STOCK ASSESSMENT: WHY?

by

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PREPARATION OF THIS DOCUMENT

This document has been prepared in FAO to give some guidance to non-specialists on why stock assessment is necessary, and how it is conducted.

ABSTRACT

Stock assessment is needed to give advice to fishermen, fishing industries, and fishery managers concerning the resources and their state of exploitation. The precise needs will vary with the stage of development of the fishery, with a need for greater detail and precision as the fishery develops. The main techniques for stock assessment are outlined, and the advantages and disadvantages of different approaches (including the needs for different types of data) are discussed.

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1. INTRODUCTION

Every subject has its fashions. In fisheries it is the fashion now among administrators and scientists to talk a lot about stock assessment, and how important it is. This importance is often better recognized in words than in practice. Adequate support is often not given to scientific research; when support exists, the research actually carried out may not be well directed towards the more important problems, and when good research is done it is very often not properly used. This is largely due to a lack of understanding - of why stock assessment is done, how it is done, and how the results are used. The last is the most important. Once policy makers in national fishery administrations (and also in the fishing industry) appreciate how useful, indeed vital, is the advice that can come from stock assessment studies, to the decisions they have to take, then they will see that stock assessment studies are done. They will also see that they are done in an effective and relevant way.

This note has therefore been written to increase the understanding among administrators and scientists of what is involved in stock assessment. In particular it has been written to dispel two illusions that are particularly prevalent among developing countries; first, among administrators that stock assessment studies are only needed in a few highly developed, and seriously over-exploited fisheries, and second, among scientists that proper stock assessment involves such obstruse and advanced mathematics and biology that it can be undertaken only by a few experts in large laboratories in Europe and North America. The truths are that nearly all decisions taken by fishery administrators, investors in fisheries (including development banks) and the fishing industry generally will benefit from some input from stock assessment studies; that the problems which many fisheries throughout the world are now facing do need some stock assessment studies for their solution, and that the basic models and assumptions made in fish assessment studies are extremely simple. For example some of the more important assumptions are that the more fishing is done, the fewer fish will be left in the sea; that all fish die. but only die once; or that any big fish was once a small fish, and can only become big if it is not caught when small.

Of course matters are not always simple. Much more is involved in most decisions than an assessment of the state of the stock, and in some cases the actual work of making assessments, with the detail and precision required, can be difficult and expensive. Indeed even in an area as well studied as the North Sea there are important questions, e.g., "would the rebuilding of the depleted herring stock have an adverse effect on the fisheries for demersal fish (cod, plaice)?", cannot at present be answered definitely. These difficulties should not discourage scientists in developing countries from tackling their national problems where valuable answers can be obtained even with limited resources.

While stock assessment is much talked about, there is no clear definition of what is meant by stock assessment. Probably there are as many definitions as there are scientists who consider themselves as stock assessment experts. For the purposes of the present note a fairly wide definition will be used. Stock assessment comprises any scientific study to determine the productivity of a fishery resource, the effect of fishing on that resource, and the impact (on the resource and the fishery) of changing the patterns of fishing, e.g., from the implementation of management or development policies. The work of the stock assessment expert should lead to the formulation of advice to those responsible for taking decisions on the management and development of the fishery. Stock assessment studies therefore ranges from, at one extreme, looking at the area and depth of an African lake, and the number of fishermen present, and thus determining from the known relation between these variables (Henderson and Welcomrne, 1974) that if more fishermen entered the fishery, the total catch would not increase, to the complex multi-species modelling studies of the North Sea, which can require the full capacity of a large computer (Andersen and Ursin, 1977).

2. WHEN IS STOCK ASSESSMENT NEEDED?

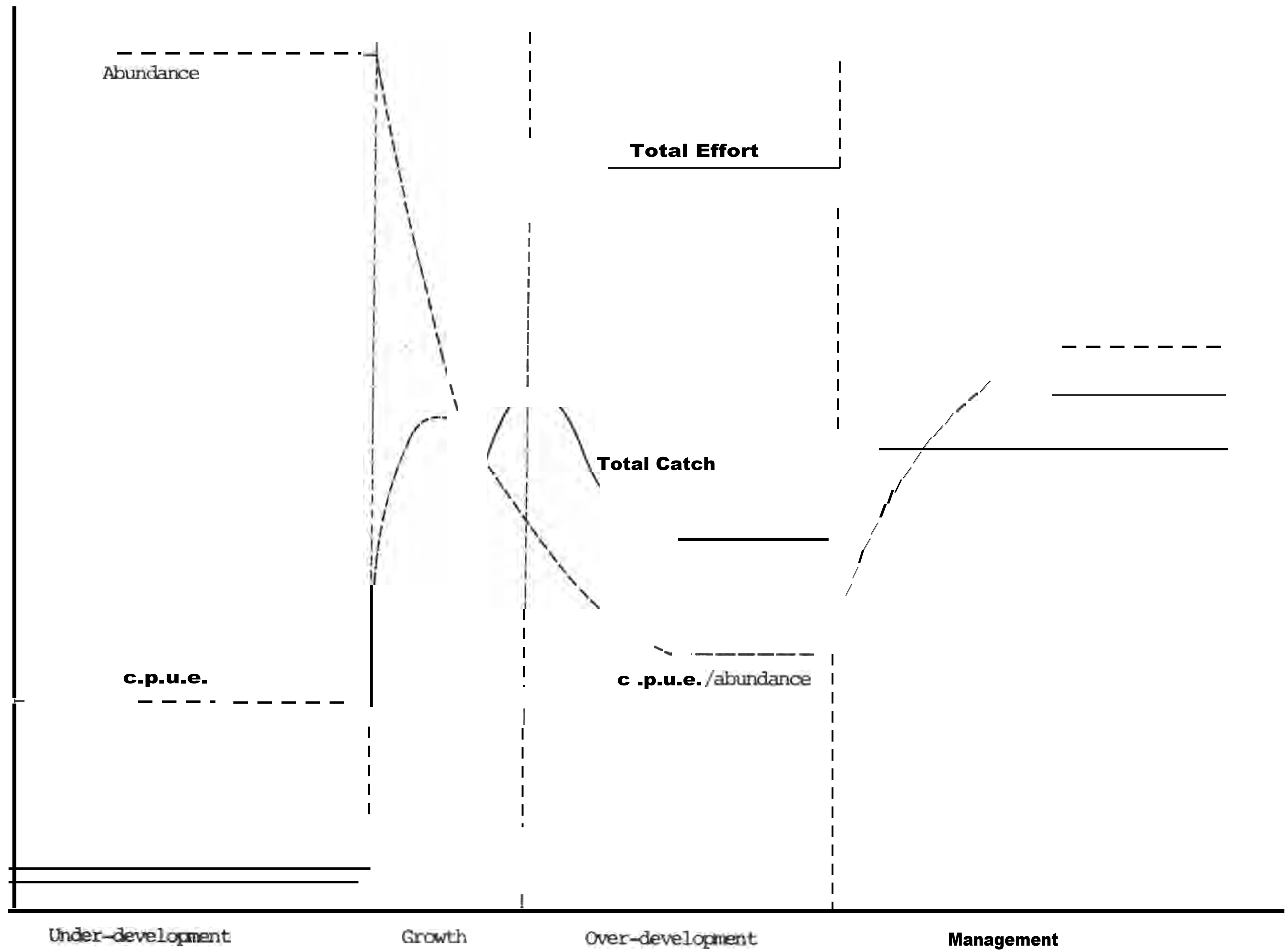
Stock assessment studies are needed (with very few exceptions) whenever fishery policies are being made, and decisions being taken that affect fisheries. The questions may be very broad. A country may have established an Exclusive Economic Zone out to 200 miles (perhaps ten times as far as local boats have traditionally fished), and would like to know whether there are enough fish in the new zone to be worth planning the development of a substantial new fishery, and if so, of what kind. Many developing countries with large numbers of inshore fishermen using traditional types of gear in the coastal belt are worried about the impact on the traditional fisheries of the development of a mechanized fishery to exploit the resources slightly further from the shore. In some other countries, notably in South and Southeast Asia, where an industrial fishery has already developed, conflict between the two groups of fishermen now exist and measures are needed to reduce or eliminate it. These countries need to know which measures will be biologically effective. A country with a well estblished shrimp fishery will want to know whether the catches can be increased, or whether, even if no increase in catch is possible, the costs can be decreased. In a fishery that has been over-exploited and is now being managed by enforcing a catch quota, or total allowable catch (TAC), the manager needs to know what level of total catch should be allowed in the coming season to achieve certain objectives.

Answering each of these questions requires stock assessment information. Their variety illustrates the variety of stock assessment work, and the fact that the nature of this work depends on the stage of development of the fishery. This is illustrated in Figure 1 (adapted from Kesteven, 1973). Four main phases are distinguished - an initial phase of under-utilizaton, in which there is either no fishing, or a small traditional fishery which takes much less than that potentially available, a phase of development, and rapid growth, a phase of over-development, characterized by over-capacity - too many boats chasing too few fish - low catch rates (catches per unit effort) and often also declining total catch, and a final phase (only achieved at present in a small minority of fisheries) of management. The trends in the main characteristics of the fishery - total catch, total effort, and catch per unit effort (c.p.u.e., i.e., the returns to the individual fishermen, and the factor mainly determining the profitability of the fishery) are shown in Figure 1. Also shown is the abundance of the stock. Once the fishery develops changes in the c.p.u.e. will correspond closely to changes in abundance, but in the early stages c.p.u.e. will be low because the fishermen will not have learnt the best gear, fishing grounds, etc., even though the abundance is high.

At each of these stages there will be a characteristic set of problems faced by the administrator, for which there will be a corresponding pattern of advice provided by the stock assessment scientist. These are summarized in Table 1.

In the initial phase the problems and questions are simple. How big is the stock? How much can be safely taken each year? What are the likely catch rates of vessels of different (specified) types? How will these catch rates change as the fishery develops? These do not need to be answered with precision. In the beginning it will usually be sufficient to know whether the possible annual yield is around 10 000 tons, or 100 000 tons, or larger, in order to decide the approach to development - whether it is worthwhile to put large efforts into the development, and what size of fishery, with associated shore facilities (cold stores, processing plants, etc.) to aim at. The answers need not be precise though it should be stressed that because of all the uncertainties involved, the initial plans should always be for a total catch that is a fraction (perhaps a half or a third) of the estimated potential. The size of the fishery - number of boats, etc. - can always be increased if the initial fishery is successful, and the assessment of the effects of this size of fishery show that further development is feasible. It is much more difficult, and is likely to involve considerable losses, to reduce the size of a fishery - involving selling boats, and putting fishermen out of employment - if the initial investment is too optimistic.

While the fishery is in the development phase there may be no obvious problems. This is the time when everyone is happy. The fishermen are making good profits and, in most cases, putting these profits back into the fishery to buy new and larger boats -often with the encouragement of the tax authorities who allow tax exemptions for pro fits re-invested in fishing. The administrator feels he can sit back, happy with the success of the development programme. This is nonsense. After the period of success, profits and growth this phase will often end abruptly as the stock becomes fully exploited. The total catch ceases to increase (and may even decrease), the c.p.u.e. falls below acceptable levels, and pro fits turn to losses. Because of the delays in the system - decisions to build a new or larger boat are usually based on catches in the recent past, and not the (probably smaller) catches that will occur when the boat is actually fishing - the development phase is likely to end, at least temporarily, in an even worse state of over-expansion than the equilibrium position of zero profit predicted by simple economic theory (e.g., Gordon, 1954; Anderson, 1977). This can be prevented if action is taken while the fishery is still actively growing. This action may be no more than the withdrawal of special incentive (tax reliefs, duty free engines, etc.) introduced to stimulate development. More restrictive measures, e.g., limitation of entry into the fishery, which is usually considered only after the fishing fleet has already grown much too large, will be less difficult to introduce when the fishery is less than fully developed. Stopping new entrants coming into a fishery is easier than removing existing fishermen or fishing vessels from an over-expanded fishery.



Main phases of developmen
of a typical fishery

TABLE 1

Problems and advice needs at
different stages of fishery development

Stage	Problems	Stock Assessment Advice
Under-developed	How can the fishery be developed? Is the resource big enough to justify large efforts to develop the fishery?	Rough estimates of the possible annual yield.
Growth	Apparently few. In reality how to slow growth down as the limit set by the resource is approached, and so reduce or eliminate risk of later problems of over-development.	More precise estimates of sustainable yield, and of the effort (e.g., number of boats of different types) needed to take this yield.
Over-development	Over-capacity, declining catch rates (and sometimes falling total catch). Economic losses. Conflict between different groups of fishermen.	Explicit advice on the specific measures (mesh size; catch quota, length of closed season) needed to achieve the manager's objectives (which themselves need to be clearly understood).
Management (a)	Adjustment to management measures (e.g., size of quotas) to take account of e.g.„ natural fluctuations in recruitment, or developments in fisheries on related species.	1) Precise and explicit advice on adjustments to, e.g., annual catch quotas, based largely on single-species models. 2) More strategic, and less quantitative advice on modifications to policy to take account of, e.g., species interactions.

Note (a): By the time a fishery reaches this stage it is likely that the complexities outside the simple description of Figure 1, e.g., natural fluctuations, or interactions between fisheries on different species, will probably have become relatively important. This is reflected in the nature of the problems and the advice.

The actions involved will probably be aimed in rather general terms, to slow down the pace of the expansion, and require correspondingly broad advice. The most important is an estimate of the potential size of the fishery (average annual catch, the number of vessels that can be supported), and the size of the present fishery relative to this potential.

The phase of over-development, which is usually a time of crisis in the fishery, is often the phase when specific questions are put to the stock assessment scientists for the first time. One class of questions is strategic, and repeats the broad questions of the previous phase in a more specific form - how does the present amount of fishing compare with that required to achieve some policy objective (e.g., to maximize the total catch, or the net economic return from the fishery). Answers to these questions can show the direction of change in the pattern of fishing (fewer vessels, protection of small juvenile fish) that are needed to move the fishery towards a more desirable state. The second class deals with tactical questions, e.g., what would be the effects of increasing the minimum mesh size, as a means of protecting small fish, or limiting the total catch in the forthcoming season. Two effects of possible measures should always be examined and presented to policy-makers: the immediate effect - which nearly always will require some short-term sacrifice from the fishermen - and the long-term effect - when the fishermen should be gaining the beneficial effects of the regulations.

As management measures are introduced, and the fishery enters the fourth phase, then the emphasis on these tactical questions will increase, and more detailed answers will be required. The administrator may wish to know, for example, how the catch quota should be adjusted from year to year to take account of favourable and unfavourable natural conditions. Limits on mechanized fishing set at some uniform distance from the coast in order to separate mechanized and traditional fishing methods may be modified locally to take account of variations in the distribution of different species of fish.

The nature of the problems faced by the fishermen and the fishery administrators, and of the questions asked of the stock assessment expert therefore vary with the state of development of the fishery, as well as with the specific conditions of the fishery, type of vessels and gear, nature of the administrative machinery, etc. In all fisheries, however, there is a consistent pattern in the flow of information from the initial perception of the problem, through the scientific studies, to the implementation of action to correct the problem. This is illustrated in Figure 2. As suggested there, the initial and final stages (on the left of the figure) are the primary concern of the administrator; the central stage - of planning research, collecting the necessary information, and analysing the data (on the right of the figure) are primarily the concern of the scientist.

Much of the success, or otherwise, of the management of the fishery depends on how the two linking stages - of framing the questions which the stock assessment studies should answer, and of providing the answers to these specific questions, and the scientific advice generally - are handled. If they are treated as marginal and as shown by the upper part of Figure 2, are kept outside the main areas of concern of both administrator and scientist, the effects can be disastrous. The research can be largely irrelevant, and if relevant research is done, the results are not available to those attempting to solve the fishery's problems. On the other hand, if these stages are treated as important areas in which scientists and administrators work closely together, as shown in the lower part of Figure 2, then the administrators can expect to have relevant and timely scientific advice to solve his problems.

3. METHODS OF ASSESSMENT

As was pointed out earlier, the basic principles of assessing fish stocks are very simple. They are not, however, so simple that it is possible to provide here, in a few pages, a guide to the methods that can be used by those scientists actually carrying out the assessments. They should turn to one or other of the existing manuals published by FAO or others (e.g., Gulland, 1969; Ricker, 1958; Saville, 1977). The purposes here are simpler. They are to provide administrators and those using the results of assessments with some idea of how these studies are carried out, and thus with an understanding of how reliable and realistic the results are, and of the support needed by stock assessment scientists if they are to do their job. At the same time these notes can provide scientists who are not themselves stock assessment specialists with some preliminary insight into the methods used, and a guide to where more detailed information can be found.

FIGURE 2

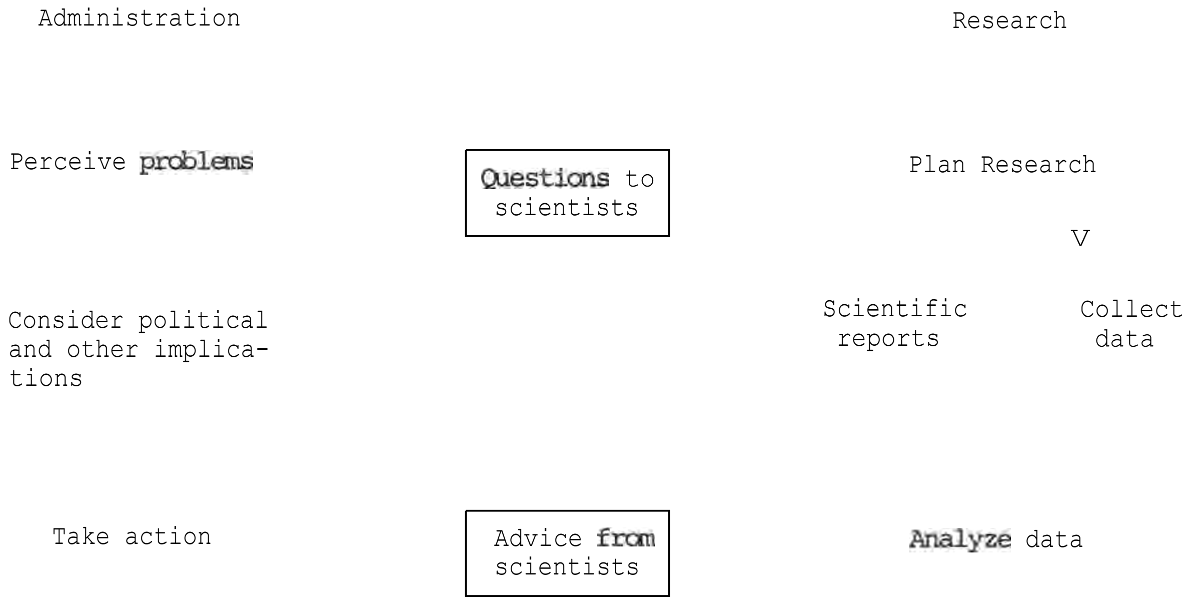


FIG.2a: Pattern of activity with weak links between administration and research. Note that the interactions between the two groups are considered as outside the main activities of each group. The links between administration and research are weak (broken lines).

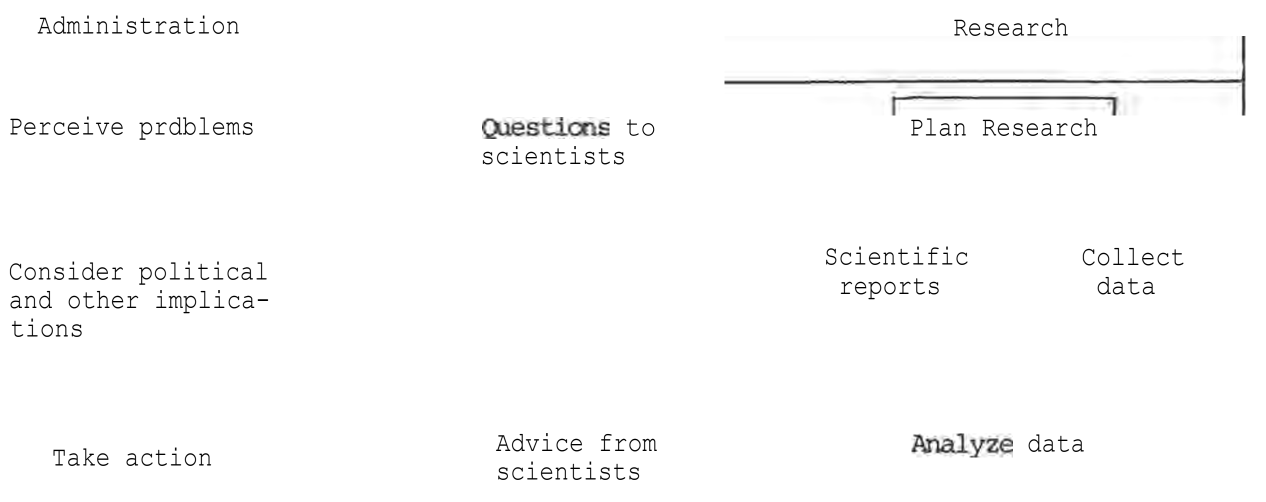


FIG. 2b. Pattern of activity when the activities of administration and research are closely linked. Posing questions to research scientists, and giving advice to administration are seen as central activities of both groups.

3.1 General estimates of potential

The method of estimating potential that makes least demands for research and information collection is the comparison between areas. The types and quantities of fish that are available for harvest depend on the basic biological production which is determined by such characteristics of the area as the nature of the currents (e.g., the degree of upwelling), supply of nutrients from the land, mean depth, etc. Similar regions will therefore have similar biological productivity, and similar potential fish harvest per unit area. Relatively simple observations of an area, combined with information on the potential from other similar, but better known areas can therefore give useful first approximations to the potential. This method has been most extensively used in lakes (Henderson and Welcomme, 1974) but has been applied to rivers (Welcomme, 1979) and marine ecosystems, e.g., reef areas in the Caribbean (Munro, 1982). Besides an estimate of total potential, these comparative studies can give some idea of the types of fish likely to be found. For example, the relative importance of shrimp in tropical regions will be determined by the extent of lagoons, mangroves and other productive inshore areas (Turner, 1977).

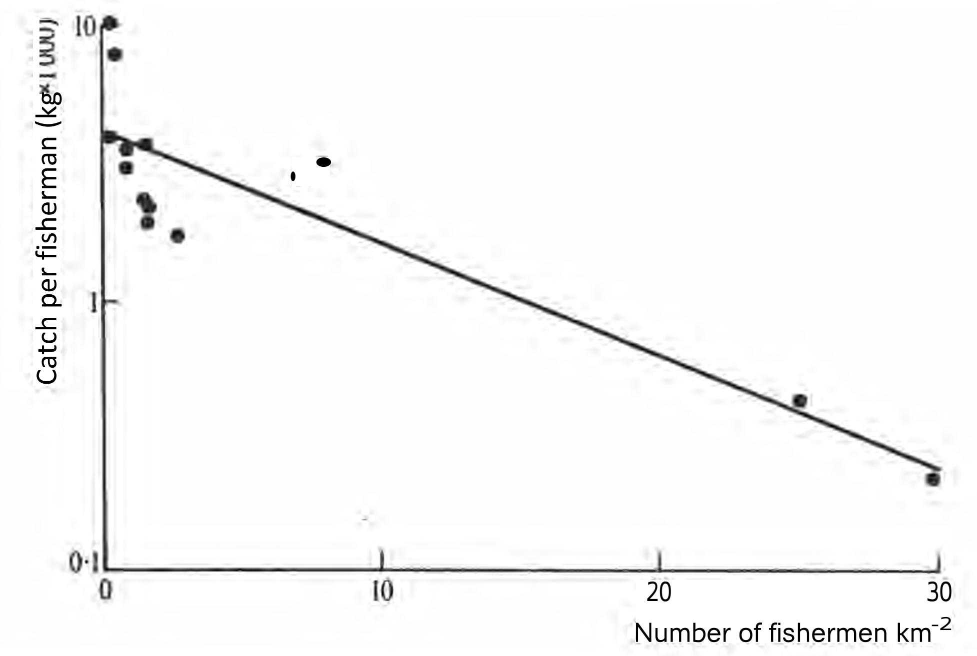
Better estimates can be obtained by looking at more detailed information. For example it seems that Munro's first approximation of the yield per unit area of tropical reefs can be considerably improved by looking at the average depth and the proportion of total area that is covered by actual living coral. If the fishing methods used are fairly similar, this comparative technique can also be used to estimate the number of fishermen, or number of boats of a standard type, that can be employed in the fishery. Figure 3 shows for a number of African rivers the relation between the yield per unit area of floodplain, and the number of fishermen per unit area (from Welcomme, 1979).

The success of this method is obviously increased when a good number of similar areas can be considered together. A variety of examples will help to establish the general pattern, the amount of scatter that occurs (and so the degree to which the yield in a particular area might depart from expectation), and possibly help to identify additional factors, not considered in the first simple formula, that need to be taken into account. Bringing together the data from many areas, which are likely to be in a number of different countries (though in the same broad ecological zone), is one of the several ways in which international regional collaboration can help stock assessment.

The general potential of an unexploited fishery can also be estimated from surveys. The commonest methods are with trawls (usually of standard commercial type, for bottom living fish), and acoustic surveys (mostly for small pelagic fish). The immediate purpose of these surveys is to estimate the standing stock, i.e., how many fish are actually present in the survey area at the time of the survey. The principle is simple. The survey shows how many fish there are in a small area (the area of bottom covered by the trawl, or the area within which fish will be detected by the echo-sounder), which is a known proportion of the total area. Multiplying the number of fish caught in the trawl (or counted by the acoustic gear) according to this proportion should therefore give the numbers in the total stock.

The first practical problems concern the sampling efficiencies of the gears used. A trawl will not catch all the fish in its path, nor is it always easy to say exactly how wide the area is that a trawl covers (is it the distance between the doors, or the width across the foot-rope, etc.). Acoustic equipment will measure the number and strength of the signals returned, but different sizes of fish, or different species of the same size will give different signals. Even the same fish can give different signals depending how it is swimming (head up, or head down, inclined a little to one side, etc.). Estimates of biomass will therefore never be exact, and should always be accompanied by some qualification, based on the extent to which the sampling efficiency of the gear used is known.

The second problem is that knowing how much fish are present at a particular moment is not particularly interesting. The numbers at some other time will be different because of seasonal factors, or year to year changes in abundance. Thus surveys should be repeated. Also the information that is of most practical interest is how much could be taken each year if a fishery developed. This is obviously related to the standing stock, but is also related to the life-span of the fish. For a long-lived fish, the standing stock is the accumulation of the production over many years, and only a small proportion can be taken each year. As a rough guide, the potential annual yield has often been estimated as half the product of the unexploited standing stock (B_u) and the natural mortality rate (M). Recent studies suggest this may be somewhat too high, and $0.3 MB_u$ or $0.4 MB_u$ may be better.



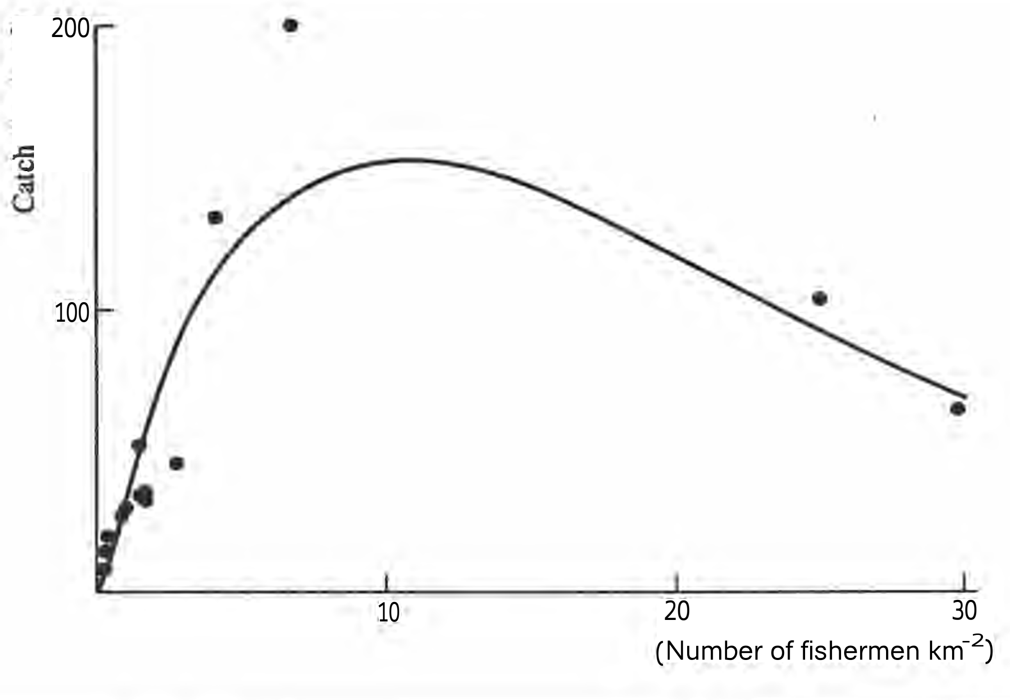


FIGURE 3: The relation between the nuMber of **fishermen** per square **kilometre** in the floodplains of **some** African rivers, and the catch per **fisherman (above),** and the total catch per sq.km. **(below).** **(From Welcomme,** 1979)

3.2 Production models

By production models is meant the class of methods of analysis that consider the relation between the abundance of a fish stock, the amount of fishing (fishing effort) and the total catch. These models consider the fish stock as a uniform mass, and do not attempt to deal with the composition of the stock (e.g., the proportion of old or large fish).

The theoretical basis of most production models is the assumption that, in the absence of fishing, any stock will tend to increase. This increase will be the net effect of the growth of individuals already in the stock, plus the recruitment of young fish, less the losses of fish dying from various natural causes. The size of the increase will be related to the size of the stock. It will be small when the stock is small (there are few fish to grow, and few adults to produce recruits), approaching zero as the stock approaches zero. At very large stocks the natural increase is also small as the stock approaches the carrying capacity of the environment. The losses by natural mortality will be high, and at the maximum size will equal the addition by growth and recruitment. Thus the relation between the natural increase (as an annual rate) and the abundance of the stock can be described by a curve, zero at zero stock and at some maximum stock, and with a maximum at some intermediate stock (see Fig.4a). The simplest curve that fulfils these conditions is a parabola, with a maximum at half the maximum stock abundance. This is the curve shown in Fig.4, though other curves, with maxima at higher or lower stocks are possible.

If at any given stock level the fishery during the year removes just this natural increase, then the stock abundance will remained unchanged. That is this catch is sustainable, and can be maintained indefinitely. The curve is therefore also the curve relating sustainable yield to stock abundance; its maximum is the point of Maximum Sustained Yield (MSY).

Production models can be approached from a different view-point, considering the relation between the amount of fishing and the abundance of the stock. As fishing increases, and removes more fish, the abundance will decrease. Reduced abundance will result in poorer catch rates to the individual fisherman. That is, the relation between the catch rates or catch per unit effort (c.p.u.e.) and the amount of fishing (total fishing effort) will be a decreasing line, starting at a maximum when there is no fishery, and falling to zero when the amount of fishing is enough to exterminate the stock (Fig.4b).

The total catch is the product of the amount of fishing (total fishing effort) and catch per unit effort. This will be zero at zero fishing, and when the stock has been reduced to zero. The simplest curve that does this is again a parabola (Fig.4c). The two curves (Fig.4a and 4c) are two ways of looking at the same phenomenon: the main difference is that the amount of fishing increases from right to left in Fig.4a, and from right to left in Fig.4c, and conversely for the size of the stock. This difference needs to be borne in mind when talking about, for example, the left hand side of the yield curve.

Production models have been modified in many ways to make them more realistic or more easy to apply. Allowance can be made, for example for time lags, e.g., for the fact that recruitment of young fish in one year depends (for long-lived fish) on the size of the adult stock some years previously, or that the abundance of the stock is affected by fishing over several years previous to the year of observation. Several forms of curve can be considered , and so on. These however do not change the basic simplicity of the approach, the advantages that not much data are needed (normally measures of, first total catch, and second, one or other of total effort, or catch per unit effort, or stock abundance), and the disadvantages that it is difficult to take account of other factors affecting the stock (e.g., oceanographic changes, or fishing on associated species), or to advice on changes in fishing pattern other than changes in the total amount of fishing. For these analytic models are needed.

3.3 Analytic models

These recognize that a fish stock is made up of a large number of individuals. The events in the stock can therefore be studied by considering what happens to a group of fish from the time they recruit to the fishery (i.e., become big and old enough to be caught) until the last one has died, either from being caught, or from natural causes (disease, predation, etc.). Five factors are important in determining these events - the numbers of young fish recruiting to the fishery each year, the rate at which they are caught (which will depend on the total amount of fishing, or total fishing effort), the

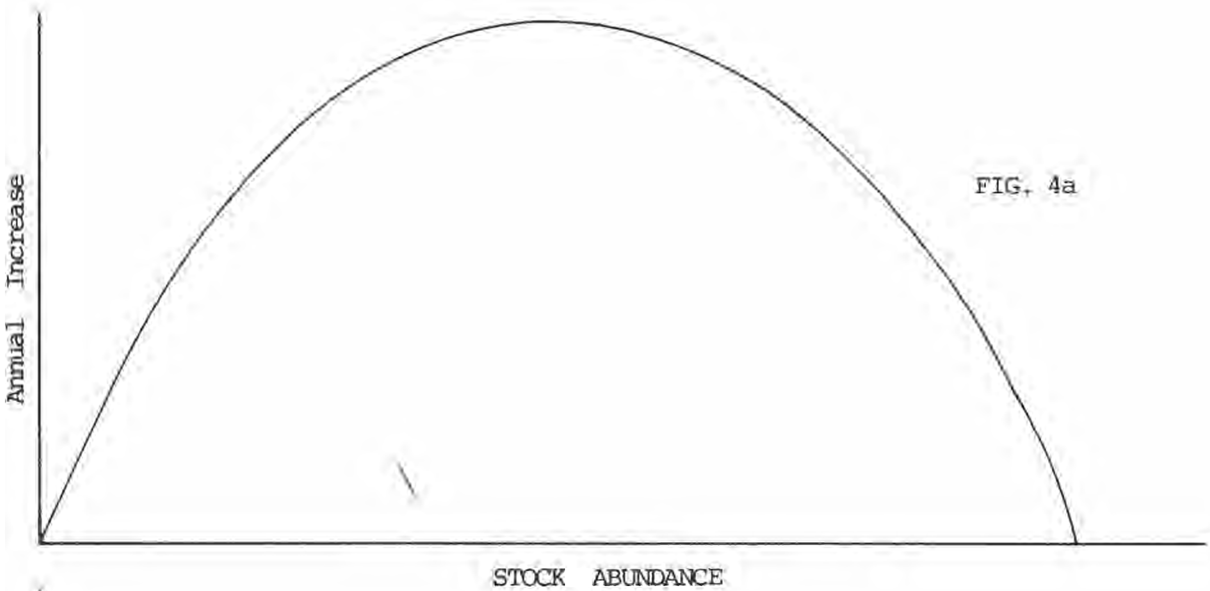


FIG. 4a

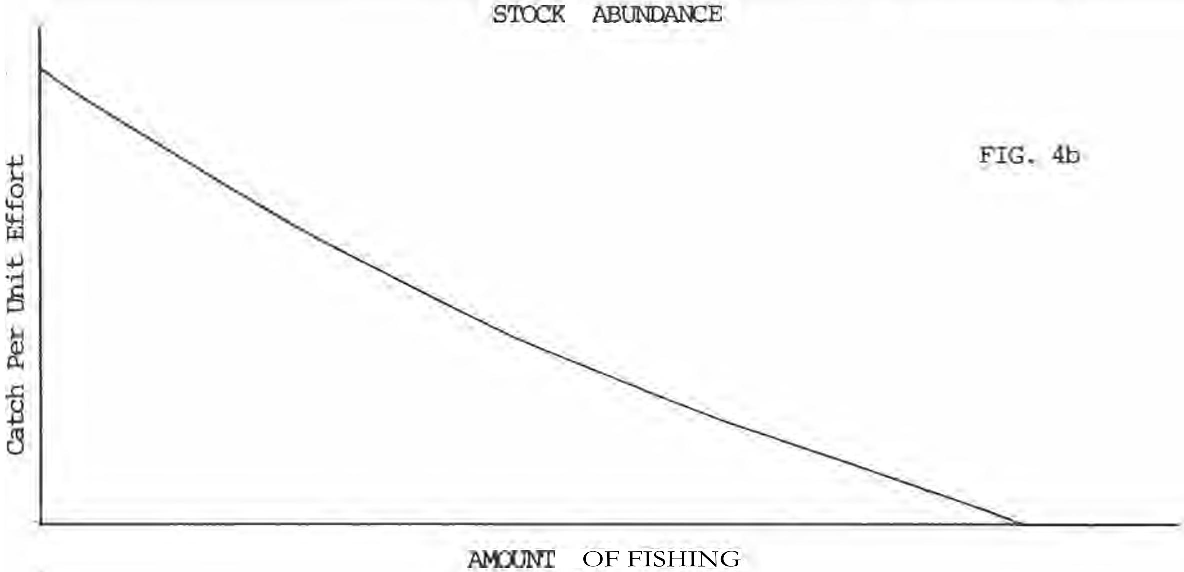


FIG. 4b

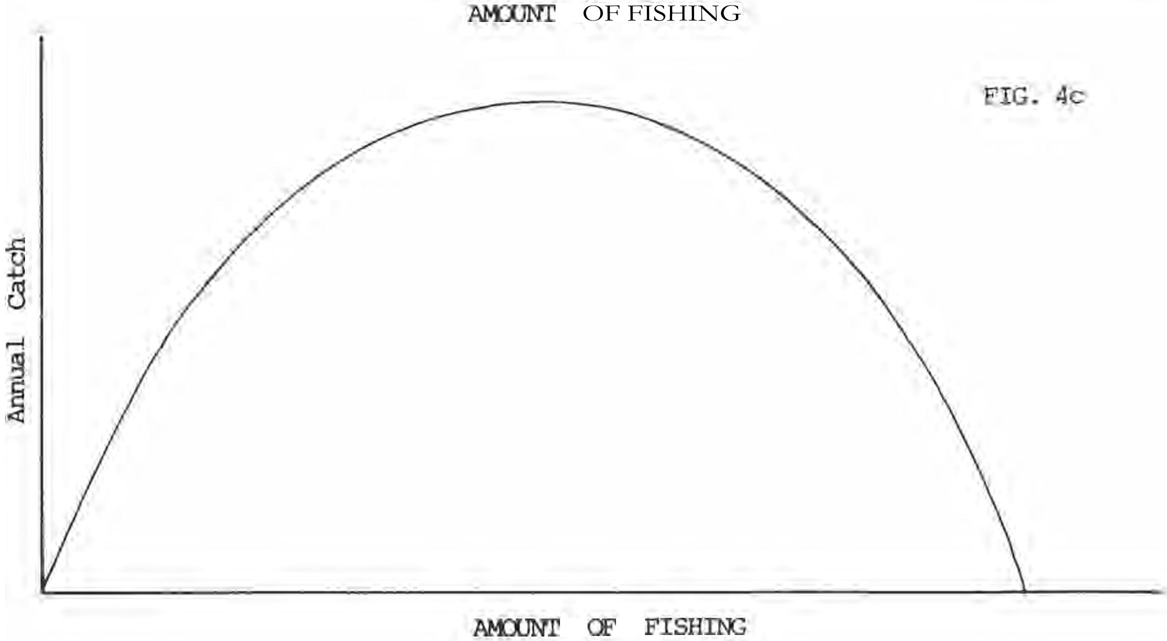


FIG. 4c

range of sizes of fish that are caught (which will depend on the selectivity of the gears - e.g., mesh size), the rate at which fish die from natural causes, and the pattern of growth of the individual fish.

These factors can be handled mathematically in various ways, but the basic principle is the same. The total life span can be divided into successive periods, during which the numbers caught will be proportional to the fishing effort (plus a factor depending on the selectivity of the gear for the particular size of fish), and the numbers dying from other causes can be considered as being proportional to some natural mortality coefficent. The numbers at the beginning of the first period considered (i.e., starting with the age of recruitment) will be equal to the numbers of recruits. The numbers at the beginning of each subsequent period will be equal to the numbers in the previous period, less the numbers caught and the numbers dying from natural causes. In this way a brood of fish can be followed through its life in the fishery. The numbers caught can be found by simple addition. The weight caught is similarly calculated by multiplying the numbers caught in each period by the average weight of fish of that age, and adding up.

As described, the model enables one particular brood of fish to be followed through its life in the fishery. In the same way other broods can be followed, so that by looking at all the year-classes - a year-class is a group of fish born in a particular year, or recruiting in a particular year - which are present in the fishery at a given time, the entire stock can be described in terms of the number of recruits in each of the previous years, and their history of growth, fishing and natural mortality. Most of the important characteristics of the stock - e.g., the number or weight of adult fish -can be computed by fairly simple arithmetic, provided the values of the parameters (growth, natural mortality and recruitment are known).

The growth of the average fish can usually be determined fairly easily, especially when the age of an individual can be determined by looking at its scales or otoliths. Natural mortality - M, the rate at which fish die from natural causes - is much less easy to estimate directly. However, it is usually possible to make a reasonable first approximation, e.g., from comparison with similar species elsewhere, which can be used in calculations. It must though be recognized that the precision of most estimates of natural mortality are low, and the interpretation of results should take this uncertainty into account, e.g., by examining the results of using different values of M.

<u>Yield-per-recruit</u>

Recruitment presents a different problem. It is as difficult to estimate as the other parameters, but it is also highly variable. It is therefore common practice to carry out the calculations, and to provide advice, in terms of yield-per-recruit, that is the average yield to be expected, under any given pattern of fishing (total amount of fishing, and its selectivity), from an individual fish reaching a fishable size. Multiplied by the recruitment, this gives total yield, and if the average recruitment does not change, total yield and yield-per-recruit will vary in the same way.

Calculating yield-per-recruit is easier than calculating total yield. In addition it often provides at least as good advice. If recruitment varies for reasons quite independent of fishing, and of the management policies adopted, then it will be difficult to predict what the actual yield in say three years' time will be, if a certain management policy is adopted. However, it is possible (with the usual reservations about the accuracy of the estimates used) to predict that the yield per recruit will increase by, say, 10%. Since this 10% increase is a measure of the effect of the new policy, i.e., the difference between the catches in three years' time which would be taken with the new policy compared with what would have been taken if no change in policy had taken place, it provides a better measure of the desirability - or otherwise -of the policy than prediction of changes in total catch.

However in many stocks average recruitment can be affected by changes in the abundance of adult stock. Most management policies will affect this abundance. Thus the yield per recruit may not give a correct prediction of the effects of different fishing policies. In particular a policy of high fishing effort (especially combined with an age at first capture much less than the age at maturity) which would lead to a low adult abundance from a given recruitment, could result in fall in recruitment. Hence the total yield from such a policy would, compared with yields under alternative policies with lower fishing rates, be less, and probably much less, than that suggested by the difference in yield per recruit.

In principle the analytic models can be extended to deal with this. By using some relation between the size of the adult stock and the subsequent recruitment the entire life cycle can be followed. Thus the total yield (and not merely the yield per recruit) can be calculated from any given pattern of fishing. In practice it is very difficult to establish a reliable stock-recruitment relation. Usually the average recruitment does not change much over a moderate range of stock sizes (though the actual recruitment can vary greatly from year to year), and only tends to decrease once the stock is depleted below some critical level. The best practical advice is often then to prevent the adult stock falling below this level - the problem then being to know what this critical level is.

With this reservation concerning recruitment, the analytic models, and specifically the calculation of yield per recruit have proved very valuable. They enable much more detailed advice to be provided than is possible with production models. Assessments can be made of the effects of changes in the patterns of fishing (e.g., changes in the size at which the fish are first liable to be caught, due to changes in the mesh size used), as well as in the total amount of fishing. Assessments car also be made of the interactions between two fisheries on the same species, e.g., one on immature and another on spawning fish. This can be done by splitting up the total deaths by fishing within each time or age interval into those taken by each fishery, and compiling the total catches for each fishery separately.

3.4 Multi-species fisheries

The models described in the previous two sections deal with the dynamics of a single exploited species. With very few exceptions the fisheries in any area harvest a number of species - a very large number in some tropical regions. No satisfactory model or method of analysis has been developed so far to deal comprehensively with the problems raised by multi-species fisheries, and studies of these fisheries are among the more important fields of current fishery research. However, analysis can be made, and advice given, in respect of a number of particular situations.

Among the simplest is when a species which is the main target of one fishery, is also taken in another fishery, which is primarily directed at some other species. This question of the so-called by-catch can raise difficult political problems when the two fisheries are quite independent, being based in different ports or even different countries. Such problems will be especially pressing when the first species is heavily fished. This situation can be readily handled by the simple 'book-keeping' approach of the analytic model. The history of a group of fish is followed through its life, taking account of the catches in the directed fishery, and by-catches in any other fisheries. The effect on the directed fishery of modifying the by-catches, or any other management policy is then easily calculated.

Another situation that is relatively easy to analyse is when a single fishery takes a great variety of species, without being directed at any one particular species. This is the situation in many trawl fisheries in the tropics or sub-tropics. Here it may be possible to treat all the fish together as a single stock. Then the production model approach can be followed, relating the catch and catch per unit effort to the total effort. Species differ in value, and the effect of heavy fishing on the fish communities is often to change the relative abundance of different species - often though not always in the direction of increasing the relative abundance of the smaller and less valuable species. It may then be more appropriate to do the assessments in terms of the value, e.g., to calculate the value of the catch per unit effort, etc.

The most difficult and important problem concerns independent fisheries which exploit different, but biologically inter-dependent species, e.g., one that feeds on the other, or two species that compete for the same food. An example of such an interaction that is receiving considerable attention is that in the Antarctic between whales and krill. Here it appears that, on the one hand, the depletion of the whale stocks may have resulted in a greater density of krill and hence better catches for the potential new krill fishery; on the other hand, there is a fear that any substantial catches of krill will depress the rate of recovery of the whales, and ultimately, the catches that might be taken from a re-built whale stock. In this example the interaction between the fisheres are in opposite directions - more whale catches (and lower whale stocks) will improve krill fishing, whereas more krill catches will harm whale stocks and any whale fishery. In other cases the interactions can be in the same direction. For example if the two fisheries are on species that are in competition (e.g., are eating the same food), then increased fishery on either of the species would improve the fishery on the other. Where the interactions are large, they can be important in modifying the advice and actions that might have been made if each species were considered in isolation. For example, if a large-scale krill fishery does develop in the Antarctic, the total allowable catch (or other control) will presumably be set very much with the effect on whales in mind, and at a lower level than if only the interests of the krill fishery were considered.

Most situations involving the interactions between fisheries on two or more species are not so straightforward. Interactions between species may be of many different kinds, and while it may seem likely that some interaction is taking place, the mechanism may be far from obvious. The eggs or very small young of a large predatory fish (e.g., cod) may be vulnerable to plankton eating fish (e.g., mackerel or herring) so that the expected predator-prey relation is reversed. Taking account of the different life-stages, and the possibility of one stage of one species eating one or other stage of a second species, or competing with some stage for a common food, the number of possible interactions between even two species is large. Thus there have in the last twenty years been large changes in the species composition of the stocks in the North Sea (Hempel 1978). It seems clear that the changes in the different species are related, and also related to the different fishing pressures on the various species. However, although the North Sea and its fisheries and fish stocks is one of the two or three best studied bodies of water, there is no clear and commonly agreed explanation of the changes. More to the point, it is not possible to identify clearly the management policy (heavy fishing on some species, light fishing on others) which would bring about any particular desired balance of species.

Nevertheless the position is not entirely chaotic. It is possible in most cases to know the direction in which any influence of one stock on another will act, and often give a reasonable idea of the magnitude of the influence. Thus analysis can be made on the basis of a single species approach, and then the qualifications can be added, e.g., that increased fishing on a competing species will tend to increase the catches of the species being considered.

4. DATA NEEDS

4.1 General needs

One of the commonest obstacles to carrying out stock assessments is the absence of adequate data. This often occurs because the main user of the data - the stock assessment scientist - does not have direct control over the collection of much of the data, especially the statistics of the commercial fishery. It is therefore important that those who do have control of the collection of data have a good understanding of why it is needed, and what is needed (type of data, details required, desirable precision, etc.).

The first point to be stressed is that, just as the fishery problems change, and the type of stock assessment advice changes, so do the data needs change. In particular there is likely to be a continual increase in the variety and detail required, and in the desirable level of precision, as the fisheries develop. The second point is, just as the stock assessment studies should be carried out before the problems for which they are needed become urgent, so the collection of data has to precede the analysis. This means that the system of data collection should be designed not only to deal with current problems, but with future problems. This is particularly important because for most methods of assessing fish stocks a series of data over a period of years is much more useful than observations in a single year or over a short period. For example, they may show whether a sudden drop in the catch-per-unit effort is typical of the stock, and is part of a sequence of highly fluctuating values with no particular trend (i.e., there is no real sign of "over-fishing") or whether it is the culmination of a period of decline correlated with increased fishing (i.e., the stock has become "over-fished"). That is, data systems should be introduced now - or be already in place - so that in a few years time stock assessment scientists will have the data on which to give good advice to the manager in dealing with the problems of the following years.

This may seem to be difficult to achieve, and to require a high degree of foresight on the part of those setting up a data system. Fortunately, the basic data needs are well-known, and it should not be difficult to establish a collection system that fulfills most of the requirements of future stock assessment scientists. These data come from two sources - the fisheries themselves, and special studies.

4.2 Data from the fisheries

The most important data from the fisheries is information on the total catch. This is usually obtained from statistics of the quantities landed. These have to be adjusted, using appropriate conversion factors, to take account of any processing (gutting, heading, etc.) done before the fish is landed. Account should also be taken of any small or unmarketable fish that are discarded at sea, though this can be difficult. Apart from knowing the total weight landed, it is also desirable to know where the fish is landed (which, apart from its social and economic value, is useful as a guide to where the fish was caught), the type of boat (if any) and gear used in taking the catch, and the species. The first two should be obtained simply when collecting the basic data, if this is done, as it should be, at the point of landing, i.e., the original records should include data of place, vessel and gear (which are readily observable), and these records should be maintained when processing the data. For ease of later interpretation the classification of vessel and gear should follow the established international standards, such as the ISSCAAP system used by FAO (Nedelec, 1982).

Collecting data on species is more difficult, especially when the number involved is very large. However, it is vital. Even quite closely related species (and species that may not be distinguished in normal market records) can differ very much in their biological characters (growth, longevity, distribution, etc.) and these can be important to the decision maker. For example, in deciding whether keeping trawlers 12 miles from the coast will help the inshore fishermen, he must know whether the same species occur along the coastline, and 15 miles offshore.

Fishermen can usually distinguish well between the various species that occur commonly in their catches on the basis of behaviour and distribution, as well as actual appearance -it is their livelihood. However, the names used can vary from village to village, and cannot always be easily matched to the scientific names. Once ashore, the distinctions between species become coarser, being based on market use and price. Thus large and small individuals of some of the more valuable species may be split - the smaller fish being lumped together with small species as mixed 'trash fish'. The routine collection system for statistics can usually do no better than follow this broader grouping. The estimation of the species composition of the total catch will therefore have to be done in at least two stages - the main routine system, giving data on broad market categories (mackerels; good demersal fish; penaeid shrimp; small shrimps; trash fish, etc.), and a second, research, stage of determining the precise species composition within each category.

Similar considerations apply to data on fishing effort and catch-per-unit effort (c.p.u.e.). Information on any trends in the amount of fishing (effort) is vital in interpreting trends in total catch, while the c.p.u.e. is often the only available index of what is happening to the abundance of the stock. These data are also valuable for economic and social studies. However, the data that can be readily collected (number of fishermen, number of boats of different types, perhaps the number of landings by each type of boat, etc.) may not, by themselves, be satisfactory for stock assessment purposes. A technical improvement, e.g., a change from traditional materials to monofilament synthetics for gill-nets, may cause a change in the effort in biological terms (i.e., the proportion of the stock removed) which is much greater than any change in the records of the number of gill-nets.

Again, a second stage of data collection is necessary. Detailed understanding of how the fishery actually operates enables the scientist to interpret, and as necessary adjust, the data coming from the basic data system. For example, it may show that up to a certain time the fisherman used the same type of gill-net in the same way and the catch per fisherman was a good index of abundance. Later they used longer nets, and stayed out fishing for more hours each day. The catch per fisherman would then have to be adjusted to account for the changes. This might be done by expressing the c.p.u.e. as catch per 100 m of net, or per hour at sea. Alternatively the catch per fisherman for the earlier period might be adjusted by some suitable factor. Catch, effort and c.p.u.e. are directly related so that it is not necessary to collect all three directly, and in practice it is often most convenient to put the emphasis, particularly at the second, detailed, stage on collecting good c.p.u.e. data (i.e., of effort and corresponding catch) from those sections of the fishery for which it is suspected that c.p.u.e. would provide a good measure of stock abundance. Estimates of total effort, for a species or group of species, can then be made from these c.p.u.e. figures, and figures of total catch.

The stages of collecting the detailed information on both species composition and effort (fishing practices) need not be done every year. It may be expected that they will not change much from year to year. It is the changes over longer periods, as a consequence of, for example, the effect of heavy fishing on the preferred species, or the spread of new technology, that is of interest to the stock assessment scientist. These can be detected by having detailed surveys of the fishery at intervals of, say, 5 years.

4.3 Research data

At the stage of collecting detailed data from the fisheries the work of the statistical group (which will usually be distinct from the research group within the national fisheries organization) merges into that of the research group. It may well be carried out by the latter group, and be combined with other work of more specific scientific interest. This should include the regular collection of data on the sizes (lengths) of the main species caught -particularly of species where there is normally a wide range of sizes in the catch. Fishing increases the death rates, and hence reduces the proportion of old (and large) fish in the population. Examination of changes in the sizes of fish caught is therefore a sensitive way of detecting the effect of fishing, and one that is largely independent of some of the natural changes (e.g., in year-class strength) that confuse other methods. Techniques now exist (e.g., Jones, 1981; Pauly, 1980) for using length composition data to make many of the standard stock assessment analyses.

A source of research data to which much attention has been given is surveys of one type or another. Undoubtedly a well-planned survey can produce data that are useful for stock assessment work. However, sending a special ship to sea, even for a short time, is expensive, and unless a long time is spent at sea the number of observations (e.g., number of trawl hauls) is likely to be such that the sampling error on any estimate (e.g., of biomass) will be large. Further, survey vessels can be used for a number of purposes other than direct stock assessment, e.g., to test new gear, or to determine the likely catch rates at a particular time and place. If different purposes are mixed, the results are unlikely to be useful for stock assessment work. For various reasons, therefore, very careful consideration of the costs and benefits of possible surveys (e.g., acoustic surveys for pelagic fish, or trawl surveys for demersal fish) should be made before they are included as one of the early items of a research programme.

What is necessary in all cases is the systematic compilation of the simple biological information on the major species. This should be obvious, but basic data on matters such as how fast does a fish grow, how long does it live, where does it occur at different times of the year or at different stages of its life, what does it eat, and what is it eaten by, need to be readily available. They take time to collect, and if not collected and compiled systematically as an early part of a stock assessment programme, much time can be wasted later when the information is needed, e.g., to include feeding habits in a multi-species model.

5. MECHANISMS OF COMMUNICATION

The best stock assessment studies, however well done, and matched to the immediate needs of the country are worthless if they are not used by decision makers. Good stock assessment advice has in the past been ignored by decision makers (e.g., because it conflicts with the short-term interests of the industry), and doubtless will be ignored again on some future occasions. However, the commonest cause of failure to use stock assessment studies is probably the absence of good communications between the scientist and the decision maker. The latter may be unaware even that the former can help him, and very often neither side will be clear on what sort of help can be provided. This failure of communication reinforces itself; if the communications are poor the nature of any scientific advice (if any formal advice is given; more often it will be assumed that the scientists' duty has been performed by the publication of scientific papers whose significance will be utterly unclear to the average administrator), will tend to be irrelevant to the administrators' problems; he will thus ignore the scientific work, which will therefore become less and less relevant, with the communication gap steadily widening. Some formal machinery is therefore desirable to ensure that the policy maker is regularly provided with up-to-date assessment advice.

An important reason for having machinery which requires the regular presentation of advice in a form that notice has to be taken of it, and which does not require a special initiative on the part of the scientist, is that the advice will often be unwelcome. For example, during the expansion phase of a fishery it will normally be the stock assessment scientist who has to point out that the resource can probably not support more than the number of vessels already in operation, plus those already being built or on order. A halt in construction is therefore called for. This may be necessary at a time when the national director of fisheries is priding himself on the success of his development plans, and hoping that his status within, say, the agricultural ministry, can be further increased by a few more years of rapid growth,. It may require a brave director of research to tell his chief that these hopes are unjustified, unless there are arrangements that advice on the state of the resources is provided at regular intervals.

The mechanics of regular stock assessment advice has been most fully developed in some of the international fishery bodies. The details vary, but typically there is a Scientific Committee (whose title varies somewhat from body to body) which meets annually to review the state of the stocks, and the report of the Scientific Committee is then used by the parent body in deciding on management measures. The Northeast Atlantic presents an interesting special case in that there is an independent scientific organization, ICES, whose advice is channelled, through its Advisory Committee on Fishery Management, to international fishery bodies, e.g., the Baltic Sea Commission, as well as to the EEC and individual governments. These arrangements mean that, on the one hand, the managers concerned have, each year, to look, in the light of the best available scientific advice at what is happening to the stocks and what, if anything, should be done to manage them, and on the other, that the scientists have, each year, to put together all they know about the current state of the stocks.

These international arrangements have, on the scientific side, two further advantages. First, they enable a mass of scientific talent in the specialized field of stock assessment, to be brought to bear on problems, which is not available to individual countries. This is useful even in the North Atlantic, where most of the countries have long-established traditions of fishing research. It is potentially much more valuable in the developing world. Second, the advice can, to some extent, be free of the pressure that exists on national scientists when they advise their administrators, who naturally wish to hear good news - catches can be increased, more boats can be built, and more investment encouraged. This independence is increased if there is active participation by scientists from FAO or similar international bodies.

With the changes in the Law of the Sea the responsibilities of international bodies for determining management measures has been greatly reduced. For example, in the North Atlantic ICNAF, in the north-west, has been transformed into NAFO (with reduced management functions) and NEAFC, in the north-east, has little or no effective function. These changes, however, have had much less effect on the scientific advisory role of the appropriate regional bodies (the Scientific Council of NAFO in the north-west, and ICES in the north-east). Their advice is regularly sought, not only in respect of stocks that are still managed by international bodies (as in the Baltic), but also by individual countries or groups of countries. In other parts of the world, where the tradition of multi-national fishery research is less well established, there may well be a considerable increase in the use of this approach to the regular supply of scientific advice. It may be noted in passing that there may be a reluctance on the part of a coastal state to reveal information about its resources in case this information should be used as a lever by distant-water fishing countries to gain access to these resources. In particular there is some fear that when the current harvest of the coastal state is less than the estimated Maximum Sustainable Yield it is then mandatory to grant access. In fact the draft LOS text talks about the MSY "as qualified by relevant environmental and economic factors, including the economic needs of coastal communities ....", which would seem to imply that a 'surplus' would exist, to which access should be granted, only if catches can be increased by foreign fishing without causing economic losses in the coastal states.

Despite the advantages of international arrangements, much advice will be carried out purely nationally. Some countries have found it convenient to follow a similar pattern to that of the typical international body, in having a Scientific Advisory Committee to review annually the information on the resources, and to advise on possible action. Such committees may bring scientists from the universities and other groups outside the government research institutes. Apart from the immediate advantages of bringing additional expertise to bear, such Committees have the longer term advantage of making the academic community more aware of the scientific problems of fisheries. Teaching may well become more relevant to national needs, and scientists in universities are more likely to channel their research towards those problems which are of practical interest, but which cannot be tackled directly by the fishery research institute.

The actual form of the regular review, whether by a formal Committee, or as a report from the Director of Fishery Research, will depend on the conditions in each country. It is likely to contain two parts, a review of all stocks, in the detail required for immediate policy purposes, e.g., in setting annual quotas in respect of any stocks managed in this way, and a more detailed, in depth, study of selected stocks - time will probably not allow for such a study of all stocks, while the rate of accumulation of new data probably does not make it worthwhile to make such a review more frequently than once every four or five years.

The important point is that some review is carried out annually, and is considered seriously by the senior fishery administration. On the research side the scientists should sit down and say what they know about the resources. On the administration side, the senior staff (e.g., the Director of Fisheries) should carefully examine the national policy for developing and managing the fisheries, and also inform the scientists where the review is incomplete, or unclear, and where more information is needed. This may not result at once in a more successful fishery, or even better stock assessment, but should lead to research that is more relevant to national needs, advice that is clearer to the administrator, and better understanding by the administrator of the value of research, and the need for support to research work. This may then lead, first to better stock assessment, and then to a better managed fishery.

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