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Research Article

Highlights on the Bio-Economic Reference Points for Fisheries Management and Planning

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Abstract

A brief discussion on the main processes ruling the exploitation of fish stocks is given. Comments on the content of main issues in stock assessment are provided. The evaluation of the socio-economic and biological consequences should include not just the biological aspects, but also the economic details to avoid undesirable biases in the assessments. The consensus of most of fisheries that have been assessed is that they are limited only to the biological aspects, and do not consider the economical components of the fisheries, which are a very important portion of these activities. Fisheries simulation in practice, intends contributing to fulfill a gap addressed to help fisheries to become truly sustainable, because the method is able to assess and to test many biological scenarios that can provide practical solutions to fisheries management in a user-friendly tool. Details of a fisheries simulation model which has been used for several decades, are presented and its capabilities are briefly mentioned. The most striking difference is that in the model presented here, fishing effort is not used as an explicit variable in calculations, this reduces most of the uncertainty implicit in the estimations; estimation of fishing effort is used here for the economic assessment of the fisheries studied. Examples of the fisheries where it has been applied are provided.

Keywords: Bio-Economic; Fisheries; Fish stocks

Introduction

The processes governing the dynamics of each fishery must be known, as well as the levels of performance (with biological and socio-economic criteria) allowing the management strategies and policies to be oriented towards sustainable exploitation in more accurate way than the procedures of common use nowadays.

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The evaluation of optimal fisheries strategies should have the following purposes:

1. To determine the levels of optimum biological yield and optimum economic yield;
2. To determine the level of direct jobs that each of the two options mentioned above could create;
3. To evaluate the consequences (biological, economic and social) of all feasible exploitation options;
4. To evaluate the optimum strategies for exploitation of the resources analyzed;
5. Planning and managing each stock on a basis that ensures its sustained development. The management of fishery resources with modern tools, makes it possible that not only specialists can understand the consequences in the fishery, or the conservation of the resource of any strategies to be adopted for the fisheries management.

A demonstration of the capabilities of a new interactive tool, allows to glimpse the consequences on the exploited population and the fishery as a whole, just by applying logical exploitation options of any kind; for example, it makes it possible to evaluate the socio-economic and biological consequences of an abrupt and excessive increase in fleet size, which in practice has occasionally occurred in some fisheries, or the effects of a change in the mesh light, which means leaving a certain proportion of adults in the sea that, when reproduced, can replace those who die from natural causes and fishing.

The future of fisheries and fisheries science

Among all the problems that society faces, in the context of a population boom and growing environmental pollution, the future of fisheries is burdened by political trends and the economic and social factors conditioning them. The development of fisheries is in the midst of the need to feed a growing human population and facing the consequences of depletion of exploited resources, motivated by economic interests is constrained by the finite volume of stocks. Economic, social and fishing dynamics face each one, multiple problems that interact, but have their own dynamics and complicate the possibility of finding isolated and independent solutions. Aquaculture seems to offer a light of hope for humanity for helping to solve the problem of food production from the aquatic environment. However, this is not a permanent solution. There are certain trends in fisheries development that, in practice, contribute to a future that can help fisheries becoming truly sustainable, such as the reduction of discharges, the gradual reduction of the manufacture of large vessels, the improvement of managing fisheries, the increasing participation of the public involved, the eco-labeling of fishery products, the reduction of illegal fishing, a relative price stability and the certification of many fisheries, among others. All these factors open a window of hope that allows us to expect that the sustainability of fishing may become a reality, rather than a utopia.

Main Tasks of Fisheries Assessment and Management

Knowledge of population parameters can be achieved with the knowledge of the age structure of exploited stocks [1-4] help of length frequency data, or by reading growth marks, as well as estimations of abundance from log data or statistical information. The FISMO model (FIsheries Simulation MOdel) is based on the general principles of the evaluation of fishery resources and the traditional equations that are usually applied in this procedure [5-12], with the difference that in the simulation the equations and the intermediate results of the process are linked to each other, additionally, it incorporates the analysis of the costs and benefits of the exploitation of each fishery that is analyzed, allowing to evaluate its socio-economic performance, as well as an easy way to determine the optimum biological, economic and social values [13].

Catch data and fishing effort. They must be obtained for a minimum period of fifteen years, generally available in the statistical yearbooks of each country. This information is necessary to estimate the Maximum Sustainable Yield (*MSY*), the Maximum Economic Yield (*MEY*), to determine how the fishing effort affects recruitment, biomass and profits; all this with the help of the FISMO fisheries simulation model [13,14].

Growth, Ages and Mortality. The growth rate, particularly the parameters of the von Bertalanffy model, must be evaluated from sampling data and can be analyzed with the help of the FISAT package [15], or through samplings, which also allow estimating mortality [16]. Age structure should be determined with reference to the catch data. One method to apply may be the analysis of the catch by age group, which starts from the assumption that the relative abundance between these groups remains constant over time (Figure 1A).

Lengths and Weight-Length Ratio. From sampling data, the size composition in the population and the weight-length ratio must be known and they are determined by the corresponding regressions (Figure 1B).

Recruitment. The abundance of adults over time should be used to determine the recruitment rate, that is, the number of juveniles in the age group I that is annually incorporated into the population as a result of reproduction. This relationship can be evaluated with the Beverton and Holt model [7], despite it is well known that steep recruitment may occur with modest changes in mortality [16,17].

Biomass and yield. The number of individuals in each age group can be estimated using the equation that describes the rate of exponential decay (Figure 1B) and the value of fishing mortality (F) is considered in the case of age groups exploited. The numerical abundance must be transformed into its corresponding biomass and with the catch equation the F is estimated (Figure 1B).

Model fitting and uncertainty. One of the first steps in fitting the model to data of any study case, is the calibration between catch data observed and estimated. There is a major change in the paradigm of traditional approach of stock assessment and the new focus applied here. It is the deliberate use of fishing effort data in the estimation of stock size. However, it is an indispensable ingredient for estimation of fishing costs and other economic ingredients of the bio-economic assessment. After many years working with fisheries stock assessment, it was found that the use of fishing effort data is a major source of uncertainty; this was found as the reason why never is found a perfect fit between recorded and estimated catch data. Then, on it is known that the catchability coefficient is a constant and the fishing effort is a variable, it was decided to suppress and when it was necessary to have an estimation, it was found by applying the catch equation backwards. By applying the calculations this way, it was possible to get a perfect fit between estimated and real catch data as showing in (Figure 2), where the unknown is the F. With this series of calculations, estimations of the stock biomass are made over the fifteen-year series of catch data used in the process. Further on, on the use of the same procedure, it is feasible to proceed to simulate fishing catch scenarios for planning and managing purposes.

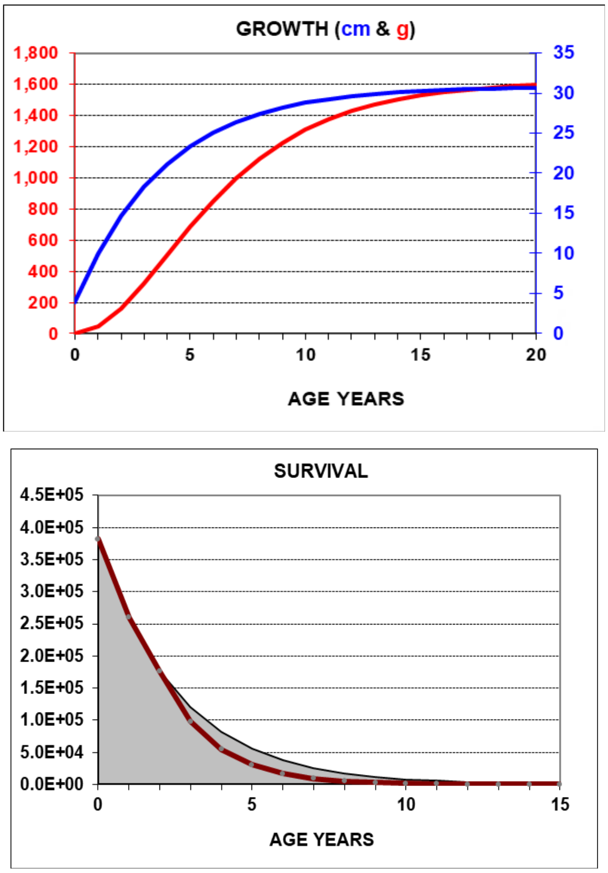

Figure 1A: Growth rate in length and weight of the Caribbean spiny lobster [17]. B. Survival of a Caribbean lobster stock as a function of age.

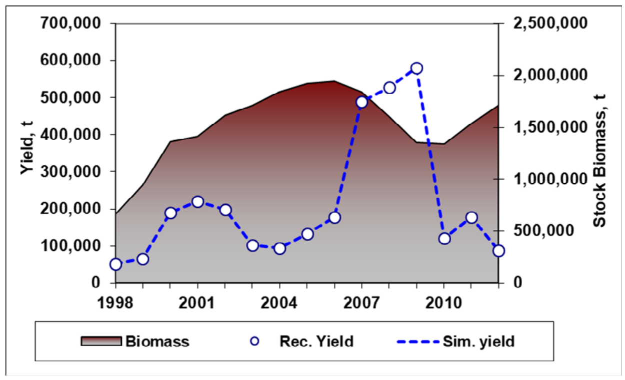

Figure 2: Trend of catch and stock biomass of the sardine population of the Gulf of California [18].

Socio-economic assessment. The model is able to fit only catch data, but it is more convenient to take advantage of this tool to go a step forward in the assessment by providing just a few data required for a socio-economic assessment, like catch value per Kg, cost of fishing per day, the number of boats fishing, and the number of trips in a fishing season. It is evident that these data are known, but usually they are not recorded systematically as the catch data. Although in this step of the analysis just one data is required, it is expected that over time, when socio-economic data become a regular portion of the analysis, whole series of data of theses variables will be a normal ingredient for the analysis. In the model as currently used, socio-economic analysis is just an estimation of the current situation useful for managing and simulating exploitation scenarios, but it is hoped that in the future, a more complete socioeconomic assessment can be a normal aspect of the socio-economic stock assessment. Fisheries is an economic activity, but for some unknown reason, up to now biologists have ignored the economic aspects of the fisheries and on other hand, most economical analysis consider only the economic aspects of fisheries for their analysis, after adding value to catch data. This lack of information leaves an important gap in the understanding of the economic aspect of fisheries, constraining an accurate approach for the assessment and further management.

Data required by the model can be obtained from interviews conducted with fishers of a fishery, from which the approximate number of vessels at the sea, the number of days of the fishing season, the number of fishers per vessel, the daily costs of fishing, costs of fishing gears and replacement time, daily catch, and the cost per Kg, before adding value. It is also required to know the proportion of the profits that is distributed among the crew members. Due to the frequent difficulty in obtaining some data mentioned in this paragraph, the model simplifies the input information and makes realistic estimations that allow the socio-economic diagnosis to be made with a very acceptable approximation.

The yield equation by Beverton and Holt [7] allows to determine the values of age at first capture and the F producing the highest yields; the one that corresponds to the Maximum Sustainable Yield (F_{MSY}), can be estimated from the values of the population parameters (Figure 3A&3B). Once a F_{MSY} value is evaluated, other reference points necessary for planning a fishery can be defined. The most important is the estimation of the Maximum Economic Yield (*MEY*), which is analogous to the *MSY*, but referred to the F producing the maximum economic returns. However, it is important to recall that the F_{MSY} is not found at the same F value as the F_{MEY}. In all cases, the *MEY* is found at a F value which is lower than the one required for the *MSY.* However, in very valuable fisheries like spiny lobster, both maximum values may coincide at the same F value. This has the important implication that it could be adopted as a management goal, instead the *MSY* as currently occurs in many world fisheries.

By examining the trends of the socio-economic variables together with the traditional biological outputs that the model provides, it is pertinent to take a look to their performance as a function of the F, and this describes a series of dome-shaped curves indicating that as a result of the fishing intensity, the production of the exploited stock attains a maximum value at some point of the F scale; for instance, the lines of Yield, stock biomass, and profits, decline at some point of fishing effort, as shown in (Figure 3A). By contrast, the cost of fishing displays a growing trend with low values at low F, but at increasing fishing intensity, it grows at a logarithmic proportion. By contrast, by

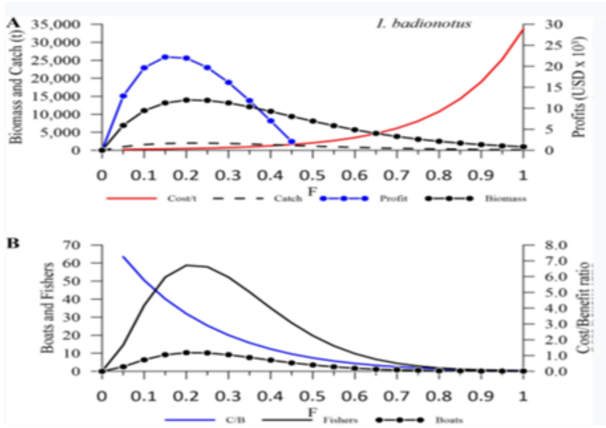

Figure 3: Biologic and socioeconomic potential yield of the sea cucumber *Isostichopus badionotus* [9] fishery of the Yucatán waters as a function of the fishing mortality F [19].

looking at the performance of the number of boats, fishers, and the Benefit/Cost ratio, it is evident that the first two variables display lines similar to those of three variables shown in Fig. 3A, attaining maximum values at the same F as the catch. The Benefit/Cost describes a declining trend, and at some F value it attains an economic equilibrium level (B/C = 1), this is when the activity stops being profitable (Figure 3B). [20,21] make specific reference to this aspect.

This point deserves a further comment, related to the conservation of the stock, because the adoption of the F_{MEY} as management target has the double advantage that it is always more convenient, because it lays in a lower range of F values, as compared to the F_{MSY} value, which is considered as the threshold of overfishing.

Discussion

Decision-Making for Management. To the extent that a tool like the one described here are adopted for decision-making in fisheries management, it will be possible to evaluate optimum strategies for exploitation of fishery resources in which they are applied. In the following paragraphs (1 to 4), potential trends of the fishery are described, and graphically represented in (Figures 3A&3B), which means,

1. From the point of view of the catch:

- Determining in advance the maximum catch volume that can be extracted sustainably.
- Forecasting the optimal exploitable volume in the following season, with known risk margins.

2. From the social point of view:

- Determining the optimum number of fishers that can participate in the activity without over-exploiting the stock.
- Evaluating for forecasting purposes, the maximum number of fishers who should fish in the following season, to ensure that the fishery operates with profits and without being overexploited.

3. From the economic point of view:

- Evaluating the levels of effort and catch that "maximize" the benefit/cost ratio.

- Evaluating the optimum level of employment that the activity can generate in the short and long term.
- Determining the maximum level of fishing effort that the fishery can sustain without reaching the level of economic equilibrium level (benefit/cost ratio = 1) and imminent risk of bankruptcy.

4. From a biological and resource conservation point of view:

- Evaluate the levels of fishing effort that guarantee the conservation of the population as a sustainably exploitable resource in the long term [22].
- Evaluating the intensity levels of the critical fishing effort that should not be exceeded due to their consequences on the over-exploitation of the population and the risk of its eventual collapse.

Services to the fishing industry

It is necessary to put at the service of the fishing industry the capacity that allows,

- Forecasting the capture performance in the following year by facilitating communication between managers and stake holders of the resource with the use of interactive graphics that are easily accessible, without having previous experience in the subject or in the use of the computer.
- Perceiving and assessing the consequences (biological, economic and social) of all exploitation options that are feasible to apply.
- Identifying and evaluating optimum biological, economic and social strategies for exploitation of fishery resources.
- To have available a tool for planning and management fisheries resources to ensure their sustained development.

Conclusion

The expected impact is to offer alternatives for the conservation of fisheries that tend to guarantee the maintenance of the economic and social activity that depends on them.

If the recommendations proposed here are considered and strict control measures are applied, most fisheries could be exploited sustainably. This option may be an appropriate procedure to plan and apply management options aimed to conservation and sustainable exploitation of fisheries.

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Appendix

Stocks evaluated with the FISMO model. As a result of the studies carried out, articles have been published on the fisheries mentioned below (based on Chávez-Ortiz, 2014, with additions).

Species	**Common name**	**Reference***
Molluscs		
Dosidicus gigas	Giant skid	[23]
Haliotis fulgens	Blue Abalone	[24]
Octopus maya	Yucatan octopus	[25]
*Strombus gigas**	Queen conch	[26,27]
Holoturids		
Apostichopus parvimensis	Sea cucumber	[27-29]
Holothuria floridana	Sea cucumber	[29]
Isostichopus fuscus	Sea cucumber	[27-30]
Isostichopus badionotus	Sea cucumber	[29]
*Parastichopus parvimensis**	Warty sea cucumber	[31,32]
Crustacea		
Callinectes bellicosus	Green crab	[33a]
Panulirus argus	Caribbean lobster	[28,29,34,35]
Panulirus inflatus	Red lobster	[33a,36]
Penaeus californiensis	Brown shrimp	[33a,37,38]
Penaeus stylirostris	Blue shrimp	[33a]
Penaeus vannamei	White shrimp	[33a,39,40]
Sicyonia penicillata	Rock shrimp	[29,30]
Fish		
Epinephelus morio	Red Grouper	[41]
Katsuwonus pelamis	Skipjack tuna	[42]
Lutjanus peru	Pacific red snapper	[43]
Lutjanus synagris	Yellow tail snapper	[44]
Brevoortia patronus	Gulf menhaden	[45]
Scomberomorus cavalla	King mackerel	[46,47]
Sardinops caeruleus	Sardine	[48-50]
Scomberomorus maculatus	Spanish mackerel	[51,52]
Totoaba macdonaldi	Totoaba	[53,54]
Tunnus obesus	Bigeye tuna	[55]