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A COST EFFECTIVE APPROACH TO STOCK ASSESSMENT AND MONITORING OF SMALL-SCALE COASTAL FISHERIES IN THE SOUTH PACIFIC REGION

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1. INTRODUCTION

This paper outlines a possible methodology for appraisal and assessment of coastal fisheries resources in the South Pacific region based primarily upon routine fishing and the collection of length-frequency data. The paper is based on two reports (Munro, 1986; Munro and Fakahau, 1987) prepared for the Forum Fisheries Agency, which deal with the scientific background to this paper and the practical aspects of monitoring, assessment and management of these fisheries.

Assessment, in essence, means evaluating the state of exploitation of the stocks. Are they fully exploited or are they yielding less than the economic or biological optimum, either as a result of "underfishing" or "overfishing"? If they are underfished the reasons for such a state need to be examined. Often economic reasons are the cause, the costs of fishing being too great or the market value of the product too low. If they are fully exploited or over-exploited the fishery needs to be monitored and managed to ensure that the harvests are optimized and that further "developments" are not needlessly initiated. The economic structure of the fishery also needs to be examined to see if there are any ways in which profitability can be increased.

2. PROPOSED METHODOLOGY FOR ASSESSING AND MONITORING FISHERIES

A basic system is proposed here as a model for monitoring, and assessing small scale coastal fisheries in the tropics. The characteristics of such fisheries are that they produce multispecies harvests, use a wide variety of fishing gears (often changing seasonally) and land catches at widely dispersed bays, beaches and small harbours and seldom at centralized fishing ports.

Industrial-scale fisheries, in which vessels discharge their catches at a limited number of centralized processing depots from which the fish enter a distribution system, are uncommon in tropical coastal areas but where they exist they are more readily amenable to data collection and monitoring than the small-scale activities and can be treated somewhat differently. Nevertheless, the system proposed here is appplicable to both types of fisheries. It is also based upon the assumption that, as is the norm in most countries, trained manpower for execution of the work is in short supply and that budgets are limited.

Assessment and monitoring is a two-part process, with assessment being a necessary precursor of monitoring. That is, a fishery needs to be assessed to ascertain the status of the resources, to determine whether or not it is over- or under-exploited and to decide on measures leading to further development or to management of the fishery. Thereafter the fishery needs to be monitored in such a way that any changes in the fishery and the fish stocks will be observed and can acted upon if necessary.

The variety of methods available for fishery assessment have been described by Gulland (1983) and Munro (1986). The methods are numerous and no single method can be prescribed as being appropriate for the assessment of <u>all</u> species and all fisheries. However it was argued that a system based <u>primarily</u> upon length-frequency data is likely to be the most cost-effective (Munro, 1983). The suggested assessment and monitoring system is outlined in the following pages and summarized in Fig. 1. The actions needed for implementing the system are outlined in Fig 2.

The scheme is based upon the assumption that no previous data are available. However, in many fisheries it is likely that all least some of the information is already available and that it will be possible to omit some of the activities or at least reduce the work to some degree. The importance of searching old files and records for such data cannot be overemphasized. Data gathered at earlier times, particularly when coastal population densities were less or conditions were different can give an invaluable insight into the changes which have occurred in the fishery. For example, length-frequency and catch per unit effort data collected in the early stages of a fishery can give invaluable insights into the mortality rates in virgin or near-virgin populations and of the relative biomasses of such populations. Replication of an exploratory fishing cruise made many years ago can provide comparative data which will give an immediate insight into the state of a fishery. For example, if an exploratory trip in, say, the 1920's yielded 20 kg of a species per unit effort and a replicate trip this year yielded only 2 kg/per unit effort there would be very strong evidence that stocks had been reduced to around 1/10th or less of their original densities. As the greatest harvests are taken when stocks are reduced to about one half to one third of their original densities it could be concluded that such a stock must now be grossly overfished.

Statistical systems for the continuous monitoring of catch and fishing effort are the norm in industrial fisheries throughout the world, where the very great values of the catches justify the costs of collection, where much of the information is in any event recorded for business purposes and where skilled manpower is available. However, there are relatively few industrial fisheries in the tropics and they are virtually unknown in Oceania. Exceptions are the skipjack tuna fisheries, trawl fisheries for prawns and some spiny lobster fisheries.

Attempts have been made to establish statistical systems to monitor the artisanal fisheries in many tropical countries but we know of no example of successful sustained implementation. The problems of dispersed landings, the multitude of species, variations in fish prices and of unrecorded subsistence catches normally combine to make the systems inaccurate and inordinately expensive in terms of manpower. Additionally, the fact that most tropical fisheries are also multigear fisheries makes the derivation of any but the crudest expressions of fishing effort almost impossible. The result has been that few meaningful or beneficial results have ever been perceived to emerge from statistical systems in multispecies, multigear fisheries and there has been a strong tendency to scale-down the work to meaningless levels or abandon it altogether.

Where statistics are gathered systematically, the output is information on trends in the annual catches and in the catch of the dominant species per unit of fishing effort. Where a long time series of data are available over the history of the fishery, curves similar such as those shown in Fig. 1 can be constructed for each species and for the total catch. However, where the fisheries have undergone major technological changes over time it becomes very difficult to assess fishing effort in meaningful units. Likewise, in a tropical multispecies fishery where different gears may be targeted on different species at different times, or on the same species at different parts of its life cycle, any simple measure of "fishing effort" is almost impossible to achieve.

For purposes of stock assessment, the main use of fishing effort data is to provide an indirect estimate of fishing mortality (the fraction of the fish stock which dies as a result of being captured). This is usually achieved by constructing an age-structured catch curve, which is a plot of the logarithms of the abundances of successive age groups against their respective ages. The slope of the line between successive points is a measure of the total mortality rate (Z) in the time between those ages (Fig. 3a). If there is a measure of fishing effort, the mortality generated by different amounts of fishing effort can be estimated and, if the data are reliable, the mortality generated by different amounts of fishing can be plotted against the corresponding amounts of effort to get an estimate of the mortality generated by one unit of fishing effort (the catchability, q). The natural mortality rate can also be estimated (e.g. Fig 3b; Widrig 1954). However, the result of much effort is often a non-significant plot owing to the large numbers of variables affecting the estimates. The process of sampling the fish stocks to get unbiased samples, ageing the fishes in the samples and estimating fishing effort is an expensive and tedious process at best but has formed the basis of fisheries assessments in temperate waters. However, in tropical fishes ages are difficult (but not impossible) to estimate from scales on other hard parts and there is always a multiplicity of species of roughly similar importance.

Many of these problems have now been circumvented as a result of the development of length-converted catch curves (Pauly 1983, 1984) which give a relatively robust measure of size-specific mortality rates in fish stocks. This is probably one of the most important developments in fisheries science in the last two decades. In length converted catch curves the logarithms of the frequencies of successive length groups divided by the time required to grow through those groups (Ln(N/dt)) are plotted against the relative ages of the fishes in those length groups. The result is a graph with a descending right-hand arm, the slope of which is a direct measure of the mortality rate at the size or ages in question (Fig. 3c).

The use of length converted catch curves derived from routine measurement of the lengths of fishes is therefore seen as a prime tool for assessing and monitoring fisheries because the mortality rates so derived give a direct insight into what is currently happening to a fish stock and the measure is entirely independent of the sorts of fishing gears which are contributing to the mortality. However, it is important to note that much care has to be taken in attempting to obtain length-frequency samples which are unbiased and which really reflect the size structure of the fish stock in question.

2.1 Sample surveys of the fishing industry

As indicated in Fig. 2, the initial need is for a sample survey of the fishing industry which will give a baseline for the planning of future work and of the assessment and monitoring scheme. Guidelines for the establishment of statistical monitoring systems or for undertaking periodic frame surveys, together with a full list of references, are given by Caddy and Bazigos (1985) and need not be repeated here.

However, it is most important that fisheries officers implementing sample surveys or establishing statistical systems have a very clear appreciation of what can be expected to emerge from such work. Statistical monitoring systems can range from the intermittent collection of data to a continuous programme of monitoring landings and fishing effort. The former is hardly worth pursuing and the latter will lock up large amounts of manpower. A well executed sample survey carried out over a full year should;

(a) give an inventory of the fishing grounds and areas based on their natural ecological characteristics and not on arbitrary boundaries,

(b) produce an estimate of the total tonnage of fish caught, broken down by principal species fishing gears and areas,

(c) provide an inventory of all fishing boats and fishing gears,

(d) give estimates of the numbers of

(i) full-time or part time artisanal (= commercial) fishermen and

(ii) subsistence fishermen (who are always part-time even though they might be specialists within their village), and

(e) show the basic seasonal trends in the fishery.

Such a survey could be repeated at intervals of, say, five years and will provide a basis for assessing changes in the productivity of the fishery.

However, sample surveys do <u>not</u> give any real insight into the potential productivity of a fishery or how harvests might change in response to changes in the sorts of fishing gears used and only a limited insight into the effect of changes in fishing effort using the existing array of gears. Thus, while a single well-executed frame survey can provide information of use to planners and economists, it does not provide more than a baseline for further work in the management of the fishery. In particular it normally provides very little information on the status of particular fish stocks.

One of the prime needs, often overlooked, is for an inventory to be made of the fishing grounds, dividing the fishing grounds into reef, lagoon, outer shelf, seagrass, mangroves or other appropriate habitats and also into depth zones and measuring the area of each habitat in each fishing area. The amount of detail available will vary from place to place. The basic features of total area of shelf or lagoon can often be derived from a large-scale nautical chart or other maps. Detailed information is now becoming available from satellite imagery and it is most important that full use be made of the available information (e.g. Quinn et al 1985).

Given the total landings and the areas of the fishing grounds, the harvest per unit area can be calculated and comparisons can be made with reported harvests from similar areas elsewhere and some judgement formed about the relative production rates from the fishery. Alternatively, fishing intensity surplus yield curves could be prepared in which the catch per unit effort in different, but ecologically similar, areas are plotted against the fishing intensity (fishing effort/unit area) (Munro 1978, 1984).

One common shortcoming of many sample surveys or statistical systems is that they fail to provide information on the most important <u>species</u> in the catches. For example, catches might be grouped by some economic category or by gears so that categories designated, say, as "groupers and snappers", "reef fish" and "small pelagics" might totally obscure the fact that one species of grouper, one species of surgeon fish and big eye scad are dominant in those categories. The biological interpretation of the results can be greatly improved if the most important species can be identified and categorized separately; for example, as grouper species A, surgeon fish species B, big eye scad and "all other species" might be far more meaningful than the broader groupings mentioned above. It is recognized that in tropical seas there are enormous numbers of species mostly of about equal importance. Nevertheless there are always a few species which by virtue of a combination of abundance and value are the most significant in the fishery. These could be considered as "indicator species" to be investigated in more detail or the grounds that, for example, the mortality rates of a common species caught by a particular gear will be similar to that of less common species in the same family.

2.2. Inventory of fishing gears, vessels, fisherfolk and socio-economic factors

An inventory of fishing gears, boats and fisherfolk is an important adjunct to sample surveys in that it provides the "raising factors" for converting average catch rates to an estimate of total catch. Similarly, knowledge of village populations, stratified if possible by sex and age will give some indication of the magnitude of subsistence catches.

Like the sample surveys the inventories need to be made in detail periodically. However within the context of what is being suggested here an attempt should also be made to monitor any changes in the fishing gear and fishing power of the communities

A wide variety of social and economic factors affect the response of the fishing community to changes in the fishery, including proposed management measures. These include such items as the costs of different fishing gears, fuel, fish prices, availability and costs of competing products, transportation costs, vessel maintenance, fuel and labour costs, catch sharing arrangements or bonus systems and other generalized economic factors such as the consumer price index, wages and opportunities for employment in other industries, and interest rates and the availability of loans.

Additionally, social factors must be identified and recorded. These include such things as constraints on the fishing operations (for example, strict observance of the Sabbath in some countries but not in others), traditional beliefs about fishing, customary law relating to fishing and access to fishing grounds and to disposal of catches, social pressures mitigating for or against accumulation of capital and any other factors which will bear on the profitability of fishing and the amount of fishing.

The services of social scientists and economists should be sought. The works of Smith et al (1983), Bailey (1982a,b), Smith and Mines (1982) and Lockwood et al (in press) are important guides to this part of the work.

2.3. Routine fishing with standardized gear

After a frame survey has been executed, as a single periodic exercise (say every five years) it is suggested that a major part of the manpower and funding in the intervening period should be directed towards routine fishing with standardized arrays of gear. It is not suggested that sophisticated research vessels be employed; preferably, the gear and methods should be as similar as possible to those employed in the fishery, with two important exceptions.

(a) the gear should not be varied seasonally but should be fished as best it can throughout the year

(b) some of the gear should be designed specially to sample fishes at a somewhat smaller (prerecruit) size than that at which they are normally taken by the fishery.

The essence of the routine fishing is therefore that the same set of gears are used repeatedly in every lunar month throughout the year. Fishing effort should not be varied greatly in response to changes in catch rates, i.e. the temptation to continue fishing in a good spot should be resisted if it is at the expense of coverage of the scheduled fishing stations.

An important aspect of this suggested methodology is that it should be under the control of fisheries officers, technicians or biologists who appreciate the reasons for undertaking the work, the need for careful recording of data and who have a positive interest in the fishermen and fisheries. It also underscores our belief that fisheries officers who regularly go fishing will have a better appreciation of the needs of the industry that those who only navigate their desks through the bureaucratic maze.

All fishes captured by routine fishing should be identified to species and measured from the snout to the end of the middle caudal ray (i.e. total length if fishes have truncate or rounded tails or fork length for fork or lunate-tailed fishes). In the first year numerous fishes should also be weighed in order to establish the length-weight relationships.

The number of fishes which should be measured each month in a study area is difficult to specify, but 200-500 of each of the five to ten commonest species and all of the less common species is a reasonable target figure. The rarest species will never be taken in sufficient numbers to provide realistic estimates of growth and mortality. However, this is not really a constraint unless those rare species are particularly valuable e.g. spiny lobsters.

Clearly, the amount of fishing effort needed to catch a statistically adequate sample of the most important species will be inversely related to stock abundance and in very heavily exploited fisheries it might never be possible to acquire adequate samples. Some species might also have more inherent variability than others as a result of biological variability and/or of distribution over wide bathymetric ranges. In these cases, or in the case of particularly valuable species, a separate sampling program needs to be established to supplement the routine fishing data. Such sampling would preferably be done at the landing places or in the markets. A preferred option for supplementing the length and catch composition data from routine fishing is to monitor the catches of selected fishermen, who are perhaps paid a small retainer to compensate for the inconvenience of having their catches enumerated. However, it would be unwise to rely entirely upon sampling commercial catches because fishermen are prone to change their fishing gears in response to seasonal changes in availability of selected fish species or in response to changes in the weather or might even cease fishing during the best periods simply because the markets are glutted and fish cannot be sold or because other food crops need to be harvested.

The routine fishing needs to be targeted on specific "typical" fishing grounds and this might include, for example, areas on the windward and leeward coasts of selected islands or island groups including in each case areas which are heavily fished, which are remote from population centres and therefore lightly fished and, if possible, very remote unexploited areas. The range of depths, habitats and geographic spread of the fishing is very much dependent upon the individual country and it is difficult to make generalizations. It is suggested that ten days of fishing per lunar month per area would normally provide sufficient data. If the area is too large to be covered in that time then several technical crews would be needed even if the same vessel crew operated continuously.

Data on catch rates will tend to be variable often for entirely unknown reasons and there is no reason to expect great consistency in the data. The average catch per unit of effort and any underlying trends in catch rates and composition will undoubtedly emerge over time and this is all that is required.

It is also important that areas are visited at the same time of each lunar month so that lunar or tidal variability is eliminated from the data and that every attempt to made to reduce any other sources of variation e.g. the same bait should be used at all times, the same mesh sizes, and the same basic techniques and under no circumstances should there any any attempt to "improve" the technique after it has been established. Of course, a new technique could be added to the routine fishing repertoire but could only replace an established technique if the techniques were operated in parallel for at least a year. This would be an extreme step as it could introduce unexpected problems and it highlights the need for careful consideration of methods before the system is formally established.

2.4. Data collection

Standardized, conventional biological data collection methods need to be established and maintained. The essential features are as follows:

(a) Catches should be examined every few hours and never gilled, gutted or otherwise processed before examination;
(b) Catches from different gears, from different fishing grounds or taken in different hook or mesh sizes should be recorded separately;
(c) All catches should be sorted to species, counted and the total weight recorded. Each fish should should be measured and the sex and state of the gonads noted. Male and female fishes very often have different growth rates and therefore need to be recorded separately, at least until there is certainty that a particular species is not sexually dimorphic.
(d) If the catches are too large to be measured in toto, the total weight and number should be recorded and a few randomly selected entire containers of fish should be measured. Alternatively, some catches could be set aside for measuring on return to port. In practice this is usually difficult to organize and can lead to errors. Shrinkage or weight loss can also occour in iced or frozen fish.
(e) Length measurement are best accumulated on waterproof rolls of graduated paper which are simply marked with a pencil and the frequencies tallied directly, clearly labelled and returned to base for processing.
(f) A detailed "cruise log" needs to be maintained, giving details of the fishing gear used, fishing effort, times, dates, details of weight and numbers of catches by species, weather conditions, water temperatures, wind speeds, etc. The cruise log should be a copy note book, preferably of the sort that does not require carbon paper and containing not more than fifty pages. The larger the notebooks are, the greater will be the loss if the entire book is mislaid. The top copies should be removed several times daily and stored in a safe, dry place.
(g) At the end of a fishing trip the "cruise log" should be checked by the "cruise" leader and any errors or omissions corrected. The "cruise" log books are very valuable documents and should be numbered and carefully filed in a secure room when filled. The top, torn off, copies should be filed separately and used for future work.
(h) Details of catches, fishing effort and other factors should be entered into a computerized data base, preferably by the technical or scientific staff members who gathered the data. This minimizes errors.
(i) Length frequency data should likewise be compiled using the ELEFAN 0 or similar computer programs and after one year of data are available the data should be used for the estimation of growth and mortality rates and selectivity of the fishing gears. For this purpose the

ELEFAN I and II programs (Brey and Pauly 1986; Pauly, in press) can be utilized or other length-frequency based programs that are now becoming available (Sparre, 1987). It is most important that every attempt be made to validate results by cross-analysis of the data using whatever analytical tools are available and subjecting the results to sensitivity analyses whenever possible.

2.5. Data analysis and stock assessments

The methods currently available for data analysis and stock assessments have been reviewed by Munro (1986) and key references supplied and the details will not be repeated here. The methods are constantly being improved and, often, simplified but the detailed analysis of data still remains a specialized field and qualified personnel are needed to ensure that correct interpretations are made.

Training in these fields is becoming widely available as post-graduate university courses. In addition, short term courses are available through agencies such as FAO, ICLARM and SPC. Specialist assistance in data analysis is also available from such agencies. The most satisfactory training would be on-the-job experience in a pilot project.

Microcomputers are considered to be adequate for most purposes and suitable computers (preferably two) are essential for data compilation and analysis. The essential features of the data analysis programme are shown in Fig 1. The output from the analysis should in the first instance be single-species yield curves and yield isopleth diagrams (Fig 4a and b) which will indicate whether or not the principal species are underfished or overfished. More elaborate multispecies summations can be attempted as more data becomes available culminating in multi-species summations for different fisheries.

2.6. A permanent monitoring system

As shown in Fig. 2 it seems likely that within 3-4 years the basic elements of a stock assessment programme could be completed. Thereafter, much of the data collection can be placed on a routine permanent monitoring basis. The experience gained in the first three or four years of the program will indicate the most cost-effective routes for further monitoring of the fishery. It will also indicate the needs for additional work on particularly valuable or problematical species.

It is highly likely that several "indicator" species will emerge, the mortality rates of which can be taken to be representative of or related to those of whole sections of the exploited communities. Likewise, it is likely that some elements of the routine fishing array could be eliminated and the level of activity reduced or refocussed on gathering length frequency and catch per unit effort data from selected boats or individual fishermen.

Continued inventories of fishermen, boats and fishing gears combined with knowledge of catch per unit of effort and information on the relative frequency with which gears are used will provide reasonably accurate estimates of total catches which would certainly be adequate for statistical purposes and general economic planning.

The assessment work will provide the basic information upon which management policies can be formulated. Continued monitoring will provide the means whereby the effectiveness of management can be evaluated and the effects of natural variability in recruitment to the fisheries distinguished from the effects of exploitation.

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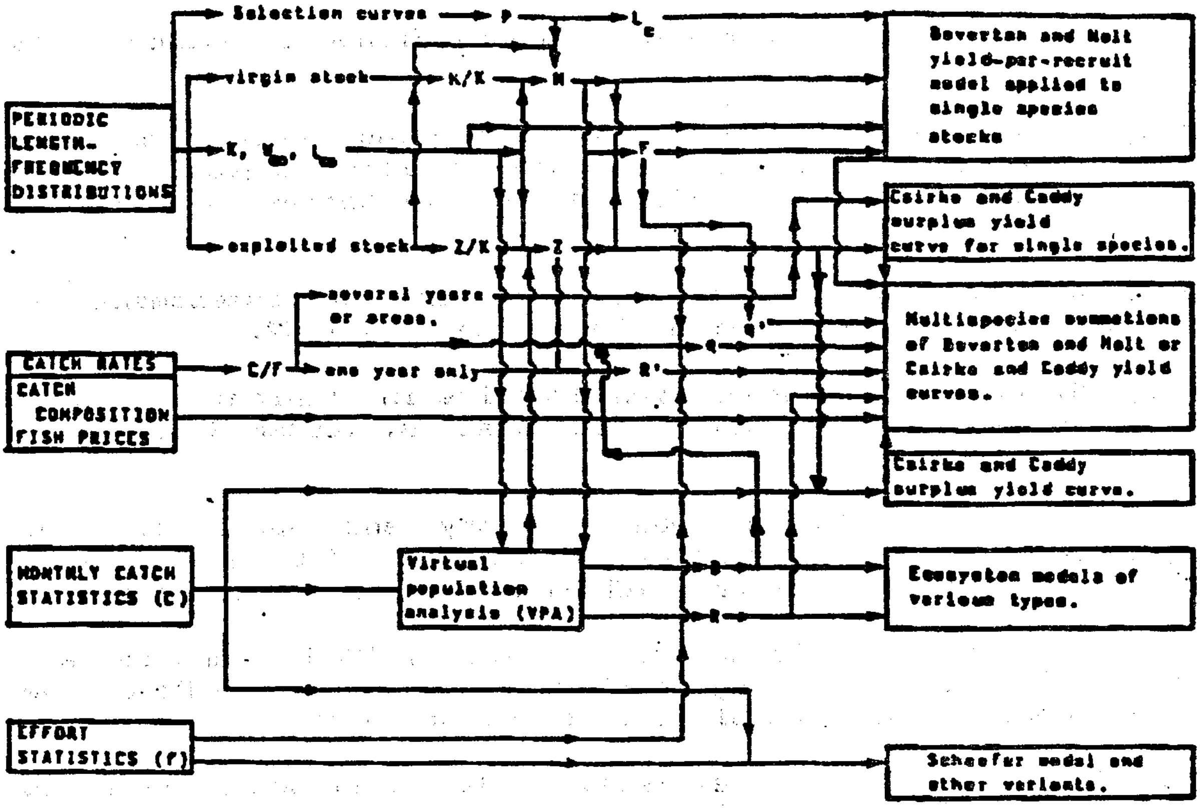


Figure 1. Flow chart for biological and fishery parameter estimations leading to fishery assessments. Required inputs are shown in the boxes on the left-hand side, outputs on the right. The notation and definitions are as follows:

B.....Biomass. The total weight of a population (or stock) of a particular species.

C.... Catch. The catch of a species by numbers or weight.

F.....Fishing mortality coefficient. The death rate caused by fishing.

K.....Growth coefficient. The rate of deceleration of growth. A parameter in the Von Bertalanfty Growth Function which is used to describe the growth curves of fishes.

L_c....Mean length at first capture. The average size at which a species of fish first becomes liable to capture by the fishery.

L_∞...Asymptotic length. Average maximum length towards which the fish are growing.

M.....Natural mortality coefficient. The death rate caused by natural factors.

p.....Probability of retention. Probability that a fish of a given length will be retained by a particular fishing gear.

q.....Catchability. The fraction of a fish population which is killed by one unit of fishing effort.

q'....Catchability index. An index of catchability equal to the amount of fishing mortality generated on a species in a particular year.

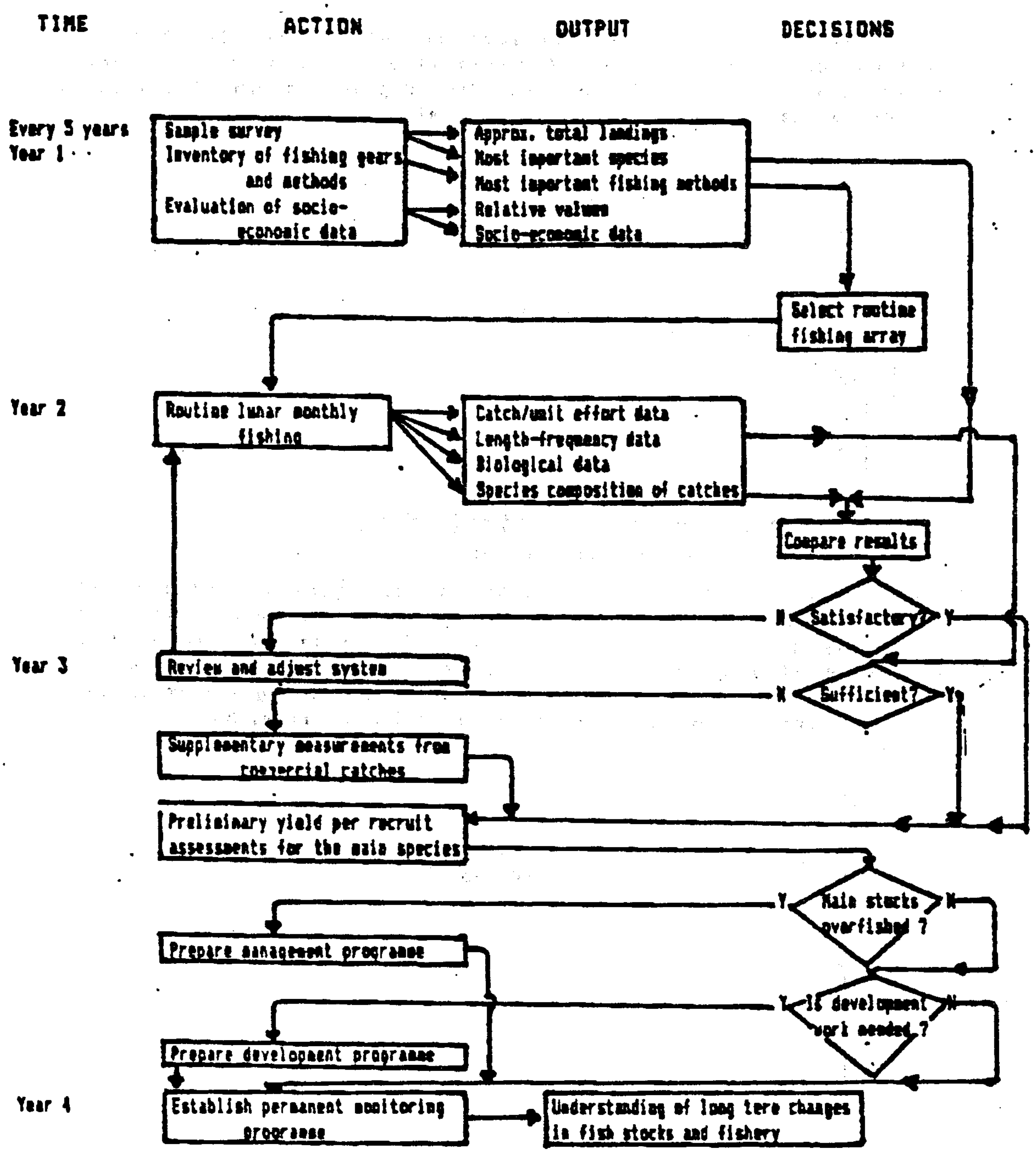
R.....Recruitment. The number of fishes reaching L_c in a year.

R'....Recruitment index. An index of the relative number of recruits in a multi-species fishery derived by dividing the total mortality rate by the catch per unit effort (R' = Z.C/f).

W_∞...Asymptotic weight. The average maximum weight towards which the fish are growing.

Z.....Total mortality coefficient. The death rate from all causes (Z = F + M).

Figure 2.
Time frames, actions, decisions and outputs of a systems approach to stock assessment, monitoring and management.



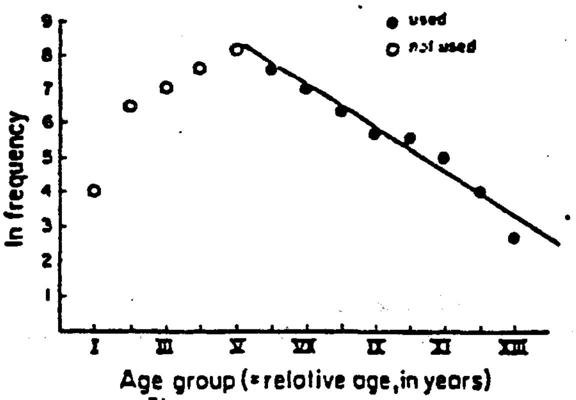


Figure 3a. Conventional age-structured catch curve in which the logarithms of the frequencies of successive age groups are plotted against age. The slope of the descending right-hand arm of the curve is equal to the coefficient of total mortality, Z.

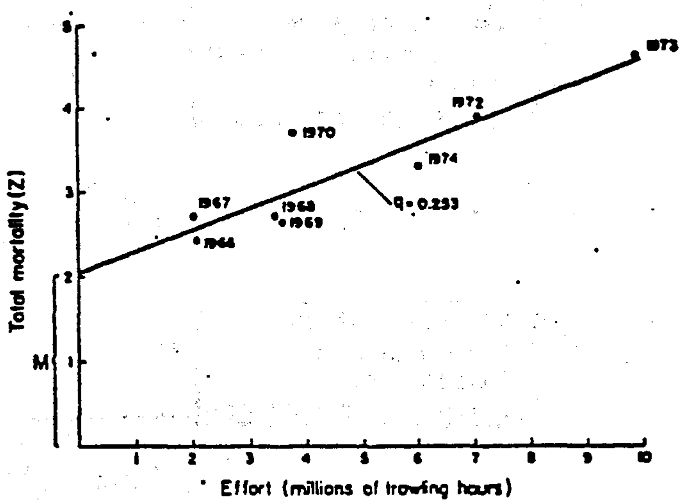


Figure 3b. If mortality rates are known for years in which fishing effort differed a regression of total mortality rate against fishing effort may give a positive regression in which the slope of the regression line is the amount of mortality generated by one unit of fishing effort and the y-axis intercept, where fishing effort is zero, is an estimate of the coefficient of natural mortality, M.

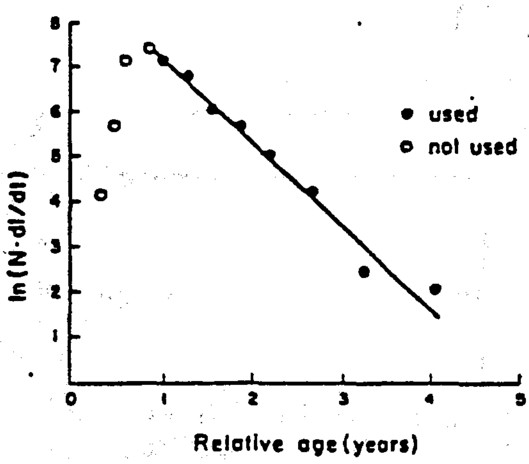


Figure 3c. Length converted catch curve, in which the logarithms of the relative abundances of successive length groups are plotted against their relative ages. Only the average difference in age between successive length-groups needs be known and the absolute ages need not be known.

a)

b)

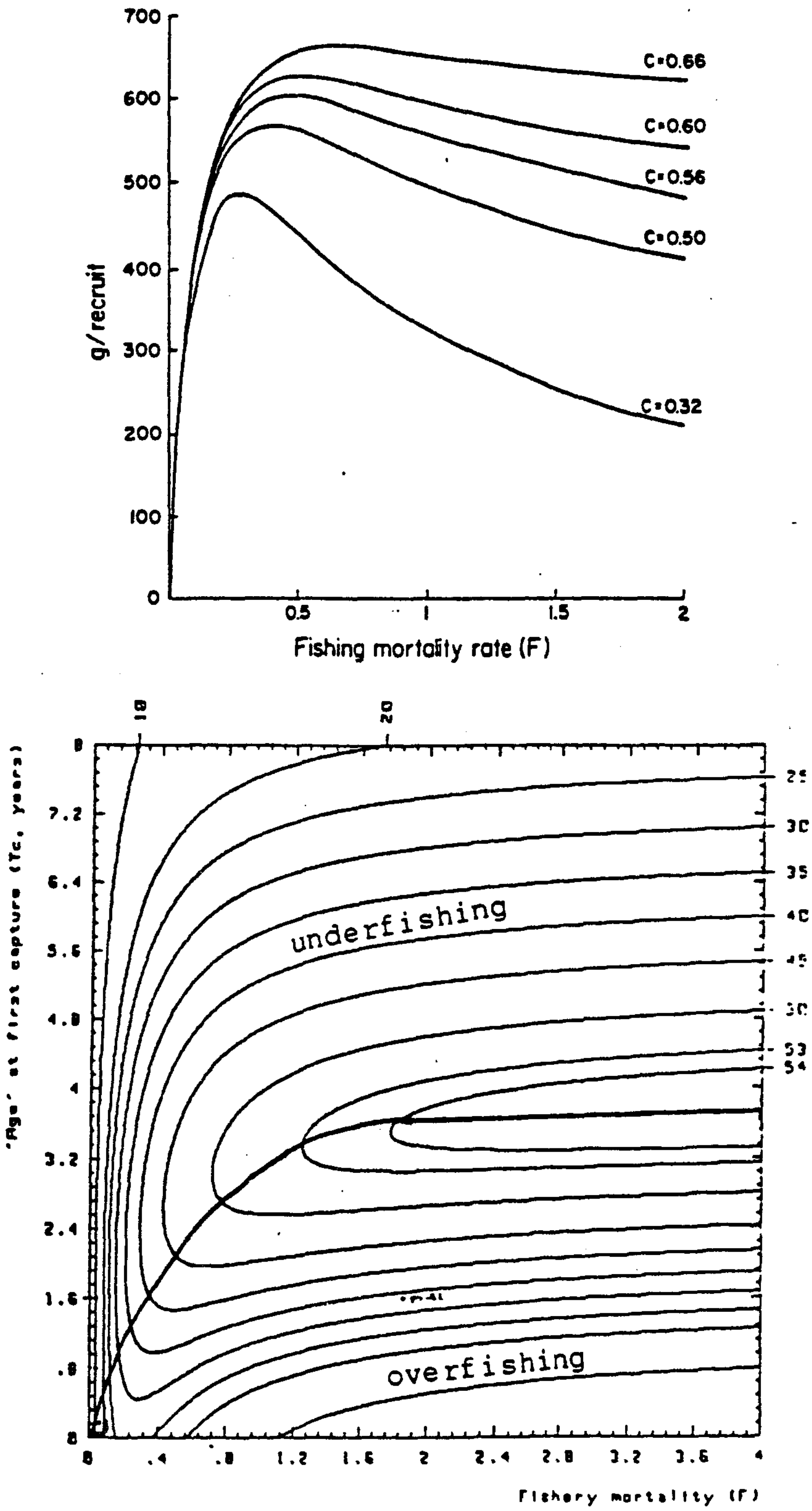


Figure 4.

a) Yield curves showing the relationship between yield per recruit and fishing mortality for various values of C, where C is the ratio of the size at entry to the fishery to the asymptotic size (from Munro 1983).

b) Yield isopleth diagram showing the expected yield per recruit for all combinations of age at entry (T_c) to the fishery and fishing mortality (F). The heavy line shows the optimum combinations of T_c and F. Combinations falling below the line constitute "overfishing", while those above the line constitute "underfishing".