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Abstract

This paper places general management theory in a fisheries management framework. 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 specified human goals and objectives through the aquatic resource. Managers usually predict the consequences of a proposed fisheries management decision in a number of ways, including rules of thumb, past experience, formal models, experimentation, trial and error, and of course, pure guess. A key and obvious problem in making accurate predictions of the consequences of a proposed management decision is the complexity of most fisheries. Numerical analysis or lack of data have often been identified as the major problems with using formal models in fisheries management, but lack of basic management theory is even more critical. A fundamental premise in all fisheries management is that all benefits derivable from fisheries management are accruable solely to man. Given this premise, a simple general theory of fisheries management can be developed in which most of the controversy surrounding fisheries management decisions revolves around which goals and objectives are selected and *who* selects them. In such a "general theory of fisheries management" biological factors are largely constraints and are only rarely major decision variables.

To analyze fisheries management and develop management theory, it is necessary to define the system of concern. A *fishery* (either recreational or commercial) is a system composed of habitat, aquatic animal and plant populations (biota), and man. 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 specified human goals and objectives through use of the aquatic resource. *Fisheries management* is the analysis of alternative decisions, and implementation of a decision or decisions to meet human goals and objectives through use of the aquatic resource. When one considers the number and diversity of components which constitute a fishery (i.e., fishes, plankton, benthos, rooted plants, chemical and physical water characteristics, various sorts of anglers, and related recreational and commercial activities), the true complexity of a fishery and fisheries management becomes apparent. A slight change in part of the fishery may result in substantial change in another, seemingly unrelated part.

Although their size is usually relatively small, even recreational fisheries are complex. There are usually many game fish populations to consider and angler diversity is also great. Some anglers exclusively pursue a single fish species, while many exhibit little species preference. Management strategies for each type of fishery differ greatly.

Prediction is the essence of all management, including fisheries management. Managers usually predict consequences of a proposed decision in a number of ways, including rules of thumb, past experience, formal 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. Depending on the circumstances, any method of prediction may be appropriate.

A key problem in accurately predicting the consequences of a proposed management decision is the inherent complexity of recreational fisheries. Even if some components of a fishery are well understood, the number of interrelationships is staggering. Further, the dynamic aspects of all components of a fishery are important because *rates* of change are as important as the magnitude of the components themselves. For example, growth rate of an individual fish is affected by many components of a fishery, even though some of those linkages may be unknown or obscure.

The definition of a *model* must 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, fisheries modeling nowadays usually connotes modeling of a mathematical nature and typically involves computer-implemented simulators.

Management Goals and Objectives

Any realistic theory of fisheries management must have a "bottom-line," or what and how much is produced through management efforts—i.e., goals, objectives, and desired performance. A management "objective" is a statement of the desired result of a decision or set of decisions. In classical management terminology, an objective is not equated with a "goal," which is defined as the end toward which a strategy tends; that is, a goal is an ideal or aim which is usually expressed in general and abstract terms. A few examples of goals in recreational fisheries management are: "best" or "wisest" use of resources; conservation, protection, and enhancement of the resource; and realization of the greatest amount of recreational opportunity for the greatest number of people. Whereas goals provide general direction to agency programs and are useful in public relations, clear, sound objectives are vital to developing sound management strategies.

Objectives can be described from many vantage points: aspirations for preferred or desirable conditions; end-points to be reached which are attainable and measurable; or simply fairly specific goals. However defined, objectives have some very important properties which affect their use (as contrasted to goals) in fisheries management: (1) objectives are clearly stated; (2) objectives are specific and not filled with broad, general terms; (3) objectives are quantifiable by some means, if not empirically, then subjectively; and (4) objectives have a performance measure which can be used to evaluate management progress and effectiveness.

Effective management of any natural resource system is based upon clear and formally stated objectives. Most fisheries managers have recognized the inherent difficulties of operating without functional objectives and have tried to institute measurable objectives (Roedel 1975). Historically, the most common management objective has been to maximize the sustained yield in weight or numbers of fish (MSY) (Larkin 1977). Some common variants are maximizing yield of certain species or certain sizes of fish. MSY is desirable because it is conceptually simple and is an objective-oriented approach to management. However, maximum sustained yield is restrictive because most anglers regard catch as only one of several measures of output from a fishery (McFadden 1969).

Most anglers agree that their interest is not solely in the fish they catch, but also in *fishing* itself (Martin 1976; Kennedy and Brown 1976). Aspects of fishing important to the angler may be the outdoor experience, environmental aesthetics, and the sporting challenge, as well as the species and sizes caught and the method by which they are pursued (Driver and Knopf 1976).

Among efforts to incorporate other criteria into objectives have been attempts to measure quantities such as man-days of use. The assumption is that measuring the number of angler-days of recreation on a particular fishery is a realistic index of benefits received. Some may also go further and assume that this approach could be used to maximize recreational benefit. However, maximizing angler-days may, in fact, reduce both individual and total societal benefits. Neither potential fish yield (all species considered) nor intolerance to angler crowding constitute foreseeable limits on potential recreational fishing in North America. The angler-day concept does not incorporate a quality aspect, but is at least measurement of management performance in human-oriented terms rather than biological ones (Radovich 1975).

Other possible objectives in recreational fisheries management are maximizing aesthetics and diversity of angling opportunity. While these are altruistic approaches, they are not readily quantifiable. Further, without a functional pricing system, the value of various recreational factors cannot be easily determined by a market survey of the angling public. Quality is an extremely vague and variable parameter to measure, but many factors which contribute to the quality of the recreational fishing experience can be presumably be delineated and measured. The number of potential variables is large, but specific fisheries may have only a few aspects which determine quality. Recent work with "proportional stock density" represents an indirect approach to quantifying the benefits of fishing through a measure of catch (Anderson 1976; Anderson and Weithman 1978, this volume).

Beyond the issue of *what* goals and objectives are appropriate in recreational fisheries management is the question of how to *select* those goals and objectives. Identifying, selecting, articulating, and ranking of goals and objectives is never easily achieved. In particular, there are many problems concerning quantifying and measuring aesthetic and environmental factors. Further, managers may be unwilling to formulate objectives because of fear that some of the "real" objectives would be disapproved under scrutiny by the public, and that some might not be approved by all interested parties. Even given a willingness to set objectives, managers may be unable to formulate objectives because of three additional major difficulties: incomplete problem awareness; incomplete knowledge of the intracacies of the problem; and inability, due to time, money, or manpower constraints, to devote sufficient thinking to the effort. Further, most classical objective-setting methodology stresses only the importance of objectives without providing practical means for determining or detailing them. However, several techniques are available and, when used in combination, could provide a reasonably 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. These are discussed elsewhere (Lackey 1975).

An issue for resolution is: *Who* should set goals and objectives: agency personnel, the public, or a combination of the two? Historically, fisheries management goals and objectives have been arrived at by professionals in organizational positions, a planning process which theoretically allows those who are best qualified and most knowledgeable to set goals. Public participation is often minimal (Scheffer 1976). An informed and concerned public is essential for fisheries management decision-making in the current social and political climate. Fisheries managers cannot rely solely on public opinion in formulating goals, but public opinion is valuable input.

Decision-making in fisheries management is characterized by a division of labor around functional specialists capable of responding to narrow problems efficiently and competently. Advantages of this type of decision-making process are that it usually employs professional ethics and standards, and it often uses rational decision-making processes in which goals and objectives are often clearly defined, pertinent data collected, and alternatives surveyed and selected. This approach is intuitively appealing in principle but difficult to apply in practice. Goal setting primarily involves *value* judgments concerning desirable or undesirable consequences of alternative fisheries management programs. Scientifically trained personnel are no more qualified than the general public to make these value-based decisions.

Procedures for establishing broad goals permit citizen representatives or panels to collaborate with professionals in decision-making. Attitude and opinion survey techniques offer promising opportunities for agencies to procure direct public input. Sampling techniques based on fishing license records can be used in mail, telephone, or personal interviews. No single procedure should be emphasized, but combinations of the various techniques used as supplements to one another will likely prove most useful. The disproportionate influence of relatively small but well organized special interests groups is something all fisheries managers should recognize and consider with whatever goal setting procedure is used (Belusz 1978, this volume).

Modeling and Fisheries Management

Management theory and modeling are often closely related because the modeling process forces the modeler to state formally his theory; in fact a model can be looked upon as a formalization of a theory. Most fisheries-related models, even those seemingly unrelated, are quite similar in philosophy and approach, but there is substantial variation among models when their intended use is studied. Models in fisheries management can be categorized into families which include one or more fisheries components (habitat, aquatic biota, and/or man). The evolution of fisheries models has not followed a discrete path, but rather has taken a disjointed and often circuitous route. Major trends in development apply equally to recreational or commercial fisheries and marine or freshwater fisheries, but different evolutionary trends are of great importance when evaluated by the scientific effort expended.

Modeling in fisheries management may be justified in many ways, some of which result in benefit/cost ratios much greater than unity and others which do not. The first and perhaps most obvious potential benefit of modeling in fisheries management is organizational. Fisheries are highly complex systems and modeling (graphical or mathematical) does provide a medium for clarification and organization. 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 is probably no better way to develop a "feel" for a fishery than to model it formally. Some fisheries models, particularly computer-implemented models, can serve as useful management exercises in agencies and universities.

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

Models used as research tools may be considered as a fourth category of potential benefits. Manipulation of the model itself may generate "data" which are unattainable from the real system. For example, rainfall and water temperature may each have an impact on certain biotic components, and certain combinations of rainfall and temperature have been observed in the field to quantify the impact. Exercising a model may permit a reasonable assessment of the general relation by interpolation (based on existing data combinations) and prediction of what impact would occur if a new combination of rain and water temperature were to occur.

The fifth and most discussed potential benefit of modeling in fisheries management is predicting the impact of alternative management decisions or external influences. Historically, fisheries managers have been interested in predicting the impact of a proposed fishing or exploitation rate expressed in the form of a season, gear type, and size or creel limit. Managers wish to estimate the impact of decisions on the number of realized angler-days, catch, or some other measure.

Ecosystem Models

Ecosystem models address either or both of the habitat and biotic components of a fishery. Ecosystem models of the habitat type include those developed to predict aquatic temperature regimes, toxicant dispersal, and sediment transport. For example, one problem which exists in recreational fisheries management is predicting the structure and function of environments in proposed reservoirs, but managers (and modelers) must first address and solve the problem of predicting future habitat characteristics, including physical and chemical parameters, before, first, ecosystem and, then, fisheries models can be accurately predictive.

Models of the biotic component of a fishery include classical fish population dynamics models and models of single- and multiple-population systems. In this category we find the Schaefer, Beverton and Holt, and Ricker models. Nearly all of the extensive literature on population dynamics as applied in fisheries science falls into this category (e.g., Schneider 1978, this volume).

Ecosystem models which address both habitat and biotic components are becoming increasingly common in fisheries science and other areas of renewable natural resources management (e.g., Bovee 1978, this volume; Prentice and Clark 1978, this volume). 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, due in part 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.

Bioeconomic Models

Models which address solely the third fisheries component, man, may be termed social models. In commercial fisheries, managers have tended to measure fisheries output as weight of fish or perhaps gross income. In recreational fisheries, output is composed of many factors, including aesthetics as well as catch. From a management and modeling standpoint, the relevant questions are: How do people 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 the biotic and human components of a fishery. Bioeconomic models are integral to management of commercial fisheries but relatively neglected in recreational fisheries. 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

Fisheries models, in the broadest sense, combine the major fisheries components of habitat, biota, and human use. At such a comprehensive level of analysis, detailed modeling borders on the impossible. However, if certain realistic constraints (i.e., economic, political, and social realities) are added to a comprehensive fisheries model, a relatively complete decision-making system can result.

Few management decisions are explicitly based on these kinds of models. Most strategies, however, are implicitly based on two widely known single population models which must assume that the main or perhaps sole measure of human use should be biomass of fish harvested: the dynamic pool model (Beverton and Holt) and the logistic model (Schaefer). 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. 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.

Large-scale, computer-implemented simulations of fisheries are becoming increasingly common. While these kinds of models may be useful in improving management in a study area, their generality is usually limited.

General Theory of Fisheries Management

If, as a basic premise in recreational fisheries management, we assume that all benefits derivable from aquatic renewable natural resources are accruable exclusively to man, then it follows that a general theory of fisheries management may be written as

$$Q_{MAX} = f(X_1, X_2, \ldots X_n | Y_1, Y_2, \ldots Y_m);$$

Q = some numerical value of societal benefit;
X_n = management decision (n = the number of all possible decisions); and
Y_m = management constraint (m = the number of all possible of constraints).

The vertical line is short-hand for "given that." The theory reads *the greatest societal benefit* (Q) *derivable from a fishery can be realized by manipulating a series of decision variables* (X's) *given a set of constraints* (Y's). Controlled or partially controlled decision variables (X's) are those regarded as management prerogatives (stocking, habitat improvement, etc.). Noncontrollable variables (Y's) are random or dependent on other factors (weather, highway development, recreational attitudes, etc.). Variables may, however, overlap both categories. Within these constraints (Y's), the manager selects decisions which maximize Q.

Clearly the "bottom line" in the general theory is societal benefit (Q). Practically, the management problem facing all recreational fisheries agencies is evaluating how best to allocate limited financial resources to meet particular goals and objectives which, in total, constitute Q. Given the quality ranked 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 state-owned lakes; (2) improving support facilities at existing state-owned lakes; (3) stocking various species and numbers of fish; (4) managing intensively with lake fertilization and adjustment of fish populations; (5) educating the angling public; (6) law enforcement; or (7) improving angler or boat access to fisheries? Some agencies have additional methods of increasing the number of angler-days, while others have few alternatives.

Management problems, such as evaluating the "mix" of decision alternatives (the X's), are not unique to fisheries management. Planning in business is integrally involved in allocating resources toward maximizing specific objectives. In fact, many current business management decisions are made within a simulation of alternative marketing strategies. With computer assistance, many past, present, and future technological conditions can be analyzed, performance measured under each, and the best course of action selected.

Angler use of aquatic resources is one of the major interactions of man with aquatic biota and habitat. Angler use may be treated as a decision variable (X), but it is typically viewed as a decision constraint (Y). Thus, the level and type of resource use is a major concern of management agencies, but use trends in recreational fisheries are generally uncontrolled (Clark and Lackey 1975). In practice, angler use trends are nearly always viewed as phenomena extrinsic to fisheries management, but in reality, they are only partially extrinsic. Virtually all management agency programs and activities have an effect on the location and intensity of angler use. Land acquisition, dam construction, pollution control, fish stocking, and access development are common examples.

Management policies in fisheries have typically been designed to respond to angler use trends but rarely to shape or influence them (McFadden 1969). If fisheries management policies were explicitly designed to regulate angler use, greater benefits might be accrued to society from fisheries. Regulation of angler use could be achieved by limiting licenses, but such a tactic is often neither politically nor culturally acceptable. A less dictatorial approach, based on subtle relations between individual management activities and angler use and preferences, might also be effective and perhaps more politically palatable.

Angling regulations, information transfer, and educational programs address human components in fisheries management, but such efforts alone cannot be relied upon to direct angler use in a desirable direction (Clark and Lackey 1975). One or two actions in a complex management system are invariably inadequate to achieve a desired change. For example, while information and education efforts are working to direct angler use along a particular course, other agency activities may be working subtly to contravene that course.

The general theory of fisheries management is not difficult to accept if one accepts the premise that all benefits from fisheries are accruable to man. Unfortunately, this premise often gets lost in semantic jargon and emotionalism. Further, many "objectives" in recreational fisheries management revolve around vague terms such as maximizing recreational "benefit" or making "best" use of the resource. These "objectives" have a strong emotional appeal and are philosophically valid, but they are too ambiguous for developing meaningful management strategies. These are really goals. Quantifiable objectives (even though they might be subjective in origin) which are defined at all organizational levels, from the local manager to the director, will inevitably make management more efficient—although not necessarily "better."

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