CHAPTER 2

THE USE OF TECHNICAL MEASURES IN RESPONSIBLE FISHERIES: REGULATION OF FISHING GEAR

by

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1. INTRODUCTION

The need for fisheries management arises as the surplus production from fish stocks is overtaken by the catching capacity of fishing fleets. Catching capacity is the product of the fishing effort and the combined efficiency of the fishing gear and the fishing vessel (e.g. loading capacity, engine power, range capacity, fish finding- and navigational equipment) as well as the skills of the crew.

Fisheries management includes different management measures. Among these are technical regulations on fishing gears in order to obtain the overall goal of high sustainable yield in the fisheries. These are regulations e.g. on mesh size to improve the selective properties of a fishing gear so that bycatches of juvenile fish are reduced - in order to safeguard recruitment to the larger size groups of a fish stock including the spawning stock.

In recent years there has been a growing focus on "ecosystem effects of fisheries", addressing the impact of fishing operations not only on the target species, but also on bycatch of or other effects on non-commercial species or habitats. Energy efficiency, reduced pollution and improved quality of the catch are also important aspects related to fishing gears and fishing operations (Code of Conduct for Responsible Fisheries, Article 7.2.2). From a situation where the development of fishing gears and methods only focused on the highest possible catching efficiency for the target species, now fisheries research, fisheries management and the fishing industry are challenged to develop gear, methods and regulations that meet the different considerations mentioned above. This is part of an emerging ecosystem approach to fisheries management.

2. FISHING GEARS

2.1 The ideal fishing gear

Some criteria for the ideal fishing gear could be:

- highly selective for the target species and sizes, with negligible direct or indirect impact on non-target species, sizes and habitats (Code of Conduct, Paragraphs 7.2.2, 8.4.7, 8.5.1 – 8.5.4) ;
- effective, giving high catches of target species at lowest possible cost;
- quality orientated, producing catches of high quality (Code of Conduct, Paragraph 8.4.4).

According to these and additional criteria that could be added to the list, it can easily be stated that the ideal fishing gear does not exist, as no fishing gear fulfils the complete list of desired criteria and properties. However, in the process of moving towards sustainable fisheries management, different fishing gears with their specific properties and potential for improvement are an important compartment in the "fisheries manager's toolbox". A basic understanding of the properties, function and operation of the major fishing gears and methods is therefore fundamental for decision-making in fisheries management, particularly when it comes to technical measures in fisheries regulations.

2.2 Classification of fishing gears

Fishing gears are commonly classified in two main categories: passive and active. This classification is based on the relative behaviour of the target species and the fishing gear. With passive gears, the capture of fish is generally based on movement of the target species towards the gear (e.g. traps), while with active gears capture is generally based on an aimed chase of the target species (e.g. trawls, dredges). A parallel on land would be the difference between the trapping of and hunting for animals.

In the following sections a short description of the major gear types is given, including their catching principle, construction, operation and common target species. Gear selectivity and properties related to ecosystem effects of fishing will be treated in Section 5.

3. PASSIVE FISHING GEARS

Passive gears are in general the most ancient type of fishing gears. These gears are most suitable for small scale-fishing and are, therefore, often the gear types used in artisanal fisheries. Some passive fishing gears are often referred to as "stationary" fishing gears. Stationary gears are those anchored to the seabed and they constitute a large group of the passive gears. However, some moving gears such as drift nets may also be classified as passive gears, as fish capture by these gears also depend on movement of the target species towards the gear.

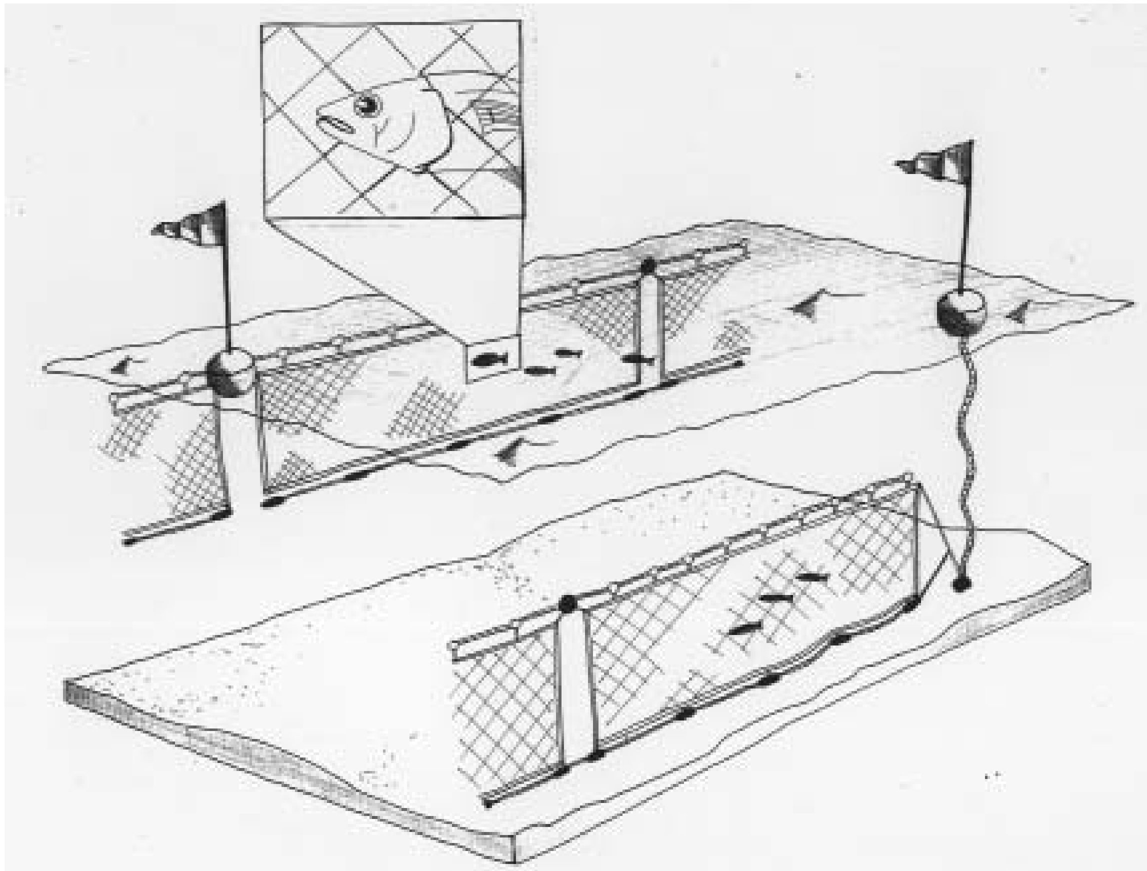

Figure 1. Catching principle (expanded view) and construction of gillnets, pelagic drift net (top) and bottom set (lower).

3.1 Nets

(a) Gillnets

The catching principle and construction of gillnets are shown in Figure 1.

Catching principle

The gillnet is named after its catching principle, as fish are usually caught by "gilling" – i.e. the fish is caught in one of the meshes of the gillnet, normally by the gill region (between the head and the body). Thus, fish capture by gillnets is based on fish encountering the gear during feeding or migratory movements. As fish may avoid the gillnet if they notice the gear, catches are normally best at low light levels or in areas with turbid water.

Construction

A gillnet consists basically of a "wall" or panel (e.g. 5 by 30 m) of meshes made from fine thread. The mesh panel is mounted with reinforcing ropes on all sides. To obtain a vertical position of the net in the sea, floats and weights are fastened at regular intervals to the top rope (float line, cork line) and bottom rope (sinker line, lead line), respectively. The size of the meshes and hanging ratio (number of meshes per length of gillnet) are chosen to fit the desired target species and size.

Mesh size is commonly given as the length (in mm) either of a whole stretched mesh or the half-length (also called bar-length).

Today, gillnets are almost exclusively made from synthetic fibres, normally nylon (polyamide) – either as multifilament thread or monofilament (gut). The latter is increasingly being used because of its low visibility and correspondingly higher catch efficiency. Multi-monofilament is also becoming more common.

Operation

Gillnets are most commonly operated as a stationary gear anchored to the bottom at either end, but may also be so-called drift-nets which float freely in the water. Stationary nets may be set on the seabed, at different depths in the water column or with the float line at the surface. Similarly, drift-nets may be operated with the float line at the surface or suspended from surface floats and corresponding float lines to the desired fishing depth in midwater.

Gillnets may be operated from vessels ranging from the smallest non-mechanised fishing boats to big, well equipped vessels capable of large-scale deep sea fishing . The gear used in small- and large-scale fishing is basically the same: the unit gillnet. However, with increased vessel size a larger number of net units can be carried and operated per day. Single gillnets are then linked into long fleets of up to several hundred nets.

Gillnets can also be operated from shallow to large depths and can be used for fishing on rough bottom and at wrecks. One specific problem with gillnets is so-called "ghost fishing". This refers to gillnets that are lost (most commonly after being stuck on a rough bottom) and continue to catch and kill fish over long periods of time. The Code of Conduct (Paragraph 7.2.2) requires that the incidence of ghost fishing should be minimised.

Target species

Gillnets are used to catch a large variety of fish species. In general, bottom gillnets are used for catching demersal species like cod, flatfish, croakers and snapper, while pelagic gillnets are used for species like tuna, mackerel, salmon, squid and herring.

(b) Trammel nets

The catching principle and construction of trammel nets are shown in Figure 2.

Catching principle

In trammel nets, fish are caught by entanglement, which is facilitated by its special construction of three panels of nets attached on the same rope with a high degree of slackness.

Construction

At first glance, a trammel net may look like a gillnet. However, while the gillnet has a single panel of meshes, the trammel net has three – one middle panel of small meshes and two side panels of larger meshes. When a fish comes in contact with the net, it will press the small mesh net through an adjacent larger mesh so that it is caught by entangling or "pouching".

Operation

Trammel nets are usually set and operated like bottom set gillnets, mainly in small-scale, near-shore fisheries.

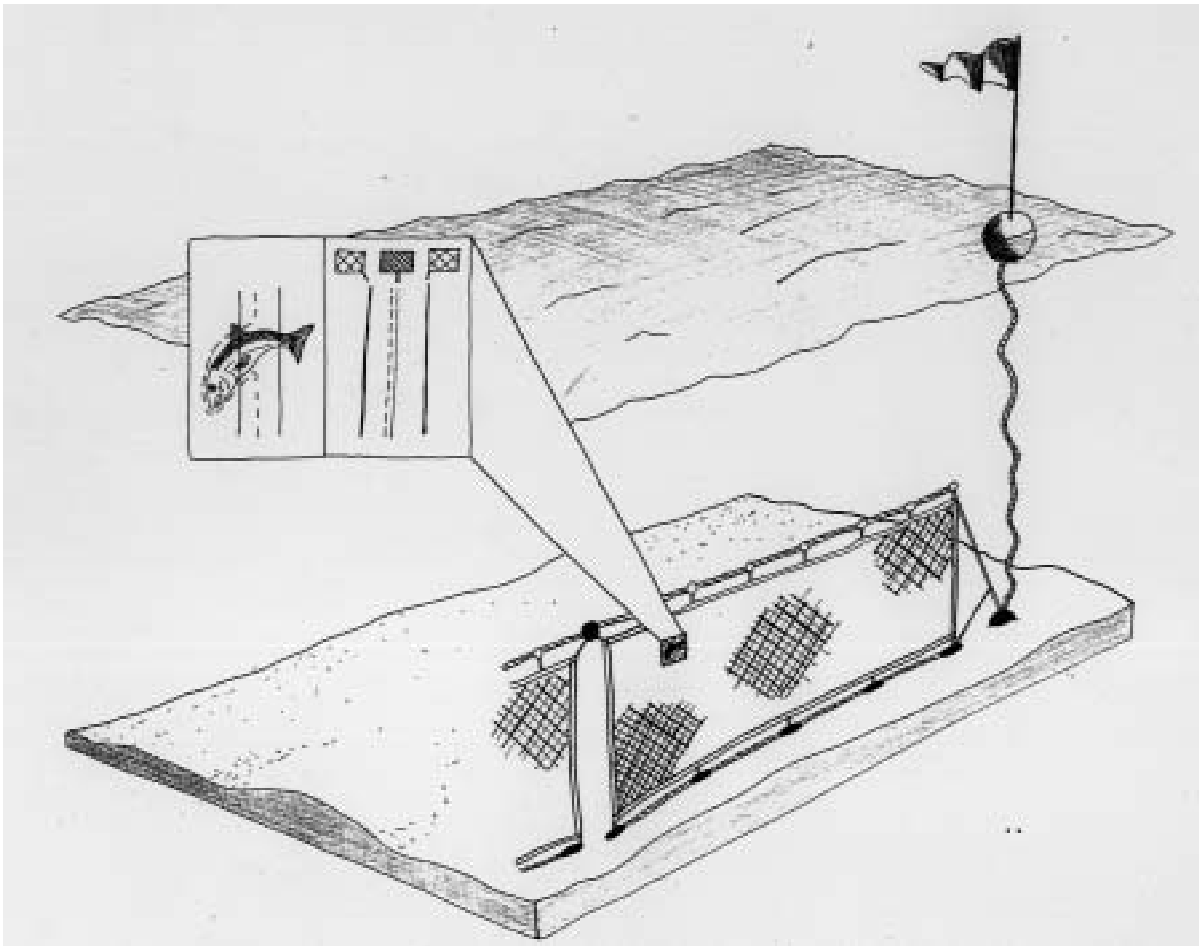

Figure 2. Catching principle (expanded view) and construction of trammel nets

Target species

Trammel nets are used for catching a large variety of demersal fish.

3.2 Hook and line fishing

Different fishing methods are based on the use of fish hooks; longlining, trolling and various forms of handlining such as jigging. The general catching principle of hook fishing is to attract the fish to the hook and entice the fish to bite and/or swallow the hook so that the fish becomes hooked and retained.

(a) Handlining and trolling

The catching principle and construction of handlining are shown in Figure 3.

Catching principle

The fish is attracted to the hook by visual stimuli, either natural bait or more commonly in the form of artificial imitations of prey organisms like lures, jigs, rubber worms etc.

Construction

The gear is simple: a nylon monofilament is commonly used as line with one to several hooks at the end with bait or lures.

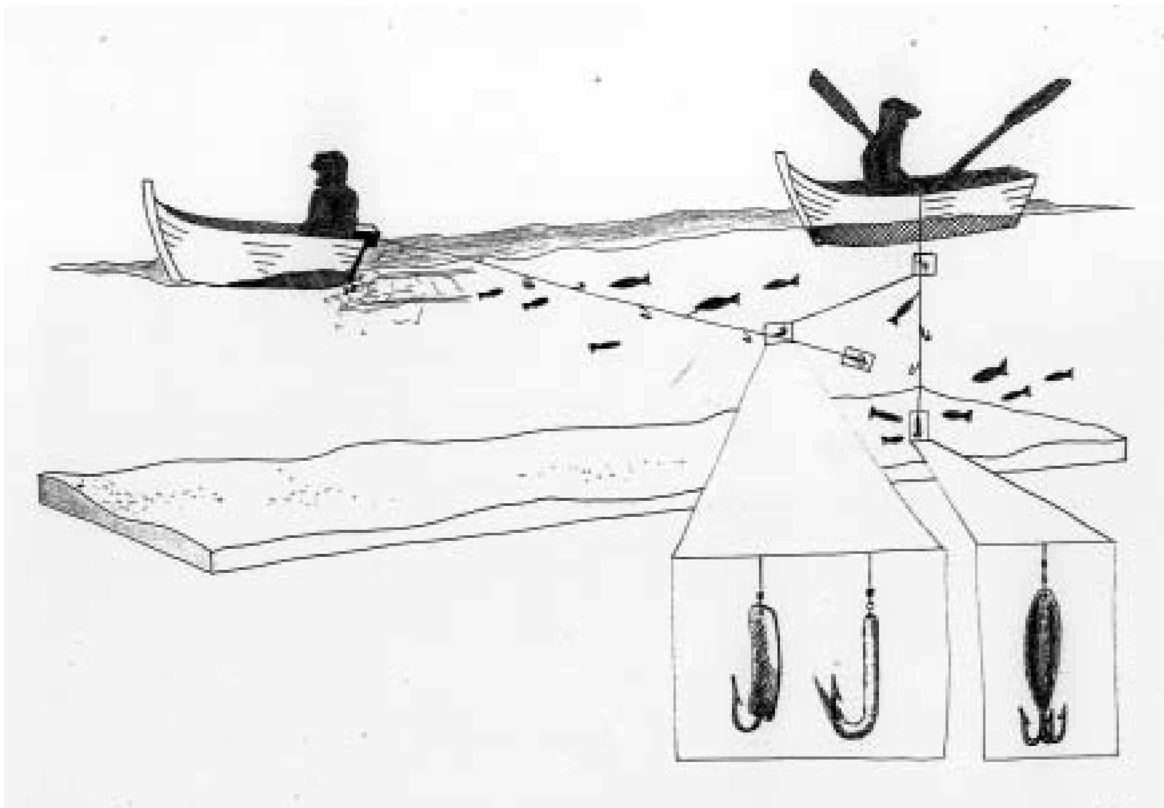

Figure 3. Catching principle and construction of trolling (left) and jigging (right). Expanded view: examples of lures and jig.

Operation

In handlining the fishing line is vertical and is operated from a drifting or anchored vessel. Handlining is also conducted from the shore, with and without the use of a pole. From using only a single line, the operation can be scaled up by using several lines on larger vessels. In recent years jigging has become mechanised and automated by the development of jigging machines.

Hook and line can also be used in trolling where the fishing line is towed behind the moving vessel. Semi-automation has also been developed in trolling where power reels are often used for hauling the lines. Trolling is considered to be a separate type of fishing gear from handlining in the International Standard Statistical Classification of Fishing Gear (Nédélec and Prado, 1990).

Target species

Typical target species with handlining are demersal fishes like cod and snapper as well as squid. Trolling is mainly directed towards pelagic species like mackerel, tuna and salmon.

(b) Longlining

The catching principle and construction of longlines are shown in Figure 4.

Catching principle

Longlining is based on attracting fish by bait attached to the hook. While handlining and trolling generally exploit the visual sense of the fish to attract it to the hook by artificial lures, longlining exploits the chemical sense of the fish. Odour released from the bait triggers the fish to swim towards and ingest the baited hook with a high probability of being caught.

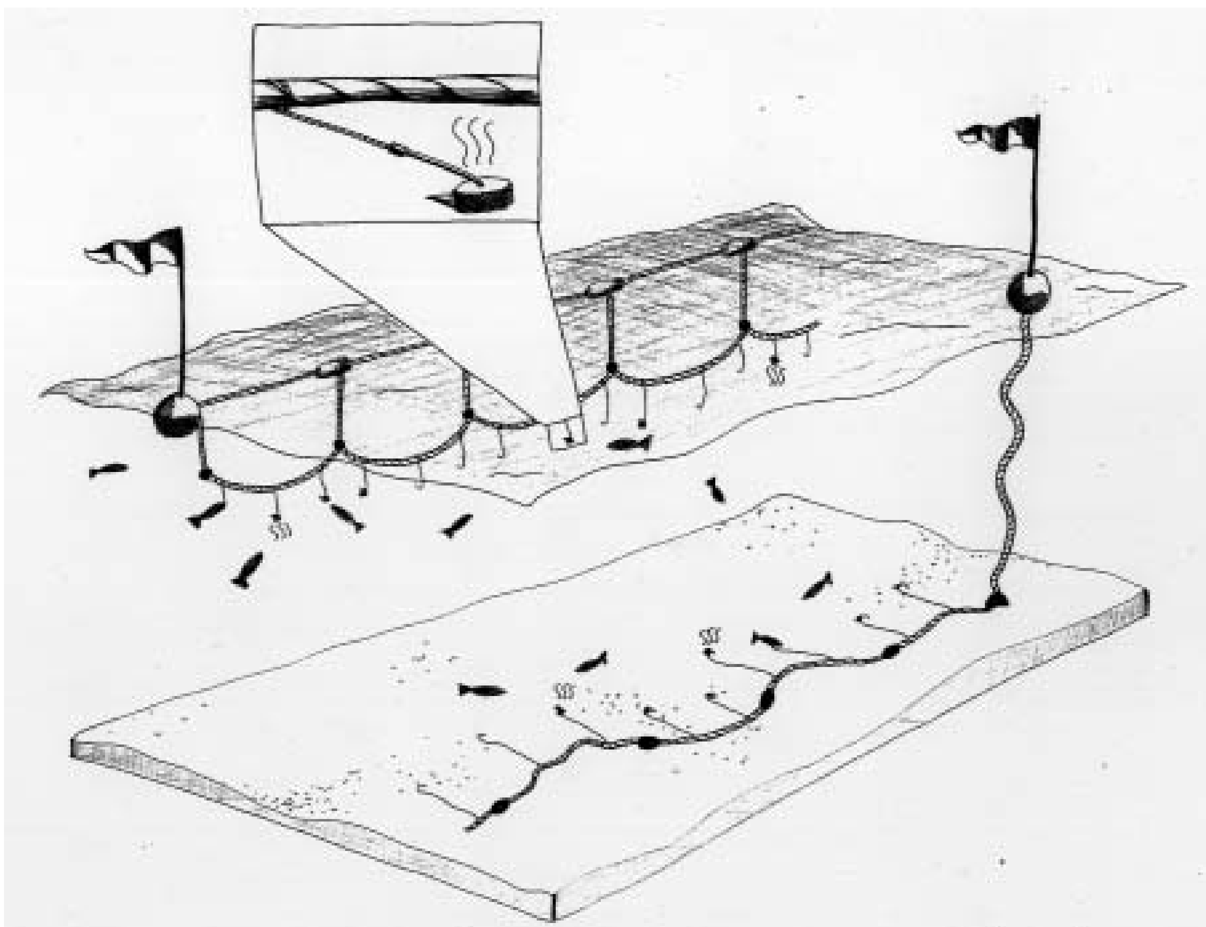

Figure 4. Catching principle and construction of longlines. Pelagic/drift (top) and bottom set (lower). Expanded view: baited hook connected with gangion (snood, branchline) to mainline.

Construction

As the name of the gear indicates, this is a long line (mainline) with baited hooks attached at intervals – connected to the mainline with relatively shorter and thinner leader lines (snoods, gangions). Depending on the type of fishery, there are great variations in the gear parameters, such as thickness and material of main and leader lines, the spacing between hooks, as well as hook and bait types.

Today, main and leader lines are almost exclusively made from synthetic materials like polyamide (nylon) or polyester. Multifilament (rope) is generally used for main and leader lines with demersal longlines (set on the bottom), while monofilament (gut) is commonly used in pelagic longlining. Hook type (size and shape) varies greatly with target species. Naturally, larger hooks and correspondingly stronger main and leader lines are used for larger fish. There is also a great variation in baits used in different longline fisheries, but the major types of bait are either different pelagic fish (e.g. herring, mackerel, sardine, saury) or different species of squid.

Operation

The longline fishing cycle includes the following main operations: baiting (threading a piece of bait on each hook), setting, fishing ("soaking" the line for some hours), retrieval, removal of fish and old bait, gear maintenance, baiting, etc.

As with gillnets, the gear is basically the same in small and large-scale operations with the length of the line and number of hooks increasing with vessel size. Small, open vessels normally fish a few hundred hooks, while the largest longline vessels (LOA 50-60 m) may operate 50-60 km of longline and as many as 40-50 000 hooks per day.

With increased vessel size there is normally an increased degree of mechanised gear handling. Most longline vessels are equipped with power haulers. In so called auto-lining the laborious baiting process is also mechanised with machines that can bait up to four hooks per second as the line is set into the sea.

Target species

Pelagic (drifting) longlines are typically used for catching species like tuna, swordfish and salmon, while bottom set longlines are used for demersal species like snapper, cod, haddock, halibut, ling, tusk, hake and toothfish.

3.3 Pots and traps

Pots are considered within the International Standard Statistical Classification of Fishing Gear to be a type of trap (Nédélec and Prado 1990) but are described separately here because of the differences in catching principle and construction between pots and other forms of trap. The general catching principle of pots (creels) and traps is to entice or lead the target species into a box or compartment from which it is difficult or impossible to escape.

The catching principle and construction of pots and traps are shown in Figure 5.

(a) Pots

Catching principle

As with longlining, pot fishing is normally based on attracting target organisms by bait (chemical stimuli). When attracted to the pot, the target organism must enter the pot to gain access to the bait. This can be done through one or several entrances (funnels) of the pot.

Construction

Typical pot shapes are box, cone, cylinder, sphere or bottle. The size of pots may vary from small crayfish pots (conical: 0.3 m diameter and 0.2 m height) to large king crab pots (box shaped: 2x2x1 m). The pot entrances are usually funnel- or wedge-shaped so that the target organism is led into the pot fairly easily, but with low probability of escaping. Pots may be constructed from various materials like wood, palm leaves, metal frames lined with webbing, wire mesh or plastic materials.

Operation

Pots are normally set on the bottom, either as single pots with a buoy line to the surface or in strings of several pots connected to a main line at certain intervals. Pot gear is usually soaked overnight, but longer soak times may be used in certain fisheries. The operation cycle is similar to that of longlining, with baiting, setting, fishing and retrieval. The bait is either freely suspended in the middle of the pot, or put in perforated bait containers to prevent it from being eaten by scavengers. As in longlining, different pelagic species like sardines, herring and mackerel are typically used for pot bait, but most kinds of fish and mussels etc. may be used.

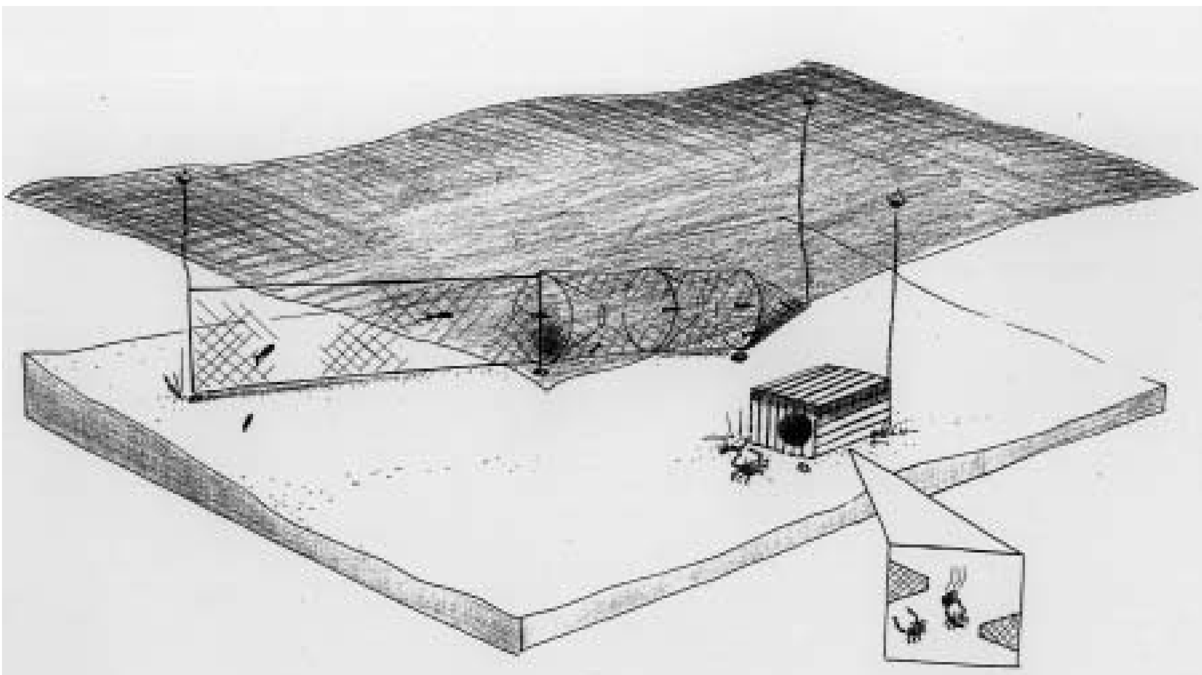

Figure 5. Catching principle and construction of pots (lower) and traps (fyke net - top). Expanded view: schematic illustration of entrances (funnels) and bait.

Target species

Pots are most widely used to catch different crustaceans, like crabs, lobsters and shrimps. Pots are also used for catching different species of finfish like sablefish, tusk and cod in temperate waters and reef fish such as groupers in tropical waters. Other species that are caught with pots are whelks and octopus.

(b) Traps

Catching principle

Traps are normally not baited, but catch fish and other organisms by leading them into the trap, eventually to the fish compartment, that is designed for holding the fish entrapped with low possibility of escaping.

Construction

Compared with pots, traps are usually larger and often more permanent constructions. Tidal traps are based on walls or fences forming V-shaped constructions that entrap fish that have come in with the tide as the tide goes out. Typical salmon and cod traps are cage-like constructions made from webbing with long leader nets to guide the migrating fish into the trap. Tuna may also be caught with traps of this type. The fyke net (Figure 5) is a smaller form of trap, with a leader net connected to the trap or "fyke" which usually consists of three compartments with funnels leading from the outer to the middle and finally to the inner compartment or "fish bag".

In tidal traps the fish are confined sideways by the leader walls, above by the sea surface and below by the sea bed. In floating fish traps like those used for cod and salmon, the fish are confined by side and bottom net panels while the sea surface serves as the top confinement. Fyke nets are set under the surface and thus the fyke (trap) has to be completely lined with webbing to confine the fish.

Operation

Tidal traps are usually permanent constructions where the fish compartment is emptied at low tide. Cod and salmon type traps are usually set out for the season and operated for one to a few months, emptying the fish compartment on a daily basis. Fyke nets are operated like pots, set one by one in the littoral zone, from one to ten meters depth, and are usually moved to another spot after retrieval, usually on a daily basis.

Target species

A variety of target species are caught by tidal traps, both finfish and crustaceans, e.g. shrimps, naturally dominated by species living in the tidal zone. As mentioned above, traps are traditionally used for catching cod and salmon (N. Atlantic), tuna (Mediterranean), small pelagic species in Far East Asia, some species of weakfish (members of the Sciaenidae) and others. Fyke nets are used for catching various species, but are particularly used for eel and cod.

4. ACTIVE FISHING GEARS

Fish capture by active gears is based on the aimed chase of the target species and combined with different ways of catching it.

4.1 Spears and harpoons

This is one of the most ancient ways of active fish capture.

The catching principle and construction of spears and harpoons are shown in Figure 6.

Catching principle

Capture with spears and harpoons depends on visual observation of the target species, which is then impaled by the spear or harpoon from a relatively short distance.

Construction

Basically, the spear or harpoon is designed for easy penetration of the target organism, but the spear head is equipped with barbs or flukes that hold the prey when it is hit. Usually the spear or harpoon is connected to the fisher and boat by a line, so that it can be retrieved, with or without catch.

Operation

Spears and harpoons are most often operated from a vessel, but can also be used from land.

Target species

Common target species with this fishing method are flatfish, swordfish, tunas and whales.

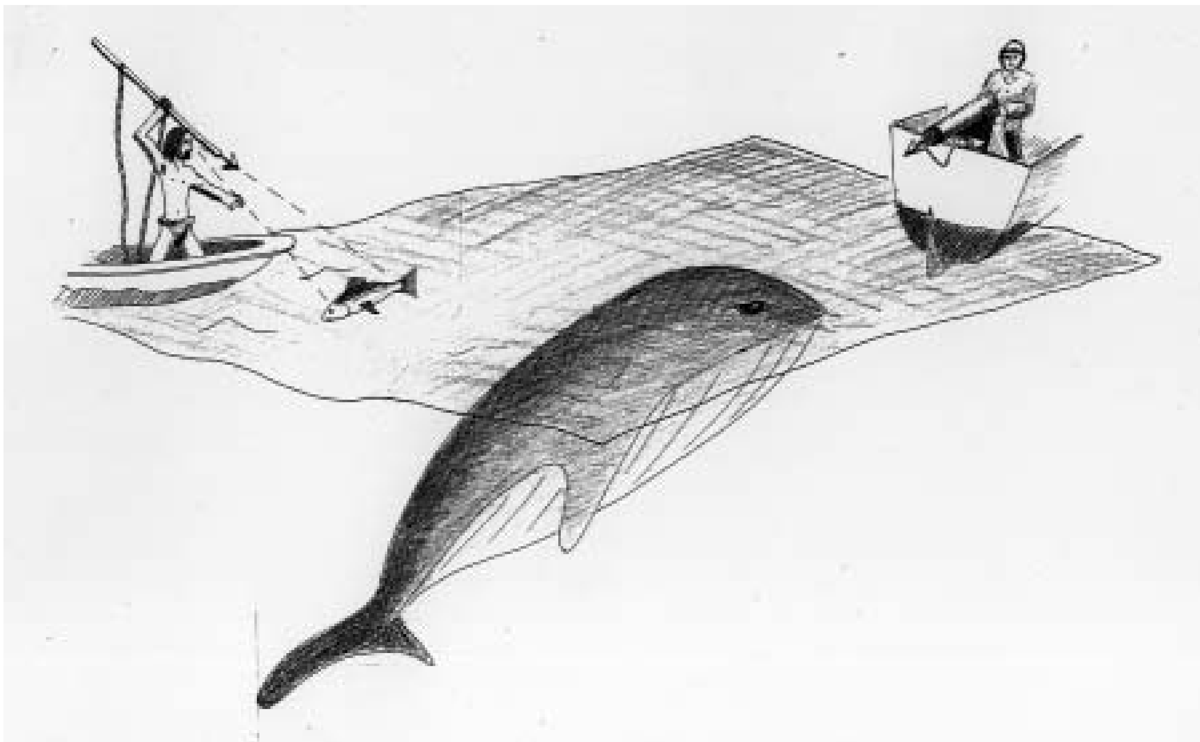

Figure 6. Catching principle and construction of spears and harpoons

4.2 Trawls and dredges

Trawls and dredges are often called towed gear or dragged gear.

Catching principle

The catching principle and construction of trawls are shown in Figure 7.

Construction

Trawls and dredges are in principle netting bags that are towed through the water to catch different target species in their path. During fishing, the trawl entrance or trawl opening must be kept open. With beam trawls and dredges this is done by mounting the trawl bag on a rigid frame or beam. With otter trawls the opening is maintained by so-called otter boards (trawl doors) in front of the trawl which keep the trawl open sideways while the vertical opening is maintained by weights on the lower part (ground-rope) and floats on the upper part (headline). With pair trawling, the vertical opening is also maintained by weights and floats, while the lateral opening is maintained by the distance between the two vessels that are towing the trawl. In otter trawling, the trawl is connected to the trawl boards by a pair of sweeps (rope or steel wire) and the trawl doors are connected to the vessel by a pair of warps (normally steel wire). In otter trawling and partially in pair trawling, the sweeps and warps are also part of the catching system, as they will herd fish towards the centre of the trawl path and the approaching trawl, so that the trawl may catch fish over a larger area than that of the trawl opening. With beam trawl and dredges there is little or no herding of target species in front of the trawl, so the effective catching area is that of the trawl or dredge opening.

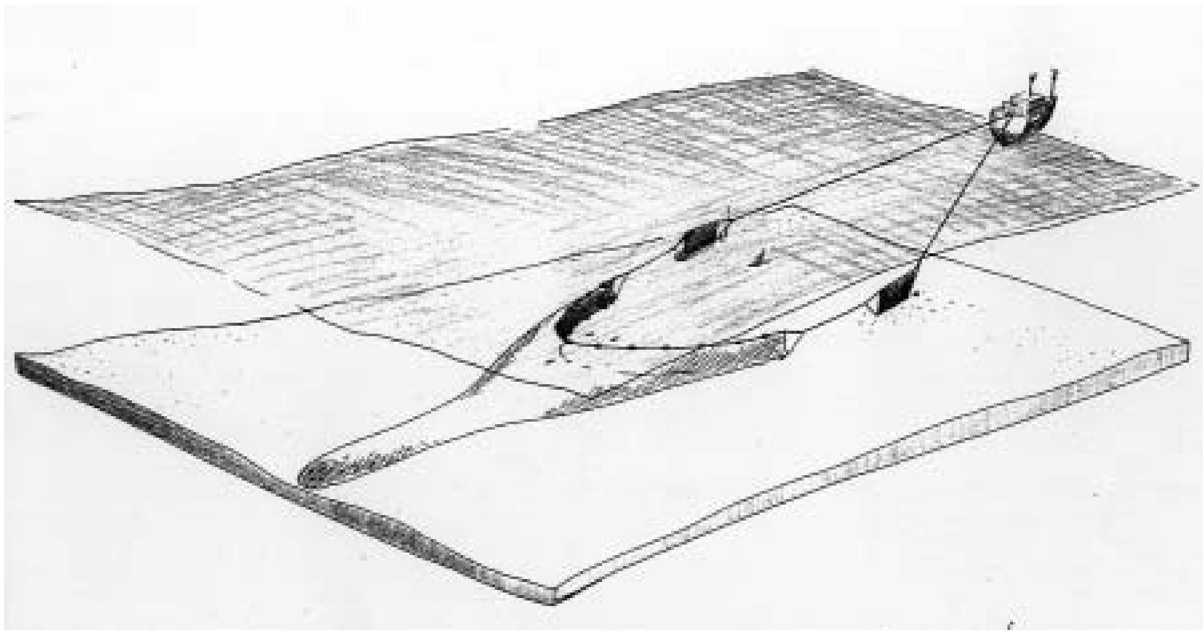

Figure 7. Catching principle and construction of an otter trawl, showing the trawl connected by the sweeps to the trawl doors (otter boards) and the warps between the trawl doors and the vessel.

Operation

Beam trawls and dredges are exclusively operated on the bottom, where they are towed for a certain length of time (towing time) and distance before being retrieved for the emptying of the catch and being set again for another tow.

Otter trawls and pair trawls are most often operated on the bottom to catch different demersal target species. However, these gears are also commonly used for pelagic (or mid-water) trawling at different depths between the surface and the sea bed. This is done by attaching more floats to the head rope of the trawl opening as well as regulating the trawl depth by varying the length of warp and towing speed. In most pelagic trawling, the trawl depth is monitored by depth sensors on the trawl, so that the fishing depth can easily be adjusted to that of the fish targets.

Target species

Beam trawls are mainly used for catching flatfishes such as plaice and sole as well as for different species of shrimp. Dredges are commonly used for harvesting scallops, clams and mussels. Demersal otter and pair trawls are used to catch a great variety of target species like cod, haddock, hake, sandeel, flatfish, weakfish, croakers as well as shrimps. Pelagic trawls are used in the fisheries for various pelagic target species, like herring, mackerel, horse-mackerel, blue whiting and pollock.

4.3 Seine nets

Catching principle

The catching principle and construction of seine nets is shown in Figure 8.

Seine netting (including two variations known as Danish seining and Scottish seining) can be described as a combination of trawling and seining (see below). When setting the gear, the first warp (rope) is attached to an anchor with a surface buoy (Danish seining) or a buoy only (Scottish seining) and set in a semicircle. Then the seine bag is set before paying out the second

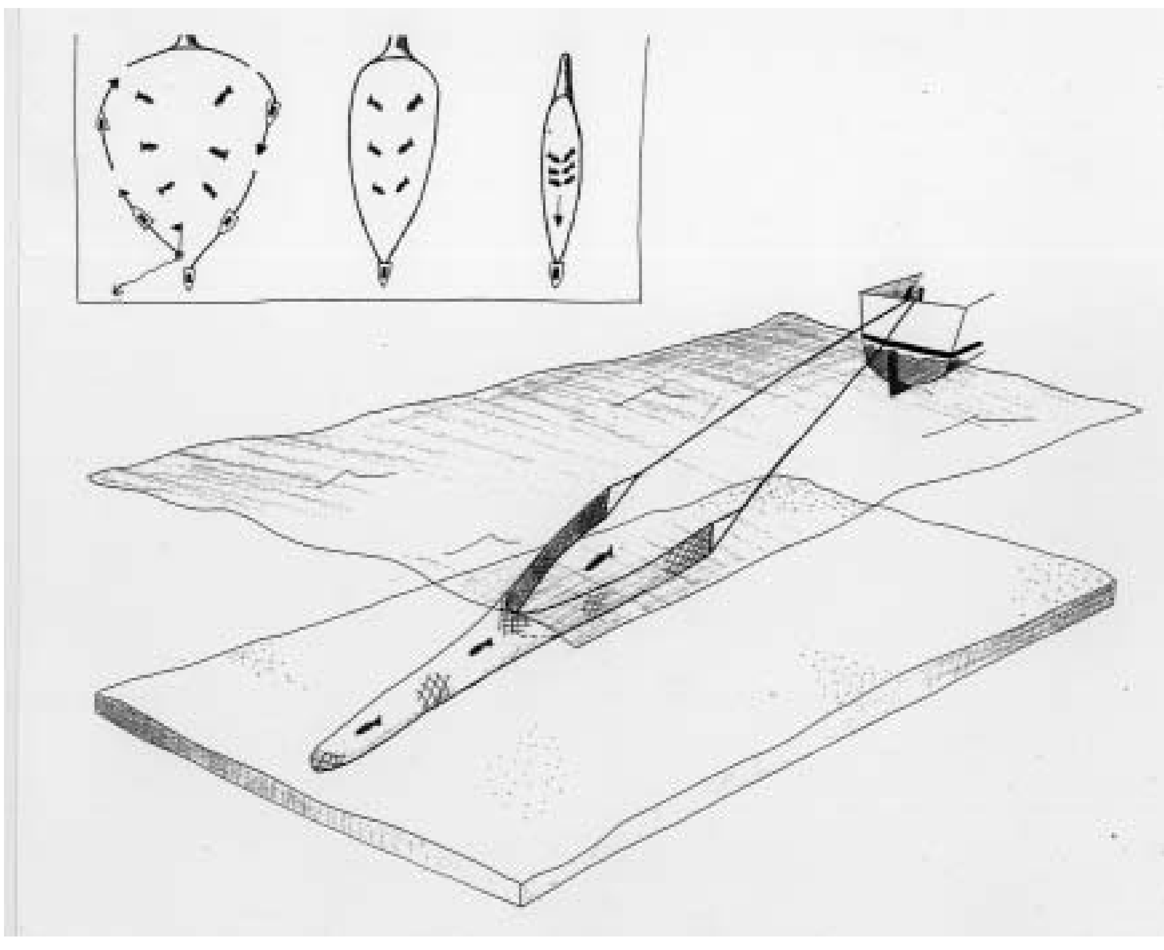

Figure 8. Catching principle and construction of seine nets. Expanded view: three stages of the catching process.

warp in another semicircle back to the buoy (attached to the anchor in Danish seining). When the seine and warps have sunk to the bottom, the warps are hauled. As they are tightened, the warps move inwards towards the centre line between the vessel and the seine bag. Fish in the encircled area will then be herded towards the central part of the area. As the warps are further tightened, the seine bag moves forward and catches the fish .

Construction

As mentioned above, the main parts of a seine net are the seine bag and the warps. The seine bag is similar to a trawl bag, where the entrance is kept open by floats on the headline and a weighted ground line (foot rope). The warps are usually made of heavy rope, so that they maintain good contact with the bottom for as long as possible during tightening in order to herd the fish towards the central area for later capture by the seine bag.

Operation

The seine net was originally constructed for the capture of flatfish on soft and smooth bottoms and operated as described above. In later years this gear has also been developed to be operated on rougher bottoms and in the pelagic zone. A more recent mode of operation is for instance used on mid-water shoals of cod. The fishing depth of the seine net is then determined by large surface floats connected to the head rope of the seine net by lines, the length of which corresponds to the desired fishing depth.

Target species

The seine net is still commonly used to catch different flatfishes such as plaice and sole, but has in recent years become an important gear also for cod and other demersal target species.

4.4 Beach seines

The catching principle and construction of beach seines are shown in Figure 9.

Catching principle:

The operation of beach seines is based on encircling fish schools by a netting wall, made of webbing where the meshes are so small that the target species does not get entangled.

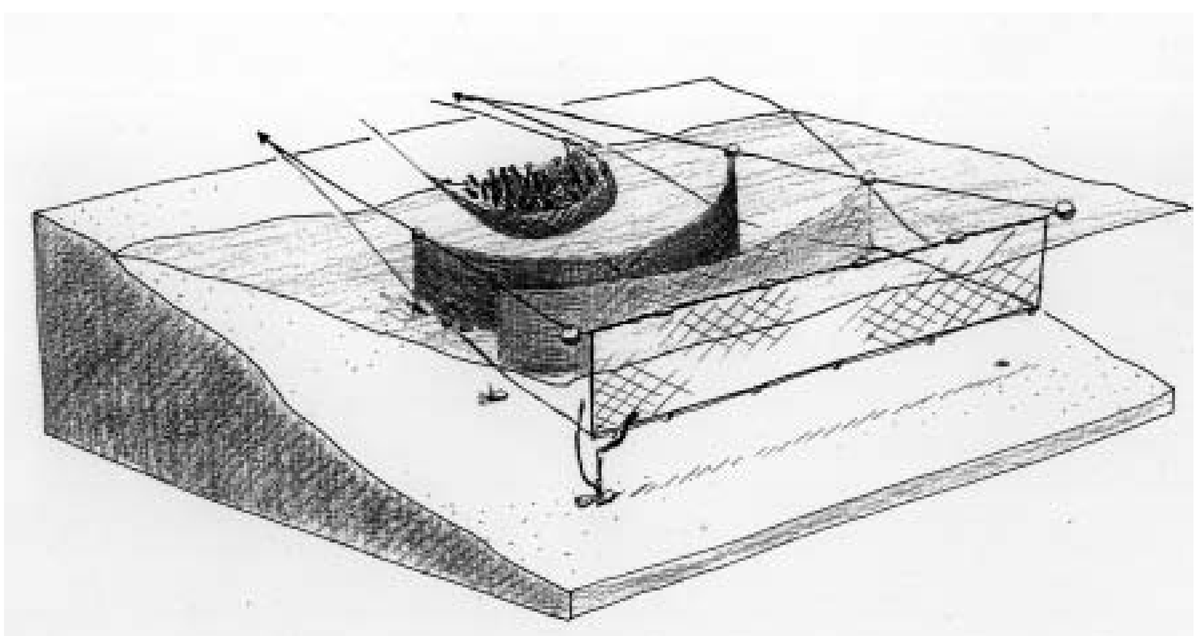

Figure 9. Catching principle and construction of (beach) seines, showing four stages of the catching process.

Construction

The beach seine is an ancient gear that is still widely used. The seine consists of a wall of webbing, e.g. with a depth of 5m by 100m length, with an upper float line and a lower sinker line. In principle a similar construction to the gillnet, but with smaller meshes so that the fish is entrapped instead of being gilled or entangled. At either end of the seine there are long warps (rope).

Operation

As the name indicates, the beach seine is operated from the beach – using the beach as an additional barrier in the catching process. The gear is normally operated from a small vessel. First, one of the end warps is paid out perpendicular to the beach. Then the seine is set parallel to the beach and the second end warp is taken back to the beach. The warps are pulled in so that the seine approaches the beach in a semicircular form – and most of the fish in the area between the seine and the beach are likely to be caught. In many seine fisheries, both beach seine and purse seine, light is used to attract and concentrate fish before the seine is set.

Target species

Beach seines catch a variety of inshore fish species, both demersal and pelagic.

4.5 Purse seines

Catching principle

The purse seine is used to encircle fish schools in mid-water, close to the surface, by a netting wall with small meshes. The lower part of the net is then closed to prevent escapement by diving.

Construction

The purse seine was developed in the 20th century, for offshore fishing. Basically its construction is similar to that of the beach seine. However, below the sinker line, the purse seine is equipped with a series of metal purse rings spaced at regular intervals. By hauling in the purse line that runs through the purse rings, it is possible to purse and close the bottom part of the seine so that the encircled fish cannot escape.

Operation

The purse seine is always operated from a vessel, varying in size from small coastal purse seiners of 15m in length to large ocean going purse seiners as large as 100m length. When a fish school has been located, the catching operation starts by dropping a surface buoy with a line connected to the end of the seine. As the vessel moves forward, the drag from the buoy line will pull the purse seine overboard and the seine is paid out in a circle around the fish school. When the setting is completed, the buoy is picked up, and the purse line is pulled in to purse and close the bottom of the seine. Then the seine is pulled in until the fish are concentrated in the last (and often reinforced) part of the seine, from where it is taken on board with a brailer (large dip net) or by a fish pump.

In modern purse seine fisheries, hydro-acoustic equipment (sonar) is widely used for locating fish schools and also for monitoring the position of the school relative to the gear during the setting of the seine.

Target species

Purse seine fishing is used almost exclusively for pelagic fish like herrings, sardines, sardinellas, anchovies, mackerels and tunas.

4.6 Other fishing gears and devices

The most common fishing gears and methods are briefly described above. There are , however a great variety of different gears which are specialized varieties of the main gear types and methods. For more details or description of gears that falls beyond the scope of this manual, it is recommended to use some of the more comprehensive works on fishing gears and methods cited under Section 7 "Recommended Reading". Some devices and techniques are, however, used with different fishing gears to improve the catch efficiency:

Light is used to attract fish in many fisheries, but is most often used with purse seining, beach seining or other varieties of seine fishing. In darkness the light will either attract the target species directly or indirectly by attracting and illuminating prey organisms. The light source is often lamps mounted on a vessel or small raft. After some time the net is set around the light source with the attracted fish.

FADs (fish aggregating devices) are also commonly used in some areas to aggregate fish. These can consist of anchored rafts of logs or other material and act as artificial habitats that will attract fish and other organisms over time and hence create good fishing spots that can be exploited by different gears. This is also the case with artificial reefs that either are made by shipwrecks or by deliberately dumping objects on otherwise flat and sandy sea beds to create fish habitats. The Code of Conduct (Paragraphs 8.11.1 – 8.11.4) encourages the use of such structures providing they are used in a responsible manner.

Different stupefying devices are also used to capture fish. Explosives (dynamite) will stupefy fish, some of which will float to the surface so that they can be picked up. The use of explosives with fishing is, however, regarded as a very destructive practise as the explosion most often kills much more fish than those that are caught – and can in addition ruin valuable fish habitats like coral reefs.

Different chemicals can also be used in the same way. Rotenone (a poison derived from plants) is one of the best known examples used to stupefy fish, mainly in fresh water systems. As with explosives, the use of chemicals gives a high risk of killing much more fish and other organisms than those that are harvested. The use of chemicals with fishing should therefore be considered as not responsible.

The Code of Conduct (Paragraph 8.4.2) specifically calls for the prohibition of "dynamiting, poisoning and other comparable destructive fishing practices".

5. GEAR SELECTIVITY AND ECOSYSTEM EFFECTS OF FISHING

Before commenting on the selectivity properties and ecosystem effects of different fishing gears it may be useful to give a brief description of relevant factors and definitions.

The catching process

The catching process starts as the fishing gear is deployed in the water and ends as it is retrieved from the water, be it ashore or on the deck of a fishing vessel. Throughout the catching process there may be encounters between the gear and various fish and other marine organisms, including sea birds, and bottom habitats.

Ecosystem effects of fishing

The effect of fishing on the ecosystem is primarily the removal of the organisms caught in the fishery, but also includes the direct and indirect effects caused by the gear during the catching process – like destruction of bottom habitats (e.g. corals), "ghost fishing" by lost fishing gears, pollution etc.

Selectivity

The selectivity of a certain fishing method depends on its ability to select the desired ("target") species and sizes of fish from the variety of organisms present in the area where the fishery is conducted.

The total selectivity of a fishing method is the combined result of the inherent selective properties of the fishing gear and the way it is operated. With most fishing gears it is possible to impair or improve the selectivity by changing the gear configuration or the operation. For example, in trawl fishing the catch of small fish can be reduced by increasing the mesh size and/or by the use of sorting devices like sorting grids or large mesh panels that allow for escapement of the smaller fish (See Figure 10). The fisher can also select for target species and sizes by avoiding areas and periods where there is a high probability of catching small fish or otherwise undesired bycatch. The Code of Conduct requires the minimisation of the catch of non-target species and of discards (Paragraph 7.2.2 and Sub-article 8.5).

Bycatch

Bycatch is anything that is caught in the fishing process beyond the species and sizes of the targeted marine organisms. There is a great variety of bycatch species, ranging from sponges and corals to unwanted or unmarketable fish species or sizes, as well as turtles, marine mammals and sea birds. Bycatch can be classified into three main groups: marketable and legal; non-marketable; and/or non-legal. Non-economic bycatches consist of organisms that are non-marketable for the fisher, while non-legal bycatches are sizes or species of marine organisms that are protected by regulations.

Thus, marketable and legal bycatch is welcomed by the fisher, while all other bycatch should be avoided. However, the capture of some bycatch is normally unavoidable. Most fisheries regulations do therefore allow for a certain amount of bycatch, e.g. a certain percentage of undersized catch of a target species or a certain amount of an otherwise protected species. For example, in the New Zealand trawl fishery for squid, a certain number of sea lions are tolerated as bycatch, but the fishery is closed as soon as this number is reached for the specific fishing season. In the Barents Sea cod fishery, a bycatch of 15% (in numbers) of undersized fish (less than 42 cm) is tolerated within the legal frames of the fishing regulations.

Discards

Discarding, which means to throw parts of the catch back into the water is a common practice in most fisheries, although the amount of discard varies significantly between different fisheries. Discards are most often organisms that are not marketable or give a low price compared with the more valued target species. The survival of discarded organisms depends on the ability to survive in air, the time they are kept out of the water and how they are handled before being discarded. However, it should be expected that most discarded organisms suffer high mortality, which adds a "hidden mortality" to the fishing mortality that is calculated from the landed catch.

Unintentionally, modern fisheries management has encouraged increased discarding in many fisheries. With the introduction of quotas and licences for different species it is often illegal to catch and land certain species of fish. Thus it is not uncommon, particularly in mixed-species fisheries, to find large-scale discarding of valuable, marketable fish (e.g. cod and saithe) because the trip quota or monthly quota has been exceeded. In addition, in some fisheries, small fish under the legal size limit for landings may also be discarded.

"High grading" is another form of discarding where only the most profitable part of the catch is retained, while less valuable fish are discarded. This phenomenon is also often linked to a quota system where the fisher tries to get the maximum value from a limited quota by keeping only the most valuable part of the catch and discarding the rest.

By-mortality

By-mortality is the mortality of marine organisms from injures caused by encounter with the fishing gear during the fishing process. One example is fish that die from infections or osmotic imbalance caused by scale loss after escapement through trawl or gillnet meshes. The introduction of mesh size regulations e.g. in trawls should therefore take into account, and be accompanied by studies of, the survival of fish that are released through trawl meshes or sorting devices. If the released fish suffer high mortality there is little to be gained by sorting it out of the fishing gear, which is the case with vulnerable species like herring. On the other hand, studies have shown that cod and several other demersal species have high survival rate after escapement from or encounter with fishing gear.

Ghost fishing

The term "ghost fishing" is used to describe the capture of marine organisms by lost or abandoned fishing gear. This is particularly a problem with gillnets, trammel nets and pots. The gear is usually lost because it becomes stuck on rough bottoms containing corals and stones, causing the buoy line to break during retrieval. Nets or pots may then continue to fish for years. Captured fish and crustaceans will die and serve as attracting bait for more fish and other organisms. Ghost fishing may therefore represent a serious problem in many areas, causing "hidden fishing mortality" over a long period of time. Paragraphs 7.2.2 and 8.4.6 of the Code of Conduct draw attention to the need to minimise ghost fishing.

Habitat effects

Destruction of bottom habitats is particularly a problem with the use of dragged demersal gear like beam trawls, otter trawls and dredges. Corals and other epifauna have been and may be destroyed over large areas. It is still debated as to whether these gears have any real negative effect on soft, sandy bottoms. However, it has been documented that trawling has ruined large areas of coral, which has a very low recovery rate, and other epifaunal organisms. Here, the Code of Conduct calls for the development and use of environmentally safe fishing gear (Paragraph 7.2.2).

Catch quality

Properties of fishing gears and the way in which they are operated also affect the quality of the catch, thus having an indirect ecosystem effect by the misuse of natural resources. In gillnet fishing, poor quality results from too long a soak time. This results in fish dying in the nets and either rotting or becoming damaged by scavengers; therefore, that part of the catch is not marketable and has to be discarded. This may also be a problem in longline and pot fishing. In trawling, particularly with large catches, it is not uncommon that part of the catch is ruined by squeezing in the trawl bag or becomes of inferior quality because of too long storage on deck before it is processed. This too is contrary to the requirements of the Code of Conduct (Paragraph 8.4.4).

Energy efficiency

Use of energy, particularly fossil fuel, is also an ecosystem related aspect of fisheries. The energy efficiency (i.e. fuel consumption per unit of landed catch) varies considerably with different fishing gears and methods, from negligible use of fuel to more than 1 litre of fuel per kilogram of landed catch. This is covered in Sub-article 8.6 of the Code of Conduct, calling for energy optimization.

Pollution

Fisheries can contribute to air pollution through emission of combustion gases. The relative pollution effect from different fisheries is closely related to their energy efficiency.

Pollution of water from fisheries is mainly by loss of fishing gear or by deliberately discarding old gear and equipment as well as oil products and chemicals at sea. These two aspects are covered by Sub-articles 8.8 and 8.7 respectively of the Code of Conduct.

5.1 Selectivity properties and ecosystem effects of different fishing methods

The following is a description of the general selectivity properties and ecosystem effects of the different fishing gears and methods mentioned under Sections 3 and 4. For a proper evaluation of the ecosystem effects of fishing, each specific fishery has to be analysed separately, as the selectivity properties and ecosystem effects of a certain fishing method may vary considerably with geographical area, time of year and how the gear is operated.

A few examples are the following.

- Gillnets that are operated in shallow water and are hauled on a daily basis will yield catches of higher quality and with less risk of gear loss and ghost fishing compared with gillnets operated in deep water with a soak time of several days.

- Pelagic gillnets that are fished in the vicinity of sea bird breeding sites may have high bycatches of sea birds in the breeding season, but not in other periods.

- Bycatch of juvenile fish in demersal trawling may vary considerably with the availability of juveniles, the species composition, towing speed and general catch rates.

So even if the intrinsic selective properties and other ecosystem impacts of a certain fishing gear may be regarded as fairly constant, the effects caused by the gear on fish stocks and the rest of the ecosystem may vary with diurnal, seasonal and long term changes in species and size composition of organisms available to the fishing gear and with differences in fishing practice.

(a) Gillnets

In general gillnets are considered to be very size selective, with catches of fish sizes that correspond well to the chosen mesh size. However, due to entangling a small proportion of larger and smaller fish may be taken. The species selectivity of gillnets is not particularly good and as different fish species grow to different sizes, there is always a possibility of catching juveniles of a large species when using small mesh gillnets for a smaller target species. Another negative impact of gillnets is the bycatch of sea birds, marine mammals and turtles. Although little information exists on the real effect of such bycatches on the populations of these organisms, it has generated concerns, particularly for pelagic gillnet fishing.

Information on by-mortality of fish after escapement from gillnets is scarce. However, observations of fish with wounds from gillnet meshes are commonly made in catches by other gears, but the actual mortality rates from such injuries are not known.

Ghost fishing is one of the most criticized aspects of gillnet fishing, and may have severe negative effects, particularly in deep water gillnet fisheries. The energy efficiency of gillnet fishing is generally high with a correspondingly low air pollution effect.

As mentioned above, the catch quality of gillnet caught fish can be high. However, gillnets that are operated with soak times of several days tend to produce catches of inferior quality, as fish caught early in the fishing period may die and start to deteriorate long before the nets are retrieved.

(b) Trammel nets

Compared with gillnets, trammel nets have very poor size selective properties and they will also catch a greater variety of species. The problem of ghost fishing is, however, lower as trammel nets generally are operated in shallow water with less risk of gear loss, but ghost fishing problems should nevertheless be anticipated due to loss of trammel nets that get stuck on rough bottoms like coral reefs.

(c) Handlining and trolling

Handlining and trolling are not particularly size selective and in principle not very species selective either. However, these gears are commonly used in specific seasons or at specific grounds where the fishers, by experience, are able to catch only one or a few species, so that the catches are usually dominated by a few targeted species. Otherwise, handlining and trolling are generally regarded as ecosystem-friendly ways of fishing which produce catches of high quality.

(d) Longlining

Despite the fact that longlines may attract and catch a large variety of fish species and sizes, this gear is considered to have medium to good species and size selective properties. The species selectivity of longlines can clearly be affected by the type of bait used, as different species have been shown to have different bait preferences. The size selective properties can partly be regulated by the hook and bait size as many studies have shown a correlation between the size of hook and bait and the size of the fish caught. The longline attracts fish from several hundred meters away, and as large fish have a greater swimming and feeding range than smaller fish, this adds to the size selective properties of longlines.

Bycatch of marine mammals is no particular problem with longlining, but there might be significant bycatches of different seabirds, which mainly are caught as they try to catch the baited hooks during the setting of the lines. This problem has been recognised by FAO member States, leading to the development of the FAO International Plan of Action (IPOA) for Reducing Incidental

Catch of Seabirds in Longline Fisheries[1]. The IPOA specifies some optional technical and operational measures for reducing the incidental catch of seabirds, including, for example, increasing the sinking rate of baits and the use of bird scaring lines which are towed behind the vessel, above the longline being set.

Little is known about the by-mortality of fish in longline fishing, but fish that are lost during retrieval of longlines do often suffer mortality. Ghost fishing may be regarded as a minor problem with longlining and this gear is not considered to cause significant adverse habitat effects. The energy efficiency of longlining is generally high, with typical energy coefficients from 0,1 to 0,3 (kilogram fuel per kilogram of landed catch), which is in the same range as that of gillnetting.

Longline caught fish are in general of high quality, but as is the case for gillnetting, long soak times may lead to reduced catch quality mainly due to bottom scavengers (sea lice, hagfish) that may attack and eat parts of the hooked fish.

(e) Pots

As with longlines, the species selectivity of pots may be regulated by the bait used. Lobster fishermen do for instance often use "sour" or rotten fish as bait to avoid catching crabs in their lobster pots. As with longlines, the attraction of fish and crustaceans to baited pots tends to attract the larger animals in the fished area. The size selectivity of pots may be further improved by the use of so called escape gaps, the size of which allows for escapement of smaller animals. By-mortality is not regarded as a problem with pot fishing and this gear has negligible effect on bottom habitats. There is, however, a certain risk of ghost fishing, as lost pots may continue to fish long after they are lost. This can be reduced by having certain parts of the pot made from a bio-degradable material. Furthermore, pot fishing is regarded to have a high energy efficiency and good to superior catch quality, as the catch normally remains alive and in good condition.

(f) Traps

Traps are usually constructed of relatively fine meshed webbing to avoid the tangling of fish and other organisms, so their size and species selectivity is generally low. As the caught animals usually stay alive, and as traps are most often operated in shallow water, they allow for easy release and high survival of unwanted catch organisms. With responsible fishing practices, the actual selectivity properties of traps may therefore be good and the by-mortality is low. Traps in general have little adverse impact on bottom habitats , they do not create ghost fishing problems and the energy efficiency and catch quality of trap fishing are high.

(g) Spears and harpoons

The capture of fish and other animals by spears and harpoons is probably one of the most environmentally friendly fishing methods. As the target is identified before capture, the fisher can be very selective regarding both species and size of prey. Fishing with spear or harpoon may give some by-mortality of wounded animals that escape and, when used in reef areas, the use of spears can lead to damage of coral, but apart from these, there are no substantive adverse effects related to ghost fishing or habitat destruction and the energy efficiency and catch quality is high.

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[1] See http://www.fao.org/fi/ipa/incide.asp for the full text of the Plan of Action.

(h) Pelagic trawls

Pelagic trawls generally have high species selectivity as they are commonly used for catching schooling pelagic fish that tend to occur in single-species aggregations. The size selectivity is poorer as the fish bag of the trawl is usually made from small mesh webbing to avoid meshing by smaller individuals. Successful trials have been done with sorting grids that effectively release the smallest fish (e.g. with trawling for mackerel). However, these have not been applied in practical fishing, as many pelagic fish seem to suffer high mortality after being released from the fishing gear – mainly caused by the loss of scales which easily leads to secondary infections and osmotic imbalance. At present, sorting systems for the release and protection of juvenile pelagic fish is therefore not recommended. By-mortality is hence a minor problem with pelagic trawling and this gear, naturally, does not have any ghost fishing or habitat destructive effects.

The fuel consumption of pelagic trawling can be high, but still the energy efficiency might be relatively good as large catches are often made during short time periods. The catch quality of pelagic trawls is also relatively high, although large catches may give some squeeze and pressure damage to the fish in the trawl.

(i) Demersal trawls

Demersal trawls are used for the capture of a great variety of bottom fish and crustaceans (mainly shrimps and prawns) while dredges are used to harvest molluscs (clams and scallops).

(i1) Fish trawls

Otter trawls are widely used for the capture of different demersal fish species – most often in so-called mixed-species fisheries. The size selectivity may to a certain degree be regulated by the cod-end mesh size. Ideally, a certain mesh size should allow for the release of all fish below a certain size. However, the mesh size selection of trawls may be hampered in many ways. With increasing catch load in the cod-end, the meshes tend to stretch and close, so that the effective mesh size is significantly reduced. Clogging (closing) of meshes by fish getting stuck in them is another common problem that leads to poorer selectivity. The choice of mesh size for a certain target species may not give ideal selection of other species with different growth characteristics, a problem that is related to all mixed-species fisheries.

Considerable research and development effort has been spent in recent years to improve the size and species selectivity of trawl gear. Different solutions have been developed and implemented, like the sorting grid that is now used in many demersal trawl fisheries. Figure 10 illustrates the sorting grid which is now mandatory in the Barents Sea bottom trawl fishery for cod and other demersal species. Most of the juvenile fish will escape through the openings between the metal bars of the grid, while larger fish will be retained.

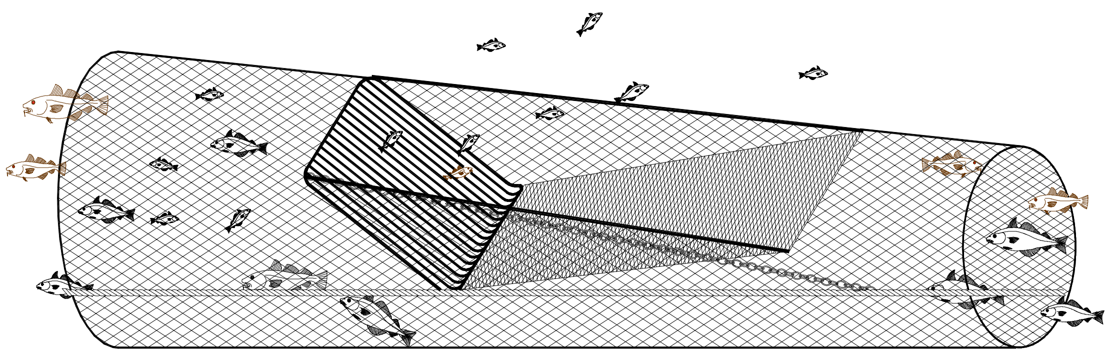

Figure 10. Section of fish trawl with sorting grid. Smaller fish are released through the grid slots, while larger fish swim or are swept down under the grid and go to the cod end.

Where introduced, sorting grids and other selective devices such as larger square mesh panels and escape gaps have lead to improved selectivity of bottom trawls, first of all the size selectivity, but also the species selectivity, although there is still a need for further improvements.

Releasing juvenile fish has little benefit if they do not survive. Extensive studies that have been carried out on demersal target species like cod and haddock have shown very low by-mortality of fish that have escaped through meshes or sorting grids. Although studies of survival after escapement so far have only been done for a restricted number of species, there seems to be a general indication of high survival of demersal fish after encounters with and escapement from fishing gears, when the fish are sorted out and released at fishing depth.

Demersal trawls do inevitably have an effect on bottom habitats. Several studies have been carried out within this field, however, without any general conclusions. On soft and sandy bottoms, there might be an inverse effect on the species composition in an area with a shift towards species that are less dependent on the epifauna removed by trawling. Most studies do, however, indicate that soft bottom habitats will be restored after some years without trawling

On hard bottom, trawling is likely to cause more long lasting or irreversible habitat effects, e.g. by destroying corals that have restoration periods from decades to more than a hundred years. Large areas of coral bed have already been destroyed by bottom trawling, particularly with the development of heavier and stronger trawl gear.

Trawls are occasionally lost, but this gear loss is not associated with any risk of ghost fishing.

The energy efficiency of demersal trawling is low and air pollution from the emission of exhaust gases is correspondingly high due to the high energy needed for pulling the net, doors, sweeps and warps through the water.

The catch quality of trawl caught fish varies with the amount of catch and the towing time. Large catches do often lead to lower catch quality because of the squeezing of the fish in the trawl bag and a longer time before the last part of the catch is processed on board.

(i2) Shrimp trawling

Shrimp trawls are in principle comparable to demersal otter trawls for finfish capture and also have comparable ecosystem effects, except that the selective properties of shrimp trawling are very poor. This is due to the small meshes that have to be used in shrimp trawls in order to retain these relatively small target species. Shrimp trawling does therefore produce relatively large amounts of bycatch and a high proportion of this is discarded. The development of sorting grids has, however, improved the species- and size selectivity in many shrimp trawl fisheries, as most fish over a certain size are released from the trawl through the sorting grid or bycatch reduction device (Figure 11). Bycatch of the youngest fish groups (1-2 year olds) is still a problem, as they have overlapping sizes with those of the shrimps.

Bycatch of turtles during shrimp trawling operations is a problem in some areas but is being widely addressed through the use of Turtle Excluder Devices (TEDs) which operate on similar principles to other bycatch reduction devices.

(i3) Beam trawling

The ecosystem effects of beam trawling are to a large extent comparable to those of demersal otter trawls. Compared with otter trawls, however, beam trawls will generally have a poorer energy efficiency and a stronger impact on bottom habitats.

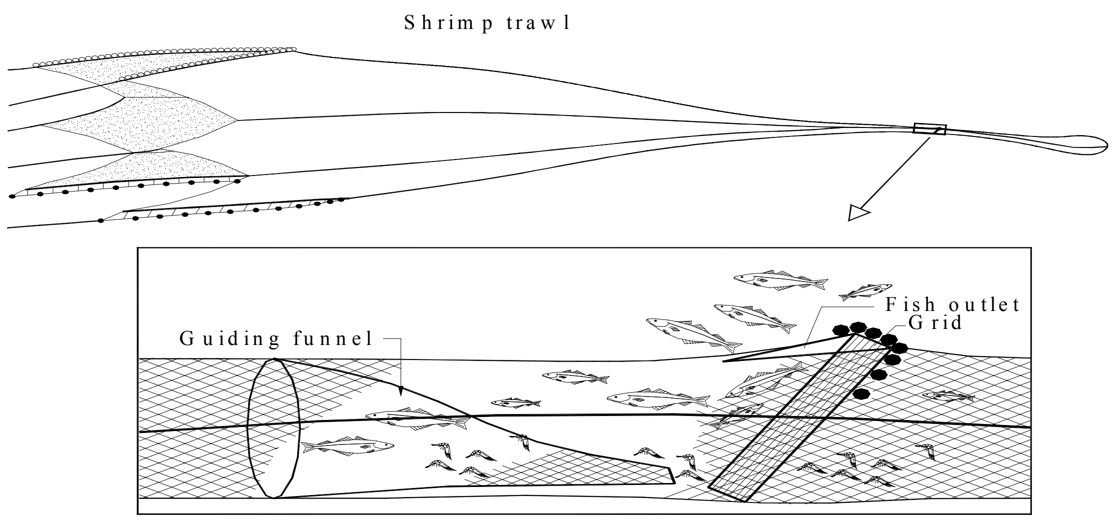

Figure 11. Shrimp trawl with sorting grid (expanded view). Shrimp and fish that pass backwards in the trawl are guided by a funnel to the bottom of the backwards slanting metal grid. Shrimp and fish of comparable size will pass through the slots of the grid and go to the cod end, while larger fish and other organisms (e.g. jellyfish) will slide upwards over the grid and are released through the

(j) Seine nets

Seine netting is also fairly similar to demersal trawling with respect to most ecosystem effects. However, the seine net is considered to cause less habitat destruction, is more energy efficient and does produce a better catch quality overall.

(k) Purse seine

Purse seining is a non-selective gear regarding fish size, as the mesh size is chosen to be so small that there should be no risk of mass meshing of fish, even by the smallest size groups of the target species. However, in cases where the fish size in the catch is too small, as estimated from samples taken from the seine, there is usually an opportunity to release the fish. The species selectivity is fairly high and both from the fishers experience and by use of modern sonar equipment it is not too difficult to identify the species before the seine is set.

There is a certain risk of by-mortality in purse seining. Pelagic fishes are in general sensitive to contact with fishing gears which easily leads to loss of scales and resulting mortality. This can be related to the above-mentioned release of unwanted species or sizes of fish, but the main cause of by-mortality in purse seining is the escapement of fish after net rupture due to large catches and/or bad weather.

There is extremely low risk of ghost fishing with lost purse seines. The energy efficiency is high because of the relatively large catches that give a high catch-per-unit-effort in this fishery. Catch quality is normally also high, particularly in modern purse seining, where the catch is pumped directly into refrigerated tanks on the fishing vessel.

Purse seining has generated some adverse publicity as a result of bycatches of dolphin in some tuna fisheries, but effective methods to avoid such capture have been developed.

(l) Beach seines

Beach seines have poor selectivity properties, catching a variety of species and sizes of fish and other organisms. There may be some by-mortality associated with beach seining, while the energy efficiency and the catch quality of this gear is generally high.

6. MANAGEMENT CONSIDERATIONS: SELECTIVITY AND OTHER ECOSYSTEM EFFECTS OF FISHING

Table 1 gives an example of how the properties of different fishing gears could be evaluated in terms of their selectivity and ecosystem effects. Here the various ecosystem effects are given a rank from 1 (non-favourable) to 10 (favourable), giving an overall index of average ecosystem effect. This table must of course only be regarded as a guideline and an example of how to approach an evaluation of different fishing gears and fisheries from a management point of view. Thereafter the specific fishery in an area should be analysed in more detail and the proposed ecosystem factors should also be weighted according to their importance in a local or regional case. Although a fishing method might be characterised as being more or less responsible in general, attention should be paid to where, when and how it is being used. The evaluation and elaboration of technical regulations should be done in co-operation with the fishers to establish better understanding by them of the aim of the regulations and to hear and consider their advice on the regulations and their implementation (Chapters 7 and 8).

Table 1. Generalized estimate of ecosystem effects of fishing for different fishing methods – ranked on a scale from 1 (non-favourable) to 10 (highly favourable) with respect to different ecosystem related factors.

Ecosystem effects and Gear type	Size selection	Species selection	By-mortality	Ghost fishing	Habitat effects	Energy efficiency	Catch quality	Ecosystem effect index
Gillnets	8	4	5	1	7	8	5	5,4
Trammel nets	2	3	5	3	7	8	5	4,7
Handlining	4	4	6	10	9	9	9	7,3
Longlining	6	5	6	9	8	8	8	7,1
Pots	7	7	9	3	8	8	9	7,3
Traps	5	5	8	8	9	9	9	7,6
Spear, harpoon	8	9	5	10	10	8	9	8,4
Pelagic trawl	4	7	3	9	9	4	8	6,3
Demersal trawl	4	4	6	9	2	2	6	4,7
Beam trawl	4	4	6	9	2	1	6	4,6
Shrimp trawl	1	1	7	9	4	2	6	4,3
Seine net	5	5	6	9	4	5	8	6,0
Purse seine	-	7	5	9	9	8	8	7,7
Beach seine	2	2	5	10	6	9	9	6.1

Other specific factors, for example their socio-economic implications, could be added to a specific evaluation, as a guideline to future management strategies with respect to choice and priorities between different fishing methods. These factors should be included with the information used to assist in the design of management strategies (Chapter 5).

This form of evaluation can also be used to identify present or future ecosystem-related weaknesses with existing fishing methods and practises as a baseline for research and development aiming at improvements of selective properties and undesired ecosystem effects.

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