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Winter School on

Towards Ecosystem Based Management of Marine Fisheries – Building Mass Balance Trophic and Simulation Models

INFORMATION ONLY

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Technical Notes

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FISH STOCK ASSESSMENT – AN OVERVIEW

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1.Introduction

During the last five decades there has been a tremendous increase in fish production, concomitant with the improved technologies in the harvest and post harvest operations, and the extension of fishing areas beyond the conventional grounds. In most of the countries, however, the production trends in respect of the commercially important fishery resources have been showing gradual decline. The situation is no different in India. The phenomenal increase in production triggered by market growth was achieved through adoption of modern methods for exploitation and extension of fishing from the traditional near shore waters to deeper regions. This has also brought in its wake regional and sectoral imbalances in the exploitation of the common resources. The artisanal sector is increasingly marginalized by the growth in mechanized and motorized sector. Many of the resources in different regions of our EEZ are reportedly over-fished. The catch rates of the commercially important resources were observed to be declining. Concerned with the dwindling catch rates, apprehensions of damage to the ecosystem and for ensuring sustainability of the exploited resources, the maritime states of India have imposed statutory regulations for fishing by imposing ban/restriction of fishing by certain gears and closure of fishery during specified periods. Although, the benefits accruing from such management interventions are a subject of considerable debate, it is significant that the fishery managers and stakeholders have realized that resources are limited and need appropriate harvesting strategies for long term sustenance and welfare of the coastal rural folk. Fish stock assessment thus becomes necessary for choosing appropriate harvesting strategies to realize sustainable yields without damage to the ecosystem and through the optimal utilization of the available infrastructure.

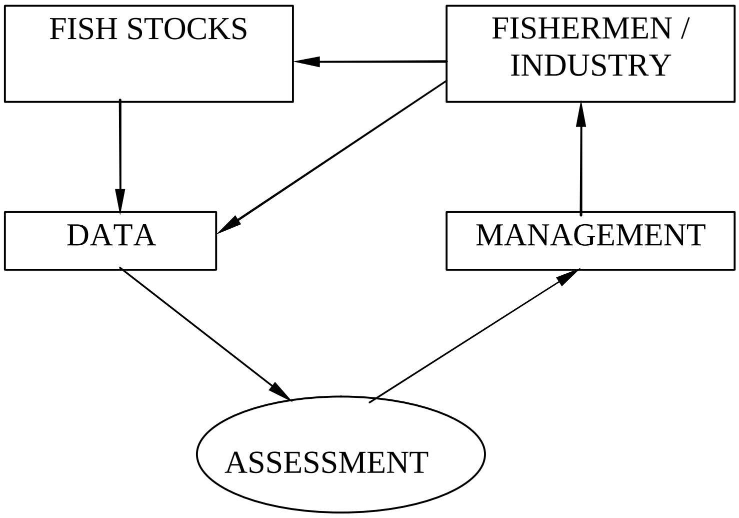
2. Stock assessment

2.1 What is stock assessment?

According to Hillborn and Walters (1992) stock assessment involves the application of statistical and mathematical calculations to relevant data in order to obtain a quantitative understanding of the status of the stock as needed to make quantitative predictions of the stock's reactions to alternative management choices. The direct impact of fishing on an exploited stock shall forms the essential basis for the more complex and realistic analysis of stocks dynamics. Techniques of stock assessment were developed initially addressing issues to single species and single gear systems for the temperate regions. Based on the experiences gained in such system, the assessment methods were generalized for more complex multispecies and multigear system using sophisticated computer intensive techniques. Models and methods arising out of such efforts are being currently used as basis for management of fisheries in many parts of the world. Relevance and direct application of such approaches in tropical resource assessment has been the subject of research in the recent part and the efforts are still continuing.

It is well recognized that stock assessment also involves understanding of the dynamics of fisheries. Modern stock assessment is not a mere exercise in predicting static equilibrium yields but involves forecasting about the time trends expected in response to policy change. It must also be realized that fishermen are an important and integral part of the dynamics of fisheries and stock assessment therefore also needs to take into account as to how they respond to the suggested interventions, if any.

A typical stock assessment process is illustrated below.



The objectives of stock assessment should address issues relating to the biological, technological, social and economic aspects of the fisheries. This involves collecting information on the indicators of the biological and technological status, economic performance and livelihood status of the dependent communities.

John A. Gulland categorized the main issues confronting fisheries administration as follows.

1. How big is the resource, and how many fish can be caught each year while maintaining the stock for the future?
2. Given the potential catch, how should this is to be used for the greatest benefit of the country?
3. What action needs to be taken to achieve these objectives?

There are two types of models that are employed in studying the dynamics of fish populations. The first type is the micro models or the analytical models (or methods) while the other type is the macro models or the global (surplus production) models. Models that can be solved in the closed form mathematically are called the analytical models. For such models it is possible to obtain a general solution, which is applicable to all the situations that the model can represent. In the analytical models we take into consideration the various components that affect the stock, namely, recruitment, 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 outputs (yield in weight) from a given population.

2.2. Data requirements

For assessment of status of the stocks and for evolving rational harvesting strategies several types of information are required. They include data on species composition, distribution and abundance data, biological data, environmental data, socio-economic data, besides fleetwise/sectorwise production data. To describe the effects of fisheries on fish stocks, it is necessary not only to know a great deal about the stocks but also to have an intimate knowledge of the fisheries themselves such as the quantities of each species removed, the time and location of removal and the size and age composition of the catch. For a proper evaluation of the stock, statistics of catch and effort along with the data on the relevant biological characteristics over time and space are very essential. Needless to say, the validity of resource evaluation depends largely on the precision of the database, which is governed by the scheme of data collection including the mode and frequency of data collection. Data types can be split into two groups, dependent or independent of the fishery. Fishery dependent data comprises of four usable types, the total catch, amount of fishing, (the combination known as) catch per unit effort (CPUE), age or size composition data. Catch data is essential for most stock production models, inaccurate or biased collection can have damaging long term effects.

When age data is sparse or the species cannot easily be aged, length based assessments are an alternative. Comparison between age and length structured yield-per-recruit models showed length structured techniques better incorporated information observed from fisheries, but age structured methods gave more precise and conservative estimates of yield-per-recruit. This is the main reason why age structured models are chosen from the conservation perspective in fisheries management. A potential strength of fishery science will be the adoption of multi-species models and ecosystem based models to fisheries that currently utilise single species methods.

2.3 Methods & Models

Having collected the required data for resource evaluation, the next step would obviously be to search for or explore an appropriate model (method) that would amply describe the underlying processes and estimate the parameters that govern the processes. This requires the application of mathematics and statistics. The use of mathematical models in fish stock assessment was established in the late 1950's by Beverton and Holt. Building on this cornerstone, many fishery scientists, statisticians and mathematicians have developed various mathematical models which have greatly helped in understanding the system better. The application of mathematical models for the assessment of fish stocks forms the core of the resource evaluation activity. Model formulation is an important exercise in fish stock assessment. The purpose is not only to evaluate the magnitude and the variations in the various parameters of the fishery, but also to formulate the guidelines for the harvesting strategies for the rational exploitation of the stocks on a short term and long term basis. This calls for checking the validity of the chosen model from time to time. Similarly, there can be different manifestations of a model (which can be termed as 'derived forms') and one can choose an appropriate derived form depending upon the requirements. Thus, the exercise in model evaluation is an important aspect of resource assessment in judging its performance in respect of its ability to estimate the components of the underlying processes more precisely and provide meaningful predictions, if necessary. If the system is simple enough, it may be possible to derive analytical solutions to the parameter estimation. Traditionally, the approach to modeling in fisheries focused on the interrelationship of fishery dependent factors and the yield. The other factors are clubbed with 'random noises' or were assumed in the long run to cancel out each other. A simple approach is to ignore uncertainty and random fluctuations. Such an approach leads to static, deterministic models. Application of such models for highly dynamic fish populations living in a fluctuating environment may lead to hazardous results. Thus, it is imperative to consider the various sources of bias, and the variations in estimating the parameters of the model for a proper understanding of the system and how the model parameters and the functions of the parameters react to the 'noise' caused by the various sources of bias and variations.

The analytical models are developed as functions or individual components of the system such as the recruitment, growth, mortality, etc. Various approaches are followed in estimating these parameters either singly or in combinations. These parameters are vital to stock assessment and the harvesting strategies depend on the reliability of the estimates of the parameters. Various methods are applied to calculate estimates of recruitment, stock sizes, and age groups. It is apparent that stock assessment techniques are highly dependent on available data, whether long or short-term predictions are the aim, both strengths and weaknesses are influenced by the abundance of this information. For correct predictions many techniques require large inputs of unbiased data, therefore the strength of any stock biomass prediction will be influenced by the weakness of the available inputs; validating final modal estimates of a fishery.

2.4 A summary of models and methods commonly used

Method	**Description**	**Data required**	**Output**	**Remarks**
Production model (also known as global model, surplus production model or catch-effort model)	Method of estimation of the past and current level of biomass and the state of the stock, from the analysis of the relationships between effort and catch. It is based on a growth equation, the relationship	Historical series of catch-effort data (usually on an annual basis) of one species.	The three parameters of the production model are obtained: Carrying capacity (equivalent to Virgin Biomass), catchability and growth rate. These three parameters allow drawing	Gives a very general view of the current state of the fishery and its history. Easy to relate to sound reference points. Inapplicable to multi-species fisheries, mainly due to the difficulties of effort allocation. Not suitable when clear

	$F=q \cdot E$ and the catch equation $C=F \cdot B$ There are several dynamic (non-equilibrium) models.		the equilibrium curve in the catch-effort plane. If the observed path of the fishery is also drawn on the same graphic, a very general and useful view of the fishery's history is obtained. MSY and E_{MSY}	changes of catchability (although this parameter can also be modelled) or changes in selectivity. The only control parameter is the effort.
Yield per recruit (Y/R)	Computes the yield that produces one recruit given particular exploitation pattern (*F* vector) at different intensities of effort.	Fishing mortality vector (*F*) Natural mortality vector (*M*) Age-length key or parameters of the growth model	Equilibrium surface of yield as function of overall *F* (or effort) and exploitation pattern (selectivity). Y_{MAX}, F_{MAX}, virgin biomass. All these results are relative (it means "by recruit")	The output is very synthetic and gives a general overview of the state of the fishery. Easy to relate to reference points (maxima, current stock vs. virgin stock, etc.). With this method it is easy to detect growth overfishing and get the clues of management alternatives. Assumes steady state
VPA (Virtual Population Analysis). Also called Cohort Analysis (particularly when Pope's	From catch-at-age data and some parameters, VPA reconstructs the past history of stock in terms	Catch-at-age of several years by operational unit (this implies previous age estimations and length composition of	Numbers of individuals and biomass at sea by year and age (thus series of recruitment, total biomass at sea etc.)	The most efficient standard assessment method. Many parameters are needed, some of

approach is used)	of number of individuals and fishing mortalities. The VPA, and its variants, is the most standard and reliable method of stock assessment.	catches) *M* vector Terminal *F*s (this imply tuning, through surveys or CPUEs) Length-weight relationship (if biomasses are wanted in the output)	Fishing mortality by year, age and operational unit	them assumed (*M*). Tuning is required. It is difficult to get a general view of the resource.
LCA (length cohort analysis)	A modification of VPAEssentially is a VPA on a pseudocohort that can be run also on the length frequency distribution of the catch. Steady state is assumed	A length or age frequency distribution of the catch representing the pseudocohort. *M* vector Terminal *F*s (this imply tuning, through surveys or CPUEs) Length-weight relationship (if biomasses are wanted in the output) Total catch in biomass by operational unit	Numbers of individuals and biomass at sea by age (recruitment, total biomass at sea etc.) Fishing mortality by age or length and operational unit	With short data series (even one year) something can be said about the state of the stock Since the steady state is assumed (pseudocohort), important biases can be obtained if this hypothesis is far from reality.
Time series analysis	The standard ARIMA method is the analysis of a time series (usually monthly structured) which is split off into trend (including cycles), seasonality and noise. Some further	Series of data, usually catch, CPUE, effort, data on vessel characteristics, environmental etc.	Most frequently the trend and seasonality of the variable analysed are obtained. When additional information (i.e. environmental) is added, it is possible to relate the	Absence of underlying biological hypotheses has both pros and cons. It is a powerful method to reveal hidden structures in the data. Useful for short term forecasting, with due caution in its

	developments, as transfer functions, allow to associate these outputs with environmental or other external variables, or intervention analysis to detect anomalous events.		behaviour of the dependent variable to other variables, such as effects of environment. Short term forecasting.	interpretation. Mainly descriptive.
Ecological approaches	Multispecies modelling. Some approaches are straight expansions of the indirect (population dynamics) assessment methods taking into account the biological interaction between species (technical, or technological interaction??can be studied by the classical methods). Multispecies VPA or MSVPA belong to this group. Other recent development is the individualbased approach Ecological modelling	In addition to the single species analysis data needs, it requires the interaction factors, particularly the quantification of the predator-prey relationships, diet composition data etc.	Quantified pathways of matter and energy between the different species (in steady state).	It approaches much better the real ecological system than the single species does. Huge amount of biological information is required. The number of interaction parameters to be estimated grows with the square of species considered (hence the unknowns become more numerous than the equations)

	based on mass balance and food webs approach – ECOPATH & ECOSIM			
Bio-economic approach	Approach including the population dynamics and the economic structure of fisheries. There are two main kinds of approach: simulation and optimisation techniques.	All population dynamics parameters Economic parameters concerning all aspects of extractive activities and commercialisation (costs, profits, prices, etc.)	Depends on the type of methodology used. Conditions giving optima according different criteria (optimisation approach) or results	Since the economics is, an important aspect driving the fishing activities, bio-economic modelling is much more realistic than purely biological (or purely economic) approaches. Many parameters are needed, hence the complexity of the model increases its uncertainties.
Simulation	Indirect (population dynamics) method that reproduce in the computer the dynamics of a stock. Often with the aim to test the effects of different environmental situations or alternative management actions.	All population dynamics parameters A recruitment-stock relationship	Projection to the future of different variables (biomass, catch) and trends at short and medium term. In the case of stochastic models confidence intervals are provided. Several management scenarios.	Very useful to analyse and compare the possible results of alternative management measures at short and medium term. To understand complex natural systems. Uncertainties in the projection, particularly because of the stock recruitment relationship.

3. Conclusion

In tropical fisheries such as those existing in India, it is quite difficult to age many fishes and then age structured analysis is not found practical with the development of length based methods such as the ELEFAN and LFDA. During the mid eighties there was an urge in the tropical fish stock assessment. In recent years, application of such methodologies was subject of considerable research and the statistical validity of some of the length based methods has been mentioned. Inspite of dubious validity of such approaches, these methods are still in vogue and extensively used in estimating population parameters.

Of late, multispecies and ecosystem based approaches are gaining currency. Biomass dynamics models too are increasingly being used to derive management reference points. Therefore, there is an urgent need for concerted research effort to establish the validity of the above approaches for management of tropical fisheries and evolve appropriate management options. For the application of ecosystem models such as the ecopath, sufficient data is required for use in the model such as diet composition etc. need to be generated. Application of biomass dynamic models need to be critically investigated in the context of impact of seasonal closures on the fishery and the biomass of the exploited stocks. Besides, there is urgent need to understand the socio-economic dynamics of the fisherfolk and the stakeholders directly involved in fishery and the related activities.

There is a need of better understanding of the dynamics of fish populations to do a better job of managing them. In doing stock assessments, the idea is to bring in as many kinds of information to assess the health of the stock, including numbers of fish, age distribution, sex distribution, and size distribution, because all of those factors affect the population dynamics and determine how the stock will respond to fishing pressure. Moreover, there is a need for development of new techniques that can better accommodate incomplete and variable data and can account for the effects of environmental fluctuations on fisheries. Such techniques should allow the specification of uncertainty in key parameters (rather than assuming constant, known values), should be robust to measurement error, and should include the ability to show the risks associated with estimated uncertainty. Therefore, the stock assessments should

- Incorporate Bayesian methods and other techniques to include realistic uncertainty in stock assessment models.
- Develop better assessment models and methods to evaluate the impacts of the quality of data on stock assessments.
- Account for effects of directional changes in environmental variables (e.g., those that would accompany climate change) in new models; and
- Develop new means to estimate changes in average catchability, selectivity, and mortality over time, rather than assuming that these parameters remain constant.

It is quite obvious from the foregoing analysis that fish stock assessment is an important exercise in fisheries resource management. However, there is increasing focus now on the assessment of the status of the communities and ecosystems where individual stocks are mere components, for a greater understanding of the dynamics of the total system. In this approach, socioeconomic variables are also integrated appropriating to facilitate decision making leading to sustainable development of fisheries, ecosystems, fishing communities and the industry. Nevertheless, modelling will never be able to provide estimates that are as accurate as direct knowledge obtained by measurement and experimentation. Thus, if future stock assessments are to avoid some of the past problems, management agencies must devote the necessary resources to monitor and investigate fish populations in a stable research environment that fosters creative approaches.

New approaches to fisheries management must be explored. These approaches should necessarily take into account the perspectives of the stakeholders. This calls for co-operative research that should involve the stakeholders, scientists and administrators. It should attempt cooperative efforts in data collection, assessment of exploited resources and evolving appropriate management measures. Community based management approaches should be attempted on a priority basis. For efficient implementation of suggested management strategies, regional fishery management commissions with necessary statutory power need to be formed.

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