Bioeconomic Modeling and the Management of Capture and Culture Fisheries

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Fisheries are amongst the most complex of human activities, linking people with the aquatic environment and its renewable resources. The formulation of management and development schemes must take into account the multiple objectives and multifaceted nature of the system if meaningful and usable results are to be obtained. From a research perspective, fisheries studies must, of necessity, be interdisciplinary in nature.

But what research and management tools can assist us in the task of integrating the various biological, economic and social factors in a meaningful and useful way? This is a key challenge of fisheries analysis. In this article, we focus on one approach to this challenge, that of bioeconomic modeling.

Models are simply tools for representing the real world in ways that can be analyzed reasonably easily, so that we can explore the implications of management and development options prior to implementing them in practice. Models can be expressed verbally, graphically, physically or quantitatively. The last mentioned type of model, whether mathematical or computer-based, can be viewed as a form of "theoretical laboratory" for exploring the interactions in a fisheries system.

Bioeconomic models are quantitative models characterized by the fact that they integrate the natural and the human sides of the fisheries equation, linking biological and economic elements. Given the principally biological tradition of fisheries science, this linking may be considered a quantum leap in fisheries analysis.

The Concept of Bioeconomic Modeling

Bioeconomic models fall into two broad classes:

- behavioral models - designed to explain and predict fisheries and fisher dynamics, providing realistic tools to examine development and/or management scenarios,
- optimization models - oriented toward determining "optimal" management or development strategies, given a set of specified objectives.

Bioeconomic models have served well in describing key elements driving a fishery, particularly biological aspects relating to the fish resource (such as population dynamics and fish ecology) and economic factors that shape human behavior in fish harvesting (such as supply and demand, and the investment dynamics that determine entry to and exit from the fishery). The bioeconomic modeling approach has been successful in at least two respects: (a) enabling researchers to develop analyses with considerable intuitive appeal, capturing the dynamics of both fish and fishing vessels, and (b) providing a language which can help bridge the gap between biologists, economists and others working on common fisheries projects.

While bioeconomic models continue to provide important insights, they have yet to achieve their potential in terms of influence on real-world fisheries and aquaculture policy development in (tropical) developing countries. Indeed, the existing bioeconomic literature contains little in the way of applications to such fisheries. The following discussion highlights challenges for bioeconomic modeling in the context of tropical fisheries and aquaculture.

Modeling Challenges in Tropical Capture Fisheries

Fisheries in developing countries, ICLARM's geographic focus, are primarily found in tropical ecosystems, where fish resources are mostly multispecies and the degree of biotic diversity and interspecies interaction is greater than that found in temperate areas. In such fisheries, there tend to be multiple gears and significant technological interrelationships in the harvesting process (where most fishing gears have limited selectivity).

There is a pressing need for management of tropical fisheries, which have been subject to pervasive overexploitation. However, the design of appropriate management programs requires that such management be based on a suitable level of knowledge of the fisheries resource system. In particular, bioeconomic modeling can help to address three complexities that characterize tropical fisheries (and indeed other fisheries as well): the multispecies nature of the fisheries resource, the multiobjective nature of exploitation and management, and the multifaceted interdependent nature of the fisheries system as a whole.

Multispecies Bioeconomic Models. Since tropical fisheries involve multiple species and multiple gear types, the use of single-species models may lead to erroneous conclusions.

Various models have been developed to incorporate multispecies and multigear aspects of fisheries while maintaining a reasonable level of modeling tractability. These models are significantly more realistic than single-species or single-component approaches. However, the various components of the fisheries resource system are rarely given equal attention; usually there is an emphasis on either technological and economic interactions, or biological (interspecies and/or intraspecies) interactions. A key thrust in bioeconomic modeling of tropical fisheries resource systems lies in developing models that, to the extent possible, incorporate multispecies interactions and system components in a balanced manner.

Multiobjective Bioeconomic Models. Fisheries everywhere, and particularly those in developing countries, serve a variety of ends. Management objectives may include: resource conservation, economic performance, equity (social needs), food production, employment for fishers, and maintenance of fishing community well-being and viability.

Often the objectives are not complementary, which poses difficulties in managing the resource. Fisheries resource use may be viewed as one of seeking the optimum balance amongst a set of conflicting objectives. Analysis of tradeoffs between objectives thus can be of great importance to decisionmakers.

Within the context of bioeconomic modeling, this involves specifying an "objective function" that balances the goals of the hypothetical decisionmaker. This may take the form of a weighted sum of the various conflicting objectives, or a "multicriteria approach". These methodologies originate in management science (operations research), where they are used in the fisheries context; for example, a technique known as multiobjective programming has been applied empirically to a small pelagic fishery in the Philippines. Dynamic programming, goal programming and simulation are other operations research tools which have been already applied to fisheries problems, but which may still merit further analytical extensions.

"Integrated" Multifaceted Bioeconomic Models. Most bioeconomic modeling to date has focused on the harvesting level of the fisheries resource system, and has been restricted to biological and econmic components. However, recent efforts have been made to (a) incorporate postharvest components, notably the processing sector, and (b) to add key insights from disciplines other than biology and economics. Each of these additions has taken place at the level of theoretical modeling, but each has clear applications in tropical fisheries systems.

The trend toward multidisciplinary analysis has led to a broadening of research beyond simple bioeconomic models, which are restricted to fish population and fishing effort variables, to incorporate social, cultural, political and management variables as well. Such models include those referred to as "bio-socio-economic" (with added social variables) and "bio-regunomic" (with political and regulatory variables).

These extended models move in the direction of a fuller resource-system modeling approach. However, if such aspects of the fisheries system are to be modeled appropriately, there is a need to develop methodologies for quantifying, to the extent possible, the social and management variables that are involved in fisheries decisionmaking. This is undoubtedly a difficult and rather controversial challenge, but one which is crucial in developing nations where

Box 1

The Simplest Biological Production Model and Bioeconomic Model with Application to the Philippine Small Pelagics Fishery

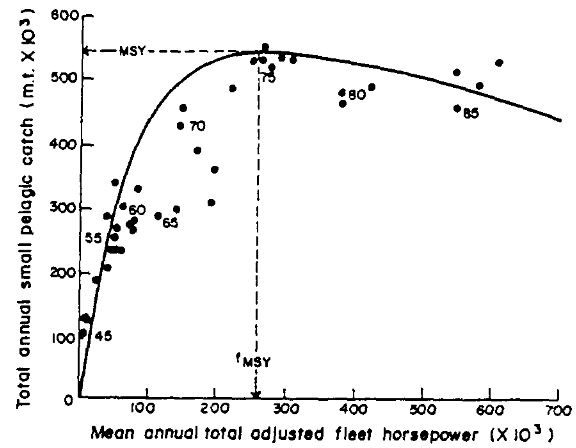


Fig. 1a. Biological surplus production model.

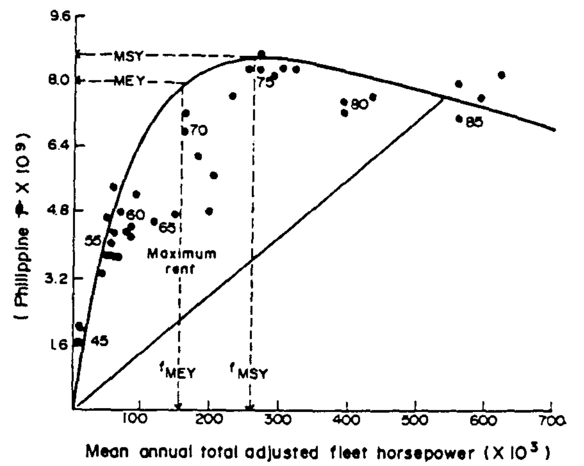
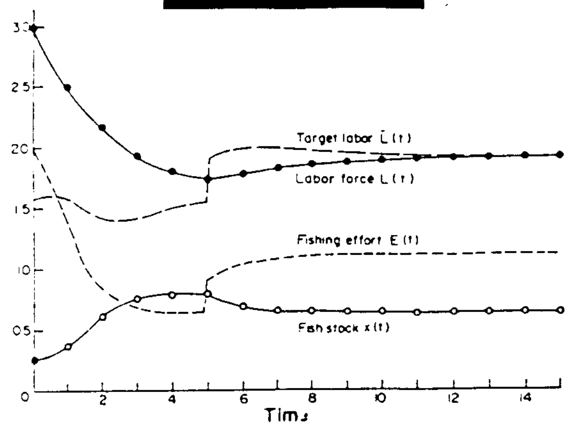


Fig. 1b. Bioeconomic model: an extension of the biological surplus production model.

The upper panel shows one management option for the fishery which is setting the fleet horsepower to about 260,000 hp to catch the largest possible yield from the fishery. By introducing fishing costs and fish prices as shown in the lower panel, we are able to evaluate economic implications of the MSY. Maximum rents from the fishery cannot be derived by catching the largest sustainable yields but at the lower catch level (MEY) and at lesser fishing intensity (f_{MEY}).

Box 2



Dynamic modeling can be used to predict how real-world fisheries systems might respond over time to developmental measures and management policies. Consider a hypothetical fish stock x(t), governed by inherent population dynamics and exploited by fishing effort E(t). The latter effort is exerted by a labor force L(t), which adjusts over time toward a target "carrying capacity" L(t), determined by the current fish stock and fishing effort, as well as fishing profitability relative to the external alternative. The resulting "bio-socio-economic" fisheries dynamics are shown, assuming an initially small fish stock, a large labor force, and an increase in the harvest rate after the first 5 years. In this particular scenario, an equilibrium is reached after adjustment to a higher stock size and a lower labor force than initially.

fisheries management is virtually impossible without allowing for socioeconomic ramifications.

Bioeconomic Modeling in Tropical Aquaculture

To the extent that the production of fish can be controlled in aquaculture systems, the questions to be addressed by bioeconomic models are different from those concerning capture fisheries. Conceptually, aquaculture is more similar to forestry and animal husbandry than to traditional ocean fisheries. Nevertheless, since aquaculture involves both biological and economic factors, a bioeconomic modeling approach is relevant and can be applied usefully both in the planning of aquaculture development and to the management of aquaculture ventures.

Most bioeconomic models in aquaculture have been formulated from the point of view of the fish farmer, whose primary concern is assumed to be that of maximizing private profits. For example, a key area of study has been the determination of optimal profit-maximizing harvest timing; various established approaches in fisheries science have been applied in this regard, as well as in determining feeding schedules and feeding rates. A further area for future research worldwide lies in modeling problems of social planning in aquaculture.

To date there has been little application of bioeconomic models to tropical aquaculture, yet such approaches might be adapted for use in evaluating new aquaculture technologies or the performance of new fish breeds under alternative conditions. Corresponding benefits and costs in each case may be quantified to aid in the development of appropriate management plans. A key goal of bioeconomic modeling for tropical aquaculture systems lies in developing "appropriate" models, drawing upon the very limited literature available so far.

Conclusions

The value of bioeconomic modeling can be judged both by its generation of useful "theoretical" insights into the operation of fisheries systems, and by its application to real-world fisheries. It has proven highly successful in the former, but has not realized its potential in the latter area. In particular, there is considerable scope for application in the development of management plans and policy advice, notably in tropical regions. With respect to its use in developing regions, in addition to the specific challenge discussed above of integrating the various fisheries resource components, two other considerations should be highlighted.

- A major stumbling block in the application of fisheries models is often seen to be the (un)availability of fisheries-related data. On the other hand, it could be argued conversely that such data are not collected because there are no models that make use of them. In any case, it is helpful to design bioeconomic models in such a manner as to be applicable even in data-sparse fisheries; this might be done by making available a continuum of models with varying degrees of data requirements.
- To be truly useful, a bioeconomic model must be "accessible" in that (a) its use must be less demanding of detailed knowledge than its original creation, and (b) it shoud be directly usable (or easily adapted) to analyze fisheries which differ in their characteristics and their information availability from those for which the model was developed. While simple highly-aggregated bioeconomic models have been developed that meet this criterion of accessibility, these tend to be too simplistic for practical application. On the other hand, the more realistic and complex bioeconomic models can be made accessible through software packages that are user-friendly or which "hide" the complex representations of biological, economic and social concepts (in a manner somewhat similar to that of the ELEFAN computer programs, which were designed to aid in estimating basic parameters of fish population dynamics). It should be noted that suitable computerized bioeconomic models must provide not only rules-of-thumb but also specific and realistic approaches for management decisionmaking.

Further Reading

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Cover

Powder-blue surgeonfishes (Acanthurus leucosternon), *an abundant indicator species of reef health.* *See p. 4-7.* PHOTO BY DR. ALEC DAWSON-SHEPHERD