CHAPTER 2

Appraisal, Assessment and Monitoring of Small-Scale Coastal Fisheries in the South Pacific Region[1]

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I. INTRODUCTION

SMALL SCALE COASTAL FISHERIES

The region specifically addressed in this volume comprises the coastal waters of the member states of the South Pacific Forum. Coastal waters include those covering lagoons, reefs and outer shelves and extending offshore to the distance for which it is practical for small craft to operate, usually a few kilometers. The depth limit at which it is practical to fish for demersal species is usually the boundary between the lower limit of the deep reef zone and the upper levels of the bathyal zone, at around 300 m. It is important to note that such boundaries are defined by environmental factors and not just by depth. Beyond the "deep reef" or "outer slope", the snappers and groupers disappear and the communities are characterized by caridean prawns, which appear to be the principal items of possible commercial interest at such depths (King, 1984). Dog-fish are being harvested from these depths in the Solomon Islands for their liver oil, and stocks of *Beryx* spp., which are found on the deeper seamounts, appear to offer commercial possibilities.

The basic groupings of the coastal fisheries are simply into reef, lagoon and shelf fisheries, further subdivided into demersal or pelagic. The term "reef" includes all areas of hard bottom, "lagoon" areas are non-reef sandy, silty or muddy areas enclosed by reef formations and "shelf" areas are those areas bounded to seaward by the open ocean but not covered by reef-building corals. This would include soft bottom shelves and estuaries (for example in the Gulf of Papua) but more typically includes those deeper areas below the zones in which reef-building corals thrive. The intertidal zone is a special area which is often intensively gleaned at low tide and has a resident fauna and flora of organisms which are resistant to desiccation to some degree. Other animals which visit the intertidal during high water but move out with the ebb tide are merely transients which are members of the reef, lagoon or shelf faunas.

Of the coastal fisheries in the region, those for demersal reef fish and for pelagic lagoon species appear to be of the greatest overall importance, but this will vary considerably by country. With the exception of Papua New Guinea, there are few trawlable shelves and few extensive shelf areas which could be described as island shelves.

STAGES IN THE DEVELOPMENT OF A MANAGEMENT REGIME

All fisheries must, at least theoretically, pass through a four stage process if they are to be managed on the basis of the best available scientific and socioeconomic information. These stages include the appraisal of an unfished resource, the development of the fishery, assessment of the fishery and periodic or continuous monitoring of the status of the resources.

Appraisal, in essence, includes all of the exploratory fishing activities which have characterized the efforts of many development agencies over the past few decades. Clearly, fishery appraisals have been a continual process ever since people first ventured near the shores of lakes, streams or seas in search of food and there are now very few fisheries which have not yet been fully appraised. In the context of the South Pacific region, the activities aimed at developing fisheries for the hitherto unutilised or underutilised deep-dwelling snappers and groupers are an example of a fishery appraisal. Market research is also an important part of an appraisal.

Where initial appraisals are favourable, development of fisheries usually follows. On a global basis, there are now very few fisheries which are not yet exploited. Those that are unexploited or are only lightly exploited and thus producing less than their maximum biological potential, usually fall into these categories for economic reasons, in that the costs of fishing and/or of transporting the catch to market are uneconomically high or that the local markets are oversupplied, therefore the catch almost worthless. Many of the coastal fisheries of the South Pacific region fall into this category, although there are examples of intensive local exploitation close to major urban centers.

The final stage leading up to management of a fishery is that of assessing the status of a resource. The principal question to be asked is whether or not the resource is producing its optimal biologically- or economically-sustainable yield and if this is not so, whether the resource is under- or over-fished. The whole question of the need for stock assessments was concisely reviewed by Gulland (1983a), together with a brief outline of the scientific basis for conventional methods, and this paper is recommended to those who have no formal training in this field.

Irrespective of the status of a resource, management options arise and decisions need to be taken; for example, on whether or not more investment is required or more controls should be placed on a fishery. Management measures need to be based on a very wide array of often conflicting, biological, social, economic and political considerations. If the resource is shared with adjacent countries, it may also have international implications.

All fisheries should, under ideal circumstances, be continuously monitored in terms of the total catch, catch rates and catch composition and in terms of economic factors. Such data form the basis for the continuing assessment of the status of the resource and lead to effective management, with the objective of optimizing long-term, sustainable harvests. Unfortunately, there are relatively few fisheries on a global basis for which monitoring has extended back over any significant period of time and for most of the world's fisheries neither current nor historical data are available. Reasons for the lack of data include the high costs and complexity of the data acquisition process, shortages of technically-skilled staff, reticence of dealers and fishermen to divulge information which could be of assistance to their competitors or to tax collectors and, most often, a lack of any clear perception by governments of the possible value of such records. The latter point is not surprising because it is only in the past 35 years that significant use has been made of such information in the developed countries and only in the last 15 years that the credibilities of the agencies which use such data have been widely recognized.

RESOURCE APPRAISALS AND FISHERY DEVELOPMENT

In the context of the South Pacific region, the basic appraisal of resources has to a large extent been accomplished over the past few thousand years and these appraisals are embodied within the traditional knowledge and sealore that has been passed down over the generations. However, technological innovations also lead to a need for reappraisals of fisheries when previously unavailable resources are made accessible as a result of a technological development. For example, the development of modern purse seining technology and the effective deployment of fish-attraction devices has led to a dramatic increase in the harvest of tuna from the South Pacific.

Even relatively inefficient fishing methods can exert a significant mortality in a fish stock and it is most important that it be recognized that highly efficient modern technologies can often rapidly bring stocks into an overfished condition. It is therefore essential that, even in the early stages of development, the biological and ecological limitations of any natural system must be borne in mind. For example, there are clear limits to the tonnage of fish, crustaceans and molluscs or other edible organisms which can be removed from a coral reef each year without causing a long-term decline in production from the entire system. This is because the reef is functionally a system which either captures light energy by photosynthesis or entraps live or dead organic matter by filtering it from the waves or currents which pass over the reefs. Both of these activities are largely a function of the area of a particular reef and no amount of "development work" will persuade the reef to entrap more basic energy or to pass it along the food chain more efficiently.

A different aspect of the limitations of resources, which cannot be overemphasized, is that it is well established (*e.g.* Gulland, 1983a) that the harvest that can be taken from a particular resource increases from zero in response to fishing effort, reaches a maximum, then declines back to zero at very high levels of fishing effort. The curve describing this is roughly parabolic and a corollary of the shape of the curve is that if the catch is divided by the effort, the catch per unit of effort will decline from a very high value at negligible effort levels to very low values at high levels of effort. Depending upon the shape of the curve, when the maximum annual harvest is being taken, the catch per unit of effort will have declined to one half or one third of the initial values. This is illustrated in Fig. 1a, b, and c.

As an example of the foregoing, consider the appraisals of the snapper and grouper fisheries of the "deep reef" which were conducted in Vanuatu (Crossland and Grandperrin, 1980; Grandperrin and Brouard, 1983) and elsewhere in the South Pacific (Preston and Dalzell, *in prep.*). When the appraisals commenced, harvests on handreels in Vanuatu averaged as much as 9.6 kg.line hour^{-1} in the best areas and 5.4 kg.line hour^{-1} in all areas (Brouard and Grandperrin, 1985). The facts of fishery life dictate that these rates will fall to one half or less if economic factors promote the full development of the fishery. It is imperative that economic planners use these lower values when planning for the development of a fishery. Unfortunately, this is often not the case, resulting in a fishery becoming overcapitalized, in intense competition for the remaining resource and a consequent failure of the least efficient operators.

RESEARCH TOOLS FOR FISHERIES ASSESSMENTS

In recent years there have been great strides in fisheries research methods, aided to a large degree by the advent of relatively inexpensive, but powerful, microcomputers. The development of microcomputer-based methodologies is of particular importance in that complex problems which hitherto could only be investigated in highly sophisticated laboratories in the developed countries can now be tackled in remote tropical field stations or even at sea. The ability of a fisheries officer to rapidly process data, draw conclusions and act upon these conclusions has the potential to lead to far more effective control of fisheries.

An important adjunct to the development of microcomputers has been the emergence of powerful "application programmes" which have the potential to

Figure 1. Sequence of figures illustrating the basic concepts underlying "production" or "surplus yield" curves. Note that the curves are not necessarily perfect parabolas and may be skewed to either side.

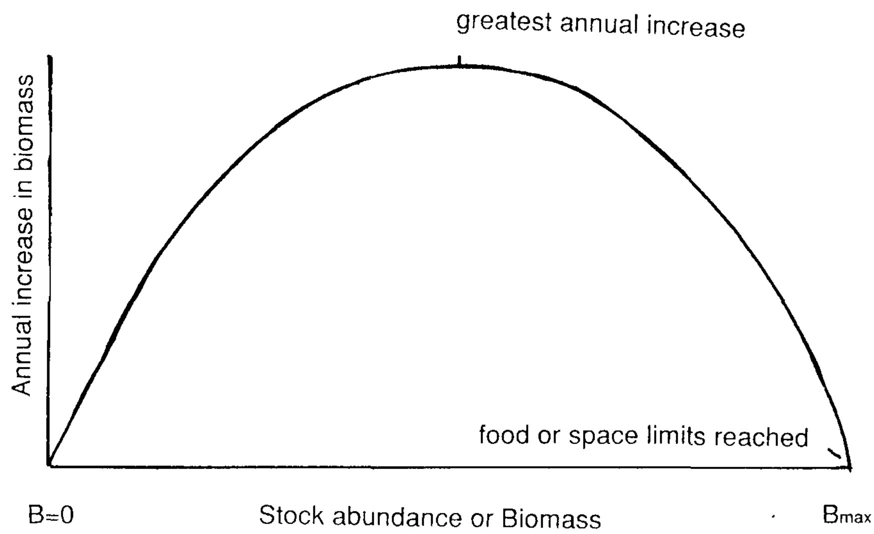

Figure 1(a). Curve illustrating the relationships between stock abundance or biomass (B) and the annual increase (in weight) in the biomass of that stock. When the biomass is zero there can be no increase and when it is low there can be very little increase because there are too few breeding stocks to produce sufficient eggs and too few individuals which can grow. When stocks reach their maximum possible biomass (B_{max}) they become limited by their food resources, starve and can neither grow nor reproduce. Therefore, if a stock is reduced to about one half of its greatest possible biomass the annual, removable, increase in biomass will be maximised. The annual increase in biomass is referred to as the "surplus production" and if this amount is removed the initial biomass or stock abundance will remain unchanged.

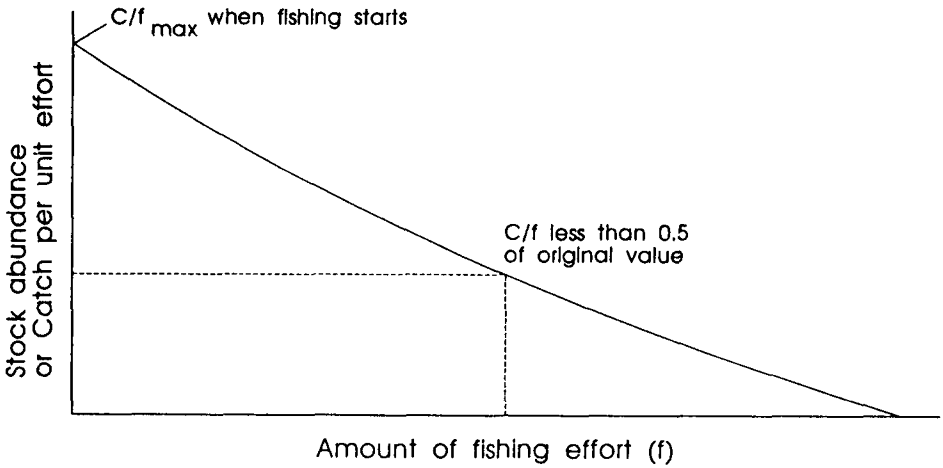

Figure 1(b). The catch per unit of effort (C/f) is roughly proportional to biomass and, like the biomass, declines when fishing effort (f) increases; being at a maximum when fishing effort is very low and biomass is high and declining to zero when biomass is reduced to zero. When the stock is producing the greatest possible yield the C/f will have declined to about one half of its initial value (C/f_{max}). If the relationship between C/f and f is not linear the maximum surplus yield will be produced when C/f declines to between 0.33 and 0.50 of C/f_{max}.

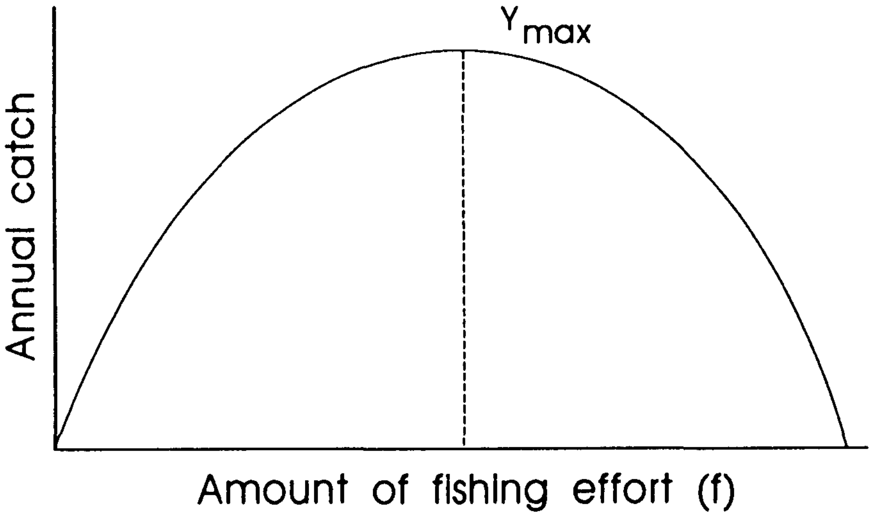

Figure 1(c). The production curve is the product of the amount of fishing (f) and the catch per unit of effort (C/f) and rises from zero when fishing is zero to a maximum when the catch per unit of effort (and biomass) are reduced to around one half to one third of the original magnitude.

permit persons with no knowledge of programming languages to develop formats for relatively sophisticated data analyses. The principal tools in this regard are the various spreadsheets and database management systems which are now widely available.

II. FISHERIES ASSESSMENT METHODS

METHODS FOR FISH STOCK ASSESSMENT

The basic methods for assessment of small scale fisheries have been reviewed by Munro (1980) and by Gulland (1983b). Only a few years ago stock assessment models were divided into two functional categories: one involved analysis of catch and fishing effort statistics and the other the derivation of yield curves based upon estimates of biological parameters of growth, mortality and recruitment. However, the distinctions are becoming progressively blurred as methods are found to integrate them. The original basic dichotomy lies in the fact that the "production models" require catch and effort statistics whereas the analytical models can, in their most basic form, be utilized in the absence of any statistics.

The prime combination of the models is in virtual population analyses or cohort analysis in which estimates of growth and natural mortality rates are combined with catch statistics in order to back-calculate the history of a cohort or year class.

These basic methods are briefly outlined below.

Comparative harvests: One of the simplest and most often overlooked methods for estimating the potential of a fishery is simply to compare the current harvests per unit area with those taken by similar fisheries operating in similar habitats. For example, if an established fishery is yielding 4 metric tonnes per square km per year ($mt.km^{-2}.yr^{-1}$), then it is reasonable to assume that a fishery operating in a similar habitat elsewhere will be able to produce a similar amount.

Examination of fishery statistics covering the widest possible area can give a rapid appraisal of the largest reported harvests per unit area and some concept of the maximum harvests possible from a given area (Marten and Polovina, 1982; Marshall, 1985). For example, coralline shelves with a good cover of actively growing corals commonly yield a harvest of all species of 3-5 $mt.km^{-2}.yr^{-1}$ if all areas between the intertidal and 200 m are included. This gives an immediate approximation of likely harvests based only upon a standard nautical chart and access to a planimeter for estimating the area (*e.g.* Munro, 1977). The use of satellite imagery and aerial photography has been shown to greatly improve perceptions on the extent of different shallow water habitats (Quinn *et al.*, 1985; Preston, 1991) and can be expected to become an essential adjunct to coastal fisheries management in the near future.

Production models: The basic "surplus production models" developed by Schaefer (1954) and Fox (1970) are reviewed by Sparre *et al.* (1989). They utilize statistical information on total annual catches over the history of a single-species fishery and the amount of fishing effort required to produce those harvests. Munro and Thompson (1973) extended this concept to comparisons of yield and fishing intensity in ecologically similar areas.

More recent variants of this model utilize the catch and total mortality rate (increases in this parameter being a direct consequence of fishing effort) (Csirke and Caddy, 1983; Garcia *et al.*, 1989) and a combination of total catches and estimates of corresponding fishing intensity in both time and space (Caddy and Garcia, 1983).

The major limitation in the use of these models is that they are descriptive of a current or past situation and cannot be used to *predict* catches if fishing strategies (methods, mesh sizes, areas, etc.) were changed. Polovina (1989) proposed an adaptation of Schnute's (1977) variant of the Schaefer model, which is based on a system of simultaneous equations for multispecies or multiarea applications, which is highly relevant to the small island situation.

A number of notable developments in age-based methods for assessing fisheries have emerged in recent years. These include models developed by Walter (1973; 1980), Deriso (1980), Ludwig and Hilborn (1983), Ludwig and Walters (1985) and Lawson and Hilborn (1985), all of which require information on the absolute or relative ages of fishes and/or quite detailed statistics of catch and effort. As such, their current usefulness in most small-scale tropical fisheries is limited. Nevertheless, opportunities to utilize these new developments need to be sought, particularly for some of the more important individual fisheries (*e.g.* for deep-water snappers).

Yield per recruit models: The analytical model originally developed by Beverton and Holt (1957) has been extensively used in temperate water fisheries (Jones, 1957; Beverton and Holt, 1964). Use of the model requires reliable estimates of growth, natural and fishing mortality rates for individual species. If catch statistics are available the recruitment rate to the fishery can be back-calculated and absolute harvests predicted. The model can also be utilized in the absence of catch statistics to produce estimates of likely changes in response to different fishing strategies, *e.g.* changes in effort or mesh size in terms of yield per recruit. Elaborations on the model include the works of Pauly and Soriano (1986), Polovina (1990) and Silvestre *et al.* (1991).

The model is also amenable to econometric analysis as the production curves can easily be expressed in terms of value.

Virtual population analysis (VPA) and cohort analysis: These are sophisticated methods applied to industrial fisheries. The methods require catch statistics for individual species, accurate estimates of age or size composition of the catches and estimates of growth and natural mortality rates.

In essence the methods involve back-calculation from the catch statistics of the numbers of fishes that reached successive ages. For example, if the relative numbers of four year old fish in the catch are known in a particular year and the numbers of three year old fish in the preceding year then their survival rate can be calculated and related to fishing effort. If statistics covering the whole age range of the fish are available, the total numbers of a particular cohort (those hatched at the same time) can be tallied over the years to give the total catch from that cohort. If allowance is made for those that died naturally, the total numbers of recruits to the fishery can be calculated for a particular year (Gulland, 1965; Pope, 1972).

This can provide a very detailed insight into the history of a fishery and its response to changes but is very demanding of accurate statistics, careful sampling and biological analysis. For this reason, it has not yet been applied to any tropical small-scale fishery.

A more recent innovation is length-frequency based (as opposed to age-frequency based) VPA (Jones, 1984) in which the analyses are based on the relative sizes of fishes in the catches even when their actual ages are unknown. Length-based VPA has been successfully applied to the Peruvian anchoveta fishery by Pauly and Tsukyama (1983).

Multispecies assessment methods: The only options currently available are simply to treat the total biomass of the catch of all species as if it were taken from a single stock or simply to sum up the calculated yield curves for individual species.

The total biomass production curves, in which the total catch of all species is plotted against the total effort over time (Brown *et al.*, 1976) or against the fishing intensity in different areas (Munro and Thompson, 1973; Gulland, 1979), have proven to be surprisingly robust and have been used to describe several fisheries (Brown *et al.*, 1976, Caddy and Garcia, 1983, Munro, 1984a, Garcia, 1986). Basically, applying these "models" involved plotting catch per unit of effort against fishing effort over the recorded history of the fishery or, alternatively, plotting the catch per unit of effort against the fishing intensity in different sections of the fishery, in one or more years. The form of the plot can be proportional or semi-logarithmic, with the latter apparently giving the better fit in most cases.

Simple summations of the calculated yield curves for individual species have been done for some tropical multispecies fisheries but as the interactions between species are not well understood, some caution needs to be exercised in interpreting the results at high levels of exploitation (Munro, 1975).

Studies of the interactions between species and the effects of selective exploitation on these interactions and upon the composition of the aquatic communities are also receiving much attention. These are important in that, while it is known that the compositions of multispecies stocks change as a fishery develops (Pauly, 1979; Munro and Smith, 1985), the mechanisms controlling these changes are not well understood and the type and degree of change cannot be predicted.

The problem of assessing multispecies stocks is currently receiving much attention as it is now realized that entire communities need to be managed if resources are to be optimally exploited. Several extremely elaborate models have been developed for the analysis of multispecies fisheries (Andersen and Ursin, 1977; Laevastu and Favorite, 1978) but the huge number of species-specific parameter estimates necessary for running the models are simply not available for any tropical fishery; furthermore, they seem unlikely ever to be available.

However, a relatively simple model called ECOPATH (Polovina and Ow, 1983; Polovina, 1984) and a further development called ECOPATH II (Christensen and Pauly, 1991) yield insights into the way that complex communities are structured and can be used to describe the steady states which will be attained by the various elements of an exploited community.

Economic appraisals: The understanding of the economics of fishing and of the interrelationships among assessments, economic considerations and management strategies have improved dramatically in recent years. Pitcher and Hart (1982) give a very clear and concise chapter on this topic which is recommended to readers. More advanced treatments can be found in Clark (1985).

Current theory holds that fish stocks are unlikely to be reduced to extinction by overfishing, because it becomes uneconomical to fish well before the fish stock is extinct. However, a feature of multispecies, multigear fisheries which seems largely to have been ignored is that it *is* possible to extinguish totally a desirable, high-valued, component of the resource if it is caught concurrently with a less catchable, more abundant, species. For example, groupers have high catchability (defined as the fraction of a population which is caught by one unit of fishing effort) in a variety of fishing gears (spears, traps, hooks, gill nets). Most of these gears will also catch other reef fish (*e.g.* goatfish, surgeonfish) which are vulnerable to fewer sorts of fishing gears. Consequently, the fraction of a goatfish population caught per unit of effort will be much less than that of a grouper stock, with the result that the groupers can actually be reduced to extinction while catches of other reef species are still at a relatively high level and the fishery is still operating profitably and offering every inducement to continue fishing.

PARAMETER ESTIMATION

One of the characteristics of the most sophisticated stock assessment methods is that they are age-structured; that is, that the methods are dependent upon information being available on the relative abundances of different age groups of fishes in catches. This is feasible in temperate areas, where annual marks are often clearly seen on scales, otoliths or other hard parts. Gathering the necessary data is a laborious process, involving taking scales or otoliths from selected samples of fishes, preparing these samples for microscopical examination in the laboratory, carefully counting the numbers of marks on the scales, and thus deducing the age of individual fishes. From these data the growth rates can be derived and the age structure of the entire catch deduced.

However, in the tropics, annual marks on scales and otoliths are usually difficult to discern and there is no ready means to estimate the ages of individual fishes. Consequently, less direct methods need to be used. Of principal importance in this respect are length-frequency based methods. Although length-frequency data have been used for over 100 years to derive information about fisheries, it has only been in the last 15 years that major advances have been made in interpreting these data and undertaking fish stock assessments based to a large degree on length-frequency data. The works of Powell (1979), Pauly (1980a; 1982; 1983; 1984), Schnute and Fournier (1980), Sparre (1987), and Shepherd (1987) are central to this development. Many of these methods were examined at a conference on the theory and application of length-frequency based stock assessment techniques (Pauly and Morgan, 1987) at which the reliability and robustness of length-based methods were examined. As a result of this conference, a set of "second generation" methodologies emerged and new version of the ELEFAN (Electronic LEngth-Frequency ANalysis) suite of microcomputer programs (Gayanilo *et al.*, 1989) incorporating the most recent innovations emerged. This in turn is being superseded by a package called FISAT (FAO and ICLARM Stock Assessment Tools) which blends the work of the FAO Fisheries Department (Sparre *et al.*, 1989) and ICLARM into a single package.

Length-based methods can be used to estimate growth parameters, selection curves, natural and fishing mortality rates and to conduct length-cohort analyses or virtual population analyses. Two additional features which are of great relevance to fisheries in tropical developing countries are that the necessary data can be gathered by relatively unskilled personnel and do not require elaborate laboratory facilities for further analysis. However, it should also be noted that some of the methods are highly sensitive to the quality of data and to the natural individual variability in growth parameters within a fish stock (Isaac, 1990) and it is therefore very important that independent verification be sought for estimates of growth and mortality parameters and that the limits of applicability be clearly recognised.

The underlying principles involved in estimating growth parameters from length-frequency data are that fishes hatched at the same time will grow at approximately the same rate and such groups will be discernible in a length frequency sample as discrete modes or peaks in the samples. If a series of samples are available, collected at regular intervals (ideally a lunar month, but up to three calendar months is sometimes feasible), modal progression might be discernible. That is, the average growth of the cohorts during a month will be reflected in the movement of the modes. Over the months the modes will progress until after a full year the smallest mode will have progressed to around the size of the second smallest in the first sample. In practice, it is often difficult to follow the modal progression and to decide which of several "progressions" accurately reflect the growth.

Computer programs which have been developed for extracting growth parameter estimates from length-frequency data include ELEFAN I (Pauly and David, 1981; Gayanilo *et al.*, 1989), LFSA (Sparre, 1987) and MULTIFAN (Fournier *et al.*, 1990). All attempt to derive the parameters of the von Bertalanffy growth function (K, the coefficient of growth; L_∞, the asymptotic size and t_0, the theoretical time at which the animals were of size zero) in the most objective possible way.

Estimates of mortality rates are usually obtained by constructing an age-structured catch curve, (*e.g.* Sparre *et al.*, 1989) in which the slope of the line between successive points is a measure of the total mortality rate (Z) in the time between those ages. 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 by the method of 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 or other hard parts and there is always a multiplicity of species of roughly similar importance.

If size-frequency samples are accumulated over a full year, they may be given appropriate statistical weightings and summed to give the "annual average size frequency of a catch". If the growth rate is known a "length-converted catch curve" can be derived from these data by dividing each of the observed size frequencies by the time required to grow through that size group. The underlying principle is that the number of animals recorded in a size-frequency class is a function both of their actual numbers and *of the time required to grow through that size class*. Thus, relatively few small fishes might be found in a sample, not because they were rare, but because they are of that size for a rather short time. The slope of the descending right hand side of the curve is an estimate of the mortality rate of the fish stock. A most important feature of these curves is that they reflect size specific mortality rates and, if samples of a fish stock are obtained *using a fishing gear which catches fish at a pre-recruitment size*, the catch curve will have an initial portion reflecting the natural mortality in the pre-recruits, followed by a steepening of the curve as the young fishes are recruited into the fishery (Munro, 1984b).

The left-hand side of a length-converted catch curve also gives vital information in that the observed frequencies are a function of the numbers of animals present in successive size groups, the natural mortality rate and the size-specific fishing mortality rates generated by the selectivity of the fishing gear. If a preliminary estimate of the natural mortality rate is available (*e.g.* derived from Pauly's (1980b) empirical formula) the selectivity of the fishing gear and the size at recruitment (L_r) can be estimated by back calculation. Alternatively, if the selection curve is established by other independent means, the natural mortality rate might be estimated using the method proposed by Munro (1984b).

The foregoing does not suggest that all other methods for parameter estimation should be ignored. These include the more conventional age-frequency based systems, in which the ages of fishes in samples of catches are individually estimated from scales or bony structures, either on the basis of annual, periodic or daily rings or marks. The problems of applying age- structured methods in the tropics have been discussed by Pauly (1984) and by Sparre *et al.* (1989).

In many tropical situations mark and remeasure projects have produced valuable data. Results can be incorporated into the ELEFAN V routine (Gayanilo *et al.*, 1989) and add considerably to the confidence in the resulting parameter estimates (Morgan, 1987) or, given sufficient returns, be analyzed separately, yielding estimates of all relevant population parameters and affording a basis for comparison with results obtained by other methods. Opportunities to utilize them need to be constantly appraised and exploited if the chances of success appear to be reasonable.

Of all of the length-frequency based methods, the most important is that in the ELEFAN II program (Gayanilo *et al.*, 1989) which permits the estimation of mortality rates from the average annual size composition of catches. This is because, if mortality rates can be estimated on a routine basis, a relatively precise measure of the status of exploitation of a fishery is available and management decisions can be made accordingly. Although this routine has been shown to be particularly sensitive to the accuracy of growth parameter estimates (Isaac, 1990), the estimates can, nevertheless, be used on a *comparative* basis to monitor annual changes in the relative mortality rates in a particular fish stock. That is, progressive changes in the slope of the right-hand limb of a length-converted catch curve will reflect real changes in the mortality rate of the fish stock, despite any inaccuracy in the growth parameter estimates.

Due in no small part to the scientific and technical advances of the past fifteen years and to added interest in the topic, a number of generalizations have emerged from the accumulated information on tropical fisheries. A basic understanding of the rates of growth which are characteristic of various species groups and families and on the normal variation that can be expected in these groups. It is now possible to identify a growth performance index (Ø or Ø') for fishes and invertebrates (Munro and Pauly, 1983; Pauly and Munro, 1984) based on the following equations:

$$\varnothing = 2/3 \log W_\infty + \log K$$

or

$$\varnothing' = 2 \log L_\infty + \log K$$

in which W_∞ and L_∞ are the asymptotic weights and lengths and K is the coefficient of growth of the species concerned. These parameters vary from species to species but Ø and Ø' tend to be constant within a species group. Thus if Ø or Ø' is known, and W_∞ or L_∞ can be estimated from field data (or approximated as $L_\infty = 0.95\ L_{max}$), a preliminary estimate of K becomes calculable. Moreau *et al.* (1987) showed that within a genus, Ø' values are the most normally distributed and have the least variances of a number of indices used to estimate the growth performance of fish.

Also, a start has been made towards an understanding of the relationship between growth and natural mortality rates (Ralston, 1987) and of the basic relationships between growth rate, asymptotic size, temperature and mortality (Pauly, 1980b).

Although these generalizations need further refinement, or will inevitably be refined as more and better parameter estimates become available, they are already useful in permitting rough stock assessments to be performed based on minimal amounts of data.

RECRUITMENT

The principal characteristic of modern fisheries research is that it has become more sophisticated in its detailed application but more comprehensible and less experimental in its routine methodologies. This is a natural consequence of the wide range of fisheries investigated on a global basis, leading to acceptance or rejection of research methods on the basis of their reliability, robustness and data requirements. In essence, the basic methodologies have become simplified and streamlined to the point that all of the *basic* routines of stock assessment can now be performed with nothing more than the most inexpensive microcomputers. Confidence in the analytical process has also been strengthened in recent years by the development of efficient simulation programmes to test a variety of hypotheses and methods.

The basic processes of growth and mortality which govern the productivity of a given fish stock are becoming relatively well understood and the focus of modern fisheries research is shifting towards investigations of the process of recruitment of new stock to a fishery. Satisfactory correlations between the abundance of adult spawners, environmental conditions, a host of other ecological factors and the subsequent appearance of new recruits remain highly elusive. This is unsatisfactory in that the principal variable which affects fish production is the number of new recruits to a fishery. Good and poor year classes or cohorts (groups of fishes spawned at the same time) have been recognised for many centuries but the conditions which engender such good or bad years remain largely unknown.

Within the tropical context, there has been rather vigorous debate on whether or not coral reef fish populations are recruitment limited (see Munro and Williams (1985) for a review). One view holds that coral reefs are constantly saturated by newly-settled juveniles, most of which subsequently die as a result of failure to find suitable living space on overcrowded reefs. The other view is that most reef fish larvae never find a reef onto which they can settle and consequently die, leading to reefs being recruitment limited.

The most prominent feature of this problem from a fisheries viewpoint is that it still is not possible to make any accurate predictions of the total future harvests from a fish stock because one of the principal parameters, the number of recruits, cannot be predicted far in advance. Short-term predictions of the relative abundance of recruits of some species can be derived by monitoring nursery areas but this is usually only relevant to a few species. For example, it is routinely done for the Western Australian spiny lobster fishery (Phillips, 1986).

It has been clearly established that there is a degree of interdependence of stocks of a variety of fishery resources between islands and nations, in that many of the species are widely distributed and there is no evidence of any major genetic differences. It is therefore highly likely that there is an interchange or at least a downstream drift of larvae from one country or island to the next. However, the numbers of larvae which drift in from elsewhere in comparison with the numbers originating from local spawning are not known for any species. As a result, it cannot yet be conclusively demonstrated that the consequences, if any, of wise or unwise management will be felt by neighbouring islands.

Also, while it is very clear from all of the evidence that oceanic fishes such as skipjack tuna spawn on the high seas and their eggs and larvae are thus a regional resource, it is still not known what effect, if any, the deployment of heavy fishing effort on coastal fishes in one area will have on subsequent recruitment of young fish to another area. Special cases are those of spiny lobsters, bone fish, tarpon and eels in which the larvae are so long-lived that they inevitably must be dispersed over great distances and, with few exceptions, individuals are unlikely to recruit to their particular natal areas.

In the case of other coastal resources, the information is much less conclusive. Only a few studies have attempted to find the larvae of reef fish and other coastal fishes up-current and down-current of islands. These studies suggested that there was little entrainment of reef fish larvae into the passing flow, therefore little interdependence between islands. However, this cannot be substantiated at the present time, even if it does seem likely that those who mismanage their resources will usually be the only ones to bear the consequences of their actions.

Stock enhancement, whereby natural recruitment to a fish stock is supplemented by the release of hatchery-reared fingerlings, is a very old concept. Many salmon stocks in temperate waters are largely derived from hatchery-reared recruits, and in Japan a wide variety of species are routinely reared and released (Cowan, 1981). However, it is only in recent years that hatchery technology has improved sufficiently to lower the unit costs of fingerlings to modest levels and give the process realistic prospects of economic viability (Sparks, 1990). The possibility of supplementing natural recruitment of shallow-water coral reef fish and invertebrates is now receiving serious attention, particularly as it is known that many coral reef species are habitat restricted and individual reefs, particularly if isolated by relatively deep water, could act as unfenced fish farms (Munro and Williams, 1985).

III. A SYSTEMS APPROACH TO ASSESSMENT AND MONITORING

THE NEED FOR COST EFFECTIVE SYSTEMS

In an ideal world, the management of fisheries in order to optimize harvests would be based upon socioeconomic parameters supplemented by a steady input of data on the catches, catch rates, fishing effort and biological features of each fish stock. In particular, estimates of mortality rates would be acquired on a routine basis. Such data are usually obtained by the laborious gathering of catch and effort statistics, accompanied by separate investigations designed to produce estimates of the biological and fishery parameters which govern the productivity of stocks. In most tropical countries, the diversity and complexity of multispecies, multigear artisanal fisheries makes conventional stock assessment very difficult to execute and often prohibitively expensive (Munro, 1986). As a result of these constraints, there are extremely few fish stocks in the tropics which have been assessed and which are managed on the basis of such assessments.

The basic problem facing fishery managers in the South Pacific region is that the monetary value of the coastal fishery resources is not necessarily very large even though the resources provide a significant component of the daily fare of the coastal people. Large portions of budgets are therefore seldom allocated to assessment and management. Perceptions of the value of this asset might be changed if estimates were provided of the cost of importing substitute foods if harvests were decreased as a result of overfishing or the use of destructive fishing techniques.

In many countries outside of the region, the neglect of serious attempts to assess the status of fishery resources, combined with ill-conceived "development" schemes, has led to massive over-capitalization of already over-exploited nearshore fisheries and to almost total wastage of capital inputs. These disasters could have been avoided if reasonable assessments of the fisheries had been available.

There is therefore a need for stock assessments which will in some measure ensure that development efforts are properly directed and to form a basis for management measures in established fisheries. However, it is recognized that there are constraints in terms of recurrent budgets for data acquisition, laboratories for data analysis and, often, in the availability of highly skilled and specialized stock assessment experts.

What is therefore needed is a reasonably simple yet reliable systematic approach to basic stock assessments which can be implemented by relatively unspecialized fishery biologists using data acquired by unsophisticated technical staff.

Over the past decade, the development of length-frequency based stock assessment methodologies and the concurrent development of inexpensive microcomputers has made it feasible to envisage a relatively simple systems approach to stock assessment problems which will permit fisheries managers to aim to progress in orderly fashion through basic single-species assessments to highly complex multispecies assessments. The most important feature of these developments is that the parameters necessary for a basic assessment of the state of a fish stock can largely be derived from the routine collection of length-frequency data.

Where particular species of organisms are notably valuable or the fisheries have unusual features, there will always be a need for special investigations and data acquisition programmes, although the basic features of the system are unlikely to change.

It is also worth emphasising the files of some fisheries departments have been found to contain records of size distributions and catch rates which were gathered many years ago when fisheries were not intensive or yet developed. Many of these data are amenable to reanalysis using modern techniques which were not available when the data were collected and such analyses could give very valuable insights into the characteristics of the fisheries; for example, on catch and mortality rates in unexploited or very lightly exploited stocks.

A BASIC SYSTEM

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.

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 applicable 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 be acted upon if necessary.

There are many methods available for fishery assessment (see Gulland, 1983a; Pauly, 1984; Sparre *et al.*, 1989) and no single method can be prescribed as being appropriate for the assessment of *all* species and all fisheries. However, it has been argued that a system based *primarily* upon length-frequency data is likely to be the most cost-effective (Munro, 1983; 1986). The suggested assessment and monitoring system is outlined in the following pages and summarized in Fig. 2. The actions needed for implementing the system are outlined in Fig. 3.

The scheme is based upon the assumption that no previous data are available. However, in many fisheries it is likely that at 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

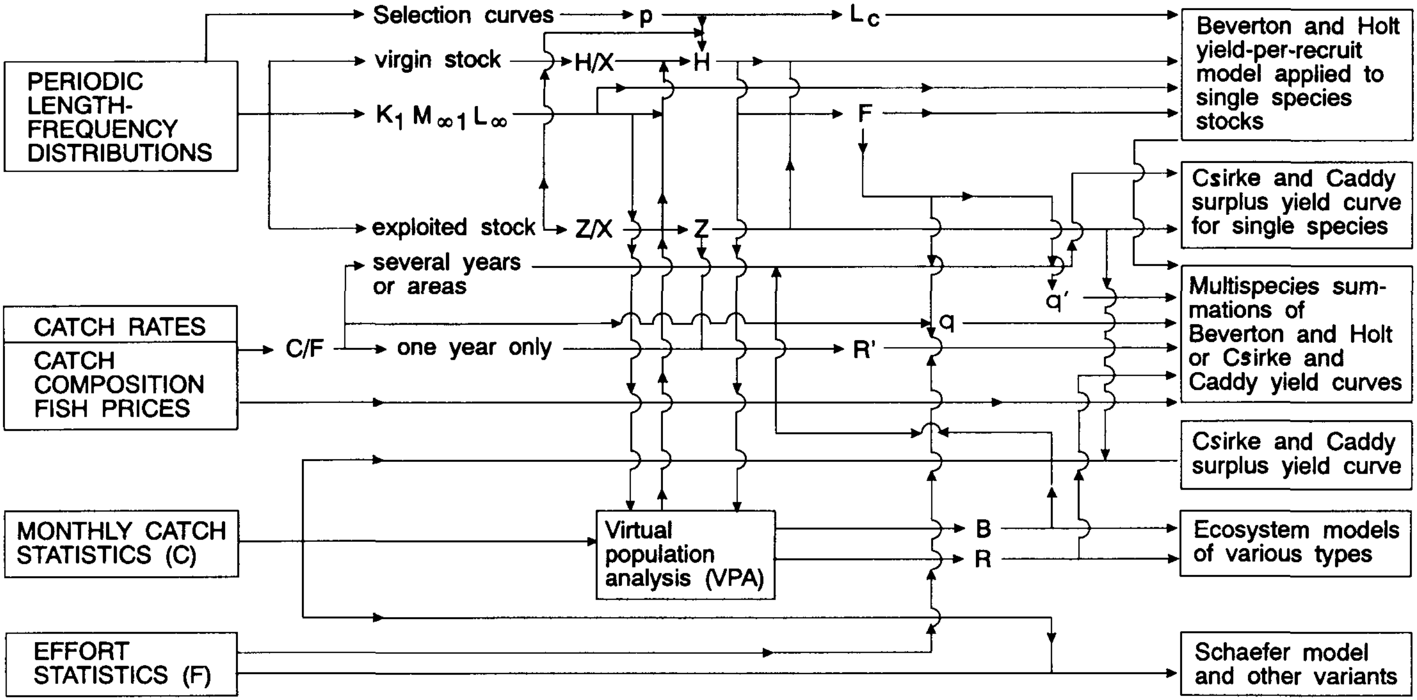
PERIODIC LENGTH-FREQUENCY DISTRIBUTIONS
CATCH RATES
CATCH COMPOSITION FISH PRICES
MONTHLY CATCH STATISTICS (C)
EFFORT STATISTICS (F)
Selection curves
p
L_c
virgin stock
H/X
H
$K_1 M_{\infty 1} L_\infty$
F
exploited stock
Z/X
Z
several years or areas
q'
q
C/F
one year only
R'
Virtual population analysis (VPA)
B
R
Beverton and Holt yield-per-recruit model applied to single species stocks
Csirke and Caddy surplus yield curve for single species
Multispecies summations of Beverton and Holt or Csirke and Caddy yield curves
Csirke and Caddy surplus yield curve
Ecosystem models of various types
Schaefer model and other variants

Figure 2. 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 notations 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 Bertalanffy 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).

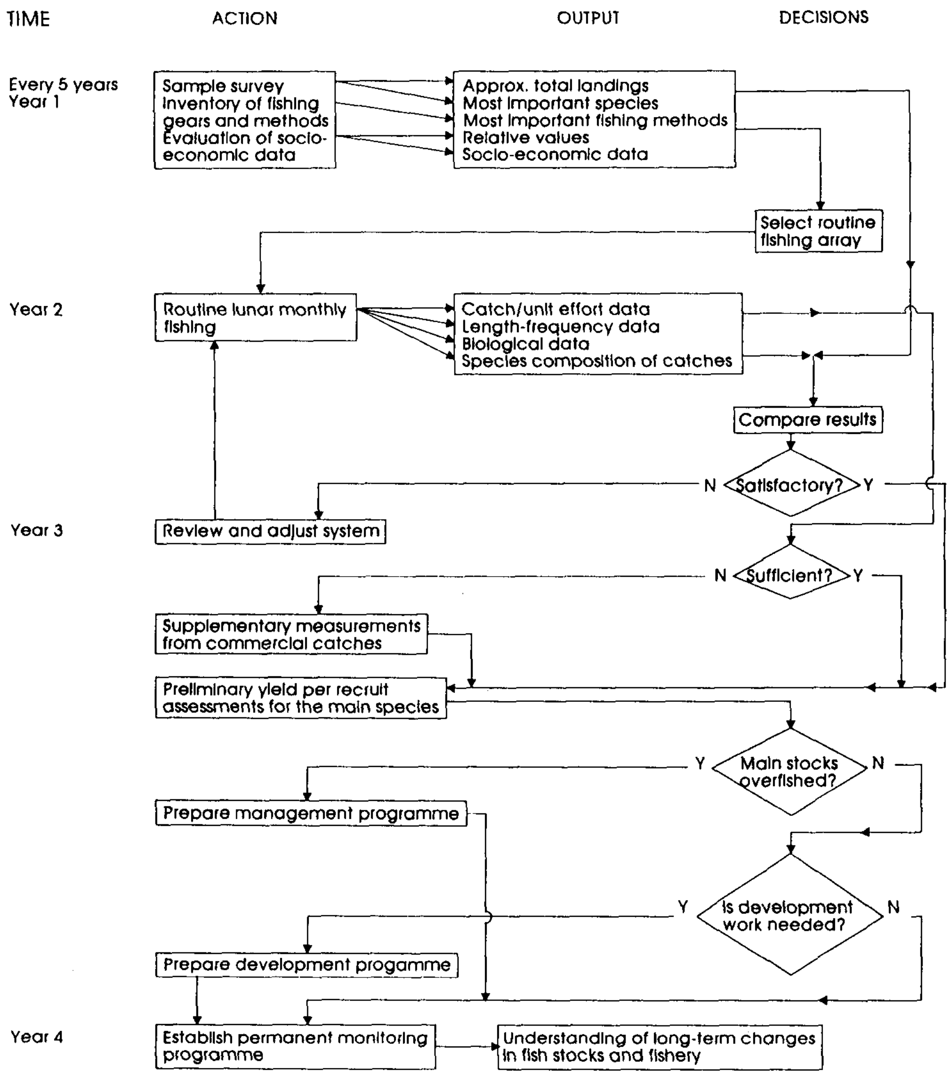

Figure 3. Timeframes, actions, decisions and outputs of a systems approach to stock assessment, monitoring and management.

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 immediate insight into the state of a fishery. For example, if an exploratory trip in, say, the 1920s 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 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 to 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). However, effort is very difficult to measure with any accuracy in small scale multigear fisheries. As described previously, the problem of estimating mortality rates has been circumvented to some degree by the development of length converted catch curves. These catch curves can be derived from routine measurement of the lengths of fishes and therefore are a prime tool for assessing and monitoring fisheries. 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.

SAMPLE SURVEYS OF THE FISHERY

As indicated in Fig. 3, the initial need is for a sample survey of the fishery 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.

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, 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 would provide a basis for assessing changes in the productivity of the fishery.

However, sample surveys do *not* 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 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 species 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 one species of 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 on the grounds that, for example, the mortality rates of a common species caught by a particular gear will be similar to those of less common species in the same family.

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 Bailey (1982a; 1982b), Smith and Mines (1982), Smith *et al.* (1983) and Lockwood *et al.* (1985) are important guides to this part of the work.

ROUTINE FISHING WITH STANDARDIZED GEAR AND DATA COLLECTION

After a sample 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 and

(b) some of the gear should be designed specially to sample fishes at a somewhat smaller (pre-recruit) 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 than those who only navigate their desks through the bureaucratic maze.

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 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 occur in iced or frozen fish.

(e) Length measurements 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 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 utilizing one of the length-frequency analysis programs that are now becoming available. 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.

(j) 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 to 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 centers 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 is 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. Under no circumstances should there 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.

The alternative to test fishing is simply to enlist the aid of selected fishermen and possibly pay a small retainer to them to compensate for the inconvenience of having their catches measured and weighed. However, monitoring the catches of artisanal fishermen must be considered to be an inferior alternative to test fishing. The ideal situation would be one in which both test fishing and monitoring were conducted simultaneously.

If reliance is placed solely on monitoring fishermen's catches, gaps will occur in the data when fishermen periodically change strategies in order to target species which are seasonally or intermittently highly catchable. Species might disappear from catches simply because some other species are more desirable or more readily available and not because the species in question is less catchable. This will cause distortions in the data.

An important aspect of the routine fishing system is that it should normally be done using boats which are as similar as possible to those used in the artisanal fishery. In particular the system does not call for the acquisition of numerous research vessels. As a general case, it is apparent that research vessels are needed for survey and development work in the early stages of a fishery or for very advanced scientific studies. There is no obvious need for routine operation of sophisticated research vessels by government agencies in those developing countries where most exploratory work has long since been accomplished and where the shortage of scientific manpower precludes effective use of a major vessel. It should, in passing be pointed out that a case can be made for the acquisition of a fisheries research vessel with a regional role and function, which would be able to meet the research needs of the small island states by mounting a programme of research on the resources discussed in this volume; resources which are, in the main, common to all or most of the countries of the region. An important point is that few, if any, of the island states have the trained scientific manpower to meet all aspects of their research needs, but collectively the entire range of fisheries science can be covered relatively easily.

For specific small-scale fisheries, usually operating on a quasi-industrial scale, there will be a need for detailed catch and effort statistics. Catch rates and catch composition can then be derived from the commercial fleet. As stated previously, the use of monthly catch statistics in combination with length-frequency data for Virtual Population Analysis permits an evaluation of all parameters of the fishery including total biomass and numbers in the stock. An example of this technique applied to the Peruvian anchoveta fishery is given by Pauly and Tsukayama (1983).

DATA ANALYSIS AND STOCK ASSESSMENTS

The methods currently available for data analysis and stock assessments 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. 2. 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 become available, culminating in multispecies summations for different fisheries.

A PERMANENT MONITORING SYSTEM

As shown in Fig. 3 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

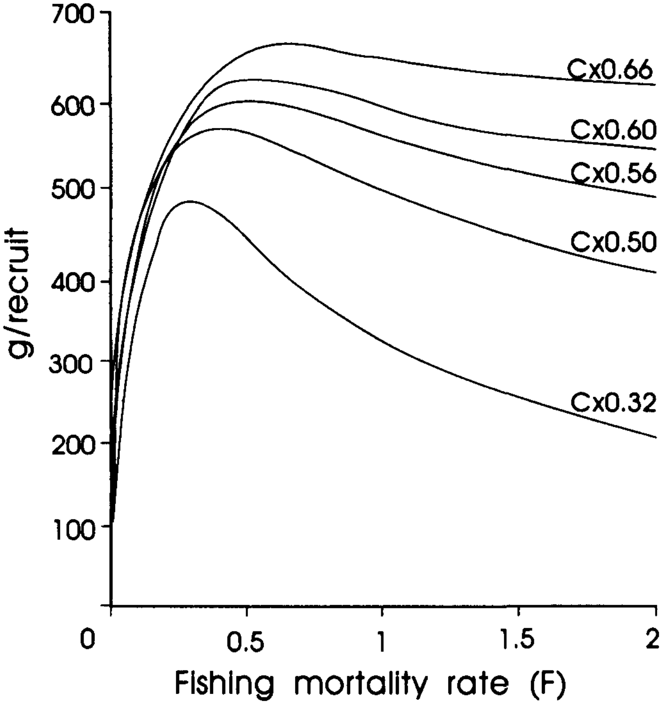

Figure 4(a). Yield curves showing the relationship between yield per recruit and fishing mortality for various values of C, where C is the ratio of the size at entry to the fishery to the asymptotic size (from Munro 1983).

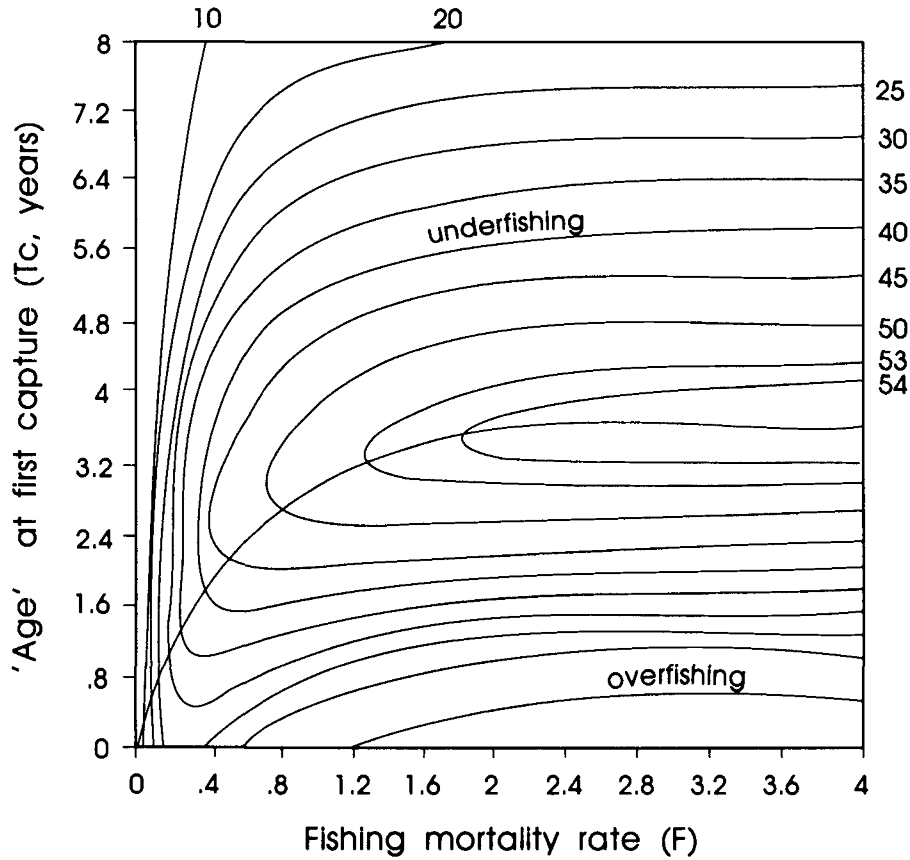

Figure 4(b). Yield Isopleth diagram showing the expected yield per recruit for all combinations of age at entry (T_c) to the fishery and fishing mortality (F). The heavy line shows the optimum combinations of T_c and F. Combinations falling below the line constitute "overfishing", while those above the line constitute "underfishing".

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.

It needs to be clearly stated here that the proposed system is not advocated as a means for providing an instantaneous solution to stock assessment problems, nor is it suggested that established systems for the collection of catch and effort statistics be dismantled in favour of this system. What is advocated is that the system be tried in situations where no data base exists or where conventional data acquisition systems have been abandoned as a result of financial constraints. None of the procedures outlined in Fig. 2 are new. Well-tried methods have merely been tied into a package in an attempt to suggest the most cost-effective approach to the problem of assessment of small-scale, multispecies, multigear fisheries.

Nor is it suggested that attempts should not be made to obtain confirmation of estimates by independent techniques. Indeed, such independent verification is the very essence of good science and opportunities for independent verification of estimates must constantly be sought.

The first attempt to implement this system was made in Tonga over three years (1987-90) and resulted in the first complete inventory of the fishermen and fishing gears of Tongatapu and of the composition of the catches by species, gear type and area (Felfoldy-Ferguson, 1988). The inventory was repeated in the Ha'apai group. The routine fishing with a standardised array of gears (gillnets, Antillean fish traps and handlines) was only carried out for one year but yielded a substantial database, including estimates of growth and mortality rates for some of the principal species. However, the fishing programme was not sustained after the contract officer left and much of the data have not yet been analysed.

ENVIRONMENTAL MANAGEMENT

A point which is here only dealt with in passing concerns the impact of environmental degradation upon fishery yields. The high vulnerability of reef and lagoon fisheries to environmental contamination needs little amplification, and it need only be pointed out that efforts to assess and manage fisheries are a total waste of time and funds if the environment of the organisms is permitted to be disrupted, contaminated or chronically stressed. The rival demands of economic and social pressures and of fisheries management are well known, with fisheries and other conservation interests usually being unsuccessful in preventing developments such as dredging for sand and construction of causeways or sewer outfalls or the removal of mangroves because of the inability of fisheries managers to demonstrate conclusively that the fisheries will be damaged. The weight of ecological evidence most assuredly indicates that this is so, but the present solution can only lie in public education and vigorous defense of the environment.

NOTE

1 ICLARM Contribution No. 785

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