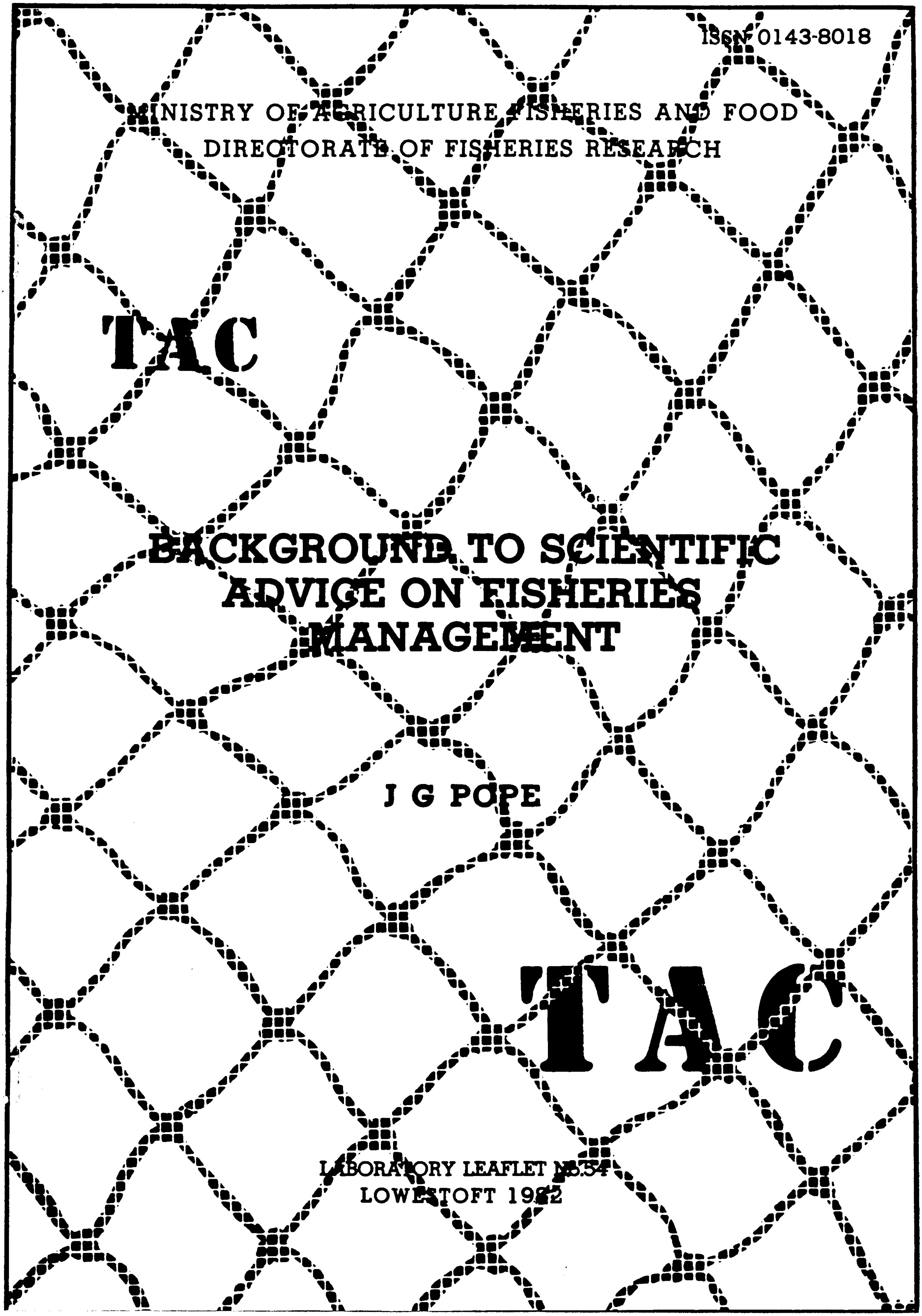

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MINISTRY OF AGRICULTURE FISHERIES AND FOOD
DIRECTORATE OF FISHERIES RESEARCH

TAC

BACKGROUND TO SCIENTIFIC ADVICE ON FISHERIES MANAGEMENT

J G POPE

TAC

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CONTENTS

FOREWORD

Catch limitations and catch quotas have become an important part of fisheries management. This leaflet by John Pope explains the scientific basis for Total Allowable Catches (TACs). In view of the very considerable difficulties in securing international agreement to the allocation of quotas within TACs and the very real problems of enforcing them the interested reader should appreciate this exposition of how TACs are arrived at, their accuracy and the alternative methods that might be employed.

A. Preston
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Laboratory Leaflet Number 54

BACKGROUND TO SCIENTIFIC ADVICE ON FISHERIES MANAGEMENT

J. G. Pope

1. INTRODUCTION

Fishing is unlike other extractive industries in two important ways. Firstly, unlike coal or oil, fish are living and self-renewing: so if they are harvested wisely, they can provide a valuable continuous production. Secondly, fish in the sea are not owned by the extracting industry or even in many cases by one country: so individual fishermen are not in a position to husband the resource on which their industry is based; restraint by an individual simply makes more of the resource available to his competitors. These two features of fishing mean that fisheries need to be managed and this management cannot be left to the individual producer.

The essence of managing fisheries to give a sustainable yield is to prevent too many fish being removed in any one year and to prevent fish being caught at too young an age. What proportion to remove and at what age will of course vary from species to species.

There are various ways in which this protection can be given. The age at which fish can be caught might be influenced by the mesh size of nets, by imposing minimum sizes on fish which can be landed or by introducing closed areas and/or seasons for fishing to protect nursery areas. Similarly the proportion of fish removed in a year can be regulated by restricting the catch or by restricting the number of fishing boats. Alternatively, this proportion might be regulated by measures which cause the fishing to be less efficient, for instance, closed areas or closed seasons to protect the fish when they are most easily caught, for example, when they are spawning. Limiting the catch of fish by imposition of catch quota is currently the most commonly adopted of these regulatory measures for North Atlantic areas.

To be able to arrange this protection fisheries managers need advice from scientists. This scientific advice is rather like the advice that a ship's navigator gives his captain. They give the current position of the fish stock and the course that the managers should take in order to achieve their objectives. As with the ship's navigator, the choice of objective is not the scientists' job but they may have to quantify the stated objectives of the managers.

The objective of this leaflet is to explain in non-specialist terms how fisheries scientists provide the biological advice for fisheries management. As catch limitations and catch quotas are now such an important method of fisheries management, the way in which they are derived is the main theme of this leaflet. Paragraphs marked with a marginal line deal with technical explanations which the non-mathematical reader may prefer to skip.

2. A BACKGROUND TO FISHERIES MANAGEMENT ADVICE

2.1 Why management is necessary

A fishery only occurs when fish are available to be caught, when men and vessels are available and able to catch and process them, and when a market is prepared to buy them at a price making catching worthwhile. Thus the health of a fishery must be judged by the catch of fish, the viability of the fish stock which gives the catch, the profitability of the vessels which fish it, and the earnings and employment prospects of the men employed in the industry.

As with most real life situations, the existence of more than one way of judging success of a fishery means that its relative health will seem different to different people. Consequently, there will be no one 'best situation' for a fishery to be in. Nevertheless, it may well be possible to find some situations which form an acceptable compromise from the viewpoint of most people concerned.

It is clear from a study of the history of fisheries that such reasonable compromise solutions do not occur naturally. Indeed, in several well-documented cases a state of affairs has been reached in which the fishery is unhealthy from all viewpoints (no catch; no fish; no vessels; no fishermen). Clearly a laissez-faire policy cannot be relied upon to ensure fisheries success, and some form of fisheries management is generally necessary.

2.2 Biological objectives

The conclusion that fisheries management is necessary begs the question of what precisely should it try to achieve. It has been realised for many years that the catches from fish stocks obey the law of diminishing returns. Thus, if twice as many vessels go fishing for a stock of fish the catch in the long term will not be twice as big; indeed, it is quite possible that the total catch may actually get smaller. Figure 1 shows a typical production curve, the relationship between the amount of fishing and the long-term fish yield. In this figure the amount of fishing at position B is twice that at A and half that at C. If the amount of fishing increases from A to B (a 100% increase) the yield in the long term goes up from 170 000 tonnes to 210 000 tonnes, an increase of only 24%. If the amount of fishing again increases by 100% from B to C then the long-term catch drops to 145 000 tonnes, a decrease of 31%. It must be stressed that the yields discussed here are the long-term catches: the short-term effect of doubling the amount of fishing would be an increase in catch, but this would not be sustained. The catch at the peak of the yield curve (at B in Figure 1) is called the Maximum Sustainable Yield (MSY). Levels of fishing effort higher than that at B are regarded as over-fishing. Point D represents fishing to extinction.

2.3 Economic and social objectives

A policy which maximises the long-term catch from the fishery might not be considered ideal, either for vessel owners or for fishermen who understandably measure success in money and employment. How these criteria of success may be affected by the amount of fishing can be seen from

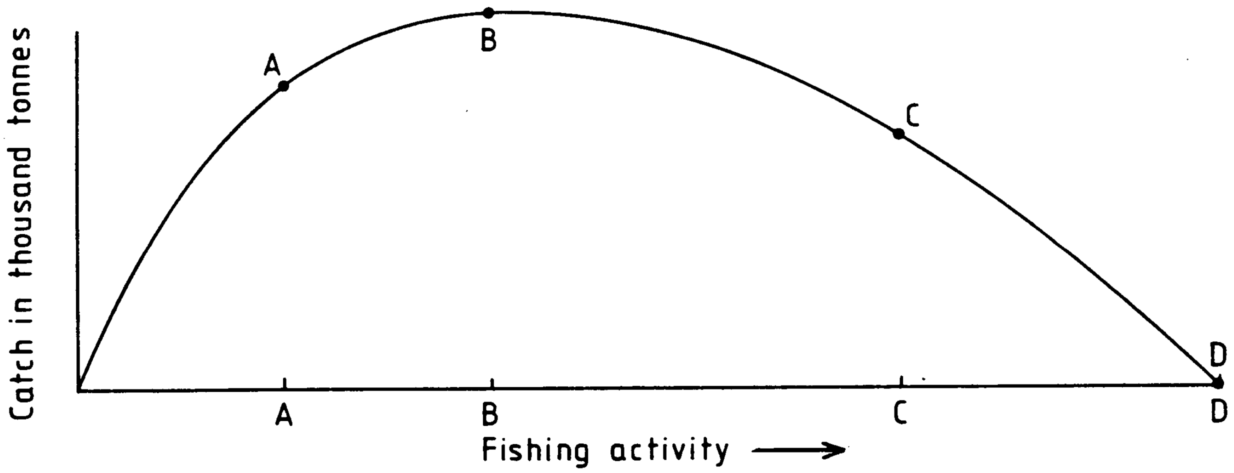

Figure 1 A typical production function for a fish stock.

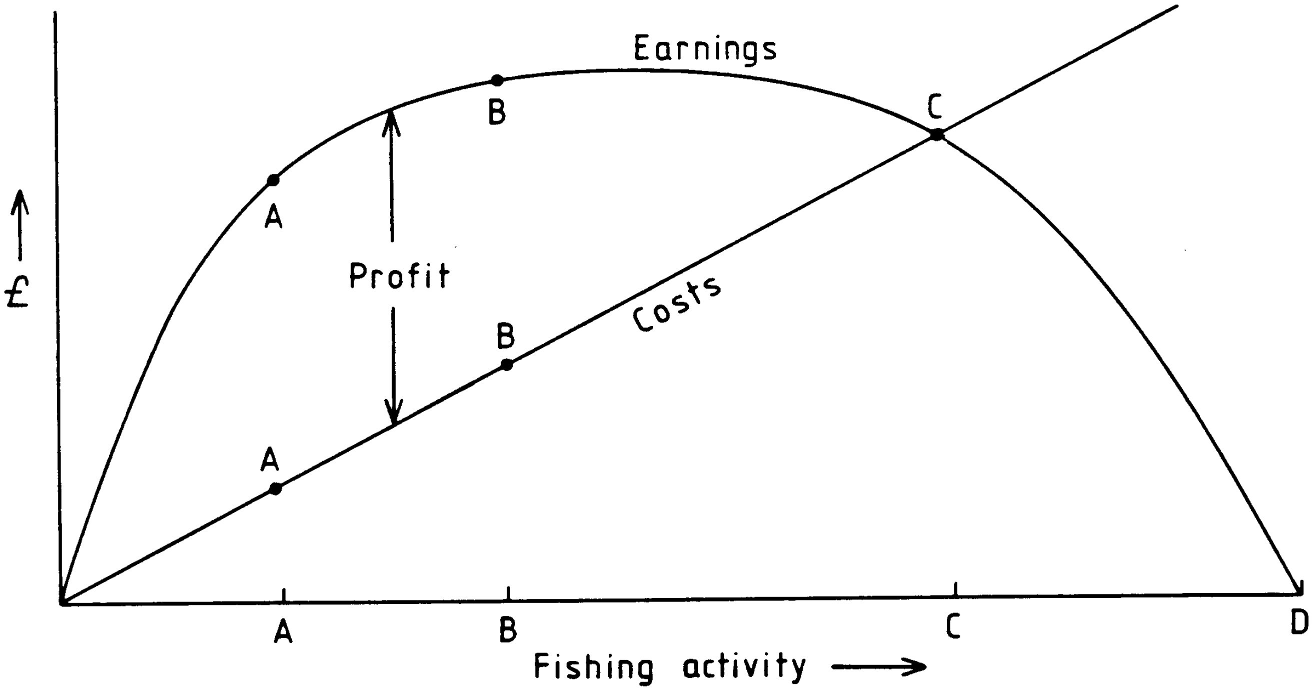

Figure 2 Relationship of earnings and costs to fishing activity.

Figure 2 which shows the costs and earnings that might be related with the fishery described in Figure 1. The cost curve shows proportionate increases as the amount of fishing increases. In other words, doubling the amount of fishing doubles the cost. The earnings curve shows an initial increase followed by a decrease. Earnings increase more rapidly and decline more slowly than the catch shown in the yield curve in Figure 1, because the unit value of fish tends to adjust to the level of supply. The difference between the costs curve and the earnings curve is, of course, profit. It can be seen that this is at a maximum at or near point A rather than at point B which, as we saw before, is the level of fishing at which the catch is maximised. The catch at A is sometimes called the Maximum Economic Yield.

In this particular example, the two curves happen to intersect at point C. At this point the fishery just breaks even - not an advantageous situation since the catch is well below the maximum and there is no profit. However, fisheries are a very competitive business and, because restraint in fishing by one company or country would simply leave room for expansion by competitors, the tendency is for fisheries to drift towards the break-even point. This over-capitalised situation might be the best for maximising employment for fishermen, but not for maximising their earnings. From most points of view, therefore, a reduction in overall fishing levels might well seem desirable.

2.4 Short-term effects

The arguments given above refer to the long term. In the short term a move from a higher level of fishing to a lower level implies an immedidiate loss of catch and therefore probably an immediate loss of earnings. The situation is analogous to that of a man whose sole income is from £30 000 invested at 10% - if he wants to double his long-term income he must reinvest some of his current income in order to build up his capital to £60 000. Similarly, the implications of fisheries management theory to a fishery in an overfished condition are of 'jam tomorrow' at the expense of some 'bread and butter' today. In an industry with narrow operating margins there is understandably a reluctance to make such a transition rapidly. The exception to this would be where the fishery was approaching the point D in Figures 1 and 2, i.e., the point at which the fishery is effectively extinct. In this situation the need to protect the stock must necessarily take precedence over all other factors.

2.5 The choice of objectives

From these considerations it is clear that the various interests are not all likely to be satisfied simultaneously at one particular level of fishing. The policy therefore will be some compromise between the various interests. It is the job of fisheries managers to seek such a compromise and to translate it into management action. In practice this is bound to be difficult, particularly for international fisheries. Different countries involved in a fishery have different cost and earning relationships and will give different weightings to the various objectives. Because of this lack of agreement on management objectives and because the non-biological objectives are rarely quantified, the biological concept of MSY tends to be adopted. The strategy of trying to achieve this yield is, however, modified in practice in the case of heavily over-exploited fisheries by the realisation that a rapid reduction from high levels of fishing to MSY levels of fishing would be extremely disruptive in the short term. Similarly, for developing fisheries where increases in fishing might be expected, it would certainly be a good idea to limit the rate of development to fairly small percentage increases in order to avoid overshooting the objective. For these reasons the long-term objectives of fisheries management are usually expressed as the attainment of MSY but the short-term objectives are expressed as some percentage change from the current level of fishing activity.

2.6 Defining the immediate objective

So far in this leaflet we have talked about fishing activity in a loose way. Obviously the concept of fishing activity will be understood in different terms by different people. To a vessel owner it might be measured in numbers of vessels or perhaps more properly in operating costs. To someone interested in employment in the fishing industry it might relate to numbers of men employed as fishermen or as ancillary shore workers. To the fisheries scientist, however, it means the level of fishing mortality on the fish stock.

Paradoxically, instead of referring to deaths of fish, the precise scientific definition of fishing mortality refers to survival. That definition is 'the negative of the natural logarithm of the proportion of fish surviving fishing in a year'. This is guaranteed to puzzle and confuse non-specialists. If you understand it you can skip the next few paragraphs marked with a marginal line. If you do not understand this and loathe mathematics you should also skip those marked paragraphs but first look at Figure 3 which shows how this quantity that scientists call the

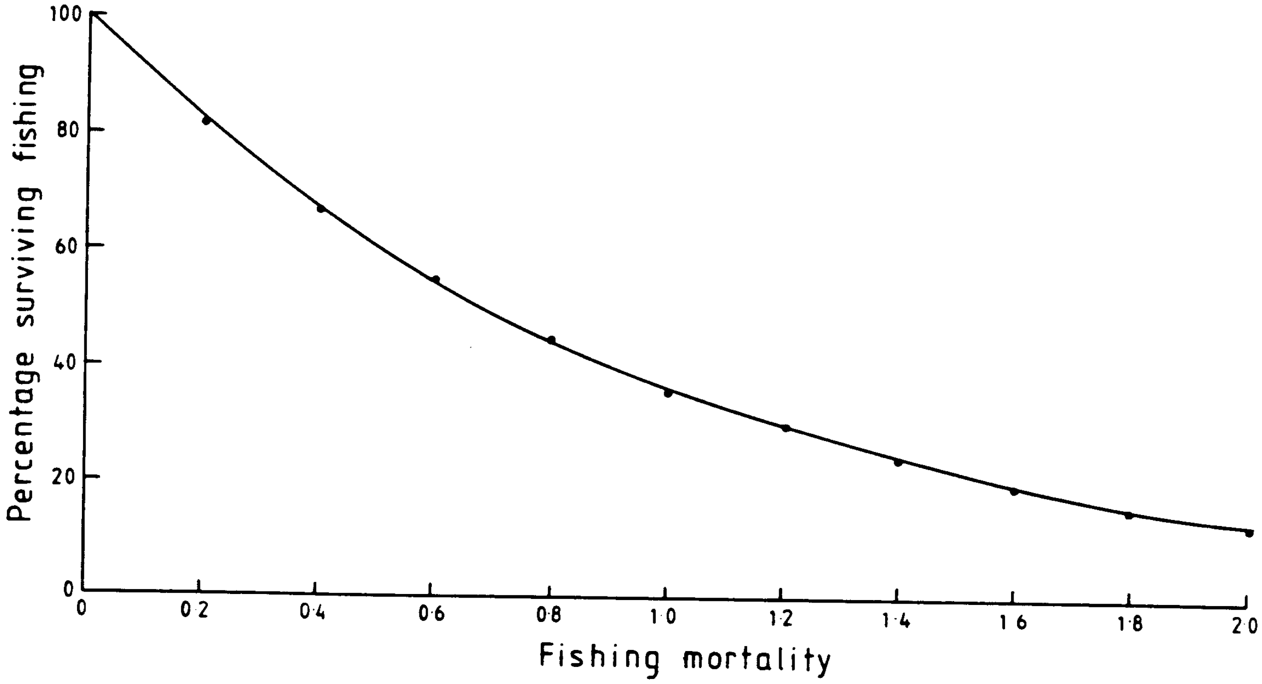

Figure 3 Relationship between fishing mortality and the percentage of fish surviving the year.

fishing mortality (usually indicated by F) relates to the proportion of fish surviving fishing. In this, you will notice that if you have a value of fishing mortality of about 0.7 then half of the fish survive, but if you double this to 1.4 then only a quarter of the fish survive. You can see, therefore, that the higher the fishing mortality the less fish survive fishing.

The definition of fishing mortality given above may seem complicated to a non-specialist but it actually makes a great deal of sense. Since an understanding of fishing mortality is rather fundamental to a discussion of fisheries management it is worth taking a little trouble to understand it.

When we first think about the mortality of fish we usually first think of the proportion dying. For example, a particular fishing fleet might kill 60% of a particular fish stock each year. In practice it is not very useful to consider the proportion dying, because such proportions cannot be added together. For example, if the fleet killing 60% were doubled, obviously it could not kill 120% of the fish. Even using poison or explosives only 100% of the fish could be killed! What happens in such a case is that half of the fleet kills 60% of the fish leaving 40% alive and 60% of this 40% is killed by the other half, leaving 16% of the total alive. Thus the proportion killed by the total fleet is 84%.

You can see from this that describing mortality rates in proportions killed is hardly very convenient. The proportion surviving is somewhat more convenient since the proportion surviving the fishing of two fleets, Fleet A and Fleet B together, is simply the product of the proportion surviving each fleet separately.

Thus

$$\text{Proportion surviving A and B} = \text{Proportion surviving A} \times \text{Proportion surviving B.}$$

It is convenient to take logarithms of this equation because then we get

$$\log(\text{Proportion surviving A and B}) = \log(\text{Proportion surviving A}) + \log(\text{Proportion surviving B}).$$

A nice feature of the logarithm of survival rates is that we can add them together to get the logarithm of overall survival rates. This is very convenient but the logarithm of a proportion (which is always less than 1) is negative so it is helpful to use the negative of the logarithm and get a positive number.

For various technical reasons it is also helpful to use natural logarithms rather than the logarithms to the base 10 usually taught in schools. This is usually written as ln, so we get a new equation

$$-\ln(\text{Proportion surviving A and B}) = -\ln(\text{Proportion surviving A}) \quad -\ln(\text{Proportion surviving B}).$$

Now this negative of the natural logarithm of the proportion surviving is just what we defined as fishing mortality. It is usually written as F, and we can write

$$F_A = -\ln \text{(Proportion surviving A)}.$$

To obtain an equation in terms of the survival rate we need to take the inverse of the logarithm on each side of this equation. The inverse of a natural logarithm is the exponential function which for a value x is usually written as e^x or as Exp(x). Since it is the inverse the relationship

$$\text{Exp}(\ln x) = x$$

always holds. We can therefore take the exponential of both sides of the equation above to give

$$\begin{aligned} \text{Exp}(-F_A) &= \text{Exp}\big(\ln(\text{Proportion surviving A})\big) \\ &= \text{Proportion surviving A}. \end{aligned}$$

Let us now come back to our example. If 60% of fish were killed by the fleet 40% survived, so fishing mortality, F, is given by

$$F = -\ln(40/100) = 0.9163.$$

If we double the fleet we get a fishing mortality of

$$0.9163 + 0.9163 = 1.8326$$

and the new proportion of survivors is

$$\text{Exp}(-1.8326) = (16/100) = 16\%$$

so you can see that with this definition of mortality we have a quantity which should go up or down at the same rate as the amount of fishing goes up or down and which enables us to relate fishing intensity to the survival of fish in the sea.

From the scientific point of view this measure of the amount of fishing is most convenient since it relates directly to the change in the numbers of fish with time in the fish stock. Moreover, it is absolute in that a fishing mortality of, say, 0.7 in 1968 is the same as one of 0.7 in 1978 or any other year; this is not likely to be true of the other potential measures of fishing level. The short-term objectives of management are therefore usually expressed as some level of fishing mortality. For many fisheries this will be closely related to other measures of activity such as money, ships or men.

2.7 Ways of achieving the immediate objective

Expressing the short-term management objective as a desirable level of fishing mortality immediately poses the problem of how it is to be fixed. A fisherman cannot be told to create a fishing mortality of 0.05 next year. Clearly, fishing mortality has to be translated into something more tangible. The most obvious choice is to limit either the amount of fishing done by vessels (fishing effort control) or to limit the catch (catch quotas).

Effort controls present several practical difficulties when applied in international fisheries, not the least of which is the lack of the detailed statistics of fishing effort generated by the various countries concerned. Another practical problem is that effort controls often require a comparison between the amount of fishing effort generated by different types of vessels using different gears for different species. For instance, how should we equate beam trawling with purse-seining? This is most difficult to calculate and makes negotiations difficult. For these reasons managers have generally tended to favour catch quotas, these being somewhat easier to negotiate between countries than effort restrictions. Thus the advice which the managers require from the fisheries scientists is usually the level of catch corresponding to some chosen level of fishing mortality. The scientists call this level of catch the Total Allowable Catch (TAC). The TAC is the maximum total catch that can be allowed to be taken from a stock by everyone fishing it in any one year to meet a specified management objective. Scientists recommend TACs; managers may accept a recommended TAC as it stands or modify it to arrive at an agreed TAC which they then divide up into agreed national quotas.

3. ASSESSING THE CURRENT STATES OF FISH STOCKS

In order to give advice on TACs, fisheries scientists need to discover the current condition of the stock. They also need to find out what would be the optimal state of the stock. Like the ship's navigator they

Figure 4 Measuring North Sea cod on Lowestoft Market.

need to find out where they are and where they want to go to before they can calculate a course. Both the current condition and the optimal state of a fish stock may be considered in this analogy as fixed in terms of a latitude of fishing mortality and a longitude of fish numbers. Unfortunately it is impossible to count directly how many fish are in the sea, so the problem of estimating these numbers has to be approached indirectly. This section of the leaflet explains how the available data are used to estimate these co-ordinates.

3.1 Commercial fishery statistics

The most important types of data are those which describe the commercial fishery. The weight of fish caught and where they are caught are certainly the most crucial items of data to be collected. Also of importance is the estimate of the amounts of fishing in each region.

For accurate assessments to be possible, the total commercial catch from any one fish stock by all countries must be sub-divided into the numbers of fish caught at each age. This can be done if the countries involved in the fishery measure samples of their commercial catch regularly (Figure 4) and find the ages of representative samples of the fish at each length. The measurements give an estimate of the numbers of fish of each length caught by a country. Then, knowing the fish ages, such numbers of fish at each length can be converted into numbers of fish at each age. It is possible to determine ages because many fish species

Figure 5 Cross-section of a cod otolith showing annual rings landed at Grimsby in 1981. The cod was 6 years old and 96 cm in length. Width of cross-section is 9 mm.

caught in European waters carry a record of their age in their bone structure or on their scales. For fish like cod and haddock the otolith or ear stone is the most convenient to study. In a large cod it is about the size and shape of one segment of a runner bean seed (Figure 5). It has a ring structure which, when seen in section, corresponds to the age of the fish (rather like a tree stump). Consequently estimating the total international catch numbers at each age is a feasible undertaking for many species of fish. At present this type of information is made available regularly from the British catch for all the fish stocks shown in Table 1. This is a considerable undertaking but one which is essential if accurate fisheries assessments are to be made.

Table 1 Fish stocks sampled by MAFF for catch numbers at age sampled

	North Sea	West of Scotland	Irish Sea	Channel	Westerly	Other areas (No. of stocks)
DEMERSAL FISH						
Cod	✓	✓	✓	✓	✓	✓ (3)*
Haddock	✓	✓	✓	-	-	✓ (3)*
Whiting	✓	-	✓	✓	-	
Saithe	✓	✓	-	-	-	✓ (3)*
Ling	-	-	-	-	✓	
Plaice	✓	-	✓	✓	-	
Sole	✓	-	✓	✓	✓	
INDUSTRIAL FISH						
Blue whiting	*	*	-	-	-	✓
Sandeels	✓	-	-	-	-	
PELAGIC FISH						
Herring	✓	-	✓	✓*	-	
Mackerel	-	-	-	-	✓	
Sprat	✓	-	-	✓	-	
Pilchard	-	-	-	-	✓	
Scad	-	-	-	-	✓	

*sampled as opportunity arises.

3.2 Other sources of assessment data

Commercial statistics are the chief source of data for stock assessments. This is because they relate directly to the problem of estimating fishing mortality. However, there are questions which commercial statistics do not answer and for these research vessel data are needed. Indeed, in some cases where adequate commercial data are not available, research vessel data may be the only basis for making assessments. This is particularly likely to be the case where a new fishery develops, such as that for the blue whiting to the west of Britain or where a fishery is closed, e.g., the North Sea herring in recent years. Some of the most useful types of research data for assessment purposes are the results of tagging experiments, egg surveys, young fish surveys, echo surveys and groundfish surveys.

Tagging experiments consist of labelling large numbers of fish at sea using one of the many types of fish tag. These are individually numbered so that each fish's origin of tagging can be traced and the details (length, position, etc.) of the fish, when it is recaptured by commercial fishermen, can be compared with those at the time of tagging. Such results are particularly useful in the earlier stages of the assessment of a stock of fish when it is necessary to decide the sea area that the stock inhabits, for instance, to show that North Sea cod are separate from Faroe cod. The tagging experiment results are also valuable for determining mixing rates between different stocks of fish. In simple cases tagging results can also be used to investigate mortality rates and population sizes.

Echo surveys seek to estimate the size of a population of just pelagic fish, by using echo-sounding equipment to plot the density of fish; this is difficult to do, particularly where various species are found in the same area. Even where species are found in comparative isolation such as the blue whiting to the west of the British Isles (see: Blue Whiting, by M. G. Pawson, Laboratory Leaflet, MAFF, Directorate of Fisheries Research Lowestoft, No. 45) it is difficult to obtain accurate estimates of abundance because of the size of the area to be surveyed, the logistic problems of sampling, and technical problems in interpreting the echo signals received by the surveying vessels. Nevertheless, such estimates can be valuable in the setting of precautionary catch levels intended to protect the stock while more precise estimates are being developed.

Egg surveys are another way of estimating the size of a fish population. Most fish (herring is a notable exception) produce eggs which float and develop in the plankton. In an egg survey, plankton net hauls are made in the region where the fish spawn and the total number of eggs they produce during the year is estimated. Given a knowledge of the number of eggs a female fish produces during a year, it is then possible to estimate the number of adult female fish in the population. The total number of fish can then be arrived at by using the relative proportion of adult females to adult males and all juveniles that are found in the catch.

Groundfish surveys are an attempt to measure directly the abundance of demersal fish each year by using a bottom trawl as a survey instrument. By repeating surveys annually, it is possible to monitor changes in the abundance of the numbers of fish at each age and hence to estimate mortality directly.

All research vessel work inevitably suffers from the comparatively small amount of sampling that can be achieved, so estimates based on it tend to be less precise than those based on the far greater amount of sampling of the fish stock that is given by studies of commercial fleet landings. Nevertheless, such surveys are very useful for obtaining estimates where commercial data do not exist and for giving cross checks where they do. In some cases a number of estimates obtained in the different ways described above can be combined to give a far more accurate stock assessment than can be obtained by the use of one method. Of course, as our experience of both the stock and of the data base grow, our estimation of the stock improves in accuracy.

3.3 Estimating the numbers of fish at age and the level of fishing mortality

In order to be able to predict future catches, scientists have to be able to estimate how many fish at each age are in the sea now and what proportion of each age group will be caught each year.

People are often surprised to hear how long some fish can live. For example, large plaice are regularly found which are 20 years old and even specimens of 30 years or more are not unknown. Another feature of fish stocks which frequently causes surprise is the large variation in the numbers of fish entering the fishery each year. For example, the number of 0-year-old (in their first year of life) haddock in the North Sea in 1967 was about 33 times greater than the number in 1969. These two features of fish stocks make a knowledge of the current age structure of the population very important when estimating how catches are going to change in the future. They also make it important to know how the fish change in weight with age and how the numbers in each brood or cohort change as the group gets older. Changes in numbers for most fish stocks after the larval and juvenile stages are chiefly due to catches (fishing mortality), so it is necessary to know how this may vary from one age group of fish to another.

In order to estimate how many fish there are in the sea, fisheries scientists start off by estimating how many there were some years ago. This is done using a method known as cohort analysis. A cohort of fish is another name for a brood or year-class, the fish spawned in a particular year. The cod spawned in 1970 are one such cohort. They were 0 years old in 1970, 1 year old in 1971 and so on. Cohort analyses are made using the total catch at each age of life. This information is available because over the years many countries have collected catch-at-age data in the way explained above. It is thus possible to obtain the total international catch of such species for each age each year. From these data it is simple to pick out the total catch each year of the various year-classes.

Considering just one of these, the 1970 year-class of North Sea cod for example, would give catch-at-age data from 1971 when it was 1 year old to 1980 when it was 10 years old. The problem then is to reconstruct the number of fish at each birthday (taken to be the first of January) which give rise to the catches from the year-class. If fishing were the only source of death this would be very straightforward since obviously

$$\text{Number (age 9)} - \text{Catch (age 9)} = \text{Number (age 10)}. \qquad \text{(Equation 1)}$$

If the number at 1 January 1980 of 10-year-old cod from the 1970 age group were known, then it would be straightforward to use equation 1 to calculate the number at 1 January 1979 of age 9 cod. A similar equation to equation 1 would give the number of age 8 fish at 1 January 1978 and so on.

The number of 10-year-old cod in 1980 is, of course, not initially known but it is possible to make an intelligent guess to use in equation 1. For North Sea cod an intelligent guess might be that the number of 10-year-old fish on 1 January 1980 was twice the number caught in 1980. Using this guess or assumption it is then possible to estimate the numbers of fish at age 9, age 8 and so on in the preceding years. Table 2 shows the total international catch of North Sea cod from the 1970 year-class

Table 2 Estimates of the numbers at age of the 1970 year-class of North Sea cod made using cohort analysis

Age	Year	Catch numbers at age in thousands	A	B
			Numbers at age estimated using Equation 1. (No natural deaths)	Numbers at age estimated using Equation 2. (Natural death of 18% per year)
1	1971	80 551	355 018	497 485
2	1972	196 498	274 465	335 147
3	1973	52 670	77 969	97 540
4	1974	14 869	25 299	32 462
5	1975	6 484	10 430	13 201
6	1976	2 439	3 946	4 975
7	1977	926	1 507	1 878
8	1978	364	581	705
9	1979	127	217	250
10	1980	45	90	90

and the resulting numbers at each age, assuming that the number of 10-year-old cod on 1 January 1980 was double the catch. Column A of this table shows that, with this assumption, the number of fish of age 1 on 1 January 1971 was 355 018 000. It is clear that this would change very little in percentage terms if a different assumption about the numbers of 10-year-old fish had been used. For example, if it were assumed that there were in fact twice as many cod aged 10 on 1 January 1980, then the estimate of the number of 1-year-old fish in 1971 would become 355 108 000, an increase of only 0.03% on the first estimate. It is clear from this that the estimate of the numbers of the young fish are very little altered by the assumed numbers of 10-year-old fish.

The estimates of numbers at age made above were, however, made disregarding natural deaths, for example those caused by being eaten by other fish. These can be regarded rather like a discount rate in business. For cod in the North Sea, if there was no fishing, numbers would be reduced by about 18%* a year. Thus the 8-year-old cod at 1 January 1978 are the

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*For mathematicians:
Natural mortality is defined in a similar way to that already described for fishing mortality. It is usually denoted by the letter M. For North Sea cod its value is about 0.2 per year, so a proportion of Exp(-0.2) would survive each year if there was no other mortality. Since Exp(-0.2) is approximately equal to 0.82 (i.e., 82% survival) it follows that if this were the only cause of death 18% of the North Sea cod would die each year. In a similar way, in half a year a proportion of Exp(-0.2 x 0.5) would survive. Since Exp(-0.1) is approximately equal to 0.905 (i.e., 90.5%) it follows that 9.5% of the North Sea cod would die in half a year if natural mortality were the only cause of death. The values 1.10 and 1.22 in equation 2 (on page 14) are, in fact, just approximations to the inverse of the survival rates, i.e., Exp(0.1) and Exp(0.2). That equation can be written more generally as

Number (age a) - Catch (age a) x Exp(M/2) = Number (age a+1) x Exp(M).

This is known as Pope's cohort analysis formula.

survivors from the number of fish at 1 January 1977 reduced by 18% due to natural deaths. On the other hand, the catch was taken on average about halfway through the year, so they are really the survivors from the number of fish at 1 January 1977 reduced by about 9.5% by natural deaths. It follows that if the numbers at age 8 are increased by a factor of 100/(100-18), which equals 1.22, and the catches are increased by a factor of 100/(100-9.5), which equals 1.10, then equation 1 can be rewritten to take account of natural deaths of North Sea cod. The new equation is

$$\text{Number (age 9)} - \text{Catch (age 9)}\ 1.10 = \text{Number (age 10)}\ 1.22. \qquad \text{(Equation 2)}$$

Equation 2 can be used in the same way as equation 1 was to generate the numbers of the younger ages of cod. As before, the number of 10-year-old cod has to be assumed. Column B of Table 2 shows the resulting numbers at age for the 1970 cohort of North Sea cod. In this way it is possible to estimate how many fish were in the sea at each age in past years. This information is extremely valuable since it allows other information about relative abundance to be calibrated to absolute numbers, for example, the catch rate of the commercial fleet increases when the exploitable biomass of fish is high and decreases when it is lower. It is then possible to calibrate these catch rate changes and to see how the size of the exploitable biomass has changed in the most recent year. This information can then be used to correct the initial estimates of the numbers at age of fish in the most recent year used in the cohort analysis. In this way it is possible to estimate the numbers of each age of fish caught in the last year for which catch data are available and to calculate the fishing mortality.

Clearly, the cohort analysis results are fundamental for fish stock assessment and this is the reason why fisheries scientists stress the importance of the proper reporting and sampling of commercial fisheries data: they are not alchemists who can make gold out of dross.

3.4 Estimating the optimal state of a fishery

How fisheries scientists decide which fishing mortality is optimal can be best explained by a simple example. Figures 6 and 7 show what happens to an imaginary fish (the "squarefish") stock at two different levels of fishing. These fish live for four years until they spawn and die. Thus, the only catches are of fish aged 1, 2 and 3 years; these fish have weights of 1, 4 and 9 kg respectively. The diagrams show the numbers caught, the numbers surviving and the numbers dying of natural causes at each age from a cohort of 100 fish at their first birthday. Figure 6 shows these when 36% of fish are caught each year, 14% die from natural causes each year and 50% survive to the next year.* Thus the

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*The background to this is that the equation for catch numbers is

$$\text{Catch} = \text{Population} \times \frac{F}{F+M}\left[1 - \text{Exp}\left(-(F+M)\right)\right]$$

where M is the natural mortality, and F is the fishing mortality.

Natural death numbers are given by the equation

$$\text{Natural Deaths} = \text{Population} \times \frac{M}{F+M}\left[1 - \text{Exp}\left(-(F+M)\right)\right]$$

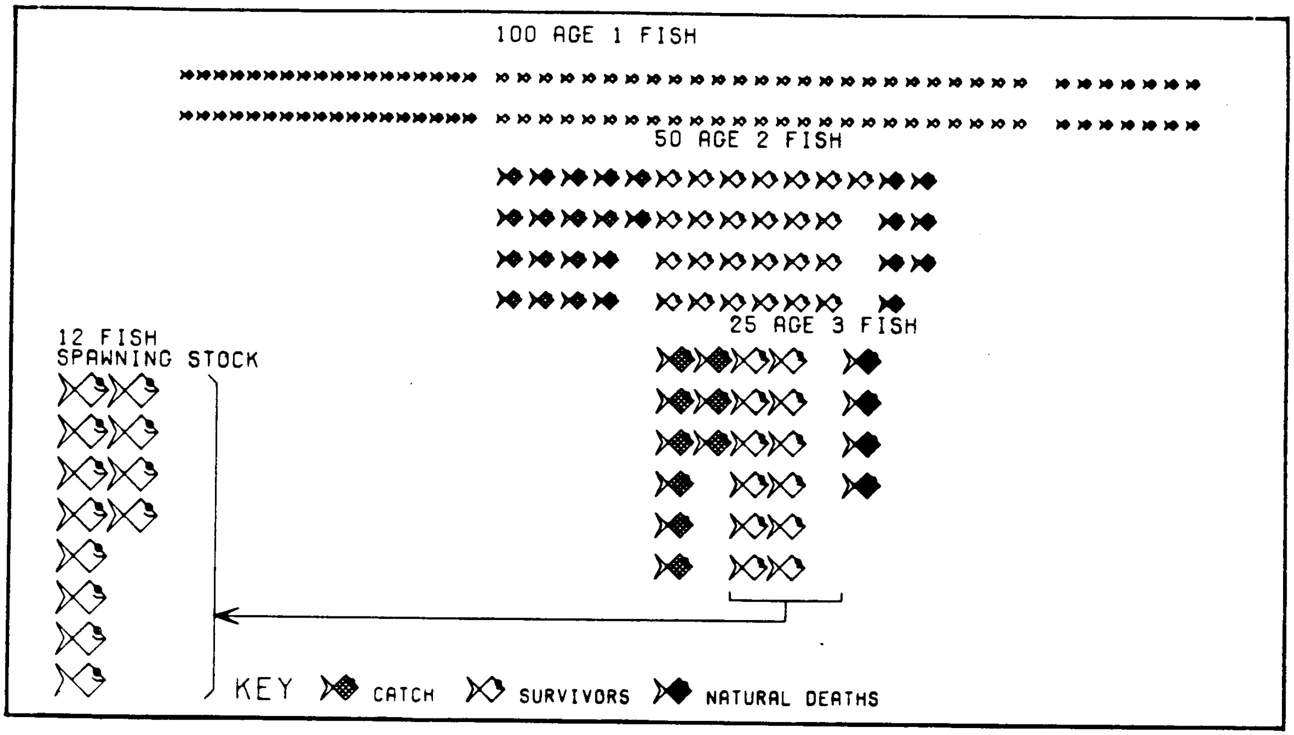

Figure 6 The squarefish. An example of yield from a fish stock at an intermediate level of fishing mortality.

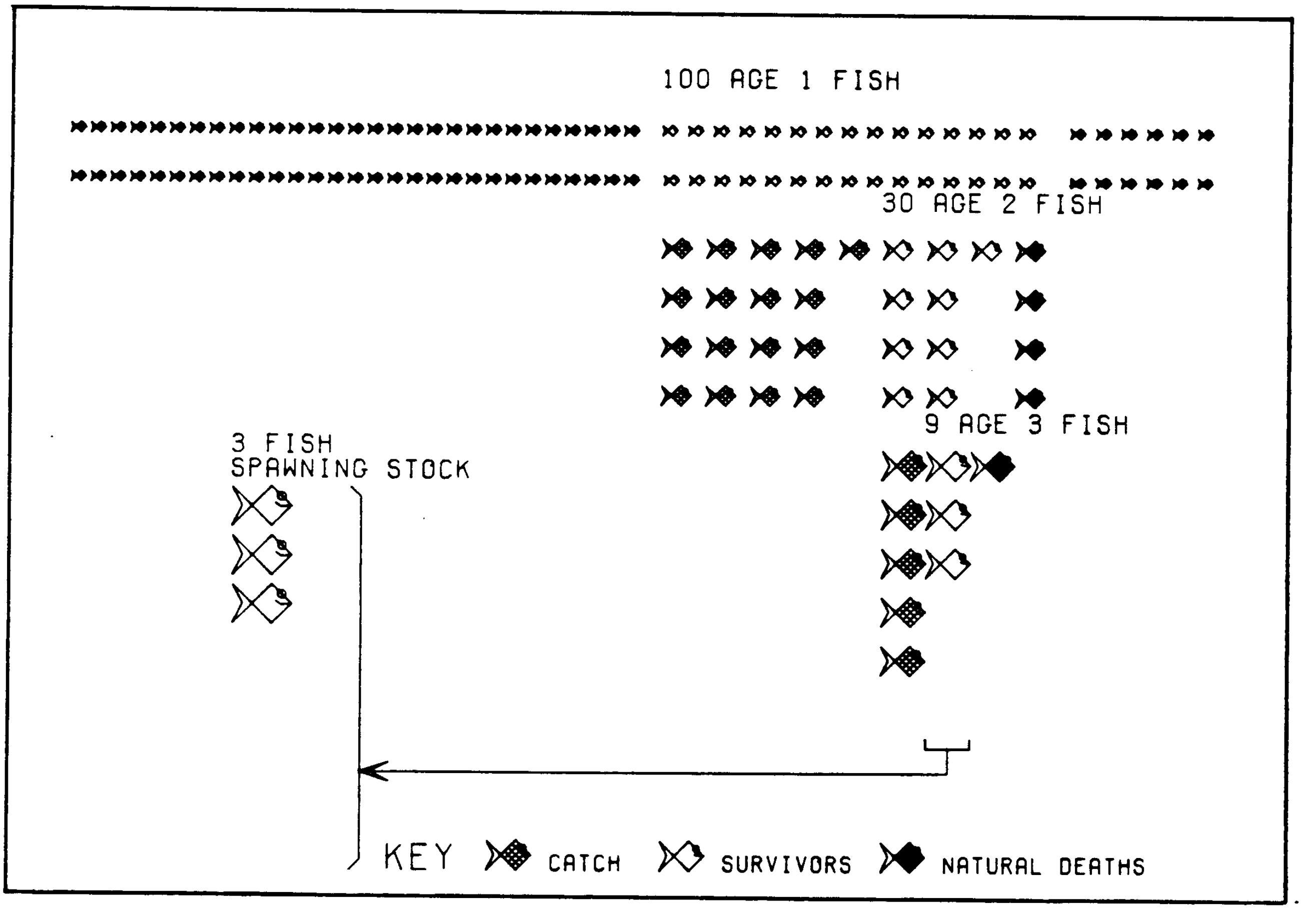

Figure 7 The squarefish. An example of yield from a fish stock with a high level of fishing mortality.

catch numbers are 36 at age 1, 18 at age 2, and 9 at age 3. To obtain the yield, these catches are multiplied by the weight at age of the fish and this gives a total yield of 36 x 1 kg plus 18 x 4 kg plus 9 x 9 kg = 189 kg. Figure 7 shows the result of doubling the amount of fishing. The effect is that catch numbers become 58 at age 1, 17 at age 2, and 5 at age 3. The yield is now 58 x 1 kg plus 17 x 4 kg plus 5 x 9 kg = 171 kg. Thus, although increasing the amount of fishing has increased the total numbers of fish caught from 63 to 80, the weight of catch has decreased because too many were caught at too young an age. The yield could in both cases be expressed in terms of the average yield given by a single fish recruiting to the fishery at age 1. This is called the yield per recruit and is 1.89 kg per recruit in the first case and 1.71 kg per recruit in the second. Expressing yields in this way allows the relationship between the numbers of fish born and the level of exploitation to be considered separately. Similar calculations could be made at a number of different exploitation rates until a relationship between the yield per recruit and the fishing intensity could be plotted. This would indicate the point at which the greatest yield per recruit could be obtained from the fishery.

Thus, estimating the effects of changes in fishing intensity is fairly straightforward, at least in yield per recruit terms. In each of our examples so far we have postulated a fixed number of recruits. The situation in real life is, however, not so simple. If the relationship between the level of fishing and the numbers of fish entering the fishery (the recruits) was straightforward, then it would be an easy matter to convert yield per recruit curves into overall yield curves. This would be achieved by multiplying the yield per recruit value obtained at each level of fishing mortality by the numbers of recruits at that level of mortality. Unfortunately, such a relationship is usually very difficult to identify clearly. It can be seen from comparing Figures 6 and 7 that more spawning fish were produced in the cases when the fishing intensity was lower. Intuitively, one would say that larger numbers of older fish, which would be available when fishing intensity is low, might be expected to give more recruits. In practice it is usually difficult to demonstrate that this occurs. This is due to the variability in the numbers of recruits from year to year. This occurs because of fluctuations in the natural environmental conditions and also because of the inherent compensations which occur within fish stocks and which can cause lower survivals in years when there are more eggs spawned and *vice versa*.

Fish stocks seem able to compensate to a certain extent for reduced levels of spawning stock, but for some the point at which the spawning stock is no longer able to replace the stock can and has been reached. If this happens, the basis of the fishery rapidly disappears unless the drastic management measure of closing the fishery is quickly adopted. Unfortunately, in the past this situation has on several occasions been recognised too late and the management action has been too little and too late to save the fishery. The southern North Sea herring is a classical example of such a collapse. It is easy to see that this type of over-fishing (recruitment over-fishing) has far more serious consequences than the type of over-exploitation that only reduces the yield per recruit (growth over-fishing). It is less easy, however, to deal with because the relationships between the size of the spawning stock and the subsequent number of fish recruiting to the fishery are difficult to establish before the point of collapse has been reached. Despite this, it is possible to adopt two useful rules for dealing with this situation: (1) be vigilant in monitoring recruitment, so as to give early warning of any stock collapse (this monitoring can best be done by research vessel surveys); (2) prefer management options which give a larger spawning stock size. Management advice is usually given in yield per recruit terms but these rules for preventing recruitment overfishing should nevertheless always be carefully observed.

4. THE CALCULATION OF TOTAL ALLOWABLE CATCHES

4.1 Basic concepts

The basic ideas behind calculating a Total Allowable Catch (TAC) are very simple. Section 2 explained that the objectives of fisheries management are generally expressed as a desired level of fishing mortality. This can be interpreted as the proportion of the available fish which it is intended to catch in a year. The problem of estimating the catch which will achieve this mortality (the TAC) is therefore simply that of estimating the biomass of the fish which are available for capture in the year for which the TAC is to be set.

4.2 The nature of exploitable biomass

The exploitable biomass of fish is the total weight of fish available to the fishery during a year. Thus, it is the sum for all ages of fish, of the numbers of fish in each age group, times the weight of a fish of that age, times the availability of fish of that age. This quantity, in fact, is not often directly calculated by fisheries scientists when calculating TACs, because its use implies some approximations to the theory of fisheries which can be circumvented by other means. Nevertheless, as a concept for explaining how TACs are constructed, it has the great virtue of simplicity.

Consider first the availability of fish at the various ages. Differences in availability with age are partly an effect of mesh size and partly an effect of the grounds fished. Suppose that the nets used catch fish when they attain a certain size, and that this size is attained on average at an age of 2.5 years. In this simple case fish of ages 0 and 1 would not be caught at all, while fish of 3 and older would be caught with the full fishing intensity. Fish of age 2 would only suffer the full fishing intensity for half the year. The availability is therefore zero for age 0 and age 1 fish, 0.5 for age 2 fish and 1.0 for fish of age 3 and older. In practice this simple picture tends to be complicated by the fact that the fish of a given age have quite a wide range of sizes. The availability factor is also affected by the fact that the size and age of fish caught differ from place to place and from one time to another. A fishery based on spawning fish will have a very different age structure in its catches from one based on the nursery areas of the same fish stock. Such differences could alter the proportion of fish available for capture at the various ages. Fisheries scientists call this proportion the exploitation pattern. They regard it as modifying the fishing mortality on the various ages of fish; but, for simplicity and without serious error, we can think of it as the proportion of the fish at each age which are available for capture. To estimate it, an average of the proportions of the fishing mortalities acting on the various ages of fish in past years is used. This, of course, is one of the results obtained from cohort analysis.

Consider next the weight of the fish at each age. This is based on the average results from previous years. As with other biological characteristics, it may vary from place to place and year to year.

The last factor to be considered is the numbers of fish at the various ages. This is the most difficult factor to estimate, because the number of fish born each year varies widely and consequently the numbers of fish at the various ages can vary considerably from year to year. It is obvious, therefore, that estimates of the number of fish at age cannot safely be based on long-term average results. It is necessary to find out how many fish there actually are.

The way in which these three factors can be estimated is best described using an example. Unfortunately, the fish stocks for which scientists make assessments do not afford simple examples. This is because in real life various complicating details have to be taken into account (e.g., fish discarded at sea). In explaining how TACs are calculated these details would prove confusing, so the process can be better explained in terms of an imaginary fish stock which we may call the North Sea pseudofish.

4.3 Setting a TAC for the North Sea pseudofish

In making this assessment of the North Sea pseudofish we must put ourselves in the situation of an ICES* working group. Let us imagine therefore that we are the ICES Pseudofish Working Group meeting in the spring of the current year. Our objective is to set a TAC for the pseudofish next year, so that by the end of this year the managers can meet and agree national allocations (quotas) for next year. The immediate objective of the management is to reduce fishing mortality next year to 90% of its level last year. Our first problem, therefore, is to estimate what the fishing mortality was last year. For this we need to use cohort analysis, which requires catch-at-age data.

At the time when our working group is meeting no catch-at-age data are available for the current year. But complete catch-at-age data are available for last year and for previous years. We therefore interpret this catch-at-age data to give fishing mortalities and population sizes in past years, using cohort analysis. The fishing mortality results of the cohort analysis can then be used to calibrate fishing effort data, based on North Sea trawlers, in terms of fishing mortality. The level of this fishing effort last year indicated that fishing mortality was 0.9 on the 2- and 3-year-old fish last year. This means that the fishing mortality on ages 2 and 3 should be reduced to 0.81 (0.9 x 90/100)and corresponding reductions should be made on other ages. In turn, this means that next year about 51% of the exploitable biomass should be removed.

The next question we need to ask is how large will the exploitable biomass be next year. To answer this we need to know how many of the various ages of pseudofish will be present in the North Sea next year, how much each age of fish will weigh, and how available the various ages of fish are to capture.

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*ICES is the standard abbreviation for the International Council for the Exploration of the Sea, whose headquarters is in Copenhagen, Denmark.

Weight at age is a fairly straightforward problem. Most of the countries involved in the fishery have been ageing fish and recording their weight. We are therefore able to estimate an average weight for each age of fish. If we wish, we may check these average weights at age by multiplying them by the numbers caught at each age last year. If our average weights are correct then the sum of these products should equal the total weight landed by all countries. If it does not, we may need to adjust our results in the light of the discrepancy.

The availability of each age of fish to capture (the exploitation pattern) is also fairly easy to estimate since we will use the average availability at age that we have observed in past years from the cohort analysis results. We might, however, need to change these if new mesh size regulations were to be enforced next year.

The biggest problem we are likely to have is in estimating the numbers of fish at each age that will be in the sea next year. Firstly, since the youngest pseudofish caught in any year are one year old, we need to recognise that only fish which would be 3 or older next year appeared in last year's catch-at-age data. These fish, which will be three years old next year, were, of course, only one year old last year. From experience, the working group knows that it is difficult to estimate the numbers of such young fish from commercial catch data because their availability fluctuates from year to year. Thus, in this example, only that part of the exploitable biomass based on fish aged 4 or older can be extrapolated from previous catch-at-age data based on commercial catches. Fortunately, the numbers of the 1-year-old pseudofish and 2-year-old pseudofish are quite well estimated from the results of the ICES North Sea International Young Fish Survey. Figure 8 shows a plot of numbers of fish caught per hour in this survey in past years compared to the number of fish entering the fishery as 1-year-olds (estimated using cohort analysis). It is clear that there is a strong relationship between the survey index and the numbers of fish entering the fishery. Nevertheless, the estimates of the numbers of fish at age 1 based on the survey index are by no means exact. For example, the survey indices were much the same in 1966 and in 1972, but the numbers of 1-year-old fish as estimated by cohort analyses were 283 million and 158 million respectively. It follows that using survey indices to estimate the numbers of 2- and 3-year-old fish next year considerably reduces the uncertainty as to their numbers but does not eliminate it. The numbers of 1-year-old fish next year are, of course, not estimated by any survey results because at the time of our working group meeting this year these fish have only just been spawned and their final numbers have not been established. Consequently, it is necessary to use the long-term average numbers of 1-year-old fish as an estimate of their numbers.

The fish aged 2 years or more next year would be in the fishery this year. Consequently our estimates of their number have to be modified to take care of losses due to natural deaths and to fishing this year. Obviously, at the time when our working group meets it is impossible to be certain as to how many fish will be caught in the year. If an agreed TAC had been set for this year, this could have been used as the figure for the probable catch, but quotas are not always met and are sometimes exceeded. Clearly, there will always be some uncertainty as to the level of catch to be expected in an interim year. In the case under consideration, uncertainties about the EC Common Fisheries Policy relating to North Sea pseudofish might make it very difficult to decide how many fish will be

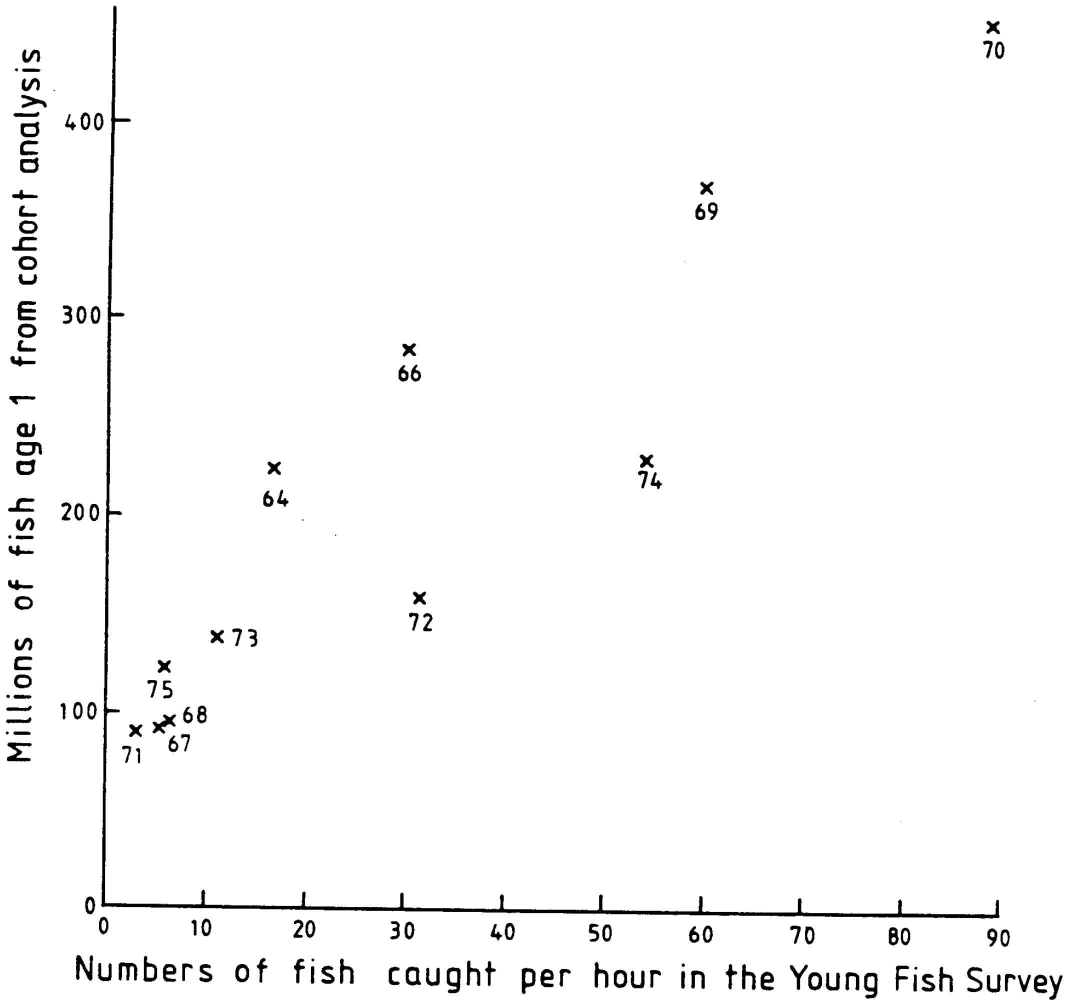

Figure 8 Relationship between the catch rate in the ICES North Sea International Young Fish Survey and estimates of numbers of North Sea pseudofish obtained from the subsequent commercial fisheries.

caught this year, so the working group may be forced to give TACs calculated under two assumptions about what may be caught this year. One assumption which would lead to the results shown in Table 3 would be that the fishing mortality in the current year would be the same as last year. A second assumption might be that the TAC recommended for the current year would in fact be enforced. Real life working groups frequently have the same problem as the imaginary North Sea Pseudofish Working Group had here! Considering just the first assumption, we can calculate the numbers at age, the weights at age and the availabilities at age (the exploitation pattern) that would apply next year. These are all shown in Table 3. Calculating the biomass available at each age and summing these for all ages then gives an estimate of exploitable biomass for next year of 353 372 tonnes. Since management has earlier decided that the TAC should be 51% of this we arrive at a TAC for next year of 180 220 tonnes.

Table 3 The calculation of exploitable biomass for North Sea pseudofish

Age	Numbers at age in 1000s	Weight at age in kg	Availability at age	Exploitable biomass at age in tonnes	%
1	206 000	0.55	0.31	35 123	10
2	108 287	0.94	1.00	101 790	29
3	68 010	2.07	1.00	140 781	40
4	10 400	3.91	0.78	31 718	9
5	5 548	5.89	0.73	23 855	7
6	1 556	7.82	0.73	8 883	3
7	703	9.33	0.73	4 788	1
8	237	10.62	0.73	1 837)	
9	324	11.51	0.73	2 722)	2
10+	209	12.29	0.73	1 875)	
Total				353 372	

Calculating the exploitable biomass does show the importance of the various ages. For example, 3-year-old fish contribute 40% of the exploitable biomass, while fish of 4 years and over contribute only 22% of the exploitable biomass. The proportion of exploitable biomass given by 1- and 2-year-old fish is 39% in this particular year. From this we can see that estimating recruitment levels (the numbers of young fish entering the fishery) will be very important if we are to estimate accurate TACs for North Sea pseudofish. The same conclusion is also likely to be true for real species of fish such as cod, haddock and whiting, which have high fishing mortalities like the pseudofish of our example.

4.4 Setting TACs on developing fisheries

So far we have considered the approach to setting a TAC for a fishery when there exists both a reasonable time series of commercial data and other appropriate information, e.g., the survey indices of abundance in the case of the North Sea pseudofish. Where such data do not exist, as in the case of a developing fishery, setting a TAC is obviously more difficult. From the fisheries scientist's point of view a gradual development of the fishery would be best, since it would allow the appropriate data to be accumulated while the stock was not under great pressure. From the point of view of fisheries administrators or fishermen the current state of the fishing industry may indicate that fully exploiting such stocks at once is very desirable. In these circumstances the fisheries scientists obviously need to be able to recommend TACs which, while as large as possible, are reasonably safe. To do this an obvious first requirement is for some data to be available with which to make an assessment. Echo surveys, fishing surveys and egg surveys are perhaps the best of the established methods. All of these methods are, however, likely to be less precise than methods based on longer time series. It is probable, therefore, that TAC advice on developing fisheries will be less precise than that on developed fisheries. Consequently, when such advice is given, it should be conservative in its assumptions and the administrators should tend to favour the more pessimistic of the various options where different approaches give conflicting advice. There obviously is a need to collect accurate commercial data as soon as possible so that a time series of commercial catch-at-age data can be built up without delay. Mackerel - A problem in fish stock assessment, by S. J. Lockwood (Laboratory Leaflet No. 44, MAFF, Directorate of Fisheries Research Lowestoft) explains the process of assessing and giving TAC advice for the Cornish mackerel fishery which has developed substantially and rapidly in recent years.

5. WHY TACs VARY

Total allowable catches do vary from year to year and this is naturally disconcerting both to administrators who have to negotiate fresh quotas and divisions of quotas and to fishermen whose livelihoods depends on the fish catch. It is perhaps natural for both to suspect that these variations occur because of failings of the fisheries scientists. Certainly the estimates of TACs do contain some uncertainties due to problems of assessment, but the most important source of the variations in TACs is the inherent variability of fish stocks. Another cause of variation in TACs is change in management strategy aimed at increasing the long-term yield. For example, an increase in mesh size can be one way of improving long-term yield. Such changes are typically followed by a short-term reduction in catch followed by a longer-term increase. All of these sources of variation can be reduced by a suitable management strategy. This section will consider how these variations in TAC come about and how they could be reduced.

Table 4 Recruitment variations in North Sea fisheries, 1963-1978. Number adjusted to a value of 100 for the most outstanding year-class of each species. Ratio is the ratio between the numbers in the strongest and weakest year-classes in the period.

Year	Cod	Haddock	Whiting	Saithe	Plaice	Sole	Sprat
1963	50	6	30	21	100	100	
1964	47	11	43	28	29	21	
1965	67	8	30	22	28	11	
1966	60	31	38	62	26	11	
1967	20	100	100	64	22	18	
1968	18	21	18	69	28	9	
1969	78	3	44	35	33	26	
1970	100	47	54	34	26	7	
1971	17	24	68	36	22	16	
1972	35	5	73	41	57	20	
1973	29	36	48	100	49	19	59
1974	50	4	68	34	34	7	81
1975	24	6	35	25	27	20	35
1976	88	12	42	14	54	23	51
1977	37	18	46	29	46	7	100
1978	34	24	45	42	34	0.2	32
Ratio	6	33	6	7	5	500	3

5.1 Variations due to biological changes

In Section 3 it was seen that the number of fish entering the fishery each year varies considerably. For example, the North Sea haddock year-class strength has varied by a factor of over 33. It is not surprising that such changes cause changes in the size of the exploitable biomass of fish stocks from year to year and hence changes in TAC and quota levels. For example, the large 1967 year-class of North Sea haddock caused such a great change in exploitable biomass that the total international catch which had been 167 000 tonnes in 1967 increased to 672 000 tonnes in 1970.

Table 4 shows the year-class sizes of various North Sea fish stocks from 1963 to 1975 expressed as a percentage of the largest year-class of each stock. If the mortality on the stock is very high, most of the fish would be caught in the year they entered the fishery. Thus, in this extreme case, the variability of catches would be exactly the same as the variability of the year-classes. When mortality is low, however, fish are in the fishery for many years and thus the catch comes from both large and small year-classes. This means, of course, that in this case much of the variability in year-class strength is averaged out in the catch. It is clear, therefore, that variations in year-class strength can cause considerable variations in TACs. These variations can, however, be reduced if a lower level of fishing mortality is adopted, since this helps to average out year-class fluctuations. As an example of this we can compare the total catches of North Sea plaice and of cod over past years. In the North Sea both of these fish stocks have had year-class strength variations on a similar scale but the catches of cod have varied more wildly about the average than have those of plaice. This effect can be seen clearly in Figure 9, and it results from plaice having a mortality which is about half that of cod.

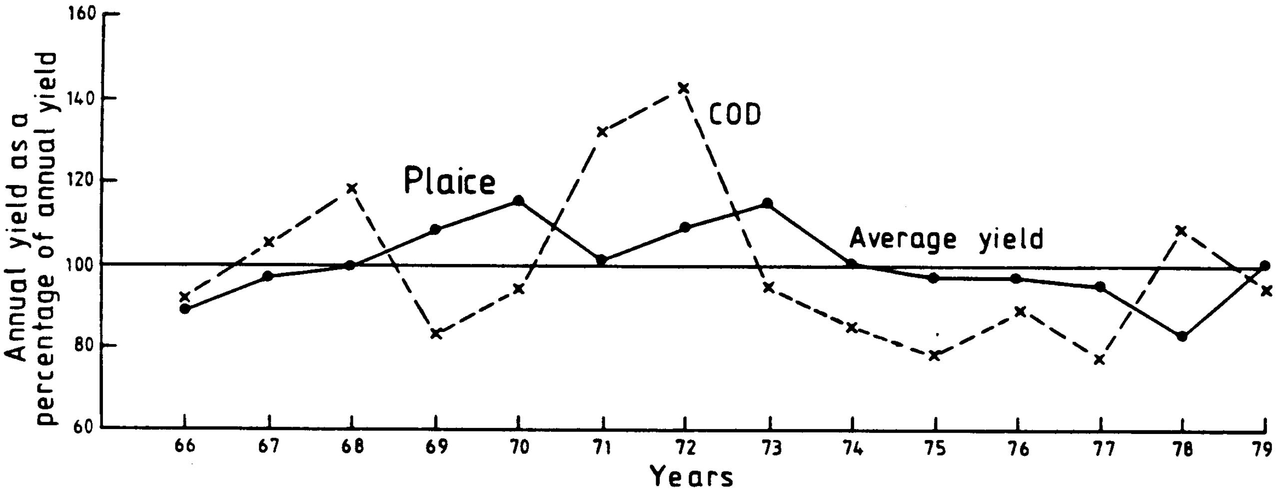

Figure 9 Annual variations of yield about the average level (1966-79) for North Sea cod and North Sea plaice.

5.2 Variations due to changes of management objective

From the arguments above we can see that if we were to halve the mortality on North Sea cod the catches would vary less from year to year in the long term. In the short term, however, halving fishing mortality would cause catches to drop by about 40% which would, of course, be a major disruption.

This is a typical example of the disruption caused by a rapid change of management strategy aimed at reducing levels of exploitation from high current levels to lower levels. Similar disruptions in yield would be caused by imposing large increases in the mesh size of nets. These disruptions can be minimised by phasing the changes over several years. For example, if the North Sea cod fishing mortality could be continually reduced by 10% per year until a level equal to 50% of the current level was reached, the yields would be far less disrupted than by an abrupt change. This policy of gradually changing the fishing mortality levels downward should, on average, give a trend in yield which is gradually upward. This would be easier for administrators and fishermen to accept than one requiring considerable initial sacrifice. Such changes in mortality could be further cushioned by choosing a time to impose the reductions in fishing mortality when the exploitable biomass was increasing. The effect on yield could then be minimised. Such a time would occur when a strong year-class of young fish was entering the fishery.

The policies suggested above for reducing the disruption caused by a change of management strategy would not be appropriate if the stock were suffering from a severe reduction in recruitment due to overfishing. In these circumstances management action must be swift and drastic. The disruption caused by a fishing ban this year is to be preferred to the total loss of the stock next year!

5.3 Variations due to uncertainties in assessment

In Section 4 the calculation of the 1979 North Sea pseudofish TAC showed that 78% of that TAC came from ages of fish which could not be satisfactorily estimated from data obtained from commercial statistics. Their numbers therefore had to be estimated from research survey results. It was seen that these survey results were very useful in reducing the uncertainty about the numbers of the younger ages of fish, but that some uncertainty still existed. Fortunately any errors in the survey estimates for the number of 2- and 3-year-old fish will not necessarily be in the same direction. For example, one estimate could well be too high while the other was too low. On average these errors will partly cancel out. They do nevertheless cause some errors in estimates of the TAC. Such errors are what a statistician calls random errors. They may tend to make the TAC too large or too small, but on average they will cancel out. Consequently, the TACs derived are the best advice available. To consistently increase them to the upper limit of possible error at the stage when national quotas are being negotiated is certain to result in overshooting the objective of the management scheme.

In the past scientists have avoided giving limits of errors on TACs in case the upper boundary were to be interpreted as a permissible upper limit of the TAC. This reticence about errors of TACs should not be necessary. While managers should use the TAC as the best estimate of what the appropriate catch should be, they should be properly concerned with the error limits of these estimates. Their concern should be that, if TACs are seriously in error on a year to year basis, the TAC approach to management might be inappropriate. The errors in TAC estimates can in some cases be reduced by reducing the level of fishing mortality. In time this causes less of the TAC to be composed of the younger ages of fish whose numbers are particularly difficult to estimate. It also helps because any errors that have been made tend to be amplified at higher levels of fishing mortality. Therefore, one way to reduce assessment errors is to adopt lower values of fishing mortality as the objective of management. Another way is to improve the level of sampling of the various components which go into calculating a TAC.

6. MANAGEMENT BY TAC: DISCUSSION AND CONCLUSIONS

This leaflet describes the scientific processes that are adopted in setting the current short-term objectives of fisheries management. In particular it attempts to clarify the scientific basis of TAC regulation. As such, it may allow the reader to comprehend more clearly the nature of current approaches to fisheries management and be in a better position to judge its merits and deficiencies. It is worthwhile to rehearse these briefly. On the positive side some limitation on the amount of fishing is desirable for many fish stocks, either for the health of the stocks or for the economic wellbeing of fishermen. TACs provide a politically realistic though difficult way of providing this limitation. As this leaflet makes clear, scientific advice to support this form of management is generally available. Against this stands the need for a TAC to be reset on an annual basis and for the scientific advice to be provided on an annual basis. This is necessarily more expensive than a once and for all regulation such as an effort regulation.

A further problem is that successful TAC management relies upon the accurate and trustworthy reporting of catches by interested countries. A suspicion that some are cheating will undermine confidence in the system. Equally, misreporting of catches, unrecorded discards at sea, or the non-provision of appropriate scientific information by some countries may undermine the scientific methods by which TACs are calculated.

Turning to the social and economic effects of fisheries management, present experience would suggest that TACs by themselves may not secure all the economic benefits that might accrue from reducing fishing mortality. This is because, on a national level, the quota is frequently shared between more vessels than would serve to catch it, and consequently vessels may spend a proportion of their time idle. This may, however, have a positive effect, at least in total yield terms, by encouraging diversion of fishing effort on to other less sought-after species. It may also have valuable side effects, such as higher employment levels in fishing and ancillary services. Moreover, the existence of an internationally agreed TAC would not preclude the introduction of a national effort limitation scheme to secure the full economic benefits of the catch limitation, if this were considered desirable. Thus a TAC might be regarded as preferable to an effort limitation insofar as it would allow participating countries to decide for themselves how to partition the social and economic benefits of fisheries management. By contrast, an internationally agreed effort regulation would tend to maximise economic benefits to the possible detriment of other objectives.

In economic terms there are undoubtedly costs (possibly high costs) resulting from the variability of TACs due to both natural causes and lack of precision in the scientific advice. As Section 5 points out, the effect of both sources of variability can be minimised by adopting lower levels of exploitation than those currently acting on most fish stocks. This suggests that TACs are most likely to be appropriate for those species for which low rates of exploitation are appropriate, as is the case for many human consumption fisheries. For industrial species, however, the intrinsically higher rates of exploitation needed to harvest them optimally may rule out catch quotas as an appropriate management tool, due to the problems in providing adequate scientific advice.

In conclusion, therefore, TAC management has advantages and disadvantages and the weight which is given to each of these is likely to vary with the standpoint of the reader. Clearly, the provision of appropriate scientific advice and its cost is one factor in the equation and it is hoped that this leaflet may help non-scientists to appreciate how to give it a proper weighting.

7. BIBLIOGRAPHY

BURD, A. C., in preparation. Mesh selection. Lab. Leafl., MAFF Direct. Fish. Res., Lowestoft.

CUSHING, D. H., 1974. A link between science and management in fisheries. Fishery Bull. U.S., 72: 859-864.

GULLAND, J. A., 1969. Manual of methods for fish stock assessment. Part I. Fish population analysis. F.A.O. Man. Fish. Sci., 4: 154 pp.

GULLAND, J. A., 1974. The Management of Marine Fisheries. Scientechnica Ltd., Bristol, 198 pp.

HALLIDAY, R. G., 1972. A yield assessment of the Eastern Scotian Shelf cod stock complex. Res. Bull. int. Commn NW Atlant. Fish., (9): 117-124.

I.C.E.S., 1978. Report of the North Sea Roundfish Working Group. ICES C.M 1978/G:7, 89 pp. (mimeo).

LOCKWOOD, S. J., 1978. Mackerel: a problem in fish stock assessment. Lab. Leafl., MAFF Direct. Fish. Res., Lowestoft, (44): 18 pp.

POPE, J. G., 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Res. Bull. int. Commn NW Atlant. Fish., (9): 65-74.

POPE, J. G. and GARROD, D. J., 1975. Sources of error in catch and effort quota regulations with particular reference to variations in the catchability coefficient. Res. Bull. int. Commn NW Atlant. Fish., (11): 17-30.

PAWSON, M. G., 1979. Blue whiting. Lab. Leafl., MAFF Direct. Fish. Res., Lowestoft, (45): 17 pp.

SHEPHERD, J. G., 1981. Matching fishing capacity to the catches available: a problem in resource allocation. J. Agric. Econ., 32: 331-340.

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