assigns ownership, and introduces a legal framework of regulation. Once manipulation is embarked on then a precautionary approach should be adopted. This entails adherence to agreed and planned manipulation protocols and the continuing evaluation of potential impacts with contingency plans to either adapt or end the manipulation if adverse impacts are detected. In addition, there are now case studies from around the world that highlight decades of past manipulation research, dozens of species released and many fisheries targeted. In general, there does appear to be a trend emerging, which is that successful manipulation tends only to occur where the species is not migratory on a large scale, is part-contained by habitat availability, and is dependent on relatively low levels of recapture in order to be economically or socially viable. These type of criteria are best represented by low volume, high value fisheries where environmental carrying capacity can be increased. In addition, manipulations that have been undertaken in parallel with habitat enhancement schemes (for example, artificial reefs, nursery ground restoration or protection) have been among the most successful.

See also

Coral Reef and Other Tropical Fisheries. Crustacean Fisheries. Demersal Species Fisheries. Marine Fishery Resources, Global State of. Molluskan Fisheries. Open Ocean Fisheries for Deep Water Species. Open Ocean Fisheries for Large Pelagic Species. Salmon Fisheries: Atlantic. Salmon Fisheries: Pacific. Seabirds and Fisheries Interaction. Small Pelagic Species Fisheries. Southern Ocean Fisheries.

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FISHING METHODS AND FISHING FLEETS

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doi:10.1006/rwos.2001.0446

Introduction

Since the early days of mankind fishing has been an important source of food supply. The means to collect fish and other aquatic animals evolved from very simple tools to the present, often sophisticated, fishing methods. Nevertheless, many of the ancient fishing gears are still in use today, in one form or another. Even if their contribution to the total world catch is negligible, they are often very important for the economy of local communities. The efficiency of a limited number of fishing methods, such as trawling and purse seining, has become very high. Associated with this efficiency and the increased growth of the world fishing fleet are the many problems that fisheries have to face at present. Many aquatic resources, long regarded as unlimited, are now subject to overfishing and the fishing industry is confronted with criticism on the negative environmental impact of some major fishing methods.

This article deals with the technical aspects of fishing in general. It gives a review of the different fishing methods introduced by some considerations about the basic principles of fishing. In a second section the composition and evolution of the world fishing fleet is dealt with. Finally some of the most stringent problems directly associated with fishing operations are briefly discussed.

Basic Principles of Fishing

Fundamentally fishing is based on a limited number of basic principles. The fishing process can be split up into three fundamental subprocesses:

1. attracting or guiding the fish to the fishing gear;
2. fish capture, consisting of collecting and retaining the fish;
3. removing the fish from the water.

To attract or guide the fish to the fishing gear the fish behavior is manipulated, influenced, or controlled. The main mechanisms are frightening and luring. Both aim at directing the fish towards the fishing gear or into an area where the capture can more easily take place. The stimuli to obtain these reactions are diverse. Fish can be frightened by sounds and moving objects through the water. Light, natural and artificial baits, and also electricity are used to attract fish.

The efficiency of fishing operations depends on a thorough knowledge of the natural behavior of the target species. Knowledge of the distribution in time and space is needed to decide where and when the fishing gear has to be deployed. Aggregation of fish at spawning times allows catching large quantities in relatively short times. The schooling behavior of many pelagic species led to the development of large surrounding nets. Pelagic fishes show a strong preference for water layers in a specific temperature range, which is often related to the availability of food. The performance of static gears such as entangling gears and certain traps depend on the encounter of fish and fishing gear and hence on the movement pattern of fish. The latter is often determined by factors such as water flow, foraging, and antipredator behavior. Appropriate stimuli are particularly important in active gears like seines and trawls. The rigging of these gears is adjusted to make optimal use of the response of fish to external stimuli, e.g., to herd the fish towards the entrance of the net.

To realize fish capture four essential mechanisms are used:

1. tangling or enmeshing;
2. trapping;
3. filtering;
4. hooking/spearing.

These mechanisms are easily recognizable in the different fishing methods described below.

Classification of Fishing Methods

A classification of fishing gears permits an overview and better understanding of the numerous fishing gears in use around the world. In such a classification, fishing gears using the same basic principles and techniques to catch fish are brought together in a limited number of larger groups of fishing methods. Fishing gears can also be classified according to their aim (commercial versus recreational fishing), their way of operation (passive versus active), or their scale of application (artisanal versus industrial), but these groups will eventually fall apart into subgroups based on the catching principle. Each main group in the classification contains a number of gear types. They differ in construction and/or in the way they are operated. Further subdivisions can be made when different species, fishing grounds, water depth, etc. require specific adaptations of the basic gear.

A classification of fishing gears is also required for management and statistical purposes. The classification presented here is based on the FAO classification of fishing gears.

Surrounding Nets

Surrounding nets are used for the capture of pelagic fish. The fish are caught by surrounding them both from the sides and from below thus preventing them escaping in any direction. Often lights are used to concentrate the fish in the capture area. Two types of surrounding nets can be distinguished.

Surrounding nets with purse lines or purse seines A purse seine consists of a large wall of netting, up to several thousand meters long and several hundred meters deep, which is set around the fish school (**Figure 1A**). Numerous floats on the

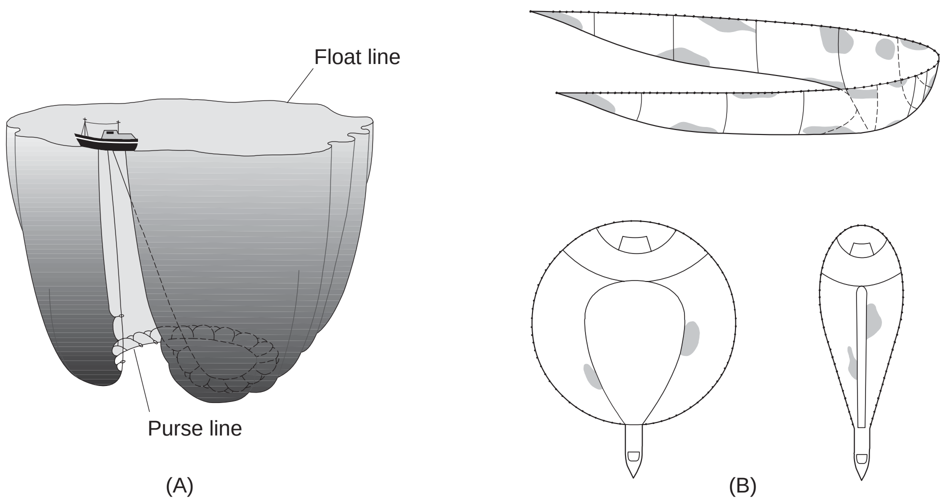

Figure 1 Surrounding nets. (A) Purse seine; (B) lampara net. (Adapted with permission from Nédélec and Prado, 1990.)

floatline keep the net at the surface. A so-called purse line runs through rings attached to the lower side of the net. By hauling the purse line at the end of the encircling procedure the net is closed underneath, preventing the fish from escaping by diving.

When the purse line, the rings and most of the netting is taken onboard the fish is bailed out or pumped on board the purse seiner. The part of the netting keeping the catch, called the bunt, is stronger and has the smallest mesh size.

The nets are operated by one or by two boats. Single boat operation, with or without an auxiliary skiff, is most usual. Purse seining is probably the most important fishing method for catching pelagic fish.

Surrounding nets without purse lines The most representative net in this group is the lampara net (**Figure 1B**). The net is shaped like a dustpan and is provided with two lateral wings. As for the purse seine the net bag or bunt has a smaller mesh size. The typical protruding bottom is obtained by using a weighted groundrope, which is much shorter than the floated upper line. When the wings are simultaneously hauled the lower part of the net closes preventing the fish from escaping underneath.

Seine Nets

Seining is one of the oldest fishing methods known, and is employed at least since the third millenium BC. Seine nets consist of a wall of netting with very long wings to which long towing ropes are connected. More or less in the middle of the net there is a section capable of holding the catch, called the bunt or bag. This can simply be a section of netting with smaller meshes and more slack or a real bag. The gear is set around an area supposed to contain the fish and towed to a predetermined location by means of the two towing ropes, which also have the important function of herding the fish. The net can be hauled to the shore (beach seines) or a vessel (boat seines). Seine nets are also widely used in freshwater fisheries.

Beach seines Beach seines are operated from land in shallow waters (**Figure 2A**). The net is set by a boat or even just a fisherman, enclosing the area by the first towing rope, followed by the first wing, the bunt or bag, the second wing and finally the second towing rope, the end of which normally remains ashore. The net, the bottom and the water surface enclose the fish. The first towing rope is led to the shore again where both ropes are simultaneously hauled.

Boat seines Boat seining in sea fisheries is a much more recent development in which the seine net is operated from a boat. A typical example is the Danish seine or 'snurrevaad' (**Figure 2B**). The seine is set out by a vessel from an anchored buoy to enclose the area to be fished. At the end, the vessel is back at the anchored buoy to start the hauling operation. The two very long seine ropes drive the fish into the net when they are slowly hauled. While hauling, the seiner maintains a fixed position. A variant of the Danish seine is the Scottish seine where the vessel slowly moves forward while hauling the gear.

Trawl Nets

Trawl nets are funnel-shaped nets with two wings of varying length to extend the net opening

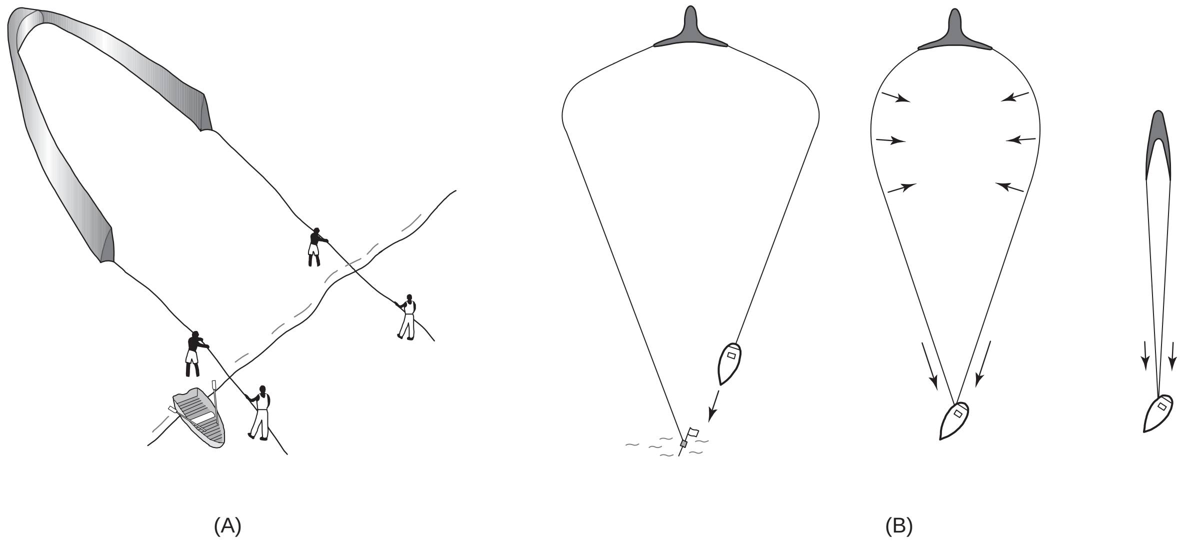

Figure 2 Seine nets. (A) Beach seine; (B) Danish seine. (Adapted with permission from Nédélec and Prado, 1990.)

horizontally and ending in a codend where the catch accumulates. Trawls are towed on the bottom or in the midwater by one or two boats. In certain demersal fisheries two or more nets are towed by one vessel. Modern trawls are among the most-efficient fishing gears.

Bottom trawls Bottom trawls are operated on the seabed. The vertical net opening varies according to the occurrence in the water column of target species. Consequently a distinction is sometimes made between low opening bottom trawls aiming at the capture of demersal species and high opening bottom trawls suitable for the capture of semidemersal or pelagic species.

Beam trawls The net of a beam trawl is kept open horizontally by a beam supported at both ends by two trawl heads (**Figure 3A**). In modern fisheries the beam is made of steel and is up to 12 m long. Relatively light beam trawls are used to catch shrimps. Flatfish beam trawls are equipped with an array of tickler chains to disturb the flatfish from the bottom. Generally two beam trawls are towed at the same time by means of two derrick booms (double rig operation) but a single rig operation, mostly over the stern of the vessel, is also possible.

Bottom otter trawls In these trawls the horizontal opening of the net is obtained by two otter boards, which are pushed sideward by the water pressure (**Figure 3B**). The otter boards are connected to the net by means of wires called bridles. The otter board/bridle system also has the essential function of herding the fish into the path of the trawl.

Bottom pair trawls Two vessels towing the trawl simultaneously assure the horizontal opening of the net (**Figure 3C**). Since there are no otter boards, the warps are connected directly to the bridles.

Otter multiple trawls Otter twin trawls consist of two otter trawls joined in a single rig (**Figure 3D**). The inner wings are attached to a sledge or weight and the outer wing of each trawl is connected to an otter board. The twin trawl principle is also used to tow three or even four nets at the same time. The advantage of multiple trawls is that the same area can be fished with a gear with a lower hydrodynamic resistance than a single net with the same horizontal opening, as the total amount of netting is less in the multiple trawl.

Midwater trawls Midwater or pelagic trawls can be operated at any level in the midwater, including surface water. Midwater trawls are usually much larger than bottom trawls in order to be able to enclose large schools of pelagic fish. To reduce the resistance of these large trawls, very large meshes or ropes are used in the net mouth.

Midwater otter trawls In these the horizontal net opening is controlled by two hydrodynamically shaped otter boards. The vertical opening is assured by weights in front of the lower wings (**Figure 4**).

Again, the combination of otter boards, bridles and large meshes or ropes in the front part of the net herd the fish to the center of the trawl. The depth of the trawl is controlled by changing the length of the warps or the towing speed.

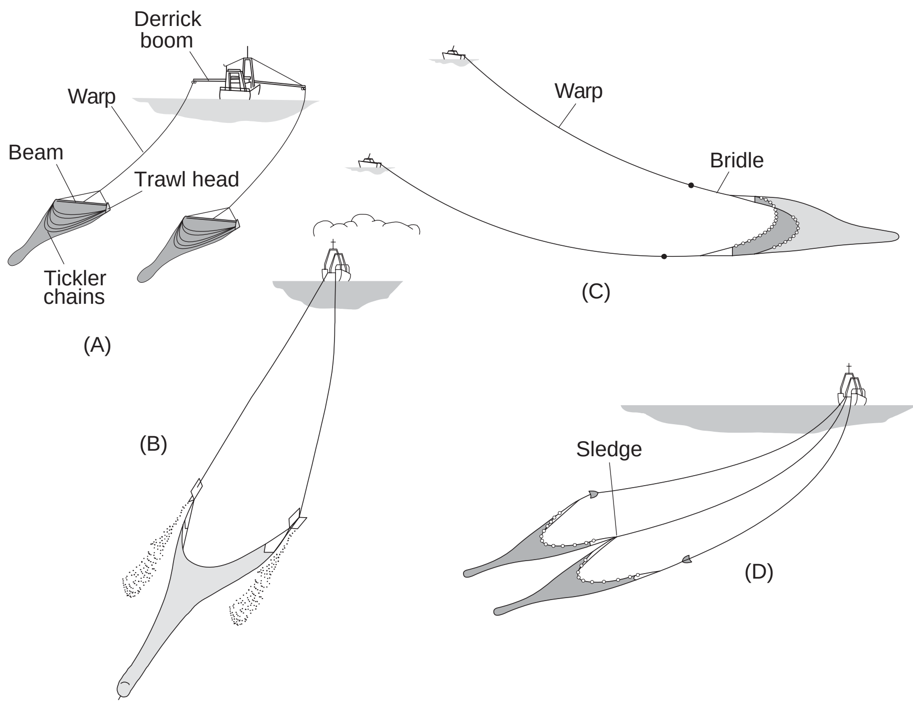

Figure 3 Bottom trawls. (A) Double rig beam trawl; (B) bottom otter trawl; (C) bottom pair trawl; (D) otter twin trawl.

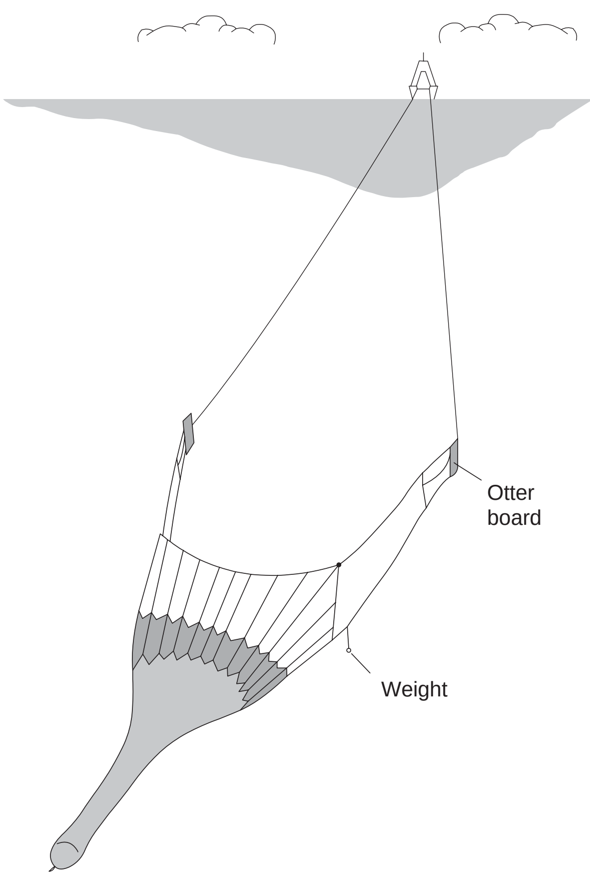

Figure 4 Midwater otter trawl.

Midwater pair trawls In these the net is kept open by two boats towing the trawl simultaneously.

Dredges

Dredges are designed to collect mollusks (mussels, oysters, scallops, clams, etc.) along the bottom. A bag net attached to a fixed frame retains the mollusks but releases water, sand and mud.

Boat dredges These are dredges of varying shape, size, and construction, in general consisting of a metal frame to which a bag net, completely or partly constructed of iron rings, is attached. Often the underside of the frame is provided with a scraper or teeth and the upper side with a depressor to keep the dredge close to or into the seabed (**Figure 5**).

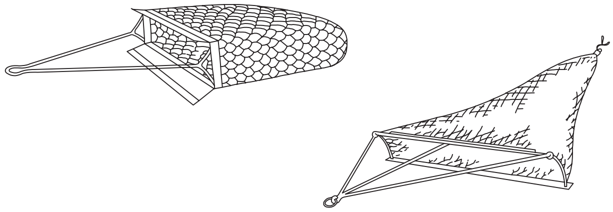

Figure 5 Boat dredges. (Adapted with permission from Nédélec and Prado, 1990.)

Boat dredges are operated in different ways. A vessel can tow one, two, or more dredges, sometimes by means of beams, or vessel and dredge can be towed towards an anchor by means of a winch. To increase the efficiency, especially when the shells are deep in the sediment, high-pressure water jets may be used to dig them out. To handle large catches suction pumps or conveyer belts may be used. These gear systems are usually regarded and classified as 'harvesting gears.'

Hand dredges These dredges are smaller and lighter and are operated by hand in shallow waters.

Lift Nets

In lift nets the gear consists of horizontal or bag-shaped netting with the opening facing upwards, which is kept open by a frame or other stretching device. The net is lowered onto the bottom or at the required depth and the fish above are filtered from the water when the net is lifted. Before lifting, the fish are often first concentrated above the net by the use of light or bait. The nets can be operated by hand or mechanically, from the shore or from a boat.

Portable lift nets These are small, hand-operated lift nets, often used to catch crustaceans.

Boat-operated lift nets Larger lift nets, including the so-called bag nets and blanket nets, are operated from one or more boats (**Figure 6A**). Blanket nets may be very large and the sheet of netting is kept stretched by several vessels or by large, sometimes fixed, constructions.

Shore-operated lift nets These gears are often operated from stationary constructions along the shore (**Figure 6B**).

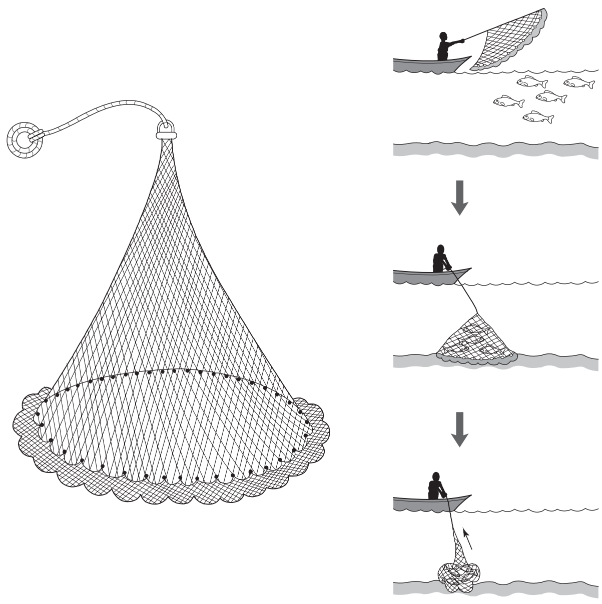

Figure 7 Cast net.

Falling Gear

The principle here is to cover the fish with the gear. Falling gears are usually used in shallow water.

Cast nets These nets are cast over the fish from the shore or a boat. When hauling the net closes from underneath and encloses the fish (**Figure 7**).

Cover pots, lantern nets These simple hand-operated gears are put over the animal that is taken out through the opening at the top. Used by a single person in shallow water.

Gillnets and Entangling Gear

These passive gears consist of very fine netting kept vertically in the water column by a ballasted ground-

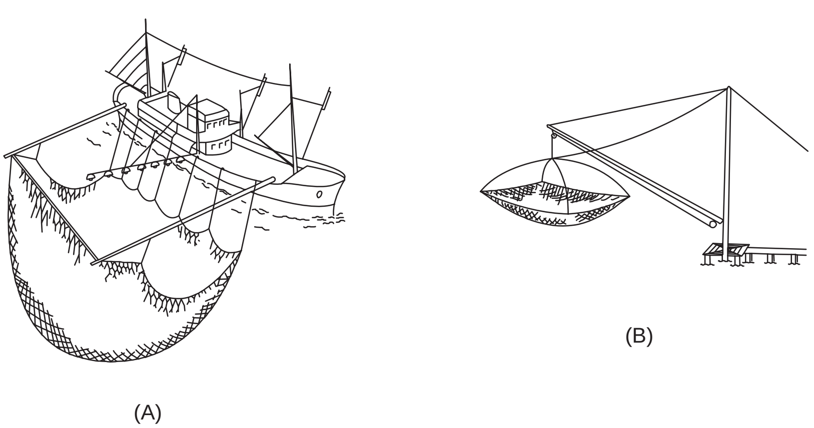

Figure 6 Lift nets. (A) Boat-operated lift net; (B) shore-operated lift net. (Adapted with permission from Nédélec and Prado, 1990.)

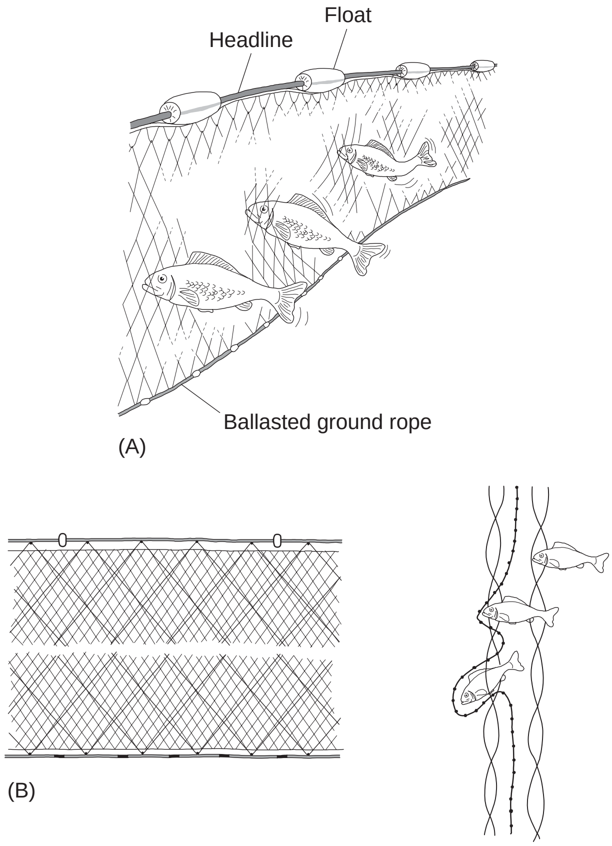

Figure 8 Gillnets and entangling gear. (A) Gillnet; (B) trammel net. (Adapted with permission from Nédélec and Prado, 1990.)

rope and a buoyant headline. The fish are gilled, entangled, or enmeshed in the netting which may be single (gillnets) (**Figure 8A**) or triple (trammel nets) walled (**Figure 8B**).

Sometimes different types of nets are combined. Usually a number of nets are connected to each other thus forming a so-called fleet. Depending on the design and rigging the nets can be used on the seabed, in the midwater, or at the surface.

Set gillnets (**anchored**) These nets are fixed to or near the bottom, usually by means of anchors.

Drifting gillnets These gears are kept near to the surface by means of floats and can freely drift with the currents. Most often they are connected to the drifting boat.

Encircling gillnets These are shallow-water gear operated at the surface. The encircled fish are driven to the nets, by noise or other means, and gill or entangle themselves in the netting.

Fixed gillnets In these the netting is attached to stakes in coastal water and the fish are collected at low tide.

Trammel nets These bottom-set nets consist of three walls of netting (**Figure 8B**). The two outer walls have a larger mesh size than the loosely hung inner wall. The fish can pass through the meshes in the outer walls but are entangled when trying to pass through the inner wall.

Combined gillnets – trammel nets The lower part of these bottom-set nets is a trammel net to catch bottom fish; the upper part is a gillnet to catch semidemersal or pelagic fish.

Traps

These gears are constructions in which the fish can freely enter but are unable to get out again. These gears are very variable in size and operation.

Stationary uncovered pound nets These are usually large netting constructions, anchored or fixed to stakes and open at the surface. They are generally divided into different chambers, closed at the bottom by netting, and provided with leaders (**Figure 9**).

Pots Pots are made from different materials and have one or more entrances (**Figure 10A**). They are usually set on the bottom, often in rows. They are designed to catch fish or crustaceans and are often baited.

Fyke nets These nets consist of a cylindrical or conical-shaped body usually mounted on rings and provided with leaders to guide the fish to the entrance (**Figure 10B**). Fyke nets are used in shallow waters where they are fixed on the bottom by anchors or stakes.

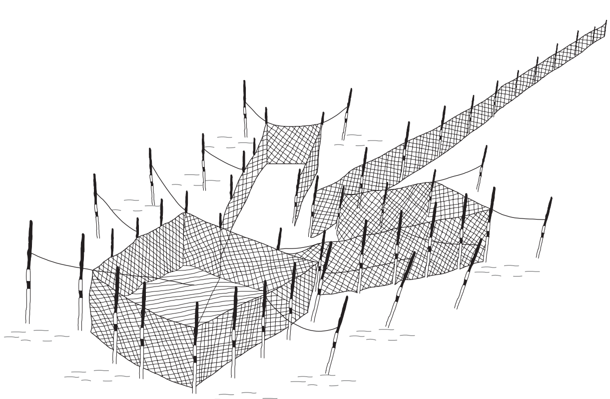

Figure 9 Stationary uncovered pound net. (Adapted with permission from Nédélec and Prado, 1990.)

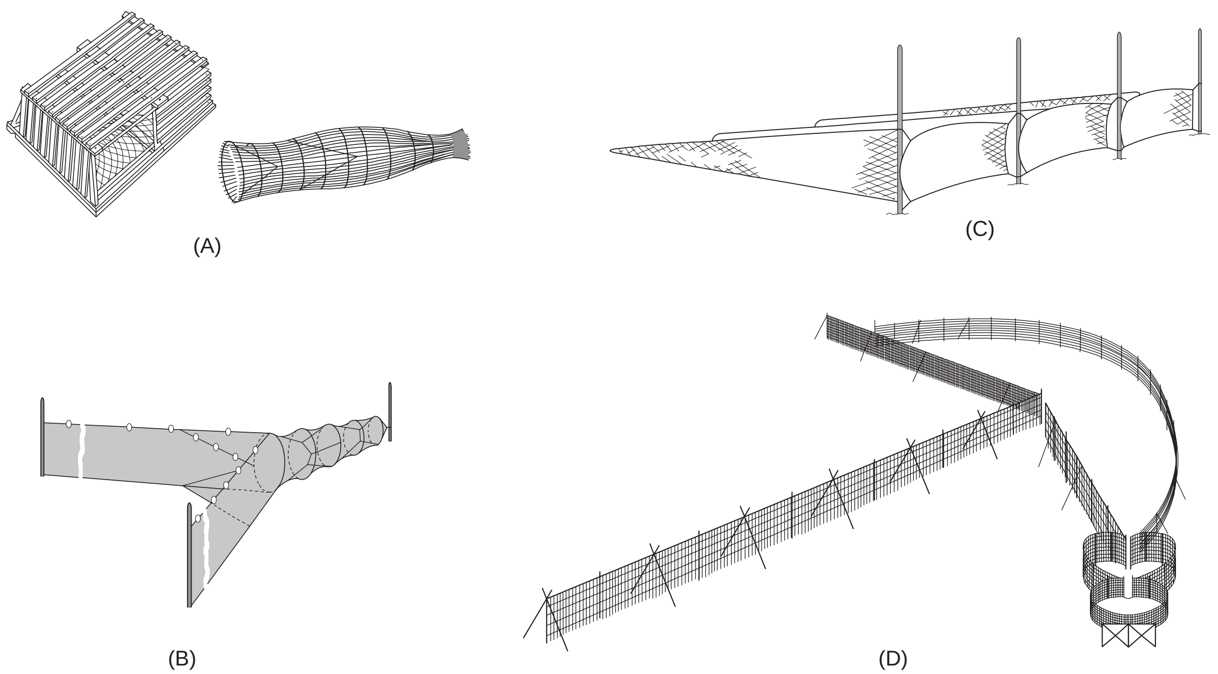

Figure 10 Traps. (A) Pots; (B) fyke net; (C) stow net; (D) corral. (Adapted with permission from Nédélec and Prado, 1990.)

Stow nets These nets are used in waters with strong currents, e.g., rivers (**Figure 10C**). The conical or pyramidal nets are fixed by means of anchors or stakes and can also be deployed from a boat. The net entrance is usually held open by a frame.

Barriers, fences, weirs, corrals, etc These gears are made from a variety of materials and are set up in tidal waters (**Figure 10D**). The fish are collected at low tide.

Aerial traps Jumping and gliding or flying fish can be collected on the surface in horizontal nets (veranda nets) and also in boxes, boats, rafts etc. Sometimes the fish are frightened to jump out of the water.

Hooks and Lines

The fish are attracted by natural or artificial bait attached to a hook at the end of a line, on which they are caught. Hooks can also catch the fish by ripping them when they come near by. A well-known example is the jigging lines for squid. Hooks and lines are used in both commercial and sport fishing.

Handlines and pole-lines (**hand operated**) Handlines may be used with or without a pole or rod, or using reels, mostly in deep waters. This fishing method also includes hand-operated jigging lines.

Handlines. and pole-lines (**mechanized**) Mechanized handlines are operated with powered reels or drums (**Figure 11A**). Tuna are sometimes caught with mechanized pole-lines, i.e., the pole movement is automated.

Set longlines These are bottom longlines, baited or not, set on or near the bottom (**Figure 11B**). They consist of a main line with snoods attached to it at regular intervals. Longlines may be several hundred or even a thousand meters long.

Drifting longlines The very long lines are kept near to the surface or at a certain depth by means of floats and can drift freely with the currents. Drifting longlines can also be set vertically, hanging from a float at the surface.

Trolling lines Trolling lines are lines with natural or artificial bait that are towed near the surface or at a certain depth. The towing vessel is usually provided with outriggers to tow several lines at the same time (**Figure 11C**).

Grappling and Wounding Gear

This group contains gear for killing, wounding or grappling fish or mollusks. Examples are harpoons, spears, arrows, tongs, clamps, etc.

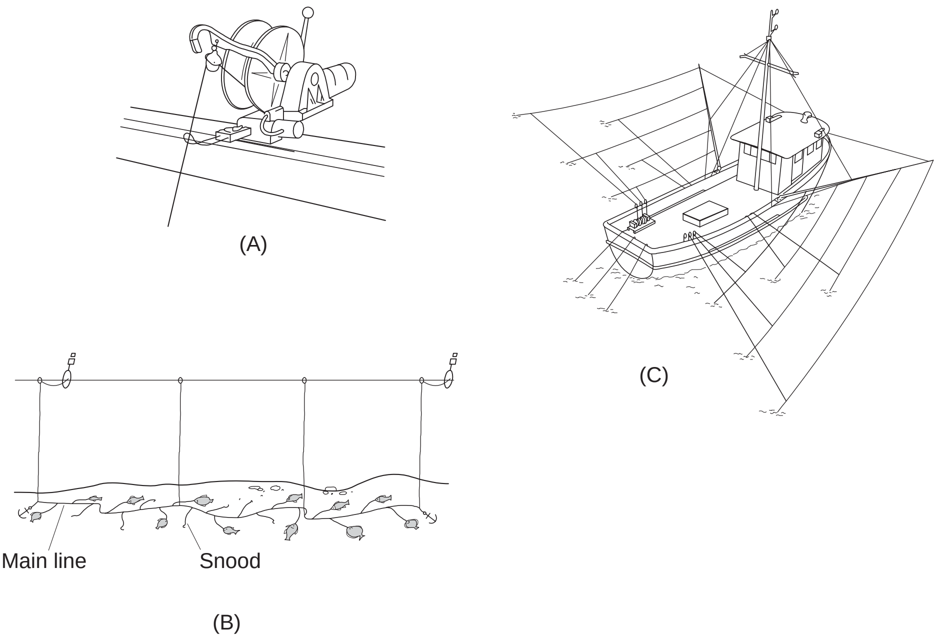

Figure 11 Hooks and lines. (A) Mechanized handlines (adapted with permission from Nédélec, 1982); (B) set longline; (C) trolling line. (Adapted with permission from FAO, 1985.)

Harvesting Gear

Modern and very efficient gears are used to extract fish or mollusks directly from the sea by pumping or forced sifting.

Pumps With these the fish, usually attracted by light, are directly pumped on board.

Mechanized dredges Mechanized dredges use strong water jets to dig out mollusks. The mollusks are then transferred to the boat carrying the dredge by a conveyor belt-type device or by suction (**Figure 12**).

Miscellaneous

A great variety of fishing methods have no place under the gear categories described so far. The most important of these are:

- gathering by hand or with simple tools;
- scoop nets and landing nets;
- poisons and explosives;
- trained animals;
- electrical fishing.

Fishing Fleets

In 1995 the FAO estimated the number of vessels in the world fishing fleet at 3.8 million. Only one-third of these vessels is decked and the remaining are generally less than 10 m in length. Also only one-third of the undecked vessels is equipped with an engine. The number of undecked fishing vessels and the total tonnage of decked fishing vessels increased in the 1970s and 1980s (**Figures 13** and **14**). This increase was mainly due to the growth in Asia. Since the end of the 1980s the expansion rate of both decked and undecked vessels has slowed down.

Only 1% of the decked vessels is larger than 100 gross tonnage (GT), equivalent to about 24 m. This category of vessels is capable of fishing beyond the

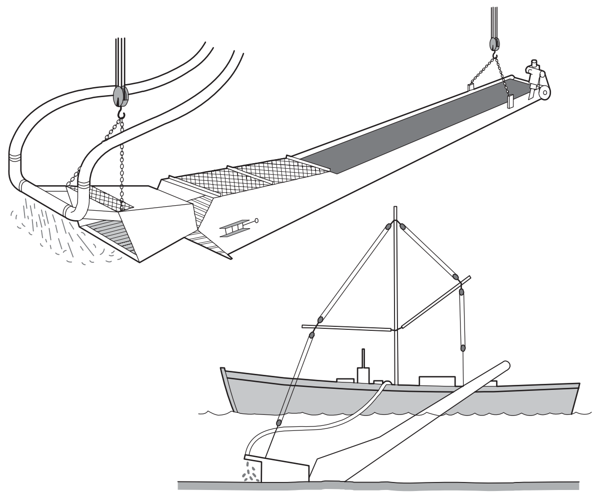

Figure 12 Mechanized dredge. (Adapted with permission from Nédélec and Prado, 1990.)

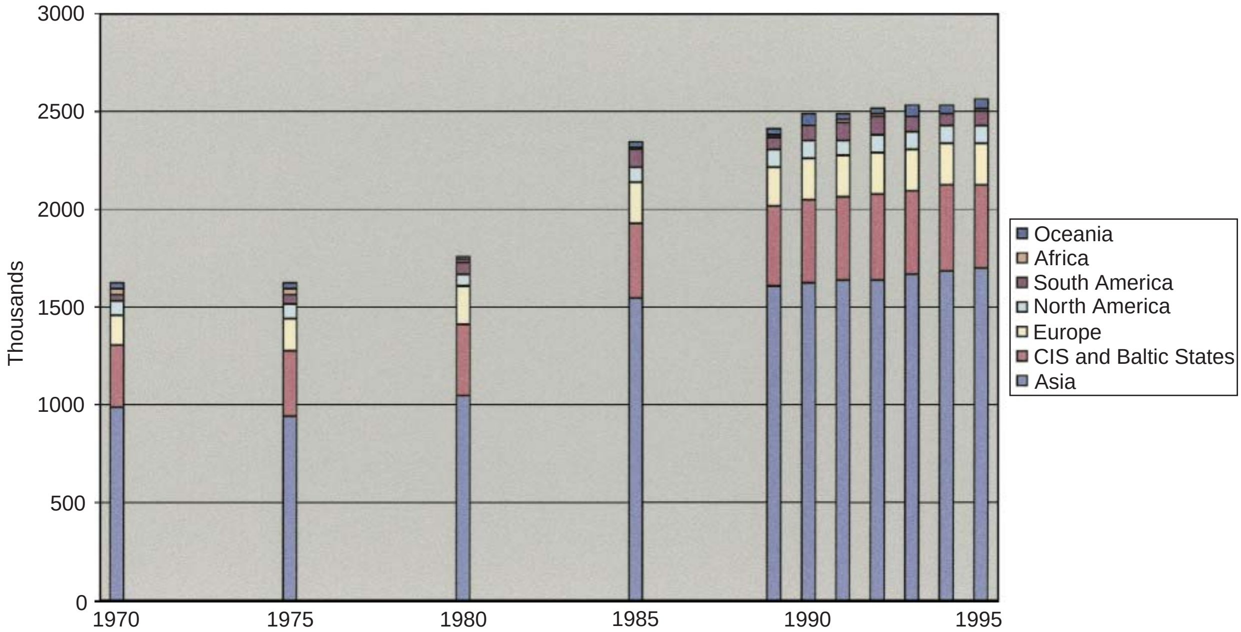

Figure 13 Number of undecked vessels by continent. (Adapted with permission from FAO, 1999.)

200 nautical mile exclusive economic zone (EEZ) limits, although the majority operate on the continental shelf within the EEZ of their own flag state. An analysis of vessels of 100 gross registered tonnage (GRT) or more in the databank of Lloyd's Maritime Information Services (MLIS) showed that the world industrial fishing fleet grew until 1991, with nearly 26 000 vessels, and has declined since to 22 700 in 1997. The Lloyds database, however, contains only 1% of the Chinese fleet. The Chinese fleet has continued to increase, from about 3000 vessels in 1985 to about 15 000 in 1995. With regard to the vessels over 100 tonnes, China accounts for around 40% of the world's fishing fleet. The Chinese vessels, however, are of low horsepower and hence have a lower fishing capacity. The general decline indicated by the Lloyds database is more or less compensated by the growth of the Chinese fleet. As

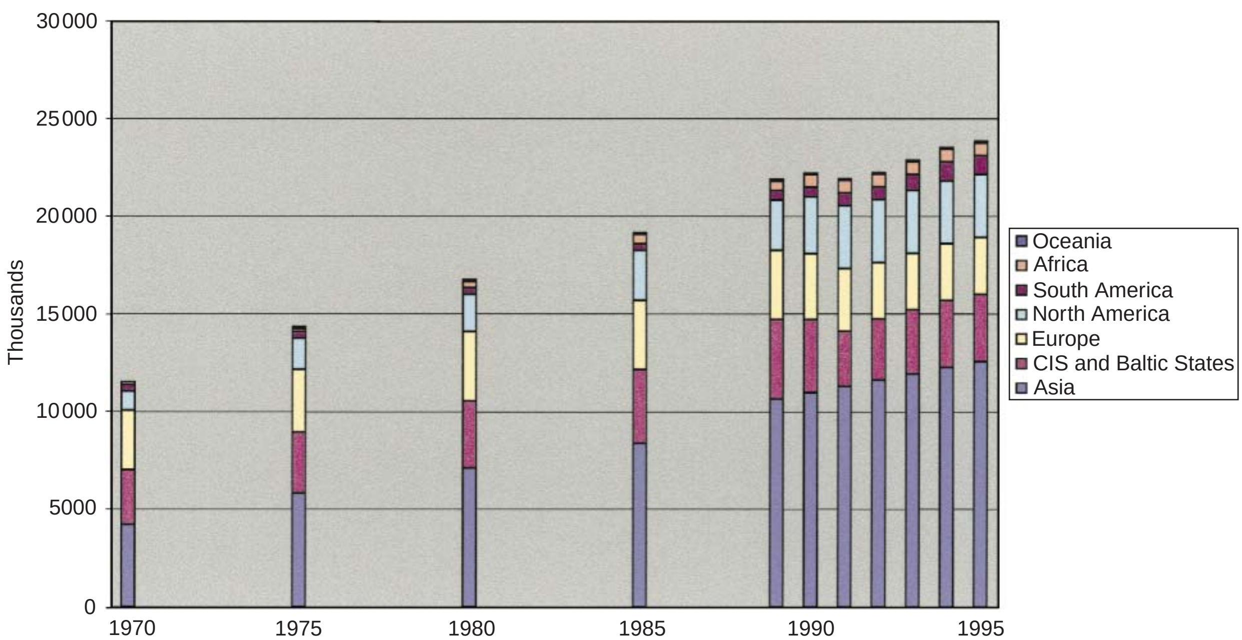

Figure 14 Total tonnage of decked vessels by continent. (Adapted with permission from FAO, 1999.)

a result the world fishing capacity remained approximately steady over the 1990s. The number of vessels in many of the main fishing nations of the world (Japan, former USSR, USA, Spain) shows a declining trend. A decrease is also noticed in most European countries as a result of the decommissioning policies of the EU. The fishing fleets of Latin American countries and developing countries are still growing.

Since 1988, the annual number of newly built vessels has steadily decreased from 1000 to around 200 in 1997. This is likely to be due to the overcapacity of the world fleet in the early 1990s and to the imposition of licensing systems by many developing countries. As a result of the low renewal rate the world fishing fleet comprises more and more old vessels. Taking into account the building rates, the predicted scrapping rates and a loss factor, it can be estimated that by 2008 the Lloyds database will contain no more than 14 000 vessels. With regard to changes in national fishing fleets, reflagging has become a more important factor than building or scrapping. The trend is for a flow of vessels from developed to underdeveloped countries. The general idea that both the average vessel size and the horsepower are increasing is not supported by the data analysis. In fact, both show only slight changes over the period 1970–1997. It should be borne in mind that these findings are valid for the global fleet but may be different for some national fleets.

Gillnets and lines are the most frequently used fishing gears (**Figure 15**). Trawlers, however, are the largest and most powerful fishing vessels, accounting for about 40% of the total gross tonnage (**Figure 16**).

Problems Related to Fishing Gears and Fishing Fleets

Efficiency

The efficiency of a fishing method depends not only on the fishing gear itself but also on many elements which make up the complete fishing system. Among these are the fishing vessel, navigation and fish detection, handling and monitoring of the gear, schooling and training of the fishermen. As a result, the efficiency of the different fishing methods varies enormously. Artisanal, mostly passive gears, have a low input of modern technology and consequently have a rather low efficiency, as is shown by the labor productivity of fishermen given in **Table 1**.

Active fishing methods, like trawling and purse seining, make use of the best available technical means to increase their efficiency. The use of synthetic netting materials and the mechanization of the gear handling on board makes it possible to construct and use larger fishing gears. Mechanical power for the propulsion of the fishing vessels together with precise navigation and electronic fish-finding devices have drastically improved the efficiency of modern fishing operations.

Excess Fishing Capacity

For years excessive fishing capacity in many fisheries or even at the global level has been a matter of

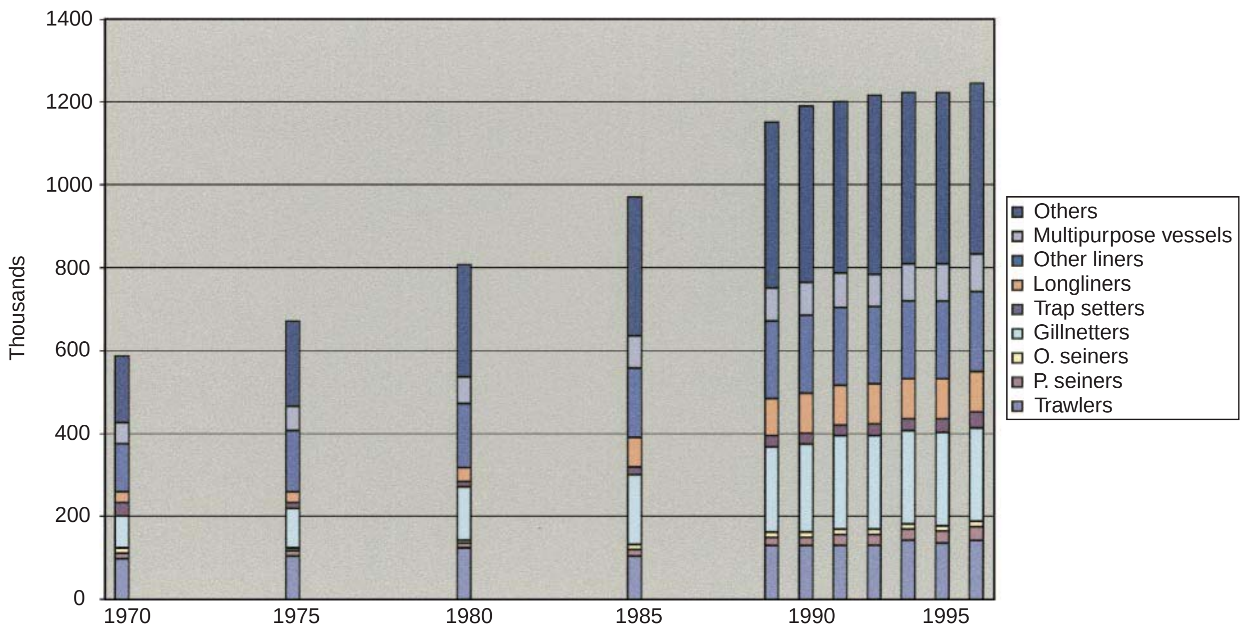

Figure 15 Number of decked vessels by type. (Adapted with permission from FAO, 1999.)

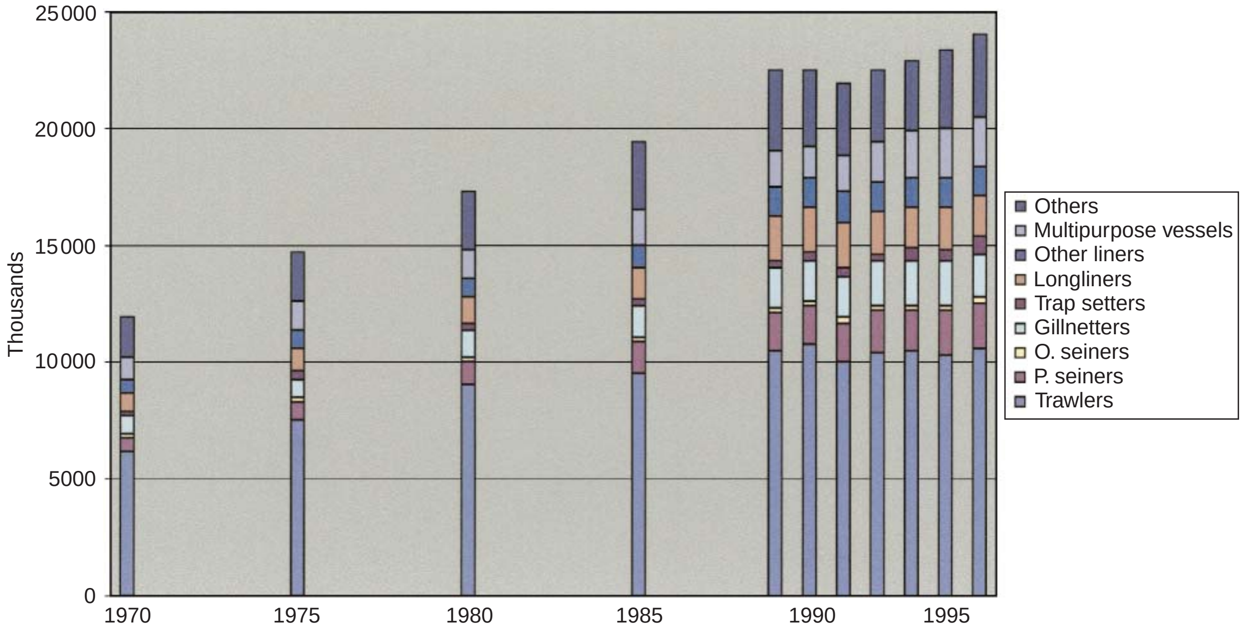

Figure 16 Tonnage of decked vessels by type. (Adapted with permission from FAO, 1999.)

increasing concern. Excessive fishing capacity is thought to be largely responsible for the degradation of marine resources and has a large impact on the socioeconomic performances of the fleets and industries concerned. The FAO estimates an excess of fishing capacity of at least 30% on the principal high value, mostly demersal, species. These species represent about 70% of the landings but exclude many pelagic and low-value species. When aggregating all resources, on a global scale, there is no overcapacity in relation to maximum sustainable yield. This situation clearly indicates a full or overexploitation of some stocks while other resources, generally of lower-value pelagic species, still offer opportunities for increased landings. Due to the limited mobility of the fleet, the excess in capacity cannot be easily transferred from overexploited to the underexploited resources.

Table 1 Labor productivity of fishermen

Annual catch per fisherman (tonnes)	*Gear types*
1	Traps, pole and hooked lines and nets from rowing boats
10	Inshore longlines, entangling nets, and trawls from small vessels
100	High seas trawls from large vessels
400	Purse-seines from super-seiners

Adapted, with permission, from Fridman (1986).

By-catch and Discards

In general the catch of a fishing gear does not solely consist of the target species. With the target species the catch will usually contain a so-called by-catch which may consist of other, not primarily sought, marketable species and also animals that will not be landed but returned at sea or discarded. Discarding has become one of the major problems of modern fisheries. The FAO Technical Consultation on Reduction of Wastage in Fisheries in 1996 estimated the global discards of fish in commercial fisheries at 20 million tonnes. There are several reasons why a fisher can decide to discard the catch or part of it. It is often illegal to land undersized animals and for management reasons it may not be permissible to land species for which the quota has been reached. Some by-catch species have a low commercial value and animals of a certain size may not be attractive enough for the fishing industry and are discarded for economic reasons. As the survival of most species returned to the sea is low, discarding practices contribute significantly to the problem of overfishing. In recent years the catch of nonfish species such as marine mammals, turtles, and seabirds has gained special attention, not least due to pressure from environmental groups.

Fishing Gear and Fishery Management

To protect the resources and to reduce by-catches and discard practices, many fishing gears are subject to a number of technical measures. Most of these measures aim at improving the selectivity of the gear or at a reduction of the fishing effort. Two types of selectivity should be envisaged, namely, length selectivity and species selectivity. The implementation of minimum mesh sizes to prevent catches of immature fish or other marine organisms is a worldwide practice to regulate the length selection of fishing gears constructed of netting. In other types of gears, such as traps, length selectivity is controlled by laying down the space between bars or lathes. The selectivity of hooks is determined by the size and shape of the hooks.

The species selectivity of fishing gears can be improved by technical modifications. Most adaptations have been made to trawls since they are often used in mixed-species fisheries. The techniques used involve separator panels, separator grids or grates and square mesh panels. These techniques take advantage of differences in behavior between species to the fishing gear. In a separator trawl a netting panel divides a bottom trawl in two horizontal sections. Benthic species that stay close to the bottom are caught in the lower section, whereas species that tend to swim upwards are caught in the upper section. Each section can be provided with a cod end with its own appropriate mesh size. Inclined netting is used in various configurations to separate different species but mainly shrimps from finfish. The shrimps can pass through the small meshes in the panel but the larger fish are guided along the panel through an escape opening in the top panel of the trawl. Separator grids are based on the same principle and are widely used to separate crustaceans from finfish. The netting panel is replaced by a grid or grid system inserted in the aft part of the trawl. Turtle excluder devices are successfully used in US shrimp fisheries to minimize the by-catch of turtles. Comparable gear modifications are applied to give escape to cetaceans caught in midwater and bottom trawls. For similar reasons, traps are often equipped with escape vents.

The ability of square meshes to remain open under tension is exploited to give roundfish better escape opportunities. Conventional diamond-shaped meshes, on the contrary tend to close when the drag increases. As a consequence the selectivity of, for example, cod ends will decrease. Square mesh windows inserted in the cod end or in the top panel of a trawl present a constant mesh opening and offer juvenile fish an escape route. In mixed fisheries, some species will take advantage of the square mesh window while species with a different body form will not.

Management options like time and/or area fishing restrictions and effort reductions are important measures that contribute to solving the by-catch and discard problem. The number of gears employed, e.g., traps, may be limited. In some fisheries the maximum vessel size is restricted. Vessel-size and gear-size restrictions may be limited to certain areas and for well-determined periods, for example, on nursery grounds.

Individual transferable quotas or other forms of management in which property rights are well defined strengthen individual responsibility.

Ecosystem Effects of Fishing

The impact of fisheries on the marine ecosystem and habitats is an issue of growing concern. Especially since the 1980s scientists have paid increasing attention to environmental effects of fishing other than the decrease in population size of the target species. It is now recognized that fishing can cause alteration of the seabed and may adversely affect the seabed communities. As a consequence of discarding practices large-scale changes in the abundance and distribution of scavenging sea birds have been observed in some regions. Discarding also affects the food supply of many marine animals and may even be beneficial for the productivity of commercially important species.

Although the effects of fishing on the marine environment should not be minimized, it should be recognized that the effects of fishing are added to the impact of other anthropogenic activities and natural changes. Moreover, one should realize that it is extremely difficult to distinguish between different causes of the complex changes in the marine ecosystem.

At present a number of measures to reduce adverse environmental effects of fishing are under discussion. Generally effort reduction is regarded as the most effective measure to protect marine ecosystems. Ecologically valuable and vulnerable habitats can be protected by creating permanent closed areas. Technically the impact of fishing gears may be reduced by gear substitution and gear modification. A milestone in the issue of environmental considerations, including the by-catch and discard problem, was the adoption in 1995 by the FAO Conference of the Code of Conduct for Responsible Fisheries.

See also

Coral Reef and Other Tropical Fisheries. Crustacean Fisheries. Demersal Species Fisheries. Marine Fishery Resources, Global State of. Molluskan Fisheries. Open Ocean Fisheries for Deep Water Species. Open Ocean Fisheries for Large Pelagic

Species. Salmon Fisheries: Atlantic. Salmon Fisheries: Pacific. Seabirds and Fisheries Interaction. Small Pelagic Species Fisheries. Southern Ocean Fisheries.

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FLOATS

See **DRIFTERS AND FLOATS**

FLOC LAYERS

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doi:10.1006/rwos.2001.0223

Introduction

Over much of the ocean area the deep seafloor receives a periodic supply of material from the overlying sunlit zone reflecting the seasonally varying rate of primary production (*see* **Primary Production Processes. Primary Production Methods. Primary Production Distribution**). In many regions this input of material forms a temporary detrital layer up to several centimeters thick resting on the seabed. This phytodetrital layer is subsequently eaten by organisms living on the seafloor, dissolved, or incorporated into the underlying sediment. It may also be advected to another region. This material is rich in certain biochemical entities and although it is expected to have a high organic carbon concentration, this has not always been found to be the case. It nevertheless supports some specialist species of organisms that grow rapidly in response to its deposition. The layer has very different physical characteristics from that of the underlying sediment being resuspended at low current velocities and this exposes the material to populations of near bottom zooplankton that are likely to use it as a food source.

The Seabed as an Interface

The seafloor represents the interface between the ocean and the solid earth beneath it. It controls the exchanges of dissolved chemicals between these environments and furthermore supports a diverse and rich benthic fauna. This community remineralizes more than 90% of the material arriving on the seabed. The presence of such layers in shallow waters has been a familiar sight to subaqua divers for many years. However, in the deep sea it was only within the last two decades that this interface has been thought to show any seasonal change or in fact to be different from the underlying geological sediment recovered by aggressive gravity corers.