Bio-socio-economic dynamics and multidisciplinary models in small-scale fisheries research

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DYNAMIQUES BIO-SOCIO-ÉCONOMIQUES ET MODÈLES MULTIDISCIPLINAIRES DANS LA RECHERCHE SUR LES PÊCHES ARTISANALES.

RÉSUMÉ

Les modèles intégrés des systèmes de pêche artisanale doivent inclure des objectifs multiples et les dynamiques complexes des pêcheurs et des communautés de pêcheurs, ainsi que le comportement des stocks de poisson et des flottilles. Cet article s'interroge sur la quantification des objectifs de la pêche et introduit le concept de «modélisation bio-socio-économique» comme outil multidisciplinaire de recherche pour analyser les dynamiques et les spécificités inhérentes aux pêches artisanales.

1. INTRODUCTION

Small-scale fishery systems involve complex interactions between resource stocks and the people involved in harvesting those stocks. While the population dynamics of fish stocks have received considerable attention in the ecological literature, the dynamics of human communities dependent on the fishery are equally important. Indeed, the joint dynamics of the fish stocks and the fishermen must be taken into account in determining appropriate management policies.

At the same time, fishery management must balance a wide spectrum of objectives, such as conservation, income generation, employment, and community stability. This is a complex task, given the importance in community-based fisheries of such factors as tradition, family ties, group decision-making, employment-sharing, income support programs, and involvement in the «hidden economy».

Naturally, the various «players» in fishery systems place quite different priorities on each of the objectives. From the fishery research perspective, it is also important to recognize that biologists, economists, and sociologists,

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amongst others, also differ in the importance they place on fishery goals. Indeed, even the frameworks within which fishery problems are discussed vary greatly across disciplines. To what extent might it be possible to provide a unified approach for interdisciplinary analysis of artisanal fisheries ?

Quantitative fishery modelling provides one possible approach to the integration of fishery analysis, and has considerable potential to provide useful policy insights. To accomplish this, integrated models of fishery systems must include the objectives and dynamics of fishing communities and the fishery labour force, as well as those of fish stocks and capital stocks.

This paper addresses the quantification of fishery objectives, and discusses recent research in integrated fishery modelling and analysis, as this work pertains to small-scale fisheries. The concept of «bio-socio-economic» models is introduced as a multidisciplinary research tool which can be used by researchers to help understand the dynamics and the tradeoffs inherent in fishing systems.

2. QUANTITATIVE MODELLING APPROACHES

2.1. Bio-economic models

Over the past two decades, the development of «bio-economic» models (CLARK, 1976, 1985) has captured considerable interest amongst both fishery biologists and fishery economists. The idea is a natural one : link biological concepts (population dynamics, fish growth, etc.), with economic ones (investment dynamics, supply and demand, etc.) using techniques of mathematical modelling to merge the concepts together. In fact, efforts to develop integrated analytic approaches combining these aspects of fisheries date back to the 1950's (SCHAEFER, 1954 ; SCOTT, 1955), although the key introduction of methods to address dynamic changes in fisheries arose in the late 1960's.

The bio-economic approach has been highly successful in at least two respects :

- from a methodological perspective, bio-economic modelling has enabled researchers to develop analyses with considerable intuitive appeal, capturing the dynamics of both fish and fishing vessels ;

- bio-economic modelling has provided a language which can help bridge the gap between biologists and economists working on common projects.

There are, however, two potential disadvantages which need to be considered :

- until recently, some familiarity with mathematics has been required in order to construct bioeconomic models, and indeed there has been a tendency for both biologists and economists to «prove» their mathematical skills by developing and analysing complex models. Yet mathematics need not be a major stumbling block, since the microcomputer revolution has made it a relatively simple task for those not mathematically inclined to specify graphical relationships between key fishery variables, and have these incorporated into bio-economic models. This approach is particularly effective within a process of teamwork in modelling workshops ;

- a more substantial concern about the use of bio-economic modelling lies in its relevance to real-world policymaking. The integration of biological dynamics and economic dynamics has gone a long way towards describing the operation of many fishery systems. Bio-economic modelling has developed largely as a tool to provide insights into the operation and management of fisheries, and has been quite successful in that task. But while theoreticians obtain insights, those in real-world fisheries tend to view such models as abstract playthings, of little relevance to fishery policy development. It is this concern about the relevance of existing fishery models which will be addressed in the following sections.

2.2. Multiple objectives in fishery models

Real-world fisheries are managed on the basis of multiple conflicting objectives (CHARLES, 1988 ; LAWSON, 1984). Yet while it is widely agreed that such multi-objective management is desirable in fishery systems, substantial difficulties are encountered in quantifying the various goals and in providing a framework for comparison between objectives. Efforts to deal with these problems have been undertaken by several authors, including HEALEY (1984), HILBORN et WALTERS (1977), and KEENEY (1977). Here, we briefly discuss four key socio-economic objectives, with a view to their quantification and use in multi-objective fishery models :

- the generation of economic wealth, usually quantified in monetary terms as the «economic surplus» between fishery revenues and fishery costs, has been a dominant objective not only in the theory of fisheries economics, but in fishery modelling as well. While this economic wealth is usually referred to as economic «rent», fishery economists are well aware that the concept of rent can include much more than just monetary, commercial benefits ;

- fishermen income levels, or net benefits *per capita*, are also very much relevant in fishery analysis, since these provide a measure of an individual's economic well-being. Furthermore, equity considerations can be incorporated if we examine *per capita* income relative to the average income in the overall economy ;

- employment is a traditional concern of fishery managers, particularly in small-scale or isolated fisheries. The employment objective might be quantified by an employment rate, representing the fraction of the labour force that is involved in providing fishing effort at any point in time. If society desires as great a utilization of the labour force as possible, maximizing this rate is appropriate ;

- finally, fishing community viability (or «health»), is an important factor in any determination of social welfare, yet its appropriate measurement is by no means clear. We might attempt to determine community welfare quantitatively using the growth rate of the relevant local population (or labour force) over time, since other things being equal, a growing population indicates a healthier situation than a declining one.

2.3. Fishery socio-economics and fishery models

While few links have existed between socio-economic fishery research and fishery analysis based on the use of quantitative models, this is likely to change in the near future. For example, TERKLA *et al.* (1985) argue that «understanding labour adjustment processes is likely to be crucial for implementing efficient and equitable management policy» throughout the fishing industry. Such understanding will tend to require some type of dynamic model to address adjustment mechanisms in a systematic manner.

A framework for socioeconomic modelling of fishery labour dynamics in a developing country context has been laid in research such as that by PANAYOTOU (1982), who provides an equilibrium approach for depicting optimal fishery management subject to various assumptions about objectives and relevant labour costs, and by PANAYOTOU and PANAYOTOU (1986), who undertake an empirical study of labour dynamics in the fisheries of Thailand.

With respect to fishermen behaviour in North American fisheries, GASKILL *et al.* (1986) have recently considered a dynamic decisionmaking model in which fishing communities are assumed to make harvesting effort decisions in order to maximize community well-being. The empirical work of OPALUCH and BOCKSTAEL (1984) examines fishermen's goals other than profit maximization, and the process by which decisions are made concerning such factors as the desired levels of harvesting effort.

Theoretical research in this area is also worth noting. In terms of «behavioral models», classic work by SMITH (1968) was based on the development of a set of differential equations to describe fish population dynamics together with fishing effort dynamics, the latter driven by available profits in the fishery. Optimization analyses include that of MUNRO (1976), who deals with the optimal dynamics of fish stocks and fish harvests due to adjustments in the opportunity cost of labour, as the employment options of fishermen change over time.

2.4. Bio-socio-economic models

Future efforts to incorporate the multiple objectives and socio-economic factors discussed above into quantitative fishery models may best be accomplished within a suitably integrated and systematic framework. A «bio-socio-economic» approach to fishery modelling can be useful in this regard, incorporating fish population dynamics together with the decision-making and adjustment processes of fishing communities and their labour forces. This extends the bio-economic modelling approach through an emphasis on the dynamics of people in the labour force, rather than on fishing vessels or hypothetical «fishing firms», and the explicit use of multiple objectives for fishery management, to incorporate both societal goals and those of the fishery participants.

Mathematical and simulation methods can be used to study the bio-socio-economic dynamics of the fishery system and the interactions of management objectives in determining the future of the fishery. An example of such a modelling approach is provided in the next section.

3. A MULTIDISCIPLINARY MODEL

The discussion here will focus on the situation of a fishery-dependent local economy, operating as one part of a larger multi-sector economy. Within this local system, the fishery is sufficiently dominant that its labour force and the overall community population are closely tied; as the fishery goes, so goes the community. Typically, there is limited labour mobility, with workers able to move into and out of the local economy (i.e. the fishery) to a certain extent, depending on both internal and external conditions.

3.1. Dynamics

Consider a dynamic model based on two key variables in this bio-socio-economic fishery system; the fish stock itself and the corresponding fishery labour force. Together with the capital stock embodied in the fishing fleet, these variables serve as key inputs to the harvesting process.

We suppose that the fish stock at any time t is described as a single aggregated population or biomass x(t), with net growth at any time t given by the differential equation :

$$dx/dt = F(x) - h$$

where the instantaneous rate of harvest, h = h(t), is subtracted from the resource stock's natural rate of growth F(x). The latter rate is dependent on the current size of the population x = x(t), while the rate of harvest is to be determined in the fishery management process.

The labour force, L(t), is assumed to follow «modified logistic» dynamics, involving expansion if fishery conditions are good relative to the external economy, and contraction if the reverse is true (eg. if the fish stock x(t) is very small). To model this process, we require measures of internal fishery conditions and the state of the external economy.

The internal conditions in the fishery are modelled through a time-dependent «desirability» function f(R,L,E), involving three determinants : fishery rent R(t) (given by total income minus operating costs and opportunity costs of labour), the total size of the labour force L(t), and the fishing effort E(t), representing the component of the total labour force which is able to operate in the fishery.

The natural level (or carrying capacity) of the labour force at any time is given by the product of the internal and external factors, f(R,L,E)M, where M represents the state of the external economy. The relevant differential equation describing the dynamics of the labour force L(t) can then be written as :

$$dL/dt = sL(1 - L/fM)$$

where s is an intrinsic population growth rate parameter.

The state variables x(t) and L(t) are determined by the two differential equations above, once the harvest level h(t) and the fishing effort level E(t) are specified. The fish stock, the desired fishing effort, and the labour force all vary over time, with the latter tending continuously towards its constantly-shifting «natural» level.

3.2. Behavioral Analysis

The above dynamics can be used to predict the evolution of the fishery system, if we can specify how the fishermen, or the managers, will vary fishing effort and/or harvest rates over time. For example, SMITH (1968) assumes that the time rate of change in fishing effort E(t) is proportional to the difference between current fishery rents and a base level, perhaps representing the possible profit in alternative economic activities. Hence, in the SMITH' model, high rents lead to increased effort, while low (or negative) rents lead to a reduction in effort.

Of course, this is but one possible assumption about the determinants of fishing behaviour. It is also possible that fishermen might adjust their collective fishing effort in order to fully utilize available labour and capital inputs, or to maintain either constant fishery rents or fishermen incomes. Alternatively, fishery management may set a constant effort or constant harvest rate strategy (such as the «F[0.1]» approach used for groundfish stocks on Canada's Atlantic coast). From a research point of view, the modelling approach presented here has the flexibility to allow a comparison amongst these various possible effort strategies, and the resulting labour dynamics.

3.3. Optimization Analysis

In theory, dynamic optimization procedures can be used to determine the «best» harvesting schedule h(t) at each time t, once a suitable objective function has been specified. This process is discussed in detail by CHARLES (1989) - essentially it involves quantifying the objectives, as discussed in Chapter 2 above, and incorporating these into an appropriately- weighted objective function, in which the benefits are summed over time, with discounting if desired.

4. DISCUSSION

Small-scale fisheries are complex systems which present a variety of challenges to researchers, due in large part to the balancing of multiple objectives and to the interaction of ecological and socio-economic dynamics.For these reasons, small-scale fisheries research needs to be carried out within an integrated multidisciplinary framework. «Bio-socio-economic» models can be useful in this regard. Such models involve the determination of appropriate adjustment processes to predict the response of fish stocks and of fishermen to changing conditions in the fishery, and the use of these dynamics to undertake multi-objective management of fishery harvests.

The application of any fishery model to specific artisanal fisheries naturally requires the collection of suitable data to «fit» the model. In the case of bio-socio-economic models, it is necessary to assemble time series of data on fishery labour forces, fishing community populations, and fishery participation rates (eg. COPES, 1983), as well as data on fish stock dynamics and economic parameters. While the information needs are great, it is also true that in most small-scale fisheries, efforts to date have not been sufficient in collecting and consolidating existing data in preparation for an integrated analysis of the fishery system.The modelling framework discussed here may be of use in highlighting the information requirements needed to undertake such an analysis.

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