially and temporally, and have most likely resulted in concomitant increases in environmental impact. The development and uptake of profit increasing technologies is likely to continue in future while the incentives that encourage such developments persist.

Environmental impact mitigation technologies. These have been developed mostly in the public sector and have been implemented by managers on many occasions in recent decades, largely in response to concerns over the environmental impacts of the catching sector. Some of the technologies have successfully reduced environmental impacts, but some have met with fisher resistance as they have reduced the short-term profits for those affected. The efficacy of such 'unpopular imposed' impact mitigating technologies is reduced if fishers adulterate the technology in order to negate its 'profit-decreasing' properties.

Impact-mitigating technologies currently available have potential to further reduce the environmental impacts, but all need to be evaluated and potentially modified to suit the conditions particular to each recipient fishery.

Technologies are currently available to (potentially) successfully mitigate the impacts attributable to lost/abandoned fishing gears (ghost nets) and to reduce seabird by-catches in longline fisheries. Marine mammal by-catches in pelagic trawl fisheries may also be reduced if excluder designs currently under development are successful and implemented. Acoustic deterrent 'pingers' have the potential to reduce mammal by-catches in static net fisheries. Most fishing gears can be modified by a variety of technical means to render them more selective and to reduce catches of incidental/unwanted non-target fish and invertebrates.

Successful technologies to reduce benthic impacts and damage to vulnerable habitats are, however, probably the least developed in the field of impact mitigation. Some incremental progress has been made and research is currently under way on this topic.

Total mitigation of all environmental impacts of fish capture using technological means is not possible at present, given the current level of available technologies. Some technologies may reduce short-term profitability and could therefore be met with resistance if imposed under present conditions. A number of new impact-mitigating technologies are currently undergoing development, and these should be available in the future.

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3 Aim and description of the work

The aim of this work is to inform the Royal Commission on Environmental Pollution on the broad types of technology currently used in the commercial capture fishing industry, the likely technological innovations that could be taken up by industry, and how this may affect environmental impacts. The methodology has employed desktop-based investigations into the following key issues in accordance with the tender specifications:

- An overview of the Northern European and UK fishing fleets
- An assessment of the types of environmental impacts associated with capture fishing
- Identification of the existing and emergent technologies used to locate, catch and handle fish
- Identification of the major drivers of technological development in these fields
- Identification of the factors that influence their uptake by the fishing industry
- An assessment of how technological advances in the above fields can affect the environmental impacts of capture fishing
- An assessment of factors likely to influence uptake of new technological advances by the capture industry in the future

This work has a focus on the European capture fisheries, but it makes reference to global fisheries throughout and is written for the non-specialist. An overview of the main issues is contained in the body of the main report (only some 20 pages), but more detailed information is contained within the Appendices.

4 An overview of the Northern European and UK fishing fleets

4.1 Northern European fleets

Fishing vessels from the EU, Norway, the Faeroe Isles, Iceland, Russia and the Baltic States exploit the waters of Northern Europe. Within European Community waters, commercial fish capture is exclusive to vessels from Member States[1] and produces some 6 - 7 million tonnes of fish per annum (7% of global production[2]). Spain, UK and France have the largest fishing fleets in the European Community[3].

Demersal fishing: Demersal[4] trawling is the most widely used fishing technique in Northern European waters, however beam trawling, gillnetting, potting, dredging, seine-netting and long lining are also used to catch demersal species[5]. Northern European fishers target a variety of economically important demersal gadoid[6] species, including cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*), whiting (*Merlangius merlangus*), Norway pout (*Trisopterus esmarkii*) and pollock (*Pollachius pollachius*). Demersal fish such as redfish (*Sebastes marinus*), Norway lobster (*Nephrops norvegicus*), anglerfish (*Lophius piscatorius*), numerous flatfish and elasmosbranchs[7] are also important commercial species. In deep water off the continental shelf, a variety of deep-water demersal species are targeted[8]. In 2003, the European Community TAC[9] of demersal fish species was 3.3 million tonnes, of which nearly one-third (0.9 million tonnes) were sandeels, mostly allocated to Denmark.

Pelagic fishing: Purse-seining and pelagic trawling are used to catch most pelagic[10] species in Northern Europe, although some minor pelagic fisheries use floating gill nets, floating long lines or pole and lines. Pelagic trawlers and purse-seiners dominate the Community pelagic fisheries, which have a TAC (2003) of some 4.5 million tonnes. Pelagic species such as mackerel (*Scomber scombrus*), herring (*Clupea harengus*), swordfish (*Xiphias gladius*),

[1] Non EU States (e.g. Norway) may gain restricted access under negotiated agreement
[2] Global production is around 90 million tonnes (2002) (Table 4 in Appendix 13.1).
[3] In terms of fleet gross vessel tonnage / engine power (Table 5 in Appendix 13.1)
[4] Seabed related
[5] See Table 8 - Table 10 in Appendix 13.1 and Appendix 13.2 for illustrations of these fishing techniques)
[6] Cod family of fish
[7] Sharks and rays
[8] See Appendix 13.3.
[9] Total Allowable Catch (in EC & Norwegian waters but excluding the Mediterranean Sea)
[10] Midwater related

anchovy (*Engraulis encrasicolus*), horse mackerel (*Trachurus trachurus*), blue whiting (*Micromesistius poutassou*), sprat (*Sprattus sprattus*), capelin (*Mallotus villosus*) and tuna species are all caught in Community waters.

4.2 UK fleet

The UK fishing fleet consists of some 7700 registered fishing vessels[11] of which, 74% are less than 10m long. Vessels and fishers engaged in the UK capture sector has steadily declined during the past decade, while the fleet registered tonnage has risen overall, indicating a steady trend towards fewer and larger vessels[12]. Around 15 000 UK fishers are currently employed in the industry. Few new vessels were built during the past decade, with the consequence that the UK fleet (>10m)[13] has an average age of 23 years.

A total of 738,000 tonnes of sea fish were landed by the UK fleet with a total value of £574 million in 2001. Demersal landings were 270,000 tonnes (£281 million), pelagic landings were 324,000 tonnes (£114 million) and shellfish landings were 144,000 tonnes (£179 million).

Demersal fishing: In the UK, demersal trawling remains the most commonly practised fishing technique and is practiced around the entire coastline targeting a wide range of species. Profitability and investment in demersal trawlers have fallen dramatically in the last few years owing to stringent fish quota restrictions and increased fuel costs. The number of beam trawlers has also declined during the past decade (by 50%) probably due to high fuel prices. Beam trawling is mainly undertaken in the North Sea, Irish Sea, and English Channel and off Southwest England, primarily targeting flatfish. Gillnet fleets also operate in these waters and target cod, hake, sole and monkfish. Long liners fish around the entire UK coastline and mainly target cod, elasmosbranchs, ling, turbot and conger eel. The shellfish fisheries catch a range of demersal shellfish species all around the UK, including scampi prawn, lobsters, crabs, scallops, shrimps, whelks, mussels, oysters and cockles. The shellfish sector use a variety of mobile and static fishing techniques, including traps, dredges, trawls and beam trawls.

[11] See Table 6 in Appendix 13.1
[12] See Table 7 in Appendix 13.1.
[13] Vessels with a hull 'Length Over All' exceeding 10 m

Pelagic fisheries: The UK pelagic fleet consists primarily of pelagic trawlers / purse seiners and is small and profitable, producing landings valued at around £115 million a year. Catches of herring and mackerel account for 85% of these landings. Reinvestment (new vessels) in this sector of the industry is high.

5 The environmental impacts of capture fishing

The environmental impacts arising from the capture fishing industries (i.e. fishing vessels) may be classified into two categories:

- *Impacts common to the operation of all merchant vessels*
- *Impacts that specifically arise from activities unique to fishing vessels*

This work considers only the latter source of impacts and does not cover impacts common to all merchant vessels (i.e. exhaust emissions, noise, light, bilge effluent, collisions, etc).

The environmental impacts associated with fishing vessels when no fishing gears are deployed (i.e. when steaming to and from the fishing grounds) are broadly comparable to that of equivalent merchant vessels. It is their deployment of fishing gear that differentiates such vessels from other merchant vessels and results in additional environmental impacts, which generally are specific and unique to the fish capture industry. Commercial fish capture is intrinsically linked to a wide array of incidental environmental impacts. Even the core intentional purpose of capture fishing (the removal of target fish from the seas) has consequent environmental impact.

The environmental impacts from capture fishing are globally ubiquitous in marine and freshwater where capture fisheries are prosecuted. The severity and the significance of these environmental impacts may depend on many factors, including fishing gear design and construction, gear dimensions, timing and duration of deployment, area deployed, frequency of deployment in an area, the zone of influence of the gear, the selective properties of the gear, speed through the water (mobile gears), contact with the seabed, interaction with the water column, presence and abundance of target/non target species, and fisher competence and knowledge.

The environmental impacts of capture fishing can be classified into the following seven broad categories and are described in moderate detail in the Appendices listed:

- Capture of target species of marketable/legal size (Appendix 13.4)
- Capture of target species of non-marketable size (Appendix 13.5)
- Incidental capture of non-target species (Appendix 13.6)
- Benthic[14] habitat damage (Appendix 13.8)
- The effects from lost and abandoned fishing gear (Appendix 13.9)
- Ecosystem change (Appendix 13.10)
- Incidental mortality (Appendix 13.11)

Mobile gears (i.e. fishing gear actively towed by the fishing vessel) are generally considered to have a greater negative impact on habitat and greater levels of unwanted incidental catches of non-target species, in part the result of their less selective nature. In contrast, static gears (i.e. fishing gear not towed by the vessel) are considered more environmentally friendly in terms of unintentional or incidental environmental damage, but they may produce incidental catches of birds and mammals. Fishing gears lost/abandoned at sea can cause environmental impacts for extended periods of time (ghost fishing); this phenomenon is restricted to static gears.

Mobile pelagic gears do not damage the seabed and are used to target pelagic fish species. However, the incidental by-catch of mammals in some of these fisheries is considered to be problematic and unacceptably high. Mobile demersal gears impact on the seabed communities and habitats and exhibit high levels of incidental fish and invertebrate by-catch, but they are not generally associated with significant incidental catches of mammals or birds.

Considering the costs of environmental damage of fishing gears without taking account of the benefits may lead to misconceptions about the net economic effects of these activities (Appendix 13.12).

[14] Seabed related

6 The drivers of technological advancement

Technological advancements in the fish capture industry invariably affect the environmental impact of fishing operations and have two main drivers. As a general rule, the driver for 'profit increasing' technology results in increased environmental impact, whereas the driver for 'impact mitigation' technology reduces environmental impact, although there are some exceptions to this rule.

- The need/desire to maintain or increase profitability of fish capture operations has been the traditional and long-standing driver of technological progress. Much advancement has been made over the years in this arena, but it has been generally accompanied by little consideration of environmental impact. The majority of such advances have been pioneered by the private sector or industry led, although some public bodies aid their development. Technologies in this field have generally increased environmental impact because they have precipitated both the temporal and spatial expansion of fishing effort (Appendices 13.13 to 13.22).

- In contrast, concerns about the environmental impacts of fish capture have driven the development of impact mitigation technologies. Technological developments in this arena have been primarily financed through state funding and undertaken by public bodies. Environmental impact mitigation technologies have successfully reduced environmental pollution, but sometimes result in decreased profitability and can therefore be unpopular with some fishers (Appendices 13.23 to 13.44).

A few sporadic technological innovations affecting environmental impacts have arisen from other drivers, such as improving onboard safety and comfort (Appendix 13.45).

6.1 Drivers: Profit increase

Capture fishing is an economic activity, and simple economic forces primarily drive participation in the industry. Profit increasing technologies either reduce costs or increase revenue. Cost reductions can be accrued through the adoption of technologies that offer increased durability of components, lower maintenance, lower running costs, etc. The biggest running costs of a fishing vessel in Northern Europe are crew and fuel.

Increased revenue results from technologies that enhances the catching power of a fishing gear and increases the encounter rate with target species, or that adds value to the catch once it is onboard.

New fishing opportunities can also offer fishers the chance to increase revenue. Such opportunities become available as profitable new markets develop for under/non-utilised species previously ignored or discarded, or as access is made possible to previously under/non-utilised fishing grounds. Advances in technology may precipitate the birth of new opportunities through improved vessel and fishing gear designs that permit vessels to fish in distant waters, extreme weather conditions or on previously unfishable grounds. Recently, most new fishing opportunities have come about in deep water, because the bulk of the fishing grounds and stocks on continental shelves are exploited (Appendix 13.3).

Some management interventions[15] may also stimulate the development of profit increasing technologies. Many interventions are unpopular with industry, because they can result in short-term reductions in revenue for the affected fishers. In response to such interventions, some fishers embrace tactics/technology that minimise the short-term losses or circumvent the intervention completely.

6.2 Drivers: Environmental impact concerns

Concerns about the environmental impacts attributable to fish capture industries have increased over recent decades and have in many instances resulted in the introduction of specific impact mitigating legislature. Such technologies have the potential to reduce environmental pollution if they are effective, enforceable and widely adopted, and a wide range of impact mitigation technologies has consequently been imposed on fishers by managers throughout Northern Europe and the rest of the world.

The efficacy of these technologies may sometimes be diluted or negated if the technology is adulterated or if it displaces impacts rather than reduces or eliminates them (an example is given in Appendix 13.44).

[15] Management interventions are typically imposed on the fish capture industry to protect vulnerable fish stocks from over-exploitation and to protect habitats and species from unnecessary harm. Typical management interventions include restrictions governing vessel length, engine size, dimensions of fishing gears, types of fishing gears, satellite tracking systems, catch recording, area recording, vessel licensing, access to fisheries, levels of effort, closed areas, closed seasons, minimum landing sizes, catch composition, and catch limits.

7 Examples of 'profit increasing' technological advances in the fish capture industries

Profit increasing technological advances have historically been made in the fields of fishing gear, fishing methods, bridge electronics, vessel design, propulsion systems, deck machinery and catch preservation. Overall, these technologies have the effect of increasing environmental impact, although there are some exceptions. In most cases, specific, quantifiable increases in environmental impact, which can be linked to a particular technological advancement, are not available. Increased environmental impacts can be inferred, however, largely as a consequence of the spatial/temporal increases in fishing activity that result from the technological advance. Some examples are given in this section and in the relevant Appendices.

7.1 Bridge electronics

Modern fishing vessels are equipped with the most sophisticated electronic aids available to mariners. This technology increases the encounter rates with target species by reducing uncertainty in the fish capture process and provides information and tools that aid the skipper to choose when and where to fish most profitably, reducing the risk of unprofitable fishing. Advances have been made in the technologies of accurate vessel position location, radar, sonar, fish finding, echo sounders, seabed mapping, electronic chart plotting, fishing gear sensors and autopilots (Appendices 13.13 and 13.14).

Of these, the GPS[16] satellite system has been particularly important and has enabled the fisher to record the vessel location at sea to an accuracy of 5 m[17]. The availability and growth of powerful microprocessors has facilitated the development of electronic charts and plotters and has allowed once-discrete electronic aids to be networked, giving rise to new integrated functionality. Technological advances in bridge electronics and instrumentation have precipitated changes in fishing patterns in recent decades that are likely to have had both positive and negative environmental impacts (Appendix 13.15).

7.2 Fishing vessel and propulsion gear design technology

The biggest advances in propulsion technology were experienced during the first 50 years of the 20th century, when vessels changed from sail to steam to heavy oil and finally to diesel

[16] Global Positioning System

propulsion. During the past few decades, marginal technological advances have been achieved by the adoption of under-utilised existing technologies, such as the bulbous bow and the Kort nozzle (Appendix 13.16). Catamaran designs of fishing vessels have also become increasingly popular with fishers in certain inshore sectors. These few recent advances have primarily reduced fuel consumption or given more pulling power to vessels, whereas the transition from sail to diesel propulsion was fundamental in the expansion of fisheries on a global basis, During the past few decades, the impact of technological advancement in this field has probably had only a marginal increasing effect on environmental impacts.

7.3 Fishing gear twines

The shift from use of natural fibres such as hemp and sisal in the construction of fishing gear to stronger, more durable and hard wearing synthetic polymer-based fibres has resulted in increased environmental impact. Synthetic polymers[18] are resistant to degradation by bacteria, fungi, insects, algae, moth larvae, seawater and ultraviolet radiation, so they persist in the environment much longer than natural fibres in situations where gearis lost or abandoned (Section 13.9).

The use of monofilament synthetic polymers has enhanced the catching power of static nets by virtue of its decreased visibility in the water.

A new fibre, Dyneema®[19], reputed to have superior strength qualities to that of the commonly used synthetic polymers, has recently been developed. This new fibre has the potential to increase environmental impact by allowing vessels to tow larger nets with no fuel penalty. Conversely, the use of thinner twines in fishing gears has now become possible and could give rise to improved selectivity and reduced environmental impact. The actual changes in environmental impacts attributable to the use of this new fibre are unknown at present, because it has not yet been widely adopted by the catching sector.

7.4 Trawls, nets, doors and ground gear

Many technological improvements have been made to trawls; nets, headline floats, doors[20] and ground gear. The main thrust of this development work has been in the fields of:

[17] Further spatial resolution is unlikely to be of value to fishers
18 Polyamides / polyesters (polyvinyl chloride, vinylidene chloride, polyethylene, polyvinyl alcohol)
[19] Registered to DSM High Performance Fibres, The Netherlands

- Optimal tuning of trawl systems to maximise catch
- Developing trawls to exploit new fishing grounds
- Developing trawls to exploit new species
- Developing twin and multi-rig trawling (see Appendix 13.19)
- Increasing the catching power of fishing gears

There can be little doubt that much of this technological development has contributed to an overall increase in the environmental impact of the capture fisheries by increasing temporal and spatial fishing effort. A good overview of the range and scope of this type of developmental work can be obtained by examining the work undertaken by Seafish (Technology)[21] during the past 20 years (see Appendices 13.17 and 13.18).

7.5 Static gears

Significant advances have been made through the automation of longlining, which has greatly increased the catching power of longliners by permitting more hooks to be baited and deployed per unit of time than was previously possible. Advances in hook technology and in the use of swivels and stronger backing lines have also served to make this fishing technique much more effective (see case study in Appendix 13.3.2.). Pot and trap design improvements have resulted in the parlour pot[22] and collapsible/stackable pots[23]. These static gear technical innovations are likely to have increased environmental impact by increasing fishing effort.

7.6 Fishing techniques

New and more effective fishing techniques evolve over time and replace less efficient techniques. In the past 100 years, Northern European fishing fleets have embraced many new fishing techniques and abandoned less profitable techniques. For instance, in the European demersal fisheries, seine-netting was the preferred fishing technique for significant numbers of UK and Scandinavian fishing vessels, catching large quantities of good quality roundfish and flatfish. During the past few decades, seine-netting has largely given way to demersal trawling and beam trawling, and only a few seine-netters remain in the UK. Similarly, in the past 50 years, side trawling has been largely replaced by more efficient stern trawling in the UK and by beam trawling in the Netherlands.

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[20] Otter boards that hold the trawl open (see Appendix 13.2).
[21] St Andrew Dock, Hull, UK
[22] More effective than traditional pots at preventing escapees
[23] Permit vessels to carry many more pots out to sea than was previously possible

In the pelagic fisheries, small numbers of efficient large pelagic trawlers and purse-seiners now dominate, whereas once the fishery was prosecuted by many hundreds of small driftnet and ringnet fishing vessels.

Many newly built vessels are constructed as 'multi- purpose' vessels and are able to switch between fishing techniques, choosing the most profitable options at any particular time. It is probable that the evolution of new, more effective and profit increasing fishing techniques is accompanied by associated increases in environmental impact; two recent examples of this (multiple rig trawling and twin beam trawling) are described in Appendices 13.19 and 13.20.

7.7 Deck machinery

Technological advances in deck machinery have had some effects upon the environmental impacts of capture fishing. The advent of hydraulic systems has enabled much larger and heavier gears to be hauled aboard than was previously possible. Powerful net haulers and net flaking machines have permitted the gill-/tangle net sectors to increase the amount of netting they can shoot and handle each day. The introduction of power blocks and net drums on trawlers has allowed vessels of all sizes to increase the size of trawls used and to carry out twin and multiple rig trawling (Appendix 13.19). Auto-winch control systems keep an even load on the trawl winches and maintain optimal fish catching net geometry, so improving the efficiency of capture. In the brown shrimp fisheries, the automation of catch riddling has enabled fishers to handle and process significantly larger catches than previously possible with the hand riddles (Appendix 13.21). All these technologies have incrementally allowed vessels to increase their catching capacity.

7.8 Ice, refrigeration and onboard processing

The ability to effectively preserve the catch, or to add further value to the catch through onboard processing is a principle that has been adopted by virtually every modern fishing vessel. The onboard use of ice, liquid ice, vivier tanks[24], refrigeration and freezing plants has made longer voyages economically viable and helped pave the way for the expansion of fishing into distant fishing grounds. This technology has served to spatially expand capture fishing and environmental impacts. In recent decades advances in this field are likely to have had only marginal effects on environmental impact.

[24] Vivier tanks are able to hold live crustaceans in circulating seawater tanks for extended periods and have precipitated the advent of large UK 'crabber' vessels targeting crustaceans on offshore fishing grounds.

7.9 The exploitation of new opportunities

New opportunities for exploitation by capture fisheries have continually become available throughout history and as technology has advanced. These new opportunities manifest themselves as new fishing grounds or new species and have served to maintain or increase profits in the fish capture sector. Every exploited fishery that exists today was once a 'virgin' unexploited fishery at some time in the past, and it is only through technological development that exploitation has been possible. A case study on the development of the Irish RSW[25] pelagic fleet is given in Appendix 13.22.

New fishing opportunities continue to become available to this day and have been particularly notable with the opening up of deep-water fisheries (Appendix 13.3). The expansion of fisheries through the exploitation of under-utilised stocks or by moving to new fishing grounds generates new revenue for the industry, but has simultaneously increased the overall spatial distribution of environmental impact.

7.10 Response to management interventions

Tactics and technologies sometimes develop in response to unpopular fisheries regulations, in order to dilute or circumvent the 'offending' management measure. Levels of environmental impact may therefore be maintained at undesirably high levels despite the existence of mitigating management measures.

A typical example of such technology relates to the design of modern fishing vessels. Many such vessels are now designed and constructed to fall just within the specific length or engine power designations defined by management. These vessels are designed and built to have the same fishing capacity as larger vessels, but are exempt from management restrictions that apply to larger, more powerful vessels. This has contributed to the evolution of 'short and stumpy' fishing vessel designs[26] and to new classes of vessel, such as the Euro cutter (see Appendix 13.16).

[25] Refrigerated Sea Water
[26] Often known as 'rule beaters'

8 Examples of drivers for environmental impact mitigation technology

Considerable developmental work in impact mitigation has focused on improving the size selectivity of fishing gears by mesh size manipulation, and has been used as a measure to protect juvenile fish in overexploited stocks. Widespread use of this technology has failed to halt the decline of many fish stocks in many European fisheries. More recent developments in the field involve the use of escape panels and modified codends[27], which are often constructed from alternative mesh shapes. Most European demersal fisheries are mixed species fisheries, and developments have taken place to make the fishing gears used more species-selective, particularly against the background of quota restrictions. This research has so far resulted in grids, sieve nets, separator trawls and cut away trawls. Much research and development work continues in this field.

Successful technologies have been developed for use in the longline fisheries to reduce incidental catches of birds, and include streamers, sinker weights and setting tubes. Back-down manoeuvres used in combination with medina panels are reputed to have resolved cetacean by-catch in the purse-seine fisheries. Pingers, grids and modified sieve nets are currently being developed to reduce the incidental capture of mammals in the pelagic and static gear fisheries. Fairly simple technologies can reduce the impact of lost and abandoned fishing gears, and include retrieval programmes, addressing the causes of loss/abandonment and biodegradable release mechanisms on fish traps/pots.

The advent of VMS[28] is facilitating the spatial and temporal enforcement of impact mitigating fisheries regulations, and could potentially be further aided through the use of electronic log books and the tagging/marking of fishing gears. The strategic placing of sensors onboard a vessel and on the fishing gears which are linked to the VMS system has significant potential to provide extremely valuable data for scientists and managers.

Some technologies aim to reduce benthic habitat damaging properties of fishing gears, but most are in the developmental stages and are not used commercially to any large extent. This field of impact mitigation technological development is the least advanced.

[27] The bag at the rear of towed fishing gears that collects and retains the catch
[28] Vessel Monitoring System (on board vessel tracking satellite based system)

A summary of these technologies can be found in Table 1 on page 29, with further detail in the Appendices.

9 The future

9.1 The future development of profit increasing technologies

Technologies are continually advancing in bridge electronics, propulsion, vessel design, gear design, deck machinery and refrigeration, and incremental advances in these technologies will undoubtedly continue into the future. Technologies that permit the exploitation of new opportunities or reduce costs are likely to be particularly attractive to fishers during times of stringent quota restrictions and poor profitability.

9.2 Future potential uptake of emergent profit increasing technologies by the industry

The capture fishing industry is undergoing a continuing and incremental process of technological advancement. The main thrust of this technological advancement aims to increase profitability and has been concomitant with a general increase in environmental impact. New profit increasing technologies have traditionally been taken up, regardless of considerations of environmental impact. Many of the fisheries in Northern Europe have depleted or declining stocks, and fishers act under competitive conditions whereby only the most cost-effective will remain in the fishery. This trend in 'profit increasing' technological advancement is likely to continue if the current incentives in the fisheries persist. The incentives to develop and take up profit increasing technologies are primarily economic and reflect the fishery management strategies in place. Profit increasing incentives can exist in fisheries where one or more of the following conditions prevail:

- When there is competition for a scarce resource
- When increased catches result in increased revenue
- When profits are declining
- To gain access to a previously unprofitable fishery

A discussion on the economic incentives to adopt technology under alternative management strategies is contained in Appendices 13.46 and 13.47.

9.3 *The future development of impact mitigation technologies*

9.3.1. Reducing incidental catches in demersal trawling and seining

Demersal trawling is the most common and widespread fishing technique in Northern Europe and is characterised by poor selectivity (high rates of incidental capture of fish and invertebrates) and impacts on the seabed. The size and species selectivity of demersal trawls has been improved over the years, but are still relatively poor in many fisheries. The selectivity of Norway lobster and some industrial trawls are particularly low and mitigation technologies are required. Some fish species, e.g. elasmosbranchs such as skate (*Raja batis*) as well as cod (*Gadus morhua*) are becoming scarce and may warrant particular protection from capture. A variety of selectivity enhancing tools are available (Table 1 to Table 3, pages 29-30), but all require specific individual adaptations and evaluations for each fishery in which they are to be used.

9.3.2. Reducing incidental catches in pelagic trawling

The main environmental impacts of pelagic trawling relate to the incidental catches of aquatic mammals (notably cetaceans[29]). In many fisheries, incidental catches may be reduced by the use of modified sorting grids/panels/pingers although the technology requires some development and evaluation (Table 1 to Table 3, pages 29-30).

9.3.3. Reducing incidental catches in gillnetting

The main environmental impacts of gillnets are the incidental catches of seabirds and mammals, and ghost fishing when the gear is lost/abandoned (see 9.3.6.). Pingers have the potential to reduce mammal by-catch, although habituation may be a problem. An effective technology that prevents diving bird entanglement in gillnets, does not appear to be available at present (Table 1 to Table 3, pages 29-30).

9.3.4. Reducing incidental catches in longlining

The main environmental impacts of longlining relate to the incidental catch of diving seabirds and can be effectively reduced by the use of streamer lines. Sinker weights and setting tubes may also help to reduce bird by-catch. The selectivity of longlines can be improved through hook and bait modifications (Table 1 to Table 3, pages 29-30). The sourcing of the bait for long lines may be a potential problem in the future in fisheries with a falling CPUE[30].

9.3.5. Reducing incidental catches in purse-seining

The main environmental impact of purse-seining has been the incidental bycatch of mammals (notably cetaceans). The use of medina escape panels and the back down manoeuvre are

[29] Collective name for dolphins, porpoises and whales
[30] Catch Per Unit Effort

reputed to have effectively resolved this problem (Table 1 to Table 3, pages 29-30). Purse-seining around FADs[31] can result in unwanted catches of elasmosbranchs and is considered a problem (Valdemarsen and Suuronen, 2001). FADs are typically used in tuna fisheries, and a solution to this problem has yet to be found.

9.3.6. Reducing the impacts of lost and abandoned fishing gears

The environmental impacts of lost and abandoned static fishing gears may be reduced by simple mitigation measures, including addressing the causes for loss, establishing formal retrieval programmes of lost gears and the registration and marking of static gears (Table 1 to Table 3, pages 29-30). In the case of pots and traps, the additional use of biodegradable catch release mechanisms on pots and traps could further help to mitigate any ghost fishing problem (Table 1 to Table 3, pages 29-30).

9.3.7. Reducing the benthic impacts of towed fishing gears

Little progress has been made in the development and uptake of benthic impact reducing technologies in towed gears, although some research on this field is currently under way (Table 1 to Table 3, pages 29-30). Benthic release panels show promise and may partially mitigate the problem. The development of potential high-tech solutions such as the electric beam trawl and remote controlled otter boards (smart trawling) are undergoing development and may provide solutions in the future, although they are likely to be expensive.

9.3.8. Unaccounted mortality and ecosystem effects

Little progress has been made in terms of technological advancement to mitigate these poorly understood environmental impacts.

9.3.9. Infrastructure and strategies for the future development of impact mitigation technologies

Infrastructure for the continued development of environmental mitigating technologies is strong and exists in virtually every fishing nation. International collaboration of workers in this field is high and is greatly facilitated by the ICES FTFB[32] working group.

It is unlikely that any single technological advancement will completely mitigate all environmental impacts in any fishery. Impacts can, however, be reduced through the incremental introduction of mitigating technologies as and when they are developed. Fisheries managers could therefore formulate short- and long-term realistic impact reduction strategies.

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[31] Fish aggregation devices
[32] International Council for the Exploration of the Sea. Fishing Technology and Fish Behaviour working group.

Technologies can be used successfully to reduce the environmental impact of capture fisheries, and are probably most effective when used in conjunction with other management techniques, such as effort/catch restrictions.

9.4 Future potential uptake of emergent impact mitigating technologies by the industry

Successful environmental impact mitigating technologies have been developed, or are under development, largely financed through public funds, and fisheries management have implemented some of these technologies. The overall efficacy of these technologies may be diluted/negated if they are adulterated. There is considerable evidence[33] indicating that some fishers will adulterate impact mitigating technology if it reduces short–term profitability. This tendency to adulterate 'profit decreasing' impact mitigating technological is likely to continue if current incentives in the fisheries remain. In the future, the closer co-operation/participation of the industry throughout the process of design and development of impact mitigation technologies should serve to reduce the chances of failure attributable to fisher non-acceptance.

Some impact mitigation technologies have little or no profit decreasing effect, in which case they are more readily accepted. Emergent impact mitigation technologies are more likely to be accepted by fishers and mangers in the future, if they meet all the criteria detailed in Table 2 (page 30), while failure to meet all the criteria makes potential acceptance less likely. Several impact technologies are available or are emerging and are summarised and evaluated in Table 3 (page 30), although most fail to meet <u>all</u> of the optimal criteria detailed in Table 2 (page 30).

Rewarding fishers for the adoption of impact reducing technologies has the potential to increase uptake in cases where fisher profitability is reduced. For instance, the Marine Stewardship Council aims to reward fishers through the niche marketing of fish produce harvested from sustainable fisheries (Appendix 13.48), and major fish processors and retailers in the UK appear supportive of the practice.

Ideally, all impact mitigation technologies should be developed and evaluated individually in each individual fishery where usage is intended/planned. They should be optimised to suit each fishery and to take account of local conditions particular to each fishery. The imposition of single, unilateral and broad-sweeping impact mitigating technologies across diverse fisheries and fleets is unlikely to be either successful or effective and should be avoided.

10 Main report tables

Table 1. Technologies that reduce environmental impact

	Reduce catches of target fish (e.g. undersize)	Reduce incidental catches of non target fish	Reduce incidental catches of birds	Reduce incidental catches of mammals	Reduce catches of invertebrates	Reduce benthic habitat damage	Reduce effects of lost/abandoned gear	Improve enforcement	Reduce unaccounted mortality/ecosystem
Mesh modification (Appendix 13.23)	X	X			X				?
Escape panels (Appendix 13.30)	X	X		X					?
Square mesh codends (Appendix 13.31)	X	X			X				?
Grids (Appendix 13.24)	X	X		X	X				?
Sieve nets (Appendix 13.25)	X	X		X	X				?
Separator panels (Appendix 13.26)		X							?
Cut away trawls (Appendix 13.32)		X							?
Blow out panels (Appendix 13.33)	X								?
Headline/footrope manipulation (Appendix 13.34)		X							?
Selective longline hooks (Appendix 13.35)	X	X							?
Streamers lines (Appendix 13.28)			X						?
Sinker weights (Appendix 13.28)			X						?
Setting tubes (Appendix 13.28)			X						?
Altered float lines (Appendix 13.36)			X	X					?
Back down manoeuvre (Appendix 13.36)				X					?
Fyke net excluder (Appendix 13.29)		X		X					?
Escape vents traps and pots (Appendix 13.37)	X				X				?
V Notching (Appendix 13.38 and 13.39)	X								?
Pingers (Appendix 13.40)				X					?
Remote controlled doors (Appendix 13.41)						X			?
Alternative stimuli (Appendix 13.41)						X			?
Alternative ground gears (Appendix 13.41)						X			?
Benthic release panels (Appendix 13.41)		X			X	X			?
Ballast elements (Appendix 13.41)						X			?
Droppers (Appendix 13.41)					X	X			?
Wheeled beams (Appendix 13.41)						X			?
Multibeam sonar location (Appendix 13.42)							X		?
Retrieval programmes (Appendix 13.42)							X		?
Biodegradable components (Appendix 13.42)							X		?
VMS (Appendix 13.43)								X	?
Electronic logbooks (Appendix 13.43)								X	?
Gear tagging and marking (Appendix 13.43)								X	?

NB: Impact reductions pertaining to unaccounted mortality and ecosystem changes for all of the technologies remains largely undetermined.

[33] Much of it anecdotal

Table 2. Optimal criteria for impact mitigation technology

Code	Criteria
A	Consistent and effective impact mitigation
B	High survival rate of escapees
C	No crew or vessel endangerment
D	No impediment to fishing operations
E	No reduction in profitability
F	Simple
G	Robust
H	Inexpensive
I	Enforceable
J	Available

Table 3. Where impact mitigation technologies commonly fail

Impact mitigation technology	**Evaluation criteria failure**
Mesh size modification (Appendix 13.23)	**A E**
Escape panels (Appendix 13.30)	**E**
Square mesh codends (Appendix 13.31)	**E**
Grids (Appendix 13.24)	**D E**
Sieve nets (Appendix 13.25)	**E**
Separator panels (Appendix 13.26)	**E I**
Cut away trawls (Appendix 13.32)	**I**
Blow out panels (appendix 13.33)	-
Headline/footope manipulation (appendix 13.34)	**E I**
Selective longline hooks (Appendix 13.35)	-
Streamers lines (Appendix 13.28)	-
Sinker weights (Appendix 13.28)	**D**
Setting tubes (Appendix 13.28)	**A**
Altered float lines (Appendix 13.36)	-
Back down manoeuvre (Appendix 13.36)	-
Fyke net excluder (Appendix 13.29)	-
Escape vents traps and pots (Appendix 13.37)	**E**
V Notching (Appendix 13.37)	**H**
Pingers (Appendix 13.40)	**H I**
Remote controlled doors (Appendix 13.41)	**H J**
Alternative stimuli (Appendix 13.41)	**A C D E F G H J**
Alternative ground gears (Appendix 13.41)	**A E**
Benthic release panels (Appendix 13.41)	**G**
Ballast elements (Appendix 13.41)	**E**
Droppers (Appendix 13.41)	**E**
Wheeled beams (Appendix 13.41)	-
Multi beam sonar location (appendix 13.42)	**H**
Retrieval programmes (Appendix 13.42)	**H**
Biodegradable components (appendix 13.42)	**A**
VMS (Appendix 13.43)	**H**
Electronic logbooks (Appendix 13.43)	**J**
Gear tagging and marking (Appendix 13.43)	-

NB: Evaluation criteria used are given in Table 2

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12 Selected Internet information sources

12.1 Entanglement in fishing gears

http://www.neseabirds.com
http://www.coastalstudies.org
http://crei.nmfs.hawaii.edu/
http://www.wsg.washington.edu/
http://www.seaworld.org/
http://alaska.fws.gov/
http://www.eurocbc.org/
http://www.wwfus.org/
http://www.cetaceanbycatch.org/
http://www.vaquitamarina.org/
http://www.hectorsdolphin.org.nz/
http://fishinglinerecycling.org/research.htm
http://www.ukmarinesac.org.uk/activities/fisheries/f4_2.htm
http://www.internat.naturvardsverket.se/
http://www.nwstraits.org/
http://www.defenders.org/
http://www.wa.gov/puget_sound/Programs/Derelict_gear.htm
http://www1.countygovt.brevard.fl.us/
http://www.eurocbc.org/
http://www.susanscott.net/
http://www.surfbirds.com/news/albatross.html
http://www.pbs.org/odyssey/voice/20000409_vos_transcript.html
http://www.seaweb.org/resources/5oceanrep/tross.html

12.2 Ghost fishing

http://www.cbfwa.org/files/province/mitigation/projects/23013.htm
http://www.eurocbc.org/page294.html
http://www.earthsky.com/2002/es020325.html
http://www.wdcs.org/
http://www.forest-bird.org.nz/Marine/fishingmethods/setnets.asp
http://www.kcc.org.nz/animals/hectors/gillnets.htm
http://marine-litter.gpa.unep.org/facts/effects-people-economy.htm

12.3 Research into mitigation measures

http://www.seafish.co.uk/publications/reports
http://www.nmfs.noaa.gov
http://www.marlab.ac.uk
http://www.fao.org

Appendices

Appendices to the study:

A study on the consequences of technological innovation in the capture fishing industry and the likely effects upon environmental impacts

Submitted to:

Royal Commission on Environmental Pollution
5-8 The Sanctuary, Westminster, London, SW1P 3JS
Tel: 020 7799 8980
Fax: 020 7799 8971
www.rcep.org.uk

Submitted by:

The Centre for Environment, Fisheries and Aquatic Sciences (CEFAS)
Pakefield Road, Lowestoft, Suffolk, NR33 0HT
Tel: 01502 562244
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Contract lead administrator: Mrs Sue Bramford (CEFAS)
Tel: 01502 524355 email: s.m.bramford@cefas.co.uk

13 Appendices

13.1 Fisheries statistics

Table 4. The global production and utilisation of fish produce

Global production and utilisation of fish produce (million tonnes)	1996	1997	1998	1999	2000	2001
Production						
Capture fisheries	93.5	93.9	87.3	93.2	94.8	91.3
Aquaculture	26.7	28.6	30.5	33.4	35.6	37.5
Total	120.2	122.5	117.8	126.6	130.4	128.8
Utilisation						
Human consumption	88.0	90.8	92.7	94.4	96.7	99.4
Non-food uses	32.2	31.7	25.1	32.2	33.7	29.4

Source: FAO fisheries statistics

Table 5. Fleet tonnages and main engine powers (1998)

Country	Aggregated Gross Tonnage (all fleets)	Aggregated Fleet Main Engine power (all fleets) (kW)
Spain	578 294	1 465 308
UK	252 615	1 026 542
France	179 469	987 586
Holland	146 581	399 891
Portugal	123 156	396 626
Denmark	105 421	396 040
Germany	66 150	155 894
Eire	58 603	179 744
Sweden	49 792	248 007
Finland	24 080	219 438
Belgium	23 099	64 896

Source: Anon. 1998b

Table 6. Main activity of the UK fishing fleet, by segment (at year end 2001)

	Number of vessels	Registered tonnage	Main engine power kw
Pelagic Gears	47	51,753	108,144
Beam Trawl	116	24,352	91,538
Demersal trawls and seine nets	1,158	114,484	353,460
Lines & Nets	146	13,667	38,978
Shellfish: Mobile	229	10,702	51,336
Shellfish: Fixed	301	6,507	43,960
Distant Water	11	15,426	23,393
Under 10m	5,713	20,167	290,839
Total	**7,721**	**257,056**	**1,001,648**

Source: Defra

(See Appendix 13.2 for diagrams of fishing techniques)

Table 7. Trends in the main activity of the UK fishing fleet 1992-2001

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2001 as % of 1992
Pelagic gears	76	69	68	67	58	49	50	46	44	47	62%
Beam trawls	227	240	212	220	215	153	123	114	111	116	51%
Demersal trawlers and seiners	1,860	1,751	1,644	1,549	1,451	1,428	1,318	1,235	1,208	1,158	62%
Lines and nets	339	329	300	267	224	214	187	172	165	146	43%
Shellfish (mobile)	214	181	206	194	265	227	241	243	211	229	107%
Shellfish (fixed)	306	312	305	283	339	352	311	301	297	301	98%
Distant water	16	14	13	12	15	13	14	12	13	11	69%
Under 10m	7,831	8,128	7,607	6,757	6,091	6,022	6,027	5,916	5,769	5,713	73%
Non active / non TAC	692	668	472	371	0	0	0	0	0	0	0%
Total number of vessels	11,561	11,692	10,827	9,720	8,658	8,458	8,271	8,039	7,818	7,721	67%
Total registered tonnage of vessels	217,254	218,961	210,542	211,449	210,505	210,526	213,752	240,583	251,049	257,056	118%
Total power of vessels (kw)	1,262,033	1,271,358	1,197,340	1,136,750	1,052,989	1,026,542	1,006,072	978,644	980,636	1,001,648	79%

Source: Defra

(See appendix 13.2 for diagrams of fishing techniques)

Table 8. Fishing techniques used on vessels from EU Member States (1988)

Country	Fishing technique	Aggregated Fleet Gross Tonnage	Aggregated Fleet Main Engine power (kW)
Belgium	Beam trawlers	21 346	61 141
	Demersal trawlers	1 753	3 755
	TOTAL	23 099	64 896
Denmark	Small scale coastal	8 631	77 856
	Netters	7 258	33 081
	Trawlers and seiners	81 295	269 282
	Purse-seiners and pelagic trawlers	8 237	15 821
	TOTAL	105 421	396 040
Germany	Small scale coastal	4 038	28 227
	Passive gears >12 m	1 800	5 237
	Trawlers	10 439	33 329
	Beam trawlers	1 731	6 303
	Beam trawlers	12 441	50 233
	Trawlers	18 264	11 749
	Trawlers	17 437	20 816
	TOTAL	66 150	155 894
Spain	Artisanal <12 m	23 664	204 568
	Trawlers	137 171	395 319
	Fixed gear	48 720	143 496
	Purse-seiners	51 729	173 503
	Trawl and mobile gear	191 758	334 427
	Fixed gear	49 559	99 953
	Tuna fleet	75 693	114 042
	TOTAL	578 294	1 465 308
France (1.1.97)	Small scale coastal	12 602	170 809
	Trawlers 0-30 m	60 610	393 326
	Trawlers > 30 m	34 364	85 388
	Non trawlers 12-25 m	11 764	67 908
	Non trawlers >25 m	1 249	3 295
	Pelagic trawlers >50 m	5 857	8 580
	Medit. Small scale specialised	4 915	96 877
	Medit. Trawlers	8 412	48 644
	Medit. Seiners	4 974	25 965
	Dakar pole & line	1 744	3 935
	Int. waters seiners	32 978	82 859
	TOTAL	179 469	987 586
Eire	Polyvalent	37 229	135 723
	Pelagic trawl and purse seines	20 244	38 893
	Beam trawl	1 130	5 128
	TOTAL	58 603	179 744
Holland	Small scale coastal		
	Pelagic trawlers	55 523	57 188
	Cutters >221 kW	76 566	297 670
	Eurocutters <= 221 kW	14 492	45 033
	Small vessels		
	TOTAL	146581	399891

Source: Anon. 1998b
(See Appendix 13.2 for diagrams of fishing techniques)

Table 9. Fishing techniques used on vessels from EU Member States (1988) (continued)

Country	Fishing technique	Aggregated Fleet Gross Tonnage	Aggregated Fleet Main Engine power (kW)
Portugal			
(Mainland)	Small scale coastal	10 500	93 985
	Fixed gear >=12 m	21 810	84 717
	Trawl	17 742	51 556
	Seine	7 832	36 848
	Polyvalent trawl and longline	48 185	63 779
(Madeira)	Small scale coastal	565	3 588
	Fixed gear >=12 m	4 516	15 245
	Seine	219	965
	Small scale coastal	2 275	17 662
(Azores)	Fixed gear >=12 m	9 512	28 281
	TOTAL	123 156	396 626
UK	Small scale coastal	19 991	287 554
	Pelagic trawl and purse-seines	41 220	69 757
	Beam trawl	26 323	106 143
	Demersal trawls and seines	115 468	390 150
	Lines and nets	16 282	51 550
	Shellfish fixed	7 305	49 512
	Shellfish mobile	10 197	46 872
	Distant waters (EU)	10 371	16 863
	Distant waters (outside EU)	5 458	8 141
	TOTAL	252 615	1 026 542
Finland	Small scale coastal (pelagic)		
	Small scale coastal (salmon)		
	Trawlers (pelagic)		
	Trawlers (demersal)		
	Passive gear, gillnet and longline		
	TOTAL	24 080	219 438
Sweden	Small scale coastal	7 221	84 213
	Trawlers (shrimp and demersal)	5 020	20 243
	Trawlers, purse-seiners	20 000	66 899
	Bottom trawlers	14 702	61 527
	Passive gear > 12 m (cod)	2 466	13 344
	Passive gear > 12 m (salmon)	383	1 781
	TOTAL	49 792	248 007

Source: Anon. 1998b
(See Appendix 13.2 for diagrams of fishing techniques)

Table 10. Structure of the Norwegian fishing fleet (2002)

Vessel type	Number
Coastal gillnetters	1 173
Offshore gillnetters	4
Total gillnetters	1 177
Coastal longliners	312
Offshore longliners	45
Total longliners	357
Coastal Danish Seine	119
Sandeel trawlers	41
Wetfish trawlers	68
Factory trawlers	16
Total trawlers	125
Coastal purse-seiners	177
Offshore purse-seiners	46
Offshore purse-seiners & pelagic trawl	47
Total pelagic	270
Coastal shrimp trawlers	114
Offshore shrimp trawlers	44
Total shrimp trawlers	158
Total (full time)	2 206
Artisanal fleet (part time)	8 443
Total	10 649

Source: The Norwegian Directorate of Fisheries.

13.2 Fishing techniques

Figure 1. Demersal trawling (single rig)

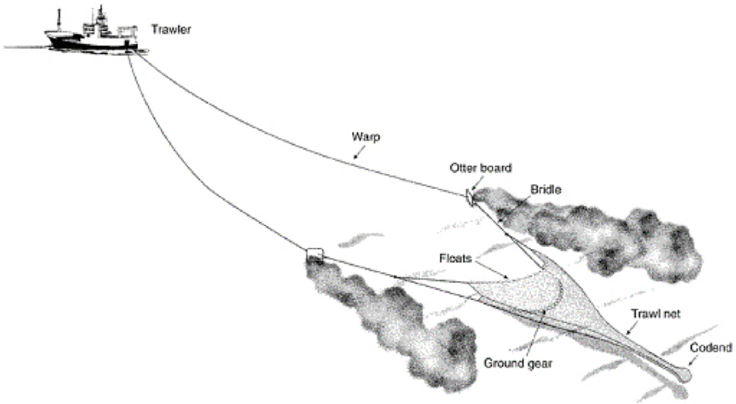


Figure 2. Demersal trawling (twin rig)

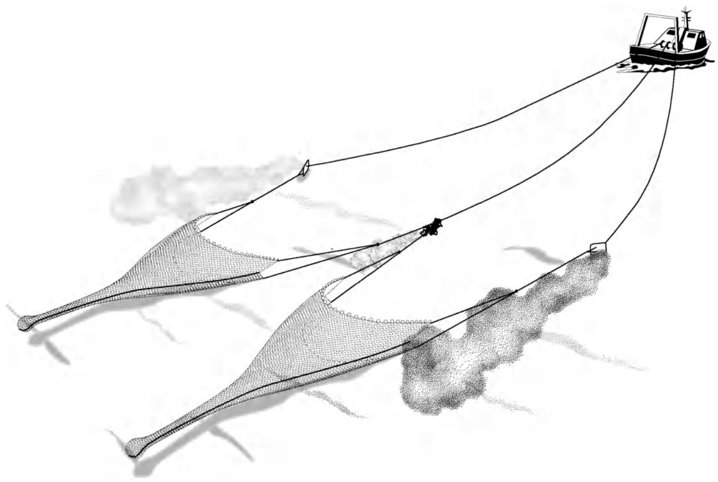


Figure 3. Demersal pair trawling

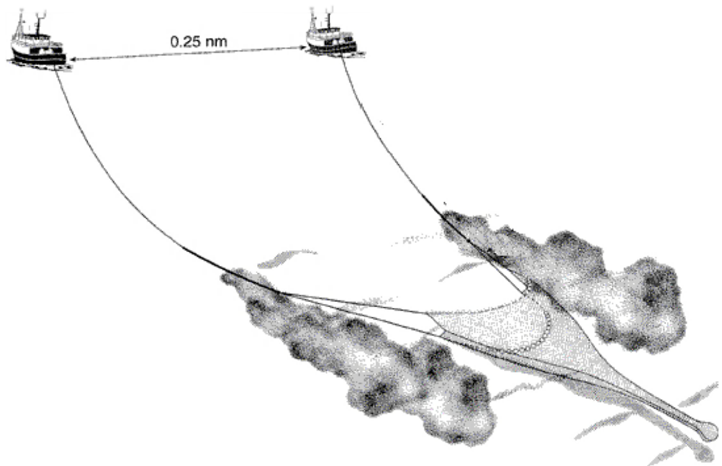


Figure 4. Seine netting (single vessel)

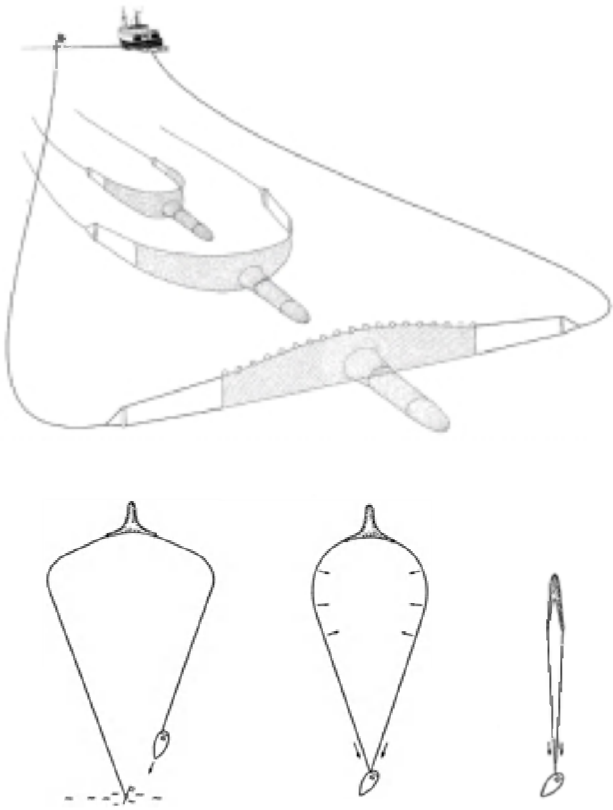


Figure 5. Pair seine netting

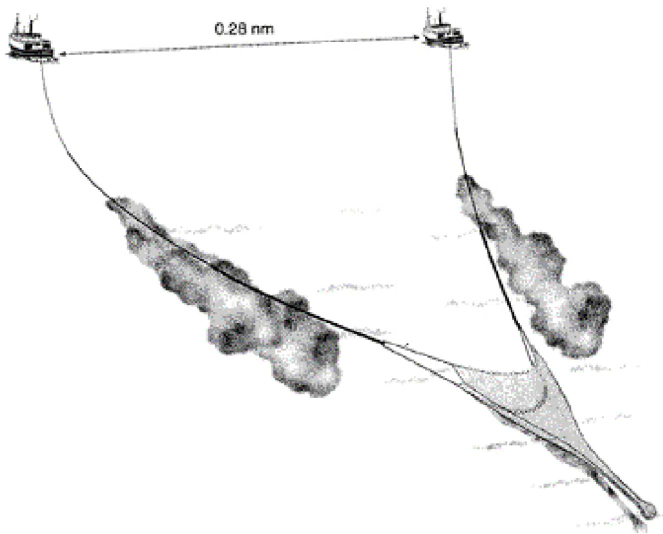


Figure 6. Twin beam trawling

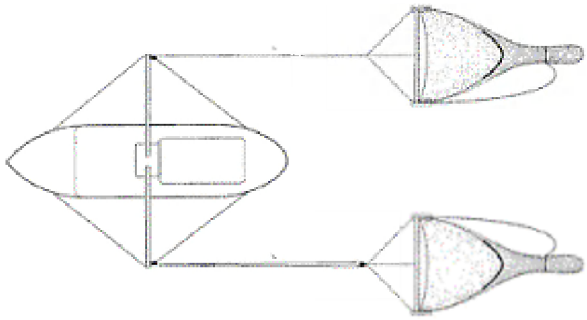


Figure 7. Single beam trawling

Figure 8. Beam trawl with tickler chains (left) chain matrix (right)

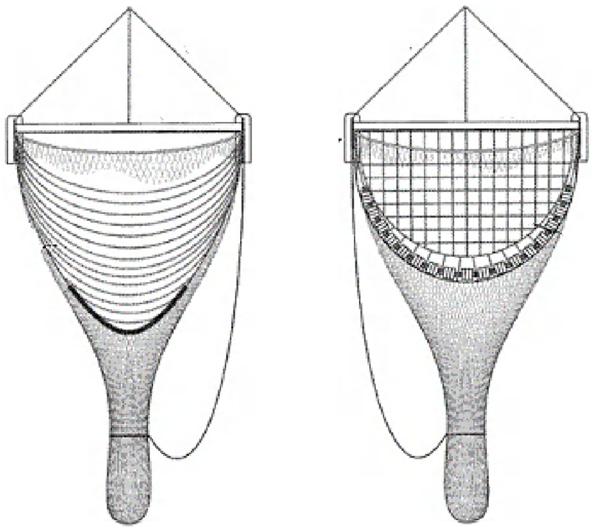


Figure 9. Scallop dredging

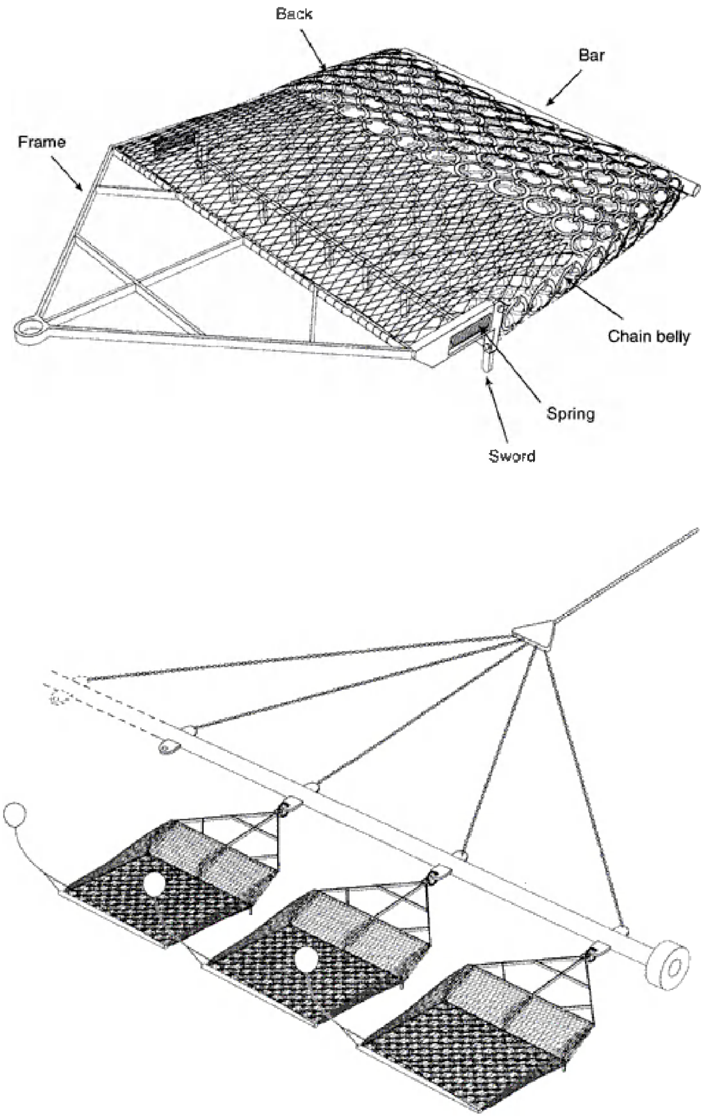


Figure 10. Pelagic trawling (single vessel)

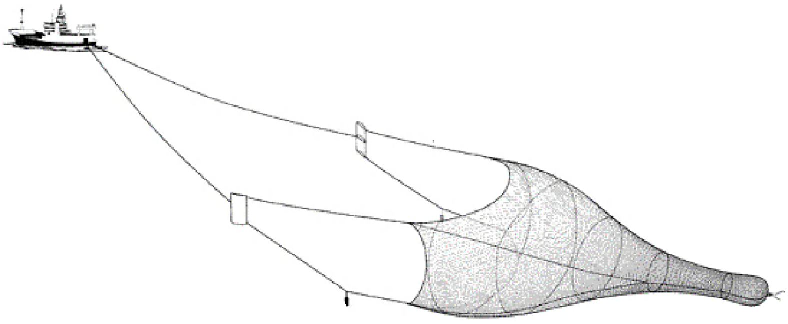


Figure 11. Pelagic pair trawling

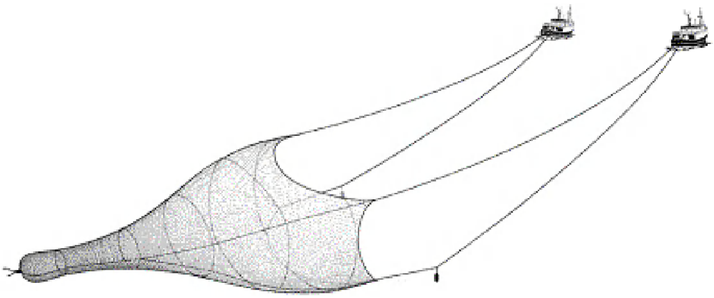


Figure 12. Purse-seining

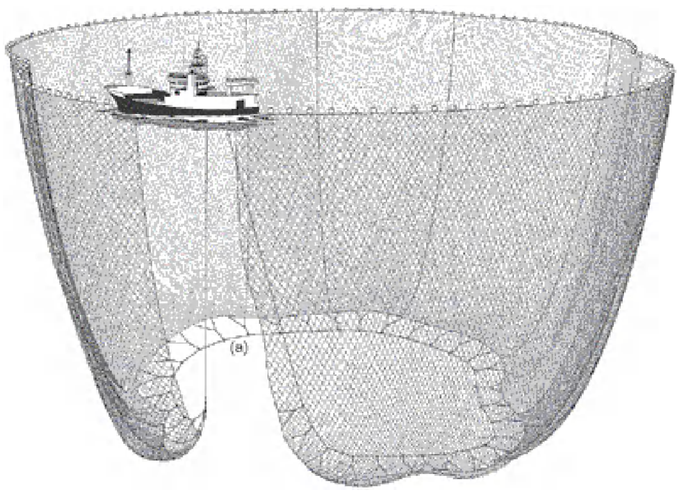


Figure 13. Static gear: pots, traps and creels

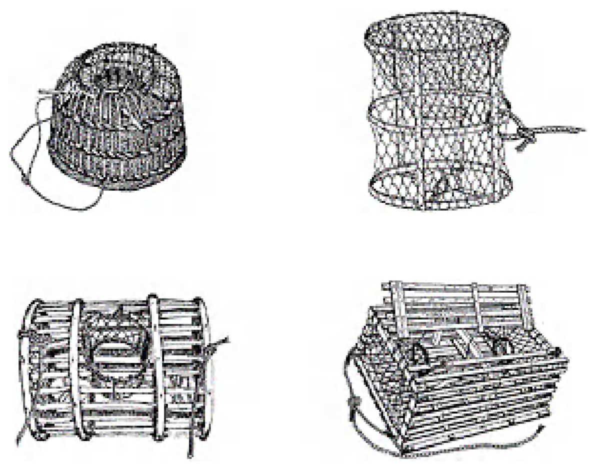
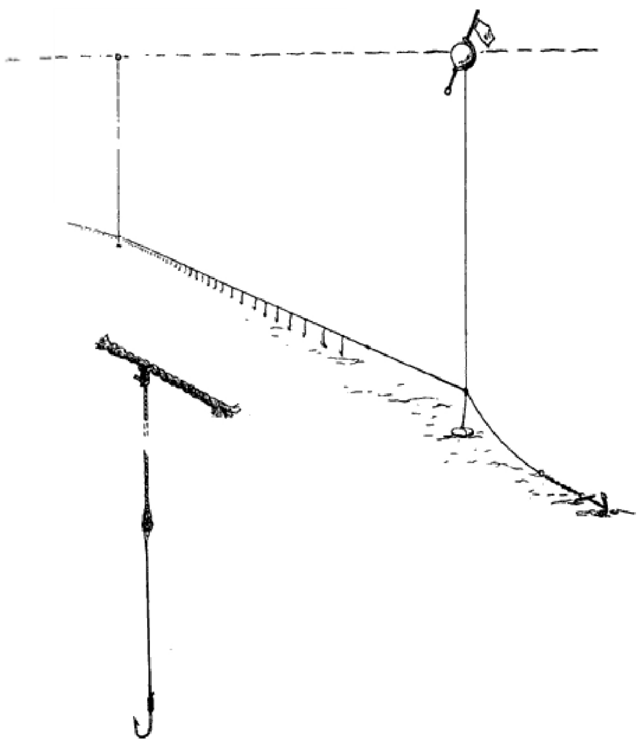
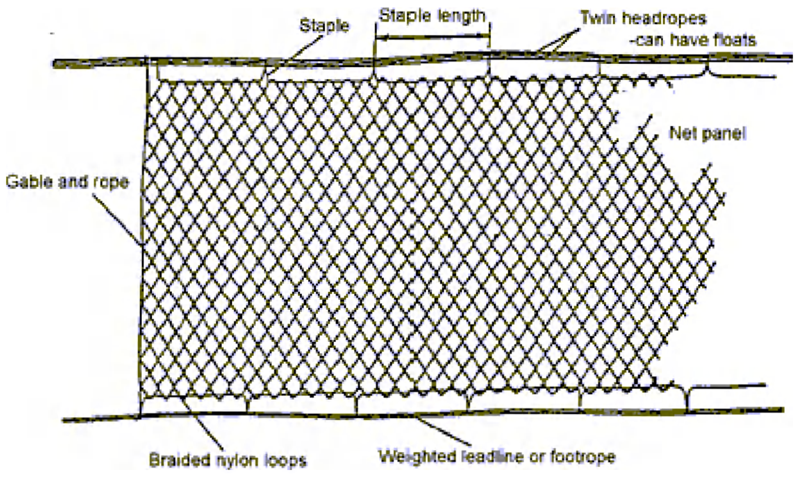


Figure 14. Static gear: Longline fishing



NB: Figure shows bottom set longlines
Longlines may be set to fish midwater or near-surface depending on the target species

Figure 15. Static gear: Gill, tangle, trammel nets



NB: Trammel nets and tangle nets are variants of the gillnet shown above. Gillnets can be set on the seabed or near the surface (drift nets)

Figure 16. Static gear

13.3 The deep-water fisheries of the Northeast Atlantic

13.3.1. Overview

The deep-water fisheries of the Northeast Atlantic are quite diverse in nature. Longline and trawl fisheries presently dominate, ranging from coastal artisanal fisheries to highly mechanised high-seas operations. Some fisheries are directed at single species, but most are mixed fisheries targeting several species. A full description of the deep-water fisheries in the Northeast Atlantic is given in Gordon *et al.* (in press). The major features of the trawl fishery to the west of Britain have been described by Allain (1999), Anon. (1994, 1996, 1998, 2000a, 2002a), Gordon (2001), Gordon and Hunter (1994), Koslow *et al.* (2000), Lorance and Dupouy (2001) and Basson *et al.* (2002).

The longest established deep-water fisheries in the Northeast Atlantic are the handline and longline fisheries off the Azores catching a range of species including red (blackspot) seabream (*Pagellus bogaraveo*) and alfonsino (*Beryx* spp.), off Madeira and Portugal primarily targeting black scabbardfish (*Aphanopus carbo*), and off Iceland, Norway and the Faroe Islands harvesting ling (*Molva molva*) and tusk (*Brosme brosme*). The longline fisheries for ling and tusk have a very long history but are now prosecuted by highly efficient, mechanised vessels fishing over a wide geographical area in the northern parts of the Northeast Atlantic (Bergstad and Hareide, 1996; Magnússon *et al.*, 1997)(see section 13.3.2. .

In contrast, many deep-water trawl fisheries have developed comparatively recently, reflecting a migration of fishing from largely overexploited and highly regulated traditional continental shelf fisheries towards resources that were largely unfished and, until recently, mainly unregulated.

Improved vessel design, gear technology, skipper ability, and marketing have assisted this expansion. Some trawl fisheries target single species and have relatively small by-catches of other species (*e.g.* fisheries for greater argentine (*Argentina silus*) and directed fisheries on spawning aggregations of blue ling (*Molva dypterygia*) and orange roughy (*Hoplostethus atlanticus*). Other trawl fisheries are mixed species fisheries with targeted species changing according to season and fishing depth.

The bottom trawl fishery began in the late 1960s when Soviet and other eastern bloc countries started fishing for roundnose grenadier and alfonsino in international waters to the west of Britain and on the Mid-Atlantic Ridge. In the early 1970s, German trawlers harvested spawning aggregations of blue ling for a few years. By the mid to late 1970s, French trawlers which had traditionally fished along the shelf edge for species such as saithe (*Pollachius virens*), moved into deeper waters to fish for blue ling (Charuau *et al.*, 1995) and gradually replaced the German fleet. In the early years of the deep-sea bottom trawl fishery, by-catches of roundnose grenadier (*Coryphaenoides rupestris*), black scabbardfish, deep-water sharks and many other less abundant species were discarded. It was only in 1989 that these species began to be landed as a result of a marketing initiative by the French industry. Trawlers targeted roundnose grenadier when not fishing for blue ling, and the quantities of other species landed, such as black scabbard fish and deep-water sharks depend on such factors as fishing depth. This fishery continues to the present, although most species now taken are overexploited and most stocks are depleted. Directed fishing for blue ling is now prohibited because stocks are outside safe biological limits (Anon., 2002b).

These multispecies bottom trawl fisheries should not be confused with the French and Irish fisheries for orange roughy. As fishing skippers became increasingly adept at trawling in deep water, they also took note of developments in other deep-water fisheries around the world. The prosperous orange roughy fisheries in the southern hemisphere stimulated the search for this species in the Northeast Atlantic. Spawning aggregations were located in ICES Sub-area VI and a French fishery quickly developed in the early 1990s, taking place at a greater depth (down to about 1 600m) in areas of steep slopes and seamounts. Initial landings were around 3 500 tonnes in 1991. However, these aggregations were quickly fished down and current annual landings are less than 200 tonnes. This is consistent with a 'mining' approach, in that aggregations are located and then fished down on a sequential basis. A similar pattern of exploitation is taking place in ICES Sub-area VII, where both French and Irish trawlers are active.

UK deep-water fishing activity comprises both directed and by-catch fisheries. England and Wales longliners and gillnetters, fishing to the west of Britain and landing mostly to Spain, target hake (*Merluccius merluccius*) and anglerfish (*Lophius* spp.), with deep-water sharks and other deep-water species as by-catch. Depending on market prices, sharks can be targeted. Greater forkbeard (*Phycis blennoides*) and blue ling are taken in trawl fisheries for mixed demersal species including hake, anglerfish and megrim. There is also a net fishery in ICES Sub-area VI for deep-water red crab (*Chaceon affinis*), most of which is landed into ports in Spain. In recent years, Scottish trawlers have fished for mixed deep-water species in the Rockall Trough and Faroe-Shetland Channel, and have also taken a by-catch of deep-water species in fisheries along the shelf edge for anglerfish and megrim (*Lepidorhombus whiffiagonis*) (Anon., 2002a). Vessels move between these fisheries and traditional fisheries on the Rockall Bank and on the continental shelf according to fishing opportunities, fish prices, quota restrictions and weather. Most vessels are modern and, since 1997, have been built to work as twin rig trawlers (Basson *et al*, 2002). Large pelagic trawlers exploit greater argentine west of Scotland, mostly landing to ports abroad.

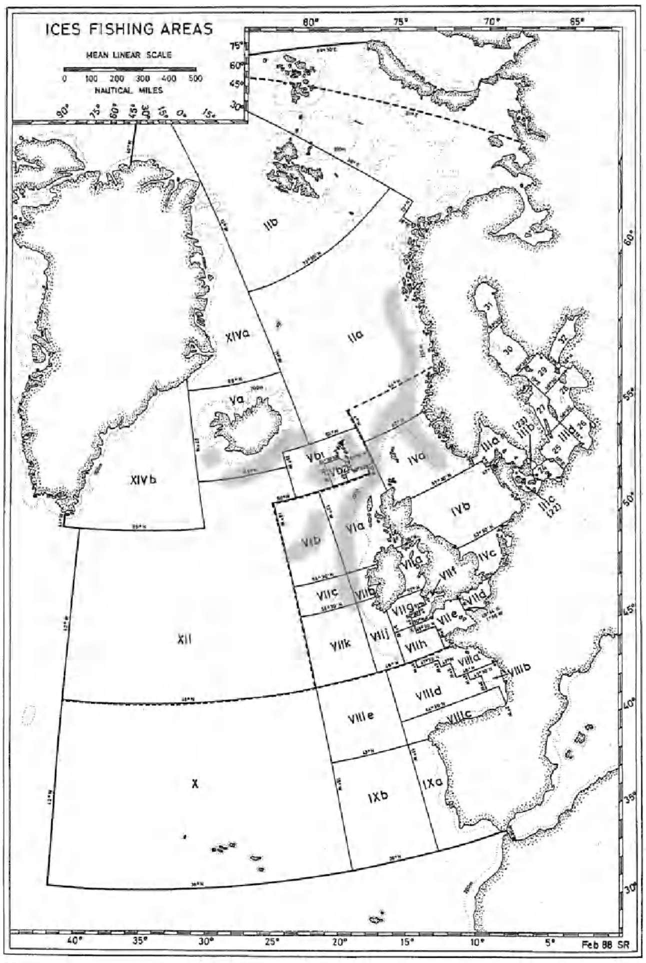
In recent years, deep-water fishing activity in the Northeast Atlantic has continued to increase. Fishing vessels from France, Norway, Spain, Portugal, Russia, Ireland, the United Kingdom, Iceland, Faroe Islands, Denmark, Poland and the Netherlands are now actively involved in deep-water fisheries. Exploratory cruises by commercial fishing vessels continue to identify/locate 'new' resources, particularly in international waters on the Hatton Bank and along the Mid-Atlantic Ridge.

13.3.2. Case Study[34]: The development of the Norwegian deep-water longline fishery for ling (*Molva molva*), tusk (*Brosme brosme*) and blue ling (*Molva dypterygia*)

History

The Norwegian offshore fishery for ling and tusk began in the 16th century in an area of the upper continental slope known as the Storegga off Møre (Strøm, 1762). At that time fishers using open boats 30-60 nautical miles offshore mainly conducted the fishery during summer. Drop-lines as well as longlines were used, at depths between 150 and 400 m. Each trip lasted for 3-5 days and each vessel made 10-12 trips during summer. Total landings of ling varied between 210 and 260 tons of ungutted fish per year. Total landings of tusk and blue ling are not known (Moltu, 1932).

Figure 17. The ICES Fishing Areas and the most important fishing grounds of the Norwegian Deep Sea longline fisheries for ling, tusk and blue ling (shaded areas).



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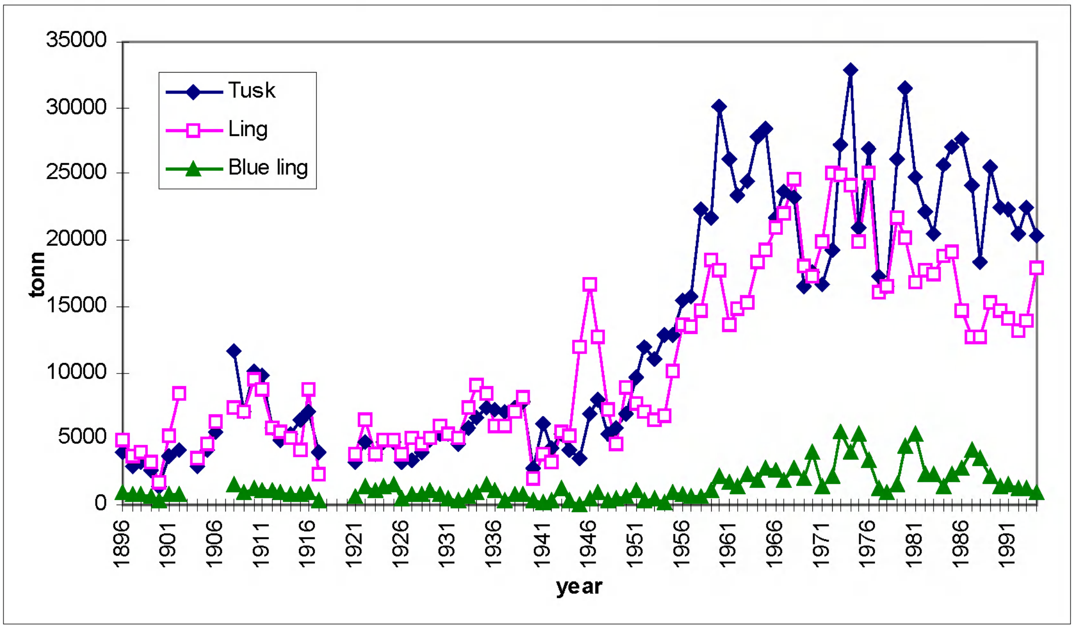
[34] Case study by Nils-Roar Hareide, Hareide Fisheries Consultants, Ulsteinvik, Norway

Figure 18. Total Norwegian catch of ling, tusk and blue ling, 1896-1994



In 1861, Swedish fishermen began a longline fishery in the Storegga, using smacks fitted out for offshore fishing. The fishery was successful and expanded rapidly. In 1862, 13 Swedish and two similar Norwegian vessels were involved in the fishery, and in 1863 about 20 Norwegian smacks were fishing in the area.

Around 1900, steamships became more common and the longline fishery expanded into more remote areas such as Tampen, the Shetlands and the Faeroe Islands. The target species on unexploited banks was often Atlantic halibut (*Hippoglossus hippoglossus*), but the catch rates of this species often declined rapidly, and ling and tusk became the target species. The landings of ling, tusk and blue ling increased as a result of the introduction of steam-powered vessels (Figure 18).

During these early stages of the fishery all the work was done manually and the lines were set and hauled from dories. Further expansion of the fishery to even more remote areas was limited by the inability to preserve fresh bait for more than two weeks and by the First World War. After the war, larger vessels made it possible to land bigger catches, but the duration of the trips was limited to about two weeks because of the problems with storing bait. There was a decline in the fishery in the early 1920s as a result of the economic crisis. However, during the 1920s a special group of 50-60 foot motor vessels specialised on a fishery for ling and tusk, with Atlantic halibut as an important by-catch. This fishery remained almost unchanged for the next 50 years.

The fishery in remote areas and on the Norwegian slope was interrupted by World War II. High catch rates and good prices after the war led to a new expansion of the fleet, with vessels in the 60-90 foot range. The geographical range of the fishery also expanded to include the banks to the west of Ireland and around Rockall.

During the 1950s the total landings increased from about 10 000 tons in 1950 to about 40 000 tons by 1960. This increase was partly a result of technical improvements (described later). However, one of the main reasons was the reduction in the stocks of cod during the 1950s, as considerable effort was transferred from cod fishing to fishing for ling, tusk and blue ling; since that time there has been interplay between the two fisheries. A reduction in cod landings generally coincided with an increase in landings of ling and tusk and *vice versa*.

In the 1960s a few new vessels were built, mainly constructed of steel and of length greater than 100 foot. In the late 1970s, however, 15 new 100-120 foot vessels were built, some equipped with the autoline system. This expansion ended in the early 1980s when the stock of Atlantic cod was declining, and at the same time there was a drop in prices of ling and tusk. During that decade, most longliners installed the autoline system, primarily to compensate for the reduced catch rates in the ling and tusk fishery.

The prices of ling and tusk increased again, and peaked historically in 1986. At the same time the strong 1983 year class of Northeast Arctic cod led to expectations of higher cod quotas and to a longliner building boom. Fifteen new vessels were built in the years 1984-1986, all 115-150 feet long with a fish carrying capacity of 150-250 tonnes. They were all equipped with the autoline system and the catch could be frozen onboard, which resulted in the duration of the trips increasing to 6 weeks. In 1989 there was a reduction in the cod quotas and the longline fishery became far less profitable. Then, in the period 1988-1994 the fleet was reduced from 65 to 52 vessels (23%). During the 1980s cod became a more important target species and the effort on the species was equal to or surpassed (in 1988) the ling and tusk effort. In 1994, 52 vessels of length >80 feet were engaged in this fishery for approximately six months of the year along the continental shelf off Norway, the Shetlands, the Hebrides, Ireland, the Faeroes, and on the Rockall Bank (Figure 17).

Figure 19. The effort of Norwegian longliners and gillnetters by gear, fishing area (ICES area in parenthesis) and target species

YEAR		1974	1976	1978	1980	1982	1984	1986	1988	1990	1992	1994	1995
Number of vessels:		103	95	93	83	74	72	72	65	60	53	52	56
Total number of weeks: (Longline+Gillnet)		4049	3812	3747	3428	3144	3185	3067	2875	2722	2448	2366	
Longline effort (thousands of hooks)		238095	235294	381356	326667	292857	445313	357143	406667	438462	424528	531915	572831
GEAR:	Autoline				1%	58%	71%	81%	94%	93%	95%	93%	
	Handbaited line	86%	83%	84%	88%	32%	21%	14%	1%	4%	2%	4%	
	Gilnet	12%	14%	14%	11%	10%	8%	5%	5%	3%	3%		
PERCENT EFFORT BY FISHING AREAS:													
	Shetland/Orkney/Faroes/Hebrides/Rockall	61%	64%	53%	62%	61%	48%	56%	47%	55%	39%	40%	
	Norwegian coastal banks 62°-69° N (IIA)	18%	24%	22%	13%	5%	6%	7%	?	8%	11%	4%	
	Skagerrak/North Sea (IIIa+IVa)	15%	8%	11%	12%	9%	15%	4%	?	6%	11%	5%	
	Barents sea and Northern Norway (IIa)				5%	11%	9%	24%	41%	13%	27%	38%	
	Greenland (XIVb)										4%	4%	
PERCENT EFFORT BY TARGET SPECIES:													
	Ling & Tusk	63%	68%	59%	75%	70%	64%	63%	45%	65%	53%	47%	
	Cod & Haddock	6%		18%	10%	19%	28%	31%	49%	30%	44%	47%	
	Saithe	11%	11%	8%	10%	10%	6%	3%	3%	3%			
	Dogfish	16%	13%	14%	3%						2%		
	Greenland Halibut											3%	
		1500	1600	2250	2450	2050	2850	2250	1830	2850	2250	2500	
	total effort	238095.2	235294.1	381355.9	326666.7	292857.1	445312.5	357142.9	406666.7	438461.5	424528.3	531914.9	

(Source: The Norwegian Directorate of Fisheries).

Gear handling

Before 1903, when the first manually operated longline winch was introduced, all handling of longlines was done by hand. Soon the winches were powered by steam. The first hydraulic winch, introduced in 1938, was an important stage in the development of present longline technology. The hydraulic winches were precise and powerful and were operated by the man removing the fish from the lines. The development of an automatic coiler by the end of the 1950s was the next stage in the development and, by the early 1960s, they had become common on all vessels in the Norwegian fleet.

The longlines were baited and set by hand until about 1930. Various improvements followed that made it possible to set and haul far more lines a day. An automatic system for taking the fish off the hooks was developed in the late 1960s and became common on most vessels in the early 1970s. This made it possible to haul the line continuously, because there was no need to stop hauling to take off fish. The first system for precise automatic baiting (the Mustad Autoline system) was introduced in 1971. The breakthrough for this system came in 1976/77. By 1980 about two-thirds of the fleet had adopted the autoline system. The main benefit was that fewer men were required for hauling and baiting the lines, and fishing could go on day and night. The effort per day increased substantially. The system required a reduced distance between hooks, so the number of hooks increased by 30-35 %. However, the baiting was not as good as that done by hand, and about 20% of the hooks were not baited.

Hooks

The shape of longline hooks remained almost unchanged for several hundred years. The traditional J-shaped hook was the most common, but in the mid 1970s new types of hooks began to be developed. The first step was to twist the sharp end of the hooks. In 1987 a new type, Mustad EZ, was developed by O. Mustad & Son and the then Institute of Fishery Technology Research in Bergen (now incorporated in IMR as the Gear Technology Section). This hook gave a significant increase in catch rates, which for ling and tusk was 15-25% (Bjordal, 1987). The new hook totally replaced the traditional J-shaped hook during the period 1987-1990. Improvements in the quality of the hooks such that they required less sharpening or replacing also led to increased catching efficiency. In 1995 the Mustad Autoline System was modified to handle circular hooks that are expected to be about 20% more efficient than the EZ hook. From 1996 onwards, many vessels started using circular hooks, once again resulting in a marked increase in efficiency.

Main line

Since the early 1970s, 7-mm polyester lines have replaced the older hemp lines. These polyester lines are far stronger and have a greater resistance to wear, making it possible to increase the hauling speed and to haul in difficult weather. In 1987 the "swivel line" was introduced. This line type has a swivel connection between main line and gangion.[35] This line gave a 10-20% increase in catch rates (Bjordal, 1987, 1988). Presumably the main reason for this was that fewer fish are lost during retrieval of the gear because the swivel prevents twisting and tangling of the gangions. Another benefit of the swivel line was that the hauling speed is increased. Bjordal (1988) found an increase of 7% in the amount of line that could be hauled per day compared with traditional longlines. Swivel lines were introduced to the whole fleet during the period 1988-1990 and are now used by all Norwegian deep-sea longliners. In 1993, 9-mm polyester line was introduced because of the demand for stronger lines for fishing in deeper water. During 1994 and 1995, 11.5-mm longlines for fishing even deeper were introduced (e.g. for Patagonian toothfish (*Dissostichus eleginoides*) off Argentina).

Bait

Herring was the most common bait until about 1970, but when the herring stocks in the North Atlantic declined, mackerel replaced it. In the early 1970s squid was introduced in the longline fishery for ling and tusk. It became common to use about 70% mackerel and 30% squid. In 1981, 50% of the total weight of bait used was squid. Bjordal (1983) found that squid gave significantly better catch rates than mackerel. The increase was 6 and 9% for tusk

[35] Short line connecting main line to hook

and ling respectively. This resulted in a slight change in the species selectivity of the gear, but no change in size selectivity. Løkkeborg *et al*. (1983) found that the force required to tear squid off a hook was three times higher than that for mackerel, which resulted in less bait loss. Artificial bait is being developed and was introduced on the market in 1996. The main advantage of this bait is its low price compared with traditional baits. Lower bait costs will reduce the total costs of fishing operations and may lead to greater fishing pressure on otherwise unprofitable grounds (i.e. lower fish densities).

Summary

The longline technology was modernised steadily from the 1880s to the 1930s, but was almost unchanged from the 1930s to the end of the 1960s. In the two following decades there were some major developments in technology that improved the catch rates by 1) increasing the numbers of lines hauled during a given period of time and 2) by enhancing the efficiency of the gear by introducing new types of hooks, baits and lines. The most important step was the introduction of the autoline system at the end of the 1970s. During the period 1974-1994 the number of vessels was reduced by 50% but the total capacity doubled. This meant that an average longline vessel had four times higher capacity in 1994 than in 1974.

Figure 20. Number of vessels and total capacity (number of hooks (adjusted for hook efficiency) for the Norwegian longline fleet 1974-1994

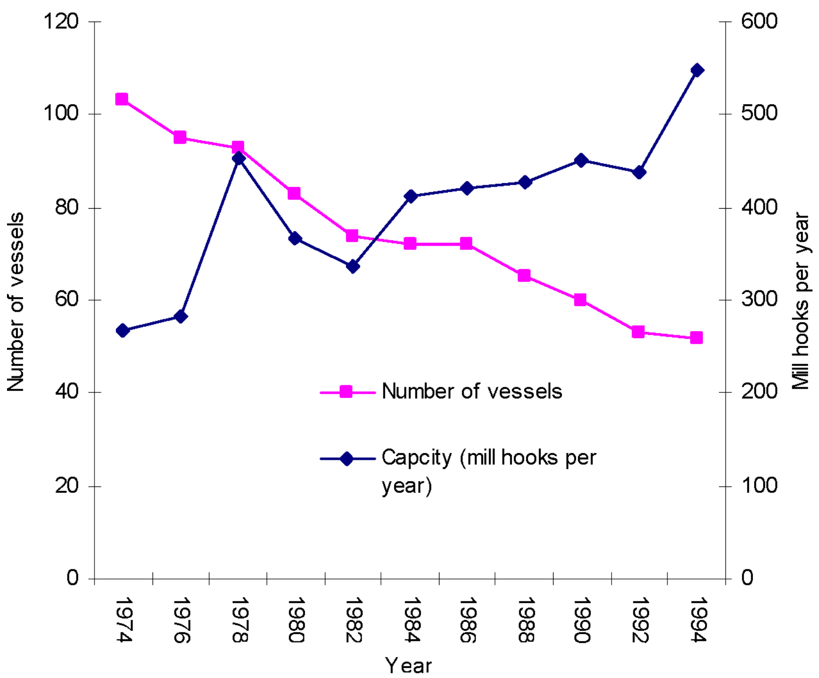
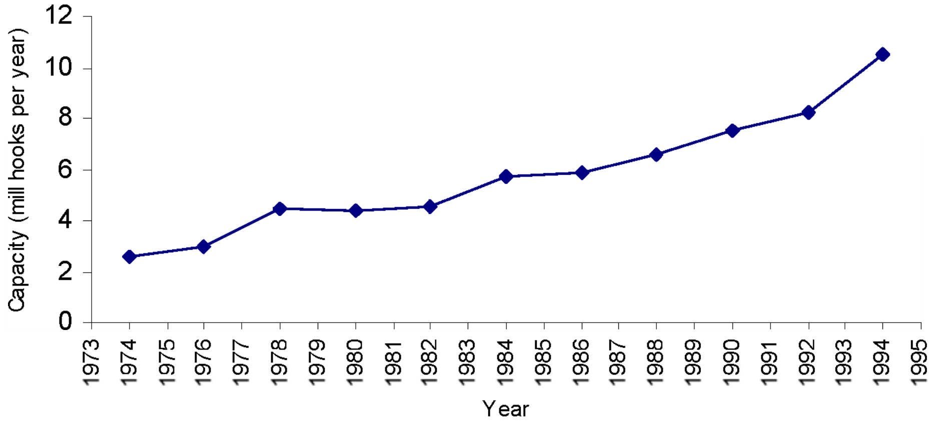


Figure 21. *Average capacity, mill hooks (adjusted for hook efficiency) per year per longline vessel 1974-1994*



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Moltu, P. (1932). Fiskarsoga frå Sunnmøre og Romsdal. Sunnmørspostens bok - og aksidenstrykkeri, Ålesund 280p.

Strøm, H. (1762). Beskrivelse over fogderiet Søndmør, beliggende i Bergens stift i Norge. Facsimilia topographia Vol V. 570 p.

13.3.3. Case Study[36]: Development of Irish Deep-water Fisheries

Deep-water fishing trials for non-quota and under-utilised species commenced in Ireland in 1998 assisted by the European Commission's exploratory fishing voyage scheme[37]. Prior to 1999 Irish landings of deep-water non-quota species were limited owing to a lack of suitable whitefish vessels in the fleet. Any fishing effort during this period was confined to technical trials and biological cruises, which began in 1992 and continued sporadically until 1999. Biological cruises were also carried out for the Marine Institute of Ireland by two Norwegian longliners in 1997 and 1999, which also serves to highlight the lack of suitable vessels at the time.

Under the Irish Government's Whitefish Renewal Scheme[38], a number of vessels entered the fleet during 2000 and 2001. This programme was the most significant targeted investment in upgrading and modernising in the history of the Irish State, and was brought to fruition despite the backdrop of wholesale cuts being proposed by the EU under MAGP IV[39]. A total of 44 new and modern second-hand vessels was introduced into the fleet, replacing old and inefficient units, although the introduction of these vessels did not in anyway increase the overall tonnage and horsepower of the Irish fleet in excess of EU levels. It was considered vital to upgrade the Irish whitefish fleet to enhance competitiveness, safety and operational efficiency, because the average age of the Irish fleet prior to the Scheme was in excess of 30 years. In addition redirecting effort onto new, more challenging, fishing opportunities and more selective fishing technologies including the development of deep-water fisheries, were also largely behind the rationale of the programme.

During 2001, a total of 15 vessels participated in the fisheries, 13 trawlers and 2 longliners, of which eight were involved directly in technical trials and a scientific data collection programme instigated by BIM and the Marine Institute[40]. Irish boats targeting deep-water species in 2001 concentrated their efforts in four distinct areas of the continental slope off the continental shelf of Ireland and the UK. Vessels worked waters down to 1 294 m deep off the north, west and southwest of Ireland using bottom trawls, where catches were dominated by siki shark, black scabbard fish and roundnose grenadier. A few of the larger boats targeted

[36] Case study by Dominic Rihan. (Fishing gear technologist). Bord Iascaigh Mhara (BIM) Dublin, Eire
[37] Anon, 1988. "Exploratory Fishing Voyages for Non-quota Species by the "Atlantic Challenge" and Western Endeavour". Final Report EXP/IRL/1/88 for the European Commission.
[38] Bord Iascaigh Mhara, 1998. Fishing Fleet Development Measure. "Towards Competitiveness, Safety and Operational Efficiency in the Whitefish Fleet".
[39] 98/125/EC: Commission Decision of 16 December 1997 approving the multiannual guidance programme for the fishing fleet of Ireland for the period from 1 January 1997 to 31 December 2001. Official Journal No. L039, 12/02/1998 P.0041-0046.
[40] Anon., 2001. Executive Report of BIM Deepwater Programme 2001. BIM Report 25 pp.

aggregations of orange roughy on seamounts west and northwest of the Irish coast. Following a period of familiarisation with the area and the fishing techniques required, these boats proved successful and accounted for most of the orange roughy catch landed during 2001. A small number of boats worked colder waters 500-600 m deep along the edge of the continental shelf north of Scotland. All Greenland halibut and redfish catches are derived from these vessels, with the majority of the landings being made into the Scottish port of Scrabster.

Landings[41] of 7 000 tonnes valued at €15m were achieved in 2001, giving a return on the investment by the State (around €2 million) in developing the fisheries on the order of 750%. In 2002 landings of deep-water species remained stable at approximately 6 500 tonnes valued at around €12m with nine vessels involved, eight trawlers and a longliner.

All vessels entering the deep-water fishery were required to carry both scientific and technical observers on all trips, and observer coverage of more than 80% on vessels participating in the fishery was achieved. This approach was based on the need to collect data in order to satisfy the general principles of the United Nations Convention on the Law of the Sea relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish and the complementary FAO Code of Conduct for Responsible Fisheries. These agreements stress the crucial need to undertake research and data collection in order to improve scientific and technical knowledge of fisheries, in support of fishery conservation and management. The implementation of a system of data collection in conjunction with an increase in fishing effort on deep-water species was in accordance with the advice from ICES that fishing should not be allowed to expand faster than the acquisition of the information necessary to provide a basis for sustainable exploitation.

Despite this approach, a major stumbling block to further development of deep-water fisheries in Ireland came with the introduction by the EU of TACs and quotas for selected deepwater species during 2002[42]. The new regulations followed two years of extensive negotiation between Member States, although the outcome heavily favoured France. Under EU regulation 2347/2002, Ireland received a total of 2 372 tonnes or 4.7% of the total allocations of deep-water species, with France in comparison receiving more than 16 000 tonnes (32%), and for some species more than 98% of the total TAC. Reliance on TACs for the conservation of these species is contrary to the Commission`s previous position and is not supported by the

[41] Department of the Marine and Natural Resources – Official Landing Statistics for 2001.
[42] Council Regulation (EC) No 2347/2002. of 16 December 2002 fixing for 2003 and 2004 the fishing opportunities for deep-sea stocks. Official Journal No. L356/1 31.12.2002.

poor experiences that other countries have hadwith deep-sea species, for example orange roughy in New Zealand, roundnose grenadier in Canada and argentine in Noway. With quotas for traditional species being drastically reduced and further restrictions on fishing opportunities forced upon the Irish fleet, these restrictions have made the situation for offshore vessels to remain viable even more difficult. What is more, the EU in setting the TACs and quotas have seemingly disregarded scientific advice by ICES, STECF and NEAFC, who pointed out on a number occasions that "*TACs are not likely to be an effective tool for deep-water stocks*[43]".

In order to try and ease the impact of these restrictions, BIM have started a programme aimed at identifying a variety of other species with commercial potential. It is widely acknowledged that the level of discarding in deep-water fisheries is very high, with levels in excess of 45% regularly recorded during the 2001 observer programme trials. The main reasons for this are a lack of knowledge of potential markets and a lack of knowledge on how to handle and process many species correctly. Certain inroads have recently been made to improve the utilisation of some of these species, including cardinal fish (*Epigonus telescopus)* and birdbeak dogfish (*Deania claceus).* Since 2002, BIM have been collaborating with the National Food Centre of Ireland on a project aimed at promoting the marketability of a variety of under-utilised species through various product-enhancement trials. A variety of processing, packaging and cooking techniques have been tested on these species, and results are promising.

In addition a BIM report entitled "European Markets for Deep-water Species"[44] concluded that there is real market potential in this fishery because many of the species offer a viable alternative to diminished traditional whitefish stocks. It was also noted that increased onboard processing, size grading and quality handling would further broaden the market base for Irish-caught deep-water species. Other countries, particularly in the southern hemisphere, e.g. Australia and New Zealand, are much more evolved in terms of utilising a larger volume of their total catch and also utilising a higher proportion of their by-products. This is another area that will be looked at during 2003, particularly by-products from deep-water shark species and rabbitfish (*Chimera monstrosa*), including unsaturated hydrocarbons and diaclgycerol ethers and indeed valuable wax esters from species such as orange roughy. This is a particularly important area, because a lack of knowledge and handling and processing systems will limit adding value to products before they are exported and also limit the

[43] Marine Institute. 2000. The Stock Book. Report to the Minister for the Marine and Natural Resources. Annual Review of Fish Stocks in 2000 and Management Advice for 2001. MFSD. November 2001,pages 273-298.
[44] O'Sullivan G. 2001. European Markets for Deep-water Species. A report prepared on behalf of An Bord Iascaigh Mhara. November 2001. 38 pp.

consumption of species in home markets. Given the high value of by-products from deep-water species it is vitally important that methods of collection, handling, storage and processing/extraction are obtained.

In summary, the development of deep-water fisheries for Irish vessels is an example of how new opportunities can be created for new or under-utilised species and can assist in diversifying effort from traditional fish species. Had the Irish fleet not been upgraded, then it is doubtful whether, in its then existing state, it would have been able to face the challenges of diversification and sustainability within an increasingly globalised industry. The further development of deep-water fisheries has at this stage been somewhat curtailed by EU policy, but in this case through improved utilisation of species and identification of by-products, at the very least, the current number of vessels will be able to continue to be economically viable within the available opportunities.

13.4 The capture of marketable/legal-sized target species

A significant environmental impact of capture fishing relates to its core activity and purpose, namely the removal of target fish from the aquatic environment. In northern Europe, fishers deliberately target large and mature adult fish[45], which is the exploitation pattern recommended by stock managers and scientists. This exploitation pattern of fish stocks is likely to be sustainable in cases where sufficient numbers of adult fish have the opportunity to mate and spawn, where the recruitment of new cohorts to the stocks is strong and regular and where the removal of fish (both in numbers removed and age of fish removed) is kept at the desired level. A fish stock becomes depleted, overexploited or may even collapse economically if such factors do not successfully transpire on a regular basis.

The FAO[46] estimated in 2002 that around one-quarter (28%) of global fish resources are overexploited, depleted or recovering from depletion. In all, 18% of stocks are overexploited and further stock decline is probable unless remedial management action is taken to reduce patterns of overexploitation. Some 47% of the fish stocks globally are fully exploited and producing catches approximating to their maximum sustainable limits.

The Advisory Council of Fisheries Management of ICES[47] also reports that many European stocks in 2002 are overexploited and that their spawning stock biomasses are below safe biological limits (Anon., 2002d). In many of these cases fishing mortality is in excess of desirable limits.

[45] Unwanted small juveniles are also caught and removed - see Appendix 13.5
[46] Food and Agriculture Organisationof the United Nations, Rome, Italy.
[47] International Council for the Exploration of the Seas, Copenhagen, Denmark.

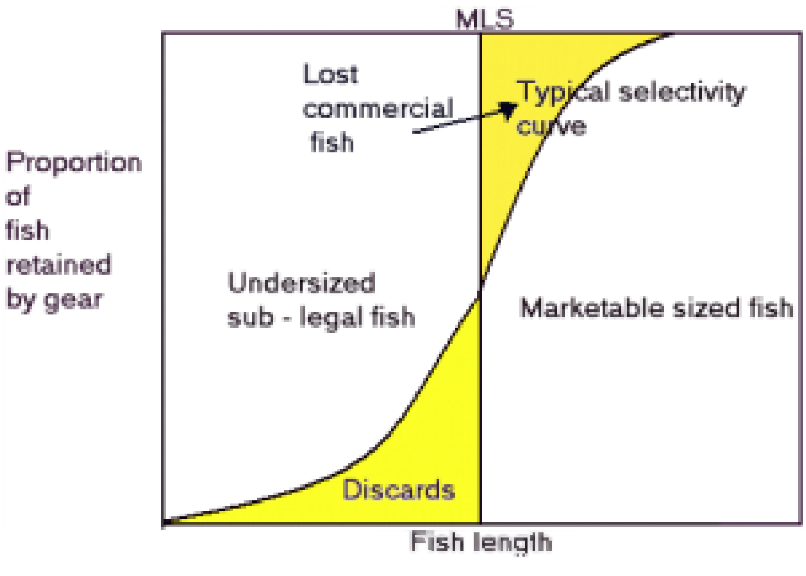
13.5 The capture of non-marketable/sub-legal sized target species

Small, unwanted sub-legal specimens of target fish species are frequently caught in numbers when non-selective fishing methods are used. Mobile fishing gears are generally the most non-selective and are used most commonly in northern Europe and throughout the world (Figure 22).

The setting of minimum landing sizes (MLS) is a common tool used by fisheries managers in northern Europe to define the length of fish that is sub-legal and cannot be landed or sold. The setting of a MLS is usually a management compromise between minimising discard levels and minimising the losses of marketable sized mature fish for the fishers (Figure 22).

In fisheries with falling profitability (i.e. overexploited with declining stocks), some fishers may use fishing gears or adulterate their gears in order to shift the selection curve to the left in order to reduce the losses of commercial fish (upper shaded section). The use of such gears allows the fisher to catch more target-sized fish, but results in a parallel increase in capture rates of unwanted undersized sub-legal sized fish.

Figure 22. The selective properties of a typical mobile fishing gear



13.6 The incidental capture of non-target species

Fishing gears are rarely totally selective towards the target species alone and the incidental capture of a wide range of non-target species is an almost universal manifestation in every fishery throughout the world. The level of incidental catch is highly variable both temporally and spatially, and catch rates differ massively between fisheries, both in the quantities and the range of species caught.

13.6.1. The incidental capture of fish

Alverson *et al.* (1994) comprehensively reviewed global patterns of incidental and unwanted fish in capture fishing in 1994. The work estimated that between 18 and 40 million tonnes of fish are discarded[48] globally each year, although this has been subsequently revised to around 20 million tonnes (Anon., 1999). This level is equivalent in weight to 25% of the global fish catch.

Shrimp trawling appears to generate a large proportion of the world's fish discards (33%), while discarding in the northwest Pacific, northeast Atlantic and west-central Pacific regions account for some 50% of fish discards globally. A recent summary of the magnitude and impact of incidental catches of species in fishing gears was given by Cook (2001), and this is itself summarised in Figure 23 - Figure 26.

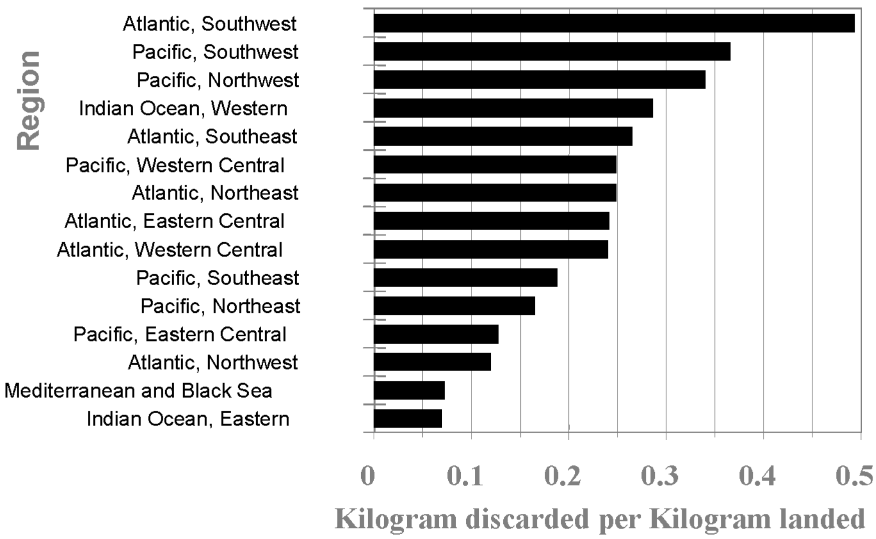
Figure 23. Percentage of global discard by regions (by weight)

Northwest Pacific	(33.81%)
Northeast Atlantic	(13.59%)
West Central Pacific	(10.28%)
Southeast Pacific	(9.63%)
West Central Atlantic	(5.93%)
West Indian Ocean	(5.45%)
Northeast Pacific	(3.42%)
Southwest Atlantic	(2.97%)
East Indian Ocean	(2.97%)
East Central Pacific	(2.84%)
Northwest Atlantic	(2.54%)
East Central Atlantic	(2.20%)
Mediterranean and Black Sea	(2.09%)
Southwest Pacific	(1.09%)
Southeast Atlantic	(1.03%)
Atlantic Antarctic	(0.13%)
Indian Ocean Antarctic	(0.04%)
Pacific Antarctic	(0.00%)

Source: Alverson *et al.* (1994)

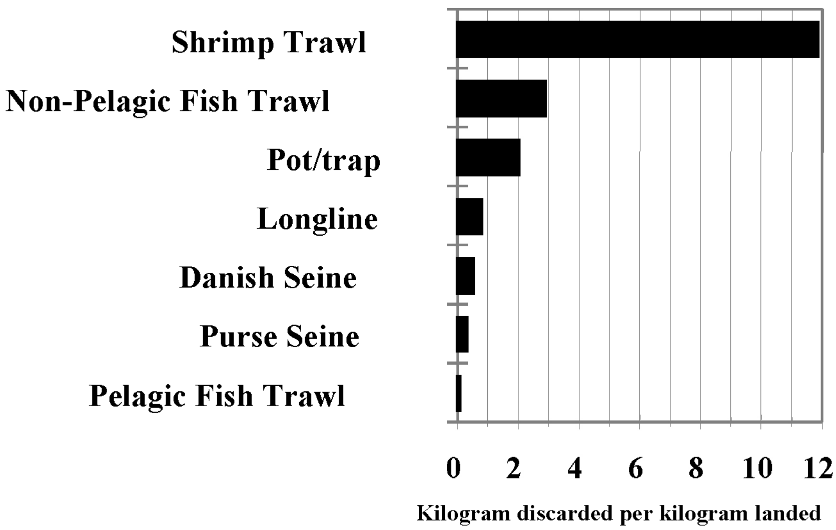
[48] Thrown back overboard at sea

Figure 24. Discard rate by region



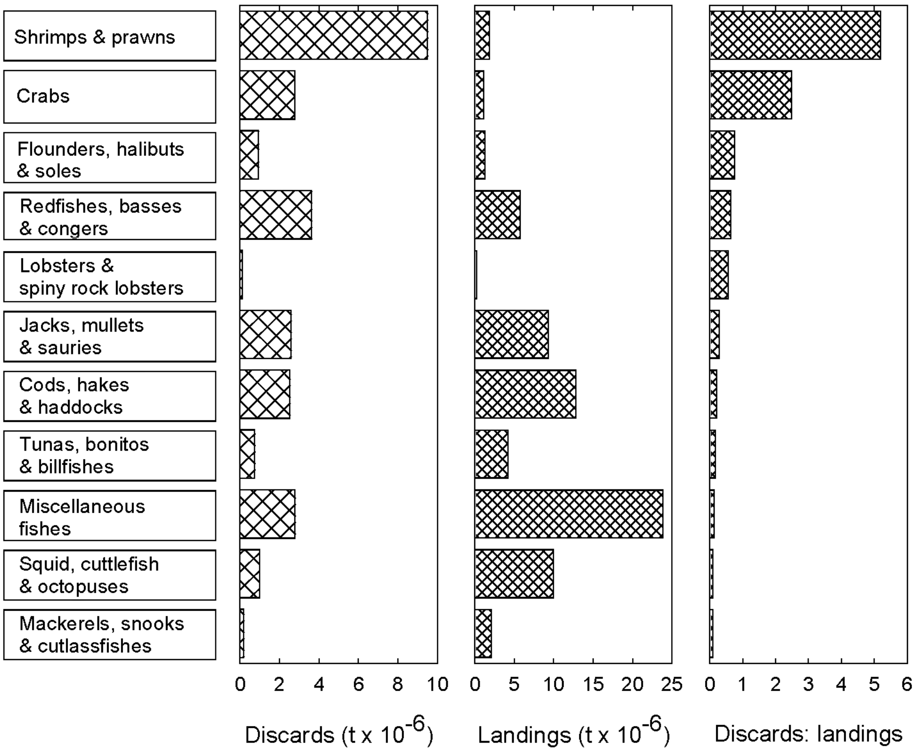
Adapted from Cook (2001) and Alverson *et al.* (1994)

Figure 25. Discard rate per fishing technique



Adapted from Cook (2001) and Alverson *et al.* (1994)

Figure 26. Discard rate per target species



Source data: Alverson *et al.* (1994)

13.6.2. The incidental capture of invertebrates

A diverse range of benthic-dwelling invertebrates is caught by demersal trawl fisheries. An example of invertebrate species caught in the Brixham beam trawl fisheries is given in Table 11. The numbers caught and discarded can be high because they rarely hold any commercial value.

Table 11. Invertebrate species caught by a Brixham beam trawler in 2002

Crustacea	European lobster	*Homarus gammarus*
	Common hermit crab	*Pagurus bernhardus*
	Hermit crab	*Pagurus prideaux*
	Hermit crab (indet.)	Pagurid in *Suberites*
	Pennants nut crab	*Ebalia tuberosa*
	Scorpion spider crab	*Inachus dorsettensis*
	Slender swimming crab	*Macropodia tenuirostris*
	Spider crab	Majidae (indet.)
	Masked crab	*Corystes cassivelaunus*
	Circular crab	*Atelycyclus rotundatus*
	Edible crab	*Cancer pagurus*
	Swimming crab	*Liocarcinus depurator*
	Flying crab	*Liocarcinus holsatus*
	Marbled swimming crab	*Liocarcinus marmoreus*
	Velvet swimming crab	*Necora puber*
Mollusca	Spotted necklace shell	*Polinices catenus*
	Common whelk	*Buccinum undatum*
	Opisthobranch	*Scaphander lignarius*
	Queen scallop	*Aequipecten opercularis*
	Striped venus shell	*Chamelea gallina*
	Cuttlefish	*Sepia elegans*
	Squid	*Alloteuthis subulata*
	Squid	Loliginidae (indet.)
	Octopus	*Eledone cirrhosa*
Echinodermata	Sand star	*Astropecten irregularis*
	Starfish	*Luidia ciliaris*
	Goosefoot starfish	*Anseropoda placenta*
	Common starfish	*Asterias rubens*
	Spiny starfish	*Marthasterias glacialis*
	Brittlestar	*Ophiura albida*
	Brittlestar	*Ophiura ophiura*
	Sea urchin	Echinidae (indet.)
Other	Sea mouse	*Aphrodite aculeata*
	Parchment tube worm	*Chaetopterus variopedatus*
	Tubeworm	*Hyalinoecia tubicola*
	Sea spider	*Pyncogonum littorale*

Many of these species do not survive the capture process, and those that do are usually returned to the sea far from where they were caught, potentially reducing their survival chances. There is much quantification of the high levels of the capture and discarding of benthic dwelling invertebrates by demersal trawlers, but there has been little in the way of attention or mitigation technology. Research currently under way using benthic release panels aims to release such species close to the point of capture in order to mitigate the environmental impacts associated with their capture and removal from the benthic habitats (Appendix 13.41.1.4).

13.7 The incidental capture of mammals, birds, reptiles and amphibians

Cetaceans[49] and other aquatic mammals such as seals and otters can sometimes become entangled or trapped in fishing gears. This notably occurs with pelagic trawls, drift nets, longlines and bottom-set gillnets, and to a lesser extent with traps. When mammals become fouled or trapped in fishing gears, breathing may be partially impaired or even completely restricted. Some animals may be unable to escape from the gear and simply drown. Others may break free, but trailing fishing gear material may remain attached to the animal, creating additional drag and potentially snagging onto objects in the sea. Normal body functions such as feeding, reproduction, movement and growth can all be impeded by entanglement and may also damage tissues, precipitating infection. Some mammals may ingest fishing gear, although death attributable to ingested fishing gear appears to be a relatively unusual phenomenon (Gorzelany, 1998).

At a recent global summit of cetacean experts[50], the consensus was that death from by-catch in fishing gears is the single biggest threat to global cetacean populations. Extrapolated US by-catch statistics gave rise to an estimated global annual cetacean by-catch rate of 65 000 – 85 000 animals through entanglement with fishing gears. Fishing with gillnets, set nets, trammel nets, seines, trawls and longlines are all believed to result in cetacean by-catch. Fertl and Leatherwood (1995) described 26 species of cetacean that died from entrapment in trawls.

The International Union for the Conservation of Nature, based in Geneva, Switzerland (IUCN), lists the status of the North Atlantic right whale (*Eubalaena glacialis*) as endangered, with a current estimated population of around 350 individuals. As a species, it is considered to be the most endangered of the great whales and has shown no sign of population recovery despite full protection from whaling since the 1930s. The WWF state, "*The most serious threats to the North Atlantic right whale's survival today are collisions with ships and entanglement in fishing gear*". Right whales most commonly become entangled in gillnets and in the backing lines that link traps. Lending weight to the concern of these animals' failure to recover after exploitation are data on the similar and also heavily exploited (to the 1930s) southern right whale (*Eubalaena australis*), which lives in the comparatively less busy (in terms of ships and fishing activity) Southern Ocean and southern Indian, Atlantic and Pacific Oceans. The population of that species is recovering at a remarkable rate.

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[49] Collective scientific name for whales, dolphins and porpoises
[50] Convened by the World Wildlife Fund in 2002.

Other endangered species of cetaceans include the smallest porpoise in the world, the Gulf of California porpoise or Vaquita porpoise (*Phocoena sinus*)[51], with an estimated population of around 500 animals and predicted by the WWF to be extinct within 10 years if current rates of entrapment and drowning in gillnets persist. Losses attributable to entanglement in gillnets is estimated to be around 40 per year, equivalent to 17% of the total population (D'agrosa *et al*., 2000).

The Philippine Irrawaddy dolphin population (*Orcaella brevirostris*) is thought to consist of fewer than 50 animals and entanglement is reported in lift nets and in fish corrals. In New Zealand, the small Maui`s dolphin population of around 100 animals is under threat from entrapment in gillnets and pair trawls. In the Atlantic, off the coasts of Brazil, Uruguay and Argentina, the Franciscana or La Plata dolphin (*Pontoporia blainvillei*) population is also reported by the WWF to be in crisis owing to high by-catch rates in gillnets.

The UK and Denmark both have significant gillnet and tangle net fisheries in the North Sea. In the Danish gillnet fisheries, nearly 7 000 harbour porpoises (*Phocoena phocoen*a) were killed by entanglement during the period 1994–1998 (Vinther, 1999). It was estimated that the UK North Sea gillnet fleet caught between 400 and 800 harbour porpoises each year and that Swedish gillnetters entangled some 50 animals annually (Anon., 2001). Tregenza *et al.* (1997) estimated that English and Irish gillnetters fishing for hake off the Southwest of the UK were catching around 2 000 porpoises each year in the mid 1990s.

Driftnet fisheries[52] are globally less common than in previous years, although many small-scale driftnet fisheries are still prosecuted by fishers throughout Europe. Sea mammal entanglement rates can be very high with such gears (Bjørge and Øien, 1995).

Pelagic trawlers use large nets, and mammal by-catches are a regular occurrence in many operations. Observers on European pelagic vessels have recorded the accidental capture and drowning of many mammal species in pelagic trawls, including harbour porpoises *(Phocoena phocoen*a), short-beaked common dolphins (*Delphinus delphi*s), Atlantic white-sided dolphins (*Lagenorhynchus acutu*s), white-beaked dolphins (*Lagenorhynchus albirostri*s), striped dolphins (*Stenella coeruleoalb*a), bottlenose dolphins (*Tursiops truncatu*s), Risso`s dolphins (*Grampus griseu*s), killer whales (*Orcinus orc*a), long-finned pilot whales (*Globicephala melaen*a) and grey seals (*Halichoerus gryptus*) (Anon., 2001; Morizur *et al.*, 1999). Pelagic

[51] Discovered in 1958
[52] Surface floating gill nets, which drift with the tide.

trawl by-catches of dolphins are widespread in the Bay of Biscay, the Western Approaches and the Celtic Sea (Tregenza and Collet, 1997).

Some mammals (including seals, cetaceans and otters) have also been known to sporadically drown in fyke nets[53], traps/pots and demersal trawls in some coastal European fisheries (Anon., 2001).

13.7.1. The incidental capture of birds

Aquatic living birds can become entangled or hooked on fishing gears. The numbers of birds killed by fishing gears appears to be a function of their abundance, diving habits and proximity to fishing activity. Diving seabirds are most vulnerable to gillnet entanglement and longline hooking, which may be high if located near colony sites.

The ICES working group on seabird ecology recently stated that gillnets and longlines are responsible for the drowning of thousands of seabirds each year (Anon., 2002). The working group cites many instances of bird kills from fishing gears, including Dunn and Steel (2001), who estimated that about 20 000 northern fulmars (*Fulmarus glacialis*) are caught annually by the Norwegian longline fishing fleet alone. Reference is made to great cormorants (*Phalacrocorax carbo*) drowned in fish traps by Follestad and Runde (1995) and auks caught and drowned in capelin and salmon nets by Frantzen and Hendrikesn (1992) and Strann *et al.* (1991). The working group considers that the North Sea populations of northern fulmar (*Fulmarus glacialis*) and the auks, common guillemot (*Uria aalge*) and razorbill (*Alca torda*) will be under moderate threat over the next decade from fishing-gear-induced mortality. Harrison and Robins (1992) have also highlighted the decline of several European auk populations and similarly implicate the coastal gillnet fisheries.

Gillnet entanglements of shearwaters (*Puffinus* spp), red-throated divers (*Gavia stellata*), Leach's petrel (*Oceanodroma leucorhoa*), gannet (*Sula bassana*), shag (*Phalacrocorax aristotelis*), razorbill (*Alca torda*), great northern diver (*Gavia immer*), Slavonian grebe (*Podiceps auritus*), scaup (*Aythya marila*), common scooter (*Melanitta nigra*), long-tailed duck (*Clangula hyemalis*) and guillemot (*Uria aalge*) have all been recorded in European waters.

Off Germany (Helgoland) in the North Sea between 1976 and 1985, 13% of dead gannets (*Sula bassana*) washed ashore were entangled in net fragments. Throughout that study period, another five gannets were found alive, entangled in fishing gear, and were subsequently set

[53] A design of trap used to catch eels (see Appendix 13.29)

free. It is reported that these birds would have died within a few days from their entanglement (Schrey and Vauk, 1987). In 1996, while monitoring two experimental ghost nets off SW Wales, UK researchers recorded the fatal entrapment of three shags (*Phalacrocorax aristotelis*) in the meshes of two experimental gillnets (Kaiser *et al.*, 1996). Seabirds can become entangled in lost or discarded fragments of fishing gear. In particular, northern gannets (*Morus bassanus*) and various cormorant species will collect such materials to use in nest construction, which can lead to entanglement of adults and especially of chicks. Mortality rates resulting from this are low, but this form of pollution has increased considerably over recent decades (Montevecchi, 1991).

Many species of albatross are susceptible to mortality from hooking and drowning on longlines, particularly in the southern oceans. Albatrosses are attracted to the baited hooks on longlines as the gear is deployed, and frequently become hooked as they attempt to eat the bait. The birds are dragged down to their deaths as the gear sinks.

The Amsterdam albatross (*Diomedea amsterdamensis*) is one of the most rare, with a single colony on Amsterdam Island in the Indian Ocean, and is listed as endangered by the IUCN. Longlining has previously adversely impacted upon it, and concerns are that it faces extinction if longline effort were to increase around Amsterdam Island (Inchausti and Weimerskirch, 2001).

The South American Patagonian toothfish fishery was estimated to have drowned 2 300 white-chinned petrels (*Procellaria aequinoctialis*) and 1 150 albatrosses in 1990/91 (Brothers *et al.*, 1999), while the Southern Ocean Patagonian toothfish fishery may have drowned more than a quarter of a million seabirds between 1996 and 1999 (Tasker *et al.*, 2000). The Southern Ocean Japanese pelagic longline fishery was estimated to have drowned about 40 000 albatrosses per year during the 1980s (Brothers *et al.*, 1999).

In the United\States, observers recorded more than 3 500 seabirds entangled in salmon gillnet fisheries in North Puget Sound in a single year (1994). The two most frequently entangled birds were reported to be the rhinoceros auklet (*Cerorhinca monocerata*) and the common murr (*Uria aalge*). Such bird entanglements contravened Washington state law, and this, coupled with concerns on the impacts on seabird populations, led directly to a subsequent mitigating research programme (Anon., 1995). In another salmon gillnet fishery, Lanza *et al.* (1997) claimed that hundreds of thousands of thick-billed murres (*Uria lomvia*) were entangled in the gillnets of the Greenland salmon fishery over the years.

In South America, more than 600 Humboldt penguins (*Spheniscus humboldti*) were reported by local fishers to have drowned in gillnets off the coast of central Chile (Valparaiso) over a five-year period (Simeone *et al.*, 1999). Lesser numbers of other seabirds, including Magellanic penguins (*Spheniscus. magellanicus*), red-legged cormorants (*Phalacrocorax gaimardi*) and Guanay cormorants (*P. bougainvillii*) were also reported as drowned. Various reports from other sites along the coastline of Chile and Peru indicate that entanglements in the nets are widespread. The red-legged cormorant (*Phalacrocorax gaimardi*) has undergone a 'spectacular decline' in Peru over the past 30 years (c. 98% decline in some localities). The *El Niño* is blamed for much of this decline, but entanglement in fishing nets is cited as a potential threat to their recovery (Zavalga *et al.*, 2002).

In Canada, *post mortem* examinations of more than 70 *Gavia immer* showed that entanglement with fishing gears was the cause of death of many (Campbell *et al.*, 1995). Similar findings were obtained by *post mortem*s undertaken in Australia on little penguins (Harrigan, 1992). In New Zealand, *post mortem*s of 185 yellow-eyed penguin (*Megadyptes antipodes*) indicated that 23% had died from gillnet entanglement (Darby and Dawson, 2000). Gillnet entanglement was subsequently considered to be a significant threat to the populations of these penguins on the South Islands of New Zealand. Also in New Zealand, populations of the white-capped albatross (*Diomedea cauta cauta*) are considered by some workers to be declining because of capture and drowning in squid trawls (Lanza *et al*., 1997).

Instances of bird entanglement in fishing gear have been reported in very remote regions, such as the Antarctic. A south polar skua (*Catharacta maccormicki*) was found dead with a fishing line in its mouth and wrapped around its neck and an Adelie penguin (*Pygoscelis adeliae*) was found immobilised and dead with fishing wire entangling its legs (Woehler, 1990). Both these entanglements were recorded in the Australian Antarctic Territory. On a larger scale, the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) in 2000 estimated total seabird by-catch from illegal fishing in the Convention area at between 105 900 and 257 000 birds over the preceding four years. This figure includes 21 900 - 68 300 albatrosses, 5 000 - 11 000 giant petrels and 79 000 - 178 000 white-chinned petrels.

Further detailed information on the impacts of capture fisheries on birds can be found in the publications by Tasker *et al.* (2000) and Melvin and Parrish (2001).

13.7.2. The incidental capture of reptiles

The incidental capture of reptiles is rare in UK and northern European waters and tends to be confined to the capture of an occasional sea turtle that has drifted northwards with the Gulf Stream. In warmer waters, the incidental capture of sea turtles has been widely reported, particularly in the US and Australia. Incidental catches of loggerhead turtles (*Caretta caretta*) were reported by observers in the US driftnet fishery for sharks off the Southeast US Atlantic seaboard (Trent *et al.*, 1997). Brady and Borman (1996) detail turtle by-catches farther north off the northeastern US seaboard. They describe loggerhead, leatherback, green, and Kemp's ridley turtle captures in four fisheries; the swordfish longline fishery, swordfish gillnet fishery, trawl fishery, and the crab/lobster fishery. The longline fishery entrapped the most. DeAlteris (1995) described the incidental capture of turtles in US fisheries as a demanding problem, requiring action. Turtles are particularly prevalent in the southern US shrimp fisheries in the Gulf of Mexico and Atlantic seaboard, and mitigation measures have been taken and implemented by Government. Kapantagis and Lioudakis (2001) report on marine turtle catch rates in longline fisheries around Greece in the Aegean Sea, the West Cretan Sea and the South Ionian Sea.

Another group of reptiles caught in fishing gear are sea snakes, most commonly in Australia. The sea snake (*Hydrophis pacificus*) was identified as being both highly vulnerable to trawling and having a poor capacity to sustain fishing mortality in an Australian study on the susceptibility of the populations of 13 sea snake species caught as an incidental catch in Australia's northern prawn trawl fishery (Milton, 2000). It has also been estimated that about 50% of sea snakes caught in Australian prawn trawls die (Wassenberg *et al.*, 2001).

13.7.3. The incidental capture of amphibians

There is little information to suggest that amphibians are caught in fishing gears in any great number. Fisheries interactions with amphibians tend to be confined to freshwater, because amphibians cannot tolerate saline water. There is anecdotal evidence of frog and toad entrapment in freshwater fyke nets used in the UK and Europe in various fisheries for eel (*Anguilla anguilla*).

13.8 Benthic impact

To assess the effects of fishing gear on benthic species and habitats, fishing gears can usefully be divided into two categories: mobile and static. Mobile gears are typically towed trawls, seines and dredges, whereas static gears are pots, traps, baited lines and gillnets. Mobile gears towed across the seabed cause the majority of fishing impacts on benthic communities. Static gears in general have smaller and more localised impacts, although the repeated setting and hauling of set nets and lines can cause damage to highly sensitive habitats such as coral reefs (Jennings and Kaiser, 1998; Kaiser and de Groot, 2000; Kaiser *et al*., 2002).

Towed fishing gears may cause changes in the structure of benthic habitats and can determine the associated species diversity, composition, biomass and productivity. Many fishing gears have direct effects on habitat structure, but there are indirect effects when fishing initiates shifts in the relationships between those organisms responsible for habitat development and degradation. The direct effects of fishing vary according to the gears used and the habitats fished, but they usually include the scraping, scouring and resuspension of the substratum. The magnitudes of changes that can be attributed to fishing often depend upon the nature of the physical environment in which a given habitat is found.

Since most biogenic[54] habitats contain large and relatively slow-growing species, bottom fishing easily modifies these habitats. Biogenic habitats are often particularly complex and slow-growing in areas of low natural disturbance, and the initial impacts of bottom trawls can dramatically change the habitat architecture and the abundance and diversity of associated species. However, even in shallow shelf seas where natural disturbance is more frequent and intense, bottom fishing has led to substantial habitat modification. In the Dutch Wadden Sea, for example, dredging led to the loss of reefs of the calcareous tube-building worm *Sabellaria spinulosa* and their replacement by communities of small polychaetes[55] (Riesen and Riese, 1982). Tube-building worms have an important role in stabilising the sediment and providing sites for the establishment of mussel *Mytilus edulis* beds. Similarly, the abundance of another habitat-structuring worm (*Myxicola infundibulum*) decreased following commercial scallop dredging in the Gulf of Maine (Langton and Robinson, 1990).

In heavily fished shelf seas there have been reductions in sessile[56] habitat forming benthic species and increases in the biomass of small free-living fauna[57]. For example, on Georges

[54] Habitats formed by living animals e.g. coral beds and reefs.
[55] Bristle worms
[56] Stationary/non-moving

Bank, Collie *et al*. (1997) compared areas that were subject to different intensities of scallop dredging and showed that infrequently fished areas were characterised by abundant bryozoans[58], hydroids[59] and worm tubes that increased the three-dimensional complexity of the habitat. Conversely, in the more intensively dredged areas, the total biomass of the fauna was lower, and hard-shelled bivalves[60]; echinoderms[61] and scavenging decapods[62] were the dominant species. Similar changes have been observed in many other fished ecosystems. In heavily fished areas, the biomass, production and diversity of benthic animals are much reduced, and large benthic animals come to play a much smaller role in bioturbation[63] and the recycling of nutrients. The benthic impacts of fishing are discussed in greater detail in the CEFAS submission of information to the RCEP.

[57] All animals in a given environment
[58] Sessile colonial animals with a plant-like appearance
[59] Soft colonial animals
[60] Molluscs with two paired shell parts (e.g. common mussel *Mytilus edulis*)
[61] Sea urchins
[62] Crustaceans with ten legs (e.g. crabs, lobsters, shrimps, prawns)
[63] Disturbance to the seabed by living animals

13.9 Lost and abandoned fishing gear

13.9.1. An overview of lost and abandoned fishing gear

Fishing gears may become lost or abandoned for a variety of reasons during fishing operations. Such loss/abandonment may be a deliberate act or may be totally beyond the fishers' control. These gears can remain in the seas for decades or longer, gradually deteriorating until they have totally disintegrated, a potentially lengthy process, because many fishing gears are constructed from polymers.

Throughout the disintegration process, the gear gradually breaks down and fragments, whereupon smaller pieces of fishing gear can become widely dispersed by currents and tidal streams. Some gear remnants may be washed ashore and carried inland by the wind; others may remain in the sea, held fast by snags on the seabed. Some pieces may entangle or be ingested by sea creatures whereas others may pose a threat to the safety of mariners by entangling vessel propellers or divers. The environmental impacts of lost and abandoned fishing gears may be summarised as:

- The incidental fatal capture and wounding of birds, mammals, fish, shellfish, crustaceans, reptiles and invertebrate species.
- The harmful ingestion of gear remnants by animals
- The destruction of delicate habitats
- The entanglement of divers and swimmers
- The entanglement of vessel propellers and the endangerment of maritime traffic and safe navigation
- The unattractive appearance of debris on beaches and in water

Fishing gears and gear remnants in the environment have a variety of names including ‘ghost’ fishing gear, ‘lost and abandoned’ fishing gear, aquatic debris, aquatic litter and derelict fishing gear.

Mobile fishing gears such as trawls and seines can only catch fish when they are actively hauled through the water, and therefore do not tend to catch sea creatures in conditions when they are static, such as when they are lost or abandoned on the seabed. They will, however, break up and fragment during the disintegration process and can cause environmental impacts as dispersed fragments. Lost and abandoned static gears may also result in habitat damage (section 13.9.6.).

As a phenomenon, ghost fishing by lost and abandoned gears is widely accepted as being confined to lost or abandoned static fishing gears, such as gillnets, trammel nets, tangle nets, pots and traps.

The environmental impact of lost and abandoned fishing gears depends upon such factors as gear design and construction, rapidity of disintegration, gear dimension, time of loss, area lost, degree of contact with the seabed/wrecks/reefs etc,, the presence/abundance and variety of species in the locality of the gear, and the oceanographic and meteorological properties of the surrounding waters.

13.9.2. Unintentional abandonment/loss of fishing gear

Fishing gear may become 'lost or abandoned' if its retrieval after normal deployment is impeded or prevented for some reason. Snags on the seabed can prevent the normal retrieval of fishing gears in part or in total, as can parting of the hauling wires/ropes or excessive weight in the fishing gear itself. The inability of the skipper to find fishing gear/fishing gear markers can also result in fishing gear loss. Damaged or detached surface marker buoys may make the subsequent retrieval of a fishing gear problematic.

Some studies have identified the causes of fishing gear loss. For instance, in Portugal, the two most common causes of static gear losses were reported to be gear conflicts with towed gear fishers and adverse weather conditions (Santos *et al*., 2003b). In Oman, gear interference, theft, vandalism and collisions with vessels were the main causes of gear loss (Al-Masroori, 2002) and in the UK, poor weather and adverse tidal conditions (43%) and conflicts with other fisheries (26%) were reported to be the most common causes of static gear loss (Swarbrick and Arkley, 2002).

13.9.3. The deliberate abandonment of fishing gear

Some fishing gears are deliberately dumped or abandoned in the sea by their owners. Damaged fishing gears that are uneconomical to repair may be dumped overboard, particularly when terrestrial disposal is cost-prohibitive or difficult to access. Fishing gears may be stripped of any valuable components (lead, floats, anchors etc) prior to dumping, although such 'asset stripping' of the gear prior to dumping does not necessarily eliminate the ghost fishing potential of that fishing gear. Short lengths of rope, twine and hooks, and small scraps of loose netting can entangle and kill aquatic animals.

There is some anecdotal evidence[64] that some fishers may deliberately abandon static gears on the seabed for prolonged periods from several weeks to months, using the seabed as a storage facility for their fishing gear during periods of absence from the fishery.

13.9.4. Longevity and catch rates in ghost traps, pots and creels

Traps (referred to as pots in England and creels in Scotland) are used throughout the world, particularly on continental shelves and in fisheries that primarily target walking crustaceans, such as crab, lobster, crawfish and prawns. Traps are also used to target fish and mollusc species in some fisheries.

Levels of concern regarding the potential environmental impact of lost or abandoned traps vary. In general, traps appear to have 'ghost fishing' lifespans greater than that of static nets (section 13.9.5.) probably owing to their more sturdy construction. Sturdy construction materials may prolong the ghost fishing activity of a lost or abandoned trap by impeding the structural breakdown by its elements (wind, wave, currents, etc.).

Laist (1996) claimed that lost traps could remain intact and catch marine life for more than a decade and that ghost fishing of some commercial stocks amounts to up to 30% of the annual landing levels. In Kuwait, ghost fishing by fish traps was estimated to cause fish losses equivalent to between 3 and 14% of the value of landings (Mathews *et al.*, 1987) and in Canada (British Columbia), ghost traps were estimated potentially to result in mortality rates equivalent to 7% of the reported catch of crabs (*Cancer magister*) in the Fraser River District (Breen, 1987).

In the UK (SW Wales), Bullimore *et al.* (2001) demonstrated that the original bait in abandoned traps was consumed within a month, although the traps continued to catch various crustaceans and fish for more than 12 months. In the US, surveys using side-scan sonar and grapples identified and recovered many hundreds of ghost traps in Chiniak Bay, near Kodiak, Alaska (Stevens *et al.*, 2000). Some of these ghost traps had been lost for periods of more than two years and were recovered with live catches of tanner crabs (*Chionoecetes bairdi*) and octopuses (*Octopus dofleini*). Even though many of the older ghost traps had damaged webbing, the catch rates were seemingly unaffected. In Canada, Vienneau and Moriyasu (1994) also found that non-baited ghost traps could catch crabs. It was concluded that they would probably have less impact on crab stocks in the short term, becoming more destructive as they became self-baiting in the longer term. Guillory (1993) studied the fishing activities of ghost traps for blue crab (*Callinectes sapidus*) in the Timbalier Bay estuary, Louisiana. Crabs

[64] Concerning Spanish deep-water gillnetters and crabbers off NE England

were observed entering unbaited traps, and although the smaller ones subsequently escaped, larger crabs tended to remain in the traps and eventually die.

Contrary to many of these findings, one study concluded that ghost fishing by lost or abandoned lobster traps was not a problem in Hawaii, because most lobsters eventually escaped from ghost pots within 56 days. Field and laboratory studies on the escape behaviour of spiny lobster (*Panulirus marginatus*) and slipper lobster (*Scyllarides squammosus*) gave rise to these conclusions (Parrish and Kazama, 1992).

13.9.5. Longevity and catch rates: ghost static nets

A variety of studies on the longevity and catch rates of ghost fishing static nets (trammel, gill and tangle) have been undertaken in the past decade. When viewed collectively (Table 12) these studies indicate that the duration of ghost static nets on the continental shelf (i.e. shallower than 200 m) will be generally less than one year. Ghost nets rapidly become fouled by weed, rendering the meshes more visible to fish, so reducing capture efficacy. Fish catches in ghost nets consistently and rapidly decline after abandonment, whereas catches of crustaceans are sustained for longer. The structural integrity of lost/abandoned nets is gradually destroyed over time and is energised by the oceanographic and meteorological forces in the surrounding waters.

Table 12. Recent studies on ghost net activity of lost and abandoned static nets

Location	High /Low energy environment	Type of nets studied	Depth of nets	Duration of fishing activity	Study period	Reference
UK North Sea	High	Wreck nets	30m	Negligible after 1 year	1999–2001	Revill and Dunlin (2003)
UK North Sea	High	Trammel	25m	Nil after 2 months	1996	Revill and Dunlin (2003)
UK SW Wales coast	High	Gill and trammel nets	20m	Nil after 9 months	1995–1996	Kaiser *et al* (1996)
Portuguese coast	High	Gill and trammel nets	18m	Nil by 8–11 months	1995–1996	Erzini *et al.* (1997)
Portuguese coast	High	Gill nets	80m	Negligible after 3 months	2000–2002	Santos *et al.* (2003a)
Northern Spain coast	High	Tangle nets	120-135m	Nil fish after 8 months	2000-2001	Sancho *et al.* (2003)
Baltic Sea	Low	Gill nets	30–40 m	> 2 years	1998-2001	Tschernij (2003)
Norwegian continental slope	Low	Gill nets	500 - 800 m	Stable catch rates beyond 45 days at 25% of initial rate	2000-2001	Humborstad *et al.* (2003)

13.9.6. Habitat damage

Lost and abandoned fishing gear can cause habitat damage in waters where the benthic (seabed) communities are delicate and slow-growing, such as those found on coral reefs. Fishing gears can be lost or abandoned on coral reefs, or simply drift onto them. Once a gear has snagged in such a habitat, it can damage delicate structures through the application of destructive forces by swinging, twisting and oscillating motions caused by tides, currents and waves. More than 15 tonnes of lost and abandoned fishing gear was reportedly removed from the coral reefs surrounding the Hawaiian Islands by US authorities (Anon., 2000), while other subsequent reports place the figure as more than 60 tonnes of fishing gear located and removed[65].

[65] www.enn.com

13.9.7. Dangers to divers and swimmers

Lost and abandoned fishing gears pose a significant threat to the safety and lives of divers and other water users. Divers frequently dive in and around reefs, underwater installations, wrecks, etc., and can find themselves entangled in lost and abandoned gillnets that are frequently found snagged on such underwater structures[66]. For example, in a survey of 11 wrecks off the northeast coast of England, the remains from 27 different lost and abandoned gillnets were found snagged (Revill and Dunlin, 2003). A diver may not be able to escape easily from entanglement in fishing gear, especially if the visibility is poor or sediment has been stirred up in a struggle to escape.

13.9.8. Hazards to maritime traffic and navigators

Lost and abandoned fishing gear can be particularly hazardous to maritime traffic by fouling propellers and steering gear. A vessel may lose all ability to manoeuvre from such fouling and collision, capsize, loss of life, etc., can easily result.

In the UK, the Marine Accident Investigation Branch (MAIB) of the Department of Transport recently published details of the causes of fishing vessel accidents over the past decade. In all, 300 accidents could be directly attributed to fouled propellers during the period 1996–1999 (MAIB, 2002) The Royal National Lifeboat Institute[67] published details of 1 185 call-outs for powered leisure craft, of which 26 were attributable to fouled propellers.

[66] A typical example of diver endangerment. British Sub-Aqua Club. Incident Report (94/099) May 1994. A diver became trapped in a gillnet while diving on the wreck of an unknown freighter, off the Sussex coast. His companion managed to cut him free after 10 minutes. The casualty notes that the standard diver's knife was next to useless at cutting him free from the monofilament net. The wreck in question is at 40 41' 13"N 00 32' 20" E, and is noted in 'Dive Sussex', site no. 382.

[67] www.rnli.org.uk

13.10 Ecosystem changes

In addition to the direct impacts of capture fishing described in sections 13.3 to 13.9, fishing also has indirect effects on marine ecosystems. These effects are attributable to the effects of disturbance and the selective removal of species, size classes and trophic[68] groups by fishing (Gislason and Sinclair, 2000). It is difficult to generalise about the indirect (foodweb) effects of fishing, because the effects vary widely in communities with different species compositions and in different environments.

One of the most widely expressed concerns about intensive and selective capture fishing is that it will lead to imbalances in ecosystem function, which have ramifications for non-target species. Thus, fishers who capture small 'forage fish' such as sardines/pilchards *Sardina* spp., anchovies *Engraulis* spp., sandeels *Ammodytes* spp. or capelin *Mallotus villosus* may compete with other predators in the marine ecosystem. Many forage fish provide food for birds and marine mammals, and in many cases the birds or mammals are species of conservation concern. In some ecosystems, particularly those with strong environmental forcing and relatively species-poor communities, fishing has been shown to have large indirect effects on foodweb structure (the Barents Sea isone such example), whereas in other ecosystems with higher diversity, the effects tend to be more localised (e.g. the North Sea).

Fishing causes direct changes in the structure of fish communities simply by reducing the abundance of target or by-catch species, but these reductions may lead to responses in non-target species through changes in competitive interactions and predator-prey relationships. These interactions are closely coupled in some systems, but much looser in others. There is still uncertainty as to whether fishing has generally driven marine ecosystems into alternative stable states and whether recovery to a former state would be possible if fishing was stopped. There are reliable examples of shifts to alternative stable states on coral reefs and in kelp forests, but few consistent examples in other ecosystems. The indirect impacts of capture fishing upon ecosystems are discussed in greater detail by Gislason (2002).

[68] Relating to the hierarchical position within a food chain/web

13.11 Incidental mortality

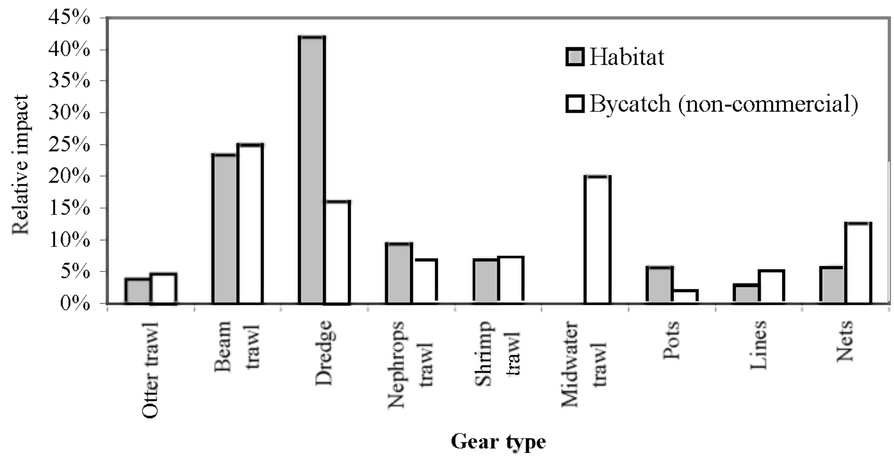
Incidental mortality is the mortality of marine organisms from injuries caused by encountering fishing gear during the fishing process but when they are not caught. Examples of this phenomenon would include fish that die from infections or osmotic imbalance caused by scale loss after escapement through trawl or gillnet meshes.

Fish with delicate scales, such as herring, are likely to suffer from this sort of injury if they come into contact with fishing gears. On the other hand, studies have shown that cod and other demersal species have a high rate of survival after escapement from or encounter with fishing gear.

Very little is known on this subject.

13.12 The relative environmental impacts of fishing gears

Figure 27. Relative environmental impacts of different fishing gears in the English Channel fishery



The percentages in Figure 27 represent the relative importance of the gear with respect to habitat damage and by-catch of non-commercial species, derived using an analytical hierarchical process (AHP). This technique combines the subjective opinions of a number of experts based on a series of pairwise comparisons (e.g. gear A is compared with gear B and a relative damage impact is given on a scale of 0 to 9). Other environmental impacts were not considered in the pilot study. The estimated impacts relate to fishing activities in the English Channel, so they are likely not applicable to other fisheries. Further, the results are based on a relatively small sample, so they need to be interpreted with caution. Nevertheless, in most cases the results are in line with *a priori* expectations[69]. Full details on the AHP and survey methodology used for eliciting these measures is given in Mardle and Pascoe (2003a).

The percentages illustrated in Figure 27are relative rather than absolute impacts. Although the percentages sum to 100%, the value of 24% for beam trawl, for example, does not imply that beam trawlers are responsible for 24% of the total habitat damage. Instead, the value of 24% for beam trawl with respect to habitat damage indicates that the habitat damage from using this gear is four times that of pots, and eight times that of lines.

Although limited in scope, the results from the pilot study illustrate the complexity of interpreting environmental damage from the different gear types. While it may be concluded

[69] One notable exception to this is the low impact of otter trawl on both habitat and by-catch of non-commercial species – lower than that of some of the static gear. The survey is ongoing and a larger sample may overcome some of these inconsistencies.

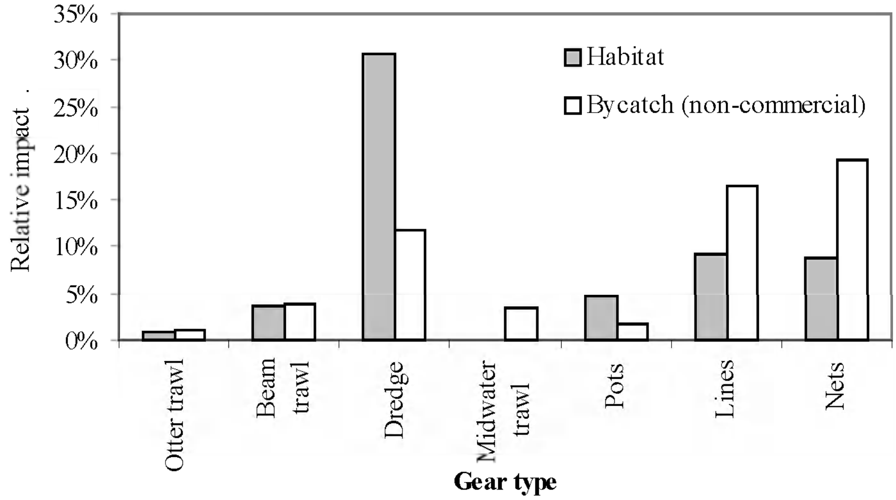
that, for example, a beam trawl is more environmentally damaging than potting, other comparisons are less straightforward. For example, dredging is considered to produce the greatest habitat damage of all gear types, but its impact on non-commercial species is lower than for some other gears. Conversely, midwater trawling is considered to have a negligible impact on the habitat, but a high impact on non-commercial species. Determining which type of damage is more important is difficult without a common numerare. Further, the significance of the damage can vary between gear types. For example, the non-commercial species affected by dredges are largely benthic (bottom-dwelling) species such as some fish, crustaceans, invertebrates and vegetation. In contrast, midwater trawls are often associated with dolphin mortality.

A potential framework for providing greater comparability in assessing the different types of environmental damage is economics, and non-market valuation in particular. Non-market valuation assigns economic values to ‘goods and services’, such as environmental goods, that do not have a formal market. Under such a framework, it would be assumed that familiar species such as dolphins would attract a higher non-market value than most benthic species rarely seen by more than a few recreational scuba divers. As a consequence, the economic impact of midwater trawling on non-commercial species may be many times greater than that imposed by other gear types if the value of the species affected is taken into consideration. However, sufficient studies that will allow the non-market costs of these impacts to be assessed have not been undertaken in the UK (or elsewhere) to date. Habitat damage also has a direct productive cost. Habitat destruction can reduce the carrying capacity of stocks, resulting in lower stock levels and smaller long-term catches. Again, however, there is insufficient information to link habitat damage with lost future production in order to derive meaningful cost estimates.

The cost associated with environmental damage also needs to be balanced against the benefits the fishing activities provide. While beam trawling, dredging and midwater trawling potentially incur relatively high environmental costs, they also produce relatively high-value output (e.g. sole, scallops and sea bass respectively). Identifying the net benefit of the fishing activity requires information on the actual value of the environmental damage, and of how this damage varies with production levels. Given this information, it is possible to determine an optimal level of environmental damage (see Appendix 13.47).

As noted above, this information is not currently available, and deriving such values is beyond the scope of this study. However, an indication as to how perceptions of environmental damage can change when the value of the output produced is factored into the analysis can be seen in Figure 28, where the relative damage measure has been normalised by the price[70] of the main species caught. With the exception of dredges, the normalised relative measures of environmental damage of the activities that create the most damage are generally not greater than that of the activities that produce the least damage. This is a very crude indicator, because it is based on just one species for each gear type, ignores the costs of capture and assumes that the non-market value per 'unit' of environmental damage is the same for each gear type. Nevertheless, it illustrates that considering the costs of environmental damage without considering the benefits can lead to misperceptions about the net economic effects of the activities.

Figure 28. Relative environmental impacts of different fishing gears normalised by the price of the main target species



[70] Price information was derived from landings statistics into south coast ports in 2001.

13.13 Recent advances in bridge electronics technology

13.13.1. Position-locating electronics

Navigation and position location at sea has radically increased in sophistication, coverage and resolution since the Second World War. The first major global navigation system was the terrestrial beacon network of 49 stations named LORAN[71], introduced after the war and which remains in use today. The current LORAN-C network replaced the old LORAN-A network in 1957 and gives a positional accuracy of 160-400m. Russia has a compatible LORAN system named Chayka (which means seagull). Accuracy can be improved to 90 m by accurately ascertaining the position of a transmission station.

A similar alternative system called DECCA was also developed during the Second World War and began commercial operations in 1946; its working life continued until its closure at the turn of the millennium. The Decca system utilised chains of land beacons and offered increased resolution (down to 50 m in some areas) over the LORAN system, but geographical coverage was not global.

A satellite-based system (Transit) was developed by the US Navy and used between the 1960s and the 1980s. The system allowed global position fixing, but was only available when the satellites passed over in orbit; it has since been discontinued. The Global Positioning System (GPS) has been available to mariners since the 1980s and makes use of geo-stationary satellites giving global coverage and position fixing with an unprecedented degree of accuracy (15 m). The resolution of the GPS system has been further enhanced by combining the satellite signals with land beacons (known as Differential GPS); it can now produce a positional accuracy of between 2 and 5 m. Accuracies down to less than 1 m are possible for authorised military personnel who have access to PPS[72] signal decoders.

All these navigation systems work on the principle that the mariner uses a signal receiver and processor to triangulate the electromagnetic signals beamed from multiple transmitters to achieve a position fix. It is probable that every modern fishing vessel in the developed world has at least one GPS receiver and processor onboard.

[71] LOng RAnge Navigation.
[72] Precise Precision System

Figure 29. A FURUNO GPS display unit, typical of the type used by the fishing industry

13.13.2. Radar

Onboard radar consists of a radome, which transmits electromagnetic radiating waves of 360°. Reflected echoes are bounced back to the radome by objects in the path of the radar beam, which are subsequently processed and displayed on the vessel's bridge. Working radar is installed on virtually all vessels at sea and is mandatory under law for many. Radar technology was pioneered during the Second World War and has been used on fishing vessels since the 1950s. In recent decades, most of the technological advances in radar have been related to increasing the quality and functionality of the display units, the interpretation of echo signals and the integration of radar units with other navigational aids such as chart plotters and GPS. The range of onboard radar units has increased over the years through technological development and can be in excess of 70 nautical miles.

Figure 30. SIMRAD radomes, typical of the type used by the fishing industry

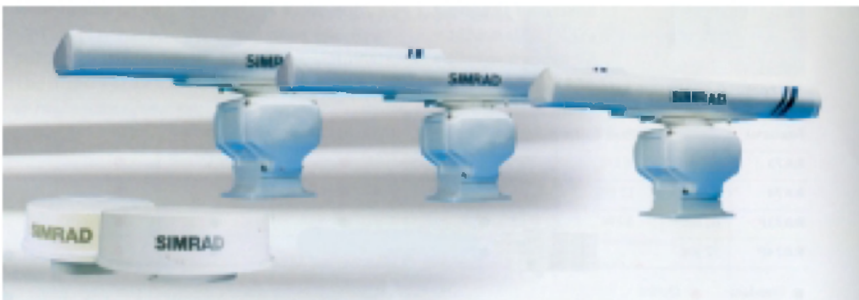
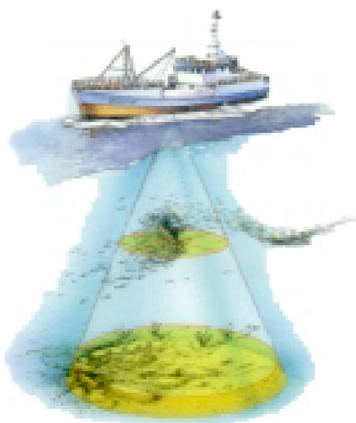


Figure 31. A FURUNO radar display unit, typical of the type used by the fishing industry

13.13.3. Fish finders/sounders/sonar

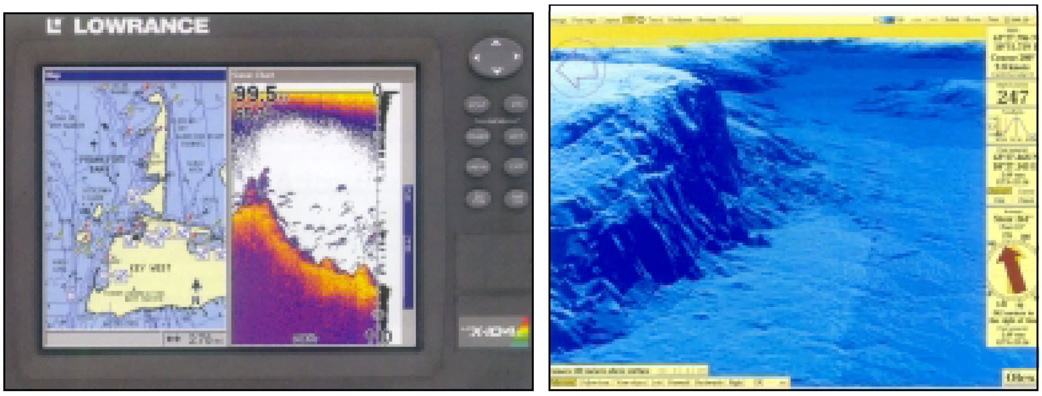
These technologies are based on the interpretation of echoes picked up by a signal receiver, which have been bounced back from the seabed or from other subterranean objects (fish, wrecks, etc.) having originated from sound wave beams transmitted by an onboard transducer fitted to the underside of the vessel. The sound beams can be used to measure depth (sounders), water temperature and to detect fish (fish finders). Some units (sonar) may allow the user to direct a narrow *'torch-like'* sound beam that can be focused to any desired angle. In general, these units use sound frequencies in the range 28-200 kHz, with frequencies at the lower end giving better ground discrimination, while higher frequencies facilitate the discrimination of fish within the water column most clearly.

Figure 32. Fish finding: (source: SIMRAD)



The transmission technology used in these units has made small advances over recent decades through increased durability of components by the use of crystals instead of wire-wound transducers. Both receiver and display circuitry has improved significantly, and the greatest advances have been in the filtering, processing and display of the echo signals and the integration of units with other navigational aids such as GPS and chart plotters. The integration of units has precipitated the emergence of seabed mapping and display. This technology has greatly improved over the past 50 years and has resulted in the present range of sophisticated devices that are available on the market.

Figure 33. LOWRANCE sounder/chart recorder (left) OLEX 3D seabed mapping system (right) typical of the type used by the fishing industry



13.13.4. Chart plotters

Electronic charts and plotters have emerged during the last two decades and have increasingly become more sophisticated. Their development has been made possible through the advent of GPS and advances in computer processing power; they have become very popular with the fish capture industry. The technology features electronically loaded charts that are integrated to the GPS receiver enabling the fisher to plot, record and store the vessel position at any given time. Electronic charts and plotters have allowed fishers accurately to record such information as tow tracks and obstructions. Some designs of plotter permit the integration of the units with other units such as radar, sounder and fish finder.

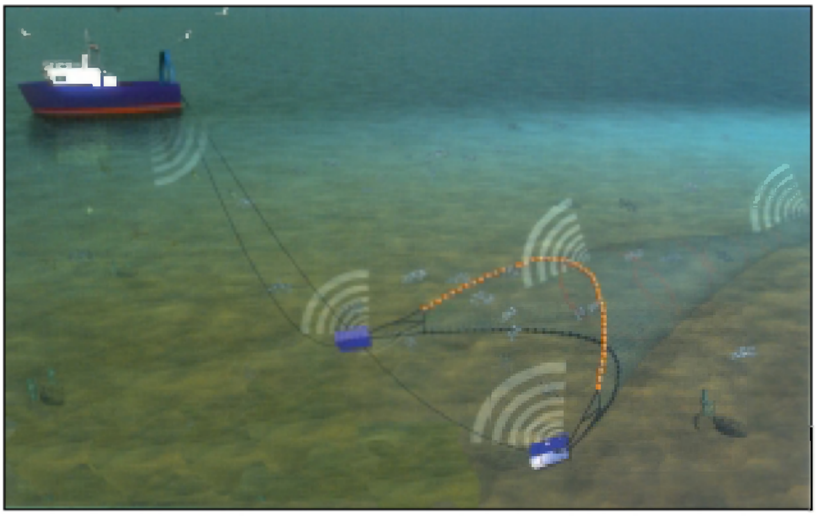
Figure 34. QUODFISH and CHARTWORK electronic plotters and charts, typical of the type used by the fishing industry

13.13.5. Fishing gear sensors

A wide array of sensors can be fitted to fishing gears to detect miscellaneous parameters and are now available on the market. Such sensors were first used on specialist research vessels but are increasingly being used by larger, and more recently medium-sized, fishing vessels. The sensors detect parameters such as pitch, tilt, roll, tension, distance, depth, temperature and speed, and send signals to a receiver on the vessel to be subsequently processed. The interpretation of the signals depends upon the type of sensor fitted to what part of the fishing gear, but it can give rise to valuable information such as headline height, trawl opening, distance between the doors[73], angle of a grid, quantity of catch in the trawl and the amount of contact with the seabed.

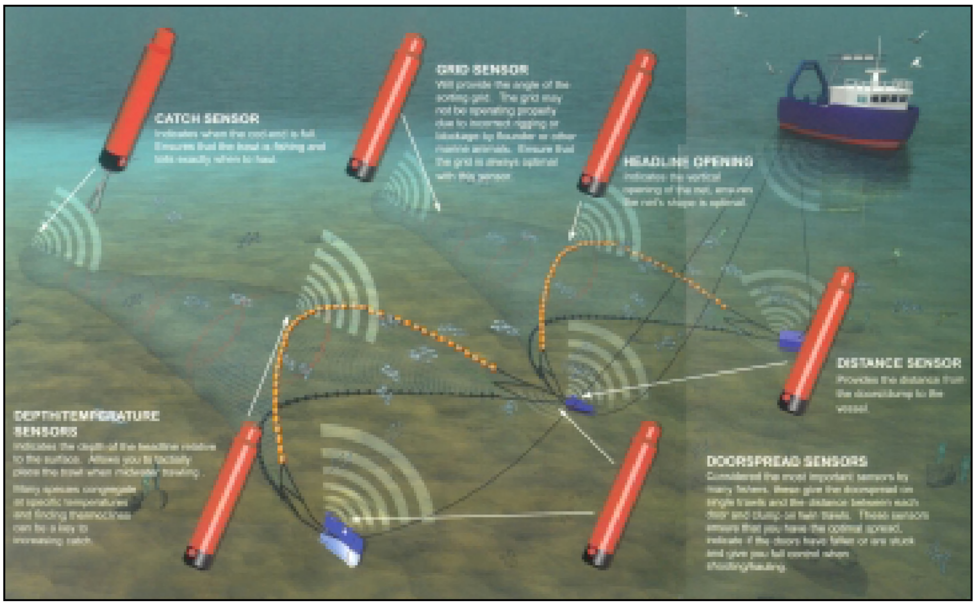
This information can be utilised by the fisher to improve the efficiency of the fish capture operation by ensuring that optimal trawl geometry is constantly maintained. The sensors facilitate early detection of problems that may cause the trawl to fish suboptimally, such as twisted codends, rips in the gear, asymmetry, blocked grids, low headlines, unstable doors, twisted warps, seabed fasteners, etc.

Figure 35. NOTUS single trawl monitoring system



[73] Otter boards

Figure 36. NOTUS twin trawl monitoring system



13.13.6. Autopilots

Modern autopilots can integrate position data from GPS and gyro/magnetic/fluxgate compasses in order to manipulate the vessel's propulsion and steering on any bearing and course to suit the fisher. They are almost universally popular among fishers, and essential in may fisheries, including single-handed fishing vessels.

Figure 37. Modern SIMRAD autopilot, typical of the type used by the fishing industry

13.13.7. Changes in the environmental impacts associated with technological developments in bridge electronics

Alverson (1959) reported that an important consequence of from the adoption of depth sounder, fish finder, radar and LORAN technologies was the expansion of the fishing grounds. This expansion was reflected in the average maximum fishing depth of the fleets, which was 144 fathoms (264 m) in 1952, though had increased to 280 fathoms (512m) by 1956 (Table 13).

Table 13. Technological advancements in 20 trawlers from Puget Sound during the years 1952 - 1956

Technology	Percentage of vessels using the technology (Year) (1952)	(1955)	(1956)
Depth sounder	100 %	100 %	100 %
Loran	30 %	100 %	100 %
Radar	0 %	25 %	25 %
Fish finder	0 %	10 %	25 %
	Average maximum fishing depth (m) of the vessels (year)		
	264	439	512

13.14 The historical uptake of bridge electronics in the Norwegian fishing fleets

13.14.1. Land-based beacon navigation systems

Before 1960, Norwegian fishing vessels used radio bearings as an aid to navigation. In the early 1960s, Loran A and Loran C was introduced. Loran C was more accurate and only for military use, whereas the less accurate Loran A became the standard equipment on most fishing vessels by the late 1960s. In 1970, Loran C was introduced as a civil system and gradually replaced Loran A, which was eventually discontinued in 1977. The Decca navigation system was introduced around 1970, and by 1975, most fishing vessels longer than 15 m used the system. Decca and Loran C were used in parallel for many years (Kjerstad, 2001).

13.14.2. Satellite systems:

The Satellite Navigator System "Transit" was introduced in 1972, but it was very expensive (£120,000) and was only used on large factory trawlers. The GPS started trial transmitting in 1984 and was made available as a system for fishing vessels around 1990. It was approximately 5 years before the whole Norwegian fleet used the GPS system. During this time, the receiver equipment became very light and inexpensive. Many vessels in Norway and the rest of the EU continue to maintain Loran C as an emergency backup to the GPS system.

13.14.3. Other navigation systems

The Omega system was introduced about 1970 and was used by merchant fleets, but not on fishing vessels. A new European satellite system called Galileo is now under development and will be introduced during next 4-5 years. Similarly the Russian system "Glonas" should be fully operational by 2008.

13.14.4. Plotters

Plotters for Decca and Loran were developed and introduced in 1975 (Kongsberg type). The system plotted on paper and was used mainly on factory trawlers. Video plotters were introduced in the early 1980s, but they did not have electronic charts. Chart plotters emerged in the market place around 1990 and have since been installed on most fishing vessels.

In 1999, Oleg in Norway introduced underwater chart-plotting technology. Later, Mack Sea and other companies developed similar equipment. These systems use information from GPS and the echo sounder to produce detailed 3-D underwater charts. The charts are made continuously during steaming and fishing.

13.15 The environmental effects of technological advances in bridge electronics

- Reduction of the uncertainty in fishing operations

Reduction of uncertainty assists a skipper to identify and accurately record (for revisiting) the best fishing grounds (those with high abundance of target species). As this technology has advanced, fishing operations will have become more spatially and temporally focused and less diffuse and speculative.

- Full exploitation of existing fishing grounds

Accurate position control and depth monitoring has allowed fishers to exploit more fishing grounds with confidence. A skipper may be increasingly able safely to steer the vessel closer to the extreme edges of fishable ground, closer to wrecks, obstructions, reef edges and dangers than was previously possible. This technology has therefore potentially increased the spatial distribution of fishing effort.

- Create new opportunities

New fishing grounds and opportunities may be identified through improved bridge electronics. This has taken the form of new and previously unexplored fishing grounds. In this case the technology has increased the spatial distribution of fishing effort. Wreck netting is reputedly to have expanded considerably as a result of these improved electronic aids to navigation.

- Adherence to spatial management measures

Accurate position control technology has given managers the confidence to implement fisheries management measures that aim to control, restrict or regulate fishing activity within a designated area. Fishers are in a position accurately to identify their location at all times and should therefore be in a position to comply. In this case the technology has reduced both the temporal and spatial distribution of fishing effort in line with management controls.

- Reduce lost fishing time

Fishing time normally lost as a consequence of twisted, poorly deployed, fouled or obstructed gears may be reduced by improved bridge electronics, as should time and resources spent on poor fishing grounds. In this case the technology has potentially increased fishing effort.

- Facilitate the retrieval of lost and abandoned fishing gear

The advent of GPS and high-resolution sonar has facilitated better recovery of lost and abandoned fishing gears. Recovery of lost gears is frequently undertaken by the fishers themselves or may be achieved through formal recovery programmes, such as a scheme currently operating in Norwegian waters. In this case the technology has been used to reduce the quantity of lost and abandoned fishing gears and the associated impacts with such material.

13.16 Some technological advances in fishing vessel and propulsion system design

13.16.1. General trends

During the 1800s, fishing vessels were powered by sail, but by the turn of the century, steam-powered vessels were beginning to dominate. By 1930, heavy-oil-burning fishing vessels were at sea and by the 1940s diesel power was the preferred choice of propulsion; that situation pertains still today. The change from sail to diesel had a huge impact on fishing vessels, opening up fisheries development throughout the world and allowing vessels to tow much larger and heavier fishing gears than previously possible. The transition from sail to diesel propulsion was therefore fundamental in the global exploitation of fish stocks.

Diesel fuel is now the second highest expense in the running of the great majority of UK fishing vessels. In the UK, crew expenses typically account for around 30% of vessel earnings and fuel expenses generally some 10–20%, although this figure varies considerably between fisheries. In beam trawling, fuel expenditure is even higher (c. 30% of earnings) while the static gear fisheries have the lowest, usually <10% (Watson and Martin, 2001).

Many of the advances in fishing vessel and propulsion design technology in recent decades, have focused on increasing efficiency through reductions in fuel consumption, particularly in vessels using mobile fishing gears. Typically, the advances have been made through the uptake of existing under-utilised technologies, such as bow thrusters, bulbous bows and propeller nozzles, rather than radical new developments. They have been implemented both during the ship design and construction phase and vessel refit procedures.

The fuel consumption and efficiency of diesel engines has not significantly improved over the past few decades, and any small improvements made have probably been offset with attempts to reduce the gaseous emissions of carbon, sulphur and nitrogen oxides of the engines in response to the IMO[74] regulations. Some fishing vessels have recently been built with diesel-electric propulsion systems[75] claim to offer a fuel saving when compared to 'straight' diesel engines.

It has become apparent in recent decades that many small and medium-sized vessels in the UK are being fitted with more powerful engines, and are built to increasingly bulbous and less streamlined designs in order to accommodate all equipment in shorter vessels. Such a design

[74] International Maritime Organisation

development runs counter to the 'fuel economy ethos', because vessels with a long thin shape at the waterline require much less fuel than short fat vessels. Vessels are built to offer the crew more comfort (Figure 38) and safety (see shelter decks Appendix 13.44) and a recent Norwegian build even included a study for the younger crew. Vessel construction has partially shifted to countries with comparatively[76] cheaper labour costs, such as China, Poland and Turkey, in order to keep costs minimised.

Figure 38. Accommodation on the recently built Norwegian long liner 'Frøyanes'

Figure 39. Newly built UK registered Euro cutter 'Admiral Grenville' built for Interfish Ltd, and based in Plymouth

A current successful modern design of vessel is termed the 'Euro cutter' (Figure 39), regarded by many as a vessel with an efficient design combination of hull and propulsion system. These vessels are fairly long and streamlined (around 20-25 m long), and are built as multi-

[75] Diesel engines powering electric motors used to run and propel the vessel.

purpose vessels, capable of beam trawling, single or multi-rig demersal trawling and even pelagic trawling.

The vessels are fitted with a single main engine of less than 300 hp[77], which is used solely to power the propulsion (i.e. no power take-offs). The vessels have auxiliary engines, which usually exceed the main engine horse power, and are used to power the bow-thruster and rest of the vessel's equipment (winches, generators etc.).

The main engine is attached to a gearbox usually with a very large reduction ratio of around 12-14: 1, enabling the vessel to power a large powerful 'slow turning' propeller (i.e. 2.5 m diameter), which is fitted with a nozzle. This class of fishing vessel has proven very efficient and popular, particularly with the Dutch, Belgians and more recently the British.

13.16.1.1 Kort nozzles

A Kort nozzle is a hydrodynamic duct surrounding a propeller, providing greater control of the stream of water passing through it. It was invented by Kort in the 1930s (Figure 40). Since then, the Kort nozzle has been repeatedly refined and is the probably most efficient method of boosting the thrust of a heavily loaded propeller. The Kort nozzle operates on a similar principle to that of everyday garden hose nozzles: a decrease in the area of a pipe translates into an increase in the velocity of the fluid passing through it. Kort nozzles can produce up to 20% additional thrust without extra fuel consumption. A fishing vessel can therefore potentially pull larger fishing gear, with up to an extra 20% drag for the same fuel cost.

Figure 40. Kort nozzles

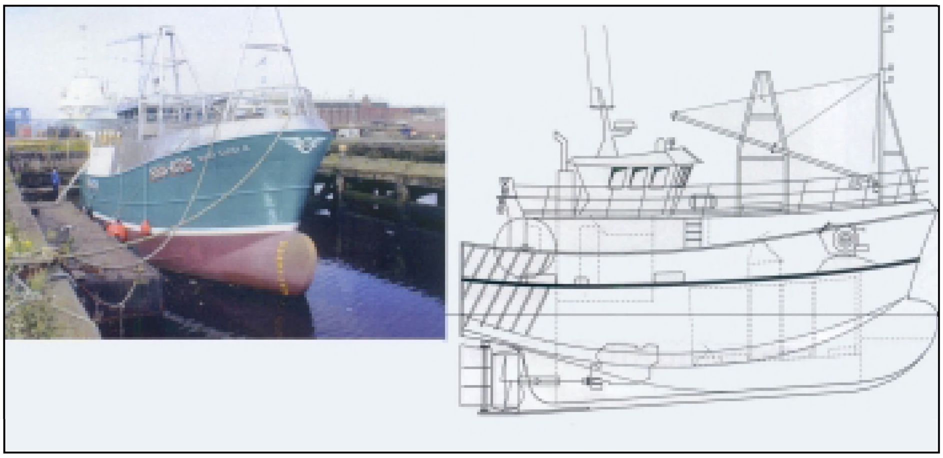
13.16.1.2 Bulbous bows

Introduced in the late 1950s and originally designed for use on large merchant cargo vessels, the bulbous bow now features on many existing and new designs of fishing vessel (Figure 41). Its purpose is to reduce drag through the water, so making the vessel more energy-efficient. It works by creating its own wave, which cancels the hull's bow wave (a source of

[76] Compared with most Western European nations
[77] Vessels with <300 hp are permitted to fish within 6 mile limits.

energy loss). Bulbous bows also increase the waterline length and reduce vessel pitch. Modern designs of bulbous bow can reduce fuel consumption by up to 25%, giving the vessel equivalent greater range or a slightly higher speed for the same power applied, whichever is preferred.

Figure 41. Vessel with bulbous bow (SK91 15m McAllister trawler built and designed by SteelKit, Aberleri Boatyard, Wales [78]



An article in the National Fisherman Yearbook of 1985 records the effect of a bulbous bow on a fishing vessel….

"In Australia a bulbous bow was retrofitted on a 50' shrimp trawler with on-board computers and monitoring devices as part of a five-year research project to test the bulb's effectiveness. The vessel is dryer, pitches less in a head sea and is more stable and manoeuvrable in a following sea. The vessels tows its net at a lower engine speed, achieves a 10% greater top speed and burns 8% less fuel over-all... The bulb absorbs energy as it is pulled up and down through the water as the boat pitches and heaves. This tends to dampen the motion, making the boat dryer and more comfortable for the crew... In MIT tank tests on a 76' trawler towed at speeds equivalent to 9-11 knots show a reduction in resistance of 20%-25% fuel savings…"

The environmental impacts associated with the introduction and use of bulbous bows into the fishing fleets are largely speculative and are not well documented. However, a vessel with a bulbous bow is certainly able to tow a larger net than an equivalent vessel without one. Similarly such a vessel would be able to go to and from the fishing grounds more quickly and could tow an identical net faster through the water and could cover more ground than a non-bulbous bow vessel. These facts suggest that this advance in technology has most likely led to an increase in the environmental impact of the fish capture industry.

[78] www.steelkit.com

13.17 An overview of fishing-gear-related projects undertaken by Seafish (Technology) Hull during the years 1980–2003.

A total of 973 Seafish consultancy reports / internal reports /external reports published by the Sea Fish Industry Authority covering the period 1980–2003 were examined. Of these, 109 were relevant to fishing gear technology and are listed in Appendix 13.18. The reports covers technologies, some of which aim to expand and make fisheries more efficient, resulting in increased environmental impact, as well as technologies that specifically aim to mitigate environmental impact. A breakdown of the reports is given below.

13.17.1. Trawling technology (including ground gears trawl testing and improvements)

In total, 26 separate reports on this subject were undertaken during the past 20 years. Some of the reports detail projects lasting 4 weeks, some longer, and all involved sea trials. The main outcome of the works was that trawlers were able to fish with increased efficiency, to exploit new grounds (e.g. Figure 42) and to tune trawls to catch different species. The consequential environmental impact of the work is likely to have been an expansion of fishing effort, as much of the work was taken up by the industry.

Figure 42. Rockhopper fishing gear developed to fish on previously untrawled rough fishing grounds

13.17.2. Twin-rig trawling

Specific reports on this subject are few (just three), but Seafish operate specific training courses and have produced a video on this subject. This work has contributed to the successful take-up by the industry of twin-rig trawling, particularly by the *Nephrops* trawler fleets. Environmental impacts have been increased as a result of twin trawling.

13.17.3. Improving the efficiency of wreck netting, tangle netting, gillnetting and drift netting

There are 16 reports covering fishery-specific projects, usually involving large amounts of staff time. The projects have been long, infrequent and have generally enabled fishers to target species more specifically with their gears. In some cases, technologies have been developed that rendered fisheries more economically viable. Industry has taken up much of this work and ideas have been quickly adopted across many geographical areas. The environmental impacts from this may have increased the occurrence of lost/abandoned fishing gear.

13.17.4. Exploitation of new fisheries

There are 16 reports in this field. They relate to projects that have been mostly desk-based, although some have involved charter work. Some of the projects have dealt with technology transfers from other EU Member States. Some work has been undertaken in relation to the exploitation of deep-water fisheries, although this has been mainly Seafish staff reporting on and organising conferences. Some of this work has led to new opportunities for sectors of the industry and fishers have been able to switch to less exploited local fisheries. A likely consequence of the take-up of this work has been further increases in environmental impact.

13.17.5. Traps, pots and creels

There are 14 reports on this subject, and research in this field has tended to be spasmodic rather then regular. The projects have been small in scale and aimed at specific fisheries. The most successful has been the introduction of trapping as a method of capture for cuttlefish, a technique that was rapidly adopted by certain sectors of the industry.

13.17.6. Improving the selectivity in static and towed gears

This area has been a heavily resourced area of research within Seafish, producing some 26 reports on various selectivity projects over the past 20 years. Most of these have been undertaken during the past 10 years and have involved considerable staff and sea time. This work has led to the successful development of discard-reduction technologies, some of which has been legislated for (i.e. square mesh panel in *Nephrops* fisheries) and some of which has not (i.e. separator trawls). When used by the industry, these technologies have the capacity to reduce environmental impact.

13.17.7. Other techniques of environmental impact mitigation

These include most notably electric beam fishing and studies on the impacts of ghost fishing. Ten reports have been produced in this field and work in the area has been spasmodic, with just two large projects and very little in between. The electric fishing work was abandoned some decades ago as the equipment developed was not sufficiently robust for commercial uptake and presented many other practical difficulties. The ghost net studies were successful in that they produced much insight and knowledge on the nature and magnitude of impacts associated with this phenomenon. They also identified areas and conditions where ghost fishing is most detrimental to the environment.

13.18 Relevant Seafish reports

CONSULTANCY REPORTS

CR153	Nov-98	Drift Netting for Tuna: The Feasibility and Costs of Alternative Fishing Methods (MAFF) J. Swarbrick
CR141	Apr-98	Technical Assessment of Multiple Bodied Trawl Development Project G. Dunlin
CR123	May-97	PESCA Funded Deep Water Trials G. Dunlin
CR119	Feb-97	Exploratory Fishing Trials for *Nephrops norvegicus* in Sea Areas Around St.Kilda M. Jacklin
CR116	Oct-96	Selectivity of Gill Nets in the North Sea, English Channel and Bay of Biscay G. Dunlin
CR108	Mar-96	Incidental Impacts of Gill Nets (Fantared) P. MacMullen, G. Dunlin
CR102	Nov-95	Selectivity of Gill Nets in the North Sea, English Channel and Bay of Biscay G. Dunlin
CR90	Oct-94	Selectivity of Gill Nets in the North Sea, English Channel and Bay of Biscay G. Dunlin
CR89	Oct 94	Improved Selectivity in the North Sea Fishery: Species Optimisation of a Selective Beam Trawl- Seafish Periodic Report No.1 J. Swarbrick
CR75	Jan-94	Otter Boards. Establishing Criteria for Design Improvements J. N. Ward
CR79	Dec-93	Summary of CR69 Improved Selectivity of the Scottish & Danish Seine in the North Sea Fishery, Contract No. TE 2-411 A. Hopper
CR66	Oct-93	Investigation of the Selectivity of Static Nets, and an Assessment of Bycatch Effort and Discards ICES Areas VIIE & VIIFJ. Swarbrick
CR60	Mar-93	Investigations of the Selectivity of Static Nets and an Assessment of Bycatch, Effort and Discards ICES Areas VIIE & VIIF J. Swarbrick
CR62	Aug-92	Square Mesh Trials on "AMARANTH" B. Ashcroft
CR55	Aug-92	Classification of Fish Using High Resolution Sonar Techniques: Phase 1 H. English
CR47	Nov-91	EC Funded Seine Net Selectivity Project TE-2-411 B. Ashcroft
CR38	Jun-91	Classification of Fish Using High Resolution Sonar Techniques: Phase 1 H. English
CR29	Jun-90	Brown Crab Fishery in Western Isles P. MacMullen
CR15	May-90	Comparative Sea Trials on "PETER ROSS" Hydrodynamic Trawl Floats J. N. Ward
CR40		Highland Region. The Creel Fisheres of Caithness and Sutherland. Prospects for Development 1991-92 P. MacMullen

INTERNAL REPORTS

IR1000	Nov '81	A working paper on fish traps.
IR1003	Nov '81	Commercial assessment of electrified beam trawl on "c.k. amber".
IR1004	Nov '81	Electro trawling trials m.t. "boltby".
IR1049	May '82	Pair trawling abroad mfv's "tradition" & "industry".
IR1051	July '82	Fish trap trials from Salcombe.
IR1052	July '82	Mechanisation of longlining autoclip system.
IR1055	Sept '82	Sfia 3 bridle butterfly wing trawl trials.
IR1057	Sept '82	Instrumentation trials on 200 h.p. single boat mid water net.
IR1063	Dec '82	Trials with the double boom rig.
IR1068	Dec '82	Mechanisation of longlining autoclip syatem.
IR1071	Jan '83	A sea voyage on board the grimsby wreck netter "mfv kelly".
IR1083	Apr '83	Gill netting survey – spring '83.
IR1085	Apr '83	Sea trials with heortness trawl doors.
IR1097	June '83	Pair trawling abroad the mfv "boy carl" & mfv "boy jason".
IR1103	July '83	Performance trials on pair trawlers – Bridlington.
IR1104	July '83	Further trials of double rig gear on linquenda
IR1111	Sept '83	Double rig trawling by small vessels and mechanisation of drift net hauling.
IR1114	Sept '83	A model of wreck net fishing for training. (Birmingham university msc thesis).
IR1122	Oct '83	Visit the Bergen institute of fisheries technology and observations on monofilament longlining.
IR1125	Nov '83	Fish handling practices and operating patterns on inshore gill netters.
IR1126	Nov '83	Squid fishing trials aboard frv g.a. reay.
IR1129	Nov '83	Squid fishing trials aboard mfv "joker" in cornwall.
IR1131	Nov '83	The van woensel shrimp peeling machine.
IR1132	Nov '83	Data sheet production 3 bridle butterfly wing trawl trials.
IR1138	Jan '84	An investigation into the performance of the electrical transmission cables/system during commercial fishing conditions on board the "zuiderkruis".
IR1139	Jan '84	Visit to see geba brown shrimp peeling machine.
IR1141	Feb '84	Methods to determine the configuration and tension of an electric cable during electro trawling operation.
IR1144	Apr '84	Trials of tangle nets for spider crabs at brighton.
IR1150	Apr '84	Monofilament lomglining – a visit to guernsey.
IR1164	May '84	Skippers report on monofilament lining (samantha rose).
IR1166	June '84	Trawl door trials s.r.v. clupea.
IR1167	June '84	A practical investigation study into the application of electro-narcosis to otter trawling.
IR1172	Aug '84	Trials with monofilament longline gear.
IR1176	Oct '84	Squid fishing aboard mfv 'emme jane' in gardenstown.
IR1195	Feb '85	Autoclip system "mfv brendianne".
IR1201	Mar '85	Trials with monofilament longline gear on mfv "gannett" in whitby.
IR1217	June '85	Trials of 8fm 3 bridle butterfly wing trawl.
IR1232	July '85	A ghost-net experiment in shallow water near Plymouth.
IR1234	July '85	Instrument trials of hard ground rock trawl.
IR1235	July '85	A study of squid and its potential in uk water.
IR1238	Aug '85	Conversion of oil rigs to fish reefs – a concept into using whole of partial oil/ gas rig installations as artificial reefs for fish aggregation.
IR1240	Oct '85	Multy rig trawling – Lowestoft sole fishery.
IR180	Nov '84	Trials of the electric beam trawling system on mfv "zuiderkruis", summer 1983.

SEAFISH REPORTS

SR177	Sept 80	Conversion of Side Trawlers to Double Beam Trawlers C.E. Tucker
SR201	Mar 83	Design Characteristics of Middle Water Trawlers: Study of Machinery Requirements H.R. English
SR203	Mar 83	Set Net Trials on MFV 'Victory of Helford' P. MacMullen
SR230	Oct 83	Trials of Nephrops/Fish Separator Trawl and survey of New Prawn Grounds in Southern North Sea B. Ashcroft
SR232	Dec 83	Double Rig Trawl Fishing for Nephrops Norvegicus H. McDiarmid
SR235	Feb 84	Gill-Netting Trials on MFV "Heart of Oak" of Helford P. MacMullen
SR248	June 84	Trials with Monofilament Longline Gear H. McDiarmid
SR253	Sept 84	Trials of Fish Prawn Separator Trawls on Fishing Grounds in the Irish Sea - ICES Area VIIA B. Ashcroft
SR255	Dec 84	Pair Trawl Trial Results - Aquila/Poseidon C. Brady
SR256	Dec 84	Towing Requirements for a Pair Trawl (2 x 340hp Vessels) C. Brady
SR257	Jan 85	The Performance of High Speed Fishing Vessels in Service N. Ward
SR266	April 85	Pair Seining Trials on Grimsby Anchor Vessels B. Ashcroft
SR278	Oct 85	Double Rig & Separator Trawl Held in Firth of Forth B. Ashcroft
SR336	June 88	Commercial Fishing Trials of a Twin Rig Trawling System Using a Twin-Warp Arrangement - 'Cygnus Star'K. Arkley
SR341	Feb 88	The Development of a Suitable Synthetic Replacement for the Traditional Cotton Drift Nets as Utilised in the Cornish Pilchard Fishery K. Arkley J. Swarbrick
SR378	May 90	The Use of Square Mesh Selector Panels as a Means of Improving Selectivity of Demersal Towed Fishing Gear K. Arkley
SR379	June 90	Selectivity Trials of Seine Net Codends - MFV 'KESTREL' (INS 253) - April 1990 K. Arkley
SR382	April 90	Fishing Trials to Evaluate the Relative Selectivity and Efficiency of Different Netting Yards Used in the Construction of Static Nets Used in the Fisheries for Sole and Place in the Eastern English Channel K. Arkley
SR383	Dec 90	Fishing Trials to Evaluate the Use of Square Mesh Selector Panels Fitted to Nephrops Trawls - MFV 'HEATHER SPRIG' (BCK 181) - November/December 1990 K. Arkley
SR384	Jan 91	Square Mesh Selector Panels as a Means of Improving Selectivity of Demersal Towed Fishing Gears K. Arkley
SR391	Apr 91	An Investigation of the Performance of Tangle Nets used off North Cornwall J. Swarbrick
SR401	Jan 92	Selectivity Trials with the Looe Pair Trawling Team of 'BUDDING ROSE' (LH134) and 'LEVAN-MOR' (FY269) K. Arkley
SR402	Feb 92	Selectivity Trials in the Static Net Fishery for Hake off Cornwall J. Swarbrick
SR406	May 92	CES Area VIIf selectivity Trials. Single Boat Demersal Trawl MFV 'OUR OCEAN HARVESTER' (PZ403) K. Arkley
SR408	Sept 92	Initial Trials to Increase Acoustic Detectability of Drift Nets used in the Albacore Tuna Fishery J. Swarbrick, et al
SR421	May 92	Improvement of Selectivity of Trawl Codends K. Arkley
SR422	May 93	Improved Selectivity in Demersal Trawl Gear K. Arkley
SR438	Mar 94	Deep Water Fisheries of the North Atlantic Slope A.G. Hopper
SR441	May 95	Improved Selectivity in Towed Gears - Sea Trials to Evaluate Selectivity of Separator Trawls used to catch Mised White Fish Species K. Arkley W. Lart J. Swarbrick
SR444	Aug 94	Exploratory Fishing for *Chaceon* (Geryon) *Affinis* on Rosemary Bank G.P. Course W. Lart
SR445	Aug 94	Further Evaluation of Square Mesh Panels to Improve Selectivity for Cod in Demersal Trawls G.N. Dunlin
SR446	Aug 94	Experimental Fishing Using Fish Traps G.N. Dunlin
SR449	Sept 94	Deep Water Fishing Along the North Atlantic Slope - Fishing Trials Onboard MFV 'Marantha III' B. Greenwood
SR453	Jul 96	The Handling, Processing, Storage and Eating Qualities of Deep Water Fish J. MacNamara
SR460	Dec 94	Further Investigations into Selectivity and Separator Trawls J. Swarbrick W. Lart K. Arkley
SR464	Jan 96	The Use of Separator Trawls as a Tool for Improving Selectivity for Cod K. Arkley

SR465	Jan 96	Cuttlefish Quality and Handling Trials M. Boulter
SR499	Dec 96	Tangle Net Fishery for Spider Crabs (Maia Squinado) G. Dunlin
SR508	June 96	Review of Technical Conservation Measures in UK Nephrops Fisheries G. Dunlin J Swarbrick P MacMullen K. Arkley
SR509	Jul 96	Scallop Dredge Selectivity: Contribution of Tooth Spacing, Mesh and Ring Size: Part 1. West of Scotland Sea Trials W. Lart R. Horton R. Campbell
SR516	June 98	The Cornwall Pilchard Fishery: Drift Net or Purse Seine? J Swabrick G.Dunlin
SR522	Nov 98	Evaluation of Bycatch Reduction Devices in UK Nephrops Fisheries: Use of Separator Trawls. G.Dunlin
SR532	May 00	Evaluation of Technical Conservation Measures in UK Nephrops Fisheries - New Trawl Designs K. Arkley, G. Dunlin
SR539	Dec 01	Investigating the Use of Low Diameter Twine for the Construction of Square Mesh Pane Arkley G. Dunlin
SR540	Dec 01	Investigating the Use of Double Square Mesh Panel Arrangements in Pair Trawls K Ark G. Dunlin
SR544	Sep 02	Further Investigations into the Use of Low Diameter Twines for the Construction of Square Mesh Panels K Arkley G Dunlin

13.19 Twin- and multiple rigged trawling

A significant technological development in trawling in recent years has been the advent of twin/multiple rig trawling. Twin-rig (Figure 43) and multiple rigged trawls (Figure 44) are more effective at catching fish than an equivalent single rig trawl and are more effective at herding fish into the nets. Catch improvements of 81% (anglerfish), 40% (flatfish) and 340% (*Nephrops norvegicus*) has been recorded with the use of a twin-rig trawl (Sangster and Breen, 1998). A twin trawl creates less drag than a single trawl of equivalent size, so vessels are able to deploy large trawls with improved catching efficiency. Triple and quadruple trawls have recently been developed, based on the same principle.

Industry take of twin-rig trawling has been substantial, particularly in the *Nephrops* fisheries around the UK, and also in the exploitation of deep-water species (see section 13.3). The increased catch rates associated with twin and multiple rig trawls has probably simultaneously increased environmental impacts by increasing fishing pressure on exploited stocks, and by increasing the quantities of discards.

Figure 43. Twin-rig trawling

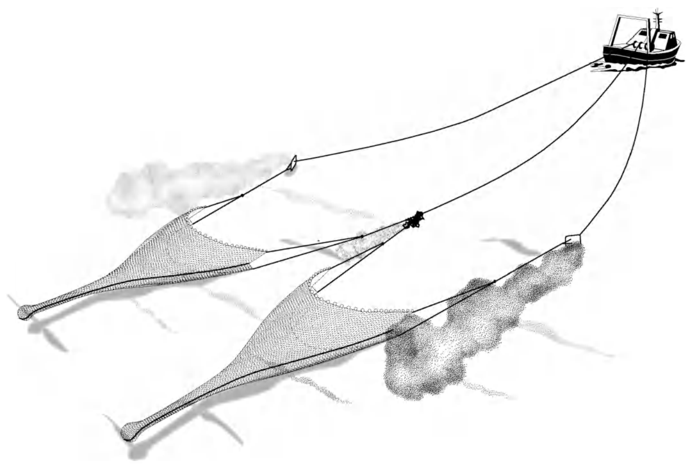
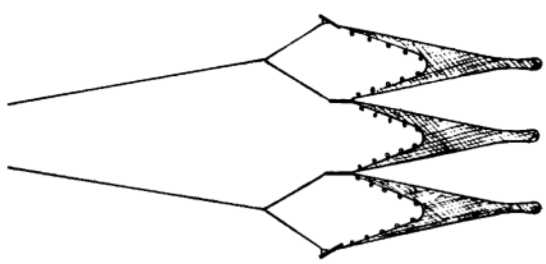


Figure 44. Triple rig



13.20 Single and twin beam trawling

Beam trawling is a fishing technique whereby a trawl is attached to a beam and shoes and is hauled along the seabed by the vessel (Figure 45). This technique allows the trawl to be pulled at speed while maintaining a constant trawl shape; it is predominantly used to target flatfish in the North Sea, Irish Sea, Southwest Approaches and English Channel. The technique is also used in inshore coastal regions to target brown shrimps (*Crangon crangon*). Traditionally many British vessels towed a single beam from the stern of the vessel, but the switch-over to twin beam trawling is now virtually universal in all these fisheries (Figure 46).

The virtual doubling of the catch rates associated with twin beam trawling stimulated the switch from the use of single beams, the effects of which are dramatically shown in Figure 47 Beam trawling has many environmental impacts and the switch in technology from single to twin beam trawling has undoubtedly resulted in a parallel increase in environmental impact (i.e. benthic impact and incidental catches).

Figure 45. A beam trawl

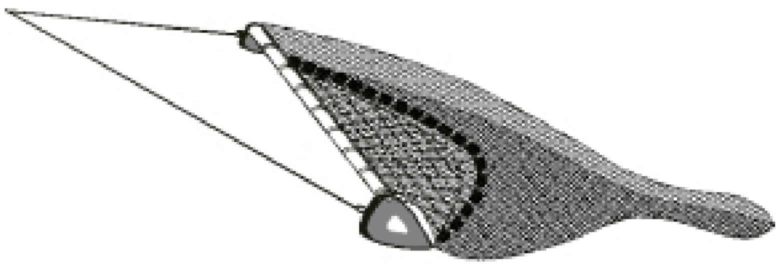
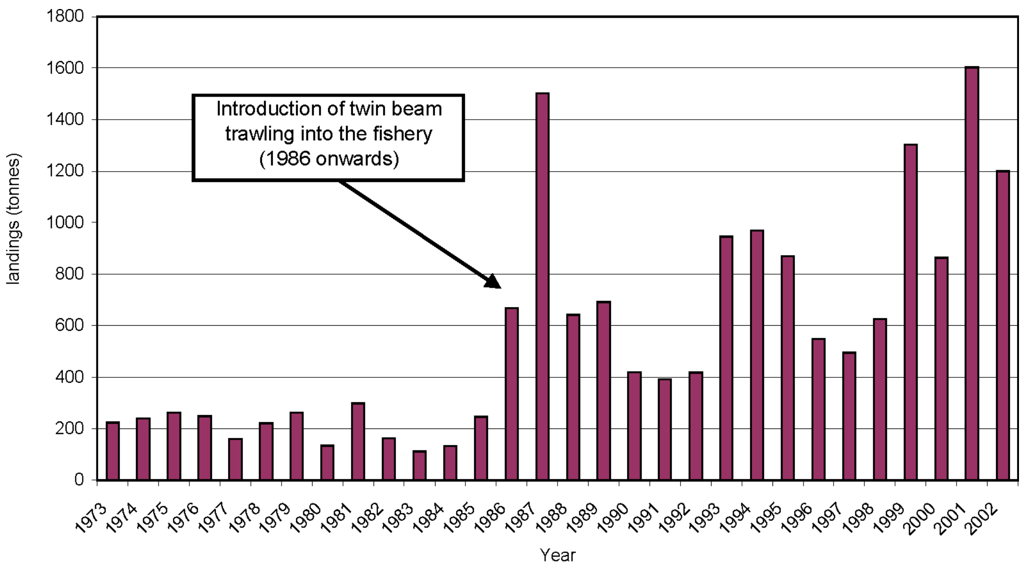


Figure 46. Twin beam trawler

Figure 47. Single beam trawler

Figure 48. Catch rates in the UK (East coast) brown shrimp beam trawl fishery



13.21 *Advancements in onboard catch riddling*

Figure 49. Modern rotary catch riddle machinery

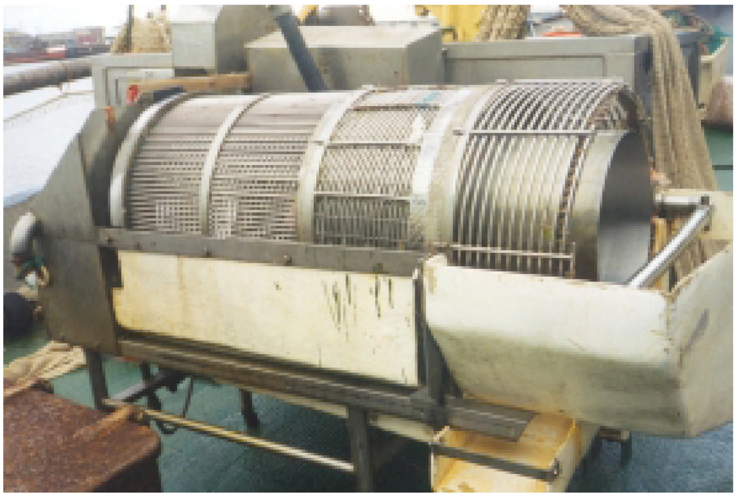


Figure 50. Traditional hand riddle

13.22 Case Study[79]: Development of the Irish RSW pelagic fleet

"Maybe we can make a career out of this, rather than just going along from day to day in a haphazard and unorganised sort of way" (Howley, 2001)[80].

In the early 1970s the Irish fishing fleet was mainly small (50-60 foot) wooden vessels, most rather antiquated and inefficient, scraping out a living on mixed whitefish species and herring. By 1975 the situation had improved slightly as new market opportunities opened, particularly for mackerel, while investment by the Irish government helped to modernise the fleet to some degree.

Observing the success of Scottish and Scandinavian fishermen in the lucrative pelagic fisheries, five of the leading Irish skippers decided in 1979 to invest in new pelagic purser/ trawlers fitted with Refrigerated Sea water Tanks (RSW), specifically to target mackerel and herring. These vessels included the "Jasper Sea" and "Albacore" and were not big by today's standards, ranging in size from 24 to 33 m, but at the time they represented a huge investment to the owners, on a scale unheard of in the Irish fishing industry. Most of these vessels were privately funded, receiving no grant aid from the Irish Government. All were rigged for trawling and purse-seining, the favoured technique in the North Sea, but all skippers switched over exclusively to pair trawling as fish off the west coast tended to be deep and the weather much more severe than in the North sea. Success was almost instant!

The following years saw a boom in the pelagic sector, with an abundance of fish and strong markets in the eastern bloc and Africa. By the beginning of 1987, there were 23 vessels in the RSW fleet, 16 in the size range 25-39 m and another seven >39 m, including the 65 m/4000hp "Atlantic Challenge" and "Western Endeavour", built in 1986 in Norway at a cost in excess of €5 million each[81]. The vessels were "state of the art" and were the result of the owners recognising the need to adapt to changing migration patterns of pelagic species and also for greater carrying capacity and seaworthiness. In the early 1990s, the markets also started to require a better quality product, which was difficult to achieve in smaller vessels with small RSW plants. These bigger vessels gave the freedom of steaming from the grounds, which could be as far away as North Sea or the Shetland area, to port with viable quantities of good

[79] Case study by Dominic Rihan. (Fishing gear technologist). Bord Iascaigh Mhara (BIM) Dublin, Eire
[80] Extract from paper given by Howley, M. 2001. "Development of mid-water trawl technology". Full Summary of Proceedings of Fishing Gear Systems Conference, March 27-29.
[81] Anon, 1987. Charting a New Course … BIM Development Strategy for the Seafish Industry 1987/91Bord Iascaigh Mhara Report, December 1987. 172pp.

quality fish. Other skippers recognised this and also either lengthened their existing vessels or built new boats e.g. “Sheanne”, “Paula”, “Father McKee” and “Brendelen”.

Throughout this period of development in the fisheries and vessels, there were considerable improvements in trawl design, with the use of new low-drag materials; in hydraulics, with the advent of fish pumps and auto-trawl systems; better refrigeration systems; and electronics, including catch sensors and forward-looking sonar. The Irish pelagic fleet has been at the forefront in the development of many of these and names such as Albert Swan, Martin Howley and John Bach are synonymous worldwide with the development of pelagic fisheries. While catching capacity particularly for mackerel increased, the Irish mackerel quota did not increase as rapidly. Therefore, to ensure viability, the pelagic fleet and particularly the newer, larger vessels, as early as 1988[82], began to diversify into other fisheries for non-quota species such as horse mackerel, blue whiting and argentines. These fisheries in their own way presented problems in relation to gear design, fish detection and fish handling which all had to be dealt with as and when they arose. Most of this work was done with very limited financial support from the Irish government, and the loss of codends valued at more than €50 000 each, or winches having to be replaced as a result of buckling of the side plates caused by the excess pressure being put on them when fishing at depths in excess of 200-300 fathoms were all costs that had to be borne by the owners of the vessels.

Currently, the Irish RSW fleet has stabilised at 22 vessels with a total GRT of 22 000 tonnes and a power of approximately 37 000 kW, employing more than 250 fishers[83] (This does not include the freezer vessel “Atlantic Dawn”). The vessels range in size from 27 to the 64m/7500hp “Atlantic Challenge” (a replacement for the original vessel built in 1986). This vessel has a carrying capacity of 1 550 m^3 in nine separate RSW tanks and cost more than €12m in 1999[84]. Currently, five more replacement vessels are on order, representing a total investment of more than €70m. Most of the RSW fleet is based in the NW Donegal port of Killybegs, ideally placed for vessels to exploit the pelagic stocks off the west coast of Ireland. Killybegs is Ireland`s premier fishing port, landing more than 85 000 tonnes of fish in 2001 with a value of €26.2m. When the many processing and ancillary services are taken into account, the value generated by fishing activity in the port exceeds €50m, of which 90% comes from landings of pelagic species by the RSW fleet, and in fact many owners have

[82] “Exploratory Fishing Voyages for Non-Quota Species by the “Atlantic Challenge” and “Western Endeavour” EU Project EXP/IRL/1/88

[83] Anon, 2002. Economic Performance of Selected European Fishing Fleets. Annual Report 2002. EU Concerted Action Q5CA-2001-0150. Pages 50-51 & 155.

invested heavily in processing facilities. It is interesting that, as the RSW fleet has developed, landings of all pelagic species by Irish vessels have increased from 56 000 tonnes, valued at €10m in 1977 to 223 000 tonnes valued at €67m in 2001. Mackerel landings have risen from €2.5 to €28m over the same period[85], while horse mackerel landings have increased from €2.3 to over €18m from 1983 to 2001.

The development of the Irish RSW fleet is a good example of how a sector of the fishing industry has adapted and evolved to overcome uncertainty and maintain viability through difficult times and in a climate of continued EU policy change in regard to fleet capacity. This has largely come about through private investment back into the industry with little or no reliance on State aids or subsidies. The sector has shown a willingness to change to improve efficiency, but also has taken into consideration changing market requirements and the need to diversify into new fisheries for under- or non-utilised species, and is now recognised as one of the most efficient fleets in the world.

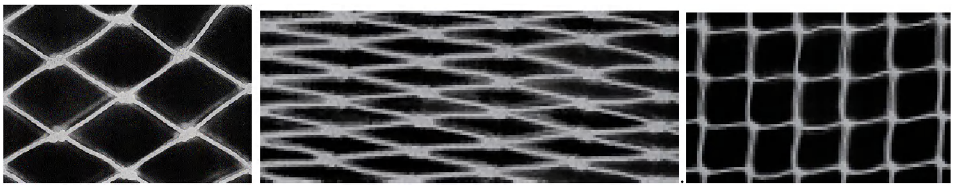
[84] Anon, 2003. Fishing Vessels of Britain and Ireland 2003. Fishing News publication. Agra Europe (London) Ltd. 366pp.
[85] Central Statistics Office, 2002. Fishery Statistics 2001. Government Publications. 12pp.

13.23 Mesh shapes

13.23.1. Mesh modifications

The manipulation of mesh size to control the incidental capture of unwanted species in fishing gears is a primary tool of fisheries managers (Figure 51). The efficacy of this tool can be diminished in mixed fisheries, or in conditions where the mesh opening is restricted, i.e. due to masking, tension, rigid twines, twisting and asymmetrical meshes. Traditionally, fishing mesh is diamond shaped, but some alternative shapes of mesh can greatly reduce the retention of unwanted species in the fishing gear.

Figure 51. Mesh shapes



Left: open diamond meshes
Centre: Diamond mesh with reduced opening
Right: Square mesh

13.23.2. Diamond mesh

The majority of fishing gears are constructed from diamond-shaped netting. The vertical distance between the top and bottom knot is termed the mesh opening (mesh size). The mesh size of netting used in the construction of a fishing gear will largely determine the size of animal able to pass through the mesh or not. Regulations governing the mesh size of nets are therefore used in virtually every net-based fishery in the developed world in an attempt to make the fishing gear as size selective as possible, thus reducing environmental impact.

The size-selective properties of a fishing gear mesh can be dramatically reduced when tension is applied, if the mesh is constructed from stiff or thick material, or side knots are not central, or mesh becomes masked, or mesh is twisted, etc. Such events occur commonly in fishing gears, either through natural processes or by deliberate fisher action, and they reduce the efficacy of the size selection process. Attachments to the gear, designed to protect meshes from damage, such as lifting bags and chafers, can also reduce the selective properties of the mesh.

Problems in achieving desired net size selectivity for a given species might be exacerbated if that species exhibits irregular growth patterns between cohorts or lifecycle changes, e.g. during spawning and feeding cycles.

Fishing grounds are usually host to a wide range of fish species, so fishing gears will usually catch a wide range of species of many shapes and sizes. Simple mesh size controls of fishing gear will rarely result in the clean selection of target species of a desired size in such mixed fisheries.

13.23.3. Square mesh

Distorting the normal lay of diamond mesh can make square mesh or it may be purposely constructed on a loom. Square mesh can allow round fish to pass through more readily (but not flatfish) than that of an equivalent diamond mesh, and it also retains its mesh shape and opening under tension.

Some problems with square mesh include knot slippage (in knotted square mesh) and can be more difficult for fishers to mend. Square mesh has been widely used in experimentation, mainly in escape panels and codends to reduce environmental impact.

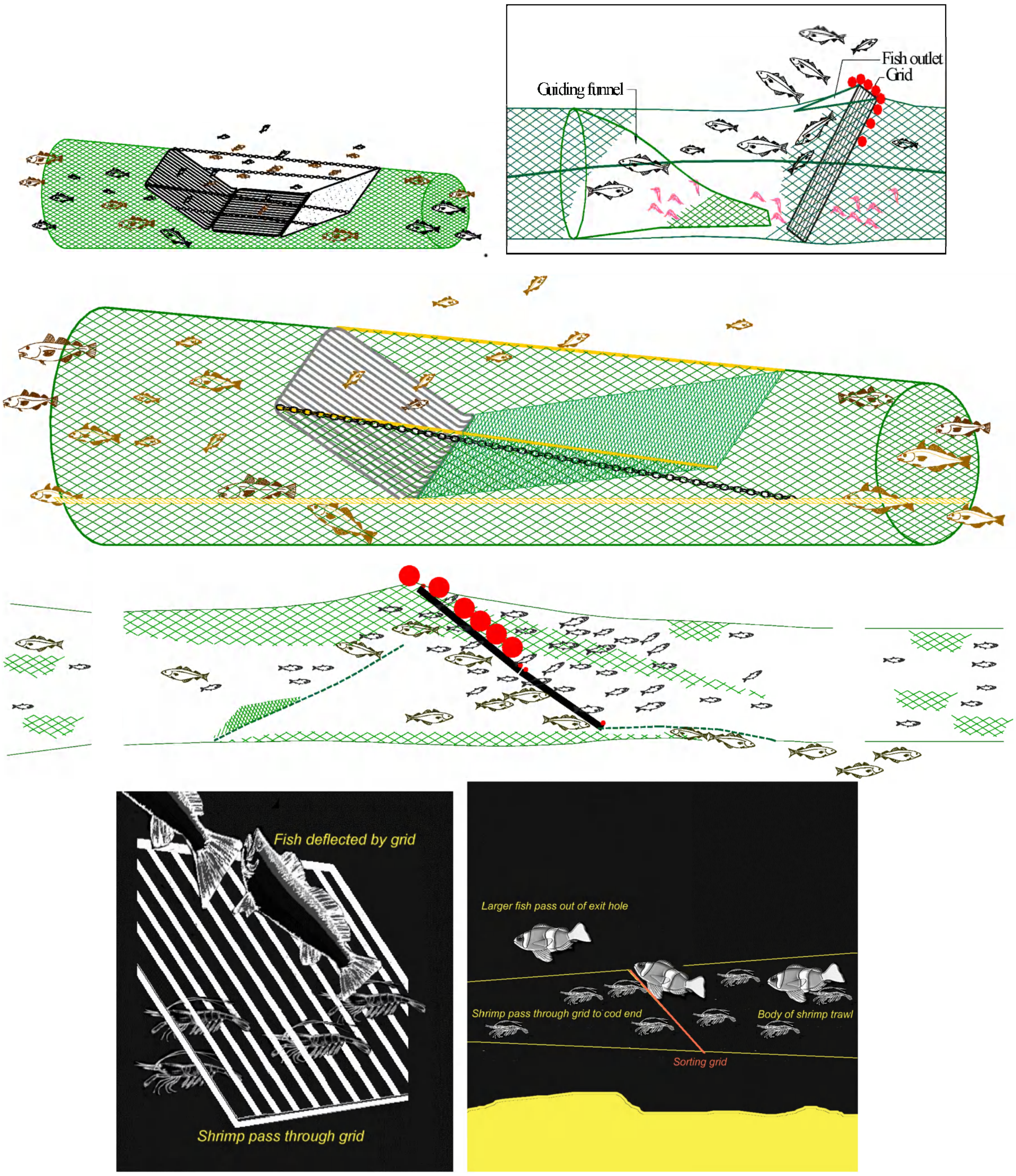
13.23.4. Other shapes

Other mesh shapes, such as rectangles, scone mesh and hexagons may have some potential application in reducing environmental impacts through net design.

13.24 Grids

Grids are rigid or semi-rigid sorting devices fitted to the inside of towed gears (Figure 52). They can be used to sort and separate catches by size and shape while the trawl is being towed. The sorting procedure is largely controlled by the bar spacing and, once sorted, the unwanted fraction of the catch can be eliminated from the fishing gear. .

Figure 52. Some grid designs[86]



[86] Graphics: Courtesy of the Institute of Marine Research, Bergen, Norway

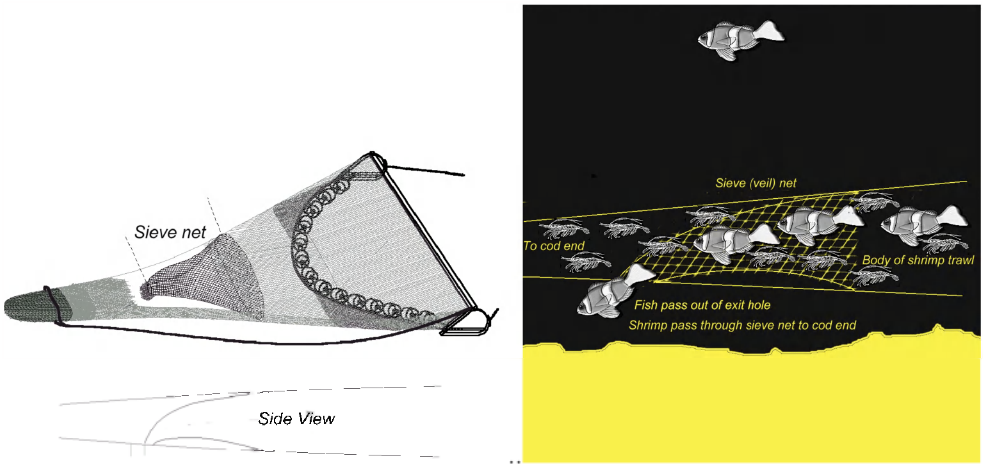
Since 1995, grids are been mandatory in the Flemish Cap *Pandalus* shrimp fisheries (NAFO division 3M) exploited by vessels from Canada, Denmark, Faeroe Islands, Spain, Greenland, Iceland, Norway, Russia, Latvia, Lithuania and St Vincent. They are also mandatory in the *Pandalus* fisheries of the Canadian east coast, Barents Sea, Spitzbergen and Iceland, and reduce by-catch rates by up to 85%. Grids are also used on a mandatory basis in the inshore Faeroese lemon sole/plaice/monkfish fishery, Canadian industrial silver hake fishery and in the United States and Australian prawn fisheries, to reduce turtle by-catch (Anon., 1998a).

Grids have a wide variety of potential applications in fisheries, but are problematic in that they can cause handling problems for the fisher and can suffer damage and blockage while being towed. To date they have worked most reliably and effectively in relatively clean fisheries.

13.25 Sieve nets

Sieve nets (also known as veil nets) work on a similar principle to that of a grid, but are constructed from netting and are cone-shaped (Figure 53).

Figure 53. The sieve net fitted into a beam trawl

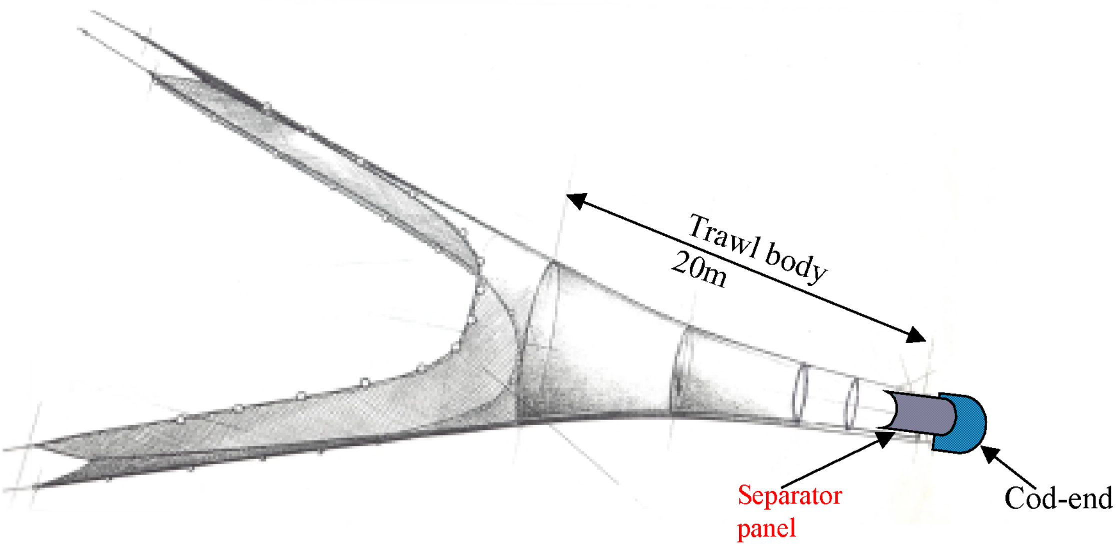


These were recently made mandatory under EU legislation in all European brown shrimp fisheries, and are preferred by the fishers to grids, which may be used as an alternative to sieve nets under the legislation. Sieve nets do not have the same handling problems as grids and are less prone to blockage, because they have a larger sorting area. Sieve nets have significantly reduced environmental impact in the brown shrimp fisheries by releasing large quantities of juvenile fish and invertebrates from the trawls during the towing process. The technology has potential for use in other fisheries, but has not been taken up yet.

13.26 Separator panels

Separator panels work on the principle that different species of fish can be separated by behavioural differences they exhibit once caught within the body of a moving trawl. Once separated the fish can be subjected to further sorting or grading by mesh size, etc.

Figure 54. The inclined separator panel



Source: Geartech, Eire

Historically, most of the developmental work in this field has been undertaken in the mixed cod, whiting and haddock fisheries of North England and Scotland. Cod tend to stay at the bottom of the trawl, whereas haddock and whiting rise up during the capture process. These two groups of fish can be separated by a horizontal separator panel in the trawl and be further sorted independently of each by mesh size, etc. More recent work has been undertaken with this technique in various fisheries in the USA. The technology overcomes some of the problems associated with use of a single mesh size in mixed fisheries (see section 13.23.2.).

Modified separator trawls (inclined separator trawls) have recently been introduced into the Irish Sea *Nephrops* fisheries to protect spawning cod stocks (see case study in Appendix 13.27). Uptake by the industry was poor, and some adulteration of the panels was reported.

Separator panel technology has not been widely adopted by the industry or legislators despite the success of the development work.

13.27 Case Study[87]: Protecting Spawning Cod in the Irish Sea through the use of inclined separator panels in Nephrops trawls

In the Irish Sea (ICES Division VIIa), the cod stock is exploited by vessels from Northern Ireland fishing with semi-pelagic trawls and an Irish mixed whitefish species demersal trawl fleet. In addition, vessels from Northern Ireland and Ireland targeting *Nephrops norvegicus*, as well as beam trawlers from Belgium and Holland, catch quantities of cod. The profile of Irish Sea landings has shown that more than 70% of the catch in 1998 was immature two-year old fish. This narrow range of age groups, together with recent poor recruitment, increased fishing mortality and low spawning stock biomass, have likely been the reason why cod stocks have declined dramatically. As a result of these serious concerns, the EU introduced closed areas and seasons in the Irish Sea for the first time in 2000[88]. The spawning areas initially defined were east of the Isle of Man and between the Isle of Man and the coast of Ireland, with the closure effective from 14 February to 30 April 2000.

During the first closure period, trials[89] on board the Irish trawler "Northern Dawn" were carried out to assess the effectiveness of an experimental inclined separator panel fitted to a *Nephrops* trawl at facilitating the release of cod. A local gear manufacturer, Gear Tech Ltd, in conjunction with BIM, designed the separator panel. It employed an inclined separator panel incorporated with the codend into a modified extension piece and fitted into a standard *Nephrops* trawl. The separator panel was fitted into the trawl in such a manner as to divert cod coming down the trawl towards an escape hole on top of the trawl located in the extension piece above the codend. In order to assess directly what was being released from the trawl, for the purposes of the trials a second codend was fitted to retain any fish escaping through the opening at the top of the panel. The experimental trawl with the panel fitted was then compared directly with a standard trawl, fished alongside it in a twin-rig system.

A total of 42 hauls was completed with the inclined separator panel, and the results revealed that the panel proved effective, with the level of cod by-catch in the trawl with the experimental trawl significantly lower at a 95% confidence limit than in the standard trawl. The results also showed cod separation, i.e. the amount of cod being released by the panel and

[87] Case study by Dominic Rihan. (Fishing gear technologist). Bord Iascaigh Mhara (BIM) Dublin, Eire

[88] Commission Regulation (EC) No. 304/2000 of 9 February 2000 establishing measures for the recovery of the stock of cod in the Irish Sea (ICES Division VIIa)

[89] Anon, 2000. Protecting Spawning Cod in the Irish Sea. Estimating the cod catch of vessels operating in the Western Irish Sea and introducing measures that might be applied to reduce their impact. BIM Internal Report, August 2000. 18 pp.

retained in the top codend, on the order of some 75%. Good separation of other whitefish species, such as haddock and whiting, from *Nephrops* was also observed.

The Irish Sea cod closure was again enforced in 2001, although under Council Regulation 300/2001[90] the measures put in place were slightly different from those of 2000 in that the closed area was reduced in size. Owing to the effectiveness of the separator panel in 2000, under Article 2(b) of the Regulation, fishing with *Nephrops* trawls with a separator panel fitted was permitted within a small, defined area. Observations[91] on three vessels, two single-rig trawlers and one twin-rigger, fishing with nets with panels fitted, were made throughout the duration of the cod closure period, with data collected from 144 individual hauls. The results were very similar to those attained in 2000, with release rates of cod for all size classes of 68% and also keeping by-catch levels of cod well below the 18% permitted limit under the Regulation. Since these trials, experimentation has been carried out with the inclined separator panel in other *Nephrops* fisheries; again the results have shown the potential advantages as a technical conservation measure.

The success of the panel is attributed to its design and it`s positioning within the trawl. It has been suggested that the good separation of cod may be because of their behaviour of staying close to the seabed after encountering the footrope becomes less pronounced farther back in the trawl, and therefore a higher proportion would swim above the panel, which is positioned in front of the codend. It has the advantage (similar to a square mesh panel) of being inexpensive and relatively ease to install and maintain. The initial rationale behind its development was that *Nephrops* fishers would gain access to fishing grounds otherwise closed, without catching quantities of spawning cod, i.e. there would be an incentive to fish more responsibly instead of total exclusion. This is similar to the use of sorting grids in Norwegian shrimp fisheries[92]. The data from the trials with the separator panel have demonstrated that the use of the panel meets these requirements, and therefore the main aim of releasing spawning cod in this case has been achieved. Problems have arisen, however, because the closure itself has proved difficult to monitor and also it has become diluted with a number of derogations for different types of vessels, including the use of semi-pelagic trawls in one particular area and the opening of the area to beam trawls. These gears unquestionably have an adverse impact on cod stocks. Also the defined area in which the separator panel can

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[90] Council Regulation (EC) No. 300/2001 of 14 February 2001 establishing measures to be applied in 2001 for the recovery of the stock of cod in the Irish Sea (ICES Division VIIa)

[91] Anon. 2001. Assessment of Measures for the Recovery of the cod stock in the Irish Sea. BIM Internal Report. June 2001. 14 pp.

[92] Isaksen, B. 2000. Incentives helped fishermen adopt sorting grids. Full Summary of Proceedings of Fishing Gear Systems Conference. March 27-29.

be used is so small as to be meaningless, and around it fishers can fish as normal with standard *Nephrops* trawls as long as they stay within catch composition regulations. Fishers have therefore simply fished on the periphery of the "separator zone" or perhaps waited until the Naval patrol ships have not been present and slipped in and out of the area without being detected. If the use of the panel had been made mandatory within the whole closure zone, then it would have been more effective. As with many conservation measure, fishers using the panel have already found ways of circumventing it, in this case apparently by lashing the opening closed. In reality a combination of these factors has meant that uptake of the panel has been relatively low, just 10-15% of vessels operating, and its actual benefit to cod stocks has been largely negated.

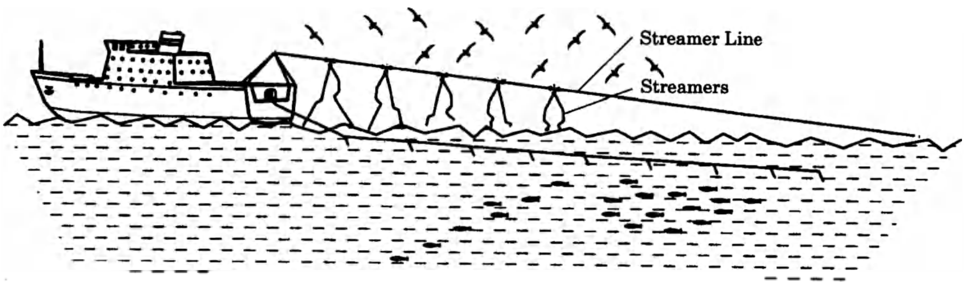
The Irish Sea cod closure has now been in place for four years, during three of which the use of the inclined separator panel has been permitted. According to the EU, the technical measures are not sufficient to tackle the depleted state of the stock, so long-term recovery measures including the use of the management tool of days at sea limitations will have to be introduced to improve stock levels. Fishers anecdotally from both Northern Ireland and Ireland claim that in fact the closure has worked and that stocks of cod in the Irish Sea have improved dramatically since the first closure in 2000, despite widespread apparent misreporting and under-utilisation of the panel. Owing to the short time-series and lack of proper monitoring, there would appear to be little scientific evidence either way to prove categorically that the measures have or have not worked. It is apparent, however, that dilution of the measures has been detrimental to the chances of success and also undermined a potential technical solution to the by-catch problem.

13.28 Seabird mitigation measures in longline fishing

The use of streamer lines trailing behind a vessel can successfully deter many birds from baited hooks as they are being deployed (up to 100%) (Figure 55), and paired streamer lines appear to be more successful than single streamers. Streamers do not reduce the catch rates of the target species. Longlines can be made to sink more rapidly by the use of additional weights, so reducing the opportunity for birds to ensnare themselves, but this can have safety implications. Longlines can also be deployed through covered 'setting tubes' (Figure 56), which are available commercially and also reduce bird by-catch, but these are thought by some to be less effective without streamers (Melvin *et al.*, 2001).

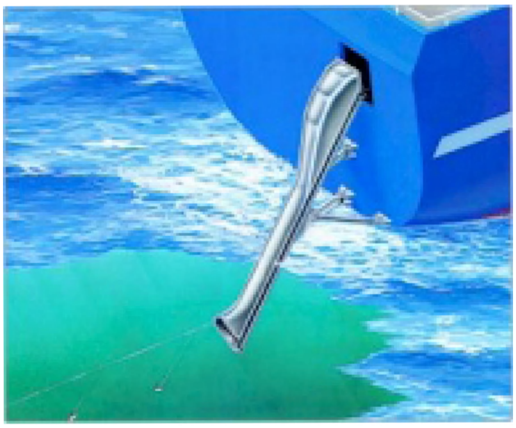
Fishers, in the US and elsewhere, are currently adopting this type of technology and it has been mandatory through legislation in some States of the US.

Figure 55. The deployment of streamers to deter bird interactions with the deployment of longlines



Adapted from Brothers *et al.*, 1999.

Figure 56. Setting tube produce by Mustad of Norway



(www.mustad-autoline.com)

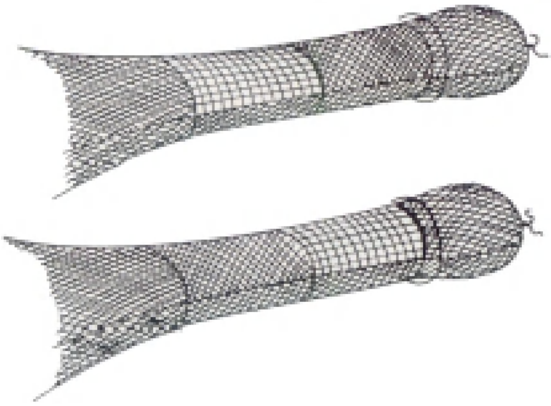
13.29 Fyke net

By-catch excluders have been fitted to fyke nets (eel traps) in Canadian fisheries and have reduced by-catch levels to below that set by the Canadian Government (Brothers, 2000). Fyke nets are used in freshwater to catch eels, but they can also catch other fish species (particularly salmonids) and aquatic mammals such as otters.

13.30 Escape panels

Escape panels have been fitted to trawls and mobile gears in a wide variety of experimental studies (Figure 57). The panels have varied in shape, size, mesh type and position, but all work on the principle that unwanted species trapped within the body of a moving trawl have an extra escape route that is additional to that offered by a standard trawl. Successful escape panels have been constructed from both square and diamond mesh. Escape panels are mandatory in several European fisheries, including the North Sea and Irish Sea *Nephrops* fisheries, Baltic cod trawl fisheries, and in several fisheries covered by the European Commissions 'cod recovery plan'.

Figure 57. Escape panels



From Sainsbury (1996)

13.31 Square mesh codends

Codends completely constructed from square mesh have reduced environmental impact in a number of experimental trials. Square mesh codends are mandatory in the Norwegian seine net fisheries (125mm) but they have not been taken up by legislators or fishers on a wide scale to date.

13.32 Cut away trawl designs

A *Nephrops* trawl recently developed in the UK has shown considerable promise in reducing environmental impact in these fisheries by reducing the incidental capture of unwanted fish species. The trawl has a cutback top panel that gives many fish the chance to avoid capture, while still catching the target species (*Nephrops norvegicus*). The trawl is currently (2003) undergoing commercial evaluation, and the principle by which by-catch reduction is achieved has potential in other fisheries.

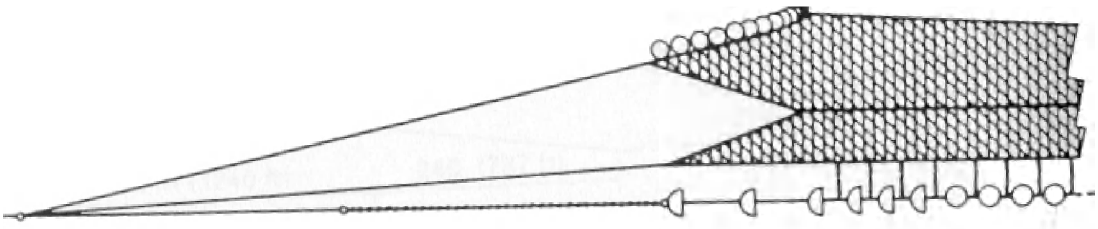
13.33 Blow-out panels

In the New Zealand orange roughy fisheries, tows are kept short, to 30 minutes or less duration, to prevent excessive catches in the spawning areas where fish concentrations are high. A small `blow out` panel constructed from weak netting is often fitted above or into the extension piece of the trawl to allow excessive catches to escape. These panels are fitted in such a way as to burst when the catch exceeds a predetermined quantity (Greening, 1988).

13.34 Headline/footrope manipulation

Some workers have narrowed the vertical opening of trawls by raising or lowering the headlines or footropes of the trawl (Figure 58). The narrowing of the vertical opening of a trawl can make it more selective towards a particular desired species if there is vertical stratification of different species in a fishery. The technique has also been used experimentally to select for size differences in cases where target species response to the ground gear is vertically stratified by size. Opposite tactics have generally been adopted by the industry, whereby the vertical opening of towed gears has been increased in order to catch more fish.

Figure 58. Altered ground line. Escape gaps allow crustaceans and flatfish to escape



From Sainsbury (1996)

13.35 Longline hooks

The mandatory use of large hooks and circular hooks are measures that have been adopted by Canadian authorities in order to reduce the unwanted by-catch of gadoid[93] species in longlines (Brothers, 2000)(Figure 59).

Figure 59. Various longline hooks

Traditional J hook (left)
Circular hook (centre)
Easy baiting hook (right)

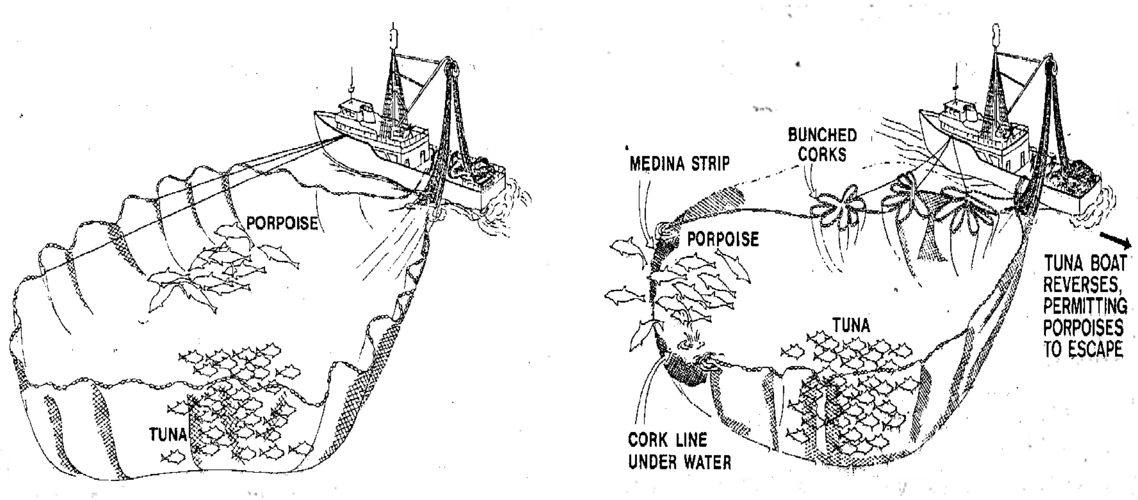
From Sainbury (1996)

[93] Cod family.

13.36 Purse-seine modifications to reduce mammal by-catch

Purse-seining was once notorious for its high levels of cetacean by catch, particularly during the 1960s and 1970s. This fishing techniques now has a negligible rate of cetacean by-catch (Hall, 1996), primarily through the implementation of simple mitigation measures, including different mesh sizes in certain parts of the purse, altered float lines and the back down manoeuvre (Figure 60).

Figure 60. The back down manoeuvre and medina panel



From Valdemarsen and Suuronen (2001)

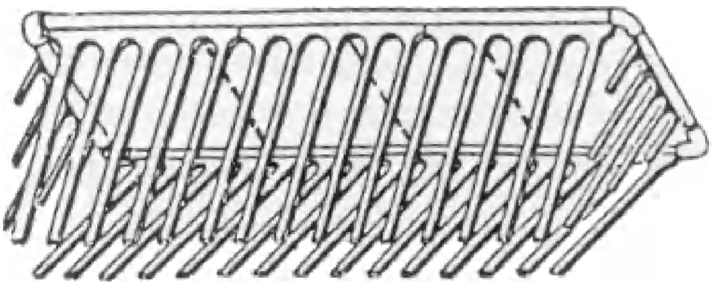
13.37 Pot and trap modifications

Fogarty (1996) describes technological developments in respect of the American lobster (*Homarus americanus*) fisheries in the US over the past few decades. The selectivity of the traps has been improved by the use of escape vents and has resulted in sharply reduced catch rates of undersized lobsters. Escape vents have been mandatory throughout these fisheries in the US since 1985. Varying designs of escape vents have also been used in traps in the US to control by-catch rates of commercially important species, including *Cancer* crabs and black sea bass.

Escape vents vary in design, but they are usually rigid-framed vents that can be laced into the body of the pot/trap. There is no current unilateral legal requirement to use such a device through the UK pot fisheries, but certain by-laws require their use in a few English sea fishery committee districts. The use of escape vents may be problematic in mixed crustacean pot fisheries if some of the target species are small, for instance the velvet crab (*Necora puber*).

Some large designs of pots in the USA have Neptune triggers (Figure 61). These may be fitted with vertical steel bars to prevent entry of halibut and large crabs and seals into pots (Sainsbury, 1996).

Figure 61. Neptune triggers

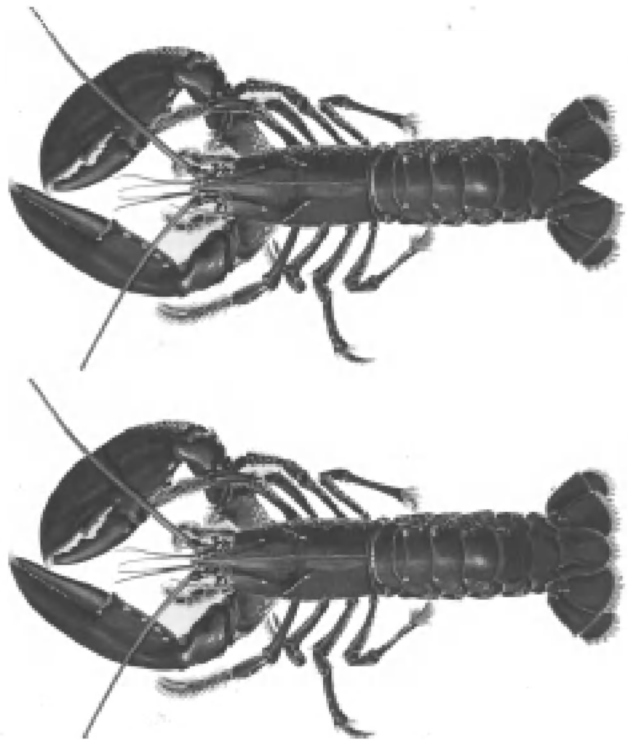


Rigged in the entrances to fish and lobster traps and designed to prevent escape. The vertical steel cross-bars prevent the entry of unwanted larger species (from Sainsbury, 1996)

13.38 V-notching

V-notching is the system of cutting V-shapes into the tails of lobsters and is a technique to conserve lobster stocks (Figure 62). Berried (egg-bearing) females are usually V-notched and are subsequently returned to the sea. The V-notcher is a tool similar to a hand-held hole puncher, producing a notch that remains visible for approximately 4 years, although it disappears after 2–3 lobster moults. The landing of V–notched lobsters is subsequently prohibited in regions where V-notching schemes are practised, which helps to maintain stock levels. There are various V-notching schemes around the UK, Eire and elsewhere. In the UK, the V-notching scheme is subsidised by public funds. A case study on the Irish–notching scheme is presented in Appendix 13.39.

Figure 62. V-Notch



13.39 Case Study[94]: The Irish Lobster V-notching Programme

"*It just got to me that there was going to be nothing there to spawn and I'd have nobody to blame only myself…so we just decided to v-notch and release. The first dozen are the hardest… this would be our fifth year of doing it now*" (Anon, 2000)[95]

Catch per unit effort in Irish lobster fisheries has fallen over the past 30 years. During that time, minimum size regulations have been put in place and have been periodically modified upwards in an effort to protect spawning stock. The adoption and various revisions of minimum landing sizes have obviously not kept pace with the increase in fishing effort that has occurred and therefore it was recognised that, in order to protect spawning stock and recruitment, other technical measures were required.

The V-notching of lobsters is a simple but nonetheless important conservation tool which has been in use in the Maine lobster fisheries in the USA for more than 50 years. Its primary intention is to protect female lobsters and involves the manual removing of a V-shaped notch from the lobster's tail when it is first caught. The V-notch is not permanent and after about 4-6 years it disappears completely. At this point the lobster can, once again, be legally taken and offered for sale, or it can be re-notched and returned to the sea.

V-notching was first introduced to Ireland in 1994 as a pilot study in the Wexford lobster fishery, funded under the EU's PESCA programme. Following the success of this work, national legislation[96] was enacted and it became illegal to offer for sale any V-notched lobster. Between 1995 and 2000, BIM, Udaras na Gaelatchta[97] and the local Irish lobster cooperatives jointly funded V-notching programmes through the EU PESCA programme. Over this period some 70 000 lobsters were successfully notched and released and 15 lobster cooperatives around Ireland had adopted the measure to conserve stocks.

As a technical measure, its impact on egg production very much depends on how many lobsters and what proportion of the stock is actually V-notched. Unfortunately, up to 2002, there has been no coordinated nationwide monitoring of the V-notch programme or of the

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[94] Case study by Dominic Rihan. (Fishing gear technologist). Bord Iascaigh Mhara (BIM) Dublin, Eire
[95] Quotation taken from Huxham M. and Madden S. 2000. Local Management of inshore fisheries: Lessons from the Irish Lobster industry. School of Life Sciences, Napier University Edinburgh. 21 pp.
[96] Department of the Marine & Natural Resources. SI 304 of 1994. lobster (Conservation of Stocks) Order, 1994
[97] Udaras na Gaelatchta is a governmental agency with the responsibility for economic development of Irish speaking areas

catch rate of V-notched lobsters in the fishery. However, a detailed study[98] of the Wexford lobster fishery between 1995 and 2000 determined that catch rates increased in the fishery 4-5 years after implementing the V-notch conservation measure. Since 1995, 1 500 or more female lobsters above the minimum landing size have been V-notched, tagged with an individual numbered tag and released annually. Logbook information from the local cooperative showed that the number of V-notched females in the catch increased substantially from year to year, with little or no migration to other areas (only 3 of about 5 000 lobsters so tagged have been caught outside the Wexford area) and disappearance from the stock of marked lobsters was almost solely attributable to natural mortality. The best estimate of increased egg production through the V-notch programme is around 15-20%, with an associated extra 750 000 stage IV lobster larvae reaching the seabed. Taking a 1% survival rate of settled lobster larvae to recruitment, it is estimated that an extra 7 500 legal-sized lobsters have been added to the Wexford stock every year as a result of V-notching. The catch rates of undersized lobster, which have more than doubled between 1997 and 1999, indicate that a strong recruitment is currently coming through the Wexford fishery. Increased egg production coupled to favourable environmental conditions for larval survival has probably caused it. This shows the importance of maintaining adequate spawning stock and shows the potential of conservation in directly benefitting catches.

In 2002 the Minister for the Marine & Natural Resources, Mr Frank Fahey T.D., announced a major conservation initiative[99] as a continuation of the work begun in 1994. The new scheme allows fishing and lobster cooperatives and associations right around Ireland`s coastline to avail of grant aid under a €1.2m "National Lobster V-notching Programme". This programme aims to V-notch more than 100 000 female lobsters over the period 2002-2006 and, through tagging and a voluntary logbook system, vital information on lobster movements, growth and reproduction will be obtained routinely. In order to provide an incentive for cooperatives to participate in the Programme, grant aid of 50% of market price plus an allowance equal to 5% of the total costs of the lobsters for expenses incurred by the cooperative in monitoring and measuring will be paid. To date, more than 20 cooperatives are actively involved.

The continuing high level of support for V-notching in Ireland among fishers from all sections of the industry operating a wide range of funded and unfunded programmes despite relatively

[98] Tully, O. 2000. Conservation and enhancement of lobster in south Wexford. Zoology Departmetn, Trinity College Dublin. 13 pp.

[99] NDP Project No. 01.SM.T1.09. National V-notch research and development programme for Irish lobster co-ops. Project submitted under the NDP Supporting measures for Sea Fisheries Development Programme 2002-2006

little government investment in enforcement, suggests that this is a tool which has the flexibility and simplicity to be used successfully in other European fisheries.

13.40 Pingers

Pingers are acoustic transmitters that generate noises to scare away aquatic mammals from fishing gears. Various trials have shown that they can be very effective at reducing cetacean entanglement in static gears. They have recently been introduced on a mandatory basis in the Danish wreck net fisheries of the North Sea, and there are plans for similar UK vessels to adopt the technology.

13.41 Technology that mitigates benthic impacts

13.41.1.1 Remote-controlled trawl doors

Scanmar is a major manufacturer of fishing gear sensor systems (see section 7.1) based in Norway This private company has recently embarked on a large research programme to develop a trawl system that avoids/reduces impact on the seabed by the use of acoustically operated manipulators fitted onto the trawl doors. It is hoped that the system will facilitate the active and accurate positioning of the trawl both vertically and horizontally in the water column. The work is partly funded by the Nordic Research Council.

13.41.1.2 Alternative stimuli

The use of novel stimuli with a reduced environmental impact, that encourage fish to rise up off the seabed and into the mouth of a moving trawl, is a topical research field and has shown promise. It is proposed that such novel stimuli would replace the heavy chains (tickler chains and chain matrices) currently used on beam trawls and that cause damage to the seabed. To date, most research effort has been in the field of using electrical pulses as an alternative stimulus, and a private company in the Netherlands is currently undertaking commercialisation of the technology. The use of electric fishing has considerable potential to reduce the environmental impact of beam trawling, but many practical, handling and safety problems need to be overcome. Small electrical systems have been used successfully in some Chinese shrimp fisheries and are also used around the world in freshwater as a tool to assist the management of such waters.

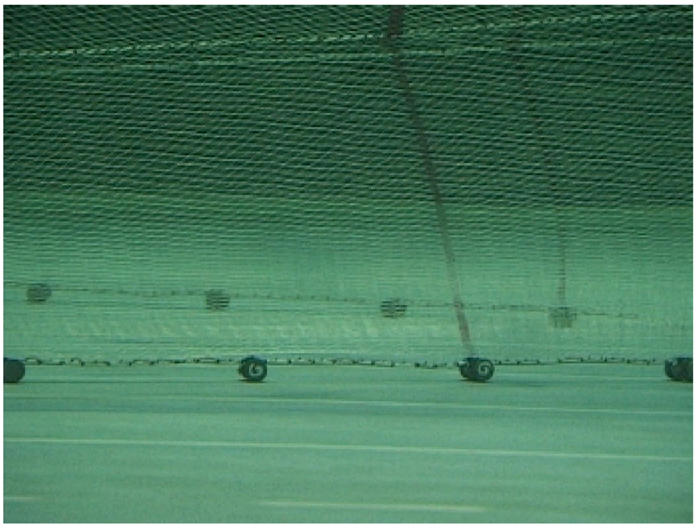
The use of water jets as an alternative stimulus to chains has also been investigated and shown some initial promise, but the commercialisation of such a technology would require considerable research and development. The use of sound as a stimulus may also have some potential but requires more thorough research.

A more detailed summary of the potential application of alternative stimulation in fisheries is contained in Marlen (1997).

13.41.1.3 Alternative ground gears

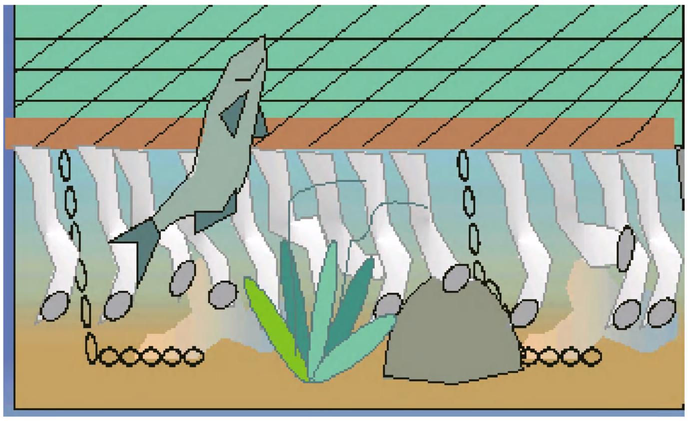
Alternative designs of ground gear have been developed in Eire in an attempt at reducing seabed impact without loss of catch (Anon., 2001a) (Figure 63). The new ground gear could potentially be used on demersal trawls, but as yet has not been adopted by the industry.

Figure 63. Irish roller ground gear designed to reduce the benthic impact of demersal trawls



The use of 'dropper chains' or ballast elements on a trawl in certain fisheries has also been studied and has enabled the fisher to tow the trawl very close to, but not on, the seabed, while still maintaining catch rates (Carr and Milliken, 1998, Glass *et al.*, 2001).

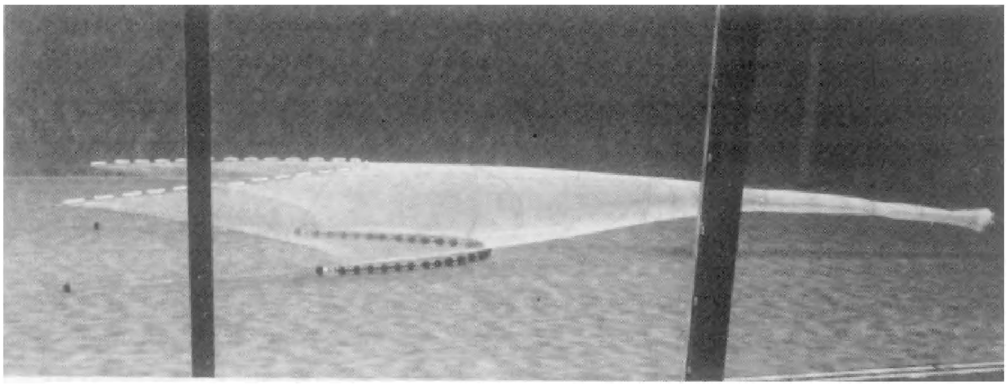
Figure 64. Dropper chains



Source: Valdemarsen and Suuronen (2001)

Demersal trawls cause environmental impacts through contact with the seabed, and designs of trawl systems that fish very close to, but not on, the seabed, can potentially eliminate benthic habitat damage and reduce fuel costs. These trawl systems have much potential to reduce environmental impact, but they are unsuitable in fisheries where the target species is strictly benthic dwelling, such as *Nephrops* and many flatfish species. Some trawls in use today are designed to have minimal contact with the seabed to reduce drag, but may reduce benthic impact (Figure 65).

Figure 65. Trawl design with minimal ground contact

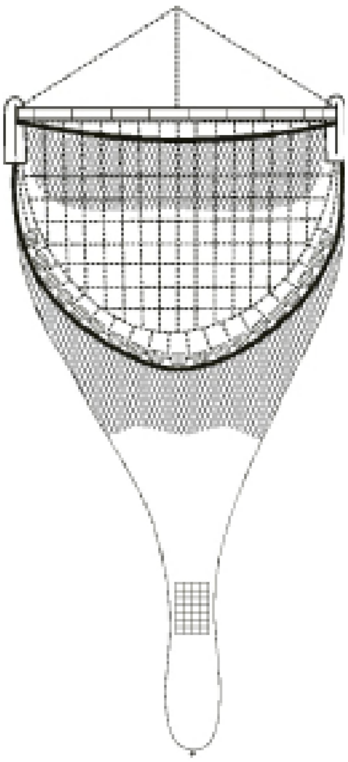


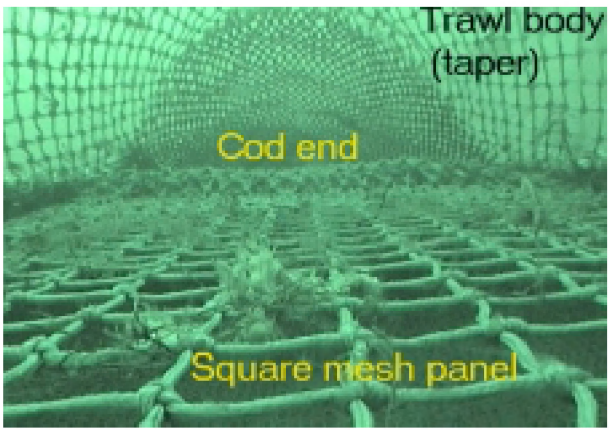
Source: Sainsbury (1996). Photo courtesy of Fishing News International

13.41.1.4 Benthic release panels

Release panels fitted to the bellies of beam trawls have been piloted in the Netherlands, Belgium and the UK (Figure 66). These panels have been constructed from square mesh and release significant numbers of benthic dwelling creatures unharmed rapidly back onto the seabed, close to the point of capture. Work with these panels is ongoing in the UK, and it has shown some good potential to reduce benthic impact. Such panels can potentially be fitted to any demersal trawl.

Figure 66. A benthic release panel fitted to the belly of a beam trawl undergoing current evaluation and development at CEFAS (2003)





13.41.1.5 Wheeled beams

Some beam trawls have been fitted with wheels to reduce drag and are used extensively by the Brixham beam trawl fleet (Figure 67 and Figure 68). There may be some reduction in environmental impact as a result of this practice, although it has not been formally evaluated.

Figure 67. Traditional beam trawl shoes

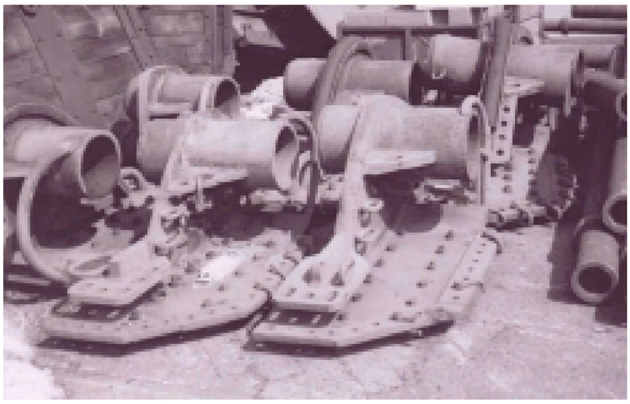
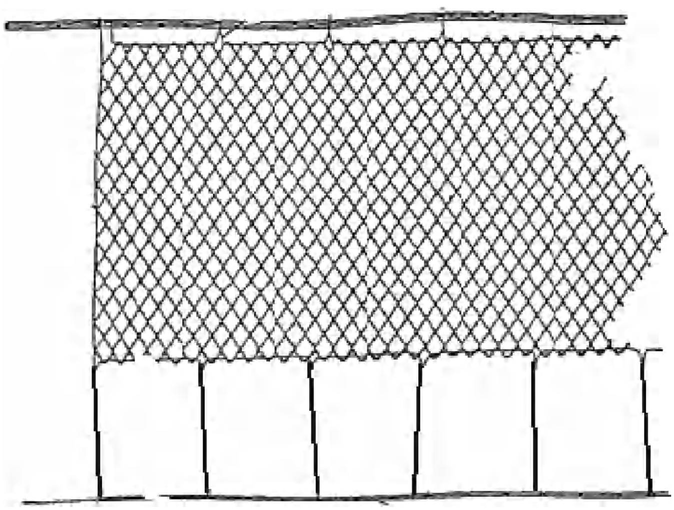


Figure 68. Beam trawls with wheels

13.41.1.6 Gillnet droppers

Bottom set gillnets can be set to lie above the seabed by using droppers (Figure 69). Such rigging reduces contact with the seabed and can lessen the likelihood of snagging, although it may decrease the catching efficiency of the gear towards certain species.

Figure 69. Bottom gillnet set with droppers



13.41.1.7 Scallop dredge modification

In pilot studies, tickler chains have been used to replace teeth in scallop dredges and have been successful in reducing shell damage to scallops. The use of water jet systems as an alternative to teeth has also been investigated, successfully reducing benthic impact but also giving lower catch rates.

13.42 Technology that mitigates the effects of lost/abandoned fishing gear

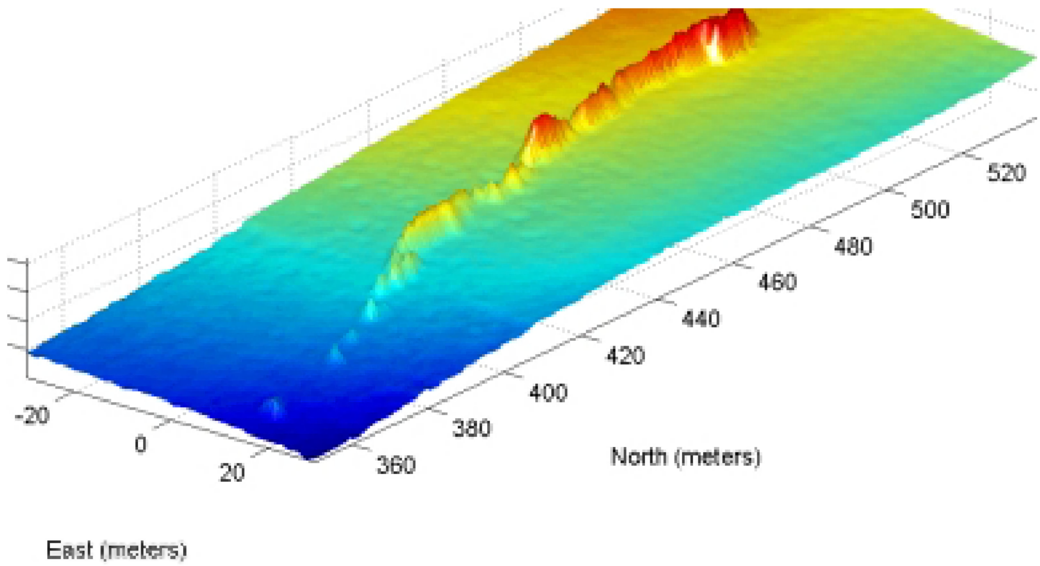
13.42.1. Location and retrieval technology

There have been some developments in sonar technology that can facilitate the location of lost and abandoned fishing gear. The technology relies on the use of multibeam sonar on a towed remote vehicle. Retrieval is best achieved by the use of creepers, but these can damage the seabed and their use may cause additional environmental impact. The use of passive pingers, which are fixed onto gears and can respond to a search transmission, has potential in facilitating their recovery. Formal retrieval programmes for lost gear are undertaken in some countries, including Norway, Canada and the USA.

13.42.1.1 Multibeam sonar

Multibeam sonar has been used in research trials to locate lost and abandoned fishing gear and was prompted after a series of unsuccessful trials using sidescan sonar. A Simrad SM 2000 sonar was mounted on a towed body and operated close to the seabed and gave promising results (Figure 70). The equipment was hired from the Norwegian company Geoconsult A/S (www.geoconsult.no/hugin.htm) and costs around £250 000 to purchase and is therefore prohibitively expensive for a commercial fisher for the purpose of finding lost gear.

Figure 70. Three-dimensional presentation of a lost fleet of gillnets registered by multibeam sonar



13.42.2. Underwater cameras

Underwater cameras can be used to identify and verify the presence of lost gear, and cameras are now available and are depth-rated to 6 000 m. The cameras would have to be fitted to remotely operated vehicles (ROVs).

13.42.2.1 Gearfinder

Gear finder is a product developed by Notus Electronics Ltd in St Johns, Canada (www.notus.nf.ca). The equipment consists of a transponder connected to the hull of the vessel and which communicates with probes connected to the gear. The equipment locates lost gear and has a range of 3 000 m.

13.42.2.2 Creepers

The most common method for retrieving lost gear is to use a creeper (Figure 71and Figure 72). There are many varied designs of creeper and the depth and the size of the vessel usually limit their size and weight. Norwegian studies have shown that, in the slope fisheries for ling and Greenland halibut, the vessels are able to retrieve 35–55 % of their lost gear.

Figure 71. Example of creeper used by Norwegian coastal vessels

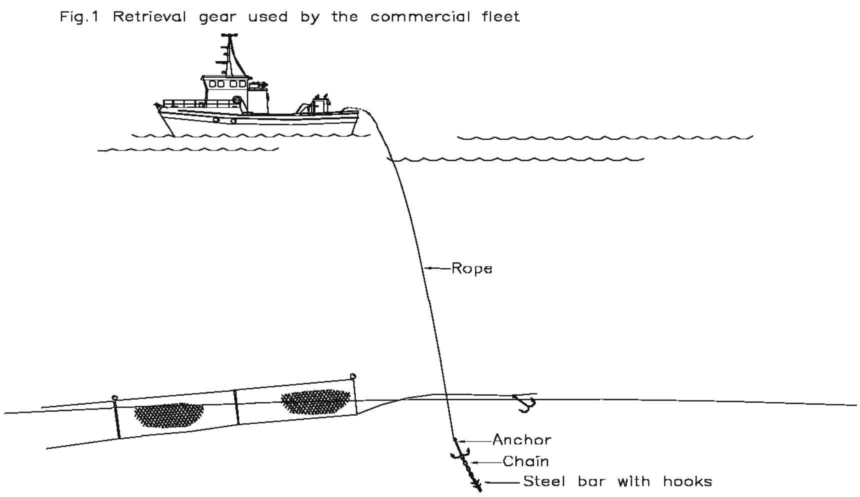
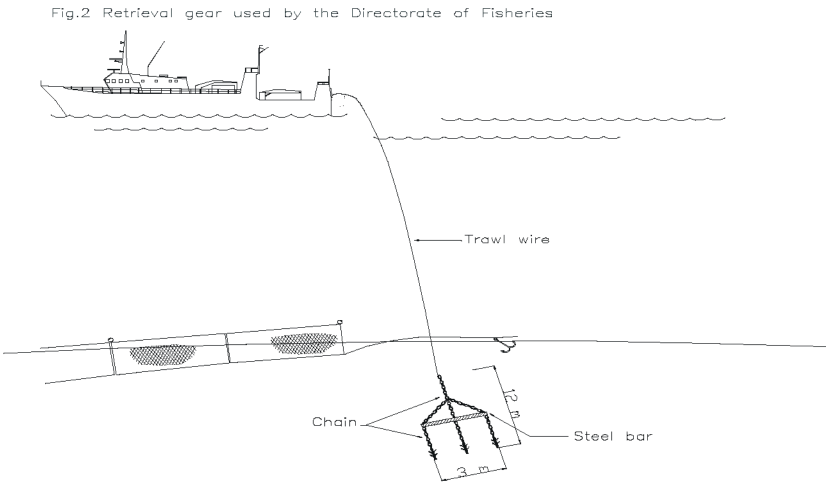


Figure 72. Creeper used by the Norwegian Directorate of Fisheries during annual retrieval surveys



The Norwegian Directorate of Fisheries conducts annual retrieval surveys for lost gillnets. A trawler is hired for the mission. Investigations have shown that 42% of reported lost gear has been retrieved successfully (Figure 73).

Figure 73. Number of nets retrieved during Norwegian retrieval surveys 1983-2002

Year	65–72° N	62–65°N	Total
2002	731	0	731
2001	141	56	197
2000			383
1999	308	93	401
1998	358	240	598
1997	487	185	672
1996	543	0	543
1995	305	396	701
1994	149	510	659
1993	503	130	633
1992	731	449	1180
1991	198	119	317
1990	0	273	273
1989	168		168
1988	153		153
1987	106		106
1986	438		438
1985	280		280
1984	401		401
1983	225		225
Total	6 225	2 451	8 676

13.42.3. Biodegradable components

Over the years, numerous workers have advocated the use of biodegradable components in traps and pots. Such a simple mechanism could eliminate the catching capacity of lost and abandoned traps and pots, once the time-release mechanism had decayed and released the trap door. Such a measure has been adopted in some countries, but not in the UK or throughout Europe. Biodegradable components have been tested and evaluated in static nets in Norwegian trials but were found to be unsuitable.

13.42.4. Time-release mechanisms to mitigate the effects of ghost fishing: traps, pots and creels

In 1998, regulations in the Barbados fishery required that all fish traps be fitted with an escape panel and also carry an identification marker. Researchers evaluated various cheap biodegradable escape panel fasteners to identify one that would release the escape panel between 3 and 5 weeks of net loss (Selliah *et al.*, 2001). Hemp twine was found to be the most suitable material for the escape panel fastener. The catch rates and species composition in the pots were unaffected and therefore the mechanism was considered to be a measure that would be unopposed by fishers.

In the US, it is the recent stated policy (Stevens, 2000) of both the National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G) to conduct research in support of Alaskan crab fisheries, in particular with regard to understanding pot loss, reducing ghost fishing, escapement behaviour and the development of devices/pot designs that allow escapement.

Fogarty (1996) indicates that the use of escape panels in conjunction with time-release biodegradable links has considerable potential for reducing the mortality associated with trap ghost fishing in the US.

Laist (1996) states that the highest priority needs are for designing and verifying the effectiveness of time-sensitive gear-disabling mechanisms (e.g. escape panels for traps), to reduce the impact of ghost fishing.

Suggested management measures to ameliorate the adverse effect of ghost fishing on the blue crab resource in Louisiana, USA, included biodegradable panels (Guillory,1993)

In Canada, stocks in the previously lucrative queen crab (Gulf of St Lawrence) fishery became depleted. Ghost fishing by crab pots lost or abandoned in the open sea was considered to be a factor contributing to this decline. Fishers were therefore encouraged to use galvanic time-release mechanisms on the traps as a mitigation measure. The time-release mechanisms were shown to be cheap, accurate and predictable (Blois, 1992).

Bullimore *at al* (2001) advocate the use of biodegradable escape panels in UK pot fisheries.

Mathews *et al*, (1987) describe a new design of fish trap fitted with a sacrificial anode door. The door is opened after 2-3 weeks, releasing fish and preventing ghost fishing.

An investigation into materials that can be used as a release mechanism for an escape panel on ghost pots concluded that jute twine and steel wire showed the most potential (Blott, 1978).

13.43 Technology that strengthens enforcement

13.43.1. VMS

A Vessel Monitoring System (VMS) is an onboard satellite tracking system that is currently used by many nations. In the EU, all fishing vessels over 24 m long must have a VMS system onboard, and there are new regulations that will introduce this technology incrementally to smaller classes of vessels. The VMS sends a periodic signal (containing position and vessel ID) from the vessel to the satellite, which relays the signal to a central location and processing unit. This technology has greatly facilitated the potential for the effective spatial and temporal management of fisheries.

The potential to link an array of underwater sensors on the fishing gear or other onboard sensors to the VMS system is feasible and could potentially offer fisheries managers and scientists vast amounts of useful information (in real time) that has never been previously possible.

13.43.2. Electronic logbooks

Electronic logbooks are devices/software that allow the fisher to record catches at precise positions and times. Data can be downloaded through a variety of communication systems (including satellite) to a central processing unit for analysis. Accurate detailed information on the spatial and temporal distribution of catches is considered to be fundamentally important for effective fisheries science and management. No such system is in use in the UK.

13.43.3. Tagging/marking of fishing gears

Mandatory tagging/marking of fishing gears, particularly those belonging to the static gear sector, would assist the enforcement of existing legislation. It is currently difficult to identify the owners of static gears when they are deployed at sea. A scheme of registration and marked/tagged gears would facilitate the enforcement of fisheries legislation, particularly in times of contravention. Such a scheme would also be a useful tool in any lost/abandoned gear assessment or retrieval programme (see section 13.42.1.).

13.44 Case Study[100] : Cetacean by-catches in tuna drift nets

"*It is hard to find cases where bans have ever been justified, every harvesting operation has its place in some part of the aquatic environment. Bans are an insult to our industry because they waste the fruits of generations of fishermen's ingenuity and enterprise*" (MacMullen, 2000)[101]

In the early 1990s, prompted by the success of French vessels, Ireland began to develop a driftnet fishery for albacore (*Thunnus alalunga*). By 1994 there were 20 vessels participating in the fishery, with landings worth in excess of IR£6 million. Bord Iascaigh Mhara (The Irish Sea Fisheries Board) regarded the development of the tuna fishery as part of an overall environmentally responsible policy aimed at diversifying into previously underexploited areas of fishing as opposed to the continued upward expansion and refinement in types of fishing where stocks were under pressure. The foundation and background to the tuna fishery development was driven by economic and environmental pressures and was followed by thorough research and sensitive development of this fishery, including a scientific investigation to ascertain the effect on the environment and in particular on cetacean stocks. This work, along with similar French studies, showed a statistical minimum for cetacean mortalities confirmed by independent observers aboard tuna fishing vessels.

In June 1998, however, the EU Council of Fisheries Minister adopted Regulation 1239/98, which effectively phased out all driftnetting for albacore in the North Atlantic and Mediterranean with effect from 1 January 2002. Ireland and France opposed this ban on the basis that the decision was arbitrary, and they pointed to the absence of clear scientific evidence of biologically significant by-catches of cetaceans, which were cited by the EU as justification for the ban[102]. In reply, the EU claimed that the fishery was contrary to UN resolution 44/225[103] of 22 December 1989, which called for a moratorium on the use of large-scale driftnets defined as "nets, which can reach or exceed 30 miles (48 kilometres) in total length". French and Irish fishers counter-claimed that the driftnet fishery in the Northeast Atlantic did not constitute a large-scale high seas fishery because the gear being used was in the region of 7-9km long. Moreover, catch rates and other data collected suggested it was a traditional, sustainable and profitable fishery. They further pointed to the fact that the ban

[100] Case study by Dominic Rihan. (Fishing gear technologist). Bord Iascaigh Mhara (BIM) Dublin, Eire

[101] MacMullen, P. 2000. Traps and gill nets: passive gear with an active future. Full Summary of Proceedings of Fishing Gear Systems Conference, March 27-29.

[102] EU Directorate General for Fisheries, 1998. "The Necessary European Union Ban on Driftnets". 7pp.

[103] UN Resolution 44/225. Large scale pelagic driftnet fishing and its impact on the living marine resources of the world's oceans and seas. 22 December 1989.

would transfer fishing effort to quota species, which were already under severe pressure and also to the results of technical trials carried out in Ireland by BIM[104], and in the UK by the Sea Fish Industry Authority[105] to reduce the by-catch figure to an absolute minimum. These included adjustments made to fishing techniques in order to give cetaceans a means of escape i.e. submerged headlines and escape gaps and investigations into the use of acoustic deterrent devices and passive reflecting devices to make driftnets more visible to cetaceans.

Measures were introduced by Council to accompany the subsequent driftnet prohibition, which provided assistance to those Member States who wished to undertake fishing trials into the use of alternative fishing gears. Ireland availed itself of these measures in 1998 and secured European Commission funding designed to permit the re-conversion of the driftnet tuna fleet to other technically and economically viable methods of fishing for albacore. Under this project[106], three alternative methods were tested: pair pelagic trawling, mechanised trolling, and surface longlining. The trials showed none of these methods to be as efficient as driftnetting and indeed trolling and surface longlining seemed to be marginal in terms of economic viability. The trials with pair pelagic trawls were reasonably successful, and up to 16 vessels have participated in the fishery since 1998 with this method. However, they did highlight the fact that incidental catches of cetaceans do occur with pair pelagic trawls and sometimes in quite high numbers, particularly along the continental shelf edge. The issue of cetacean by-catch in pelagic trawls is now considered of such concern by the EU that they requested STCEF through SGFEN[107] and ICES[108] to assess the levels of by-catch during 2002 in a number of fisheries. Since these reports, the EU have indicated that they will fund research to develop effective and acceptable gear modifications (by-catch reduction devices and acoustic deterrents) to reduce the by-catch and mortality of cetaceans in pelagic fisheries, including the albacore pair pelagic fishery currently being exploited by Irish and French vessels forced to diversify from the use of driftnets because of concerns over cetacean by-catch.

[104] McCormick, R. 1991. Deployment of Dolphin Protection Emitter units during 1991 BIM tuna fishing trials. BIM Internal Report, 4 pp.
[105] Swarbrick, J.L. 1992. Initial trials to increase acoustic detectability of drift nets used in the Albacore tuna fishery. Seafish Report No. 408,12 pp
[106] Anon. 1999. Diversification Trials with alternative tuna fishing techniques including the use of remote sensing technology. Final Report of EU Contract No. 98/010 (Commission of the European Communities, Directorate General for Fisheries). 77 pp.
[107] SEC, 2002. Report of the second meeting of the subgroup on fishery and environment (SGFEN) of the scientific, technical and economic committee for fisheries (STECF). Brussels, Commission of the European Communities: 57.
[108] ICES, 2002. Report of the Working Group on Marine Mammal Population Dynamics and Habitats. ICES CM 2002/ACE:02 Ref. E,G.

13.45 Miscellaneous drivers of technological advancement

Occasionally, new technology that aims to improve the quality of life or improve safety onboard a fishing vessel can result in unexpected environmental impacts. One notable incidence of such a phenomenon was the advent of shelter decks, designed to improve comfort and safety, but that have almost certainly increased environmental impacts by allowing vessels to fish in more adverse weather conditions than was previously possible (section 13.45.1.). Flume tanks and computer-aided modelling also have aided the design of various types of fishing gears, including those that mitigate environmental impacts and those that do not (section 13.45.2.).

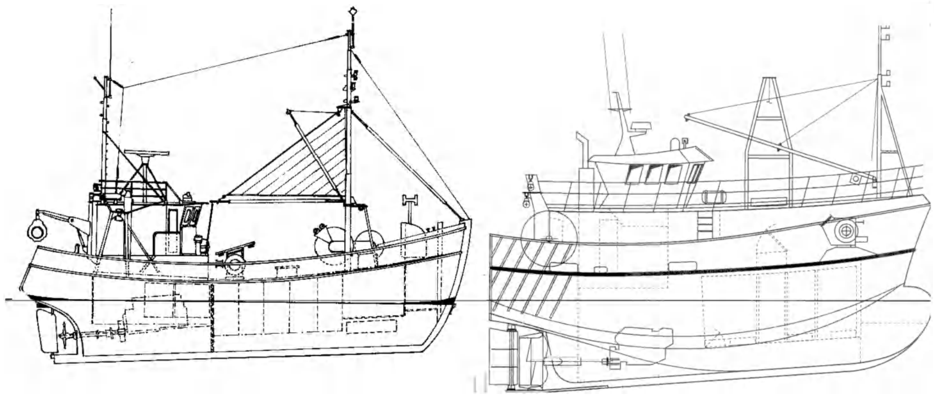
13.45.1. Comfort and safety driven technology

Some technological advancement is made in the capture fishing industry to improve the quality of life onboard the vessels. For example, technology that improves comfort, safety, hygiene or reduces boredom is constantly adopted on many fishing vessels. Such technology improves the living and working conditions for those onboard and will make for a happier crew. A contented crew is less willing than a discontented crew to seek alternative employment if profitability of the vessel declines or voyage duration is increased, to exploit new distant fishing grounds for example. Technological advances that improve the quality of life onboard fishing vessels may therefore act to offset hardship and will do little to reduce environmental pollution and may in fact marginally contribute to its increase. An example is given below (section 13.45.1.1), whereby a technological advancement has been introduced to enhance crew safety, but has probably resulted in an increase in environmental pollution.

13.45.1.1 Shelter decks

During the past 20 years, shelter-decks have been fitted (either retrospectively or at the construction phase) onto many modern designs of fishing vessel, and they undoubtedly offer the crew protection from the elements and are a positive contribution in vessel safety (Figure 74). In terms of environmental impact, shelter decks have allowed fishing vessels to remain at sea during more adverse weather conditions than was previously possible and as such have probably resulted in an increase in temporal and spatial fishing effort.

Figure 74. A traditional open vessel (left) and a modern trawler with a shelter deck (right)



13.45.2. Fishing gear modelling (Flume tanks and CAD[109])

Flume tanks are basically large circulating water tanks in which models of fishing gear and other marine structures can be demonstrated and tested. Instead of the gear being towed through the water and over the seabed, the model is held stationary while the water and tank conveyor belt move past it at a controlled speed. The first tank was built in Hull (UK) in 1976, and others have since been built in France, Spain, the Faroe Islands, Denmark and Canada, and all are dedicated to fishing gear design work. Flume tanks provide the physical environment to carry out performance evaluations, gear tests and other observations on newly developed or existing fishing gears, and can also be used as a training tool for fishers. Model testing allows real-time quantification of gear design and the effect on gear dimensions associated with rigging changes, and for many is seen as the first stage before full-scale testing at sea.

The advent of flume tanks has greatly facilitated the design and modification of many fishing gears and been instrumental in the quest for more effective fishing gears that can catch more fish. In such a role, flume tanks have contributed to the proliferation of fishing gears that have increased environmental impact. The flume tanks of the world have also greatly facilitated the testing and development of design of fishing gear that mitigates environmental impact.

In recent years, the development of fishing gear-modelling software has made possible the design and development of fishing gear on computers.

[109] Computer aided design

13.46 Economic drivers for the adoption of new technology and its relation to the management of that fishery

Environmental impacts from fishing are a function both of the level of fishing effort and the way in which fishing effort is applied (i.e. the gear used, the area fished, etc). Changes in technology can affect both of these factors. Which technology is adapted, however, is a function of the economic incentives facing the fisher and the management structure under which fishers operate.

In the absence of fisheries management, incentives exist for effort to increase beyond that which produces the maximum economic benefits from use of the marine resources. The number of examples where no management exists is, however, extremely limited, because some form of management is applied in most fisheries around the world, and in all fisheries in the UK and Europe. Management can take a number of forms and this can greatly influence the behaviour of fishers, and consequently the level of environmental damage, through the economic incentives they create.

For purposes of simplification, environmental impact can be considered to consist of two forms. The first is that which has no explicit impact on the future production of the fisher. This might include by-catch of non-commercial species or habitat damage that does not directly affect the target species[110]. The second form is environmental damage that does affect future production of the fishers.

Where there is no cost (short or long term) to the fisher, behaviour can be modified through regulation of gear use. For example, the use of by-catch reduction devices (e.g. separator panels) in shrimp fisheries is aimed at reducing unintended by-catch of fish, while the use of driftnets in the Atlantic was banned owing to the high incidental mortality of dolphins. The need for regulation of the use of such technologies is due to the fact that the fishers would not adopt them voluntarily. The costs associated with environmental damage created by the fisher are not incurred by the fisher, and do not enter their production decisions. In contrast, the adoption of these technologies potentially affects their production levels[111], increasing their costs of production and reducing their profitability.

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[110] It could be argued that given the interconnectedness of the ecosystem, any damage to one component could result in changes to other components of the ecosystem, even if a direct linkage cannot be established. Most of the relationships in the marine ecosystem are unknown, and the long-term effects of any modifications are uncertain.

[111] For example, adoption of by-catch reduction devices in the *Crangon* fisheries is thought to reduce catch rates by around 10-15% (Graham 1998, Revill *et al.*, 1998).

It is possible to create economic incentives to encourage the adoption of technologies that would not be 'natural'. For example, a by-catch tax, if it could be implemented, would 'internalise' the costs of environmental damage into the production decision. This would provide an incentive for fishers to seek gears that produced lower levels of by-catch. These may be different gears than might be imposed through regulation, because differing fishing strategies may also be employed to limit damage. While theoretically this is a valid option, monitoring and enforcement costs associated with such instruments are most likely to be greater than the efficiency losses associated with simple regulation of gear types.

Environmental damage that can have direct impacts on future production includes overfishing (i.e. catching more than the level that produces the maximum returns from the fishery) and catching juvenile fish that would be more valuable if left to mature. The incentives to adopt technologies that can have future benefits for fishers are influenced substantially by the management system in place. Under competitive conditions, such as exist in the case of limited licenses, seasonal closures or an aggregate quota, the incentives are to catch as much as possible while the fishery remains open. This can affect the technology adopted in a way that potentially increases environmental damage. The most extreme example of this is the North American Pacific halibut fishery, which was managed by limited season length. To compensate for decreasing season length, fishers introduced a greater number of vessels, and also larger more powerful vessels[112], to ensure that as many fish were taken while the season was open. The effect of this was to further constrain the season length, which reduced from months to weeks to days to hours.

Restrictions on input use are the most common management responses to limit these problems. Foremost of these in the UK is the use of technical measures, such as limited mesh size in nets, aimed at reducing the unintended by-catch of juvenile fish. Under competitive conditions, fishers have no incentives voluntarily to limit their mesh size because there is no guaranteed benefit to them in the future. For example, a fisher who used a larger mesh size voluntarily could not guarantee that he or she caught the fish that were 'saved' at a later date. Another fisher could catch these fish either in the future or in the present using a smaller mesh size. This relates to the lack of explicit property rights over the resource even under limited access, and also the free rider problem: while everyone could gain if everyone cooperated, an individual could gain more if he or she did not cooperate while everyone else cooperated.

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[112] This phenomenon is generally known as 'input substitution', as one input that is restricted (in this example, time fished) is substituted for other inputs that are not restricted. Increasing boat and engine size is also known as 'capital stuffing', as increased capital is employed to compensate for reduced fishing activity. This is further discussed in the Appendix.

Improving the level of property rights in a fishery alters these incentives. For example, under an individual transferable quota system (ITQ), individuals have explicit rights to a given share of the stock, and incentives are thereby created to adopt technologies that maximise the future value of this share. This explicitly includes measures that increase the stock size. The incentive to catch as much as possible is replaced by an incentive to maximise the value of the share of the catch. The degree to which incentives are created to minimise environmental damage are largely affected by the belief that the system will provide future benefits. Experience in other countries suggests that this increases over time (see Arnason (2002) for examples). Hence, while such systems can result in incentives to increase environmental impacts through discarding in the short term , incentives are created to reduce this in the longer term.

The creation of technologies that are less environmentally damaging are also influenced by the management structure and the incentives facing fishers. Under competitive fishing, the main demand is for technology that increases the fisher's ability to take a larger share of the catch. Incentives exist for gear manufacturers to develop gear that achieves this, even at the cost of increased environmental damage. Regulation of gear use, however, changes the incentives. Regulations that require the use of particular types of gear, or incorporate particular features such as separator grids, provide incentives to develop gears that meet these requirements without reducing the catch of the target species substantially. Such regulations can restrict the development of alternative technologies to produce the same environmental impact. For example, if a regulation requires the use of a separator panel, then there is no incentive to produce gear that avoids the capture of the unwanted by-catch in the first place through alternative methods.

Improved property rights produce different incentives again. With improved property rights, the incentives of the fishers change from maximising output per unit of fishing effort to minimising costs for a given level of output. The demand for cost-reducing technologies will consequently change the direction of technological development. This will create incentives to produce technologies that limit the by-catch of unwanted species, for example. Maximising the value of the catch will also be important, so gear that results in better quality fish will also be demanded. It is likely that this gear will also have less of an impact on the habitat.

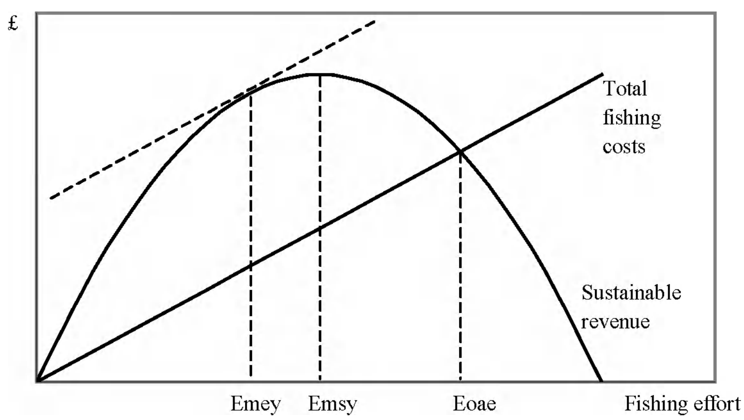
13.47 The economics of environmental damage in capture fisheries

Poor species and size selectivity of some fishing gears results in catches of some species that are subsequently discarded for either economic reasons (as outlined below), or because of regulations that prohibit their landings (e.g. minimum size or quota). Further, incentives exist for too much effort to be applied to fisheries resulting in excessive harvesting levels. This can be considered environmental damage, because the excessive harvesting reduces the potential productivity of the fishery. The problems are largely driven by economic incentives arising from the existing set of management regulations.

13.47.1. Propensity to overfish and the impact of management

The propensity to overfish in fisheries has been well established in the fisheries economics literature[113]. The fisheries 'problem' is that the existence of economic rents attracts new entrants to a fishery. Economic rents are profit levels in excess of that required to keep the firm in business (i.e. profit levels greater than 'normal' profits, where the latter are determined by the profits that could be expected if the capital invested in fishing had been invested in some alternative next best activity). These rents represent the value of the resource itself in the production process (i.e. resource rents). However, the cost of the resource is not included in the cost of the fisher, and essentially it forms part of the profit derived from fishing. Fishing effort increases until these economic rents are dissipated, and all fishers are earning 'normal' levels of profits. However, this equilibrium level usually exists at effort levels greater than that which would produce the maximum sustainable yield, and also greater than the level that would produce the greatest level of profits in a fishery.

Figure 75. General fisheries bio-economic model



[113] See for example, Gordon (1954). More recent reviews are given by Conrad (1995, 1999) and Hannesson (2002).

This has been illustrated in Figure 75, which depicts the sustainable revenue (i.e. sustainable catch levels multiplied by the price, assumed constant for the purposes of illustration) for various levels of fishing effort. The difference between the sustainable revenue curve and the total cost curve represents the potential resource rents that could be achieved. Without restrictions on entry, fishing effort will increase to the point where these resource rents have been dissipated (Eoae), generally known as the open access equilibrium. In contrast, lower levels of fishing effort could produce higher yields and profit levels. For example, the maximum sustainable yield and revenue could be produced by restricting effort to Emsy, while the maximum economic profits could be obtained by restricting fishing effort to Emey (representing the maximum economic yield, identified as the point where the slope of the cost curve is equal to the slope of the revenue curve).

Few studies have been undertaken to estimate the potential economic rent forgone through excessive levels of fishing effort. In the UK, Pascoe and Mardle (2001) estimated the potential economic profits dissipated through excessive effort levels in the English Channel fisheries to be of the order of €20m a year (from a total revenue of around €150m). In contrast, the fishery at the time was making an economic loss (i.e. the level of fishing effort was not economically sustainable in the long term) even though revenues were roughly the same as could be achieved with a smaller fleet.

The static equilibrium depicted in Figure 75 does not allow for changes in technology. These technological changes may be either output-increasing or cost-reducing. In either case, changes in technology will result in higher levels of effort being sustained in the fishery, with lower levels of biomass. Short-term benefits of increased technology can result in unsustainable fishing practices being profitable in the short term, resulting in potentially unsustainable levels of effort being generated in the fishery. With little use for fishing vessels outside of fishing, once effort is increased in a fishery it is difficult for it to exit without some form of intervention. Capital invested in the fishery has negligible alternative value. Provided revenues still exceed the variable costs of fishing, fishers still have an incentive to continue production even though the level of activity is not economically sustainable in the long term.

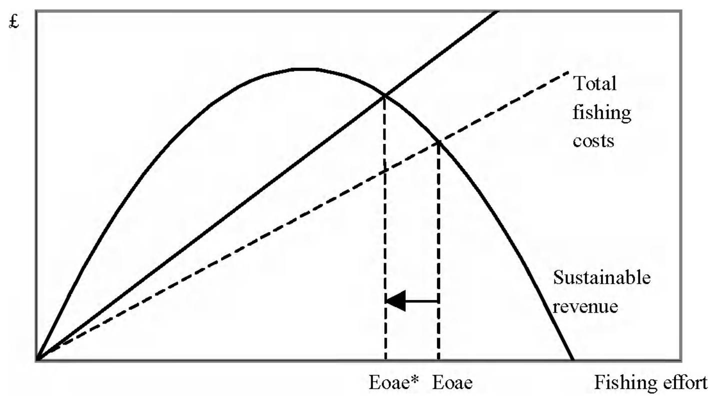
Fisheries management has been imposed in most fisheries in a bid to address the problem of open access. While the problem of open access can be addressed simply by restricting access, incentives to continue to increase individual fishing effort remain, provided some additional short term gains can be achieved. This is a consequence of the common property nature of the resource. Even with limited entry, individual fishers do not have any property rights over the level of catch, and cannot exclude others from taking as much of the resource as they wish.

Consequently, the value of future catches is heavily discounted, because there may not be a stock in the future. Hence, the rational decision-maker will attempt to gain the greatest share of the catch possible while there is still a stock to catch.

Again, fisheries management has responded by imposing restrictions on effort through regulating gear use, number of days fished and other inputs. However, restrictions on one input generally lead to increased use of unrestricted inputs (a phenomenon known as input substitution) in a bid to again capture short-term rents. This results in an inefficient mix of inputs being applied at a higher cost per unit of fishing effort. While overall effort reductions may be achieved, there is generally little (if any) improvement in economic performance (Figure 76). Again, technological improvements will erode the conservation benefits through reducing the cost per unit of effort, again resulting in increased levels of fishing effort.

Fisheries policy applied in Europe under the Common Fisheries Policy adds a further complicating element. Output controls in the form of total allowable catches to limit the level of landings have been applied to many species. In many cases, these catch limits are below historical catch levels in a bid to allow some recovery of the overexploited stocks. However, as the catching capacity of the fleet is greater than the catch restrictions allow, there is considerable excess capacity in the fisheries.

Figure 76. Short-term effect of input controls



The most recent rounds of quota reductions in the North Sea in particular create additional incentives in the fishery that may lead to longer term environmental damage in the form of overfishing. In the UK, quotas are nominally allocated to individual fishers. While some transferability is possible, the transactions cost of this under the current UK quota management system is relatively high, resulting in many individual quotas being effectively fixed. As the gear is not species-selective, and as the quotas do not necessarily correspond to the catch compositions of the different gears, over-quota catches of some species are common. These over-quota catches are either discarded[114] or landed illegally. With low quotas, many vessels are likely to be either economically non-viable or earn less than their 'normal' profit if they land only their nominal quota allocation. Consequently, incentives are created to land catch illegally in order to avoid the quota restriction. Capacity reduction programmes have been implemented in a bid to address this problem. A recent review of the effectiveness of the capacity reduction programmes is given by Pascoe *et al*. (2002).

Individual transferable quotas (ITQs) have been proposed as an alternative management system for the UK that will overcome many of these problems (Hatcher *et al*., 2002; Pascoe, *et al*., 2002). With ITQs, the total allowable catch is allocated to individuals who have the ability subsequently to adjust their quota holdings to match their catch compositions. Further, when total allowable catches are reduced, fishers can purchase more quota from fishers willing to exit the fishery. The revenue generated through sale of quota can provide sufficient incentive for some fishers to exit the fishery, reducing the level of excess capacity. ITQs also provide a form of property rights over a share of the catch, allowing fishers to adjust their harvesting strategies to maximise their returns[115].

13.47.2. Economic incentives to discard

Most fishing gear is not perfectly size- or species-selective. While gear can be modified to reduce the proportion of smaller fish caught, or in some cases the species caught, the final catch will usually end contain some species or fish not wanted by the fisher. This unintended catch, known as by-catch, is subsequently discarded[116]. Discarding is most commonly associated with quota controls, and is often proposed as an adverse consequence of using quotas to manage fisheries. However, discarding is essentially an economic activity that can take place under all forms of management (and also in the absence of management).

A common feature of fish is that the market price often varies by size. In most cases, the unit price (i.e. £/kg) increases with size, with small fish often having no or little market value. Bringing a fish to market is not cost-free. Fish require icing to remain fresh, labour to sort and box, and take up valuable room in holds. Transport is also required to get the fish to market, and a levy is often charged on the fish for commission from the selling agent. The net price of the fish is the market price less the costs involved in getting the fish to market. This net price

[114] Incentives to discard fish exist for a number of reasons. These are addressed separately below.

[115] It is beyond the scope of this report to detail the full economic incentives created under ITQs. A general review of the potential benefits of ITQs is provided by Grafton (1996).

[116] As mention in the previous section, incentives exist to land some undersized or over-quota catch illegally. For the purposes of simplification, it will be assumed in this section that fishers comply with regulations.

can be negative. Even in an unregulated fishery, fishers have an incentive to discard smaller fish if the expected net price is negative. For non-commercial species, which by definition have no market price, there is no incentive to land the fish, so all are discarded.

The incentives to discard in an unregulated fishery are increased if the boat has a limited hold capacity and catch is expected to exceed this hold capacity. Hold space has an 'opportunity cost', being the potential use of the hold to store a more valuable species or size. When the catch (or expected catch) exceeds the hold capacity, it is rational to discard low-value sizes and species in order to utilise the hold for the more valuable size of fish or the more valuable species[117]. This is termed 'high-grading', and can apply to either different sizes of the same species or different species.

Limited entry, where the number of entrants to a fishery is restricted (usually through a licensing system), is often imposed to reduce the potential for the fishery to become overexploited. If the total effort level is reduced as a result of licence restrictions[118], then there may be a short-term reduction in the total level of discarding. If effort is effectively constrained and stocks recover, discarding may again increase as individual catches further exceed the hold capacity. In such a case, the discarding is associated with a larger stock size and, from a conservation perspective, may be more desirable than when discarding (and stock size) was lower.

Management can have a direct impact on the incentives to discard. For example, minimum landing sizes may lead to increased discarding because all catch below the minimum size must be discarded. The intention of the minimum landing sizes is to prevent juvenile fish from being actively targeted. However, such fish are often caught as by-catch and subsequently discarded. Cotter *et al.* (2002) estimated that between 20 and 48% of cod, 30 and 41% of haddock and 51 and 56% of whiting (by numbers) caught by North Sea otter trawlers in 1997 and 1998 were discarded, with half of this consisting of undersized fish. Revill *et al.* (1999) estimated the annual cost to the North Sea whitefish fishery of undersized (juvenile) cod, whiting, plaice and sole caught and discarded shrimp (*Crangon crangon*) vessels to be of the order of €6.6m[119].

[117] See Arnason (1994) and Pascoe (1997) for further information.
[118] In practice, this rarely happens as licensing is often introduced to prevent new entrants, not remove existing participants. Where fleet reduction is also imposed, this is often in the form of a buy-back or decommissioning scheme.
[119] This estimate took into account also the likelihood of the juveniles surviving to legal sizes, and the proportion that realistically could be expected to be caught.

Discarding is most commonly associated with output controls. These are limits on the quantity of each species that can be caught, or more correctly, landed. Catches in excess of the quota, by law, cannot be landed and are therefore discarded. Quotas may take two main forms – aggregate quotas, where all fishers compete for a share of a total limited catch, or individual quotas, where fishers have an explicit share of the total catch. The incentives to discard differ under the two types of systems.

Under an aggregate quota system, the incentives to discard change depending on whether or not the quota has been reached. Before the total allowable catch is reached, the incentives to discard are the same as those under free and open access. In other words, small fish or lower valued species may be discarded if their net price is negative, and/or if the hold constraint is binding. Once the total allowable catch is reached, the fisher is faced with a different set of incentives. As the species without quota has zero economic value to the fisher, subsequent production decisions will be based on the (expected) value of the catch of species for which quota remains. If the value of this expected catch exceeds the additional costs of catching it, then the fisher will continue fishing and discard the over-quota catch (in the same way as any other non-commercial species). In some cases, incentives may exist to change fishing locations if alternative locations will provide a more profitable catch composition when the over-quota catch is not considered. It is likely, however, that the restricted species will still be caught and discarded. If the expected value of the marketable catch (i.e. the catch that can be legally landed) does not exceed the additional costs of catching it, then the fisher will cease fishing for the year even if some quotas are not filled[120].

With individual quotas, there is an additional 'opportunity cost' of landing small fish, that being the value of the larger fish that could have been landed if the quota had not been used up to land smaller, less valuable fish. If the expected value of landing only larger fish exceeds the costs of fishing, and the additional revenue from the strategy exceeds the cost of the additional fishing effort that needs to be expended to replace the catch that was discarded, then there are incentives to discard the smaller fish and retain only the higher grades. Individual quota-holders also face the problem of having the quota of one species used up before others, resulting in the same incentives to discard (or cease fishing) as under the aggregate quotas. With individual transferable quotas (ITQs), an individual may buy or lease

[120] Incentives also exist to continue fishing and land over-quota catch illegally (i.e. 'black' fish). These incentives are affected by a range of other factors such as enforcement levels, fines and fisher attitudes. For further details, see Hatcher (2003) for an overview of the incentives to comply with quota regulations.

in quota if unused quota were available elsewhere in the fishery, but if the total quota had been filled, then discarding may still occur.

While individual quotas can result in additional incentives to high-grade, they can also result in lower levels of discarding. Under an ITQ system, a fisher is better able to plan his or her harvesting strategy. This could result in a fishing pattern that lowers discards or increases them, depending on the spatial distribution of the stock. With transferability, fishers have the ability to adjust their quota mix to better correspond with their catch composition. The incentives to adopt more selective gear are also increased. High-grading imposes additional costs on the fisher in the form of the additional effort needed to be expended to replace the discarded catch, and the additional labour costs involved in sorting discarding the lower grade catch. If this catch can be avoided in the first place through more selective gear, then the quota can be utilised more efficiently. Hence, while a greater proportion of the catch of small fish may be discarded, fewer small fish may be caught and hence overall discards may be lower. The actual direction of change will vary from fishery to fishery. Evidence from fisheries in which ITQs have been implemented tends to suggest that, in many instances, the overall level of discarding may not be substantially greater than that which would occur under alternative management measures.

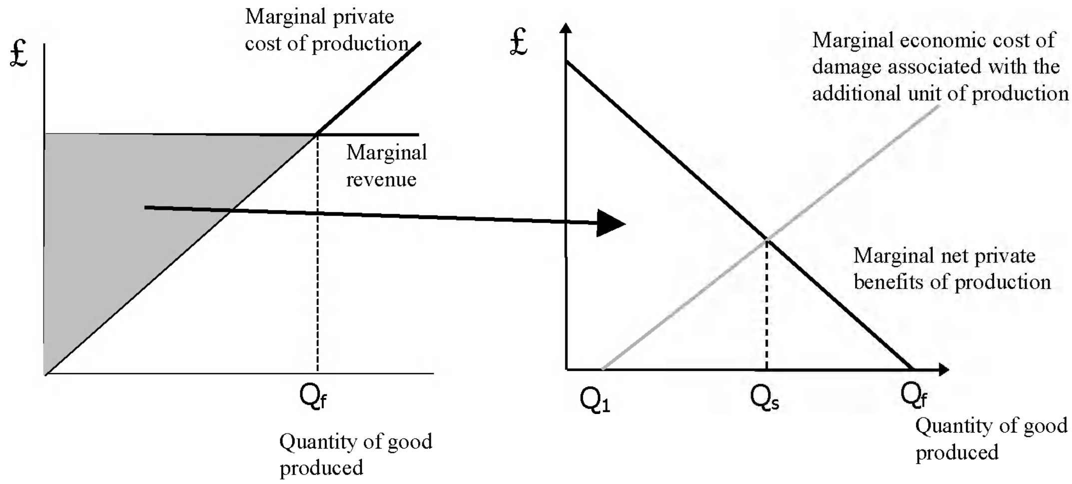
From the above, discarding (including high-grading) is a feature of every fishery irrespective of the management system. The management system can, however, alter the incentives to discard. The extent and the direction of change in level of discard is, in many respects, more a function of the characteristics of the stocks being harvested than a function of the management plan.

13.47.3. Market failure and 'optimal' environmental damage from fishing

While the environmental damage attributable to fishing can be considered to impose a cost on society, environmental damage is a part of the production process. In the absence of alternative technologies that are both efficient and less environmentally damaging, some level of environmental damage is necessary in order to provide society with the goods it demands. As a consequence, there exists an 'optimal level' of environmental damage associated with the production of fish for human use. The main issue then is not if environmental damage exists, but if the level of environmental damage is greater than the 'optimal level'.

The concept of 'optimal' environmental damage associated with fishing is illustrated in Figure 77. For the purposes of simplification, a constant price is assumed (resulting in a constant marginal revenue), and the cost of producing an additional unit of fish (i.e. the marginal cost) in any given time period is assumed to increase[121] at a constant rate. The difference between the marginal revenue and the marginal cost represents the marginal benefit of producing a given level of production. These are the private benefits that accrue to the producers (i.e. the fishers). For example, when production levels are low, there exists considerable marginal benefits from increasing production. At some point, the marginal benefit is zero, so there is no benefit in increasing production further.

Figure 77. Marginal benefits and costs of environmental damage from fishing



As noted previously, fishing produces environmental damage, the costs of which are not considered by the fisher in his or her harvesting decisions. At low levels of output, the damage is expected to be small and can possibly be assimilated back into the environment through natural regeneration. As production increases, however, the ability of the environment to recover rapidly from this damage is reduced. Assuming the marginal costs of environmental damage increases as output (and environmental damage) increases[122], then the 'optimal' level of output is Qs. Above this point, the cost of the additional environmental damage exceeds the benefits generated by the additional output. Similarly, below this level, the additional benefits that could be obtained from increasing output to Qs exceed the costs of the associated damage.

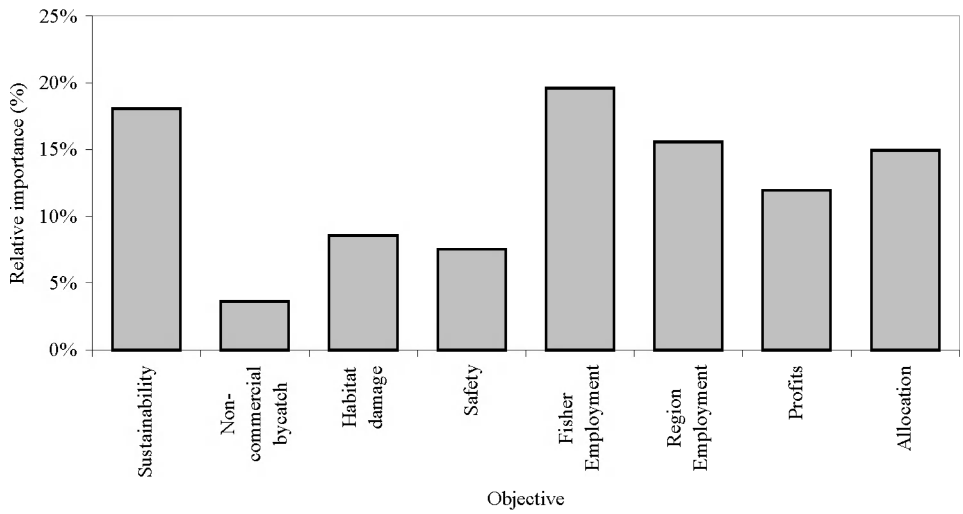
The optimal level of output (and associated environmental damage) is not realised, because the costs associated with this output are not directly borne by the fishers themselves, at least

[121] The stock is depleted over the year as fishing removes part of the biomass. As a result, catch rates fall, and increasing levels of effort need to be employed to catch a given quantity of fish.
[122] The assumption of increasing marginal cost of environmental damage is related to the assumption of increasing marginal cost of production. As catch rates fall over the season, the increased level of effort required to catch an extra unit of output results in increased damage also per unit of output.

in the short term. Even though the damage may result in reduced future production levels, the individual cannot influence this through limiting his or her production alone. By taking unilateral action to restrict fishing activity, the individual risks gaining no benefits as the activity of other producers is beyond their control. Consequently, market failure exists, because the costs of these activities are not taken into consideration in the production process, and suboptimal levels of output result.

A further difficulty in fisheries is the lack of perceived importance of the environmental damage created by fishing activity by the industry. A survey of English Channel fishers' priorities for fisheries management rated environmental damage, such as non-commercial by-catch and habitat damage, low in the set of priorities (Figure 78) (Mardle and Pascoe, 2003b). Issues such as maximising regional and fishery employment, improving profits and ensuring equitable allocation between competing user groups (e.g. fishers from different areas and/or using different fishing gears) were considered substantially more important. Hence, while there exists a market failure that prevents an optimal level of output from being produced naturally, there is relatively little demand from the fishing industry to implement policies that limit the environmental damage they produce.

Figure 78. Importance of environmental damage to fishers (English Channel)



Source: Mardle and Pascoe (2003b)

13.48 The Marine Stewardship Council's scheme for sustainable fish produce