STOCK ASSESSMENT IMPLICATIONS AND MANAGEMENT OPTIONS FOR THE SMALL PELAGICS IN THE APFIC REGION

by

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Abstract

Problems in stock assessment and management of the exploited fish stocks, especially the pelagic fish stocks, are reviewed. The theoretical and practical constraints in the application of the assessment techniques and production modelling with reference to the small pelagics are indicated. Appropriate approaches to pelagic fish stock assessment and management are outlined.

INTRODUCTION

The great stocks of the sardines, anchovies, and other small pelagics account for about one third of the world's yield of marine fish and are of key economic importance to many nations. Production of these stocks depends on a delicate balance between the physical ocean processes and the pattern (or magnitude) of exploitation. When environmental conditions in the ocean are optimal, strong year classes result and the populations grow rapidly. Under such situations, a well managed fishery could yield significant catches. Many present day populations of small pelagics display a complex pattern of vital rates, indicating the adaptations of the sub-populations to the local habitat conditions. Some sub-populations are tiny with a maximum biomass of only less than 20 000 mt while the others reach millions of mt. These sub-populations experience different environmental conditions and are natural models of how marine populations react to environmental changes. No group of marine populations is better suited for examining the linkages between the physical forces and the population dynamics and structure than the small pelagics because of their worldwide distribution, long time series in abundance and the wealth of information on their ecology and dynamics. During the last two decades, several pelagic fish stocks have been reduced to very low levels and there have been structural changes in the exploited pelagic fish stock assemblage. Many attempts have been made to understand the dynamics of the small pelagics through mathematical modelling of the fishery dependent and fishery independent factors.

PRODUCTION MODELLING

Modelling functions as a research tool that provides a basis for hypothesis testing by putting field measurements into a common framework. Such a framework is necessary to summarize the accumulated information, provide the linkage between historical data sets, retrospective studies and field process studies, and develop predictions regarding the effects of changes in the factors that govern the dynamics of the system. The use of mathematical models in fisheries work was established in the late 1950's by Beverton and Holt (1957). Building on this cornerstone, many fishery scientists, statisticians and mathematicians progressively developed various mathematical models, which helped understand the system better. We would focus here primarily on the use of some of the most commonly used models in fisheries within a management oriented framework and their role in providing information for the decision making process. The application of mathematical models to assess fish stocks is the core of resource evaluation activity. The quantitative models help predict the effects of different management options(or policies) on the fisheries systems. Gulland (1974) categorized the main questions faced by the fishery managers as follows.

(a) How big is the resource and how many fish could be caught each year while maintaining the stock for the future ?

(b) Given the potential catch, how should this be used for the greatest benefit of the country ?

(c) What actions need to be taken to achieve these objectives ?

In fish stock assessment, there are two types of models that are employed to study the dynamics of the fish stocks. One is the micro or analytical models (or methods) and the other the macro or global (surplus production) models. Models that could be solved in closed form mathematically are analytical models. For such models, a general solution applicable to all the situations the models represent, could be obtained. In the analytical models, we take into consideration the various components that affect the stock, namely, growth, mortality, size or age at first capture etc. In the macro models, we deal with only the observable inputs (say, fishing effort) and the actual ouputs (yield in weight) from a given population. The main features which attract the fishery biologist to use these models are: (i) they are simple models, (ii) the data requirements are limited, and (iii) there is high enough computational ease in estimating the model parameters.

Surplus Production Models

The most commonly used models in fisheries management are the various surplus production models such as those proposed by Schaefer (1954) or Fox (1970). Notwithstanding their original assumptions which apply strictly to the single species systems, these models have served as management tools in many fisheries. Numerous authors have shown that these models tend to overestimate both the MSY and the fMSY. Schaefer (1954) assumed that the specific rate of natural growth f(B) was a decreasing function of the biomass B and the relationship to be linear, and derived a simple relationship between the catch per unit effort (CPUE) and the fishing effort, from which, the reference points for management could be estimated. Research on surplus production models is mainly devoted to: (1) model formulation, (2) parameter estimation, (3) extension to multispecies or multifleet fisheries, and (4) the introduction of environmental information.

Schnute (1977) recast the Schaefer's model into a stochastic dynamic model. Because random errors were shown explicitly, the parameter estimation for the model was dictated by the least squares condition. The model was converted into a form directly applicable to a data stream of annual fishing effort and catches. The new version was also stochastic. Equations were given for predicting the next year's catch. Agnello and Anderson (1977), Pope (1980) and Prager(1994) proposed theoretical extensions of the Schaefer model.

Tsoa *et al.* (1985) genaralised the conventional Schaefer model to permit the estimation of the unconstrained Cobb-Douglas production function for a fishery in the absence of population data.

Roff (1983) proposed a simple auto-regressive model and compared it with the Deriso delay differential model and Schnute's version of the Schaefer model. He found that for the demersal fish stocks, this model was found to fit the data better. He could not, however, ascribe any biological significance to the model.

Alagaraja (1984) proposed a simple model in which the differences in the catches of successive years are depicted as functions of the previous year's catch and termed it as the relative response model (RRM). A suitable relationship needs to be worked out depending on the data. The simplest form is $C_{t+1} = a + b\ C_t$, which is nothing but the auto-regressive model of order 1.

Srinath (1992) dealt with some problems associated with fitting the surplus production models to unsuitable data. He contended that purely empirical models would fit the data better than the conventional surplus production models and proposed an empirical relationship between catch and effort.

In a critical review of the surplus production models, Laloe (1995) observed that: (1) the precision of some parameter estimators appeared to be good, but the strong asymmetry of the confidence intervals and the large impact of the choice of a given formula on a given formula, went against his observation of high precision of parameter estimators; (2) fishing effort standardization did not necessarily lead to useful results for management; (3) the observation error estimators gave better results though they could not be advocated as the only approach; (4) the possible progress in the use of the surplus production models was more likely to concern the quality of questions that should be observed than the response to the usual questions; and (5) the surplus production models should be used in a framework in order to give representations of fisheries, taking into account "expert knowledge" as well as a much greater set of information.

Ludwig (1981) pointed out that if random fluctuations were taken into consideration, the assessment of management strategies became more complicated. While improving the alternative harvesting strategies for the three laws of population dynamics, namely, the Beverton & Holt model, the logistic model and the Pella-Tomlinson model, it has been found that the results of the harvesting strategies change with the noise level in the population and also depend on the type of the model used.

It is well known in the exploited fish populations that the estimates of the stock size and the catch (or yield) are subject to errors, which are caused both by fishery dependent and fishery independent factors. In this context, Prager (1994) pointed out that, because process errors were propagated forward in time, it would seem that time series fisheries models (e.g., production models), should include correction for process errors, so that the system could be modeled as correctly as possible.

Analytical Models

One of the earliest analytical models developed with a management framework was that by Beverton and Holt (1957). They developed a mathematical model relating the yield per recruit with the fishing mortality and age at first capture. Reference points for management were determined from the model, based on effort regulation or mesh regulation. The F_{max} criterion propounded by them for a given age at first capture denotes the maximum of the yield per recruit on the yield per recruit curve. Their formulation was based on the assumptions that there was knife-edge selection and the fishing mortality remained constant during the exploited phase. The early theory of population dynamics of exploited fish stocks emphasized the significance of the calculation of F_{max} (the maximum level of fishing mortality for a given size at first capture) which maximizes the average yield from each recruit entering the fishery. This was one of the earliest benchmarks for fisheries management, but suffered from a number of failures.

The yield per recruit analysis suggested by Beverton and Holt (1957) suffered many criticisms. The Y/R does not take into account the effect of exploitation on the proportion of mature fish in the population. Generally, F_{max} is greater than F_{MSY} and continued exploitation at this level could lead to the depletion of the spawning stock and affect adversely recruitment. Another criticism often made about the Y/R analysis was that the yield contour surface had always the same shape. The best long-term strategy suggested by the curve will not be valid if the stock suffered recruitment failure which was often the case with the pelagic stocks. Failures in recruitment, when the spawning stock has been reduced to low levels, have been observed for several pelagic fish stocks. However, because of the larger variability in recruitment at all stock levels, it is rather difficult to predict at what stock level the recruitment failure will occur.

The sharp increase in fishing mortality and the decrease in stock size occurring before the sharp decrease in recruitment to the exploited stock (caused by reduced spawning stock) could be discovered. This means that if there is no correlation between catch per unit effort and stock size and no direct estimates are available of stock size or recruitment, the dangerous situation would not be detected, before the estimates of poor year class are available. Virtual population analysis (VPA) (Pope, 1972; Jones, 1984) is another analytical tool which has been widely used for the assessment of fish stocks over the last two decades. The method certainly gives good estimates of stock size and recruitment if good data of catch in numbers by age (or length) are available. Tuning the VPA by choosing that terminal F which gives similar variations in F to those in the fishing effort during the last years may be a valid method in the case of the demersal stocks or even in pelagic stocks to a certain extent, if it is assumed that the stock is in a rather stable equilibrium. However, when the stock is decreasing due to overexploitation and /or decreasing recruitment, the method may yield disastrous results. Multispecies and multifleet versions of the VPA have also been attempted. Research is now underway to develop a comprehensive multispecies VPA.

REFERENCE POINTS FOR MANAGEMENT

The reference points used in fisheries management are largely the outcomes from the biometric or econometric models. These criteria for management are obtained from global or analytical formulations of the exploited fish stocks. The former models take into account the information on the fishing effort and the total yield only, and the reference points are derived from an appropriate mathematical relationship between the yield and the effort. The latter approach takes into account the processes of growth, reproduction and mortality and explains the yield as a function of these processes. Another approach is to estimate the stock-recruitment relationship and thereby indicate the fate of the fishery based on the variations in the recruitment in relation to the spawning stock. In recent times, the VPA or the length cohort analysis, has been increasingly used in fish stock assessment. These are nothing but some variants to the classical analytical models.

The criterion for the management of fisheries has generally been based on the maximum sustainable yield (MSY), the optimum yield (OY) or the maximum economic yield (MEY). The MSY has been defined in various ways. Technically, it is defined as the peak of the surplus production curve. It has also been interpreted as the point of maximum surplus production on the stock-recruitment curve. However, it is most commonly understood as the maximum constant yield that can be harvested year after year. The OY is more general than the MSY. Here, the overall objective includes considerations of societal benefits, rural upliftment, employment, foreign exchange etc. However, the development of the management regimes based on such multiple objectives has rarely been attempted and especially in the case of the small pelagics, because the ecosystem management and the constraints on the environmental parameters add another but complex dimension to the problem. The MEY is termed as the realization of maximum revenue and the economist's alternative to the MSY.

The models used in the estimation of the MSY were originally equilibrium models, which implied that the catch represented by the production curve was the outcome of the corresponding standard effort applied for the years, necessary for reaching the equilibrium (Beddington and May, 1977). These models ignore the real biological processes which actually generate the biomass and the time lag involved in building the required biomass. When the age structure of the population is changing rapidly, a single functional form of the biomass may not be valid.

The analytical models such as the VPA or the cohort analysis(or more recently the MSVPA) incorporating growth and mortality rates, age at first capture, etc., are widely used in the ICES areas. However, the data required to estimate the age-structure of the exploited fish population are not available for many tropical stocks and most of these stocks are still being assessed using low precision approaches based on sparse or inaccurate data.

MANAGEMENT AND STOCK ASSESSMENT PROBLEMS

Resources management are constrained by the lack of knowledge or the uncertainty about the fluctuations in stock size and recruitment and also the factors (biotic or abiotic or both) which affect the yearclass strength. Reliable estimation of the stock size is central to any fisheries regulation regime. In some fisheries, effort regulation is implemented instead of the catch quotas. This will be successful only if fishing mortality is strongly correlated to the fishing effort and is not significantly dependent on stock size. If the catchablility is inversely related to the stock size , the regulation of the pelagic fish stocks on the basis of fishing effort would be futile and may be counterproductive (Ultang, 1980). In the absence of knowledge about the relationship between fishing mortality and fishing effort, the alternative is to manage the fishery through the application of catch quotas. However, the problem here is how to estimate the total allowable catch. Ultang (1980) enumerated the following extra problems connected with the assessment and management of short lived pelagic stocks.

1. Stock sizes and catches depend almost completely on one or two year classes. It is not possible to build up a "buffer stock" to make the stock and the assessment less dependent on varying yearclass strength.

2. When estimates of yearclass strength are available from catch data, the yearclass is often already out of the fishery.

3. The usefulness of virtual population analysis in obtaining estimates of stock size, fishing mortality and recruitment in previous years is rather limited because of the short time a yearclass is in the fishery. This makes the estimates critically dependent on the input fishing mortality on the oldest age group and on the assumed value of natural mortality which is highly uncertain.

4. The time available for making a survey estimate of yearclass strength before the yearclass comes into the fishery is usually short and often has to rely on only one estimate without any additional check on it.

5. Because of the high natural mortality, any surplus which is not taken in one year will not be available to the fishery in the next year, even to a minor extent. Therefore, the consequences of excessive restrictions on the fishery are quite different for short-lived from long-lived species.

The major constraint to the application of catch-effort methods in the assessment of the small pelagics, especially in the tropical countries, is the complex multigear and multispecies fishery systems, where the exploitation of the small pelagics is dominated by the traditional gears. If the fishery operates with traditional gears limited to a small area, the estimated changes in abundance may not be representative of the total stock.

The appropriate type of production model for a particular fishery could be known only after overfishing has occurred and the total effort that provides the MSY has been exceeded. A more rational interpretation of the MSY for a stock, subjected to wide variations in recruitment, would be the yield which could be removed in perpetuity from the resource with an accepted low probability of endangering it (Sissenwine, 1978). From theoretical considerations, Beddington and May (1977) noted that once the Fmsy has been exceeded , the stocks will fluctuate more severely and their return time to equilibrium will increase markedly. The problem becomes more complex when the fluctuations in the stock are characterized by density-dependence and long-term cyclic or irregular variations. In the context of a general framework , where the evaluation of the resource is not the unique objective, the surplus production models may, however,be very flexible tools for fishery analysis with low parameter requirements (Laloe, 1995). The F_{max} was one of the earliest benchmarks for fisheries management, but as referred to earlier, suffered a number of failures. Another reference point is the approximate MSY which is generalized as $x.M.B_0$ based on the natural mortality rate (M), with the values of x relating to the stock characteristics. Patterson(1992) found that only low values of x not exceeding 0.33 were sustainable for several stocks of small pelagics. This approach could be used for setting "Precautionary Reference Points"(Caddy and Mahon, 1995). Caddy and Csirke (1983) expressed yield as a function of Z(total instantaneous rate of mortality), which could be used to estimate Zmbp at which the maximum biological production (MBP) could be obtained.

The target reference points could also be derived from the stock-recruitment relationship or from an extension of the yield per recruit analysis, which incorporated age/size at maturity in calculating the spawning stock biomass per recruit. Due to considerable variations in the recruitment, more often than not, it was extremely difficult to obtain statistically significant stock-recruitment relationship or spawning stock -recruitment relationship. In all S-R relationships, the spawning biomass corresponding to the maximum surplus production (B_{msp}), occurs at some level between high and low stock size (Ricker, 1975). Thus, it is possible to estimate theoretically the F_{msp} that would allow the B_{msp} to survive and reproduce in that year. Because of the problems in parameterising the stock-recruitment relationship, it is rather difficult to arrive at an appropriate mathematical model. Evans and Rice(1988) proposed an ingenious method of describing the stock - recruitment relationship without the mediation of a functional relationship. They followed the Markovian chain principles and suggested strategies for short-term and long-term prediction of recruitment.

Management measures may be envisaged as either input controls or output controls. In the former, the management strategies are based on the limitation of the fleet size, mesh size, license or closed seasons. In the latter case, restrictions are imposed on the composition of the catch and the size of fish or the total allowable catch quotas. Management options from these controls could be profitably combined when stocks show indications of overexploitation. These measures are expected to be effective in the small pelagic fisheries where the fleet size and characteristics such as the gear type could be properly monitored. However, this requires the political will and social awareness about the need for conserving and sustaining the small pelagic stocks which are the major source of livelihood of traditional and small artisanal sector. Constant catch quotas for highly fluctuating stocks such as the pelagic stocks could result in varying rates of exploitation (Sissenwine, 1978). Unless it is set at a very low level, there is likelihood of overexploitation in the years of low abundance. Variable catch quotas tend to lag behind the actual variations in recruitment by one or several years. This may result in the loss of good year classes in certain years.

A number of studies have revealed the regulation of the level of fishing effort to be more advantageous than that based on the catch quotas (Hanneson, 1993). Beddington and May (1977) noted that with a constant management strategy, environmental perturbations would cause more serious departures from equilibrium conditions than when a constant effort strategy was followed. Reeves (1974) found that under recruitment variations, an effort limit produced higher catch rates than a fixed catch quota. A constant effort strategy requires that fishing effort be controlled to that corresponding to a target F value. However , it was felt that the catchability would increase due to learning by the fishermen and increase in the fishing power. Another disadvantage which would lead to a disequilibrium state, especially in the case of the pelagic stocks, is due to the increase in the catchability at low stock sizes, thus impairing the assumption of direct proportionality of the fishing mortality with the fishing effort. In the light of the recent failures of quota controls in obtaining sustainable yields from most of the so called well managed fisheries, managing the fishery through effort control warrants a critical reexamination.

According to Freon *et al.* (1992), the conventional surplus production models are not suitable for certain stocks because fishing effort variations explain only a small fraction of the total variability of the annual production and the CPUE. Often the residual variability originates from the influence of the environmental phenomena, will affect the abundance or the catchability coefficient. They developed algorithms to improve the accuracy of the conventional models by inserting the environmental models in them and built an interactive expert system software CLIMPROD for choosing and adjusting a global production model which accounts for changes in the environmental factors. One of the major constraints in the application of the surplus production models for the assessment of the pelagic stocks is the variations in the catchability coefficient(q). The high incidence of collapse amongst the small shoaling pelagic fisheries besides their high vulnerability to unrestrained fishing has been attributed to density dependence of the catchability coefficient (Csirke,1988). The assumption $F=qf$ is central to most of the fish stock assessment models in fisheries research. Here, q is assumed to be constant and independent of stock abundance. The proportionality between F and f may be violated by variability in the area inhabited by the stock, distribution of the stock and also the harvesting power of the fishing vessels. The significant feature of pelagic fish stocks which may affect q is their schooling behaviour. The relationship between F and f depends on how the effort is measured, and for stock assessment purposes, the problem is whether it is possible to find a proper measure of effort which is proportional to the fishing mortality. Assuming no correlation between effort and the yearclass abundance, it was shown that $q = k.N^{-b}$ The relation may be most easily interpreted when N is defined as the mean stock size during the year or fishing season, instead of the stock size in the beginning of the year. In this case $C = F.N = q.f.N = k.f.N^{1-b}$. If b=0, then C/f is proportional to N, and if, b = 1, then C is proportional to f and the catch per unit effort is constant. For intermediate values of b, there will be some decrease in the catch per unit effort with decreasing stock size, but it will not be proportional. MacCall (1976) reported that for the Californian Pacific sardine fishery , the catchability coefficient increased with the decrease in the stock size.

According to May (1992), the chaotic behaviour of the systems could be due to density dependence. Thus, nonconformity of the data with the theoretical surplus production model does not necessarily mean any negation of the model as such, but warrants critical examination of the trend in the data and the underlying processes that contribute to long-term and short-term variations. Thus, there is an urgent need to re-orient the research in pelagic fish stock assessment through a critical study of the pelagic fish systems in their entirety rather than exploring nonexistent simple catch-effort relationship. In otherwords, research should address the problem incorporating both the fishery dependent and fishery independent factors in the production model. It is high time that we examine the variations in the catchability coefficients for most of the hitherto overexploited fish stocks and evolve a suitable management option based on a meaningful model taking into consideration the biophysical parameters.

Evidence is mounting that the ecosystems supporting small pelagic fish populations undergo productivity changes of decadal frequencies which are expressed, *inter alia*, by "regime shifts" of clupeoid populations. The causal mechanisms need identification, perhaps using new methods for the analysis of time series of phytoplankton, zooplankton, fish, and physical data. Considerable difficulties remain in predicting the effects on the resources of short-term (seasonal) and long-term (interannual to decadal) variations in the marine environment. There is thus a need to assess the relationship between these variations and the long-term global changes. A variety of models ranging from energy budget models of key species to the physical models of regional circulation and mixing dynamics are required. Especially valuable are the models that bridge the interface between biology and physics. The unsatisfactory performance of the existing fisheries models and the derived management options therefrom warrant critical review and change in the management of fisheries using appropriate reference points for managing fisheries. Stochastic modelling approach in which the model inputs and results are given as a range of possible realizations which account for the natural randomness needs to be followed for highly variable stocks such as the small pelagics. This type of approach requires that significant amount of reliable data be available so that the acceptable confidence levels could be obtained for model predictions.

Devaraj and Vivekanandan (this volume) gave a comparative account of the small pelagic fisheries in the APFIC region. They dealt with not only the status of the exploited small pelagics, but also the various management measures that were adopted by the respective countries. The account clearly indicated that the stock assessment techniques and production modelling procedures remain more or less uniform across the countries of the region. Although it is well recognized that the stock assessment of the exploited small pelagics defies direct solutions, the assessment of these stocks continues to be carried out by the traditional population dynamics exercises (mostly valid for the demersal stocks) for want of better or more suitable alternatives. The methodologies for the estimation of the parameters for growth and mortality rates are common to both the pelagics and the demersal stocks. These parameters are increasingly being estimated using the length composition data because of the obvious difficulties in the age determination of the tropical small pelagics. Till now there seems to be no consensus on the validity of the length based estimation procedures for estimating the growth and mortality parameters. There is thus an urgent need to standardize the procedures and propose appropriate methodologies for parametric estimation. Another daunting task that confronts the fishery biologist assessing the stocks is the definition and quantification of effective effort in multispecies and multifleet systems.

All the methods of stock assessment and model formulations presuppose that the data are relevant, properly validated and reflect the reality. In the tropical developing countries, the data required for stock assessment and fishery management emanate from the commercial fish landings. There are only very few (or no) fishery surveys conducted from onboard research vessels. The method or mode of data collection varies from country to country. No study has yet been taken to evaluate the sampling procedures that are followed to collect the relevant data for fish stock assessment and management. There should be concerted effort and cooperation among all the countries of the APFIC region to address these vital issues. There should also be effort to develop a strong database on the small pelagics of the region incorporating all the factors that cause variations in the exploited stocks and thus enable the development of GIS-based management decisions.

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