Simulating Fisheries for the Assessment of Optimum Harvesting Strategies

E.A. Chávez

Abstract

Some results of a line of research explored by the author in recent years, and concerning the small-scale fisheries of Mexico are discussed. Clarity of goals for fisheries management is stressed as a departure point before taking any step towards model building. Age-structured simulation models require input data and parameters such as growth rates, natural mortality, age at first capture and maturity, longevity, the longest possible catch records series, and estimates of numbers caught per age group. The link between each cohort and the following can then be established by means of the Ricker stock recruitment or the Beverton-Holt models. Simulation experiments can then be carried out by changing fishing mortality. Whenever data on profits and costs of catch are available, these can also be analyzed. The use of simulation models is examined with emphasis on the benefits derived from their use for fisheries management.

Introduction

In a recently published paper (Beverton 1994) several issues were raised, amongst them "whether fisheries science is pointed in the right direction and equipped to meet the challenges of the future". The former statement leads to remark that the direction of fisheries assessment and management should be to guarantee a sustainable exploitation of the resources; to maintain intensity of exploitation in or near the level necessary to generate maximum yields in the long term and to achieve high profits and reasonable social benefits.

Historical exploitation of fisheries has taught that their assessment is not an easy task.Thus, in the light of experience and current tools available to fisheries science, some questions are raised such as: "How feasible is the stock assessment of a fishery despite the lack of data on fishing effort?" Also one can ask whether the results of simulation models are reliable enough for practical purposes.

An overview of some encouraging results from simulation models are given for three Mexican fisheries. The principles implicit in the models here discussed are analogous to those stated by Hilborn and Walters (1992), but for brevity's sake, the details of model structure were omitted. Readers are invited to inquire directly from the author.

Materials and Methods

- Age structure data of the stocks analyzed: growth coefficient in the von Bertalanffy's model, natural mortality (M), age at first capture (t_c) and maturity (t_m). Whenever possible, these data were taken from the literature: in other cases the FiSAT software (Gayanilo et al. 1995) was used to estimate the required parameters for length-frequency data.
- Catch and effort data: In the three cases studied, the absence of time series data of fishing effort was a common factor, constraining the reliability of conclusions;
- An age-structured model in numbers and in weights was developed in form of a spreadsheet. Time steps were months or years, depending on longevity of each stock;
- The link between each cohort and the following one was established by means of a Ricker or Beverton-Holt stock-recruitment model;
- Simulation experiments were carried on with each stock, by changing fishing mortality and numbers of recruits until simulated catch values were the same as those observed along the whole period for which data were available;
- Whenever data on profits (B) and costs (C) of catch were available, their ratio was assessed through time under different fishing intensities;
- The validation process was carried on by running the model using as input data for the first year only and tuning it up by changing values of the parameter of the stock recruitment model;
- To determine consequences of harvesting strategies, simulation of the fishery was carried on along 20-year periods beyond the last year of real data, to ensure that recruitment rate could be maintained at about the same levels as observed through the last years with data records.

For optimization of long-term harvesting strategies, the following options were tested:

1. Increasing (or reducing) fishing mortality until optimum yields (OY) were obtained;
2. Maintaining current effort.

When costs and profits were known, two additional options were tested:

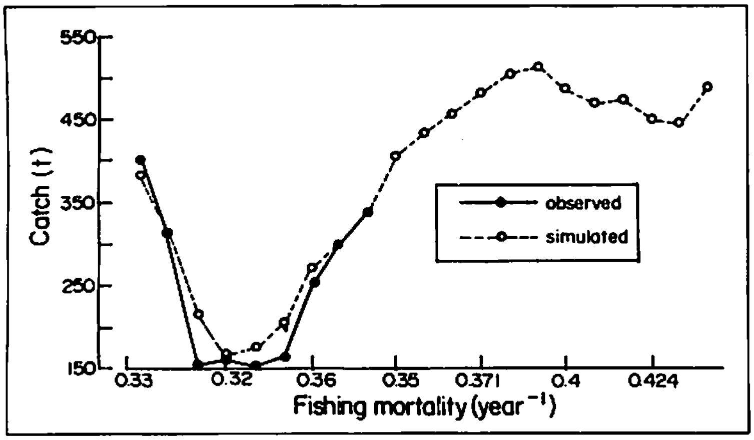

Fig. 1. Simulation of the red snapper (L. peru) fishery of the western coast of Mexico.

3. Maximizing profits under the highest possible employment levels.
4. Maximizing profits without reference to employment.

The three fisheries studies are:

Snapper fishery

This fishery is constituted of our 100 species, yielding over 2 000 t·year^{-1}. Among these, red snapper (*L. peru*) contributes about half of total catch. Two other snapper stocks (*L. argentiventris* and *L. guttatus*) were assessed and simulated. As a result of assessments (see Fig. 1 for simulation of *L. peru* stock), it was found that the three stocks are underexploited. However, it is considered that management regulations should be directed at the most important species, *L. peru*. As management strategy, gradual increments of fishing effort, authorizing new fishing permits at a rate of 2%·year^{-1} is advised until the maximum yield level is attained, which was found to occur at a fishing mortality of F = 0.7·year^{-1}, twice the current value. It is probable that some of the stocks of this species complex are overexploited, and avoiding severe depletion of such stocks might involve regulations such as the prohibition of catching certain species, i.e., allowing some of the caught animals to return to the sea alive.

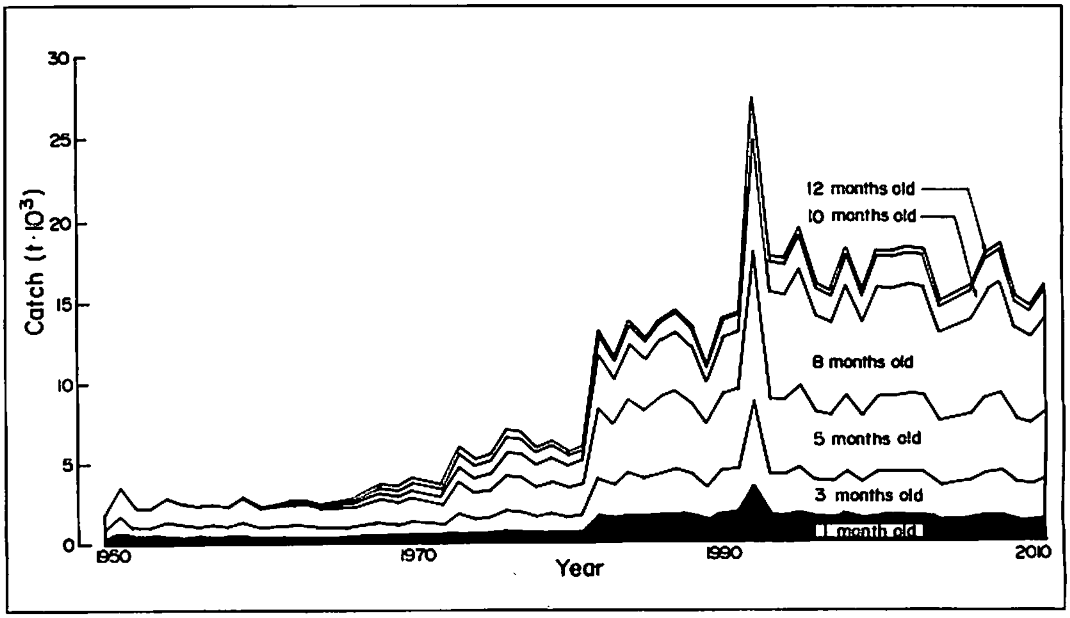

Fig. 2. Age structure of the stock of octopus (O. maya) exploited on the Campeche Bank, southern Gulf of Mexico. To test the stability of the model, a projection through time was made beyond the last year of the data series, assuming a constant fishing mortality of F = 0.7 year^{-1}.

Octopus fishery

The fishery exploits a stock endemic to Campeche Bank, Yucatan, and its annual yield amounts to about 15 000 t. Growth of the fishery has been gradual over the last 25 years (in 1970, the annual catch was only 2 000 t). Hence, it is difficult to forecast the maximum level of recruitment to be expected as a result of further increase of fishing intensity. For the purposes of the model, the simulated catches after the last year of catch records were based upon a population structure maintaining recruitment rate in about the same levels as in the most recent years (Fig. 2). A twenty-year projection allowed to assess the stability of the model and the conclusions were based upon the average values of the last ten years of projected yields. Data on costs and benefits made it possible to assess the profitability of fishing. Fig. 3 shows the results of the simulation; here, two situations deserve to be mentioned: in the first case, the fishing mortality required for optimum yield (OY) is F=0.7 year^{-1}, allowing further increments of yields up to 22 000 t. The B/C ratio decreases exponentially from high initial values, and at the OY level attains a value of B/C=2.3. To achieve this, the fishing effort generated by 7 000 fishers is required.

Economic equilibrium level (when B/C=1) is attained at F=1.3 year^{-1}. At this or higher intensities of exploitation, the fishery ceases to be profitable; however, increasing exploitation can still provide high yields (20 500 t), with a high risk of stock collapse.

The Spanish king mackerel fishery

Computer models allow linking earlier single-species age-structured models into multiple-species ones, such as the case of the MSVPA model of the ICES Multispecies Working Group (Daan and Sissenwine 1991).

The two-species models which were developed were related species of *Scomberomorus* (S. *maculatus* and *S. cavalla*), with different life cycles: Spanish mackerel (*S. maculatus*) is a short-lived species, with a life span of about eight years, whereas king mackerel (*S. cavalla*) has an estimated longevity of about 18 years. Current yields amount to 7 500 t for the Spanish mackerel (Chávez 1994), where minimum age at

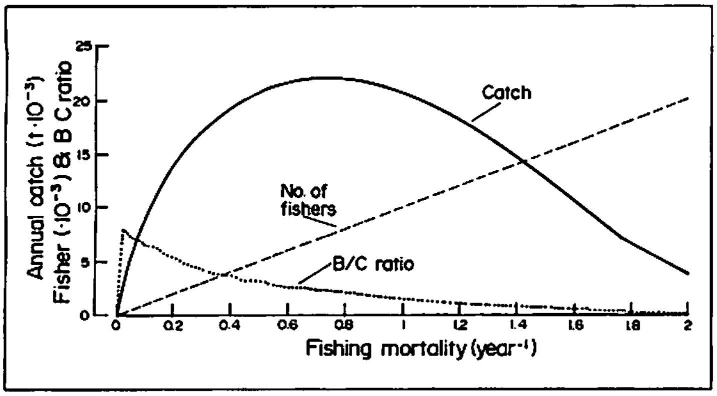

Fig. 3. Simulated trends for the octopus fishery of Campeche Bank, under different levels of fishing mortality.

first capture is 2 years, whilst the king mackerel yields nearly 2 500 t with a minimum age at first capture of 1 year (Fig. 4). Recruitment shows the same pattern in both stocks and consequently, OY levels were found at the same fishing mortality (F = 0.4 year^{-1}). However, if the management of the fishery involves a change in mesh size, it will affect the life cycles, particularly the turnover rates of both stocks, and therefore the recruitment ages. The analysis shows that the stock of king mackerel is presently overexploited (F = 0.7 year^{-1}). By contrast, the stock of Spanish mackerel is, at F = 0.45 year^{-1}, exploited very near to its OY level. The conclusion is that fishing effort on king mackerel should be reduced to about the half of its current value, and the mesh sizes should be increased even if this leads to underexploiting the Spanish mackerel. Otherwise it is likely that the king mackerel stock will collapse.

Discussion

Many decades of experience in the world fisheries have shown that there are not many cases where management based upon scientific advice has given satisfactory results: too many fisheries are depleted or overexploited. This situation is certainly not encouraging, but erroneous management practices must not be seen as the only reason for this, because climatic changes and environmental impacts caused by human acitivities also play a very important role.

Long-term management of some fisheries has taught many lessons and a consensus seems to be emerging that humans are far from making optimal use of exploited resources. Every day more fisheries scientists are recruited into the tasks of stock assessment and new and more efficient procedures for fish stock assessment enter the scientific literature. Furthermore, it is evident that modern computers play an important role as auxiliary tools to enhance the speed and quality of assessments, allowing to move from single-species toward multispecies stock assessment models (Pauly 1994). Hopefully the conjunction of these ingredients will allow to meet the need for better and more accurate methods for assessment and management of fisheries. Recent examples into this direction (Daan and Sissenwine 1991; Christensen and Pauly 1993) suggest a new direction for fisheries science, focused towards an evaluation of ecosystems, allowing to forecast the consequences on other components of the system resulting from the exploitation of another.

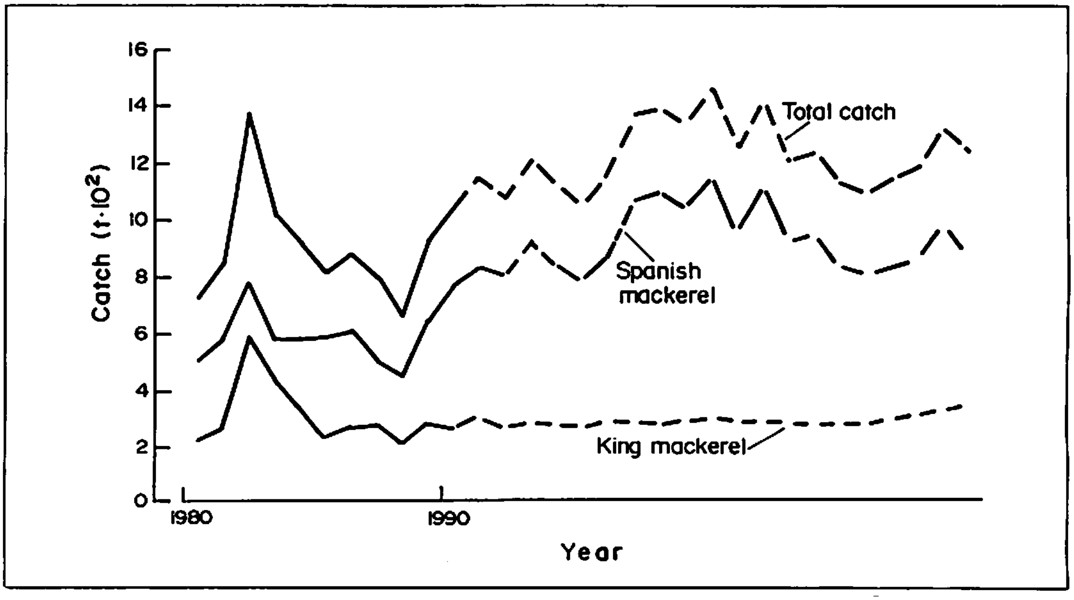

Fig. 4. Trends (observed, then simulated) in catch of Spanish (t_c = 2 years) and king mackerels (t_c = 1 year) off the southern Gulf of Mexico. Simulation of both stocks assumed that fishing mortality remained at the level required to maximize yields (F = 0.4 year^{-1}).

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E.A. CHAVEZ is from the Centro Interdisciplinario de Ciencias Marinas (CICIMAR), A.P. 592, La Paz, Baja California Sur, 23000, Mexico.