Fisheries and Ecological Models in Fisheries Resource Management

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INTRODUCTION

The professional biases I incorporate into a review of fisheries and ecological models in fisheries resource management are, in large part, attributable to my orientation toward recreational fisheries as found in North America. Freshwater fisheries scientists have nearly always been more concerned with aquatic habitat and the whole array of aquatic animal and plant populations than their marine counterparts. The reason is quite understandable: the marine fisheries scientist can rarely exert much influence on habitat or non-exploited biota. On the other hand, freshwater systems may often be manipulated as part of a management strategy. Both groups of scientists have been quite concerned with *target* fish populations, and equally disinterested in the third fisheries component, man (Lackey 1974a, Clark and Lackey 1975). The purpose of this article is to place fisheries and ecological models into a renewable natural resource management context.

A good point to start an analysis of fisheries and ecological models is by defining the system of concern: a fishery (either recreational or commercial) is a system composed of *habitat*, aquatic animal and plant populations (*biota*), and *man* (Figure 1). In a broad sense, fisheries science is the study of the structure, dynamics, and interactions of habitat, aquatic biota, and man, and the achievement of human goals and objectives through use of the aquatic resource. Management is the analysis and implementation of decisions to meet human goals and objectives through use of the aquatic resource (Lackey 1974b).

Ecological Modeling
Clifford S. Russell, Editor

Resources for the Future, Inc.
Washington, DC

1975

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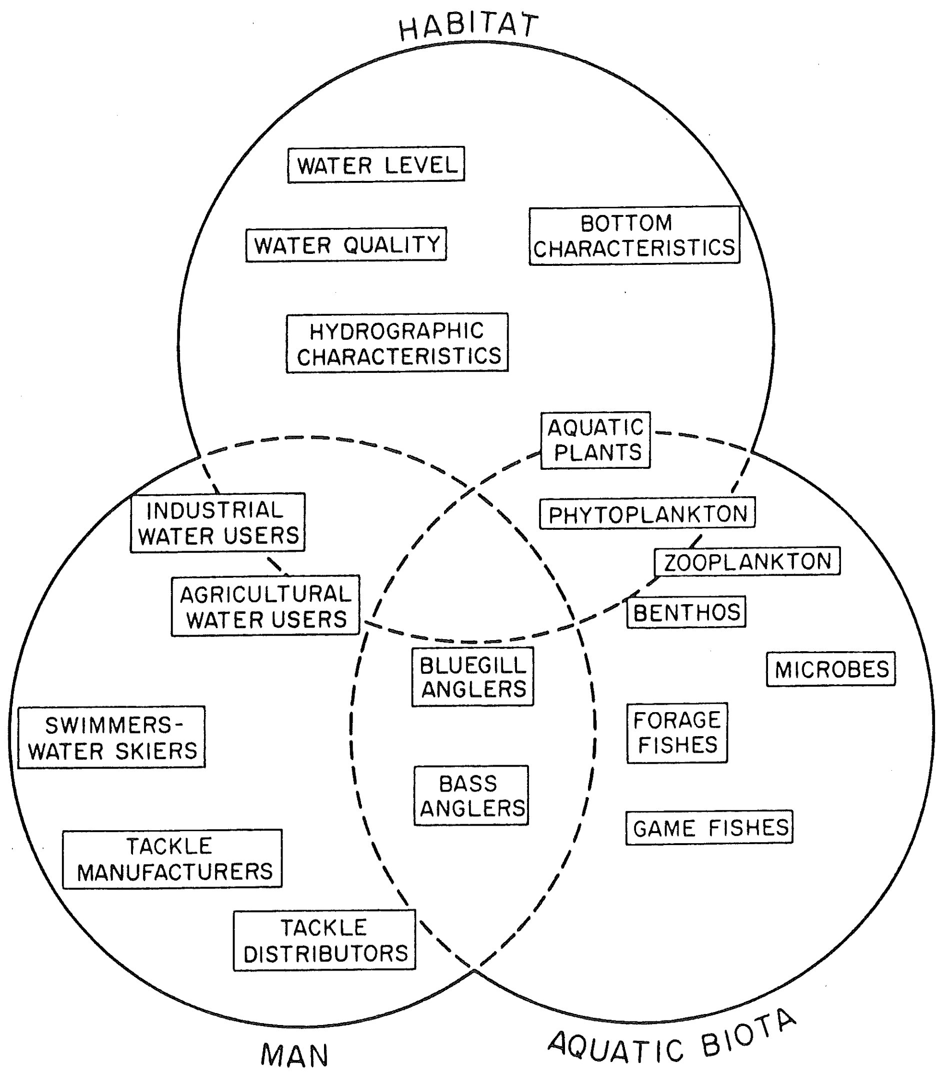

Figure 1. Schematic of a fishery system

Another concept needs to be clarified for the purpose of subsequent discussion: in a general sense, a model is simply an abstraction of a system. Models may be verbal, graphical, physical, or mathematical (including computer simulation). However, renewable natural resources modeling nowadays usually connotes modeling of a mathematical nature. Throughout this paper, modeling will mainly be used interchangeably with mathematical modeling.

MODEL INTERRELATIONSHIPS

Most models, even those seemingly unrelated, are quite similar in philosophy and approach, but there is substantial variation between models when they are viewed according to their intended use or function. Models in fisheries management can be categorized into families that include one or more fisheries components (habitat, aquatic biota, and man) (Figure 2). The evolution of fisheries models has not followed a discrete path, but rather a disjointed and often circuitous route. The major trends (as exhibited in Figure 2) apply equally to recreational and commercial fisheries and marine or freshwater fisheries, but with different developmental paths being of greater importance.

Habitat models include those developed to predict aquatic temperature regimes, toxicant dispersal, and sediment transport (Figure 2). For example, one such management problem which exists in freshwater fisheries management is predicting the structure and function of proposed reservoir environments. Managers (and modelers) must first address and solve the problem of predicting future habitat characteristics, including physical and chemical parameters, before ecosystem and fisheries models can be consistently predictive. Predicting habitat characteristics is a difficult endeavor, but because it involves prediction of purely physico-chemical phenomena, it is relatively easy.

Biological models include classical fish population dynamics models and models of single- and multiple-population systems. In this category we find the Schaefer and Beverton and Holt models (single population models in Figure 2). Nearly all of the extensive literature on population dynamics as applied in fisheries science

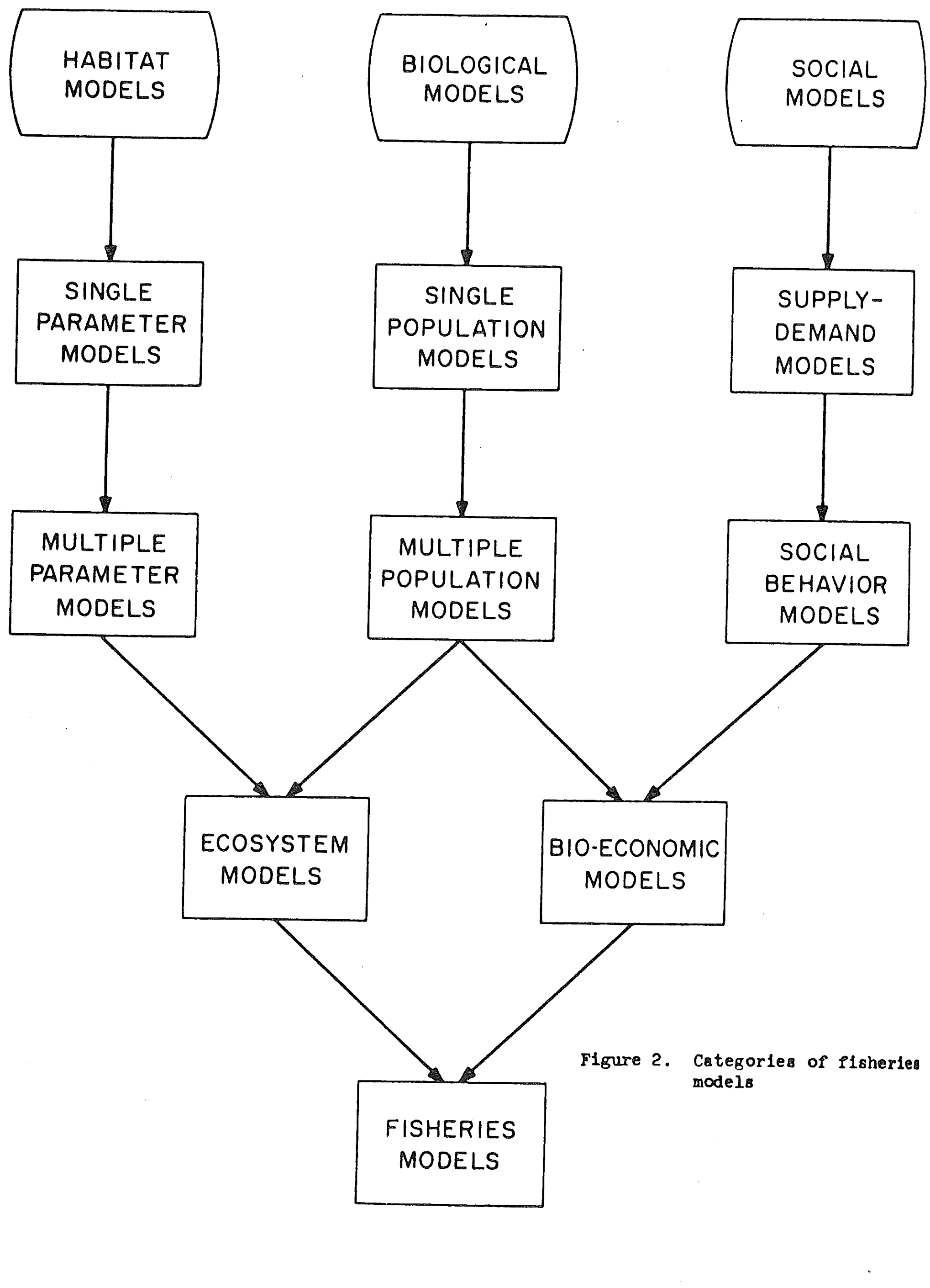

Figure 2. Categories of fisheries models

falls into this category. There has also been considerable activity on developing biological models among ecologists (Smith 1974).

Ecologic or ecosystem models are becoming increasingly common in fisheries science and other areas of renewable natural resources management. Ecosystem models combine, in varying degrees, habitat and biological models (Figure 2). Accounting for component interaction is a key point in ecosystem models and much of the profuse literature deals with interaction characteristics and mechanisms to describe them. Freshwater systems have been modeled more frequently than marine systems, in part due to the rather discrete nature of lakes and, to a lesser extent, streams. The next step in ecosystem model development may well be an effort to solve the problem of managing an evolving or unstable system.

Models that mainly address the third fisheries component, man, fall into a category which may be termed social models (Figure 2). In commercial fisheries, managers tend to measure fisheries output as pounds of fish or perhaps net income. In recreational fisheries, output is composed of many components, including aesthetics as well catch (McFadden 1969, Lackey 1974b). From a management and modeling standpoint, we must ask such questions as: How do men respond to changes in renewable natural resources? How can human behavior be predicted, or at least the behavior of part of the human population?

Bioeconomic models, as the name implies, include biological and socioeconomic components of fisheries (Figure 2). Bioeconomic models are integral to management of commercial fisheries (Pontecorvo 1973), but neglected in recreational fisheries. Crutchfield (1973) has clearly illustrated the role of social goals and fisheries management objectives. Managing trends in use of aquatic renewable natural resources may prove to be of much greater importance as human recreational and commercial demands continue to increase.

Fisheries models, in the broadest sense, at least, combine the major fisheries components (habitat, biota, and man) (Figure 2). At such a comprehensive level of analysis, detailed modeling borders on the impossible. However, if certain constraints (i.e. economic, political, and social realities) are added to a comprehensive fisheries model, one has a complete decision-making system.

POTENTIAL MODELING BENEFITS

Computer modeling in fisheries management can be justified in many ways, some of which result in benefit/cost ratios greater than unity and others that do not. As a group, fisheries modelers have, in my view, tended to oversell the potential benefits derivable from modeling, a characteristic all too frequent in emerging scientific disciplines. The potential benefits of modeling in fisheries management are many, and I would prefer to err on the conservative side as an advocate.

The first and perhaps most obvious potential benefit of computer-implemented modeling in fisheries management is organization. Fisheries are highly complex systems and modeling (graphical or mathematical) does provide a medium for clarification and organization. Used in this context, a model is a theory about the structure, dynamics, and function of a fishery or a fishery component.

A second potential benefit of modeling in fisheries management is a self-teaching device to the builder or user. There may be no better way to develop a "feel" for a fishery than to formally model it. Some fisheries models, particularly computer-implemented models, serve as useful management exercises in universities (Titlow and Lackey 1974).

Identifying gaps in our understanding of a system is a third potential benefit from modeling in fisheries mangement. In modeling, the modeler may become painfully aware of areas of missing data. Acquisition of these data may well be top priority for improving management. Sensitivity analysis in modeling will identify the parameters of most importance in determining model output, and data acquisition and/or research efforts may be allocated accordingly.

Models as research tools may be considered as a category of potential benefits. Manipulation of the model itself may generate "data" which is unattainable from the real system. For example, the impact of rainfall and water temperature may each have an impact on certain biotic components, and certain combinations of rainfall and temperature levels have been observed in the field to quantify the impact. Exercising the model may permit a reasonable assessment of the general relationship by interpolation (based on existing data combinations).

The fifth and most discussed potential benefit of modeling in fisheries management is predicting the impact of alternative management decisions or external influences. Historically, managers of commercial fisheries have been interested in predicting the impact of a proposed fishing or exploitation rate expressed in the form of a season, mesh size, or quota. Recreational fisheries managers wish to estimate the impact of decisions on the number of realized angler-days, catch, or some other measure (Lackey 1974b). As a very general guide, habitat models will potentially possess relatively good predictive power, biotic models intermediate predictive power, and social models relatively poor predictive power.

MODELS AND DECISION-MAKING

The potential benefits of mathematical modeling are not universally accepted among professional fisheries scientists. Agencies supporting or proposing to support fisheries modeling will, in my view, increasingly demand a clear itemization of the expected benefits of modeling.

Fisheries management is a very pragmatic discipline and the results of research efforts are generally expected to improve management decisions. All too often researchers have failed to bridge the gap between their work and the decision-making process. This is not to say that we need a public relations campaign to advocate modeling, but rather to present the research results in a useable manner. Research is only one input in the decision-making process and its use depends in part on ease of use.

As a final note about fisheries models and modeling, I foresee a much closer involvement between "modelers" and "decision-makers." The distinction between the two groups is purely artificial, but tends to develop by a "division of labor" approach in structuring an agency. Frequently, those actually making or recommending management decisions perceive, at least subconsciously, modelers as a threat, or worse, a pack of contemporary Don Quixotes. Modeling offers too much to resource management to fall into this image.

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