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Aide memoire on scientific advice on fisheries management

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CONTENTS   Page

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Abstract

In this "aide memoire" the basic facts of fish population dynamics are described in a concise and accessible form.

The effects of various fishery management measures, such as controls on fishing effort and minimum mesh size, on the fish stocks concerned are explained. Conservation measures often lead to short-term losses of catch before they lead to long-term gains, and the reasons for this are discussed.

1. INTRODUCTION

Scientific advice on the management of fish stocks is often given in a highly condensed and quite technical form, as in the reports of the ICES Advisory Committee on Fishery Management (ACFM). To understand this advice properly requires an understanding of the basics of fish population dynamics, and the effects of various management measures, such as controls on fishing effort and mesh size. The purpose of this short note is to set out those basic facts in a concise and accessible form. It is intended to complement other publications in the same series which give more information on important aspects of fisheries managment, ie,

- assessing the state of fish stocks (J G Pope, 1982)
- control of mesh size (A C Burd, 1986)
- the basis of management and regulations (D J Garrod, 1987)
- stability and the objectives of management (J G Shepherd, 1990)

Full details of these publications are given in Section 9 "Further Reading".

The topics considered are firstly the effect of fishing on the size and structure of a fish stock, and the way in which the stock responds to a change in the level of fishing effort. Next, the implications of this for catches are considered, with the problem of balancing short-term losses and long-term gains. The effects of adjusting the nature of fishing (rather than just the amount of fishing) through technical measures are considered, followed by the complications caused by variations of recruitment to the stock, and the implications for management.

This account deals only with single-species aspects of the matter. In reality there are also multi-species aspects, caused by the capture of several species together in mixed fisheries, and by the biological interactions between species, especially predation. These do not generally change the nature of the mechanisms described here, but they do of course make the processes more complicated, and may change the magnitude of the effects (eg, the size of the losses and gains involved).

The discussion here also concentrates on the basis for scientific advice that fishing effort, and the catches it produces, needs to be limited, but does not deal with the ways in which this may be done, or the details of the calculations required (Pope, 1982 considers these aspects).

At present, the basic method of management under the Common Fisheries Policy of the European Community involves setting Total Allowable Catches (TACs) and agreeing national quotas. These then have to be managed in some way, which usually involves direct or indirect limitations on fishing effort. There are of course differences in practice between limitation of catches and limitation of effort, but both serve to moderate the level of exploitation, and here the focus is on the way in which the level (and nature) of the exploitation affects the fish stocks. The discussion is therefore phrased in terms of changes of fishing effort, although in practice this may be achieved indirectly by restricting catches.

2. THE EFFECT OF FISHING ON STOCK SIZE

Catching fish increases their death rate above that due to natural causes, and greater fishing effort leads to a higher mortality rate due to fishing. Thus, as illustrated in Figure 1, it eventually leads to fewer fish of any yearclass[1] surviving to each age. This means that not only are there fewer fish, but in

[1] *A yearclass is all those fish (of a particular stock) spawned in any one year*

particular there are fewer old, and therefore large and mature fish, in the surviving stock. The numbers, the average age and the average size of the fish are all reduced by fishing.

The size of a stock is best expressed as its biomass - the sum of the weights of all the fish of that stock in the sea. Clearly, since greater fishing effort means that there are fewer fish left in the sea, and that they are smaller, there is therefore a smaller biomass. As illustrated in Figure 2, the effect of fishing on stock biomass can be quite dramatic. A fishing effort which leads to a fishing mortality rate which is equal to the natural mortality rate is enough to reduce the stock to half of its natural size, because this doubles the total mortality rate. This would in fact be a low level of fishing: the fishing effort in the North Sea and many other places is so high that the rate of fishing mortality is three, four or five times that of natural mortality, and the stock sizes have consequently been much reduced by fishing. The reduction to around 20% of the unexploited stock size indicated for heavy fishing in Figure 2 is not unrealistic.

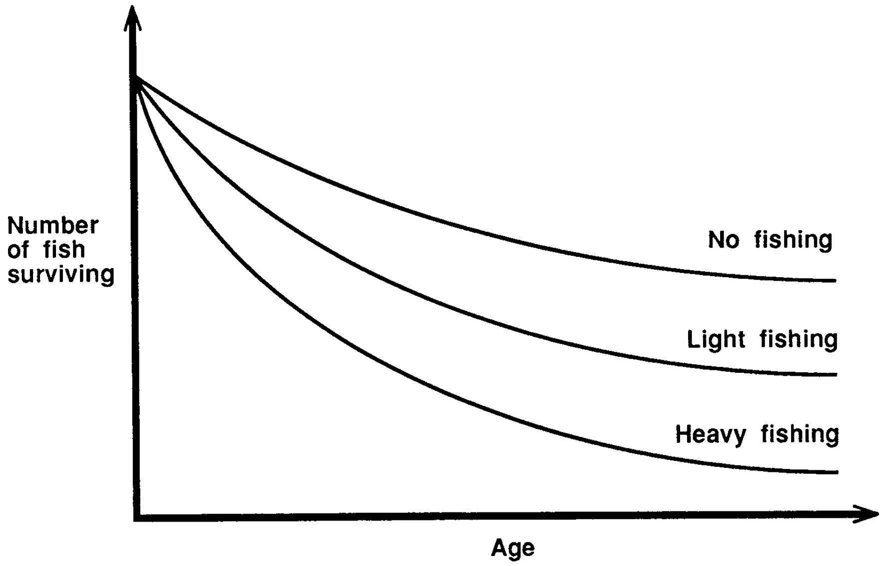

Figure 1. The effects of fishing on the survival of fish

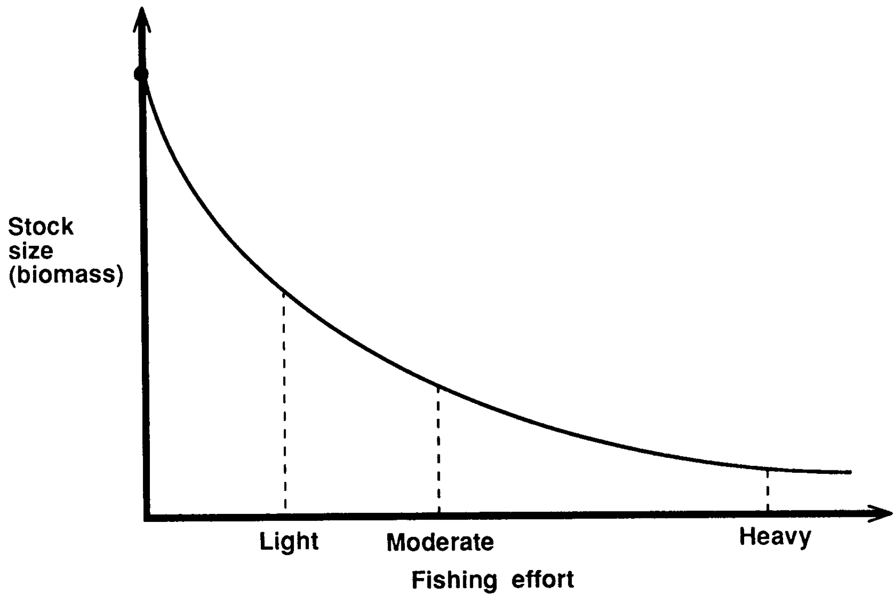

Figure 2. The effect of fishing on stock size

3. THE EFFECTS OF CHANGES OF FISHING EFFORT

Figure 2 shows how fishing affects stock size if the level of fishing is kept the same for long enough for the stock to come to equilibrium. This equilibrium (or steady state) is never reached in practice, because of variations of yearclass strength, but this does not affect the underlying processes, and is discussed further later on. If the fishing effort[2] is changed, it takes some time for the full effect to work through the whole stock - about twice the average lifetime of a fish (a few years, in practice). This is illustrated in Figure 3, which shows how the stock size responds to an increase and then a decrease in fishing effort. The benefit of any reduction of fishing effort (and in fact any other conservation measures) takes a few years to appear. Regrettably, it is just not possible to slide smoothly and quickly up and down the curve shown in Figure 2. In practice what happens is shown by the arrowed lines on Figure 4 - one only gets to the smooth curve eventually. Note also that (Figure 3) the detrimental effect of an increase of fishing effort does not show up immediately, either. There is a "honeymoon" period while the stock is being fished down to the new lower level where the full effect has worked through.

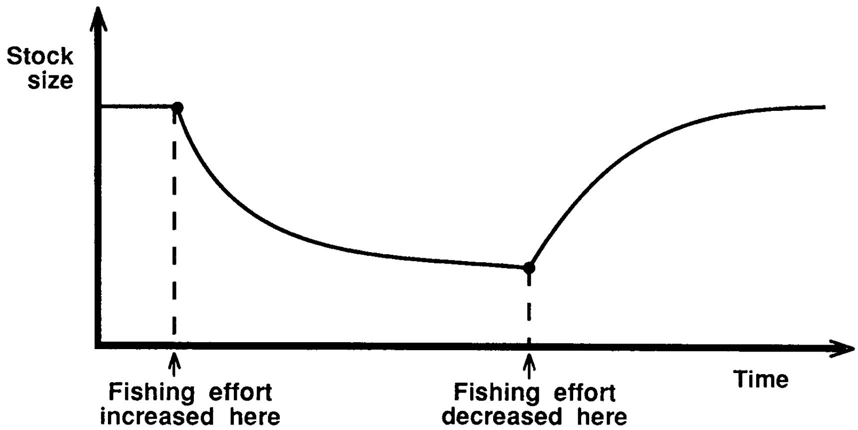

Figure 3. The response of a fish stock to changes of fishing effort

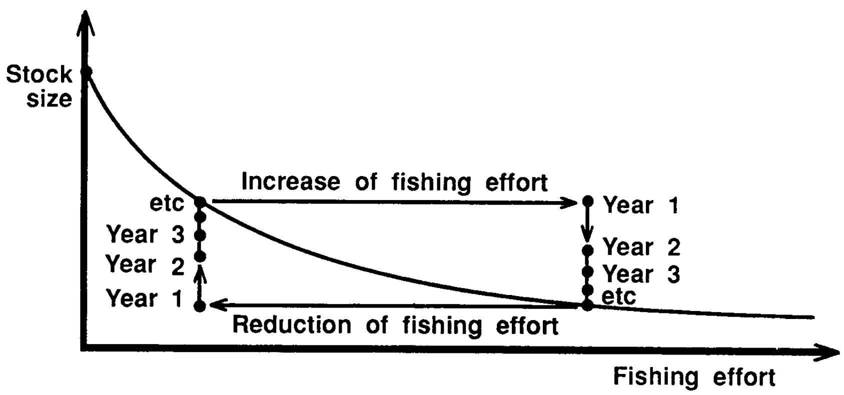

Figure 4. The same thing drawn in a different way

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[2] *Fishing effort is in fact quite difficult to define and measure precisely. Scientific advice is therefore often presented in terms of the fishing mortality rate, which for dispersed, bottom-living fish is usually proportional to fishing effort for any given method of fishing. For the purposes of this note the distinction is not important, and they may be regarded as essentially synonymous. See Pope (1982) for a full explanation*

4. THE EFFECT OF FISHING EFFORT ON CATCHES

The discussion above deals with the effect of fishing on the stock. The effect on the catch is rather different, and more complicated. In the short-term, the harder you fish, the more you catch. In any given year, if fishing effort were low, then the catches would increase roughly in proportion to any immediate increase of fishing effort. As shown in Figure 5, however, at higher levels of effort, one gets a diminishing return. If one fished very hard indeed, the greatest possible catch would be the whole of the stock that was there at the beginning of the year - thus the curve in Figure 5 levels off quite quickly at moderate to high levels of fishing.

In the longer term, things get a bit more complicated: obviously fishing hard in one year reduces the stock, so that in the next year there will be fewer fish to catch. One has to take account of this longer-term effect on the stock size (already shown in Figure 2). When this is done, one finds that the longer-term effect of fishing (shown in Figure 6) is quite different from the short-term effect. In fact, there is

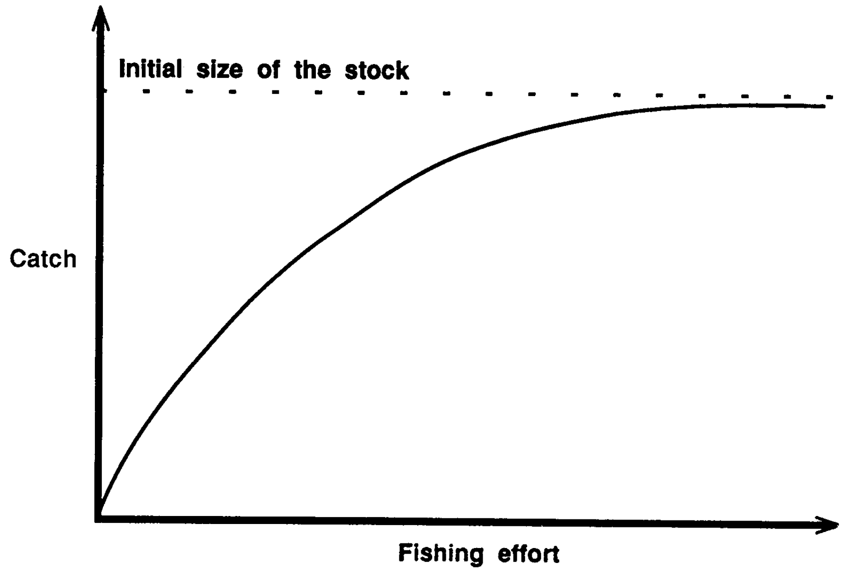


Figure 5. The short-term effect of fishing effort on catches

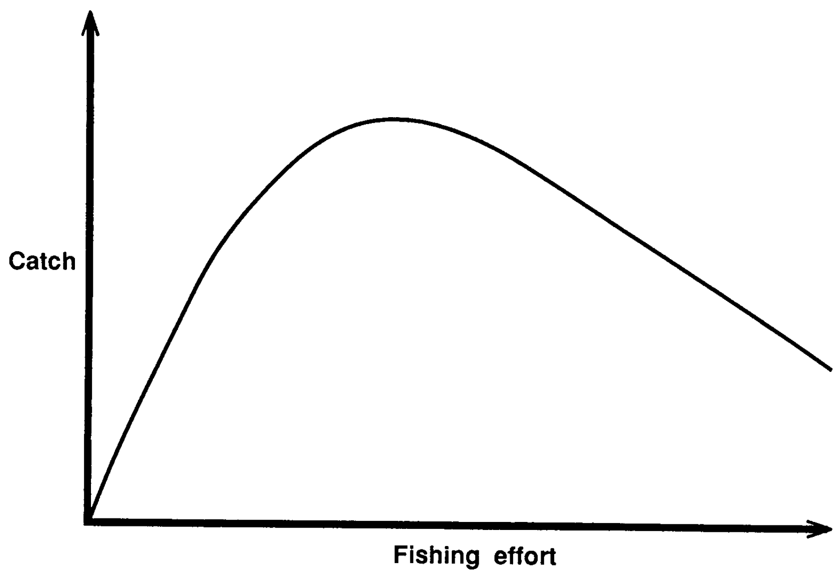


Figure 6. The long-term effect of fishing effort on catches

usually a maximum catch which is obtained at quite a low level of fishing effort. At higher levels of fishing effort one gets into a region of reduced catches (negative returns, not just diminished returns). This occurs because a fish stock is a limited renewable resource, with its own natural rate of growth and replenishment. Such resources need especially prudent management.

Now, Figure 6 is (like Figure 2) a steady-state picture - it shows what happens if things are kept the same for long enough. What actually happens to catches after sharp changes of fishing effort is shown in Figure 7. At first the response to an increase of effort is an increase of catch like that of Figure 5 (the short-term picture). However, in the long-run the stock declines, and the result becomes like that of Figure 6 - it is the long-term picture that wins out in the end. Conversely, if one then decreases effort, there is at first a loss of catch, according to the short-term picture, but thereafter the stock recovers, leading to a long-term gain.[3]

Figure 8 shows how these changes look over a period of time.

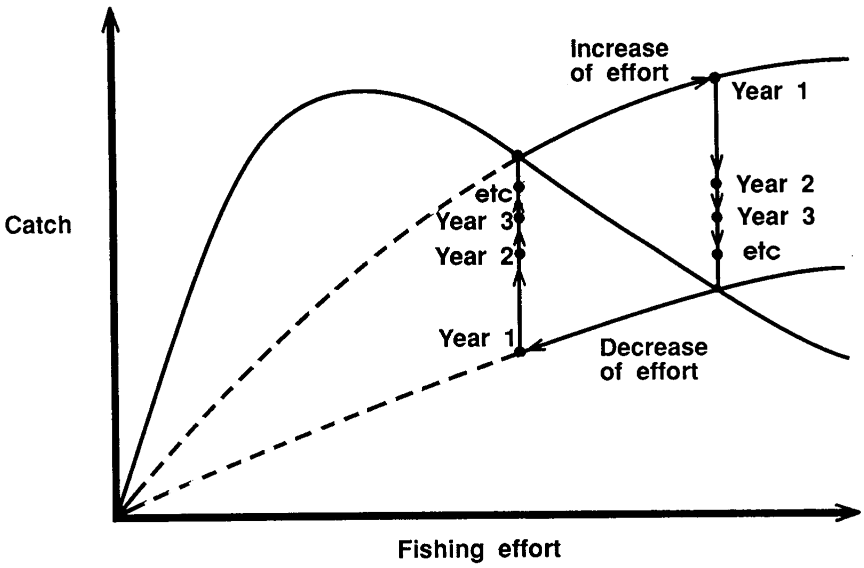


Figure 7. Short and long-term effects of fishing effort on catch

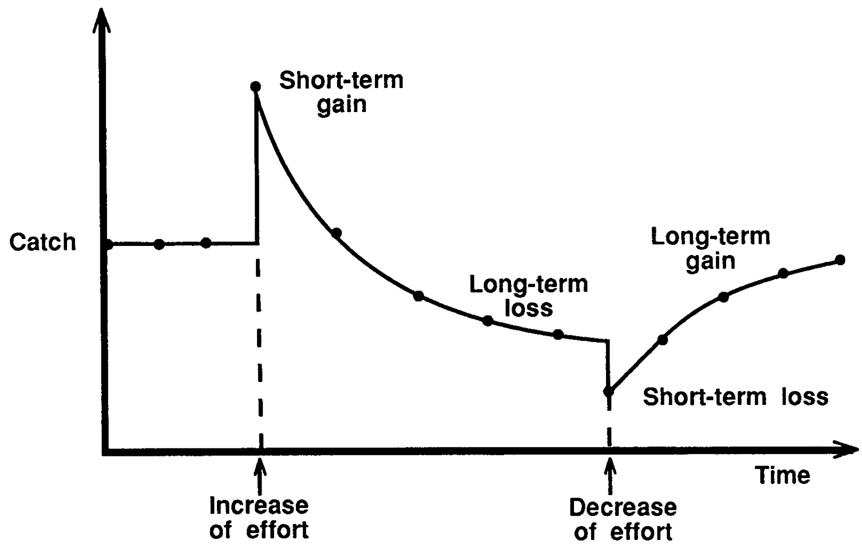


Figure 8. The same thing drawn in a different way

[3] *This assumes that the stock is over-exploited, as shown in Figure 7, with effort beyond the maximum of the curve. If it is not, there will be no long-term gain of catch, only of biomass*

5. PRACTICAL AND ECONOMIC CONSIDERATIONS

Figures 7 and 8 thus sum up the basic problem of fisheries management. In the long-term, it is a good thing to keep fishing effort low. Unfortunately, if the effort is already too high (as it usually is), getting it back down is a painful business. The fishing industry needs to accept a short-term loss of catch (and therefore earnings, since prices are not usually very elastic), if it is to reap the benefits a few years later. Finding an acceptable level of short-term loss which is justified by the future gains is a difficult trade-off to make. It must be remembered that the long-term gains are for ever, whilst the loss is only borne once. Even if one discounts future gains rather heavily, as a rough rule of thumb one might say that if the size of the short-term loss is less than three times the long-term gain, then the investment (short-term loss) is probably worthwhile. In fact, economic considerations suggest that a lower discount rate would be appropriate so that it would be worth accepting substantially larger short-term losses relative to long-term gains, but this would require the industry to take a very long-term view.

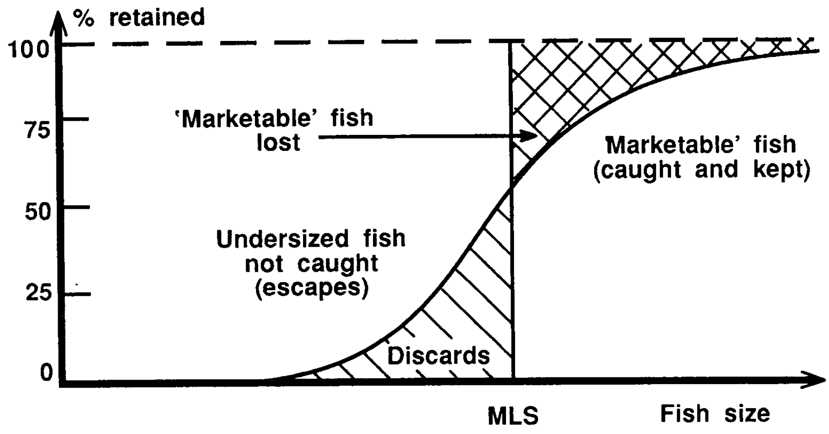
The economic effects of the short-term loss arising from a reduction of effort may also be less than they first seem. This is because going fishing costs money, so that a reduction of effort is accompanied by a reduction of costs, although probably not by the same amount. The reduction of costs will go some way to offset the loss of earnings, and thus the loss of profit is less than that of catch and earnings. Any increase of prices due to lower landings will also help. In fact, the individual fisherman's catch-rate (strictly, catch per unit of effort) and therefore his earnings per unit of effort (and costs) is for most stocks roughly proportional to the stock size. As can be seen in Figure 3, the reduction in effort is followed by an immediate growth of biomass: there is no short-term loss of stock size or catch-rates, even though there is a loss of catch. Whether or not individual fishermen suffer serious losses of profit therefore depends as much on how the reduction of aggregate effort and catches is shared out, as on anything else.

A final important point is that it is necessary to keep fishing effort down even after the stock has recovered. It is clear from Figures 3 and 8, that if the effort is allowed to rise again, the stock will be driven back to its previous depressed state. The short-term gain of catch would be followed by long-term losses of both catch and biomass (and therefore profitability). This means that the reductions of fishing effort recommended by the scientists (and economists) are intended to be permanent. The stock and the catches will increase again, but the amount of fishing effort needed, and the number of boats needed to exert it, will not.

6. TECHNICAL MEASURES: MINIMUM MESH SIZES, CLOSED AREAS AND SEASONS

So far, we have not considered the composition of the catch - the proportion of large and small fish which it contains. Most fishing gears, apart from purse seines and the small mesh nets used for midwater trawling or industrial fishing, are more-or-less selective. They allow most small fish to escape, whilst retaining most of the large ones (see Figure 9). This is useful, because it turns out that catching small juvenile fish before they reach sexual maturity is very damaging to the spawning stock size - much more damaging than fishing on the mature and spawning stock itself.

The reason for this is that any fishing mortality on juveniles kills the fish before they ever have a chance to spawn. It is therefore not only very effective, but operates again and again each year until first



Note: Fish which are of legal size (and therefore technically "marketable") may still be discarded because of market size and price factors in practice

Figure 9. Mesh selection and discards

spawning, so the effect is compounded. The same mortality operating after the fish have matured is less effective, because each year the fish have the opportunity to spawn, as well as the risk of death, and that opportunity is repeated year after year: the processes of reproduction and death act in parallel rather than one after the other. It is easy to see that if exploitation were delayed until after the majority of the fish had had the opportunity to spawn at least once, it would be very difficult to reduce the spawning stock to a very low level, however hard one fished. By contrast, even a moderate fishing mortality operating on juveniles over three or four years can easily reduce the spawning stock to just a few percent of its unexploited size.

Ideally, if one wished to maintain a large spawning stock, it would be best to catch only large fish which have already matured. In practice this is impossible, firstly because as shown in Figure 9, the selectivity of fishing gear is not perfect, and secondly because different species of fish which may be caught together in a mixed fishery have different sizes at maturity. Thus it is impossible to avoid catching some immature fish of large species (such as cod) without losing altogether the catch of smaller species (such as whiting). Nevertheless, the impact on the spawning stocks of catching a given amount of fish can be reduced to some extent by trying to ensure that the catch is composed mainly of larger fish. Minimum mesh regulations are used for this purpose.

The effects of an increase of minimum mesh size are in many respects similar to those of a reduction of fishing effort, since both reduce the effective level of exploitation of the stock. Just as shown in Figures 3 and 8, there are long-term gains of stock size, and often of catches too, offset by a short-term loss of catch. These are however caused not by moving up and down the curves as in Figures 4 and 7, but by moving (usually at constant effort) on to different curves, as shown in Figures 10 and 11. These make it clear that technical measures affect the efficiency of fishing: they lead to different levels of catch (and biomass) for the same level of fishing effort. The benefits arise because the short-term losses consist of many small fish, which escape to grow and to contribute to the spawning stock and the catch in later years.

From a fisheries management point of view, however, control of minimum mesh size is a rather limited instrument. It is possible to assist the stocks of fish which are naturally of a small size, but those species which are big will not benefit as much. Sometimes, therefore, this may be the right tool for the job, but at other times it may not be appropriate. In the same way, closed areas and seasons may be used to modify the composition of the catch, both by size and by species mix, since fish of different ages (and therefore different sizes), and fish of various species, all tend to be preferentially located in different places at different times of year. The separation is, however, very far from perfect, and as with mesh size control, there is a limit to what can be achieved by these means. These technical measures are therefore best regarded as allowing fine tuning of the basic conservation programme based on control of fishing effort through TACs, quotas and direct controls, not as a sufficient alternative to it. There is a limit to how far they can be used to compensate for the effects of excessive fishing effort.

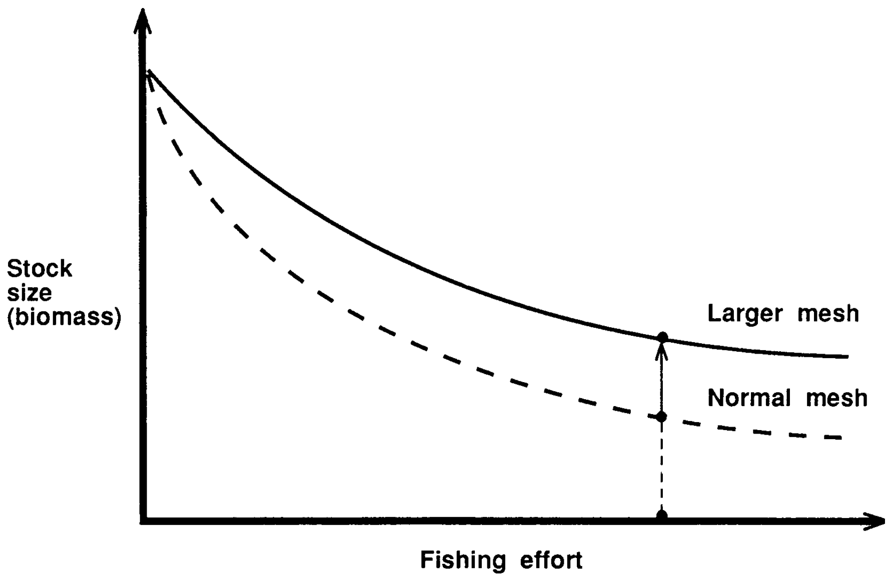


Figure 10. Effect of an increase of mesh size on stock size

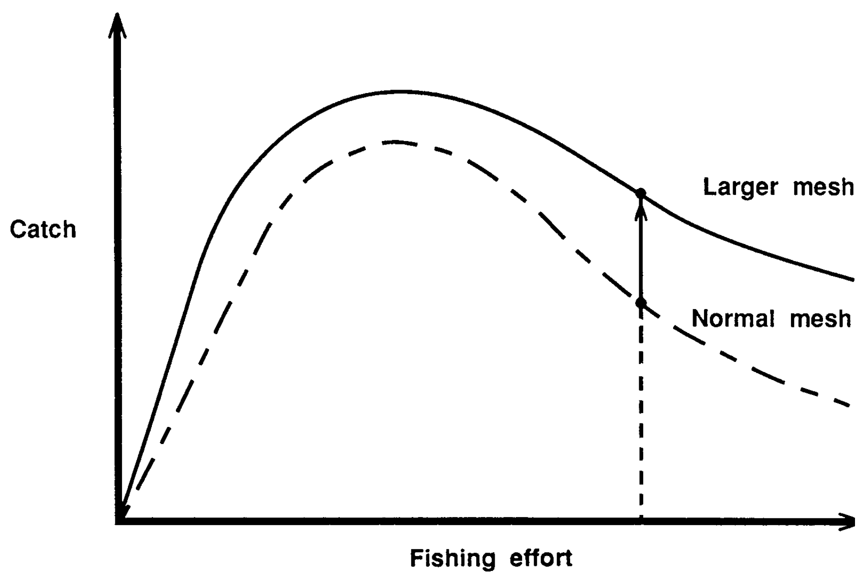


Figure 11. Effect of an increase of mesh size on catches

From an economic point of view, these technical measures have a further drawback compared to limitation of effort. This is that they act by reducing the efficiency of the fishing activity, by allowing small fish to escape, or by forcing fishermen to avoid the densest concentrations of fish. They reduce catches without any associated significant reduction of costs, and therefore result in reduced profitability at least in the short-term.

For these reasons, coupled with the fact that it is still possible to drive stocks down to a low level by excessive fishing effort even using fairly selective gear, it is generally considered that technical measures are an important but not a sufficient basis on their own for fish stock management. They are therefore used as an addition to other direct conservation measures which control the overall level of exploitation.

7. VARIABLE RECRUITMENT OF YOUNG FISH

The processes described above are complicated in practice by the natural variability in the numbers of young fish which survive their first year of life, and are able to join the stock as new recruits each year. This recruitment, or yearclass strength, may vary enormously from year to year, as shown in Figure 12, and is not very clearly related to the size of the spawning stock. The variation of yearclass strength is the other main factor, in addition to fishing, controlling the abundance of fish stocks. The reasons for it are not known, despite many years of research, and it is clearly not controlled by any single factor operating every year. Most likely it depends on the conjunction of several key environmental conditions at certain times of the year, but because the processes of growth and death are taking place over large areas of sea, the causes are difficult to study.

The variations in stock size so caused may be large, and are superimposed on those due to changes of fishing effort, etc, as described above. All of the diagrams used so far are drawn assuming constant recruitment, and in practice there would also be a lot of confusing changes due to varying recruitment.

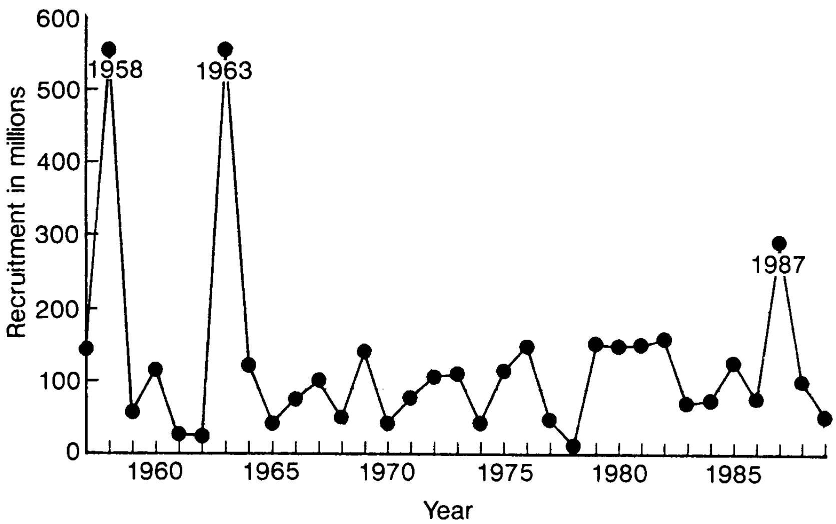


Figure 12. Recruitment of North Sea sole

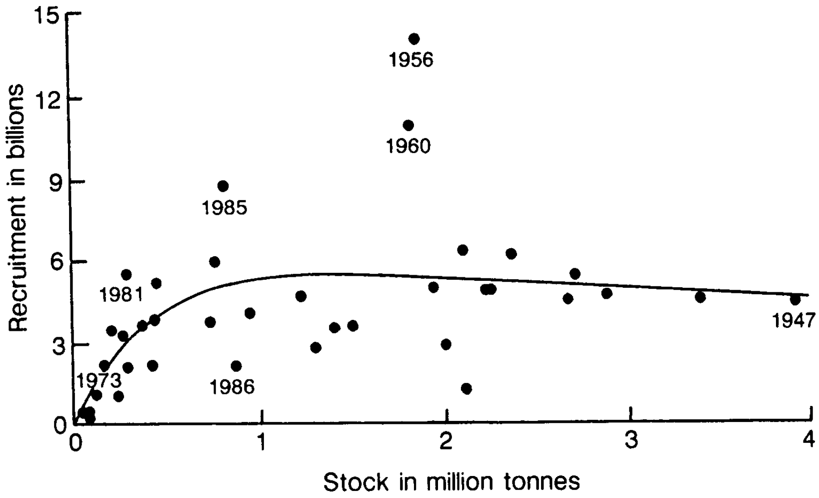


Figure 13. Stock and recruitment of North Sea herring

It is for this reason that the scientific advice sometimes proposes an increase in a Total Allowable Catch (TAC) at the same time as it calls for a reduction of fishing effort. This happens when a strong yearclass is just about to recruit to the fishery. In this case there will be an increase of the expected catch at any level of fishing due to the increased stock size, and this may outweigh the reduction which would normally result from a reduction of
effort. Varying recruitment is also the main reason for changes of recommended TACs from one year to the next. The TACs are usually just tracking the recruitment-driven changes of stock size - one cannot buck the trends imposed by uncontrollable changes of recruitment for very long at all.

These increases of TACs due to fluctuations of recruitment should not be taken as a signal for investment: no more fishing boats or fishing effort are required, since the increase is only due to the expected increase in the catch-rate of the boats already operating. Conversely, decreases of TAC due solely to poor recruitment do not mean that boats will have to fish less, only that they will catch less because there are fewer fish in the sea. Any changes of TAC due to changes of fishing mortality however do imply a need to adjust effort and capacity to follow suit.

Apart from these short-term fluctuations, the main problem concerning recruitment is the extent to which it depends on stock size. Clearly, if there are no spawning fish, there can be no recruits, but the relationship between spawning stock and subsequent recruitment is hardly ever clear, because of all the short-term fluctuations. One of the clearest examples is that for North Sea herring (see Figure 13). Nevertheless, if recruitment does decline when spawning stock size is reduced too far, this opens up the possibility of catastrophic stock collapse at high fishing mortality levels, rather than just progressive depletion; this is illustrated in Figure 14. It is believed that this is what happened to the North Sea herring in the mid-1970s, and there are several other examples of stocks collapsing after very heavy fishing, including North Sea mackerel and the haddock on Georges Bank off North America.

Fisheries scientists have great difficulty in advising when a stock collapse is likely, however, and suggested minimum stock levels and maximum exploitation rates involve a large measure of professional

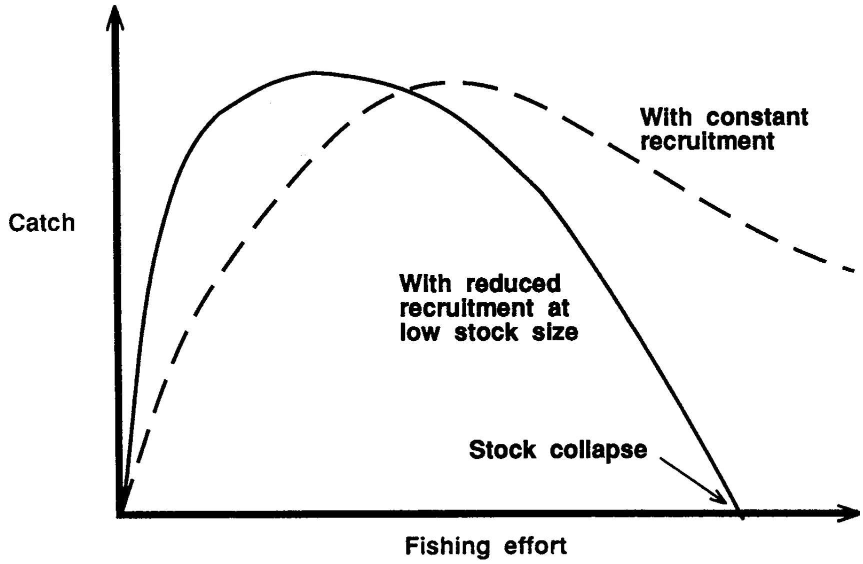


Figure 14. The long-term effect of reduced recruitment at low stock size

judgement. Nevertheless, the prospect of stock collapse is real, even if it only manifests itself as increased risk of poor recruitment when spawning stock size is low. Suggested minimum stock levels can in any case only be taken as a guide, because it is in practice virtually impossible to try to manage to maintain a fixed minimum stock size. A fishery managed in this way would suffer from severe fluctuations of TACs as strong and weak yearclasses enter the fishery, and would often be closed completely whenever recruitment was poor. For this reason the scientific advice is usually framed in terms of increases or decreases of fishing effort (or fishing mortality) as this allows more continuity of effort and supplies to the market, and avoids a precipitate response to short-term fluctuations.

8. THE IMPLICATIONS FOR MANAGEMENT

Reducing the size of a fish stock is easy: given the levels of effort which can be deployed by modern fleets, depletion to a small fraction of the initial size in a few years is quite possible. Engineering a recovery is, however, much more difficult. There is essentially little that a manager can do, except to reduce fishing effort to a low level and wait. Given reasonable recruitment, this will permit the rebuilding of the spawning stock over a period of several years, this being the time needed for the young fish to reach maturity. This increased stock should then provide the basis for improved recruitment in the future. It is, however, not suggested that stock sizes should be increased for their own sake.

When the objectives of fisheries management are considered, it appears that, although there is some conflict among them, most imply that fishing mortality rates should be kept low, and stocks high (see Shepherd, 1990). Unfortunately, the economic forces acting upon fishermen have had, and still have, a tendency to drive effort up to a level where the mortality rate is too high. Reducing effort and mortality rates through management measures has proved to be difficult, largely because of the need to bear a short-term loss in order to make a long-term gain, as explained in this paper. This is a result of the basic dynamics of fish stocks, and there seems to be no way around it.

Hopefully, this publication will help all those concerned to understand why the scientific advice on fisheries management so often calls for a reduction of fishing effort, why this is usually associated with a reduction of catches, why this reduction of catches should be temporary, whilst the reduction of effort is likely to be permanent, why the benefits of such changes usually take a few years to appear, and why control of mesh sizes is not a simple alternative to control of effort. If it does this, it may assist in the task of finding an acceptable way of making the changes that are needed.

9. FURTHER READING

Pope J G (1982). Background to scientific advice on fisheries management. Lab. Leafl., MAFF Direct. Fish. Res., Lowestoft, ***(54)***: 1-26.

Burd A C (1986). Why increase mesh sizes? Lab. Leafl., MAFF Direct. Fish. Res., Lowestoft, ***(58)***: 1-29.

Garrod D J (1986). The scientific essentials of fisheries management and regulations. Lab. Leafl., MAFF Direct. Fish. Res., Lowestoft, ***(60)***: 1-14.

Shepherd J G (1990). Stability and the objectives of fisheries management: the scientific background. Lab. Leafl., MAFF Direct. Fish. Res., Lowestoft, ***(64)***: 1-16.

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