MODIFYING FISHING GEAR TO ACHIEVE ECOSYSTEM OBJECTIVES

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ABSTRACT

There have been considerable efforts in recent years to modify fishing gears and practices to target particular sizes and species of fish and other marine organisms more efficiently, as well as to have less impact on bottom habitats. Recent developments in navigational aids and instruments for improving the classification of bottom habitats enables the fishing industry to harvest target resources more efficiently and to reduce impacts on benthic habitats and their communities. These changes hold promise for the achievement of broader ecosystem objectives, such as maintaining species and ecosystem diversities.

This paper provides a review of successful developments and applications of selective fishing techniques that have been used to achieve ecosystem objectives. For example, the introduction of turtle excluder devices (TEDs) in shrimp trawls has dramatically reduced mortality of endangered sea turtles; the declines of the by-catches and discards of finfish in many shrimp trawl fisheries has mainly been the result of the sorting grids and square mesh panels introduced in these fisheries; changes in the construction and operation of tuna purse seines have significantly reduced the mortality of dolphins that are incidentally captured; and technical measures to reduce the incidental catch of seabirds in longline fisheries have been successfully developed. By-catch considerations and gear modifications play an important role in the regulation of several major fisheries, and new by-catch reduction devices and other innovative gear modifications are continuously being proposed and tested to mitigate problems.

This paper also reviews the status of the development of gears, instruments and practices that can reduce the impacts of fishing on benthic communities and their habitats. During the last two decades there has been increasing concerns over the effects of bottom-fishing activities on benthic ecosystems in all major regions where commercial fishing is done. The evidence that fishing gears may injure benthic organisms and at least locally reduce habitat complexity and cause reduced biodiversity has appeared in various media with increasing frequency.

Finally, this paper discuss the most likely future development of commercial fishing practices, including an analysis of the likely consequences that changes to achieve ecosystem objectives might have on the efficiency of fishing. It is unlikely that gear modifications will eliminate all adverse effects completely – progress will take place by modest steps. Therefore, realistic short- and long-term objectives are necessary when attempting to minimize ecosystem impacts of a fishery. Managers should set measurable limits for by-catch levels and benthic disturbances caused by fishing

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gears. In many cases, a combination of technological improvement, active avoidance of areas and seasons of high by-catch rates (hot spots), and other management actions may be necessary to achieve the desired outcomes. Some gear modifications may make gears more expensive to construct, and more difficult to operate and maintain. Moreover, catches of marketable fish may be reduced. Measures and techniques that increase costs and reduce earnings are unattractive to fishermen. There is little point in introducing totally unacceptable concepts or modifications – they will probably fail. The fishing effectiveness and practicality of new designs are important because an inefficient gear will not be used or will be "sabotaged," or may require so much additional fishing effort that overall impacts could actually be increased. Close cooperation between the fishing industry, scientists and other stakeholders will be necessary in the process of developing and introducing environmentally friendly fishing technology.

In conclusion, technologies developed in recent years demonstrate that the impact of fishing gears on non-target species and habitats can be significantly reduced without major negative effect on the profitability of the fishing operation. Clearly, economic rewards should be offered for the creation of new types of gear and modifications that reduce by-catch and minimize impact on habitats.

1. INTRODUCTION

[1] The two major objectives of commercial fishing are to catch high quality seafood and to create employment and income for people. Commercial fishing involves a wide range of gear and techniques used in environments that are also occupied by organisms that are not targeted by the fishery. The use of fishing gear in such environments sometimes creates unintended impacts, such as the removal of organisms that, for various reasons, should not be taken (e.g. juveniles, threatened species); and habitat alterations that may be negative for the organisms living there.

[2] The removal of non-target organisms has been a cause of concern for fisheries management for many years. For instance, the extensive capture of juvenile and young fish of commercially important species has frequently been regarded as a threat to recruitment of stocks. Many fisheries harvest individuals of the target species before they reach their optimal size in terms of future yield. The use of larger mesh sizes in the collecting bag (cod end) was among the first technical measures imposed by fisheries managers to prevent the capture of juveniles. A more recent concern, beginning in the 1970s, was the unintended capture and killing of more charismatic animals, like marine mammals, seabirds and turtles, by commercial fisheries. In particular, the incidental capture and mortality of endangered or threatened species that are long-lived and have low reproductive rates has aroused growing conflict. The unseen mortality due to ghost fishing by lost gear has recently also attracted much attention.

[3] Such trends in public concern have provoked environmental groups to question the fishing practices currently in use. This stimulated extensive research and development efforts by many countries to solve the many problems. Subsequent technological modifications in fishing gear and their operation have proved successful in many fisheries that are facing by-catch problems. For example, the introduction of turtle excluder devices (TEDs) in shrimp trawls has dramatically reduced the mortality of endangered sea turtles; the spectacular declines of the by-catches and discards of finfish in many shrimp trawl fisheries have mainly been the result of sorting grids and square-mesh panels introduced in these fisheries (see Broadhurst (2000) for a review); and changes in the construction and operation of tuna purse seines have significantly reduced the mortality of dolphins that are incidentally captured in seines. Today, by-catch considerations and gear modifications play an important role in the regulation of several major fisheries, and new by-

catch reduction devices and other innovative gear modifications are continuously being proposed and tested to mitigate problems.

[4] As the upper limits of production from marine capture fisheries have become more obvious, fisheries managers have introduced a variety of new controls, including regulations to limit access to fishing grounds, to limit fishing effort, and to set total allowable catches (TACs) and by-catch limits. Many of these regulations are obviously necessary, but they also often cause additional problems for the fishing industry. In mixed species fisheries, attaining the quota of one species may prevent the exploitation of a species for which the quota has not been reached. If the fishing of these species has to continue, it may lead to unnecessary discarding (“dumping”) of restricted species, or the fishery may be closed. Such situations provide a strong incentive to develop gear modifications and other methods for separating species during fishing operations.

[5] During the last two decades, there has been increasing concern over the effects of bottom-fishing activities on the benthic ecosystems in all regions where commercial fishing is practiced. The evidence that fishing gear may injure benthic organisms, reduce habitat complexities and reduce biodiversity has appeared in various media, with increasing frequency. Many experimental studies have shown that it is possible to detect local changes in the physical structure of the sea bed and the benthic community in response to fishing disturbances (reviewed by Jennings and Kaiser, 1998). Few studies, however, have investigated and demonstrated long-term alterations in community composition due to these effects. Species that show the greatest decline tend to be slow-growing and physically vulnerable to damage by contact with fishing gear. However, very little quantitative data exists on these impacts and their overall effects on biological productivity and recovery times. There is even less information concerning how and to what extent changes in habitat structure affect fisheries resources and contribute to declines in fisheries. Clearly, before any solutions can be developed, more information is needed to identify the problems and their causes.

[6] This paper provides a review of successful developments and applications of selective fishing techniques. It also reviews the status of the development of gear, instruments and practices that can reduce the negative impacts of fishing on benthic communities and their habitats, while at the same time allowing the continued use of marine resources. Finally, it discusses the possible consequences that regulated changes to commercial fishing practices might have on the efficiency of fishing and the acceptance of these techniques by industry.

2. SELECTIVE FISHING TECHNIQUES THAT REDUCE UNWANTED CATCHES

2.1 Trawling and seining

[7] Trawling is one of the most widespread fishing methods used in the world and catches all kinds of marine organisms, from small shrimps to larger tuna species. It involves a range of gear sizes, from small gear towed by sail-driven canoes in Sri Lanka, to huge mid-water trawls that catch scattered concentrations of redfish in the Irmiger Sea. Trawling techniques have evolved over time, with the most significant change being increases in sizes of the gear, which often has resulted in better fishing efficiencies for particular targets. An inherent disadvantage of trawl gear is that, in addition to the target species, trawls often encounter and capture organisms that for various reasons should have been avoided, such as undersized individuals of the target species, endangered species, low value fish, and charismatic species like sea turtles and marine mammals.

[8] A major reason for capture of non-target organisms is that the retaining bag of the trawl (the cod end) is made from mesh that is too small to allow the non-target organisms to escape. Therefore, conservation regulations for trawls have concentrated on improving the size selectivity of cod ends. In single-species fisheries, positive results have been obtained with relatively simple constructional changes, such as increasing mesh size or modifying the shape of cod end meshes. Size-selection can also be improved by modifying the overall cod end design, type and thickness

of the twine, and by removing cod end attachments like chafers, lifting bags, etc. Sorting grids and special selectivity panels inserted into the trawl have been successfully applied in certain fisheries for size-sorting, and recent developments of flexible sorting grids offers new opportunities for practical and effective size-sorting. However, improvement in size- and species-selectivity in mixed species trawl fisheries is not easily achieved by simple gear modifications. The basic approach used in such situations is to take advantage of different behaviour patterns of target and non-target organisms during capture. The following examples illustrate some successful developments that demonstrate how trawl gear have been modified to reduce the capture of non-target organisms.

2.1.1 Turtle Excluder Devices

[9] The by-catch of sea turtles in shrimp fisheries in tropical areas has caused more public concern than most other problems related to by-catch in trawl fisheries. This issue has had wide political and economic impacts on global shrimp fisheries and trade. The problem first surfaced in the public media in the USA, where environmental groups argued that the incidental capture of sea turtles in the shrimp fisheries of the Gulf of Mexico was a threat to the populations of several turtles. The USA authorities initiated programmes to solve this problem, and have subsequently developed and legislated for the use of Turtle Excluder Device (TEDs) in their Gulf fisheries (e.g. Watson *et al.*, 1996). By various means, the USA government has also tried to enforce similar regulations in other countries seeking access to USA markets for their trawl-caught shrimp. This USA pressure has subsequently led to research and development of TEDs in other countries, including developing countries in Asia, like Thailand, Malaysia, and the Philippines, and in Latin American countries, such as Mexico.

[10] A TED is a soft or rigid device inserted in front of the cod end to guide turtles out of the trawl, whereas most of the target shrimp will pass through the device into the cod end (Figure 1).

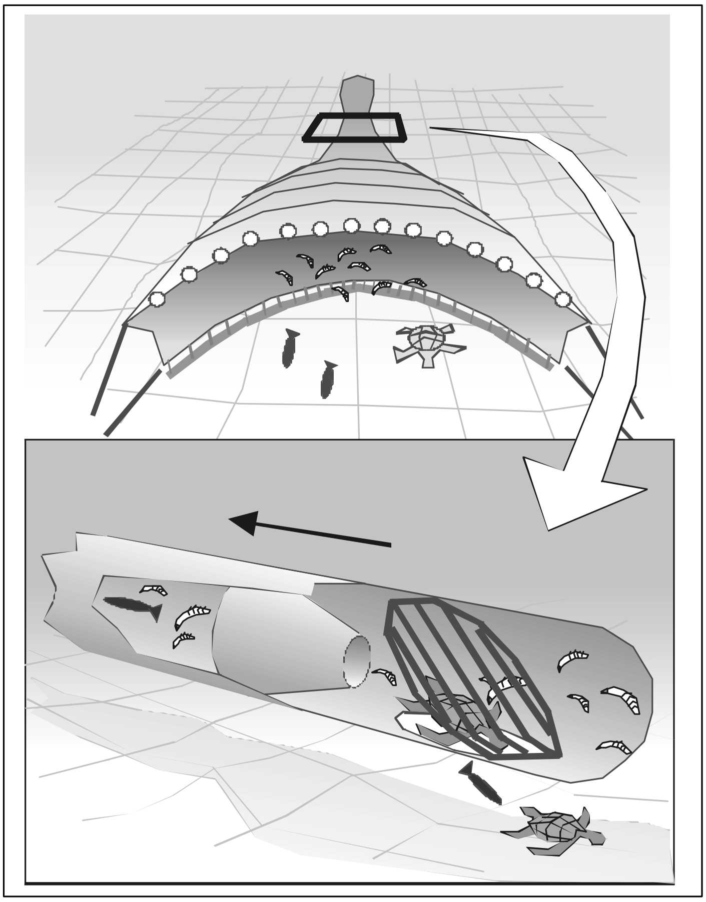

Figure 1. A turtle excluder device (TED) is a soft or rigid device inserted in front of the codend to guide turtles out of the trawl, whereas most of the target shrimp will pass through the device into the cod end

[11] The major disadvantage of TEDs is that they can become blocked by various objects, resulting in a loss of shrimp catch. In fisheries where some commercial fish species are targeted together with shrimp, losses of fish are regarded by fishers as an additional disadvantage. In general terms, however, various designs of TEDs have been developed and are mandatory in most shrimp fisheries where a problem with turtle by-catch exists.

2.1.2 The Nordmøre Grid

[12] The Nordmøre Grid is based on a rigid filtering system similar to a TED, and was developed in Norway in the late 1980s to reduce the capture of non-wanted by-catch of juvenile finfish in northern deep water shrimp (*Pandalus borealis*) fisheries (Figure 2). This device proved to be an effective fish excluder, whilst simultaneously retaining the targeted shrimp (Isaksen *et al.* 1992). Less than two years after its testing, its use became mandatory in all shrimp fisheries inside the Norwegian EEZ north of 62°N. The same or a similar device was soon made mandatory in most other northern shrimp fisheries in Russia, Canada, northern USA, Iceland and the Faroe Islands. The grid system was found to be efficient also for other shrimp fisheries where the target shrimp are relatively small and the by-catch species are comparatively larger. Some coastal shrimp fisheries in Australia have also used this technology (Kennelly, 1995; Kennelly and Broadhurst, 1995; Brewer *et al.*, 1997). In an estuarine fishery in New South Wales, the catch composition of shrimp and fish by-catch was approximately 50:50. Much of the by-catch consisted of juveniles of recreationally and commercially important juvenile fish. A modified Nordmøre grid was developed and successfully adopted by the fishing fleet, resulting in greatly reduced by-catches whilst maintaining the shrimp catches.

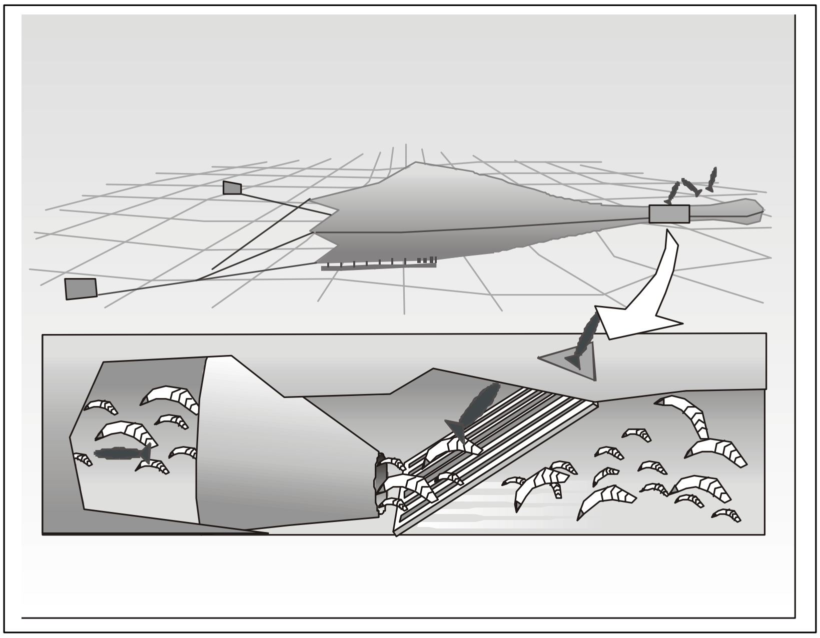

Figure 2. The Nordmøre Grid effectively reduces the capture of non-wanted by-catch of juvenile finfish in shrimp fisheries whilst simultaneously retaining the targeted shrimp

2.1.3 By-catch reduction devices in tropical shrimp fisheries

[13] In most tropical shrimp fisheries, the target shrimp or prawns are often larger in size than unwanted fish by-catch, which often includes juveniles of valuable fish species. To avoid such by-catch, which in many cases is discarded, various devices have been developed that often are based on behavioural differences between shrimp and fish. Shrimp have a non-directional escape reaction when stimulated, while most fish swim away from stimuli and seek escape through openings if such opportunities exist. Many such devices have been developed in various parts of

the world, often as a joint effort between research institutions and the fishing industry. The efficiency of such devices varies and their application in commercial fisheries is still at a very early stage in many places. Only a few countries have made such devices mandatory and the USA Gulf of Mexico shrimp fishery is the most important, where the capture of juvenile red snapper is a major concern. By-catch reduction devices (BRDs) in tropical shrimp trawls are often used in combination with TEDs, where the BRD is usually mounted behind the TED in the front part of the cod end. Experience has shown that most of the fish escape takes place during the haul-back operation, when the forward movement of the trawl stops and fish in the cod end can easily move forward to an escape opening. Some fish find the escape holes during towing, but higher water speeds outside the escape hole is a barrier for such escape. Ongoing research is trying to facilitate such escape, and some promising solutions have already been developed. It is notable that, where technologies have been applied in shrimp fisheries, this has tended to occur in developed countries.

[14] Because the avoidance of juvenile fish by-catch in shrimp trawls is only partly solved, this problem has been given a high priority by the international community. A global project, funded by the Global Environmental Facility (GEF) and FAO, and executed by FAO on behalf of UNEP, is addressing this problem by implementing selective technology in several developing countries in all global regions where such fisheries occur.

2.1.4 Other successful by-catch reduction devices and approaches

[15] Besides shrimp trawling, unwanted by-catches also occur in a range of other trawl fisheries. In particular, species that are regulated with quotas may create problems when quota species are caught together with other target species. To solve this problem, devices and techniques that have different capture selectivity for various species have been developed.

[16] In Alaska, for example, trawl fishers and researchers have developed and tested a range of BRDs (excluders) and other modifications to bottom trawls to reduce the by-catch of Pacific halibut (*Hippoglossus stenolepsis*) in cod and sole fisheries (e.g. Rose and Gauvin, 2001; Rose, 2001). These developments are motivated by halibut by-catch restrictions that often close these fisheries before quotas of the target species can be harvested. Substantial decreases in halibut by-catches have been obtained and the presence of the halibut excluders does not significantly increase handling time.

[17] Glass *et al.* (2001) demonstrated that special separator and raised footrope trawl designs developed for the reduction of by-catches in the Massachusetts inshore squid (*Loligo pealeii*) fishery successfully captured the target species (squid) while dramatically reducing by-catch of flatfishes and scup (*Stenotomus chrysops*). The different behaviours of these species were used to separate squid in the top cod end from other species in the lower cod end. Separator trawls, however, were not favourably accepted by industry because they proved difficult to rig, repair and maintain. The raised footrope design offers a more cost-effective alternative to reduce by-catches in this particular fishery. Apparently, these types of modifications have a significant potential to reduce by-catches in many other fisheries as well.

[18] Behavioural observations of species like cod and haddock have demonstrated that haddock may swim upwards when entering the trawl mouth whereas cod has less tendency to do so. One practical application of such a difference is to insert a horizontal dividing panel inside the trawl and have upper and lower cod ends that have different mesh sizes, depending on the sizes of cod and haddock to be retained. Alternatively, the upper or lower trawl could have no cod end, depending on the species that should be avoided. A modification of such a panel using these behavioural differences has successfully been developed for use in a Danish seine, which is very similar to a trawl in its performance. The aft part of the seine is divided horizontally with large square meshes and relatively more haddock than cod rise through the panel. It can therefore be used to alter the catch composition of these species according to quota requirements.

2.1.5 Size-sorting grids

[19] On the basis of the success of rigid devices in trawls to reduce non-wanted by-catch, and the wide acceptance of them by fishermen in many fisheries, gear researchers started to look into other selectivity problems where such devices might be useful. Successful attempts have been made to utilize grids for size-sorting of various demersal and pelagic fish species, shrimp and Norway lobster (Figure 3). For example, Norway has made the use of sorting grids mandatory in demersal trawl fisheries for codfishes (cod, haddock and saithe) in the Barents Sea area.

[20] An advantage of a sorting grid compared to conventional modifications to cod end meshes is that the bar spacing of a grid is constant throughout the tow, regardless of towing speed, catch rate and other factors that may reduce the selective performance of a diamond-mesh cod end. Despite this, the designs of sorting grids can still be improved. Handling problems aboard fishing vessels create significant industry resistance to the adoption of this technology. There is potential, however, in the development of flexible devices that can be more easily operated aboard most sizes of vessels (Rose, 1999).

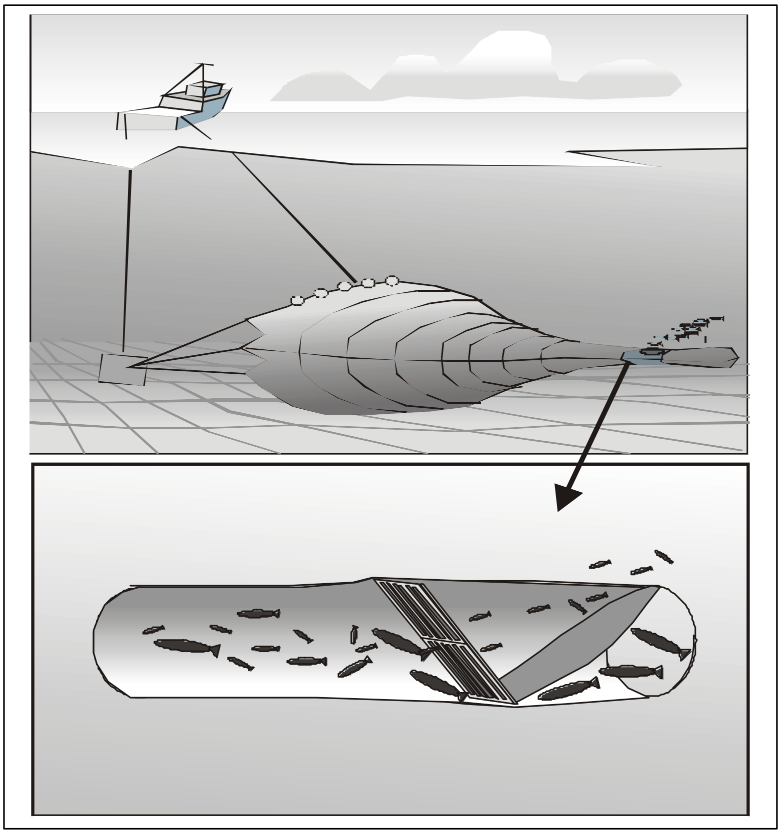

Figure 3. Successful attempts have been made to utilize grids, for example in size-sorting of shrimp

2.1.6 Square mesh cod ends and windows

[21] There are many small-scale trawl fisheries where very simple and robust solutions are needed for efficient size sorting of fish. Modifications of configuration of meshes in the cod ends offer potential for improving selectivity compared to ordinary diamond-mesh cod ends. There are two important factors to consider when designing an effective size-selective cod end: (i) a cod end with open meshes is likely to enhance the selectivity for roundfish such as cod and haddock; and (ii) fish normally escape through meshes just in front of the accumulated catch, indicating that open meshes should be positioned in this area.

[22] A cod end with all, or part, of the meshes hung in a square configuration was a simple invention to ensure that the meshes would stay open during the tow. Large numbers of

experiments were done in the 1980s and 1990s in the northern Atlantic, Australia and Alaska with various types of square-mesh cod ends, and the results generally indicated that a square-mesh cod end provides better selectivity than a conventional diamond-mesh cod end. The experiments also indicated that a conventional cod end equipped with a square-mesh window is often a more flexible and practical means of excluding undersized fish than is a full square-mesh cod end (Figure 4). An advantage with such a window is the ease by which selectivity can be quickly changed: instead of manufacturing a whole new cod end, only the window panel needs to be replaced. Despite this, such windows have often been rejected by industry. This has mainly been due to disagreements over the type of netting to be used in escape panel(s), and the proper size and positioning of the panel. The weaker construction of a window cod end has also been a cause of concern. One disadvantage with windows is that their selectivity can be easily prevented by closing them with a rope or simple piece of netting while fishing.

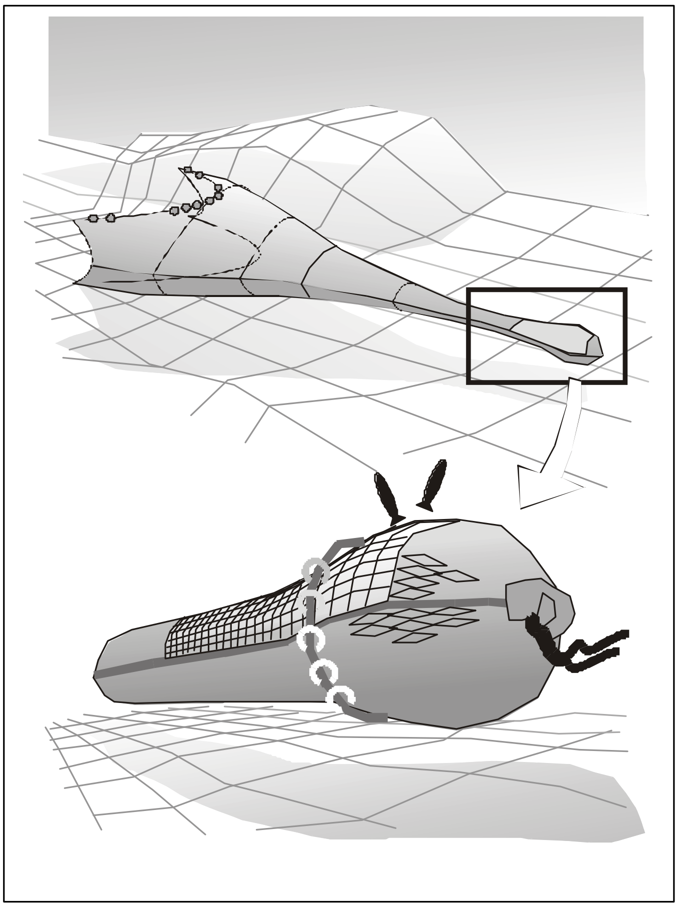

Figure 4. A cod end equipped with a square mesh window is often a more flexible and practical solution to exclude undersized fish than a full square mesh cod end or a conventional diamond mesh cod end

2.2 Purse seining

[23] Purse seining is a widely used technology, whereby a detected school of fish is encircled and captured. It is generally known as a non-selective fishing method and the incidental capture of dolphins and porpoises in tuna purse seine fisheries was a major cause of concern in the 1960s. It was actually the first case of environmental and conservation organizations forcing a by-catch issue to the top of the international fisheries management agenda. The pressure from these groups was so strong that authorities and the fishing industry were forced to find practical solutions that could substantially reduce the incidental killing of dolphins in the tuna purse seining fishery. A major reason for the problem was the practice of encircling groups of dolphins that were associated with the tuna. In the early years of this fishery, the incidental mortality of dolphins using this method was high (an average of 350 000 dolphins annually during the 1960s) which

was believed to have caused significant declines in populations of dolphins. Through the development of a series of modifications to the purse seines, release practices, and the education and training of skippers and crews, dolphin mortalities have been reduced to negligible levels (e.g. Hall, 1996). These modifications included different mesh sizes in certain sections of the purse seines, a different method of tying the cork line, a manoeuvre termed “backdown” after dolphins were encircled, the use of speedboats as dolphin rescue boats inside the seine, and avoiding places containing populations of dolphins particularly prone to entrapment. The successes of the work done in this fishery showed that it was possible to save dolphins without closing a major fishery.

[24] There have been increasing concerns recently over the discard of small fish, sharks, rays, and some other species captured as by-catch in tuna purse seines when fishing near or under floating objects and Fish Aggregating Devices (FADs). These non-wanted organisms are associated with such floating objects and therefore it is difficult to avoid their capture when targeting tunas swimming near them. This type of fishery is regarded as a non-sustainable practice where a solution is urgently needed. Some successful applications of sorting grids have been demonstrated in other purse seine fisheries, but one problem with this technique is high mortality of escaping fish, particularly small sized pelagic species (Beltestad and Misund, 1995).

2.3 Gillnetting

[25] The capture process in gillnets depends on intercepting fish as they move, and such gear can be quite effective for species that would otherwise only be captured with trawls or other active fishing gear. Size-selectivity for finfish is generally good with gillnets, but species-selectivity is often poor. If appropriate soak times are followed, the quality of the catch is generally quite high, but most fish die during the capture so there is little potential benefit from releasing by-catch.

[26] The by-catch of crustaceans and other benthic animals in gillnet fisheries can be reduced by raising the groundline a little above the bottom but this has often come at the cost of reduced catches for demersal species. Recently, the entanglement of sea birds, turtles and marine mammals has aroused concerns, and several potential solutions have been explored. Acoustic scaring devices (pingers) may be useful for deterring cetacean entanglements, although there is a chance of habituation to such signals. Setting nets parallel to the routes taken by mammals, or setting nets several metres below the surface may reduce accidental capture, and gaps between nets set in long fleets give cetaceans an opportunity to pass through. Despite these solutions, restricting the number of nets in use during critical seasons and areas may be the most effective approach.

[27] A specific problem in many coastal areas is that during certain seasons gillnets may catch substantial numbers of sea birds that become entangled in gillnets while diving for prey. The addition of acoustic alerts or visual alerts, such as strips of highly visible netting in the upper part of the net, may help to reduce this type of entanglement without significant losses in catches.

[28] There is growing concern about the impacts of ghost fishing by lost gillnets. Lost gillnets may continue to fish for several weeks, months or even years, depending on the depth and prevailing environmental conditions (light levels, temperature, current speed). This problem can be partially addressed by the use of biodegradable materials or other means to disable unattended gillnets, by increased efforts to avoid losing them, or by facilitating the quick recovery of lost nets. In some areas, active campaigns are undertaken to periodically “sweep” for lost nets in known gillnet fishing grounds.

2.4 Longlining

[29] Longlines are used in many areas of the world to catch a variety of species including tunas, swordfishes, gadoids, flatfishes and sharks. In some longline fisheries, by-catches are high but are usually alive when hauled onboard and, if released carefully, many may survive. However, barotrauma or thermal shock may jeopardize survival of released fish. Species- and size-

selectivity of a longline can be modified by bait size and type, and artificial baits that target particular species and sizes offer a promising area of research. The design and size of hooks can also affect selectivity.

[30] Baited lines can be hazardous to seabirds when they try to eat the bait on the hooks while these are floating on the surface behind the vessel. The incidental catch of seabirds occurs in most areas where longlining is done, but the problem is largest in higher latitudes in both hemispheres, where seabirds are most numerous and where longline fisheries are common. A solution to this problem is to make the baited hooks less accessible for seabirds. This can be achieved to a large extent by using bird-scaring lines above the longline when setting (Figure 5), or by setting the longline through a tube that leads the lines directly underwater, thus making the baited hooks invisible or inaccessible to birds. A range of other options have been developed, including setting longlines during darkness, and adding extra weight to lines so that they sink faster (Løkkeborg, 1998; FAO, 1999). It is believed that problems with seabird interactions with many longline fisheries could be reduced to an insignificant level were the technology more widely applied that is already available. Many of the solutions that have been developed also reduce the loss of baits and thereby increase the fishing efficiency of the gear. The international plan of action for reducing incidental capture of seabirds in longline fisheries, developed by FAO, should help to create the required awareness of the problem and also encourage states that have such problems to take appropriate action.

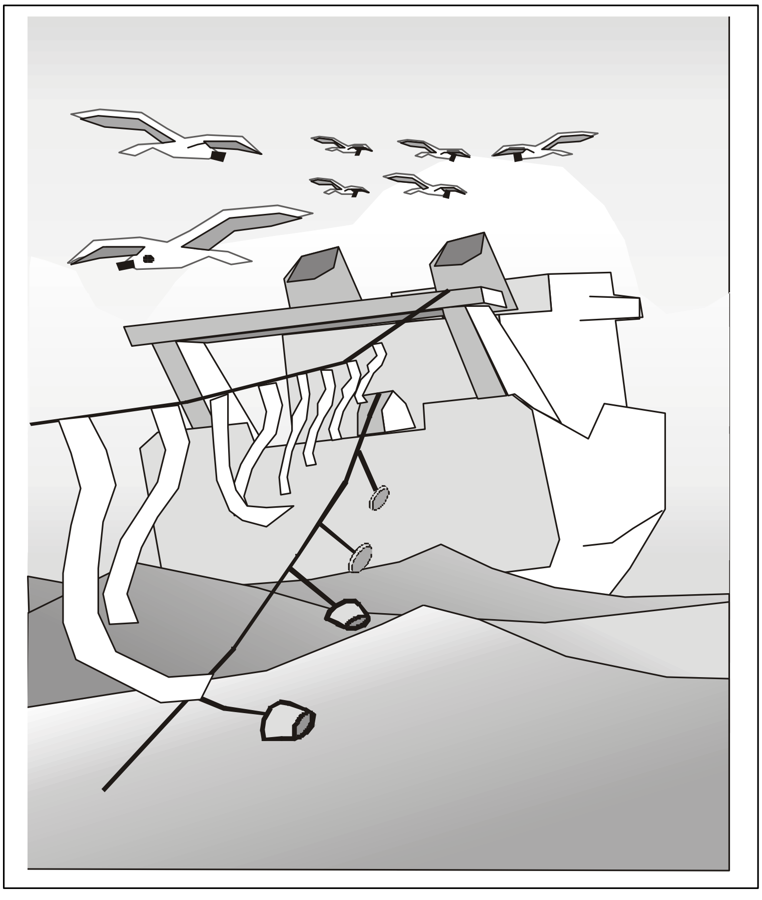

Figure 5. Significant reduction of incidental catch of seabirds in longline gear can be achieved by using bird-scaring lines above the longline when setting

[31] The incidental capture of sea turtles on longline hooks is also a problem but, unlike seabird-longline interactions, technical solutions have not yet been found. Research is therefore needed to produce hooks and baits that reduce incidental capture of sea turtles, and facilitate their release.

2.5 Trap fishing

[32] Fishing with traps normally results in catches that are alive and uninjured, so in most cases unwanted by-catch organisms can be released with a good chance of survival, although factors such as on-deck injury and exposure, and barotrauma or thermal shock, may jeopardize the survival of released organisms. Traps thus offer the potential for low by-catch mortality in comparison with many other fishing methods. By-catches from traps can also be minimized by design elements, including appropriate mesh sizes and twines, and choosing the correct size, shape, location(s) and design of pot entrances and escape openings. The use of various types of baits also has the potential to attract the target species and/or repel unwanted species. Other factors include identifying appropriate soak times for catching target species and sizes, while allowing non-target species and sizes to escape from the trap.

[33] Large numbers of traps are lost at sea and may continue to catch fish or other organisms (ghost fishing), so solutions must be found to reduce the frequency and adverse impacts of such losses. Bio-degradable materials, galvanic timed releases (GTR) and various escape vents have successfully been implemented in traps to reduce their ghost-fishing capacity. In environments with little natural structure or complexity, lost or dumped traps may add to habitat complexity and offer refuges for various species and so function in the same manner as artificial reefs.

3. REDUCING IMPACTS OF FISHING METHODS ON BENTHIC COMMUNITIES AND THEIR HABITATS

3.1 Fishing versus natural disturbances

[34] Of the commonly employed fishing techniques, bottom trawls and dredges have been characterized as having the most potential to damage marine habitats. It is difficult, however, to distinguish changes to benthic communities in the long-term directly attributable to fishing activities, from changes due to other environmental or anthropogenic perturbations (such as coastal eutrophication and pollution). Small-scale disturbances by fishing, even when frequent, may be masked by a background of natural disturbances such as tidal currents (Jennings and Kaiser, 1998). It is notable that fishing effort in continental shelf seas is not homogeneously distributed: fishers traditionally concentrate their effort in grounds that yield the best catches of commercial species and avoid areas with obstructions and rough ground that would damage their gear. In the most heavily fished grounds, the scale and frequency of physical disturbances caused by fishing can increase to a point where long-term ecological effects may be observed against a background of natural disturbance and other anthropogenic effects. So far, however, there is little evidence concerning whether this threshold has been reached.

[35] The most favourable fishing grounds worldwide are usually in the relatively shallow waters of the continental shelf and are characteristically flat, or nearly so, with substrata composed of sand, mud, gravel or a mixture. Typically, such areas are subject to wave, surge, current and tidal influences, which tend to disturb and redistribute the substratum. Existing information suggests that benthic communities inhabiting frequently disturbed environments are less likely to exhibit long-term changes in their structure and composition in response to fishing activities than those in more stable habitats (e.g. Kaiser and Spencer, 1996). The most severe and long-lasting changes are restricted to long-lived fragile species and to communities found in environments that are infrequently disturbed by natural phenomena. Effects are most dramatic on reefs, hard and stable substrata, the deeper portions of continental shelves and on deep-sea slopes. However, it is notable that in recent years, bottom trawling has been expanding into areas that are likely to have higher vulnerability (emergent structures associated with diverse habitats and populations).

3.2 Bottom trawling

[36] For many benthic or epibenthic target species, bottom trawling may be the only cost-effective harvesting technique currently available. By their nature, and in many cases because of the behavioural responses of the target species, bottom trawls are operated with at least some of their components in physical contact with the seabed. The impact of demersal trawl operations on bottom habitats and benthic communities is not easy to predict from simply the bulk or weight of the gear used. In the first place, when the gear is immersed in seawater, buoyancy forces offset much of its weight. In the second place, when a bottom trawl is being towed, it is subject to numerous hydrodynamic forces that tend upwards, thus reducing the trawl's effective weight against the seabed. Increased weight against the seabed results in higher ground friction leading to increased wear-and-tear on the gear and requires greater towing power, and therefore leading to higher fuel consumption and other operating costs. For economic and operational reasons, most modern otter trawls are therefore designed to skim lightly over the seabed with as little of the trawl as possible making contact, and with only the force needed to sustain catch rates.

[37] Otterboards or trawl doors help to take the trawl to the bottom by their weight, and develop lateral ground shear and hydrodynamic forces that spread the net horizontally. In order to function and have sufficient strength, they are heavy structures, but when they are in operation their static weight is partially offset by hydrodynamic forces. Despite this, there is little doubt that doors are the most 'destructive' part of a bottom trawl system on a per-unit-area basis (e.g. Friedlander *et al.*, 1999). Observations of trawl tracks have shown that they may dig into the substratum as much as 10-25 cm, depending on the bottom's hardness, the door design and rigging, towing speed and other operational parameters. However, the relative amount of bottom affected is relatively small, amounting to a track no wider than a few centimetres to a few metres for the largest doors. It is notable that the scars doors make in the substratum may also offer refuges for various animals, at least in environments featuring low complexity. Hence, all changes may not necessarily be negative.

[38] In a typical bottom trawl, sweep and bridles connect the net to the trawl doors. These may be short or long depending on factors like the trawl size and whether they are designed to "herd" finfish species into the trawl path. Sweeps and bridles can therefore increase the effective fishing width of a trawl many times more than its actual wingspread. Sweeps and bridles may be of wire rope, rope or chain, or they may be threaded with rubber discs, bobbins spaced at various intervals, or other components depending on the circumstances of the fishery, fishing grounds and other considerations. The lower bridle typically operates in contact with, or in close proximity to, the bottom but is under such great linear tension that its down force against a smooth bottom will be modest and infrequent. It can, however, exert powerful lateral forces against any vertically protruding structures or organisms that obstruct its forward motion, and these lateral forces can translate into downward forces if the bridle rides up over them instead of knocking them down or shearing them off.

[39] The ground gear is the part of the trawl that is designed to have contact with the bottom. It has a major functional role in the capture process, serving to keep the lower margin of the trawl in contact or close proximity to the sea bed, and protecting the rest of the net from damage due to bottom contact. There are many different types of ground gear that are used on bottom trawls. Their design depends on many factors, including the fishing strategy, the bottom composition and topography, and the target species. Ground gear can range from a simple length of chain, rope or wire rope to which the netting is lashed, to heavy, complex structures of chains threaded with rollers of steel or rubber (bobbin gear). Whilst a bare-chain footrope might appear relatively light and benign, it may undercut and shear off or topple bottom structures or organisms. Alternatively, bobbins and rollers may appear dangerously large and heavy, but in fact spread the force of footrope contact so that a wider area is subjected to lower force per unit area, and so allow the footrope to roll over boulders and other structures without dislodging them. Further, depending on their size and spacing along the footrope, large rollers may make it possible for many smaller

bottom organisms to escape unharmed under the net. Despite this, it can be concluded that large rollers, tyre gear, rock hoppers and other specialized footropes were specifically developed to allow the net to be towed over rougher, perhaps more complex substrata that may support many fragile organisms, serve as nursery areas, or possess other critical functional significance. The use of such gear has expanded trawlable areas.

[40] Obviously, the impact of demersal trawls on the bottom can be reduced if they are made lighter and have less surface area in contact with the bottom. There are many potential modifications for developing trawl gear that either have minimum contact with the sea bottom or float above it, but such work is still very much in its infancy. Further investigations should examine effects of: (i) footrope design, weight, material, spacing and rotation capacity; (ii) door design, hydrodynamic function, weight, rigging, keel form and width, and use of wheels on the base of doors; (iii) sweep and bridle construction and operation; and (iv) increased gear flotation to minimize digging and friction on the bottom. Recent developments in the use of ballast elements or dropper chains suspended from the footrope to hold it near, but not contacting, the bottom offer potential in some fisheries to reduce seabed contact while maintaining catching efficiency (e.g. Carr and Milliken, 1998; *et al.*, 2001). The potential of developing and introducing "smart trawling technology," where the distance of trawl doors and ground gear from the sea bed is constantly and automatically measured and adjusted by instrumentation (Figure 6) should also be explored, as should the use of electricity, sound, or any other additional stimulus to stir the target species into the trawl net.

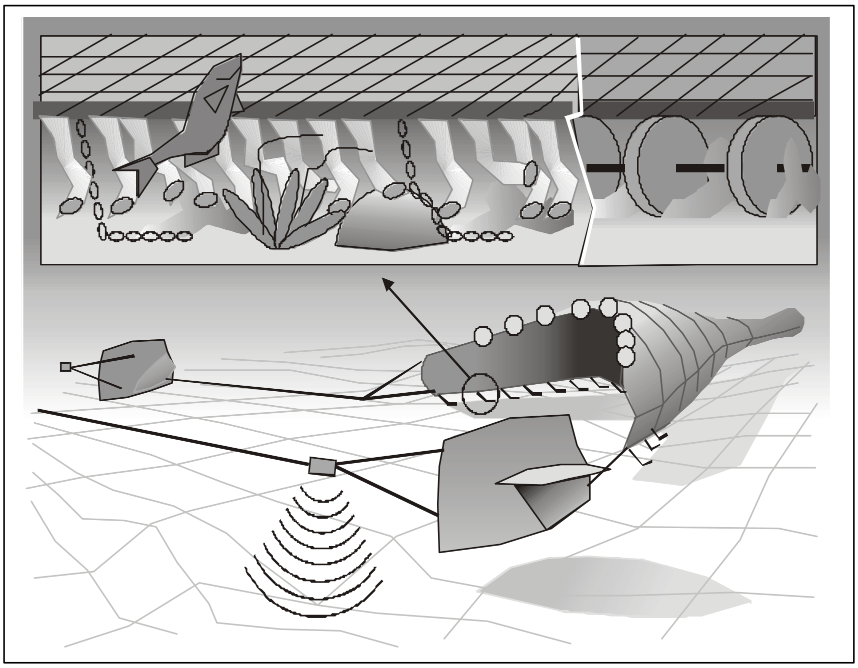

Figure 6. The use of ballast elements or dropper chains suspended from the footrope to hold it near, but not contacting, the bottom offer potential in some fisheries to reduce seabed contact while maintaining catching efficiency. "Smart trawling technology," may be the next step in this development, where the distance of trawl doors or ground gear, or both, from the sea bed is constantly and automatically measured and adjusted by special instrumentation.

3.3 Beam trawling

[41] Beam trawls are used on flat bottoms, mainly to catch flatfish such as plaice and sole, but also for shrimp. The net of a beam trawl is kept open horizontally by means of a steel beam whose length varies between 4 and 12 m, depending on the fishery. The beam is supported at each end by a trawl head that has a steel plate (sole plate, beam shoe) welded to the bottom of the beam. The steel plates are in direct contact with the seabed when fishing. Beam trawls are usually provided with tickler chains to drive the flatfish off the seabed, and, on rougher grounds, a chain matrix is used to prevent boulders from being caught.

[42] The parts of a beam trawl that are in close contact with the seabed are the trawl head, the tickler chains or chain matrix, and the groundrope. The pressure exerted by a beam trawl on the seabed is strongly related to its weight and the towing speed (reviewed in Lindeboom and de Groot, 1998). It is notable that beam trawls are usually towed at a higher speed than otter trawls – up to 7 knots. As speed increases, the lift on the gear increases and the resultant pressure force and bottom penetration decrease. Penetration into the sea bed can be roughly assessed by comparing the catch of certain indicator organisms. For a 4-m chain matrix beam trawl, the pressure exerted by the trawl heads varied from 1.7 to 3.2 N/cm^2 at towing speeds of 4 to 6 knots (Fonteyne, 2000). The pressure from the tickler chains or matrix chain elements is substantially lower than that exerted by trawl heads (Paschen *et al.*, 2000). The weight (in air) of a beam trawl varies from a few hundred kilograms up to several tons. Although larger vessels generally use heavier gear, the pressure exerted on the seabed does not increase considerably because the greater weight is compensated by larger contact surfaces and higher towing speeds (Lindeboom and de Groot, 1998).

[43] Beam trawls leave detectable marks on the seabed. Tracks have been observed to remain visible from a few hours up to a few days, mainly depending on the sediment type and hydrodynamic conditions (Paschen *et al.*, 2000; Fonteyne, 2000). Measurements made by Paschen *et al.* (2000) showed penetration depths of between 1 and 8 cm, with the largest penetrations noticed on fine muddy sand. Variations in sea bed topography and vessel movements causes variability in the bottom contact and fluctuations in the pressure exerted on the sea bed by a beam trawl. Hence, the penetration depth is not constant along a given track. When towing a tickler chain or a chain matrix over the seabed, sediments will be transported and pass through and over the links and re-settle after passage. Local variations in sea bed morphology, such as ripples, will be flattened out by the passage of the chains.

[44] In conclusion, the sea bed disturbances caused by beam trawls are visible, but there is not yet enough conclusive information to assess the degree of overall damage that they cause to sea bed habitats and communities. Nevertheless, to reduce the potential destruction of benthic ecosystems, possible modifications in beam trawls and their operations are currently being explored. Reducing the amount of chain apparently would reduce sea bed impact but would also reduce catching efficiency. Other solutions could be to avoid using excess weight, shortening the warp length/depth ratio to reduce the ground force, or use of electric stimuli as an alternative to chains for digging out flatfish (e.g. van Marlen *et al.*, 2001).

3.4 Dredges

[45] There are two basic types of dredges: dredges that harvest animals living on the surface of the seabed (e.g. scallops) by scraping the surface of the seabed; and dredges that penetrate the seabed to a depth of 30 cm or more to harvest macro-infauna such as clams (Rose *et al.*, 2000). Some surface dredges include rakes or teeth to penetrate the top layer of sediment and capture animals recessed into the seabed. Infaunal dredges can be categorized as those that penetrate the substratum by mechanical force and those that use water jets to fluidize the sediment (hydraulic dredges).

[46] Various modifications of dredges exist around the world (e.g. scallop dredge, New Bedford drag, Italian rake, Portuguese clam and razor dredge) and Rose *et al.* (2000) have described the operation and potential benthic impacts of some of these modifications. Toothed dredges used in British waters for the capture of scallops are made from a triangular frame, the base consisting of a toothed bar. A retaining bag consists of a belly section constructed from steel rings with heavy netting on top and in the rear section forming a bag. On hard substrata, damage to the toothed bar is minimized by attaching it to the frame via two shock-absorbing springs. The teeth of the dredge are typically 8-15 cm long but can be longer for deeper species, such as razor clams. Each dredge is generally 80 cm wide, with each bar having approximately 9 teeth. During its operation, depending on the substratum and sharpness of the teeth, the teeth will penetrate the substratum by 2-5 cm. A fully rigged dredge may weigh approximately 150-175 kg in air and, depending on the vessel size and power, up to 36 dredges may be operated. For most UK vessels, however, 4-16 dredges are normal (Rose *et al.*, 2000). The combined weight for these dredges may reach in excess of 4 t (in air). Dredges are towed at up to 2.5 knots.

[47] Three principal components of a mechanical dredge may cause benthic effects: the beam from which dredges may be towed, the toothed bar or cutting blade, and the bellies of the dredge bags (Rose *et al.*, 2000). Dredges either rake through, or cut into, the sediment to a depth determined by the length and structure of the toothed bar or cutting blade and the downward force of the dredge. Underwater observations have shown trenches formed by the passage of dredges over the substratum, with distinct ridges of sediment being deposited on each side (Bradshaw *et al.*, 2000). For the Scottish scallop dredge, the use of heavy chain bellies can cause significant (visible) benthic disturbance (Bradshaw *et al.*, 2000). Such physical effects diminish with time, depending on the level of natural disturbance (weather conditions, tidal strength), depth and sediment type. The degree of the impacts will be influenced by a number of factors, including the dredge type, width and weight, sediment type, number of dredges operated, method of fishing and whether any form of deflector is used.

[48] Hydraulic dredges and similar gear are usually used to harvest shellfish on sandy or finer substrata. Suction dredges fluidize sediments and use suction to pull material to the surface where shellfish are separated from sediments. One obvious effect of this is that non-catch material is distributed farther from the dredging location. A hydraulic dredge leaves visible trenches in the seabed which start to fill within a few days and usually are no longer visible after a few weeks. However, the sediment in the fished tracks may remain fluidized for a longer period. The majority of the infaunal community may be adapted to a dynamic environment and, other than initial removal and dispersal, may not be greatly affected by the dredge. In one study, the recovery following shallow suction dredging on intertidal areas occurred after about 8 weeks (Hall and Harding, 1997).

[49] In deeper water, hydraulic dredges separate the shellfish from the sediments at the seafloor and retain them until the gear is brought to the surface. Dredges use a hollow blade that protrudes into the sediment and allows high-pressure water to be jetted forward. The overall effect of the hydraulic dredge depends on the design of the dredge, its size, weight, the amount of water volume and pressure used and how it is directed, substratum type and composition, towing speed, the species present, and their abilities to withstand water pressure and to re-attach or re-bury (Rose *et al.*, 2000).

[50] There are no easy ways to modify toothed dredges and suction dredges to reduce impact without losing fishing efficiency. Restricting their use in sensitive areas is likely to be the best option to ameliorate their effects. Alternative fishing methods should be developed for such areas.

3.5 Demersal seines

[51] Rose *et al.* (2000) have described the operation and likely benthic effects of demersal seines. There are many similarities between demersal seines (Danish anchor seines, Scottish fly-dragging, pair seines) and otter trawls in that a funnel shaped net with a protective groundrope is hauled by a system of wires and ropes that contact the sea bed. However, otter doors are not used in demersal seines, and the groundrope is generally of light construction. Seines are generally used on relatively flat and clean grounds and the wires or ropes are in contact with the seabed over much greater lengths, typically several hundred metres. These wires are made of synthetic rope and have a lead core for extra weight. The seine operation involves laying the ropes in a triangular shape with the net in the middle of one side of the triangle. The two rope ends are then hauled simultaneously towards the vessel by winches or rope reels. During this process, the ropes gradually close. Although the rate of closure is relatively slow, the rope may cut into the substratum due to the longitudinal velocity and the stranded form of the rope that displaces material as it moves. The greater the tension in the rope, the greater the force exerted on an object over which the rope passes. The speed of advance of the net is very slow at first, gradually increasing to a maximum of 2-2.5 knots towards the end of the set. The lighter construction and the lower speed of hauling the net generate lower tension in seine ropes than in trawl sweeps and bridles (Rose *et al.*, 2000). Thus, they are less rigid and more able to conform to substrate features on the bottom instead of cutting through them. In conclusion, the potential benthic disturbances caused by demersal seines are likely to be minor compared to other demersal fishing gear. Therefore, the efforts for reducing benthic disturbances caused by demersal fisheries should be focused on more 'damaging' fishing gear, such as otter trawls and dredges.

3.6 Bottom-set gillnetting

[52] Bottom-set gillnets are a widely-used technique in many fisheries worldwide and improved materials and techniques have allowed the expansion of such gear to rougher grounds and deeper waters. The direct benthic effects of a gillnet fishing operation is likely to occur during retrieval of the gear, during which the nets and leadlines are more likely to snag bottom structures. Reef-forming organisms and other sessile epibenthic organisms frequently become entangled in gillnets and are damaged when they are hauled. These problems apparently can be reduced by raising the groundline a little above the bottom, but this may reduce the catching efficiency for certain target species. If nets are dragged along the bottom before ascent, the anchoring system can also affect bottom structures and organisms. The weights and anchors used in gillnet fisheries are often heavier and larger than those used with longlines.

3.7 Demersal longlines

[53] Very little published information exists regarding the direct impacts of hook and line fisheries on habitats. It is known, however, that bottom-set longlines often snag on vegetation, benthic epifauna, and irregular objects on the bottom. This snagging may damage or move objects, but often the line breaks and remains underwater and gradually entangles itself and other bottom features. The key determinant of the effects of longlines is how far they travel over the seabed during setting and retrieval, when significant distance is more likely to be covered during the retrieval period. In addition to the line and hooks, anchors can be pulled considerable distances across the seabed before ascending. In general, however, hook-and-line fisheries offer the potential to conduct fisheries without severe habitat damage.

3.8 Trap and pot fisheries

[54] During setting, and especially during hauling, traps and pots often drag over the bottom for some distance, which may cause sea bed damage. One trap by itself may cause little damage, but when large numbers are employed in a fishery or on a single fishing ground, as is commonly the case, the cumulative impacts can be substantial. At the same time, in environments where there is

little natural structure or complexity, lost or dumped traps may add to habitat complexity and offer refuges for various species, thus functioning in the same manner as artificial reefs.

[55] Traps and pots offer potential to decrease habitat impacts in fragile grounds where active fishing methods may be causing severe damages to benthic ecosystems. There are numerous specific topics that must be investigated in examining such issues. One consideration is to ensure that the demersal traps are no heavier than is needed to land upright and keep a steady position on the sea bed. The potential for designing 'pelagic traps,' where the depth of the gear can easily be adjusted according to the conditions and target species, should be explored. In principle, it should be possible to deploy traps close to the sea bottom, with only the anchor touching the bottom.

[56] The potential for catching new target species that are not currently pursued with traps should be investigated in order to facilitate the movement away from gear that feature higher levels of impact. It has been shown that the catching efficiency and species- and size-selectivity of traps can be improved by using appropriate dimensions, mesh sizes, entrance designs, baits and excluder devices. The modifications required may be relatively minor, but it is difficult to identify what these might be without conducting comparative fishing experiments.

3.9 Can navigational and electronic instruments minimize the environmental impact of fishing gear?

[57] A fisher prefers to use his gear where the density of target species is high and where the risk of damaging the gear is low. The greatest densities of certain target species are often found on or in the vicinity of uneven or rough bottoms, where the impacts of dragged gear are likely to be most severe. Avoiding fishing on such "rich and fragile" grounds could be regarded as an environmentally sound approach. The question raised by a fisher is whether this avoidance is possible without reducing capture efficiency beyond acceptable levels. To some extent, this should be possible. By having accurate information about the bottom conditions and by being able to position the gear close to, but not hitting the rough ground, a fisher might be able to avoid the most sensitive hot spots that might consist of corals or seagrass beds. Accurate information about the bottom can be obtained, including its collection and dissemination, for common use by fishers themselves. Acoustic instruments, such as the Roxan system, that use a combination of two echoes returned from the bottom, offer this possibility. The accuracy of navigation in modern fishing vessels is currently very high when using a GPS system (in the range of ±5 m).

[58] Concentrating fishing activity where the density of targets is greatest might provide environmental benefits in some fishing areas. Some benthic organisms, such as scallops, are often concentrated locally on very distinct parts of fishing grounds. Prior to using dredges on such a fishing ground, detailed mapping of the scallop distribution could help to direct the fishing where the scallops are found in greatest densities, thus leaving large parts of the fishing ground undisturbed. This is a fishing pattern now successfully used for scallop dredging on George's Bank.

[59] The improved location of fishable concentrations of exploited species with the help of electronic detection instruments and accurate navigation should help to direct fishing effort to restricted locations, and thus minimize fishing effort and interactions with sensitive bottom habitats.

4. THE EFFECT OF ENVIRONMENTALLY FRIENDLY FISHING GEAR AND PRACTICES ON FUTURE FISHING OPERATIONS

[60] This paper has briefly described some cases where the modification of a fishing gear or its operation has significantly helped to reduce by-catches. In many cases, relatively minor and simple changes in gear and operations have contributed to improvements. It should be kept in mind, however, that many of the global by-catch problems have not yet found a satisfactory

solution. Furthermore, the development of gear and techniques is still very much in its infancy from the perspective of reducing benthic disturbances.

[61] It is unlikely that gear modifications will eliminate all adverse effects – progress will take place by modest steps. In the eastern Pacific tuna fishery, it took 30 years and many innovations, most of them generated by fishers, to achieve minimal by-catch levels of dolphins (Hall, 1996). Therefore, realistic short- and long-term objectives are necessary when attempting to minimize ecosystem impacts of a fishery. Managers should set measurable limits for by-catch levels and benthic disturbances caused by fishing gear. In many cases, a combination of technological improvement, active avoidance of areas and seasons of high by-catch rates (hot spots), and other management actions may be necessary to achieve the desired outcomes.

[62] It should also be noted that some gear modifications may make gear more expensive to construct, and more difficult to operate and maintain. Moreover, catches of marketable fish may be reduced. Measures and techniques that increase costs and reduce earnings are unattractive to fishermen. There is little point in introducing totally unacceptable concepts or modifications – they will probably fail. The fishing effectiveness and practicality of new designs are important because an inefficient gear will not be used or will be "sabotaged," or may require so much additional fishing effort that overall impacts could actually be increased. Close cooperation between the fishing industry, scientists and other stakeholders will be necessary in the process of developing and introducing environmentally friendly fishing technology.

[63] The ecological, economic and social impacts of new measures and modifications must be addressed comprehensively. Innovative management and regulatory measures that offer positive incentives for the effective use of reduced-impact fishing techniques have to be implemented. All participants must accept that the inefficient, destructive and wasteful use of potentially valuable resources will, in the long run, have severe economic costs. If more environment-friendly fishing techniques are not found and adopted, tougher fishing rules will place additional burdens on existing fisheries, no-fishing zones may be established or expanded, or certain gear types and fisheries may be banned altogether. In the long term, the fishing industry can benefit economically from the use of fishing methods that have less impact on habitats and reduce by-catch. In such circumstances, it is a sound strategy for the industry to cooperate in developing better and more practical solutions.

[64] In terms of habitat sensitivity, fishing grounds can be roughly categorized into three:

(i) <u>low-risk</u>-areas, where no particular actions are needed,

(ii) <u>high-risk</u>-areas, where drastic changes in exploitation techniques are needed, or the grounds should be closed, and

(iii) <u>intermediate-areas,</u> where proper gear modifications would probably help to reduce overall impacts (most fishing grounds probably belong to this category).

[65] It is of utmost importance to provide knowledge about the characteristics of various trawl grounds in use, so that efforts to develop new technologies and practices are focused appropriately and managing authorities have the necessary information to take proper actions. An example of such action was the recent banning of trawling on a fishing ground off the Norwegian coast, where large areas of corals were identified a few years ago, some of which was already damaged by trawling activities. Protection of such high-risk areas (hot spots) would greatly benefit from the mapping of fishing grounds.

[66] Concentrating efforts to develop technologies and fishing practices on intermediate grounds is more likely to achieve the aim of reducing habitat impacts. In many cases, the most efficient way to do this would be to modify existing fishing gear so that the sea floor contact of the gear would be as little as possible. There are, however, currently no universal methods of modifying gear to reduce habitat disturbances. Solutions are specific to species, gear, fisheries and habitats, and are strongly influenced by regulatory and economic considerations. Clearly, understanding

the capture process of fishing gear in various environments is the key element in developing modifications and practices that can reduce ecosystem impacts.

[67] In conclusion, technologies developed in recent years demonstrate that the impact of fishing gear on non-target species and habitats can be significantly reduced without major negative effect on the profitability of the fishing operation. Economic rewards should be offered for the creation of new types of gear and modifications that reduce by-catches and minimize habitat impact. As shown above, there are a number of innovative technologies already available and further development will add more. Worldwide awareness of the problems will also accelerate this process.

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