THE MAGNITUDE AND IMPACT OF BY-CATCH MORTALITY BY FISHING GEAR

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ABSTRACT

Most fishing operations trap organisms that are not the primary fishing target, and are commonly referred to as the by-catch. It may include small individuals of the target species, or other species with little or no commercial value. The problem is widespread, with a global estimate of approximately 20 million metric tonnes, representing about a quarter of the total world catch. Shrimp fisheries tend to generate the largest quantities of by-catch, while fisheries for small pelagics the least. By-catch rates in mixed demersal and large pelagic fisheries are intermediate.

By-catch arises because fishing gears have imperfect selection properties, but the problem is made worse by economic pressures resulting from overexploitation. This leads to inefficient use of resources and changes in the abundance of both target and non-target species. Some by-catch species, including certain fish, reptiles, birds and mammals, may be threatened with extinction. Raised public awareness means that these conservation issues increasingly influence fishery management.

Much of the by-catch is simply discarded at sea. While not intended, the imposition of regulations such as minimum landing sizes and catch restrictions may encourage discarding. Most discards do not survive, but the material provides food for other organisms, especially scavengers, whose abundance may increase.

Technical conservation measures, which involve modifications to fishing gear or practices, offer an effective means of reducing by-catch. For trawls, these include grids and square mesh panels that sort animals by size, allowing a part of the catch to escape. For fixed gear, methods can be used to prevent the capture of large animals such as birds and mammals. The successful use of these devices, however, depends on overcoming gear handling constraints and the short-term economic losses often associated with their use.

By-catch is just one component of the total mortality of species affected by fishing. Hence by-catch is not an isolated issue. Addressing the problem requires consideration of the broader question of resource management, including the target species. Success in reducing by-catch requires that chronic problems of excessive exploitation must be tackled, and this remains a major challenge worldwide.

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INTRODUCTION

[1] Eric Cantona, an international footballer who played for France and Manchester United, was once asked if he regretted assaulting a member of the crowd who had made racist remarks. He made the enigmatic reply:

> "When sea-gulls follow trawlers, it is because they know sardines will be thrown into the sea."

[2] The observation puzzled the international press corps, but struck an immediate chord with those who study fisheries. His observation, while curious within the context it was made, neatly summarizes important aspects of the fishing process that have become of considerable topical interest. Firstly, it draws attention to the fact that fishing operations result in a by-product that is usually unwanted and hence discarded. Secondly, the discarded material is of interest to other organisms, birds in Cantona's example, and hence there is an effect on the ecosystem beyond the direct removal of fish from the sea. This paper focuses primarily on the first of these effects, though the implications of the second may be at least as important in the long-term exploitation of living marine resources.

[3] Unfortunately, the term "by-catch" is not a uniquely defined concept and experts around the world use it to mean slightly different things. While we should not agonize at length about what has an essentially intuitive meaning, it is necessary to clarify terminology for the purpose of this discussion. Most fishing operations, whether they employ towed or fixed gears, trap organisms that are not the primary target of the fisher. These organisms are commonly referred to as the by-catch. It may include small individuals of the target species, or other species that have little or no commercial value. Frequently, a large fraction of the by-catch is discarded for economic or legal reasons and this portion is commonly referred to as "discards." However a portion of the by-catch may have some value and is retained. This portion is often called the "incidental catch." It is not always clear precisely where the distinction lies between incidental and target catches, since the difference is related to the value of the species, and this may change. Notwithstanding this problem, we may summarize the total catch retained by the gear by the simple formulae:

Total catch = target catch + by-catch

By-catch = incidental catch + discards

[4] This paper focuses more on the discards, since this is most clearly the unwanted part of the catch, and the part that everyone would agree should be minimized. It is also, arguably, the larger of the two elements, but this will clearly depend very much on the fishery concerned.

REASONS FOR BY-CATCH AND DISCARDING

[5] It is easiest to exemplify the problem of unwanted catch by considering a typical trawl. While other gears may have very different fishing properties, the principles illustrated by trawls are almost universally applicable in terms of discards. A trawl can be thought of as a filtering device, where all the organisms that enter the gear are sorted by the meshes and some, by virtue of their size or shape, are retained in the net. The fisher can therefore control the characteristics of the catch by adapting the retention properties of the gear and the range of animals placed at risk of capture. The degree of control is inevitably incomplete and is the underlying cause of discarding.

Species of no commercial value

[6] While some large, densely schooling species, such as herring, capelin and mackerel, allow a fisher to target a single species, most fish occur in mixed assemblages, many members of which are at risk of capture during the passage of the gear. It is typical in demersal fisheries that a large number of species are taken together in a single haul or set. In temperate waters, this my be only a matter of dozens, while in tropical waters it may amount to hundreds. In these, all too common,

circumstances many species are caught that have no commercial value and are simply discarded. Shrimp fisheries, which take a large by-catch of fish, are one of the largest producers of discards in this category.

[7] Generally, the by-catch comprises mostly fish, but there may also be other animals, including reptiles (turtles and snakes), birds and marine mammals. The last-named grouping of higher vertebrates tends to attract special attention because of public interest, though scientifically the issues surrounding these animals are no different from other species.

Target species: individuals of low economic value

[8] Because most fishing gears have imperfect size selection characteristics, they may retain fish that are too small (or perhaps too large) to have any commercial value. Trawls, for example, usually retain a range of sizes below the minimum target size and these are typically discarded. This category can account for large quantities of discards. A further complication of this effect occurs with “high grading.” The problem arises usually when large numbers of the target species are being caught and limitations of space, processing or quota result in only the higher-value individuals being retained.

[9] Some fish, regardless of size, may be uneconomic to land. In the case of some fixed gears, such as gill nets, fish may be retained for a long period in the net before the gear is retrieved, during which time the quality of the flesh deteriorates and becomes unfit for sale. In addition, some fish may be damaged or diseased. However, this class of discard is usually of minor importance.

Target species: legal restrictions

[10] Management measures can often have a direct effect on discarding behaviour. It is common practice to set a minimum landing size (MLS) for commercial fish, with the intention of discouraging the capture of small, juvenile fish. Where gears retain fish below the MLS, these must usually be discarded, but, even if retained, they are an unwanted part of the catch, generating undesirable additional mortality.

[11] Catch quota restrictions can lead to fish being discarded. The most commonly cited reason for this is in mixed fisheries, where a quota for one species is exhausted while fishing continues for other species. When the species are taken together, the stock with no remaining quota is discarded. The extent to which discarding of this type occurs depends very much on the effectiveness of enforcement, since over-quota fish are often landed covertly. Whether or not the over-quota fish are discarded, this portion of the catch constitutes undesirable by-catch.

OVERVIEW OF GLOBAL BY-CATCH AND DISCARDS

[12] An assessment of global fisheries by-catch and discards was prepared by Alverson *et al.* for FAO in 1994. This work provides probably the most comprehensive evaluation of the problem and forms the basis of this section of the paper.

[13] Inevitably, data pertaining to fisheries worldwide are incomplete. Furthermore, the nature of discarding means that data collection must be done at sea, which is expensive and usually imprecise. These problems notwithstanding, the mean total weight of discards estimated by Alverson *et al.* was in the range of 17.9 million to 39.5 million metric tonne annually. The most recent estimates of total discards suggest they are in the lower end of this range, perhaps 20 million tonne (FAO, 1999a). This means that about one quarter of the total world catch of fish is discarded. Even at face value, this is a large biomass, but set in the context that a large number of the world’s fish stocks are already overexploited, it is an indication that by-catch is likely to be highly undesirable.

[14] Examining the distribution of discards by region (Figure 1 – at end of paper) indicates that over half the total world discards occur in only three regions, the Northwest Pacific, Northeast Atlantic and the West Central Pacific. In the Northwest Pacific, discards arise from a variety of fisheries, including crab, shrimp, mackerel, jack mackerel, cod and pollock fisheries. In the Northeast Atlantic, most discards occur in traditional roundfish and flatfish fisheries, while in the West Central Pacific, shrimp fisheries generate most discards. While these regions appear to produce the largest quantity of discards, it should be remembered they also account for the largest landings and hence do not necessarily represent the highest rate of discarding. Figure 2 shows an estimate of the discard rate by region. Clearly, the differences between the discard rates are much smaller than the absolute quantity discarded, with typical rates between 15% and 35%. It should also be borne in mind that discards have been more intensively studied in some areas, such as the Northeast Atlantic, than in others. Lower discard rates in some areas may simply be a reflection of lack of data.

[15] Figure 3 shows the discard rate, expressed as the unit weight discarded per unit weight landed, for the twenty fisheries with the highest recorded rates. It is noticeable that thirteen of these fisheries are for shrimp, while the remainder are mainly fisheries for demersal flatfish or roundfish. In fact, about 33% of all discards are produced in shrimp fisheries, and many of these take place in tropical regions. Fishing gear perhaps provides the simplest way of comparing the importance of different fisheries in relation to discards (Figure 4). While gear does not define fisheries, it is a very good indicator of the type of target species. Clearly, shrimp trawls are by far the most important gear in the generation of discards. This arises because most shrimps are small and hence small-mesh nets are used, which also retain a large variety of fish that are found in the same habitat. At the other end of the range, pelagic trawls have very low discard rates. These gears are generally used to catch small pelagic fish that are densely schooling and can be caught with very little by-catch. When discarding does occur in these fisheries, it is often the result of so-called "slippage" which is a variant on high grading. When the gear is brought to the surface, the fisher may decide that the size of the fish in the catch is unsatisfactory or the wrong species and simply empty the net in the water without bringing the fish aboard. Herring and mackerel fisheries in the Northeast Atlantic can suffer from this problem.

[16] Figure 5 shows the discard rate associated with different target species groups. It confirms the emerging picture associated with gear, where crustaceans (shrimps, prawns, crabs, etc.) and flatfish are related to very high discard rates, and small pelagics tending to be associated with low rates. Large pelagics and roundfish are intermediate.

THE BIOLOGICAL IMPACT OF BY-CATCH

[17] Figure 6 illustrates the fate of animals encountering a fishing gear, in this case a trawl, but the process would be similar for most kinds of gear. The diagram shows that on encountering a gear some fish are retained and are taken aboard the vessel. Of these some are discarded and are returned to the sea. Not all discarded fish die. Some species, notably certain flatfish, can survive the fish capture process quite well (Berghahn *et al.*, 1992) but this is not the norm. For example, Hill and Wassenberg (1990) found that only 1-2% of fish survived, though as much as 50% of crustaceans survived.

[18] Some animals that interact with the gear escape, but may nevertheless die, contributing to the overall mortality caused by fishing. Such mortality is sometimes referred to as "unaccounted mortality" (ICES, 1997) because it is rarely considered in the assessment and evaluation of fish stocks. Hence the overall direct by-catch impact of fishing will be due to the deaths of the discards and the deaths related to contact with the gear. However, as Figure 6 shows, the dead organisms are available to scavengers, and this is an additional route by which the ecosystem may be affected.

[19] The unaccounted mortality due to contact with the gear may be large (Cook, 1998), though few studies have quantified it. Species that are especially fragile are most at risk, and this includes many deepwater fish. As well as the biological impact of this largely unknown mortality, failure to quantify it can result in bias in stock assessments, particularly where evaluations of mesh size changes are concerned.

[20] While the total quantity of by-catch or discards may give an impression of the size of the problem, it does not adequately characterize the potential effects on populations or ecosystems. Even if the quantity discarded is large in terms of weight or numbers of individual animals, it still may only represent a small portion of the total population affected. It can therefore be more useful to consider the mortality rate resulting from fishing, rather than simple quantities alone. Mortality rate is a measure of the proportion of a population killed due to a particular cause. A sum of all the mortalities, such as those caused by fishing, predation and disease, is the total mortality. At a simple level, if the total mortality affecting a population exceeds the rate at which new individuals enter it, then the population will decline. Mortality due to by-catch is just one component of the total mortality and cannot, therefore, be considered in isolation. It may be especially important for a target species that also suffers a by-catch mortality since the marginal additional mortality due to by-catch might be sufficient to render exploitation non-sustainable.

[21] It can useful to distinguish between the by-catch mortalities affecting target and non-target species because the implications for managers may be different. Where a species is taken only as by-catch, then concerns will centre mainly on the conservation and ecosystem consequences of fishing. If, however, a species is also a target species, then by-catch will have additional implications for the management-directed fishery on it. It is also convenient to distinguish between the by-catch of fish and that of higher vertebrates, such as reptiles, birds and mammals, primarily because of the different public perception of these species. Each of these categories is dealt with below.

By-catch mortality: non-target species

[22] The fisheries for small Crustacea have already been noted for their large production of fish by-catch. Alverson *et al.* (FAO, 1994) note that the Australian northern prawn fishery discards more than 75 families of fish. Shrimp fisheries are implicated in high mortalities of non-target fish species (Blaber *et al.*, 1990) and are cited as the cause of the reduction of the croakers to very low levels (Tillman, 1992; Cittendon and McEachran, 1975).

[23] Where the distribution and vulnerability to fishing of both target and non-target species are similar, it might reasonably be expected that the two categories will suffer comparable fishing mortalities (Pope *et al.*, 2000). Stratoudakis (1997) found that the mortalities of Common dab (*Limanda limanda*) and Grey gurnard (*Eutrigla gurnardus*) were in the same range as the main target species (gadoids). These mortalities are large enough to result in the equivalent of growth overfishing. but without a high risk of extinction. However, some fish species that have low reproductive rates may suffer unsustainable mortalities, and this appears to be the case for the Common skate (*Raja batis*) in the Irish Sea (Brander, 1981). These large skates have low reproductive rates and, like sharks, are particularly vulnerable to even moderate mortalities. The problem is likely to be widespread and is one of the principal concerns associated with the mortalities inflicted through by-catch.

By-catch mortality: target species

[24] The biological effects of excessive total mortality on target species may be no different to that on non-target species. The significance of the by-catch mortality has more to do with the utilization efficiency of the resource and the extent to which lack of knowledge of such mortalities can undermine the assessment and management of stocks. The by-catch of target species can occur in broadly two ways. Firstly, it may arise when a fishery for one target species takes a by-catch of species that is the target of another fishery. In a study of Singapore shrimp fisheries, for

example, 32% of the by-catch was juveniles of commercially important species (Abdullah *et al.* 1983). This means that not only does the shrimp fishery remove potential yield from the directed fishery, but also, unless it is taken into account, management of the commercial fish stocks is likely to be misled by bias in scientific assessments.

[25] The second category of target species by-catch arises when discards of the target species occur within the target fishery itself. It most commonly affects small individuals of the target species. Once again, killing juveniles removes potential yield, and, unless taken into account in assessment, will detract from assessments and good management decisions. An example of the magnitude of the lost yield can be seen in Figure 7, which shows how large the gain could be for North Sea haddock if all discards could be avoided. Not only is the yield substantially improved, but also the spawning stock biomass nearly doubles (Shepherd, 1990).

By-catch mortality: reptiles, birds and marine mammals

[26] Reptiles, birds and marine mammals do not necessarily represent a distinct group, no more than fish or marine invertebrates that are affected by fishing. They do differ, however, in the public perception of their importance, especially in the Western Hemisphere, where conservation issues have tended to overtake resource exploitation considerations for these species. This separates them culturally rather than scientifically, and is the main reason for affording them particular mention. If there is a scientific characteristic that sets them apart, it is that they have low reproductive rates and a late age of maturity, which makes their populations more vulnerable to additional mortalities arising from fishing.

[27] Turtles may be taken in almost all types of fishing gear. In many instances, they may be released unharmed or taken as food. Shrimp trawls have been identified as a major cause of turtle mortality in the USA (Magnuson *et al.*, 1990) and their threatened or endangered status precipitated the use of turtle excluding devices (TEDs) in fishing gear. In at least one case, loggerhead turtles, the mortality due to fishing was sufficient to prevent stock recovery. However, the use of excluding devices is increasing and should mitigate the problem.

[28] Tasker *et al.* (2000) review the impact of fishing on marine birds. Both drift nets and long-lines have caused mortalities among albatrosses and petrels, particularly in the Southern Ocean and North Pacific, though the use of drift nets has declined. Some albatrosses have very low reproductive rates, and even very small incidental mortalities are enough to threaten some species with extinction. By contrast, another important effect of fishing is the increased availability of food to scavenging species, notably gulls. The production of discards and offal by fishing vessels makes hitherto inaccessible food obtainable to these species, and is linked to population increases in a number of seabirds.

[29] Seals and small cetaceans are the main groups involved in mammal incidental catches. For seals, it is catches in drift net, gill net and trawl gear that appear to be primarily involved. Incidental catches of seals have been implicated as the cause of decline in a number of species around the world, including fur seals and sea lions (Woodley and Lavigne, 1991). Despite incidental catches, certain seal populations are increasing, such as grey seals around the British Isles (Hiby *et al.*, 1996), at least partly attributable to a cessation of hunting.

[30] Of the marine mammals taken as by-catch, dolphins and porpoises tend to attract the greatest public attention. Most incidental catch is associated with drift nets and gill nets, but tuna purse seines are also involved. Incidental mortalities in excess of about 2% per year are often quoted as not sustainable for small cetacean populations (Perrin *et al.*, 1994). In contrast, typical fishing mortality rates for target fish species are well in excess of 10%, and it is not unusual to observe rates above 50%. This indicates that a very small additional mortality for cetaceans due to fishing is enough to endanger their populations. Inevitably, it is very difficult to obtain precise estimates of such mortalities, but those that have been made often indicate rates that are close to unsustainable. Uncertainty in the estimates leads to debate about the detrimental effects of

fishing, but it is clear that even a small by-catch of these animals is a potential threat to their long-term persistence. The International Whaling Commission estimated that 13% of 54 populations of small cetaceans studied suffered unsustainable losses due to mortality from passive gears (Perrin *et al.,* 1994). However, in recent years the use of large pelagic drift nets has increasingly been restricted, and were banned by the UN in 1991 (resolution 46/215), so some improvement would be expected.

Ecosystem effects

[31] The immediate effect of removing individuals from a population is to reduce its size. However, the biology of these populations and the way they interact with one another is complicated. In the long term in an ecosystem, there are likely to be changes contingent on fishing that are hard to predict. Other papers at this symposium discuss the ecosystem effects of fishing in more detail (Gislason; Kaiser *et al.*), but it is important that the ramifications of the direct effects of fishing are not forgotten. In general the effects of by-catch, in conjunction with the direct effect on target species, will tend to:

(i) reduce the abundance of large individuals, particularly predators;

(ii) increase the relative abundance of smaller, early maturing species with high reproductive rates (Jennings *et al,* 1999); and

(iii) favour the increased abundance of scavengers.

[32] It should also be remembered that by-catch mortality alone is not necessarily the main cause of changes to an ecosystem that can be caused by fishing. The effect on target species may be as large or larger. The particular significance of by-catch mortality is that it results in additional mortality for species or size classes that are not the intended target, and hence the ecosystem impact of fishing may be more widespread than would result from exploitation of the target species alone.

DRIVERS AND CONSTRAINTS AFFECTING BY-CATCH

[33] The reasons for discarding have already been discussed, but these reasons do not really explain why by-catch and discarding appears to be such a large element of fishing. It is not immediately apparent, for example, why fishers catch and discard so many juveniles of the target species when this directly reduces long-term yield. In practice, by-catch resulting from the technological constraints imposed by the gear is made worse by economic forces, which drive the process. A substantial by-catch problem in a fishery is usually a symptom of resource over-exploitation. This is best illustrated by considering how a fishery on a hitherto lightly exploited stock might develop. In the early stages of the fishery, the target population will comprise large individuals, which tend to realize high market value. The exploitation rate on these fish increases because fishing is profitable, but the survival rate of the fish decreases, and as a result the number of large fish available to be caught declines. Soon fishers have to target smaller fish so that their profitability can be maintained. The pressure on size continues, resulting in smaller and smaller fish being targeted, until most of the stock comprises fish that are close to the minimum marketable size. In a trawl fishery, gear constraints impose limits on trying to catch all fish of a marketable size without also catching a substantial by-catch of under-sized fish. This is illustrated in Figure 8, which shows the proportion of fish retained by the gear at each size (indicated by the sigmoid curve). Some fish of all sizes are caught, but the proportion held by the gear declines with size. In the example illustrated, the minimum marketable size is 40, and all fish below this size are discarded (hatched area).

[34] The upper panel in Figure 8 shows the situation when a fishery is only lightly exploited and larger fish are relatively abundant. In these circumstances, a fishing vessel can obtain adequate reward with a selective net that allows small fish to escape. Some fish above the minimum

marketable size escape (horizontal shading), but the losses will be small in relation to the total catch. Furthermore, the fisher avoids the handling nuisance of catching large numbers of small fish of no value.

[35] In contrast, the lower panel in Figure 8 illustrates the situation when a stock becomes over-exploited. Because so few large fish are in the sea, the fisher adjusts the gear so that more marketable fish are retained. In effect, the selection curve moves to the left. This eliminates the losses of marketable fish seen in the upper panel, but, in doing this, the quantity of fish below the minimum marketable size increases, resulting in more discarding.

[36] While the example described refers to a single target stock, similar processes affect the development of by-catch problems with multiple species. The simple process of reducing selectivity to catch smaller fish will tend also to result in greater by-catch of small species that previously would have passed through the gear. In addition, as the target species gets scarce, the fisher needs to maintain catch rates by extending the range of species taken, and will deploy the gear in areas where more species are available. In doing so, low-value species will tend to be placed at risk, resulting in increased by-catch.

MITIGATING THE BY-CATCH PROBLEM

Reducing overexploitation

[37] The previous section emphasizes the economic pressures that magnify the by-catch problem. It is important to recognize that these forces play a major role in attempts to reduce discards and by-catch. While limitations on gear design and operation set constraints on what can be achieved, success in trying to operate more selective fishing gears and practices will ultimately depend heavily on the economic forces to which fishers are subject. Nested within this is the degree to which management measures can be enforced.

[38] In the simple example described in Figure 8 it emerges that, as exploitation increases, the pressure is to reduce the selectivity of gear (moving the selection curve to the left), causing an increase in by-catch. In contrast, the traditional management response, in a trawl fishery, for example, is to legislate for improved selectivity, usually by specifying a larger mesh size. Using the example in Figure 8, this would mean moving the selection curve to the right. Thus the fisher faces the opposing forces of short-term economic pressure and long-term management pressure. Where enforcement is weak – and this is the more common situation – the short-term economic forces will prevail. If conservation measures are to be introduced to reduce by-catch, it is essential that this be done at the same time as addressing the overexploitation problem. Reducing exploitation improves the survival of fish, leading to a greater abundance of large fish, and hence provides an incentive to adopt more selective gear.

Technical measures

[39] There are a wide variety of modifications to fishing gear that can be made to improve selectivity and hence mitigate the problem of by-catch. These are often referred to as technical measures. For trawls, which are one of the least selective gears, the principle is essentially to provide larger holes for the unwanted element of the catch to escape. The most obvious way to do this is to increase the mesh size, but the main drawback is that the conventional diamond mesh of nets may close under tension. Alternatives to mesh size increases are the insertion of panels made with square mesh (Figure 9). Such panels are less susceptible to mesh closure and may be effective for roundfish if located appropriately in the net. They are less effective for flatfish due to the shape of the mesh opening.

[40] A device that has attracted increasing attention is the rigid grid, placed somewhere in the cod end of a trawl. The grid acts as a sorting device (see Figure 10), filtering larger organisms and diverting them to another part of the gear. Such devices allow either the small organisms to

be retained while the larger ones escape, or vice versa. These devices are used in some shrimp fisheries in arctic waters to allow the fish component of the catch to escape. The same principle is applied in turtle excluding devices, as used in shrimp fisheries in the USA.

[41] Grids offer a partial means of separating species, but this is primarily based on size. It is possible to sort species by exploiting their particular behaviour. This is done in separator trawls, where a horizontal panel in the net divides those species that try escape by swimming upwards from those that try to escape downwards. In the Northeast Atlantic, this device can be used to separate haddock from cod (Figure 11). By having separate cod ends for each part of the catch, it is possible to use the different mesh sizes that best suit each species.

[42] Static gears, such as gill nets and lines, offer different challenges. Gill nets and drift nets may entrap mammals, such as dolphins, because they cannot be seen either visually or by the animal's echolocation system. Devices can be attached to these to make the gear acoustically visible, and hence warn the animal of its presence so that avoiding action can be taken. For lines, selectivity can be achieved through choice of hook size and bait. Perhaps the highest profile concern is the ensnaring of seabirds such as albatrosses. Brothers *et al.* (FAO, 1999b) describe various devices, including setting lines at night when birds are absent, causing the lines to sink more quickly, or trailing streamers that discourage birds from attacking the bait.

Closed areas and seasons

[43] It is sometimes possible to identify fishing areas or seasons where by-catch problems are particularly severe. Juvenile fish, for example, may concentrate in nursery areas where shrimp are fished. Closing these areas at certain times to fishing may help to reduce by-catch problems. This is exemplified in Argentina, where a closed box is used to protect juvenile hake that are taken as by-catch in a shrimp fishery. Box closures can be simple and effective devices, but their principal drawback is that the closure is rarely complete. Other interests usually dictate that certain fisheries are allowed in the restricted area, and this often provides a loophole that significantly weakens the beneficial effects of the box.

CONCLUSIONS

[44] Examining estimates of worldwide by-catch reveals no region unaffected by the problem. While there may be differences in total quantities, by-catch rates in each region are comparable. Typically, a quarter of the catch is discarded. The largest single problem appears to be related to shrimp fisheries, though mixed demersal and large pelagic fisheries are also associated with high by-catch levels.

[45] There are perhaps two broad management issues related to by-catch. In traditional fishery management, by-catch of target species often represents an inefficient use of the resource and has exercised managers for many years. There is an established theory for quantifying the problem and it is of particular relevance to the fishing industry itself. In recent years, however, questions have been raised not only about the direct effects of fishing on target species, but also about the effects on other species, including those of no direct commercial value. These wider questions, often loosely referred to as "ecosystem concerns," might be considered conservation issues. They appeal to a much wider public than the fishing industry alone. The mobilization of environmental opinion on marine issues means that fishery managers are increasingly obliged to consider conservation issues that may directly affect the economic exploitation of resources. This process of incorporating ecosystem considerations into fishery management is likely to continue, and, in certain areas, may predominate in management policy. The question of by-catch, especially of non-target species, is inextricably linked to these issues.

[46] Technical conservation measures, involving modifications to fishing gear or practices, do offer a means of reducing by-catch. These measures can be shown to be effective, both under controlled conditions and in practical application. Their effectiveness is very much contingent on

the penalty a fisher has to pay in operating them. This may be due to difficulty in handling a modified gear, but more commonly there is a short-term economic loss associated with implementation. Successful use of these devices, therefore, depends on overcoming the short-term losses.

[47] The disturbance caused by fisheries to populations and ecosystems is ultimately related to the total mortality of organisms affected by fishing. By-catch is just one component of this total mortality and therefore should not be seen as a separate issue in its own right. There are good reasons for supposing that by-catch is exacerbated by heavy exploitation and can be an indication of overfishing. These two observations indicate that addressing the problem of by-catch requires consideration of the broader question of resource management, which includes the target species mortalities. It is unlikely that success in reducing by-catch can be achieved without addressing chronic problems of excessive exploitation, which remains a major challenge worldwide. Indeed, simply achieving more rational exploitation of many target stocks would be a major step toward addressing the wider question of by-catch.

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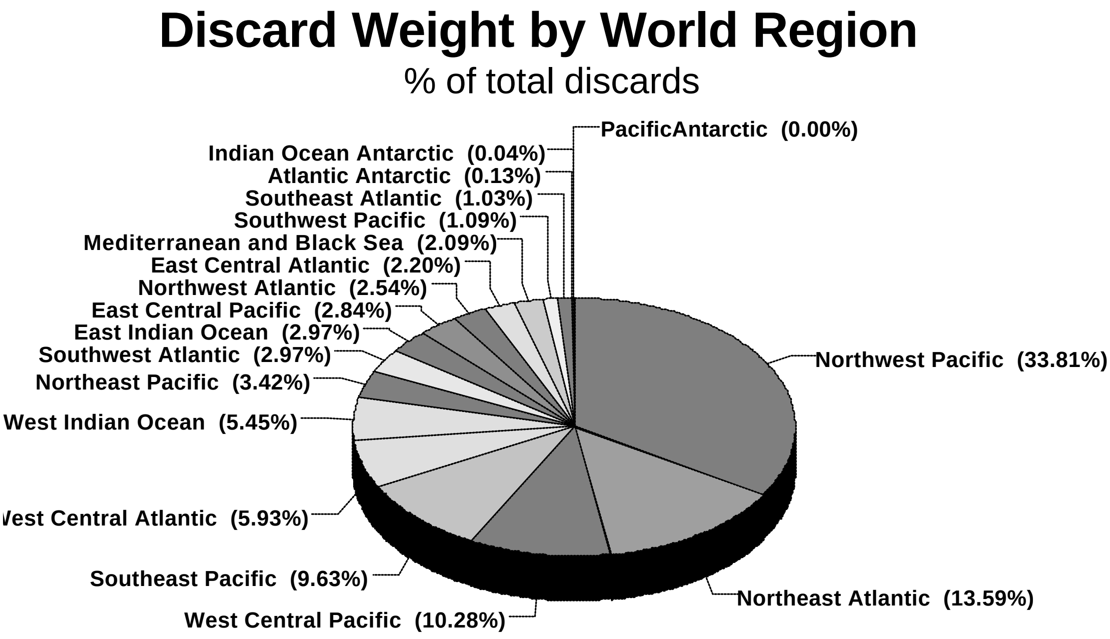

Figure 1. Of the total estimated by-catch, the proportion discarded in each world region. Data from Alverson *et al*. (FAO, 1994)

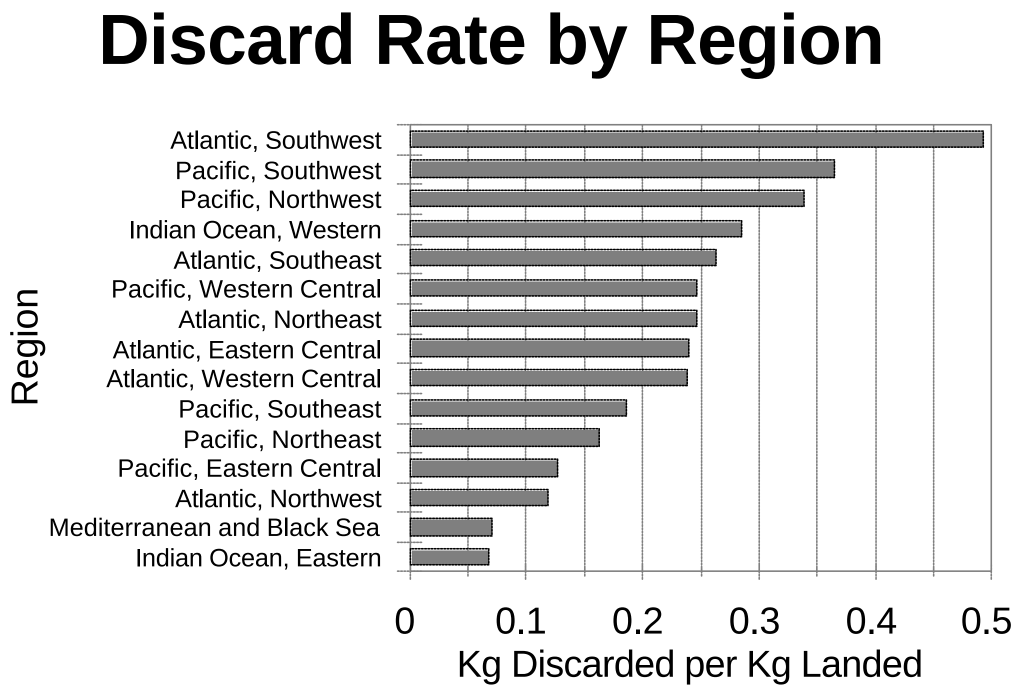

Figure 2. The estimated discard rate, i.e. the weight discarded per unit weight landed, classified by region. Data from Alverson *et al*. (FAO, 1994)

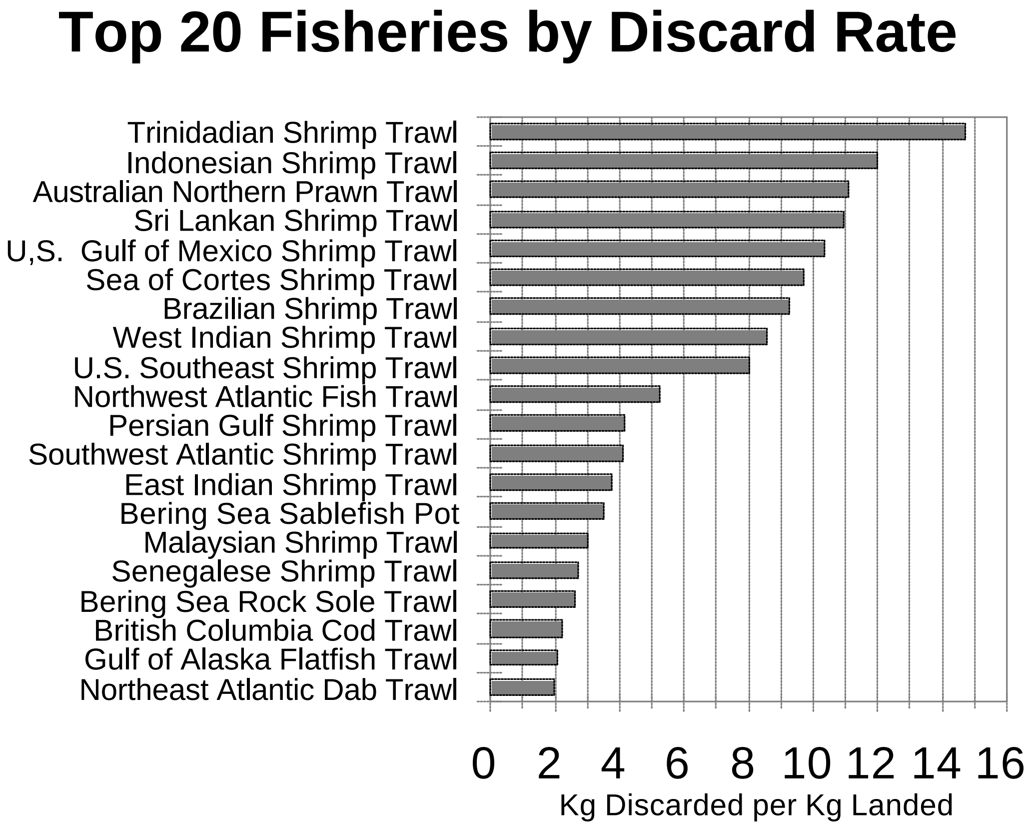

Figure 3. The twenty fisheries with the highest rate of discarding. Data from Alverson *et al*. (FAO, 1994)

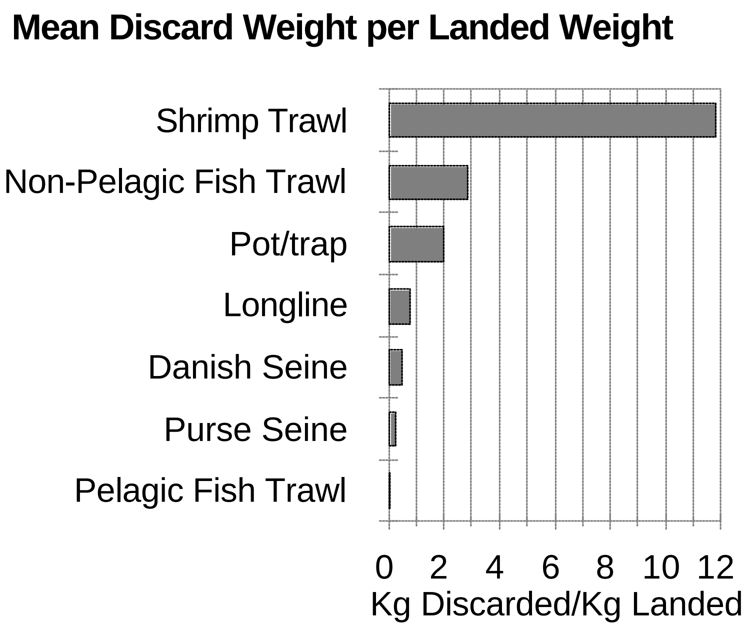

Figure 4. The mean discard rate by principal gear type. Data from Alverson *et al.* (FAO, 1994)

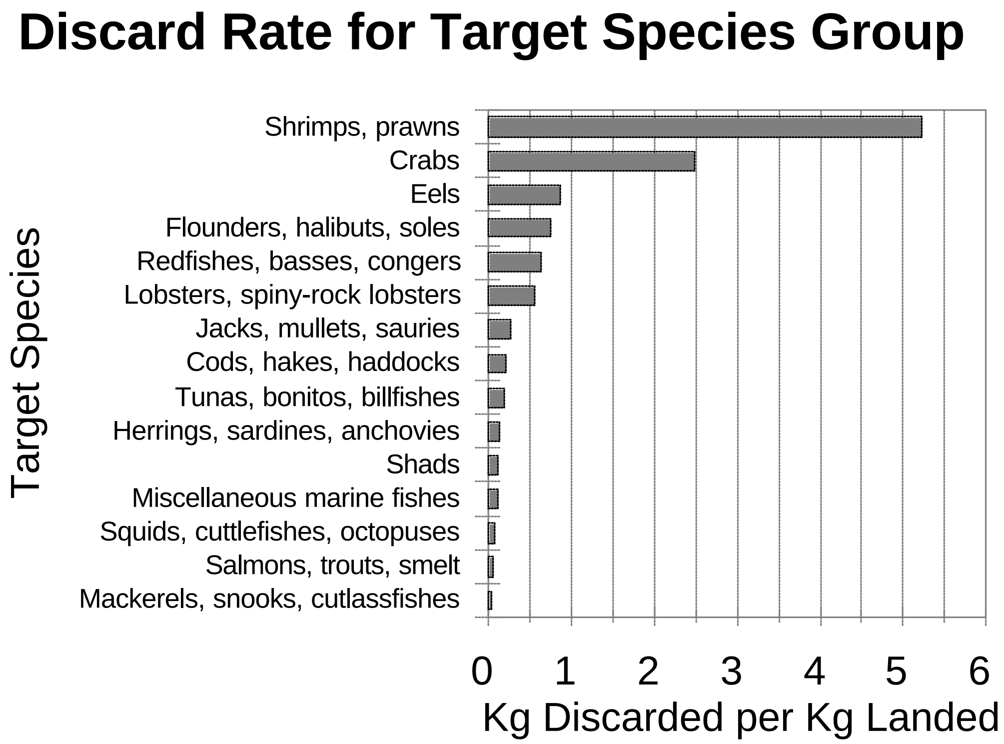

Figure 5. The discard rate associated with different target species. Data from Alverson *et al.* (FAO, 1994)

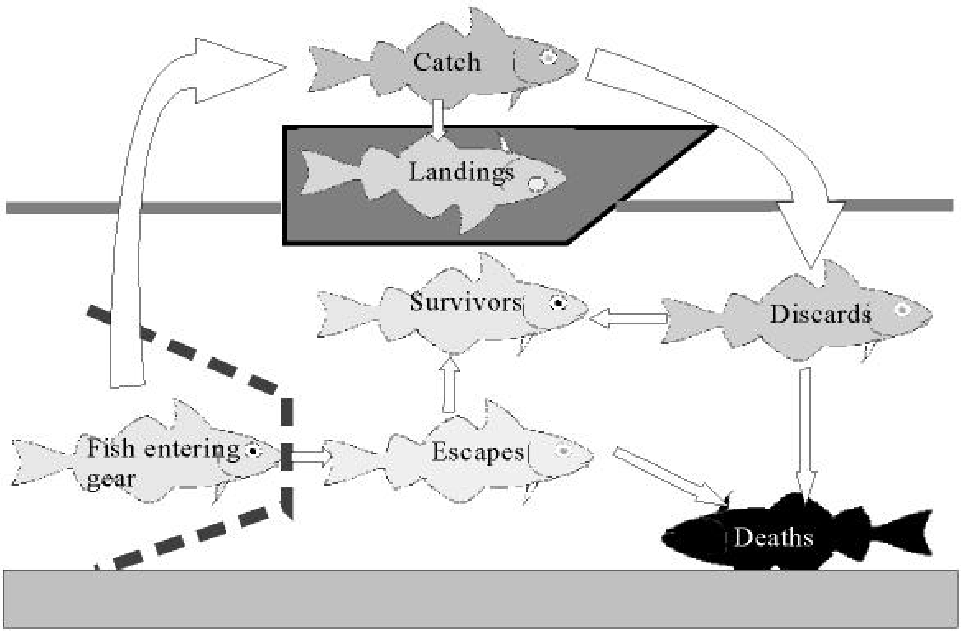

Figure 6. Schematic representation of the fate of fish that enter a fishing net.

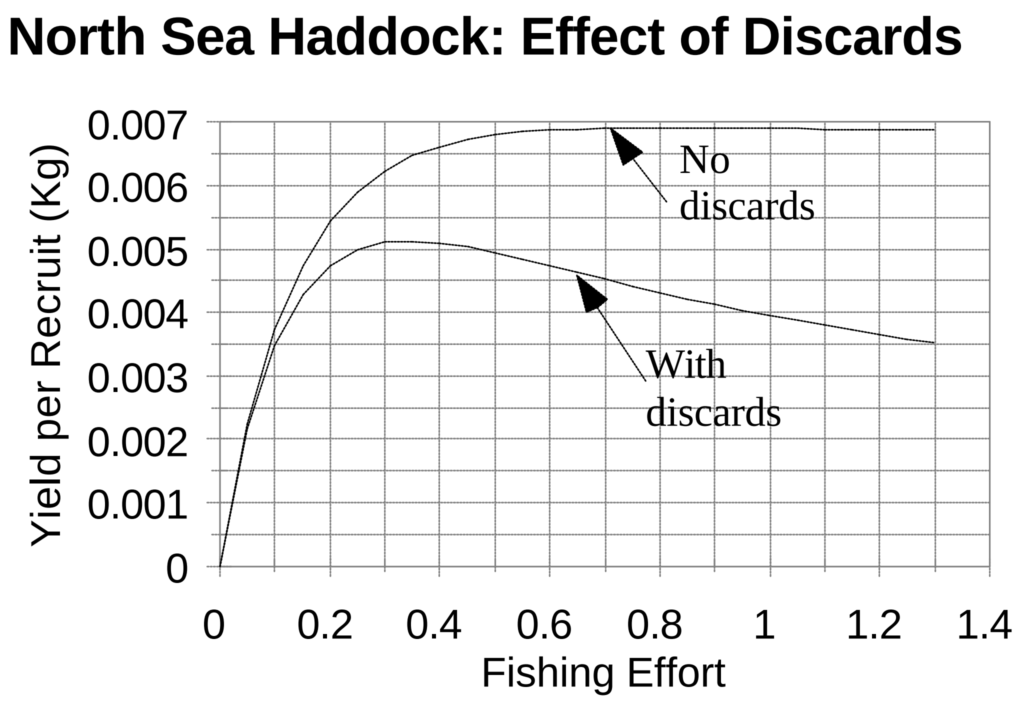

Figure 7. An example of the effect of discarding on the potential yield of a stock. The figure shows the expected yield per recruit for North Sea haddock if all discarding were avoided.

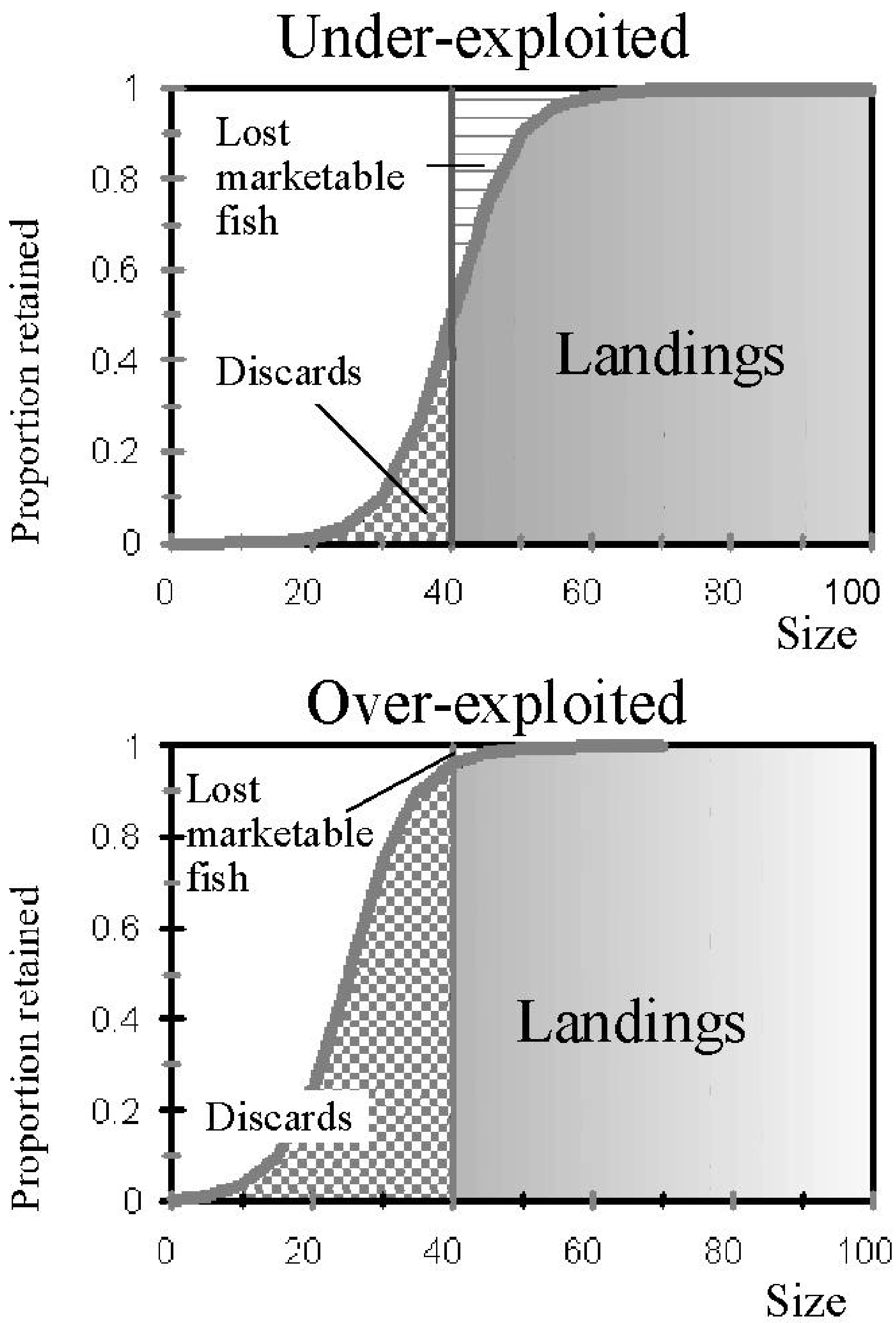

Figure 8. A diagram illustrating the effect of overexploitation on the capture of small fish. This theoretical example assumes the minimum marketable size is 40. In the upper diagram, because large fish are abundant when exploitation is low, the selectivity curve adopted by fishers tends to capture few small fish and some marketable fish escape. In the lower diagram, fishers are forced to try to catch all marketable fish and move the selectivity curve to the left. In so doing large numbers of small fish are caught as by-catch and are discarded.

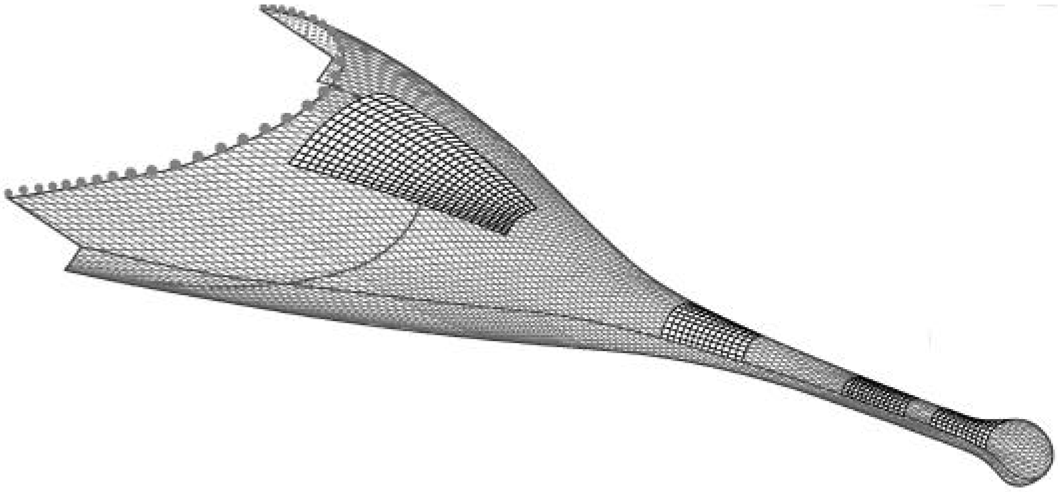

Figure 9. An example of fitting square mesh panels into a conventional trawl. Because square mesh does not close under tension, the meshes remain open, allowing small, unwanted fish to escape. The effectiveness of the panel may depend on its position. The diagram shows a number of possible positions for the panel.

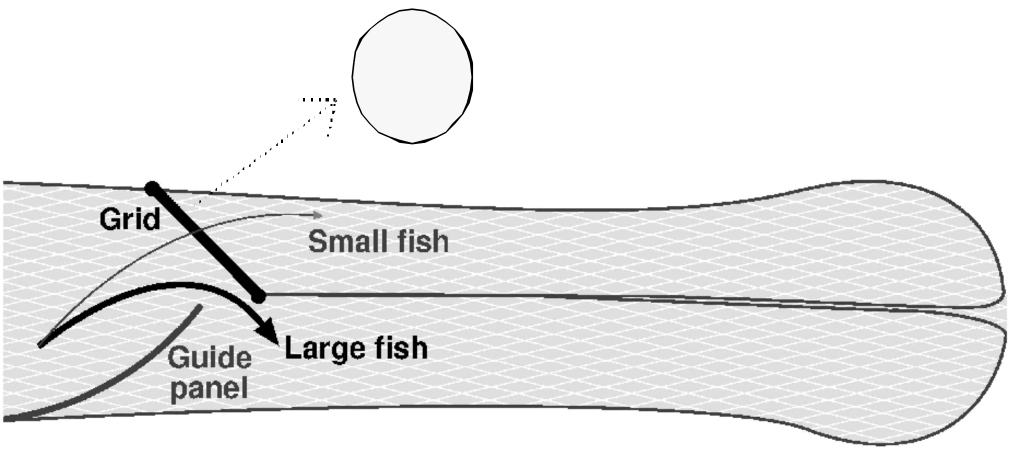

Figure 10. Rigid grids can be used to sort fish. This diagram shows one method of selecting out different sizes of fish. A guide panel feeds fish towards the grid. Small fish or shrimps pass through into the upper cod end. Large fish and animals enter the lower cod end. Choosing appropriate mesh sizes for each cod end can be used to minimize by-catch. Similar arrangements can be made to allow turtles to escape.

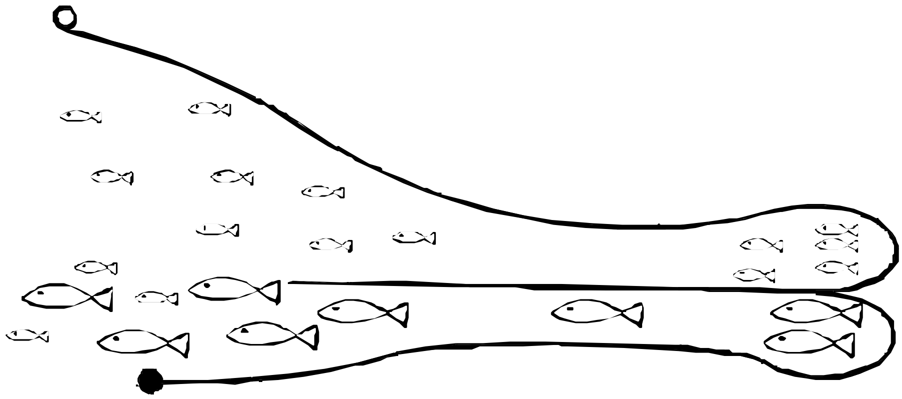

Figure 11. The principal of a separator trawl. In this example, two species of fish have differing escape responses. The small species tries to escape over the top of the net and is retained in the upper cod end. The large species tries to escape under the net and is retained in the lower cod end. Selection of the appropriate mesh size for each cod end can be used to optimize the catch composition. Such devices have been used to separate cod and haddock in the Northeast Atlantic.