# RECREATIONAL FISHERIES MANAGEMENT & ECOSYSTEM MODELING

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# RECREATIONAL FISHERIES MANAGEMENT AND ECOSYSTEM MODELING[1]

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# ABSTRACT

Fisheries management is the practice of analyzing, making, and implementing decisions to maintain or alter the structure, dynamics, and interactions of habitat, aquatic biota, and man to achieve human goals and objectives through the aquatic resource. The purpose of this article is to place ecosystem modeling into a fisheries management framework, specifically as appropriate to recreational fisheries management. Recreational fisheries are especially complex, but prediction is the essence of fisheries management. Managers usually predict the consequences of a proposed decision in a number of ways including rules of thumb, past experience, population models, experimentation, trial and error, and pure guess. A key problem in making accurate predictions of the consequences of a proposed management decision is the complexity of most fisheries. Arithmetical calculation has been the major problem with using mathematical models in fisheries management. This problem has been solved to some degree by "simulating" fisheries.

Most fisheries and ecosystem models are quite similar in approach and philosophy, but there is substantial variation between models when viewed according to their intended use or function. Models used in fisheries may be classified as to habitat, biological, or social type, or combinations of the three categories. Fisheries, when viewed in the broadest sense, includes habitat, biological, and social aspects. The future role of modeling in recreational fisheries management may or may not be great and depends in large measure on the relationship between "modelers" and "decision-makers."

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# INTRODUCTION

The professional biases which I incorporate into evaluating the role of ecosystem modeling in fisheries management are, in large part, attributable to my orientation toward recreational fisheries as found in North America, particularly freshwater resources. 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 manager can rarely exert much influence on habitat or non-exploited biota. On the other hand, freshwater habitats (and ecosystems) may often be manipulated as part of a management strategy. Both groups of fisheries scientists have been quite concerned with target fish populations, and equally disinterested in the third fisheries component, man (Lackey 1974b, Clark and Lackey 1975a). The purpose of this article is to place ecosystem modeling into a fisheries management framework, specifically as appropriate to recreational fisheries management.

Fisheries management is the practice of analyzing, making, and implementing decisions to maintain or alter the structure, dynamics, and interactions of habitat, aquatic biota, and man to achieve human goals and objectives through the aquatic resource. When one considers the number and diversity of components that constitute a fishery (i.e., fishes, plankton, bottom animals, rooted plants, chemical and physical water characteristics, various types of anglers, and related commercial activities), the true complexity of a fishery becomes apparent. A slight change in part of the fishery may result in substantial changes in another, seemingly unrelated part.

Recreational fisheries are especially complex. There are often many game fish populations to consider (e.g., bass, bluegill, crappie, catfish, and miscellaneous sunfishes in warmwater systems). Angler diversity is also large. Some anglers exclusively pursue a single fish species, while many exhibit little species preference. Management strategies for a trophy fishery may very much differ from those of a multispecies, "family type" fishery.

Prediction is the essence of fisheries management. Managers usually predict the consequences of a proposed decision in a number of ways, including rules of thumb, past experience, population models, experimentation, trial and error, and pure guess. None of these ways is totally acceptable as a predictive tool, but all have a place in fisheries management.

A key problem in making accurate predictions of the consequences of a proposed management decision is the complexity of most fisheries. Even if some components of a fishery are well understood, the number of interrelationships makes accurate prediction difficult. The dynamic aspects of a fishery are also important because rates of change of components are as the components themselves. For example, the growth rate of an individual fish is affected by all components of the fishery, even though some of those linkages may be obscure.

## Definitions

A good point to start an analysis of fisheries management and 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 (Fig. 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).

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-implemented models). However, renewable natural resource modeling nowadays usually connotes modeling of a mathematical nature.

Another problem in predicting the consequences of fisheries management decisions is time. Given that a number of potential decisions are being considered, considerable time would be needed to adequately investigate each alternative. Time and cost are related: how much of the budget is available for predicting the consequences of management decisions? Any method which can facilitate decision analysis in fisheries management would be highly useful, especially if additional funding were not required. Realistically, a manager may have several major recreational fisheries to manage with the assistance of an assistant or two.

One approach to improving decision analysis in fisheries management is by the use of modeling. The general purpose of modeling is most often to simplify complex systems to facilitate understanding, and hence, improve management. Modeling in fisheries management is merely a highly formal mode of organizing facts and influences occurring in a complex system.

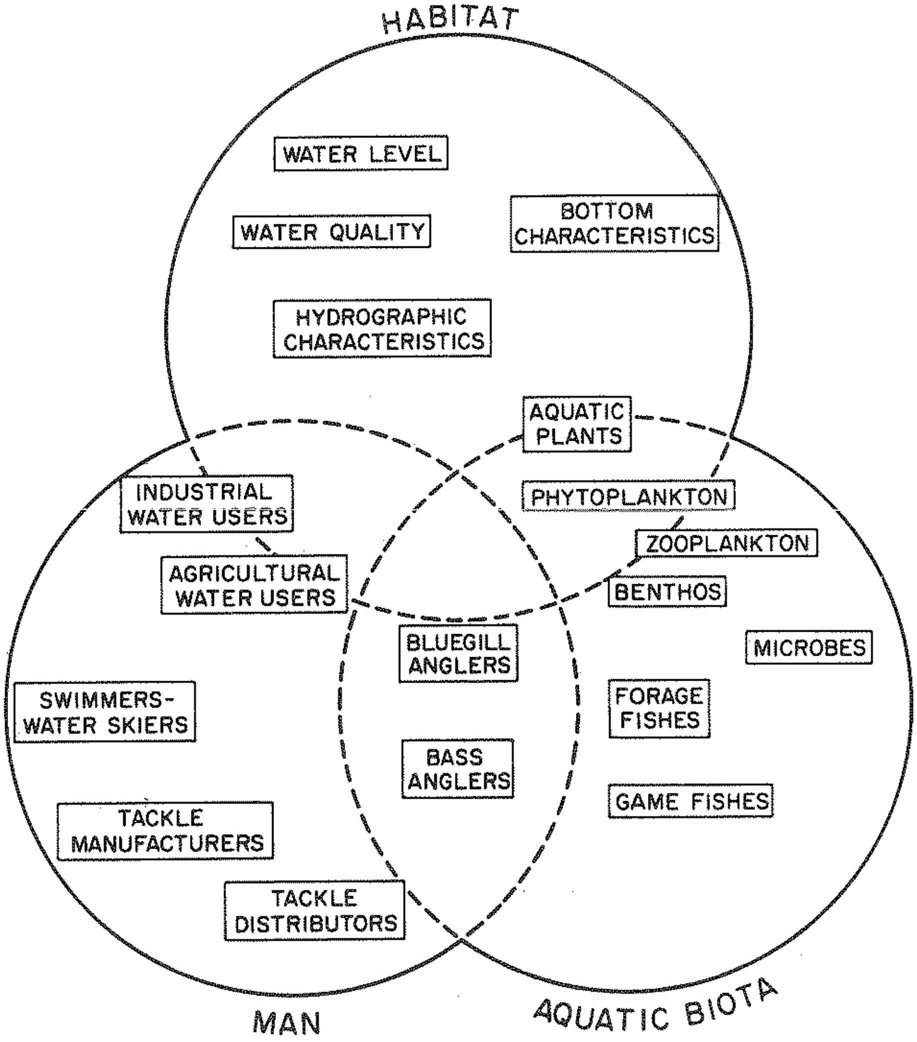


Figure 1. Graphical model of a generalized freshwater recreational fishery. Only major system components are included.

## Models

There is nothing inherently exotic about modeling or models; we all use models intuitively. A model may be simply a verbal abstraction, such as "Once fish reach a certain size, that age class will die at a fairly constant rate (Fig. 2). Fisheries may also be described via graphical models (Fig. 1 and 2). The importance of verbal and graphical models in fisheries management lies in their initial simplifying description of complex phenomena. Modeling breaks a complex system, a fishery, into components. In this way we can begin to realize what parts are related and the general trends of these relationships (inverse relationship or direct relationship). Using graphical models (Fig. 2), the relationships are more vividly expressed so that they may be useful in preliminary decision analysis.

Another kind of model utilizes physical representation of the system under consideration. For example, a laboratory model of a reservoir may be built to test waterflow patterns resulting from various water release schemes. Some fisheries scientists have utilized aquaria to study fish population dynamics. In fact, almost all laboratory studies in fisheries science are physical models of ecosystems. In these models many variables are controlled such that the effect of an isolated few may be discerned. Though controlling variables highly simplifies the system, the laboratory model is still a useful physical representation of the real system in some kinds of management situations.

The most rigorous type of model is that utilizing mathematics to describe a system (Fig. 2). Mathematical models, until the last decade or two, have been relatively simple because analytical tools have not been available to solve complex systems of equations. It is often stated that a certain amount of calculation, which could be done by many workers over several months using calculators, can be accomplished on a computer in a few minutes. Practically speaking, hand calculation if often impossible in modeling work.

Arithmetical calculation has been a major problem with using mathematical models in fisheries management, but has been solved to some degree by "simulating" fisheries. Simulation is done by coding mathematical relationships in computer language for numerical analysis. In this way, time can be expanded or contracted to investigate important aspects of the fishery. For example, 10 years of catch output may be simulated in seconds; and seconds of a physiological process concerning a fish may be simulated in minutes.

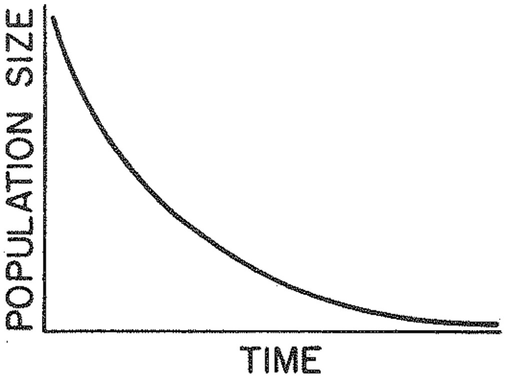
| MODEL TYPE | EXAMPLE |
|---|---|
| VERBAL | "ONCE FISH REACH A CERTAIN SIZE, THAT AGE CLASS WILL DIE AT A FAIRLY CONSTANT RATE." |
| GRAPHICAL |  |
| MATHEMATICAL | $N_t = N_o e^{-Zt}$<br>WHERE,<br>$N_t$ = POPULATION SIZE AT TIME = $t$<br>$N_o$ = POPULATION SIZE AT TIME = 0<br>$e$ = NATURAL BASE<br>$Z$ = TOTAL MORTALITY RATE<br>$t$ = TIME (GREATER THAN 0) |

Figure 2. Verbal, graphical, and mathematical models of population change over time. Each model can be useful, depending on the use at hand.

Closely related to the analytical capability of computers is the option to use logic statements in arithmetical analysis. For example, in a computer program you may hypothesize: IF we fertilize this lake, THEN the growth of largemouth bass will be according to the following relationship . . . . IF not, THEN the relationship will be . . . . Using computer programming logic statements, we can approximate relationships over the range of the variables with which we are concerned.

The purposes of computer simulation in fisheries are to improve understanding of the system, enhance decision analysis, and, in turn, benefit fisheries management. Computer simulation is characterized by: (1) providing a framework for describing complex systems; (2) allowing rapid and inexpensive evaluation of alternative management strategies; (3) identifying gaps in available data; and (4) forcing the modeler to organize his thoughts into formal statements.

Providing a framework for describing complex systems can be a very useful role of simulation. Each component of a fishery is in itself "relatively" simple. For example, changes in individual populations may show that the population level of one age class of a species affects young-of-the-year of another species. Similar relationships between components may be determined. Very rapidly, however, the model becomes extremely complex. The relationships must be systematically written in logical and arithmetic statements (computer simulation) for bookkeeping by computer.

A manager is continuously faced with the question: "What will happen *if* I follow a particular management strategy?" Often computer simulation is the tool best suited to address such a question. For example, if we had constructed a good simulation of a fishery, a manager could examine the probable impact of changing angling regulations, stocking schemes, or habitat alteration.

One of the least appreciated aspects of modeling and simulation is their relation to raw data. One of the most difficult decisions in management or research is deciding which and how much data to collect. Data are expensive to collect, analyze, and interpret. Simulation is a clear and formal statement about current understanding of the system at hand. In use, a simulation may make one painfully aware of data gaps and how useful various pieces of data are. Simulation can thus serve to identify the type data to be collected, and its location and frequency of collection.

Modeling and simulation are very definitely learning experiences (Titlow and Lackey 1974). A modeler must state his perhaps hazy thoughts in a very exact manner. Relationships that the modeler had never considered must now be addressed and his best estimates provided. The self-teaching aspects of modeling may well be its most beneficial aspect.

# THEORY OF RECREATIONAL FISHERIES MANAGEMENT

If, as a basic assumption in recreational fisheries management, we assume that all benefits derivable from aquatic, renewable, natural resources are accruable exclusively to man, then it follows that

$$Q = \text{MAX } f(X_1, X_2, X_3, \ldots X_n \mid Y_1, Y_2, Y_3, \ldots Y_n)$$

where,

$Q$ = a numerical value of total benefit

$x_n$ = management decision (n = the number of all possible decisions), and

$Y_n$ = management constraint (n = the number of all possible of constraints).

Controlled or partially controlled decision variables (X's) are those regarded as management activities (stocking, habitat improvement, etc.). Non-controlled decision variables (Y's) are random or dependent on other factors (weather, highway development, recreational attitudes, etc.). Variables may, however, overlap both categories. Within constraints (Y's), the manager tries to select a series of decisions which maximize Q.

A management problem facing all state recreational fisheries agencies is evaluating how best to allocate limited financial resources to meet particular objectives. Given the angler-day (or some other quantity) as a measure of output (Q) from a fisheries management program, how can an agency allocate its resources to increase angler-day production within a relatively fixed budget (one of the Y's)? For example, how many angler-days accrue from: (1) building additional lakes; (2) improving support facilities at existing state-owned lakes; (3) stocking various species and numbers of fish; (4) managing intensively as with lake fertilization and fish population adjustment; (5) educating the angling public; (6) enforcing laws; and (7) improving access to fisheries. Some agencies have additional methods of increasing the number of angler-days, while others have fewer alternatives.

Efforts to determine how to best allocate financial resources to achieve particular management objectives are found in many resource management areas (Chappelle 1972). Evaluating decision alternatives requires a system model (conceptual or quantified) in which to make an allocation analysis. Because resource allocation decisions are made in a very complex matrix, including uncertainty, time lag, poorly understood and quantified variables, and obscure interrelationships, decision-makers should interact in developing model structure (Morgan 1971).

One example of methodology to predict outputs accruing to state fish and game agency activities and expenditures is an angler-day simulator (PISCES) developed at Virginia Polytechnic Institute and State University (Clark and Lackey 1975b).

PISCES is a computer simulation model of a state recreational fisheries management system. It is a methodology for predicting the consequences of alternative budget allocation strategies for a fisheries agency. The measure of performance for each allocation plan is its effect upon the number of angler-days within the state. The overall objectives of PISCES is to improve investment decisions made by state fisheries agencies. Its planning horizon is one fiscal year.

Input for the model is arranged in two categories. The first is a data block containing the management decisions. The decision-maker must supply data such as budget expenditures, regulation changes, locations of access areas to be developed, and estimates of the amount of water to be gained or lost to the state's total fisheries resource. The second category consists of data which characterizes the state such as the amount of fishable water, location of functional access areas, and costs of particular management activities. Once the two data blocks are complete, the planner can test alternative budget allocations in the model.

The management programs which must be allocated funds include: (1) pollution control; (2) law enforcement; (3) information and education; (4) coldwater hatcheries; (5) warmwater hatcheries; (6) access area development; (7) research; and (8) state-managed lakes. Other management decisions considered to affect the number of angler-days are: (1) regulation changes including season length and license fees; (2) water gains as from construction of reservoirs or land access and acquisition; and (3) water losses as from pollution or inundation.

The choice of angler-days as the common measure of output for PISCES was based on the importance of people management to fisheries management. The effects of management upon angler-days considered in PISCES are angler-day production, loss, and migration. PISCES treats an angler-day as a two-dimensional entity. The first dimension, physical location, is partitioned into the state's management regions. Thus, when the output is analyzed an angler-day in one part of the state can be weighed either more or less than one in another part. The second dimension, fisheries type, is partitioned into the five fisheries types. Thus, an angler-day of bass fishing can be weighed either more or less than an angler-day of trout fishing.

Another example of a tool to aid decision analysis in fisheries management is the deer hunter participation simulation (DEPHAS) developed by Bell and Thompson (1973). DEPHAS is a computer simulator designed for predicting outputs resulting from state wildlife agency activities by allowing state wildlife administrators to analyze interaction between input and output of their proposed management policies. Many other examples of operations research models for use in natural resources management are given by Titlow and Lackey (1974), Mills (1974), and Bare (1971). Another example of development of wildlife management plans through simulation modeling also involves deer management (Walters and Gross 1972). Their simulator is aimed at evaluating alternative paths of action and estimation of consequences in complex management situations. This same simulation approach has been applied in a number of other cases (Walters 1969; Walters and Bandy 1972). A general computer model, FARMS, was developed to look at land use and big game populations in British Columbia (Walters and Bunnell 1971). Although the model was initially developed as a management game, the application to decision-making is a logical and reasonable extension. The model allows users to vary: (1) harvest rates of game and forest; (2) stocking rates of cattle; and (3) range burning practices.

Simulation is certainly not the only approach to resource allocation problems and, in fact, it is sometimes regarded as a "last resort" attack (Wagner 1969). As another approach to evaluating resource allocation strategies, linear programming has been used (Lobdell 1972). Salmon management problems have been studied extensively by linear programming and simulation procedures (Rothschild and Balsiger 1971; Booth 1972; Carlson 1969). Salmon management consists of: (1) predicting the number of fish in future runs; (2) selecting a number of salmon to allow to spawn; and (3) allocating the remaining fish to the fishermen throughout the season. Allocation strategies have been used to maximize the value of the catch given the required number of fish reaching spawning grounds. Booth (1972) developed a discrete time maximizing model based on basic fisheries stock-recruitment theory. The essential property of this model is the decision whether a manager "invests" in spawners (which provide future yield) or "sells" potential spawners today. A blend of classical fisheries population dynamics (logistic model) and economic theory has been advanced as one solution to meeting management decisions (Carlson 1969). The key problem was not so much with modeling, but lack of a clear and generally accepted management objective.

Nearly all fisheries consist of two or more game or commercially important species and management activities affect each to a varying degree. Modeling at this level is quite difficult, but Riffenburgh (1969) has shown the promise of using energy flow in projecting trends in the biological components of fisheries. Subsystems were connected by energy flow links with a computer program performing necessary bookkeeping. Such a modeling strategy could be considered in systems where a "common denominator" was present.

Management problems, such as evaluating decision alternatives, are definitely not unique to resource management (Dale 1970; Jacoby and Loucks 1972). Planning in business is integrally involved in allocating resources toward maximizing specific objectives. In fact, most current management decisions are made within an alternative marketing strategy simulation (Snyder and Swackhamer 1966). With computer assistance, many past, present, and future technological conditions can be analyzed, performance measured under each, and the best course of action selected. Engineering techniques, like optimal control theory, have application in some fisheries management allocation problems (Ahmed and Georganas 1973).

Angler consumption of fisheries resources is one of the major interactions of man with aquatic biota and habitat. Thus, consumption is a major concern of management agencies, but consumption trends in recreational fisheries are generally out of control (McFadden 1969). In practice, consumptive trends are nearly always viewed as phenomena extrinsic to fisheries management, but, in reality, are only partially extrinsic. Virtually all management agency programs and activities have an effect on the location and intensity of angler consumption. Land acquisition, dam construction, pollution control, fish stocking, and access development are common examples.

Recreational fisheries management is largely involved with forecasting the demand and providing an adequate supply of fisheries resources. Producing or maintaining the necessary supply of fisheries may be difficult because all agencies have political, technical, and ecological constraints, and limited financial resources. In many cases, angler consumption of fisheries resources threatens to exceed managers' ability to supply angler-days of the desired quality.

Management policies have been designed to respond to consumptive trends but rarely to shape them. If fisheries management policies were designed to regulate angler consumption, greater benefits might be accrued from fisheries resources. Regulation of angler consumption could be achieved by limiting licenses, but such a tactic is often not politically or culturally acceptable. A less dictatorial approach, based on subtle relationships between individual management activities and angler consumption, might also be effective and perhaps more politically palatable.

Angling regulations, information distribution, and educational programs address human components in fisheries management, but such efforts alone cannot be relied upon to direct resource consumption in a desirable direction. One or two actions in a complex management system are invariably inadequate to achieve the desired change. For example, while information and education efforts are working to direct angler consumption along a particular course, other agency activities may be working subtly against that course. Multiple actions, each moving in the same direction and with coordinated timing and emphasis, are needed to successfully regulate angler consumption.

# MANAGEMENT OBJECTIVES

A management objective is a statement of the desired result of a decision or set of decisions. At least in classical management terminology, an objective is not equated with a goal, which is defined as the end toward which a design tends; that is, an ideal or aim which is usually expressed in general and abstract terms (Meier and Thornton 1973). A few examples of goals in fisheries management are: "best" or "wisest" use of resources; conservation, protection, and enhancement of the resource; and providing the greatest amount of recreational opportunity for the greatest number of people. A goal is a value to be sought, not an object to be achieved. Goals provide general direction to agency programs and are useful in public relations, but clear, sound objectives are vital to fulfilling goals.

Objectives have been described from many vantage points. Uleck (1971) defined what he called "ends" as aspirations for preferred states or conditions. Meier and Thornton (1973) defined an objective as an end point to be reached, and being capable of attainment and measurement. Anderson (1972) states that an objective is simply a more specific goal. Goals and objectives are not absolutes, but decision elements in a system. Besides serving as targets for management, goals and objectives give identity to the agency, imply its system of values, define the type of information required in decision-making, help describe the most effective personnel, and provide inspiration to personnel (Duerr 1974).

However defined, objectives have some very important properties which affect their use in natural resource management and modeling: (1) objectives are clearly stated; (2) objectives are specific and not filled with broad and general terms; (3) objectives are quantifiable by some means, if not empirically, then subjectively; and (4) objectives have a performance measure in order to evaluate progress (Anderson 1972). Objectives and goals are also arranged in hierarchies or chains (Meier and Thornton 1973, Uleck 1971, Duerr 1974). In a goal chain, a goal or objective is an end when viewed from lower in the chain and a means when viewed from higher in the chain. Uleck (1971) combines the properties of objectives in the term "operational," which implies that progress toward objectives can be measured objectively and that all costs and benefits of striving toward goals can be foreseen and estimated. Objectives are made operational, according to Uleck, by: (1) making objective statements clear and specific; and (2) stating objectives in terms which indicate constraints, benefits, and costs. Uleck also emphasized that objectives must be capable of being utilized in all planning steps and, most importantly, be acceptable to the affected public. Objectives must be oriented toward satisfying people through use of the resource.

Effective management of any system is based upon clear and formally stated objectives. However, many natural resource management agencies may have no formal objectives or may have ambiguous statements such as "best" or "wisest" use of a particular resource system (Lackey 1974a). The "soft" objectives serve well as broad goals and are acceptable to the general public, but sound objectives need to accompany goals for effective management to occur. Joseph (1974) feels that most fisheries scientists have functioned at the management level with no goals in mind at all.

Most managers have recognized the inherent difficulties of operating without functional objectives. Many have also tried to substitute more measurable objectives. Historically, the most common objective has been to maximize pounds or numbers of fish on a sustained basis. Some common variants are to maximize yield of a certain species or to maximize catch of a certain size. Desirable properties of this type of objective are: (1) it is conceptually simple; and (2) it is an objective-oriented approach to management. However, maximum sustained yield has some inherent disadvantages. The main undesirable property is that most anglers regard catch as only one of several measures of output from a fishery (Moeller and Engelken 1972, Brown 1970, Sport Fishing Institute 1974). Most anglers agree that their interest is not solely in the fish they catch, but in fishing itself (Ley 1967). A survey of Ohio fishermen revealed that over half enjoyed fishing even if no fish were caught (Addis and Erickson 1968). Other aspects important to the angler are the outdoor experience, environmental aesthetics, and the sporting challenge (McFadden 1969). Additional considerations are the species caught, sizes of fish, settings in which they are found, and the method by which they are sought (Sport Fishing Institute 1973). Recently, a survey of saltwater sport fishing (coho and chinook) was carried out by Richard C. Bryan of the Fisheries and Marine Service of the Canadian Department of Environment to determine the motivations of fishermen (Sport Fishing Institute 1974). It was noted that 38% of the motives of fishermen were escapism-oriented while 27% were fishing oriented. A similar study conducted on wilderness fishermen in the Unita Mountains of Utah determined that escape from routine and getting outdoors ranked above catching fish as important attractant forces (Hoagland and Kennedy 1974). Sixty-nine percent of the anglers stated they would experience no disappointment with 50% catch reductions, and 48% of the anglers reacted similarly to catching no fish.

Coomber and Biswas (1973) suspected that the public received benefits of a psychic or convenience nature which might in total amount be larger than the more tangible benefits received from recreation. McFadden (1969) viewed the social product of sport fishing as the aggregate of value which accrues to the participants from an enriching use of their leisure time. He maintained that fishing may be an escape to solitude, a social enterprise, a vigorous physical challenge, or an occasion of relaxation. McFadden viewed the sporting expereience as being composed of two basic factors: the quest--an adventure in angling methodology; and the attainment of a tangible reward, such as a fish. However, the basic core experience may be enjoyed in a variety of natural and social environments and consequently, the sport must mean different things to different people. Obviously, there are a number of important physical, social, and psychological factors related to a fishing experience which are neglected by the maximum sustained yield concept.

Among more recent efforts to institute "hard" objectives have been attempts to measure quantities such as man-days of use (Bell and Thompson 1973). The assumption is that measuring the number of man-days of recreation on a particular resource is a valid index of output. Some may also go further and assume that the approach could be used to maximize recreational benefit. However, maximizing angler-days may result in an amusement park situation. McFadden (1961) reported that a trophy trout project in Pennsylvania sustained shoulder-to-shoulder angling with a second tier of anglers on crowded days. McFadden (1969) states that neither potential yield nor intolerance of crowding by anglers constitutes foreseeable limits on sport fishing intensity in freshwater resources. The man-day concept does not incorporate a quality aspect, but at least output is being measured in more human-oriented terms.

A possible objective in recreational fisheries management is maximizing aesthetics. This is a very altruistic approach, but not readily quantifiable. Due to lack of a functional pricing system, the value of various recreational factors cannot be easily determined by a market survey conducted on the angling public. Coomber and Biswas (1973) maintain that aesthetics can never be accurately measured. However, they reason that by defining the variables associated with an object and a subject's perception of it, a reasonable understanding of aestheticism may be attained. Leopold (1969) has used a quantitative scheme for making comparisons of aesthetic factors on rivers, a first step which could be applied to fisheries management.

A second possible objective is maximizing quality-ranked angler-days. Quality is an extremely vague and variable parameter to measure, but certain factors which contribute to the quality of the fishing experience could be delineated and measured. The number of potential variables is large, but specific areas may only have a few aspects which determine quality.

Some popular fisheries management objectives (such as maximizing catch) are often not adequate measures of output and may well be replaced or modified to meet present needs in recreational fisheries (Clark and Lackey 1975a). The aspect of quality needs to be integrated into management if optimal output from fishery resources is to be realized.

## Setting Objectives

Setting management objectives is no simple task. Practically speaking, the identification, selection, articulation, and ranking of objectives are not easily achieved (INTASA 1973, Meier and Thornton 1973). There are many problems concerning the quantification and measurement of aesthetic and environmental factors. Because of the complexity of natural resources systems, establishment of management objectives may tend to be ignored by some managers. Possible reasons why decision-makers may be unwilling to formulate objectives are fear that some of the "real" objectives would be disapproved under scrutiny by the public, and fear that some objectives might not be approved by all interested parties (Miller 1970). Miller states that decision-makers may be unable to formulate objectives because of three difficulties: incomplete problem awareness; incomplete knowledge of the intricacies of the problem; and inability, due to time, money, and/or manpower constraints, to devote sufficient thinking effort. Further, Meier and Thornton (1973) feel that objective setting methodology is not sufficient to be of use to the manager. Most authors stress only the importance of objectives without providing means for determining or detailing them. However, several techniques are available and when used in combination should provide a sound framework for determining objectives. The strawman/discussion technique, tree structures, relevance trees, the brainstorming technique, Delphi method, and attitude surveys are just six objective and goal determination procedures (Meier and Thornton 1973).

The purposes of the strawman/discussion technique are to elicit ideas from a group and promote consensus through discussion. The participants simply bring a list of proposed objectives to a committee meeting for review and discussion. The strawman/discussion technique fits well with the traditional committee approach to planning, but has some disadvantages, such as the unwillingness of some people to alter their ideas. Psychological factors, such as the bandwagon effect and the dominant personality bias, are also negative features. Also, the strawman/discussion technique may not provide participants with enough detail for selecting best decisions. However, this procedure may be especially well-suited for establishing general goals.

Tree structures provide a strong framework for problem analysis by retaining focus on the overall goal. The structure is composed of branches arranged in successive levels, with the highest level representing the goal and succeeding levels representing subgoals on down to specific objectives. Phenicie and Lyons (1973) present a lucid discussion and explanation of this procedure with special reference to fisheries and wildlife management. It is simply a logical and systematic way of setting objectives.

Relevance trees are tree structures modified by providing values representing the relative importance of each branch at each level. The purpose and advantages are similar to trees, except an ordinal ranking of subgoals and objectives is generated, which may be particularly useful in allocating money and effort to the most important management objectives.

Another method, the brainstorming technique, is best suited for broad goal determination. A basic decision problem is stated to a group and potential solutions solicited from the participants. All suggestions are reviewed.

The Delphi method involves use of individual questionnaires to survey participants, followed by feedback of a computed consensus of the group's opinions. This procedure eliminates many psychological biases and tends to promote a group consensus. When used alone, it is best for determining goals, but used in conjunction with a tree, it can be a useful tool for objective setting.

Attitute or opinion surveys can provide useful input from the public. Telephone, personal, or mail interviews may be used. Giles and Lee (1975) developed a methodology which allowed the hunting public to rank objectives in setting a squirrel hunting season. The procedure provides a means for natural resource agencies to provide the greatest amount of user satisfaction from the resource. This type of research may eventually lead to the development of a fisheries management benefit unit as recommended by Lackey (1974a), which would provide a common denominator to evaluate fisheries management decisions.

## Objective Functions

Rational management of a recreational natural resource by a public agency requires maximization of an objective function which reflects benefits to the user, as well as to society as a whole. The objective most often used by public agencies to depict user-benefits is the user-day, but many other attributes may enter into the recreational experience.

In the example of a recreational fishery, important attributes of an individual's fishing experience may include water quality, scenic beauty of the area, size, number, and species of fish caught, privacy, support facilities, and access to the fishing area. Moeller and Engelken (1972) found that in their sample, anglers consistently ranked privacy more important than either number of size of fish in the catch. Results such as these question user-days as a proper management objective function because more user-days is equivalent to less privacy.

An alternative procedure is for the decision-maker to specify certain measures of effectiveness and then develop a utility function (UF) governing explicit measures or attributes. Given such a UF, the expected utility may be calculated and would be the objective function; i.e., the decision-maker would prefer the alternative with the greatest expected utility.

Becuase the UF represents the decision-maker's views as to his own preferences, there is no "right" or "wrong" associated with it. Problems arise when the decision-maker (a public natural resource manager) attempts to formulate a UF using attributes which primarily reflect benefits to the resource user, and only secondarily to himself. The manager is put in the position of making value judgments as to what he feels the public desires. In all likelihood the decision-maker's utility preference for an attribute will not coincide with the preferences of the public. To provide the decision-maker with information about the resource and the public, consultants or a panel of experts may develop a group utility function. The group utility function may be derived by taking the mean, median, or mode of the UF's of the individual members of the panel; i.e., mean, median, or mode of the coefficients of the individual's utility functions. This does not, however, overcome problems of interpersonal comparisons of utility. One must recognize the distinction between the meaning of an expert's responses to a decision-maker and to the expert himself. To the expert the utility function is a representation of his preferences; to the decision-maker the expert's UF is <u>information</u>.

## Institutional Considerations

Natural resource managers must decide who should set objectives, agency personnel, the general public, or a combination of the two. Historically, natural resource decisions have been arrived at by the consultation of professionals in institutional roles and positions, an elitist planning process (Willeke 1973, Smith 1973) which allows those who are best qualified and most knowledgeable to make decisions (Bultena 1973). However, many authors and agencies now advocate use of public input in decision-making (Meier and Thornton 1973, Anderson 1972). Meier and Thornton (1973) state, " . . . a more informed and concerned general public is currently seeking a greater role in the allocation of economic and physical resources." One of the most urgent social needs in fisheries and wildlife management is the determination of the needs and preferences of the public (Giles and Lee 1975). Thuesen (1971) attributes much of the poor planning in the past to the inability of planners to consider the needs and desires of certain segments of the public.

An informed and concerned public is essential for natural resource decision-making in the current social climate. A planning process involving the public is more nearly a democratic process and, as such, may have a higher probability for success because it provides representation from those who are affected (Willeke 1973). Management personnel cannot rely solely on public opinion in formulating decisions, but public opinion is valuable input because light may be shed on public response to management actions (Lime and Stankey 1971). The interaction between managers and the public may bring greater appreciation for both sides' points of view and problems. Greater understanding should ultimately lead to improved resource management.

The administrative expertise type of decision-making is characterized by a complex division of labor around functional specialties and the recruitment of trained personnel capable of responding to narrow problems efficiently and competently (Bultena 1973). Advantages of this type of process are that it employs professional ethics and standards, and it uses rational decision-making processes in which objectives are often clearly defined, pertinent data collected, and alternatives surveyed and selected (Bultena 1973). This theory is appealing in principle but open to question in practice. Goal setting involves value judgments concerning desirable or undesirable consequences of alternative management programs. It is often felt, especially in the public sector, that scientifically trained personnel are no more qualified than the general public to make these value-based decisions (Bultena 1973).

Public involvement is a basic cultural value which may not be compatible with efficiency through technological expertise, another basic cultural value (Folkman 1973, Willeke 1973). Natural resource agencies in the past have not been concerned with such incompatibility. A prominent view among natural resource personnel is that environmental decisions must be entrusted to experts (Bultena 1973). However, a trend toward participatory democracy exists (Giles and Lee 1973). Citizen participation has often been proclaimed as a means to perfect the democratic process and, recently, water resource agencies have come under pressure to incorporate citizen input into the planning process (Willeke 1973, Bultena 1973). Public demand is now forcing agencies to modify traditional procedures. Agencies must seek methods to bring greater citizen input into program judgments. However, incorporating public input into the planning and decision-making process is not a simple task (Stankey 1972).

Most of the procedures for generating objectives discussed to this point may be modified to incorporate public input. Procedures for establishing broad goals seem quite appropriate for using citizen representatives or panels to collaborate with professionals in decision-making. The attitude and opinion survey techniques offer a promising opportunity for agencies to procure direct public input. Sampling techniques using fishing license records could be used in mail, telephone, or personal interviews or combinations thereof. The methodology developed by Giles and Lee (1975) or similar ranking procedures, could also be utilized. In fact, no single procedure should be emphasized, but combinations of the various techniques used as supplements to one another might prove most useful.

Citizens may participate voluntarily through letter writing, attending public hearings, or joining pressure groups. However, many people fail to participate because they feel their efforts would be in vain. Agencies need to emphasize that the information derived from the public will be used to aid in making decisions. Also, agencies need to solicit public participation from the entire affected group. People who attend public hearings may not be representative and, thus, tend to project a distorted view of a management problem. Public involvement will help to insure that optimal decisions are made and therefore cannot be neglected by natural resource managers.

# ROLE OF MODELING IN MANAGEMENT

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) (Fig. 1). 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 Fig. 3) apply equally to recreational or commercial fisheries and marine or freshwater fisheries, but with different evolutionary trends being of greater importance when evaluated by scientific effort expended.

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

The first and perhaps most obvious potential benefit of 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 fisheries component.

A second potential benefit of modeling in fisheries management is as 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 resource system is a third potential benefit from modeling in fisheries management. 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.

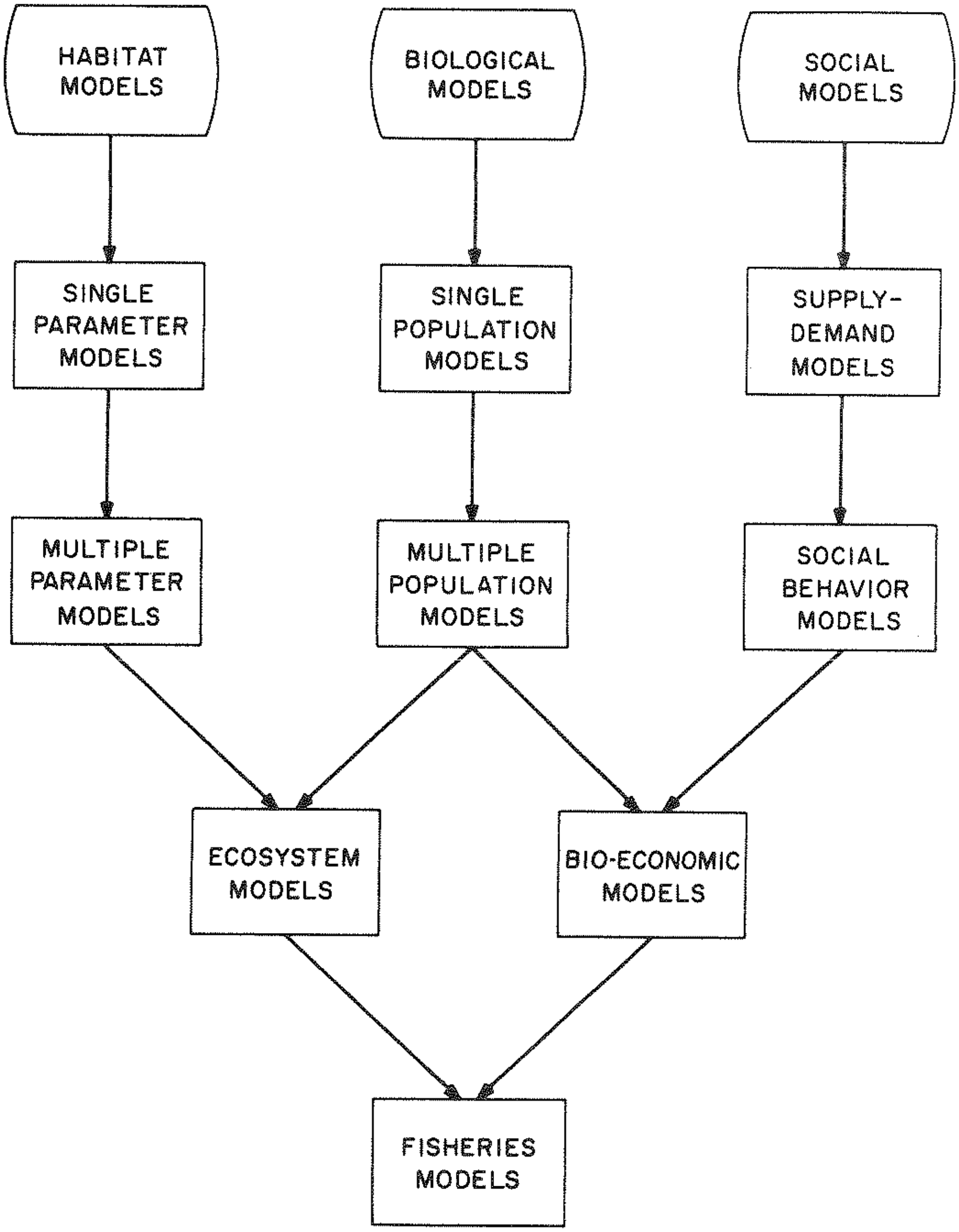


Figure 3. General relationships and evolution of fisheries component models. Only major types of models and interrelationships are shown. Note that habitat, biological, and social models are necessary components in total fisheries models.

Models as research tools may be considered as a category of potential benefits. Manipulation of the model itself may generate "data" which are 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.

# ECOSYSTEM MODELS

Habitat models include those developed to predict aquatic temperature regimes, toxicant dispersal, and sediment transport (Fig. 3). For example, one mangement problem which exists in freshwater recreational 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 accurately predictive. Predicting habitat characteristics is a difficult endeavor, but because it involves prediction of purely physiocochemical 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 Fig. 3). Nearly all of the extensive literature on population dynamics as applied in fisheries science falls into this category. Also, there has been considerable activity on developing biological models among ecologists (Smith 1974).

Ecological or ecosystem models are becoming increasingly common in fisheries science and other areas of renewable natural resources management (Lackey 1974a). Ecosystem models combine, in varying degrees, habitat and biological models (Fig. 3). 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.

In the applied sciences, such as renewable natural resources, models traditionally have been developed which have little basis in reality (Walters 1971). Such models have been useful to the resource manager because he has been willing to sacrifice realism and generality for precision. Precision has been possible since the systems of concern have been rather narrowly defined entities such as single-stock fisheries. Contemporary systems ecologists have generally preferred to deal with whole ecosystems as a means toward effective management of natural resources (Van Dyne 1969).

In order to deal with large scale ecosystem models, some ecologists have chosen to model ecological processes in detail (Watt 1968). Models developed with such a components approach have tended to be both realistic and precise, but they are criticized for lack of generality (Walters 1971).

Ecosystem models may be either discrete time systems (Lassiter and Hayne 1971) or continuous time systems (Patten 1969, Van Dyne 1969), but in either case the experimental component approach may be employed. Examples of this approach may be seen in models of random dispersal (Skellam 1951), stability and diversity (MacArthur 1955, Margalef 1958), effects of temperature on biological rate processes (Pradhan 1945, Beleradek 1957), time lags (Lewis 1972), density effects on reproduction (Fujita 1954), predation (Ivlev 1961, Holling 1965), and growth models (von Bertalanffy 1949, Paloheimo and Dickie 1965, 1966a, 1966b). The predatory-prey model of Holling is especially good because it stresses the importance of biological time; i.e., the time it takes for a biological event to occur. Glass (1971) expanded on this approach to include energetic considerations in developing models of predation metabolism. All of these models may be incorporated into ecosystem simulation in the form of subroutines.

Since an organism's presence may be felt directly (for example by an attack) or indirectly (by depletion of a resource), many of the above processes are affected by this interaction among and between species. In the next section we develop a mathematical model that describes this phenomenon.

The majority of the time and energy expended in modeling dynamics within an ecosystem is used in depicting interaction among components of that ecosystem to produce models with some degree of realism, generality, and precision. In order to do this, ecologists have factored the dynamics of the ecosystem into individual ecological processes in a manner similar to Holling (1965) with his mode of attack. Timin (1973) extended this approach to a multispecies consumption model which can be integrated as a subprogram into a generalized ecosystem simulator. In a similar vein to Holling's work, interaction has been incorporated into reproduction models (Fujita 1954). A single mathematical model incorporating interaction between components of an ecosystem has been developed which includes effects of predator-prey relationships, reproduction and aggressive behavior, as well as the flexibility to include other important interaction processes (Powers and Lackey 1975).

In order to effectively describe a natural resource, a model must be employed which reflects potential actions of the resource manager. Many of the alternative strategies available to the resource manager are not considered in ecosystem models which do not use the experimental component approach. For example, what will happen to the ecosystem if the manager wishes to improve habitat for a certain species? The experimental component approach (illustrated by Powers and Lackey 1975) allows this question to be considered. In a stream ecosystem, for example, spawning ground improvement would be reflected in the model by increasing the proportion of area available for spawning, which would in turn decrease the probability of the spawning act being interrupted. Removing cover (e.g., aquatic weeds) could also be evaluated, since it decreases the probability that a prey item will escape. These considerations can be directly implemented into the model, making it useful to the resource manager.

Viewing the natural resource as a entire ecosystem has allowed the manager to evaluate secondary effects of a perturbation of the system on other components of that system. Instead of a fishery being seen as a single fish stock, it can now be seen as a single fish stock, it can now be seen as the primary producer, aquatic insect, and fish which directly or indirectly affect the target fish. Ecological processes may be modeled with a reasonable degree of realism and precision. With this realism and precision the ecosystem model may be effectively integrated into a total natural resource management system.

# SOCIETAL MODELS

Models which mainly address the third fisheries component, man, fall into a category which may be termed social models (Fig. 3). 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 factors, including aesthetics as well as catch (McFadden 1969, Lackey 1974a). 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 (Fig. 3). Bioeconomic models are integral to management of commercial fisheries (Pontecorvo 1973), but relatively 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.

One of the more difficult problems with which fisheries managers are faced is the problem of meeting the needs of competing users of a fishery. By competing users, we mean the fishermen who fish for different types of fish and also fish for different purposes. Harvest by one type of fisherman may directly or indirectly affect the harvest by other types of fishermen. Examples of competing users of a fishery might include commercial fishermen who seine for baitfish species within a stream and the recreational fishermen who fish for game species within the same stream. Harvest of the baitfish may remove forage needed by the game fish to grow and reproduce. Thus, there might be a decrease in number and size of these fish and subsequently a reduction in angler satisfaction. Similarly, the sports fishermen, themselves, might be categorized into competing users such as trout anglers, smallmouth bass anglers, and bluegill anglers.

If a complex fishery, consisting of many fisherman types who have many different motives in fishing, is to be managed effectively, the means of analysis must be able to handle this complexity. One method of anlysis, computer simulation coupled with optimization procedures, appears to be capable of coping with this complexity (Jester and Lackey 1975).

# FISHERIES MODELS

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

Few management strategies are explicitly based on models. Most strategies, however, are implicitly based on two widely known single population models: the dynamic pool model (Beverton and Holt 1957) and the logistic model (Schaefer 1954). The dynamic pool model describes a stock in terms of the vital statistics of recruitment, growth, and mortality. Each statistic is assumed to be a continuous deterministic function of time. Implementing the dynamic pool model requires a large amount of data and generally can be successful only after substantial information has been collected on a fish population. The logistic model, also called the surplus yield model, combines the effects of recruitment, growth, and natural mortality into a single differential equation for change in population biomass. The logistic model, usually employed when information is relatively scanty, requires only catch and effort data. Jensen (1974), however, has recently shown that numbers and biomass do not act concordantly in Kostitzin's (1939) competition equations unless average individual biomass is constant. The same criticism applies to the logistic model.

Both the dynamic pool and the logistic models have been applied with some success in marine commercial fisheries management. The dynamic pool model has been used in the North Sea plaice fishery and provides an adequate description of the fishery (Gulland 1972). The logistic model has been useful in managing the Eastern Tropical Pacific yellowfin tuna fishery (Schaefer 1957, Gulland 1972). Neither, however, has been applied with much success in freshwater sport fisheries.

In large part, the inadequacy of these models is due to their continuous, deterministic description of discrete, stochastic population phenomena. Models which incorporate stochastic processes may provide better descriptions of fisheries dynamics, especially when the processes are analogous to biological processes. A stochastic approach is more appropriate where a steady state cannot be assumed, which is the case in most fisheries.

Paulik (1969) discussed several computer implemented stochastic models. These were largely special purpose models of single species fisheries. Walters (1969) developed a general simulation model with potential application in freshwater recreational fisheries. This model, however, is based on a deterministic description of a single-species fishery.

A recent simulation model of a multispecies lake fishery (Zuboy and Lackey 1975), called STOCKS, is a stochastic model which requires very little input data. STOCKS emphasized dynamic interrelationships among three game fishes: bluegill, black crappie, and largemouth bass. In this model, however, analogous processes are not defined; rather, distributions are generated about some expected value for the vital statistics.

Effective modeling requires clearly stated design criteria. Ideally, a model should cope with the structural and functional complexity of fisheries, reflect actual ecological processes, provide broad predictive range and high predictive accuracy when used for analysis of management strategies, and allow sufficient flexibility for general application by managers. Deutsch (1966) has suggested that models are devices for putting items of information into the context of other items. As statements of theories, models help us find contexts for our data; as information retrieval schemes, they help us find data for our contexts.

The technical literature on recreational fisheries management is large and diverse and contains many conflicting views. Incorporating this mass of information into a model is impossible unless done systematically. Therefore, useable mathematical models should be incorporating into a simulation model with a flexible input structure, a model of the effects of various management strategies on components of a fishery, and an output structure designed to facilitate management strategy analysis. The simulation model should be analyzed for its sensitivity to various parameters and its management implications. An analysis of the relationship between input information and the usefulness of the model for decision-making must also be performed. Finally, the model must be evaluated according to a set of generally applicable, operationally defined criteria.

Because the ideal model should be applicable in a variety of habitats, we must begin by evaluating the effects of habitat on fish populations. Where a habitat characteristic is known to affect a population statistic, such as the influence of temperature on growth rates, it may be accounted for directly. There are, however, many habitat characteristics which are correlated with population statistics but are not known to influence fish by a specific mechanism. These characteristics may also be addressed.

One approach is to classify habitats, using numerical techniques, according to characteristics without known mechanisms of influence and calculate the coefficients of various functions in the model for each class. This increases the predictive accuracy of the model without requireing any assumptions of functional form of influence where mechanisms are not understood.

Game fish are also found in a variety of fish communities and thus may interact with many different species. One cannot hope to model all of these interactions, even though such interactions may be critical to the behavior of the bass population. Perhaps ecologically similar species may be combined in analyzing community function. Therefore, a hierarchy of overlapping clusters of fish species that are ecologically similar may be used. Interactions between these clusters may be modeled, greatly simplifying the model. Since a hierarchy of clusters is calculated, detail may be added by moving further down the hierarchy. Ultimately, this could lead to a model which includes interactions with many species.

Because game fishes are frequently found in large bodies of water supporting complex fish communities, many kinds of anglers are encountered by managers. Among other implications, this is responsible for variability in creel survey results and the heterogeneity of fishing time as a unit of effort. Since a more homogeneous measure of effort might greatly increase predictive accuracy of any model, an attempt should be made to classify anglers according to behavioral characteristics, such as which species the angler prefers to catch, fishing equipment, bait, and where the angling is done. Behavioral taxonomy can then be correlated with creel content and effective angling pressure.

Once the components of the model are defined, the functional form of the model must be established. The principal functions, reproduction and year-class formation, mortalities, and growth, can be designed to reflect actual mechanisms. Constants can be calculated from data available in the literature.

The ideal model is intended to be useful in evaluating management strategies. Therefore, some flexibility must be built in. In particular, all potential users of the model will not have the same data available. Thus, maximum flexibility might be attained by allowing input of whatever data are available in a particular situation and making the best possible predictions given those data. This, of course, will make output quality highly variable so that the reliability of the predictions made should be calculated. Also, to facilitate research planning, expected gains in reliability from providing various types of additional data to the model should be calculated.

# SYSTEMS ANALYSIS

Originally, most of the "computer-oriented" individuals in resource management were associated with the management science and operations research fields. Their concepts have now spread to ecology and other sciences to the point that systems analysis appears to be integral to many disciplines, particularly management aspects of those disciplines (Watt 1968, Patten 1969). Optimization strategies now appear regularly in the ecological literature (Spivey 1973, Ahmed and Georganas 1973) and "planning" in resource management has been stressed as being of paramount importance (McFadden 1969, Uleck 1971, Gabriel 1970, Phenicie and Lyons 1973).

But through the years, recreational fisheries management, as most of natural resources management has remained a relatively qualitative field. Statistical methods are common, but many problem-solving tools such as linear programming (Taha 1971), dynamic programming (Bellman and Dreyfus 1962), and decision analysis due to risk and uncertainty (Raiffa 1970, Halter and Dean 1971) are neglected. Currently, the newly graduate fisheries manager is likely to be trained more in data acquisition techniques than in systems management. Since management of fisheries systems is complex and does not readily lend itself to dissection, managers tend to rely solely on experience rather than attempting to formalize strategies. Furthermore, the resource manager has historically been handicapped by staff chommitments at such a low level that exploration of non-crises situations is infeasible.

Systems analysis is not a new concept. In at least some aspects fisheries science is more fortunate than many other areas of natural resource management because freshwater aquatic ecosystems, such as lakes, are often fairly distinct entities, readily lending themselves to the procedures of systems analysis.

Use of systems analysis is becoming increasingly widespread. The roots of the process are in military and industrial operations research. War games, developed for use with complex military tactical problems, first showed the great potential of systems analysis in problem solving. With the advent of high speed digital computers, systems analysis and its inherent modeling aspect have been greatly facilitated.

A system is classically defined as "regularly interacting and interdependent components forming a unified whole." An ecosystem involves the simultaneous functioning of a group of populations of organisms and the non-living environment which surrounds them. Any unit that includes all of the organisms in a given area interacting with the physical environment so that a flow of energy leads to a reasonably well defined trophic structure, biotic diversity, and material cycles is an ecosystem. The functioning of an ecosystem can be analyzed in terms of the following categories: (1) energy circuits; (2) food chains; (3) diversity patterns in time and space; (4) nutrient cycles; (5) development and evolution; and (6) cybernetics. All of these are vital considerations to determining interactions taking place within an ecosystem.

The interactions taking place within an ecosystem present a complicated puzzle to fisheries scientists. No population can naturally exist by itself: it is dependent on other populations as well as its environment (i.e., the energy of the sun) for life. Such interdependence produces a multitude of relationships within an ecosystem. For example, game fish depend on forage fish for their energy requirements. These forage fish in turn rely on insect larvae which feed on algae. Algae utilize the sun's energy to initiate the food chain. And so it goes, the number of interactions taking place within any ecosystem, even the simplest, is overwhelming. Also, every ecosystem is a subsystem of some larger system and is itself made up of smaller subsystems. This is the concept of system recursiveness and it complexes the issue even further.

Several characteristics of an ecosystem are especially important to ecosystem analysis. The two most important of these are spatial and temporal relationships. No ecosystem analysis can be fully understood without a knowledge of the relationships of the activities of the organisms in an ecosystem in terms of both time and location. Thresholds, limits, and discontinuities are other important features. Thresholds refer to behavioral differences among the organisms in an ecosystem. A game fish will strike at a forage fish only after a certain hunger threshold has been reached. Pursuing the forage fish requires an additional hunger threshold to be surpassed. Limits involve non-linear aspects of an ecosystem. The gut of a game fish can hold only so many forage fish at one time. The fact that each forage fish eaten changes the hunger level of the game fish illustrates a discontinuity. Discontinuities also deal with non-linearity in ecosystems. All of these critical factors which, before the advent of computers, made systems analysis exceedingly difficult, can now be handled with special computer programming languages. For example, limit thresholds involve switching operations. If one event happens (the hunger threshold of the game fish is surpassed), then another event must follow (a desired fish is found and eaten). Operations of this type are conveniently handled by FØRTRAN IF statements.

Cybernetics is defined as the science of controls. All ecosystems have natural controls which tend to resist change in the system. Homeostasis is the property of an ecosystem to resist change and maintain itself in a state of equilibrium. Natural controls involve negative feedback mechanisms. For example, if a population begins to grow too large for its food supply, adult fish may consume increasingly larger volumes of their own young, thus tending to decrease the size of the population. All of the interactions taking place within an ecosystem tend to maintain system stability which results in a state of continuous but dynamic equilibrium.

The ecosystem analysis approach is oriented toward the whole system by study of the workings of system components. Ecosystem analysis is best explained by a series of steps. The first and often most difficult step is to define the objectives of the analysis. There is little use in proceeding past this step without having clearly defined objectives. The objectives may be regarded as the dependent variables which set the format for the entire analysis. For example, an objective of an analysis of a warmwater fishery might be to maximize equilibrium yield of largemouth bass.

The key to the analysis of any ecosystem is simplicity. Only those ecosystem components which are needed to achieve the specified objectives should be included. Each unnecessary component unduely complicates the analysis. The beauty of ecosystem analysis lies in explaining a diverse, complicated system in as simple a manner as possible while meeting the objectives.

The second step is to determine which components of the ecosystem are relevant to meeting the objectives of the analysis. These components will serve as independent variables. The best procedure here is to begin with a small number of components which are clearly relevant. The system description can then be expanded when additional components are found to be important. Regression analysis may be useful in eliminating unimportant components which have been included in the system.

The third step entails determining and quantifying interrelationships between system components. This step requires a thorough knowledge of the population dynamics of the organisms contained in the system. When dealing with a fishery, this means estimating population size, growth rates, recruitment rates, and mortality rates for each fish population included in the analysis. Initial conceptualization of the interrelationships may be facilitated by use of box and arrow diagrams. Boxes represent system components and arrows show various interactions taking place between them.

As soon as the degree to which interactions take place has been estimated, quantification must be accomplished. The statistical tool used in quantification procedures is multiple linear regression analysis. Multiple linear regression analysis related simultaneous changes in several independent variables to changes in a dependent variable. Correlation analysis differs from regression analysis in that the functional relationship of one variable to another is not considered (i.e., there is no distinction between dependent and independent variables in correlation analysis). Multiple correlation analysis measures the amount to which variables co-vary. Covariance is negative when one variable increases and the other decreases and positive when both increase or decrease at the same time. If the variables are not linearly related to each other, then covariance is zero.

After the interrelationships of the system components have been quantified, the next step is construction of a mathematical model. There are many kinds of models. Verbal (word) and graphic (illustrated) models are informal. Systems analysis involves formal models which are developed using statistical and mathematical tools. In formal ecosystem model development, the system components and their quantified interrelationships are defined in terms of mathematical equations to create an abstraction of the real ecosystem.

There are four basic elements of a mathematical model. The first of these, systems variables is used to define the state of the system at a given time. One or more system variables are used to characterize one particular component of the system. The second element, transfer functions, represents the interactions between components. System inputs are handled by equations called forcing functions. Constants used in the mathematical equations are known as parameters and compose the fourth model element. Differences in formal models are often due to the mathematical description of parameters and forcing functions. Models which include the effects of chance variation in the description of these elements are known as stochastic models. A model which allows (by some probability) for massive dieoffs due to winterkill in a fishery would be a stochastic model. Deterministic models do not include chance variation in their mathematical equations, and consequently, the possibility of a random catastrophic event is not considered. Ecosystems described by deterministic models are perceived as remaining fairly constant. Stochastic models are mathematically more difficult to develop and, consequently, deterministic models are more popular.

The basic mathematical tools used in model development are set theory and transformations, matrix algebra, and differential equations. Set theory is used with change of state models. A set consists of a group of equations which represents a particular state of the ecosystem as defined by the system variables. Given a particular state, there are a number of alternative states which the ecosystem might next assume. Certain transformation rules incorporated into the mathematics of the model determine which state will result from the given situation. Matrix algebra involves the description and manipulation of lists of numbers. Matrices are a convenient way of presenting relationships between the components of an ecosystem. Data amenable to handling by matrices can often be obtained from life tables based on creel census. Differential equations involve rates which describe changes in ecosystem components over time. A differential equation could be used to describe yearly change in fishing mortality on a largemouth bass population, for example.

After an initial working model has been developed, it must be refined until it satisfactorily mimics the real system and fulfills the objectives of the analysis. This phase of model development is popularly known as exercising and optimizing the model and often involves extensive analysis. Model analysis provides an insight into the workings of the real ecosystem. The previously discussed homeostatic properties of feedback and stability are important in model sensitivity analysis. Models help to determine the relative effectiveness of different feedback mechanisms in maintaining system stability. The equations which represent these mechanisms can be changed and the resulting responses of the model studied. Also, by varying forcing functions or input values, input-output sensitivity can be examined. Weaknesses of a model, which are due to lack of information about a certain aspect of the ecosystem, can be traced to areas of data acquisition and handling where improvements are needed.

There are a variety of uses for ecosystem models. Models may be used to guide research efforts, by simplifying and facilitating understanding of the eocsystem on which work is to be done. Also, research modeling often provides an insight into other possible projects. Many models are constructed for predictive purposes. Computer operation of models makes it possible to predict probable outcomes of various changes in system input. From such predictions, appropriate management decisions can more easily be reached.

Systems analysis in fisheries science offers potential to solve many problems confronting modern society. Special types of personnel are required for systems analysis work. Men with an educational range covering many disciplines are needed. These men should have extensive training in the fields of resource management, statistics, mathematics, and computer programming.

# MODELING AND DECISION-MAKING

The potential benefits of modeling are not universally accepted among professional fisheries scientists. Agencies supporting or proposing to support fisheries modeling will 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, a much closer involvement between "modelers" and decision-makers" will likely evolve. 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 academicians. Modeling offers too much to resource management to fall solely into this category.

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