A Review of Technological Approaches to Bycatch Reduction

A Report prepared for the

World Wide Fund for Nature (WWF-UK)

By

Coonamessett Farm Foundation, Inc

277 Hatchville Road
East Falmouth, MA 02536
508-648-2018 FAX 508-564-5073
cfarm@capecod.net
www.coonamessettfarmfoundation.org

June, 1996

Table Of Contents

A Review of Technological Approaches to Bycatch Reduction

I. Introduction

Historically, developments in fish harvesting technology have focused on improving the efficiency and productivity of the individual harvester. Although efforts have been made to address gear-related resource conservation issues, these activities have seldom kept pace with the rapid changes in gear technology. As world-wide fisheries resources continue to approach and surpass the point of maximum utilization (and allocation problems intensify), heightened emphasis will need to be given to sustaining harvests on a renewable basis while ensuring that fishing does not substantially distort the character of the marine ecosystem as a whole.

Technology can be applied to alleviate or eliminate gear-related problems that hinder effective fishery resource management. For example, some fishing gear is not very selective for individual species or size classes of fish. This can create management situations that could be improved if alternate gears were available which had sharper selective characteristics. There are estimates that over 30 million tons of fish are discarded annually in commercial fisheries around the world; a quantity equal to about one third of the landed catch. The estimated discard weight for the Northeast Atlantic is 3.6 million metric tons. In addition, there are other harmful aspects of fishing gear and its operation, such as habitat damage, that can be addressed by improved design or operational strategies.

a. Defining bycatch

This paper will focus on the subject of bycatch.There is not a simple or universally agreed upon definition of bycatch. Bycatch, as defined here, is a combination of incidental take of non-target species that are utilized, and of all species that are discarded for whatever reasons. The animal needs to be placed on deck to be counted as bycatch. If it falls out of the gear before it hits the rail, it falls into the category called "dropout", another form of incidental fishing mortality.

There are a number of key points that must be kept in mind. Not all bycatch that is discarded is dead. Some portion survives and there are usually actions that can be taken by the fisherman to increase the percentage of survival. There is also the possibility that a clean or selective fishery that only removes certain species or size animals may have long-term ecological consequences. Thus the feeling that bycatch mortality (landed or discarded) is bad, selectivity is good, may not be correct in many cases.

Ecosystems are complex, and while there might be simple solutions to their management, these solutions have not been easy to identify due to our lack of understanding of ecological relationships. Over-emphasizing bycatch issues compared to other harvesting considerations might neglect ecosystem relationships and risk causing even greater problems. Resource managers may want high bycatch mortality, high but albeit sustainable, in certain cases to maximize the values generated by a particular ecosystem. For example, a fishery harvests a fish that is the major predator on a non-commercial crab resource. The crab population thus explodes and preys upon a valuable shellfish resource that collapses under the heavy crab/human predation. To maximize the values from this ecosystem managers may want the shellfish harvesting gear to inflict non-catch mortality on the crab bycatch. The analogy would be farmers weeding their fields. The solution to fish bycatch problems in some tropical shrimp trawl fisheries has been to find commercial markets for the fish. There is also the situation where gear A has no bycatch but uses ten times more fuel per unit of target catch than gear B that has some bycatch.

In addition, bycatch laws have the potential to destroy the small multi-species coastal fisheries by regulatory burden. Accurate accounting of bycatch that is discarded will have to be verified by regulatory authorities. Since some of the bycatch that occurs at sea is discarded, and commonly not reported by the fisherman, a frequently used solution for accurate verification is the use of onboard observers. This can be very costly to the party paying for the observer; either the government or the vessel owner. Small coastal vessels often can not afford the cost of observers and in some cases do not have the room to carry them.

Commercial Bycatch

Commercial bycatch can be considered another aspect of fishing mortality, a natural cost of doing business, that must be factored into each fishing equation. It can be size and/or species related. For example, when a dredge vessel targets shellfish on certain grounds there may be an incidental catch consisting of finfish. This incidental bycatch is not necessarily unwanted, depending on the condition of the stock, if it is of legal size and can be sold. However, it is not too difficult to define some scenarios were it becomes a problem. The first scenario would be if there was significant discarding of undersized fish and associated high mortality. Discarded bycatch may survive, although for some species, especially sessile ones, displacement is a concern. The simple solution to bycatch that is ultimately discarded, is not to bring it up in the first place. A second scenario is that the fish stocks might be so overfished or endangered as to require a cessation of all fisheries catching that stock. The dredge vessel's bycatch of fish might exceed a bycatch quota, thus closing the fishery on a healthy shellfish stock.

Bycatch is the regulatory phenomena and gear selectivity is the technical issue. For example, if the minimum legal fish size is raised, the bycatch is changed. If, however, the mesh size is increased, the size selectivity of the trawl is changed. It is very important to keep these two concepts separate because today's catch might be tomorrow's bycatch without any change in gear selectivity. Whether a species is target or bycatch can also change as new fisheries are developed or new markets created. Bycatch is often created by managers allocating fishery resources. It is obviously shaped by politics; one interest group against another. Bycatch allocation is a very difficult decision process in fisheries managed by quotas.

Non-Commercial Bycatch

More recently concerns for endangered and threatened species have added a new dimension to the term's use as well as effects on resource management. Marine mammals, sea turtles, sharks, and sea birds that are caught incidentally in the conduct of fishing operations are now also referred to as bycatch. In most areas of the world there is no value to the fishermen in catching these species (There are some notable exceptions!). In fact, it can be quite costly to the fisherman measured by time lost, lost catch, and gear damage. One of the most difficult aspects of non-commercial bycatch is ascertaining to what degree it is occurring since this bycatch is normally discarded and not recorded. Fishermen are very hesitent about providing information regarding these interactions for fear of overly restrictive measures being imposed. The environmental community has focused on this one issue, in many cases separating this problem from broader ecological questions on how to manage fisheries on a sustainable basis. It is important to have an understanding of what the related issues are before arriving at the best bycatch reduction strategies for each fishery.

b. Related Technological Issues

Habitat Impact

The effects of towed gear on the bottom habitat and its potential for impacting the entire food chain is probably one of the most important issues related to fishing gear, as well as the least understood. It is known that habitat impact is related to the substrate type, sediment size, current velocity, the organisms present, and the gear being used. The gear parameters include gear type, weight, and frequency of use. What is not very well know is the long-term impact on an ecosystem that undergoes continual disruption by towed gear.

The first concerns about the impact of fishing gear on habitat were expressed by fixed gear fishermen opposed to the introduction of towed gear. There are references to such concerns expressed centuries ago in England, the Netherlands, and France. The complaints put forth the proposition that the towed gear dislodged rocks and moved substrate thus crushing and killing the important bottom organisms that provided food and shelter to the food fishes. The only way for scientist to judge the impact in the past was to observe what came up in the trawl. No definite conclusions could be drawn from such observations.

Today we have enough evidence indicating that fishing can change the species complex in an area, not only by altering the physical habitat, but also by selectively destroying sessile organisms that occupy the habitat. The destruction can be do to harvesting and subsequent removal of sessile species, sediment resuspension, mechanical contact with the gear, or physical movement of substrate. In most cases, however, it is still difficult to separate out the long-term impacts of fishing from natural processes and other anthropogenic impacts. Insidiously, the act of fishing may keep ecosystem production depressed, but undetectable, by chronic sub-lethal effects on reproduction and feeding.

Efficiency

Of all the definitions relating to gear, efficiency is the most difficult to define. In one sense it can be the ratio of the animals retained in the gear to those originally in the gear path. This gets complicated with baited gear as there is a "calling range" due to the bait attraction. In addition, with fixed gear the encounters are a function of the movement of the animals.

In a broader sense, the definition is even more complex when it combines both economic and social issues as these are not readily quantified. Conservation and management measures are usually designed to promote efficiency in the utilization of fishery resources. However, if maximizing employment in a region is an economic goal it would certainly influence the choice of fishing technology in a direction that may not be the most "efficient" from a fish harvesting perspective.

Energy Consumption

There are significant differences in the amount of energy consumed to catch a kilogram of fish by various gear types and operational strategies. Gill net vessels use much less fuel than large otter trawlers and thus are usually more efficient in catching fish per calorie of fuel consumed. However, they also tend to have more bycatch problems with non-commercial species.

Complexity

It is very important to again emphasize that the interaction of fishing gear with the ecosystem is complex as illustrated by the following example. Research from around the world has demonstrated that the act of towing scallop dredges directly and indirectly causes mortality on uncaught scallops, mostly the young. At first glance it would seem appropriate to close areas to scallop dredging that have high amounts of small scallops present to reduce bycatch and other incidental mortality. However, other research has shown that dense concentrations of young scallops attract predators and thus suffer high levels of predation and also possibly high levels of disease related mortality. Less dense concentrations seem to have higher survival rates. Fishermen have noticed that areas closed to scalloping are not as productive as areas that are fished. One hypothesis is that the act of fishing redistributes and disburses scallop concentrations with the end result being higher production levels. Another possibility is that dredging removes predators as bycatch, kills the predators, or otherwise interferes with their feeding. Whatever the mechanism, the possibility exists that the mortality to scallop pre-recruits to the fishery associated with fishing is less than that which would have occured naturally without fishing activities present.

c. Bycatch Problems Within The European Community

The European Community has an excess of fishing capacity, which it attempts to reduce using a series of Multi-Annual Guidance Programmes (MAGP). The Fourth MAGP will determine capacity reduction for the period 1997-1999. Basic information on the current size and composition of the EU national fleets and the status of many the stocks they exploit has been analysed by a group of scientists in the Lassen Report. Discussions will continue throughout 1996 with a final MAGP to be decided by the end of the year.

As the present report shows, fishing gears vary in their selectivity and impact on the marine environment. Among the criteria to be used in the determination of the capacity to be cut could be consideration of the environmental impact of the various gears used in a fishery. For example, if several gears target the same stock, but they vary in the amount of bycatch and discards they produce, or their impact on the bottom, priority should be given to reducing the size of those sectors of the fleet which are the most destructive, leaving those gears which have a lower impact. Such a policy could dramatically reduce the extent of destructive fishing in the Community.

There is a great variety in European fisheries, in terms of gears used, species targeted and geographical location. Rather than compile a list of all fisheries, we will discuss in some detail several specific ones which are representative of the problems caused by the important gear types. Other fleets of other nationalities may use similar gears, but the variability evident in fisheries means that they may have different results. In many ways each bycatch problem is unique in that it is specific to a particular fishery in each different area and biological complex. There are however some general groupings that can be made for the purpose of defining possible technological solutions. We have defined these groupings for European fisheries as follows:

a) The capture of turtles and other non-target species by hook gear.
b) The capture of seabirds by hook gear and in gill nets.
c) The capture of marine mammals in gill nets.
d) Non-target commercial species in gill nets.
e) The impact on benthos by towed gear.
f) Non-target catch in groundfish trawls.
g) Fish catch in shrimp trawls.

This is not an all inclusive list. There are many other bycatch problems as well, but the above groupings represent a significant portion of the current problems. A more detailed look at some of the specific problems follows:

(a) Swordfish Longliners in the Western Mediterranean

Target species: swordfish (Xiphias gladius), more recently also targeting bluefin tuna (Thunnus thynnus).
Nationality: Spanish (Greek and Italian longliners also take swordfish on longlines but no information available on bycatch).
Gear description: longlines up to 60 km in length with 2,400 hook fishing at depth of approximately 15-25 meters, baited with mackerel, flying squid or sardine, set in the evening and

retrieved before dawn.
Fishing region: southwestern Mediterranean between Algeria and Spain
Bycatch species: observed rates in 1991 averaged 3.85 loggerhead turtles (Caretta caretta) per 1,000 hooks, equalling one quarter of the total catch; produced estimate of 15,000 to 35,000 subadult loggerheads caught per year in 1990 and 1991, of which 20-30% may die following release; other species captured included stingrays, bream, sunfish, bluefin tuna, albacore, dolphin fish, blue, thresher requiem and mako sharks, leatherback turtles, frigate mackerel, manta rays and Rissos dolphins and various other fish.

Source: Aguilar et al. 1992

(e & f) Beamtrawls in the Southern North Sea

Target species: sole (Solea solea)
Nationality: Dutch, Belgian, German
Gear description: vessels of 1,500-3,000 HP, towing trawls with beams of up to 12 meters at speeds of 6-7 knots, variable number of tickler chains or chain matrices (according to bottom type and engine power), codend mesh size of 80 mm, net of double-braided polyethylene.
Fishing region: southern North Sea outside 12 mile zone in water 30-50 meters deep (smaller beamtrawls fish inside zone).
Bycatch species: estimated that every kg of marketable sole produces up to 8 kg dead discarded fish and 6 kg dead discarded invertebrates; total production of discards by offshore and inshore beam trawlers 270,000 tonnes fish and 120,000 tonnes invertebrates; mortality of discards variable (very high for fish, low for starfish).
Environmental damage: high mortality of benthic species which were not caught by trawl but damaged by contact with tickler chains; dead and disturbed fish and invertebrates may enhance populations of scavengers; marks of passage by beamtrawl visible for up to 52 hours; heavily trawled areas show disturbed sediment almost devoid of conspicuous epifauna compared with relatively undisturbed reference area 10 nM away; authors concluded that beamtrawling affects the structure and composition of the benthic community in the North Sea
Source: S.J. de Groot and H.J. Lindeboom 1994

(c & d) North Sea bottom gillnets

Target species: cod (*Gadus morhua*) and turbot (*Scophthalmus maximus*)
Nationality: Danish
Gear description: these two fisheries use quite different gear:
- cod fishery uses strings of several monofilament gillnets, with length 85 meters, height 4 meters, mesh size 160-190 mm, hanging ratio 40-50% for headrope and 50-60% for footrope, soak time varies from 4-6 hours to 48 hours; fishery all year round
- turbot fishery uses strings of 50-250 monofilament gillnets, with length 60-70 meters, height 1.25-1.5 meters, mesh size 250- 270 mm, hanging ratio 25% for headrope and 35% for footrope, soak time varies from 6-12 days; fishing season in the summer.

Fishing region: central and eastern North Sea
Bycatch species: - in cod fishery about 8% by weight of total catch is fish other than cod, comprising many species, most importantly plaice, saithe and starry ray; overall, 6% of catch, including some small cod, is discarded; additional annual bycatch of 2,260 or 2,696 harbour porpoise, depending on method of estimation and a few hundred guillemots.
- in turbot fishery about 62% by weight of total catch is turbot (2% discarded), 9% starry ray, 4% plaice, 3% monkfish, 17% cod plus small amounts of many other species; overall, 24% of catch discarded, mostly cod and starry ray; additional annual bycatch of 2,189 harbour porpoise, several hundred guillemots and 51 fulmars.
- catch rate of harbour porpoise per km of net is much hgher in turbot fishery than in cod fishery,

but if express relative to soak time the catch rate is much lower
Source: Vinther 1995

(c & d) Northeast Atlantic pelagic driftnets

Target species: albacore (Thunnus alalunga)
Nationality: French, Irish, British
Gear description: pelagic multimonofilament driftnets of length 6-9 km (disputes over whether legal limit of 2.5 km respected), height 15-20 meters, with stretched mesh size of 160-180 mm, soak time from dusk to dawn, fishing season from May to September .
Fishing region: northeast Atlantic south of British Isles and into Bay of Biscay
Bycatch species: albacore about 85% of catch by number, other species include several species of sharks, pomfret, billfish, other fish species, turtles; estimated catch of 1,750 cetaceans (mostly striped and common dolphins, some large whales) by French fleet in 1992 (British and Irish catches additional).
Source: Earle, Woodley and Hagler 1994, Goujon et al. 1993

(g) Nephrops trawls

Target species:Norwegian lobster (Nephrops norvegicus)
Nationality: various, depending on stock
Gear description:
Fishing region: large number of stocks throughout Kattegat and Skagerrak, the North Sea and Atlantic seaboard
Bycatch species: Nephrops comprised 33% of total catch; bycatch included 34 species of fish (54% of total catch), the most important of which was juvenile whiting (23% of total catch) and 23 taxa of invertebrates (13% of total catch); 45-75% of Nephrops were discarded, including many of legal size, as were most fish except for a few of legal size (lemon sole, plaice, whiting, cod, haddock, starry ray) and all invertebrates
Environmental damage: most Nephrops were dead when discarded, and experiments show survival propsects were low due to injury, displacement to unfavourable habitat or predation by seabirds and other predators; similar comments pertain to discarded fish; trawling can also inflict major damage to seabed.
Source: Evans et al. 1994

II. GEAR BASICS

a. Active gears

BottomTrawls

Trawling is a fishing method in which a vessel tows a net referred to as trawl gear or just "gear". The net is basically cone shaped. The large mouth of the cone is the forward end and is widened by netting extensions called wings. The aftmost narrow end is called the cod end and is where the catch accumulates. Vessels that tow the gear are referred to as trawlers and when towing bottom trawls are commonly called draggers. The net can be set and hauled from the side (side trawler) or the stern (stern trawler). Nets can be towed by one or two vessels; the latter method is called pair trawling.

In single vessel otter trawling the net is controlled (set, towed, and hauled) by either one or two towing wires (warps). A single warp is normally used with very small nets, multiple net rigs, or in very deep water. The single warp splits into two, each then attaching to a separate otter board (door). In the case of dual warps, each wire is attached directly to a door. The doors are used to spread open the mouth of the trawl net. The doors are either directly attached to the net by bridles or separated by ground gear (legs and ground cable; sweeplines) that effectively widen the area swept by the net. In pair trawling, each of the two vessels is attached to one of the warps thus keeping the net open without the need for doors. The netting of the gear consists of panels, some of which are the wings, square, belly, extension, and cod end. The forward, lower, ends of the wings and belly are attached to a footrope, or sweep, that can range from a simple heavy rope, wire, or chain to a complex rig of heavy rollers.

There are low opening trawls, for shrimp and flatfish, and high opening trawls, for semi-demersal or pelagic species. Trawls are also described as having two or four seams; the latter having side panels usually to gain more opening height. Trawls must be designed with target species behavior and the trawler parameters as key design considerations.

Pelagic Trawls

Pelagic trawling, commonly referred to as mid-water trawling, has many similarities to bottom trawling. Major differences in the gear design are centered around the fact that the gear is not designed to hit bottom thus the doors are more hydrodynamically designed, the net twine is much lighter, and there is no ground gear on the footrope. The trawls are usually much larger then bottom trawls because pelagic fish are faster and have more avenues of escape (down as well as up). There is also more of a requirement to monitor the position of the net and the target species in the water column to be able fish effectively.

Beam Trawls

The beam trawl is a relatively simple piece of bottom towed fishing gear primarily consisting of a metal or wood beam holding open horizontally the mouth of an attached net. The beam is towed by wires called bridles which usually join together at the towing wire or warp. The beam rides on steel shoes (beam heads, skids, runners) mounted at each end. The attached net has a headrope fixed to the top of the beam and a groundrope (footrope, leadline) fixed at each end to the shoes. The net tapers back to a cod end where the catch is collected. A typical large beam may be 10 meters long and ride about one meter above the seabed on its skids.

The actual fishing activity takes place at the groundrope which arcs back from the shoes and is usually preceded by a series of tickler chains. These chains can be very heavy as their purpose is to dig into the bottom to scare up flatfish and shrimp. Some Dutch beam trawlers, fishing for sole, are rigged with 15 chains with a total weight of 2000 kg. The gear of a 1900 HP Dutch beam trawler, representative of her class, can weigh 7000 kg (net material, 1200 kg; trawl heads and beams, 3800 kg; chains and ticklers, 2000 kg). This creates a large amount of drag requiring relatively substantial horsepower for towing. On the other hand, since the gear can also be towed at very slow speeds, it can be more fuel efficient under certain fishing conditions than an otter trawl (At very slow speeds the otter boards or "doors" fall down.). Beam trawls are common in the sole fishery out of Belgium and Holland as the target species is not as vulnerable to lighter gears. This fishery has opted for high speed and heavy gear towed by powerful engines.

The advantages of beam trawling, from the fisherman's perspective, are based on the fact that the net mouth opening remains fixed regardless of warp (towing wire) length (scope), vessel speed, cross-tides, course changes, substrate type, or number of heavy tickler chains. The main disadvantage is that the gear can not sweep as large an area (or volume of water) per unit time as an otter trawl for a given horsepower and is physically limited in size. Beam trawlers can be rigged with outriggers off of each side (double rigging) so that they can tow up to four trawls at once, though this is not common. Another disadvantage is the gear can load up with non-target benthic organisms and substrate thus adding sorting time and reducing market quality of the catch.

Purse Seines

Surrounding nets are probably very ancient in origin. The evolution might of been from fixed traps to movable brush weirs and then to primitive beach seines. The beach seines may then have evolved to be towed by two small boats. This method lead to net designs in the Mediterranean such as the paranzella (Italian), parega (Spanish), and the Lampera (Italian) nets. Eventually the idea of pursing the net developed.

The purse seine is the primary gear in a category known as surrounding nets. This gear type is designed to catch fish by completely encircling them with a wall of netting. They are most commonly used for schooling pelagic fish ranging in size from sardines to tuna. Purse seines are sometimes used on schooling cod fish, that are close to the sea bottom, in which case the surface floatline may be submerged. However, purse seines are usually fished as surface nets with a well buoyed floatline. Purse seines have a purseline at the bottom of the net that allows the bottom to be drawn closed (like a purse). The purseline passes through rings that are hung by short ropes (bridles) to the weighted leadline of the net. The netting that makes up the net is known as the body. The section of the body that is designed to hold the fish when the net is fully pursed is called the bunt. There are two basic designs; one where the bunt is at the center of the body, and the other where it is at one end of the body. Body ends without bunts are called wings; thus a bunt-end net has one wing-end, a center-bunt net has two wing-ends. There are usually stronger sections of netting incorporated into the rim of the body known as selvedge strips or guardings.

The purse seining operation begins with locating a school of fish. In most cases the fish schools are located by spotting birds "working the surface" (diving and feeding) from a position high up on the fishing vessel. In larger operations, aircraft are commonly employed. Other means include spotting from coastal high points, setting on porpoise schools (tuna fisheries), setting around floating objects (log fishing) or fish attracting devices (FAD's), attracting with light, chumming, or using sonar.

Once a fish school is located it is time to set the gear. The direction of movement of the school and the local current (wind and tide) conditions are factored into the setting strategy. A single vessel operation first sets a buoy with the bunt-end of the net attached. The vessel then rapidly pays out the net attempting to encircle the school. Ideally the vessel wants to end up at the buoy just as the wing end of the net goes over the side. A towline is attached to the wing end, and can be paid out, to complete the encirclement. The purse seine can also be set with the use of a skiff. In this operation, instead of setting a buoy, the skiff tows the bunt-end of the net and is rejoined by the setting vessel completing the circle.

When the vessel arrives at the bunt-end, the pursing and retrieval process begins. Wing and bunt ends are secured to the vessel and both ends of the purseline are passed over a power block to a winch. Either one or both ends of the purseline are hauled until all the purse-rings are gathered alongside. The rings are placed on a stripper and the purseline is removed. The wing-end is then placed on the power block and the hauling of the net begins. Hauling continues until the fish are crowded into the bunt-end. The fish are then removed by brailing (scooping) or by pumping.

There are many variations to the method described here. For example, there is a two boat method using a center-bunt net. However, the basic principles are the same. Many of the operational techniques have to do with timing. The sinking rate of the net is important in relation to how fast the net is pursed. If the net is pursed too fast, before the net has a chance to completely sink around the school, the fish can escape underneath. If the net is pursed too slow, the fish can escape between the net ends. Setting the net around too large a school can prevent the net from properly closing resulting in the loss of the entire catch. Setting the net around the wrong species or size of fish could cause the fish to gill in the meshes resulting in a mess.

Dredges

Dredging is a mechanical harvesting method that can be grouped into two general catagories; digging and scraping. Dredges that dig are most commonly used for moluscs, mostly clams, that are burrowed into the substrate. The gear used to harvest clams includes hand operated diggers, tongs, or rakes and towed dredges. The latter are classified as either "dry" dredges or hydraulic dredges. Dry dredges physically dig the clam out of the bottom by mechanical means while being towed. One type of dry dredge is the rocking chair dredge. As the name implies, the dredge rocks back and forth, while being towed, alternately digging into and then out of the bottom. This type of dredge is seldom used anymore as its efficiency is very low.Hydraulic dredges use high pressure water jets to do the digging. In Europe, hydraulic dredges are used to harvest cockles around the Brittish Isles. Icelandic scallops are harvested by hydraulic dredges in Norway. In the Adriatic, hydraulic dredges harvest clams (*Chamelea gallina, Venus verrucosa*). In North America, hydraulic dredges are used in most clam fisheries.

Scraper type dredges, or rakes, are most commonly used for scallops, oysters, mussels, urchins, and seaweeds. Sometimes the dredges are equipped with teeth that cut into the bottom. Others just scrape along the bottom using a steel bar or sweep chain to collect the target organisms.

b. Passive Gear Types

Gill Nets

Gill nets comprise a category of fishing gear that catch fish that swim into the netting and are enmeshed. Simple gill nets consist of a single wall of netting and complex gill nets, such as a trammel net, consist of several layers. Gill nets that are not attached to the sea bottom are called drift nets; those that are anchored are called set nets. The nets can be set out in a straight run or may be set to encircle a school of fish. Nets are usually tied together in strings or fleets. In the North Sea vessels have been known to set between 10 and 650 nets (individual net lengths of 55 to 400 m); the total length of nets being set by a single boat being as much as 43,000 meters.

Gill nets have a floatline (headrope) running along the top and a leadline (weighted footrope) running along the bottom. Anchors on set nets are usually at the ends of the strings though the nets can have additional anchors attached at set intervals to hold station. The ends of the strings are usually marked by buoys (dans). The tension in the twine of the netting can be adjusted by changing the buoyancy of the floatrope or the hanging ratios (ratio of headline length to the horizontal stretched length of the netting). The hanging ratio at the footrope can be different than at the floatrope (called hanging-in) in order to change species selectivity.

Gill netting is a very simple fishing method. It can be performed by one man in a small boat without deck handling equipment. The nets can be fished virtually anywhere geographically and within the water column (surface to bottom). It is a very efficient method of capturing fish that are either schooled or dispersed. As a result, the method is used worldwide, particularly in developing countries. High seas pelagic drift net fisheries are very different than coastal bottom set gill net fisheries. The reader is cautioned not to confuse the two gear types and methods.

This low cost and energy efficient method of fishing also has some significant drawbacks.

The gear can be relatively non-selective in the species it catches. The unwanted by-catch may consist of other fish, turtles, sea birds, and marine mammals. The gear is prone to being lost either by snagging on the bottom or buoys parting due to other vessels or storms. In the lost condition the gear is still capable of fishing ("ghost fishing") to some degree. Gill nets are usually set over the stern and paid out as the vessel moves forward. Hauling is usually performed with a net reel or powered net hauling gurdy. The main operational problem is removing the fish from the nets which is performed manually.

Longline Hook Gear

Longline fishing gear consists of a long main line, most commonly set in a horizontal direction, to which smaller branch lines (snoods, gangions) with hooks are attached. Set (anchored) longlines are usually set on or near the bottom, and drift longlines are kept near the surface. Bottom set lines usually fish for smaller demersal species, halibut being one exception, when compared to the drift longlines that target large pelagics. Consequently, the pelagic gear is stronger, has larger hooks at greater spacing, and is considerably longer (tuna longlines exceed 100 km).

Longline operations range from small wooden boats with manual baiting, setting, and hauling, to large steel vessels that are fully mechanized. The basic mode of operation, regardless of vessel size, is the same for both surface and bottom set gear. The operation begins by setting out a marker buoy over the stern. Anchor and anchor line are deployed next on bottom set gear. The mainline follows with either weights and/or buoys, attached at intervals along its length, to position the gear in the water column or on bottom. As the mainline goes out, baited hooks with gangions are either already attached (spliced or knotted) or affixed using clips at regular intervals.

The mainline (referred to as the groundline in bottom set gear), is stored on the vessel in coils, tubs, spools or racks. It is usually in a number of sections, called skates, that are attached to each other as the line pays out. Modern drift longliners store their mainline (commonly monofilament) on hydraulically operated spooling reels that can easily hold 100 kilometers of line.

The traditional, or small scale operations, usually bait their hooks by hand before going out to fish. If the groundline is coiled, the baited hooks are in the center of the coil. If the groundline is in a tub, the baited hooks line the tub rim. In operations where the hooks and gangions are snapped on, the baited lines are kept in separate boxes. The hooks sometimes are baited by a non-fishing crew on the beach, while the boat is out fishing, requiring two sets of gear. Preferably, the baited hooks are kept refrigerated.

The bait can be cut by hand or by machine, regardless of the method of baiting. Most automatic baiting operations prefer machine cut bait; some machines have cutting rates of 500 pieces per minute. Auto-baiting can either be "random" or "precision". In random baiting, the hooks are pulled (by the forward motion of the vessel) through a hopper containing cut bait, as the gear is being set. The hooks randomly snag pieces of bait, with a baiting efficiency of about 85-95%. Mustad introduced the more elaborate precision baiting process, in which each hook is baited individually and turned, so that the bait is "double-baited" or hooked twice. Nordco, of Newfoundland, developed a precision "gang baiter" which lines up a number of hooks along a whole baitfish, twists the baitfish onto the hooks, and then cuts the bait so that there is one piece per hook.

Un-baited hooks, attached to groundlines stored in tubs, are held in a hook rack. More elaborate systems hold the hooks in magazines. The hooks are then auto-baited and led over the stern through a shoot or over rollers. The gear can also be hand set by using a stick to lift the gear over the stern. Upon completion of the set, another marker buoy is attached. Soak time can vary from minutes to days depending on the fishery or weather conditions.

Hauling occurs over the side or stern. The vessel approaches the gear from leeward, picks up the marker buoy, and commences hauling. This task can be performed by hand, or with the assistance of a power hauler. As the fish come to the rail, they are gaffed and removed from the hooks. Unwanted catch (i.e., under-sized fish) is allowed to fall back over the side or might also be dislodged from the hook by being deliberately knocked against the side of the vessel (called slatting) before coming on board. The catch is also sorted on deck. Snap-on gangions are removed, by hand or machine, and the mainline is coiled or spooled. Hooks are stored, depending on the system, and can be repaired, replaced, and re-baited. Some mechanized systems have devices for removing old bait and unraveling gangions twisted around the mainline.

Main and branch line materials range from monofilament to steel wire and chain. Monofilament and twisted multifilament are most common. In semi-pelagic longlining, higher catch rates have been observed with monofilament. Swivels are used in attaching the gangions to the mainline since they decrease the rate of raveling around the mainline and thus possibly increase catch.

A modern mechanized longliner, with a seven man crew, can set and haul as many as 40,000 hooks per day. Linesetters, a form of mechanized reel, allow longlines to be set faster, deeper, and use shorter leaders. Line speed and tension sensors connected to the haulers have greatly improved the efficiency of hauling by significantly saving time (ie, hauling faster with less foul-ups).

Handline Gear

Handlining is the act of fishing one line, usually with multiple hooks or barbless jigs, from a surface craft. Commercial handlining is usually small scale, though there are some larger vessels that jig for squid. Handheld lines began to be replaced by reels early in this century, which were in turn motorized in many fisheries. In the last decade, computerized handline machines/reels have allowed one fisherman to operate several lines. The fisherman can program the machine to automatically fish at various jigging speeds and ranges and to haul when a certain weight is sensed. These machines, coupled with high speed vessels, can have significant fishing power. It is generally assumed that handlining is the most environmentally sustainable fishing method but is uncompetitive against larger and more mechanized fishing gear. The asumption about being non-competive may not hold true when fish are scarce and prices are high.

Traps

Traps, or pots, are self contained units used to catch fish or crustaceans (eg, not the fixed weir-type traps found in areas along the coastline). These traps are usually in the form of a cage that have one or more openings or entrances designed in such a manner as to prevent the target animal from escaping. Traps are normally baited and set on the bottom singly or in strings (trawls) marked on the surface by buoys. Common construction materials include wood, metal and plastic.

The amount of time a trap spends in the water fishing is called the "soak-time". Some traps are designed to be hauled very frequently (every 15 minutes) while others are left in the water for many days before being hauled. Species composition can change with soak-time.

III. Animal Behavior/Modes of Capture

Behaviors of fish other than how they react to fishing gear, that are of short-term interest to fishermen, include aggregation (shoaling or schooling) and dispersal, vertical and horizontal migrations (diurnal and long term), and spawning and feeding. These behaviors are affected by environmental factors as well as inter- and intra-species relations. An understanding of fish behavior is critical in any attempt to solve fishery bycatch problems related to gear.

In most cases, fishing gear does not act as a simple passive seive, filtering certain fish out of the water and leaving others behind. Capturing fish depends upon a host of immediate behaviors intrinsic to each individual species and size of fish. These behaviors include reaction to sound and sight, speed and swimming endurance, escape response, etc. The key to solving by-catch problems is to understand behaviors that separate the target and non-target species. For example, researchers using underwater video discovered that cod and haddock react differently to a threat such as a trawl; haddock go up, cod go down. Consequently, trawls have been tested with horizontal panels that give good separation between the two species as well as other species present in the catch.

a. Environmental Parameters

Temperature

Temperature is one of the easiest measured of the environmental parameters and as such has served as an indicator of fish behavior. Fish can perceive temperature changes as low as 0.03 degrees C. The fish may be directly responding to temperature changes (thermotactic response) or to some other factor that is temperature related, ie, the presence of food. Fish activity and metabolic processes are directly affected by temperature. Fish probably seek out desirable temperature ranges in the short term by vertical movements and in the longer term by seasonal movements in the horizontal plane. All other things being equal it is expected that fish would seek out the optimum temperature range for growth and reproduction (eating and mating). This behavior differs by species as well as age class of fish within a species.

Significant amounts of data exist on temperature and fish behavior. For example, studies have shown that cod will not eat below 1 degree C and that optimum for feeding is between 2.2 and 15.5 degrees C. Spawning has been observed for cod to occur between -1.1 and 12.0 degrees C with preference for discontinuity layers between two different temperature water masses. Migrations, for spawning or feeding, can be triggered and influenced by temperature change and other factors. The actual temperature may affect fish speed and feeding rates thus influencing when fish arrive at their migration destination. If it is a spawning ground, and spawning is consequently delayed, this can affect survival of the eggs and juveniles. There have been occasions when temperature has prevented fish from arriving at their spawning grounds necessitating a less successful spawn elsewhere.

Knowledge of fish movements that are temperature related can be used to reduce bycatch. Some Alaskan fishermen have found that pollock aggregate by size and that a one degree C change is enough to discriminate between small and large fish. Some Canadian east coast fishermen say they can tell if they will be setting on haddock or cod by the water temperature. The likelihood of entanglement of small cetaceans in gill nets may also be temperature dependent either directly, or indirectly by impacting prey activities. There is an indication that fish escapement through the meshes of an otter trawl may also be temperature dependent; fish reacting slower in colder water thus less likely to successfully escape.

Currents

Currents can be wind driven (such as the Gulf Stream), tidal (related to the movements of astronomical bodies), or created by the movement of water masses of different densities (different temperature and/or salinity). The influence of currents on fish is referred to as a rheotactic response. Fish perceive current by a mechanoreceptor organ located on the lateral line of the fish. There have been some laboratory studies that have indicated that fish do not respond to currents, either current direction or velocity of flow, unless they have a visual reference such as the bottom of a tank. However, field studies often observe fish orienting into a current.

Currents have broad impacts in that they transport eggs, larvae and smaller fish thus influencing their survival. The predators that feed on this biota are thus also current dependent, albeit indirectly. Currents can act as environmental boundaries. It has been found that in very cold water fish may allow themselves to be passively carried along by currents. Fish may choose to migrate by using tidal current (selective tidal stream transport); remaining in the water column on one tide, staying on the bottom during the opposite flow.

In experiments with small fish traps it was observed that fish will more often approach the trap by swimming up current than from any other direction if the trap is baited (most likely they sense the bait). If the trap head is oriented towards the approaching fish they are more likely to be caught than if the head is oriented in another direction. Gill net catch is also affected by currents. Herring gill netters have found that many times the fish are enmeshed in the up-current side of the net. Consequently, if they haul their nets with that side facing down, many of the dead fish drop out and are lost. The direction of tow of an otter trawl in relation to current has a significant impact on catch and thus probably selectivity.

While not directly current related, the relative speed of towed gear through the water can impact escapement of fish and other animals. Fish commonly try to maintain station relative to the moving gear which has the effect of reducing their escape attempts. Swimming along with the gear tires the fish also making the animal less likely to escape.

Light or phototactic response

Light plays a key role in fish behavior. Light affects vision and consequently all related behaviors such as feeding, mating, schooling, etc. Most fish have color vision but how well they see is questionable. Many researchers believe fish are most capable in sensing light intensity differences and discriminating movement. Gill net catch is affected by color, probably by how well the net blends into its surroundings. Fish can adapt to different light intensities by regulating depth. Some fish are attracted to light, exhibit positive phototaxis, and some fish avoid light, negative phototaxis. Hungry fish seem to be more attracted to light than fish that are not feeding.

Research has shown that some fish can swim against a strong current in light but when the light is switched off they drift. Other work indicates some species will feed on stationary prey during daylight but only moving prey at night which has interesting implications to fishermen that use hooks. The use of light to reduce bycatch is a possibility. For example, the presence of artificial light may entice fish to escape through openings in the netting of bottom trawls. Many species just swim along with the net, without attempting to escape, even when openings are present. Fish have shown an aversion to solid dark tunnels which can provoke an escape response.

Sound

The use of sound to influence fish and marine mammals is a relatively new area of study for bycatch reduction purposes. Cod can detect trawl noise anywhere from 70-80 m from the source to as great as several miles. One paper suggests cod and haddock can detect trawl noise as far away as five miles. Detection of trawl noise over the masking affect of ambient noise is an area that needs more study. It is known that in many areas significant differences have been found between summer and winter ambient noise levels; the winter having higher levels due to seasonal changes in sound propagation levels.

Compared to the vessel noise, the trawl is not a major noise source. However, research in a Maine, USA bay indicates that cod can probably detect trawl noise, at the lowest ambient noise levels, at a range of 12 km in winter and 4.5 km in summer. At the highest ambient noise levels the winter detection range is reduced to 280 m; in summer it is 330 m. Cod are capable of directional hearing so they can move towards or away from the noise source well in front of the trawl path. This may significantly impact trawl efficiency and species selectivity.

The use of noise making devices to warn marine mammals about the presence of fixed gear has been tried in many locations and has been met with some success. Harbor porpoise take in Gulf of Maine gill nets has been significantly reduced when nets are equipped with pingers. It is not known whether the pingers are influencing the harbor porpoise directly or indirectly, for example, by altering herring (prey) behavior. There is also the added dimension with marine mammals and sound in that they produce sound to echo locate and communicate.

Recent research in Israel on farmed fish has found that noise can agitate and stress fish. Stressed fish undergo changes in their metabolic processes that reduce growth rates, cause reproductive irregularities and increase disease. How these results may transfer into wild slocks and influence behavior is unknown.

Complexity

In addition to the factors discussed above there are many other environmental stimuli. There are chemical, or chemotactic, responses that fish utilize to find food, recognize sex, defend against predators, avoid toxic areas, and orient geographically. Sea surface state, sound, dissolved oxygen, and salinity among and in combination with other environmental factors play roles in fish behavior. This complexity makes it very difficult for scientists to isolate specific cause and effect relationships. Fishermen are often better interpreters and users of ecological observations than objective scientists. This trait can be very useful when applied to solving bycatch problems.

b. Active Encirclement

Trawls and purse seines actively capture fish by encirclement; surrounding and herding the fish into a containment area. Marine mammals and sea turtles are two non-target animals that are also subject to this mode of capture. At some point in the encirclement process the animals have an opportunity to escape before capture is completed. This opportunity is a function of the animals behavior in relation to the gear. For example, purse seining is considered by many to be non-selective since everything in the purse is retained. However, there is a selection process taking place when a fisherman chooses the set location. Many fish species segregate by size and sex. If in a particular instance, smaller fish are located in the upper portion of a large school, a purse seine may cut out that portion of the school when it is closed.

The best known example of incidental fishing mortality due to purse seines exists in the eastern tropical Pacific tuna fleet. As the fleet ranged the eastern tropical Pacific, "porpoise fishing" became prevalent. The fishermen learned that tuna were closely associated with porpoise schools and developed methods to herd the porpoise using chaser skiffs. When the porpoise, and associated tuna school, were tightened up properly, the set was made. Over 150,000 porpoise were being killed annually in this fishery by the early 1970's. Pressure was placed on the industry to reduce the kill. The fishermen developed the technique of "backing down" to release the porpoise over the float line and the small mesh "Medina" panel to prevent entanglement at the release point. The annual kill rates now are below 4,000 animals. Swordfish gill netters and tuna pair trawl fishermen in the Northwest Atlantic have found that they can reduce their marine mammal catch by keeping the gear below 10 meters from the surface.

Sessile organisms are commonly caught in bottom trawls because the gear is in direct contact with the bottom thus within the "fishing circle" of the gear. If the gear can be fished just off the bottom, non-target sessile organisms would not be subject to capture. Lifting the gear off the bottom provides another opprotunity of escape for swimming species. Besides having an opportunity to escape, many species require a stimulis to attempt the escape. The animal needs to percieve that there is a threat in the oncoming encirclement and then take action to escape. Targeting a specific height above the bottom can also serve to select species which frequent that height.

c. Ensnarement

Nets designed to ensnare (gill nets) retain fish through three mechanisms; wedging, gilling, and tangling. When a fish is gilled it has entered the mesh so that it cannot back out because the mesh is caught behind the gill. For a particular mesh size, there is an optimum size fish that should be retained based on morphological characteristics, which should result in sharp selection curves. However, fish may force themselves into the meshes becoming wedged and fish with body appendages tend to become tangled thus complicating the selectivity picture.

A typical gill net selection curve for a particular mesh size is bell shaped, falling towards zero on both sides. The high point in the middle represents the optimum or mean selection length. There is a relationship between fish body girth and length that is similar for different types of fish, ie, thin roundfish, flatfish, etc. This relationship is expressed as the optimum fish length equals the mesh size multiplied by a selectivity coefficient.

Species and size selectivity are influenced by the material used in the construction of the netting. Thread thickness and color are important parameters. Thread thickness, a function of the strength of the material used, impacts the elasticity of the mesh as well as the net's visibility. Color impacts visibility which is a function of water clarity, lighting, and substrate background. A fishermen will choose the thinnest, least visible twine based on the water conditions and the net strength needed for the expected catch (size of individual fish and total weight of catch). The twine cannot be too thin as it then damages the enmeshed fish.

Hanging ratio is defined as the ratio of the length of the mounted net (or length of rope to which the net is hung) divided by the stretched length of the webbing. Generally, the hanging ratio is about 0.5 for bottom set nets. Smaller hanging ratios result in increased entanglement of smaller fish, and higher ratios decrease the efficiency of the gear. Nets in flatfish or crustacean fisheries can have the headrope "tied-down" to the leadline creating a bag of netting close to the bottom.

The most familiar form of incidental fishing mortality associated with gill nets is the taking of non-target species. Bottom set gill nets take small cetaceans, pinnipeds, birds, turtles, as well as non-target fish and crustaceans. These takes vary significantly by area and season. Small cetaceans feed on aggregations of small, fatty fish. Such fish schools also attract large fish predators, such as cod, which in turn are sought by fishermen. The combination of near shore habitat, small body size and feeding behavior make small cetaceans vulnerable to entanglement.

d. Bait and Feeding

Traps and hooks exploit feeding behaviors by using bait to capture fish. As with other types of fishing gear, one of the key factors affecting species selectivity is the location and time the fisherman chooses to set the gear. Bottom species often have different preferences based on the type of substrate; some occupy sand bottom while others are only found in rocky areas. Some of these species stay virtually on the bottom while others remain close to the bottom. Pelagic species have preferences that are affected by water depth, temperature, prey species, and many other attributes that impact their location in the water column. Schools of the same species, but different age groups, can occur in different locations. Most species exhibit some degree of diurnal movement thus their location changes with time. The presence of larger fish, which more successfully compete for the baited hooks, can alter selectivity of other sizes and species present.

Where and when a fisherman chooses to set his hook or trap has a major impact on his catch of target species and bycatch, and also on damage to the catch by other predators. Shark damage, in the Northwest Atlantic swordfish longline fishery, is water temperature and time dependent. Different species and sizes of tuna are available to hooks at different depths. Moving lines from on bottom, to just off the bottom, has been shown to change the species composition of the catch.

Bait type and size is an important factor in both species and size selection of hook gear. Bait can consist of a variety of species or be artificial (man made). The bait can be whole or cut; fresh or previously frozen. Bait can attract by sight or by smell. In the latter case, bait produces olfactory stimuli that attract fish from various distances. Fish probably have different abilities in sensing bait depending on their size and species as well as the bait size and type. The release of olfactory stimuli over time changes (leaching out). In addition, the condition, or freshness, of the bait changes overtime and, consequently, this can impact the selectivity. There are many times that fish just do not go after bait either due to daily feeding cycles or longer periods associated, for instance, with spawning.

Ultimately, the catching efficiency of a hook is a function of bait retention. Bait available to catch target species is reduced by sea bird predation during setting, consumption by non-target species (fish, crustaceans, amphipods, etc.), consumption by un-hooked target species, and mechanical loss. Combinations of two baits have been found to be effective; one bait serving as a good attractor and the second having good mechanical properties in order to stay on the hook longer. There are some indications that bait size is more important than hook size in determining selectivity.

Hook design characteristics contribute to the efficiency of the gear on various size classes and species. For example, hook shape has been shown to change catch rates between species. It has been observed that wide gap hooks were superior to the traditional J-hook in the cod fishery of Norway. Circle hooks, traditionally fished in the Pacific islands, significantly increased the catch rates of halibut in North American fisheries compared to J-hooks. To overcome the difficulty in auto-baiting circle hooks, the E-Z- Baiter hook was designed with a lengthened straight shank. In all hook designs, sharpness of the point and barb dimensions are important. Earlier work indicated that there is some size selectivity due to hook size. Others question the assumption, that moderate changes in hook size alters size selectivity. However, there seems to be some relation to hook size and catch rates.

Traps have another aspect of feeding behavior that is not normally associated with hooks. Animals may not enter a trap if larger more dominent animals of the same species are already present in the trap. The presence of predators in a trap will most likely inhibit prey from entering. On the otherside of the issue, fishermen have been none to bait traps with live conspecifics as an attractant. Traps may also be self-baiting by animals that enter and die thus attracting additional entrants.

IV. Technological Approaches

In this section we will examine some specific technological solutions to the bycatch groupings outlined in Section I.c.

a. The capture of turtles and other non-target species by hook gear

Turtles

Turtles are known to be taken as bycatch in the Spanish swordfish longline fishery. A fleet of 60-80 Spanish vessels, typically 15 m wood boats of 40 gross tons and 300 HP, longline for swordfish with eight man crews. Their gear consists of a 300 m surface main line with 12 hooks (90 mm per 35 mm), 20 m apart, attached using 25 m snoods. As many as 200 of these main lines are attached together, reaching lengths of 60 km with 2400 hooks. Hooks are baited with flying squid, mackerel, and gilt sardine. Sets are made at sunset and hauled at sunrise. Bycatch also consists of stingrays, sharks, and tuna. Observers onboard 26 Spanish fishing boats during a period of 143 days, between the summer months of 1990 and 1991, recorded the captures of 1,098 loggerhead (*Caretta caretta*) and two leatherback (*Dermochelys coriacea*) sea turtles. This has led to estimates that more than 20,000 subadult loggerhead turtles are incidentally captured every year as a result of the Spanish longlining fishery activities. Turtles are usually released alive with the longline hook still lodged internally. It has been estimated that at least 20% of the sea turtles captured by this fishing gear could eventually die, due to the injuries caused by the hooks. Other Mediterranean longline fleets are also known to take turtles as well as drift net, gill net, and trawl gear. A leatherback turtle was also reported taken on a swordfish longline in the Pacific with squid as the bait. In this case light lures were being used on the line and there was some speculation that the light may of attracted the turtle. The turtle was released alive with the hook in the turtle's mouth.

There have been some suggestions, not in the literature, that turtle mortality related to hook retention could possibly be addressed by designing biodegradable hooks. There has been some successful work designing metal releases for lobster traps that maintain full strength then rapidly deteriorate. This is a possible avenue of research though this strategy can be very expensive to fishermen. The most promising area of research might be to find differences in bait preference and biting behavior between turtles and swordfish leading to different bait type/size and hook design. An artificial bait that attracts swordfish or repels turtles would be an interesting concept worth investigating. An interesting observation made during the Spanish observed trips was that while the largest fishing effort occurred between 0400 and 0800 local time, the largest turtle catches occurred between 0800 and 1100 hours. Control of when the gear is in the water may help solve the problem. For instance, setting swordfish gear after dark has been shown to decrease shark catch in the Northwest Atlantic.

Fish bycatch

Preliminary trials in Canada indicate that haddock catches in a directed fishery for cod could possibly be reduced by using larger hooks and larger bait pieces; bait size being more important. Research in Norway in the cod longline fishery found that cod length distribution was also affected by bait size, shape, and type (real shrimp vs artificial bait).

There has been success in reducing bycatch of a non-target species by feeding behavior. Baits laying on the bottom are not as likely to be taken by sight feeders as those baits that are suspended or float up off the bottom. A non-bouyant snood or weighted hook could keep a bait on the bottom.

Artificial baits may have an indirect benefit in reducing bycatch. Bait is usually obtained from small mesh fisheries which often have a bycatch of juveniles of larger species. Any reduction in these bait fisheries could have significant benefits to the ecosystem as a whole.

There is evidence in the literature that fish, and possibly other animals, can fall off the hooks during haulback due to jerking of the line by vessel motion resulting in lost target catch. This jerking motion can also result in more damage to retained animals as well as setting the hook deeper. This can have a negative impact on the animals that should be released alive in good health. This potential problem has not been researched to our knowledge. Constant tension haulers are a potential solution if this problem is found to be significant.

b. The capture of seabirds by hook gear and in gill nets

Hook gear

Diving seabirds are known to be taken by entangling nets and on baited hooks. Seabirds most likely have developed the habit of following fishing vessels because they have learned these vessels are a source of food. More birds follow vessels during hauling then during setting. Offal and unconsumed baits are the main attractants.

Critical periods in longline operations for bird bycatch are during the setting and hauling of the gear. A bird that takes a bait during the set, whether it becomes hooked or not, represents a loss of catching potential to the fisherman. One approach fishermen use to reduce this occurrance in New Zealand is the use of "tori poles" that distract the birds as the hooks go over the side. This system consists of poles with lines attached. The lines trail aftof the vessel and commonly have colored plastic strips attached at intervals. The line can also be of highly visible colored cord with cord streamers attached by swivels. Norwegian longline fisheries use similar tactics. One problem with this approach is that birds can become accustomed to scare techniques. Another approach is to use a wire snood, instead of nylon, as it is heavier and causes the bait to sink faster. More birds are taken during the setting of hook gear than during the haulback. It has been also observed that frozen baits tend to float thus they are on the surface subject to bird predation for a longer period of time than if they were not frozen. Using thawed baits should decrease bird bycatch. Bird bycatch of certain species (albatross) can be significantly reduced by setting and hauling gear during hours of darkness. This approach should be considered wherever feasible. However, some species may be more susceptable to capture at night, for example, petrels.

Some longliners have been recently fitted out with a patented stern mounted setting pipe developed by Solstrand AS, a Norwegian vessel builder. The line is fed through a hatch in the stern and passes through the pipe underwater thus greatly reducing loss of baits to birds. This system has significant benefits to the fisherman by increasing catch due to greater bait retention, safer gear handling, and operating simplicity.

Gill net gear

Diving birds are also known to get caught in bottom set gill nets. Fishermen have observed that this usually occurs during haulback when offal from cleaning previously caught fish and other discard are being discharged over the side. This bycatch can be virtually eliminated by not throwing anything over during haulback. Work in Washington State, USA, has suggested that the bycatch of seabirds can be reduced in salmon gill nets by using highly visible twine in the upper portions of the net. Salmon also avoid the visible panels but get caught in the lower portions of the netting.

c. The capture of marine mammals in gill nets

The catch rate of marine mammal in fishing gear is a function of a) the availability of the animals to the gear, ie, the number of animals in the area of the gear geographically and within the water column, b) the fishing intensity (number and/or size of nets), ie, the more nets the higher the total take of animals, and c) the vulnerability of the animals to the gear, ie, the likelihood of capture upon encountering a net. The number of animals available to the gear can be reduced by not setting the gear in the same area or depth that the animals normally inhabit. Some evidence exists that if bottom set nets are tied down there is a lower catch of harbor porpoise. However, in many cases the target and non-target species are in the same place at the same time.

The subject of fishing intensity is self-explanatory but also very complex as it involves greater fishery resource management issues. Overall net limits or bans will reduce direct take of animals but may have indirect effects. Displaced fishing effort might target or disrupt the food supply of the animals. When considering mitigation strategies, many characteristics of the potential alternatives need to be compared to those of the existing gear. For example, while an obvious solution to the interaction problem might be to ban gill nets, there may be ecological and commercial advantages associated with their use (ie, energy efficiency, cost efficiency, size-selectivity, lack of habitat damage, etc). Banning can lead to reconversion to alternate gears that have worse consequences to stocks and habitat. Thus, it is important that technical, economic, ecological and social consequences be examined when considering changes in fisheries technology.

A common tool used in fishery management is closure of an area to fishing for a period of time. The classic example is the closure of a spawning ground during the spawning period. Time/area closures are also used to close areas to gillnetting when cetaceans are known to be present. For example, a section of the coast of New Zealand is closed to recreational gill netters to prevent entanglement of Hectors dolphins. There are some practical limitations when using a closed area system. Many times it is difficult to define boundaries of closed areas due to the uncertainties in the movements of the animals involved. Thus a closed area system requires extensive data collection about separations between target and non-target species both seasonally and geographically. Ideally these areas should not contain such large concentrations of the target species as to have the effect of closing the fishery. On the other hand, maintaining many small closed areas becomes difficult to enforce.

Modifications that affect the vulnerability of non-target species to gear have received ever increasing attention by researchers and fishermen alike. The presumption is that the gear represents a fishing method worth preserving for its advantages if the problems can be resolved. The major approach has been to make the gear either visually or acoustically more apparent to non-target species so they will not be vulnerable to capture. A second approach that has been identified is to design gear so they will not entangle the animals (weak twine, nets push over, no slack twine, etc). Grey whales were being entangled in California gill nets until the fishermen increased the footrope weight and decreased the headrope buoyancy. This allowed the whales to push over the nets without getting entangled.

One of the potentially most serious marine mammal take problems in European waters may be that of harbor porpoise in gill nets. A study of the Danish North Sea gill net fisheries for cod and turbot found relatively high takes of porpoise; a rough estimate of 7000 in 1993. A similar problem with harbor porpoise take exists in the Western North Atlantic off the east coast of Canada and the Gulf of Maine down to the coast of Virginia, USA. Recently, there has been significant success in reducing this take by the use of net pingers producing a broad band signal centered at 10 kHz. In one experiment only two porpoises were taken in 423 alarmed strings compared to twenty-five porpoises taken in 421 control strings; a highly significant result. In a follow-up experiment conducted by fishermen under routine fishing conditions, no harbor porpoise were taken when previous data indicated the take should of been at least six animals. The fishermen feel strongly that the pingers work and they can use them operationally. Several companies are improving upon the pinger design to increase durability and battery life.

There are still many unanswered questions about the use of the alarms. There are concerns that the porpoise may habituate to the sounds or that there may be long-term impacts on porpoise behavior due to the ensonification of large areas. The reduced take may of also been due to lower catches of herring in alarmed nets, a key prey species of the porpoise. However, another experiment on salmon gill nets in waters of Washington state, USA, using 20 kHz pingers had equal success in reducing harbor porpoise take.

There are many ideas on how to reduce the take of marine mammals in gill nets by modifying the gear design. These ideas include attaching highly visible passive acoustic reflectors, but for these to work would require that the marine mammal is actively sonically searching. There is evidence that this is not always the case, especially when the animals are traveling in groups. Other approaches involve leaving holes or openings within the string of nets to allow paths for the marine mammals to pass through. This has not been successfully field tested to our knowledge. There is also the suggestion that a gill net's acoustic visibility can be increased by using individual floats and weights as opposed to floatline and leadline. This has not been scientifically trialed.

d. Non-target commercial species in gill nets

There are a number of ways to modify gill nets or change operational methods in order to alter species selectivity. Gill nets are relatively size selective thus if there is a difference in size between the target and non-target species, altering the mesh size usually has a significant impact. Species selectivity is also significantly impacted by the location of the gill net in the water column. For example, swordfish gill netters claim that if they do not fish their nets directly on the surface, but instead, keep their float line several meters below the surface, they can reduce their take of marine mammals without impacting their swordfish catch. Bottom set gill nets that target flounders or monkfish can have their floatropes tied to their leadlines reducing the vertical profile to under a meter. This action reduces the catch of gadoids that usually swim up off the bottom. Alternately, the lead line can be fished slightly off the bottom to reduce the catch of crabs, lobsters, flounders, and other bottom dwellers.

Hanging the gill net taught in many cases will lower the retention of species that tend to entangle, spiny fish for example. This also has the effect of sharpening the size selectivity of the gear. Different species selectivity has also been reported based on twine type, for example, multifilament vs monofilament had different impact on various salmon species. Smaller diameter twine may catch and retain larger sized fish because it can be stretched more by the more powerful larger fish. The choice of twine color has also been suggested as a means of altering species selectivity since different species have been shown to react differently to various colors.

Hauling a gill net more frequently can also change species selectivity. The removal of dead and dying fish by hauling will either reduce the catch of species attracted by the dead catch or increase the catch of species repelled by the presence of the dead or struggling animals.

e. The impact on benthos by towed gear

Towed gear impacts on habitat seem to be very location dependent. A seemingly simple solution to habitat impact problems would be to close very fragile areas to towed bottom gear, however, it may be difficult to define these areas. There may be a seasonal component to towed gear impact on habitat. For example, towing may be detrimental to newly set shellfish or early life stage fish. In this case seasonal closures of specific areas may be appropriate. However, as in our opening discussion, we do not know all the relationships between fishing gear and the environment thus any actions taken need to be well monitored to judge the actual impacts.

Trawls

There are a multitude of gear modifications that can alter the way a bottom trawl impacts the bottom and the organisms located on and near the bottom. For example, a polyvalent door would push small boulders out of its path while the steel vee door would tend to swivel and not push the rocks out of the path. Different door designs have different impacts on hard bottom.

Researchers have also found that habitat damage can be caused by the lower legs connecting the door to the trawl. Trawls with doors attached directly to the nets may greatly reduce the bottom area damaged by trawling activities, as would any modifications to the net and roller rig that would raise the lower leg lines further off the bottom. Adjusting the bridle angle can alter the size and species selectivity of a trawl by changing the herding characteristics of the trawl.. All the above mentioned changes, however, can impact the efficiency of the gear on the target species in a negative direction.

There are several basic types of sweeps, the part of the trawl that touches the bottom along the nets leading edge. The sweep can be heavy chain, rope wrapped cable, or a continuous wire filled with rubber disks. These sweeps are designed to have continuous contact with the bottom along their entire length and are usually found on gear that targets bottom dwelling species such as flounders and shrimp. There is little chance of escape of small organisms under the sweep. The other catagory of sweep gear has larger diameter rollers or bobbins spaced various distances apart. This gear usually targets near bottom species, such as the gadoids, and can be fished on more rugged bottom. Small species can escape under the sweep in the spaces between the rollers. Sweep design can thus play an important part in changing a trawl's species and size selectivity. Tickler chains and chain mats, commonly used on beam trawls, also have significant impact on what is caught by the trawl. While there has been much work examining the impact on catch and habitat of tickler chain rigged gear, there has been little effort expended on finding means to prevent unwanted benthos from entering the gear.

Dredges

A source of mortality associated with shellfish dredges is the damage to the catch caused by rocks in the dredge itself. Undersized target species and non-target species that could normally be discarded and survive are crushed and damaged. There are several design options that can minimize the retention of small shellfish and rocks in a dredge. One solution, in gear with fixed cages, is to get the cage off the bottom by mounting it on runners. The cage bottom can be sloped upward and consist of round steel bars running fore and aft. It has been found in clam dredges that if the bars are not in the same plane, but alternate in two levels, increased sorting occurs. Mounting the gear on runners most likely reduces dredge induced habitat damage.

In sumation, there are many options for reducing the habitat impact of towed gear where it is not necessary for the gear to fish hard on the bottom. However, there are many species that require the towed gear to dig into the bottom. One possible approach would be to switch to alternate gears such as trapping for shrimp and nepthrops. The other approach would be to swap individual economic efficiency for habitat protection. For example, a slower towed clam dredge would in most cases cause less damage to benthos in its path. This may not be the case for scraping gear, such as scallop dredges, because at slower speeds they often have heavier contact with the bottom.

f. Non-target catch in groundfish trawls

Size selectivity in trawl gear, in the simplest terms, is usually related to mesh size opening. In a single species fishery the choice of mesh size would have a direct relation to what size fish would be retained by the mesh and what size would escape through the mesh. Commonly, it is the cod end mesh size, and their ability to stay open, that is considered the most important for influencing trawl size selectivity.

Researchers have found that not all fish that are capable of fitting through a mesh opening escape the trawl. Two aspects of this problem are the mechanics of the trawl and fish behavior relative to the trawl. Regarding the mechanics, tension on the codend meshes of a trawl can close the mesh openings hindering escapement. Several approaches have been proven successful in reducing this problem. The cod end can be designed to hang on the "square" as opposed to the traditional diagonal or "diamond. This method keeps the meshes open regardless of the strain. Square mesh cod ends have been found to be more selective than diamond mesh for roundfish than flafish for a given mesh size. Another method is to use shortened lastridge ropes, the heavy lines that run along the net seams. This has the effect of keeping the meshes slack easing escapement. The slack twine tends to undulate which seems to create an increased escape response in the fish thus sharpening selectivity. There are other advantages to using shortened lastridge ropes for improving selectivity when compared to square mesh. It avoids the problem of knot slipage and has better selective characteristics for flatfish. Shortening the portion of the net in front of the cod end, called the extension, also improves escapement.

Modifications to the trawl that aid and encourage fish to escape have been tried. There is ongoing work using dark colored panels/tunnels in the cod end that has succesfully encouraged fish to escape through the meshes in front of the tunnels. Escapement using the tunnels increased in one case from 18% to 77%. Different colors of twine have also been tested for similar effects. The size of the trawl, how fast it is towed, and how hard it fishes on the bottom can all impact size selectivity. Larger fish, usually stronger and faster, can avoid smaller, slower moving trawls. Small fish can escape under the sweep of trawls fished light on the bottom or with large roller gear.

Species selectivity can be altered by the use of sorting grates and horizontal separator panels within the trawl. Sorting grates used in the Canadian silver hake fishery direct larger bodied species out an escape hole in the top of the net though smaller specimens are retained. This in combination with fishing areas that contain few small fish of other species has effectively eliminated the bycatch problem in this fishery. However, tests of a Sort-X grid in the Canadian cod fishery demonstrated variable results and lack of sharp selectivity. Higher success was achieved in using grates to sort out cod in the Canadian plaice fishery; 84% cod exclusion with only 8% plaice loss. The orientation and bar spacing are critical parameters. Horizontal separator panels in trawls in the UK have been sucessfully demonstrated during experimental trials to separate haddock and whiting when directing for cod and plaice. Horizontal panels are difficult to design and install correctly limiting their commercial acceptance.

The use of mesh size or square mesh as a management tool becomes complex in a mixed fishery that catches round fish as well as flat fish. Work is ongoing to determine if different size meshes in different locations can improve net selection characteristics. The Japanese deep-sea trawl fishery in the Bering Sea does not have a flatfish quota. By using large square mesh sections in the front of the belly and long attachment wires between groundrope and fishing line they have very low flatfish catches, though some target catch is lost.

The key issue with measures to reduce the non-target catch of trawl nets is that enforcement is an intractable problem. The selection is not sharp enough with known technological solutions so that some legal/marketable fish will be lost to the catch. Fishermen will modify the gear at sea to avoid this loss, especially when fish are scarce. Blocking mesh size openings with liners is the most common technique but there are also a number of subtle rigging options that will decrease the effectiveness of mesh openings.

g. Fish catch in shrimp trawls

There has been a considerable amount of work trying to separate species within a small mesh shrimp trawl to allow one or more groups to escape. Shrimp/fish separation and turtle excluder devices (TED's) are classic examples. TED's have reduced the take of sea turtles during trials by 97% with insignificant reductions in shrimp catch in the Gulf of Mexico. Once the USA government required the use of TED's, the industry came up with five improved designs that worked better than the government's TED. They are lighter, simpler, and less costly.

The work on TED's has lead to research on bycatch reduction devices (BRD's) for fish. One device is known as a fish-eye or Florida Fish Excluder. It is a small rigid frame that is installed in a cut slot in the cod end or extension that provides an opening for fish to escape. Another method is a cylindrical large square mesh section of the extension associated with an accelerator funnel. Fish-eyes have reduced fish catch by over 50% in some tests, being more effective on some species over others. They do however have shrimp loss of 5-10% in preliminary trials. The large mesh sections have also reduced catch of certain finfish without shrimp loss. Gear handling during haulback with these devices and weather seems to impact the results.

In the Scotian shelf shrimp fishery, groundfish bycatches were limited to 10% of the shrimp catch which had the affect of closing the shrimp fishery before the shrimp TAC was attained. In 1991 a shrimp separator grate (Nordmore grate) was introduced (25 mm bar spacing or less) that was placed into the 40 mm cod ends of the trawls. Experimently, bycatch reductions of 60 to 99% were obtained. Bycatch was reduced in commercial use so that by 1994 the shrimp TAC could be taken without closing the fishery due to fish bycatch. However, the problem still remains of small fish that pass through the grate and are retained. In this example the separator grate was used to solve an allocation problem more than a conservation problem.

V. Solving The Bycatch Problem

There are two major aspects to the solution of bycatch problems. The first is technical and the second is operational. In many cases the technical aspects are the easiest to address once the problem is accurately identified. However, most solutions that have been technologically proven and identified to reduce bycatch are not easy to put into operation in regulatory form or easy to operationally enforce. There needs to be a paradigm shift on how we manage fisheries if we are going to sucessfully apply technological solutions to fishery problems. The real selectivity issue that needs to be addressed is how society selects, trains, and works with its fishermen.

a. Licensing and Apprenticeships

It is important for fishermen to act as stewards of marine living resources and the ecosystem in which the animals swim. This would require that fishermen are kept well informed of the status of these resources and ecosystems and the best means to reduce unwanted bycatch. Fishermen, for the most part, do not read newsletters or informational bulletins unless they are given a strong incentive. To this end it is proposed that licensing and apprenticeship systems be initiated for fishermen for the following purposes:

a) To train fishermen in bycatch reduction strategies.
b) To control entry by training and apprenticeship requirements.
c) To foster a sense of community among the affected fishermen.
d) To improve data collection/reporting by fishermen.

The licensing and apprenticeship system should be designed to ensure a basic knowledge of bycatch reduction, continuous upgrading of that knowledge, and active participation in the field. The following is an example of one possible approach. Initially all active fishermen would be allowed to sit for their license. After the initial period, to receive a license, a fishermen would need to document that he has been fishing for a set number of years. Upon providing this documentation a written open book test would be required. The exam would focus on resource protection including laws, regulations, bycatch reduction strategies, and other related concerns. A study text would be prepared by government and academia to be used for the exam. After the initial period, fishermen that do not meet the time requirement can fish under an apprenticeship with a licensed fisherman.

The initial license would be good for five years. During that period the license holder would have to earn five recertification credits or take the exam over at the end of the period. Recertification credits would be earned by attending fishery meetings, public hearings, seminars, workshops, etc that concern themselves with the marine living resources. Typically attendance at a meeting would be worth one half credit so this works out to about two meetings per year on average. Credit could also be earned by conducting experimental fishing for management purposes and carrying sea samplers. Apprentices will also be required to earn recertification credits.

When a license holder or apprentice attends a meeting he or she would receive a certificate of attendance. At the end of a five year cycle these would be submitted for recertification. The license would be renewed annually during the period, probably with a fee and catch reporting requirement. After the initial licensing system is established it could be used to control the number of participants by adjusting the difficulty of the exams and/or the fishing time requirements for apprenticeships. Those already certified will remain so as long as they actively attend meetings and training sessions.

b. <u>Economic Incentives</u>

There are a number of ways to encourage individual fishermen to take actions that could result in a potential reduction of bycatch. These options are as follows:

a) Government provided financial assistance to switch to other gears.
b) Government provided financial assistance to buy pingers and/or modify gear.
c) Grant programs to conduct research on bycatch reduction strategies.
d) Buyback program for inappropriate gear.
e) Market-led incentives such as on-pack logos.

It may be appropriate to collect an annual fee from fishermen to fund the above incentives. This program could be modeled after some of the bird and fish stamp programs currently in existence. The funds collected would be administered by government entities but would be spent according to directives developed by an industry based Non Government Organization.

c. <u>Industry Based NGO</u>

The existing fishing industry is represented by a loose confederation of fishermens' organizations and membership seldom crosses international boundaries. Many fishermen do not actively participate or fund these organizations. The few fishermen that have taken an active leadership role in trying to solve bycatch problems have done so at great expense of there own time and money. It would best serve the cause of bycatch reduction by having strong industry groups, international in make-up, dedicated to solving the problems with adequate manpower and financial resources. The financial resources can come from stamp programs identified in item 2. These NGO's could have a Board of Directors made up of representation from the different fishing areas in proportion to the number of licensed fishermen in each of those areas.

d. <u>Performance Based Options</u>

There are many management techniques that can be used to reduce bycatch that do not lend themselves to a regulatory approach. For example, a fisherman can make a decision not to set nets in an area when he spots porpoise present. A performance based strategy relies on the results, not the individual tools used to obtain the results. Two major prerequisites are accurate assessment of the results (in this case total take) and incentives for industry to obtain the results. In fisheries with larger vessels and more revenues observers can be used to individualize the performance of each vessel. In a small boat fishery this is not an option.

e. Research and Development

Research and development programs to evaluate gear modifications and operational strategies that can reduce bycatch need to be started or strengthened where they already exist. These will need to be a long-term programs; well coordinated and funded. In addition, there should be an ongoing program within government to identify potential factors impacting bycatch estimates from existing sea sampling data bases and other sources. The research and development programs need to include formal mechanisms to encourage fishermen to conduct gear research in the field under actual conditions and provide accurate data to managers on the results. To this end, it is suggested that programs be initiated for experimental fisheries to conduct bona fide research as follows:

a) A fisherman may apply for en experimental fishery exemption.

b) The fishermen will have to present a formal proposal that includes

- Cover sheet
- Project summary
- Statement of objectives
- Plan of work
- Deliverables
- Key personnel
- Current and pending financial support
- Proposed budget

c) The proposal would be sent to the administrating agency for approval. This agency will seek the approval of the affected Industry NGO's before granting the experimental fishery. The key point is that the leadership and responsibility to find solutions to the bycatch problems should rest solely within the industry and government play a supportive role. Scientists should be advisors to fishermen using only reliable data provided by fishermen.

f. Gear Modifications and Fishing Operations

There are many combinations of gear design and fishing strategy that can possibly reduce bycatch. The modifications can include changing parameters of the gear as well as additions to the gear. Modifications need to be evaluated in terms of bycatch reduction, impact on target catch, cost, and enforceability. As previously stated, there are possible changes in gear or operational strategy that do not lend themselves to regulations and thus some alternative performance based management regime may be a prerequisite.

It is frequently suggested that certain gear, such as a gill net be replaced by alternative fishing methods, such as hook gear. The decision to use an alternative gear currently rests with the individual fisherman. The decision is usually based on the individual's economics, potential catch and associated direct costs, not the overall costs/benefits to society. It may not be feasible for individual fishermen to switch to alternative gear in certain seasons or areas. In addition, fishermen may be inappropriately forced by regulations to switch to alternative gears/practices that are even more detrimental to the ecosystem. If resource managers are convinced that there is a likelihood that positive benefits would accrue to the overall ecosystem by converting vessels using certain gear over to an alternate gear, at least seasonally, than a demonstration program needs to be encouraged.

VI. Conclusions and Recommendations

A number of technological solutions to bycatch problems have been identified that can be applied to European fisheries. However, illegal practices are so common place in European waters, it is difficult to conclude that technical measures will succeed. The fishermen have to believe that it is in their best interest to resolve particular bycatch problems.