Modeling to Improve Management of Bass Fisheries

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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 characteristics, various types of angling, and related commercial activities), the complexity of fisheries becomes apparent. A slight change in one part of the fishery may result in substantial change in another seemingly unrelated part.

Bass fisheries are especially complex. There are usually many game fish populations to consider (e.g., bass, bluegill, crappie, catfish, and miscellaneous sunfishes). Angler diversity is also large. Some anglers exclusively pursue a single fish species, whereas others exhibit little species preference. Management strategies for a trophy bass fishery may be much different than those of a multispecies 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 aspects 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 important as the components themselves. For example, the growth rate of an *individual* largemouth bass is affected by *all* components of the fishery, even though some of those linkages may be obscure.

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 adequately to investigate each alternative. Time and cost are related: how much of the budget is available for predicting the consequences of management decisions? Any method that can facilitate decision analysis in fisheries management would be highly useful, especially if additional funding were not required. A manager may have several major fisheries to manage with the assistance of a technician 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, like fisheries, 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 highly complex system.

Models

A model is simply an abstraction of a system. 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." Fisheries may also be described via *graphical* models (Figures 1 and 2). The importance of verbal and graphical models in fisheries lies in their initial simplifying description of complex phenomena. Modeling breaks a complex system, a fishery, into its 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 (Figure 2), we can more vividly express these relationships so that they may be useful in preliminary decision analysis.

Another kind of model utilizes *physical* representation of the system under considera-

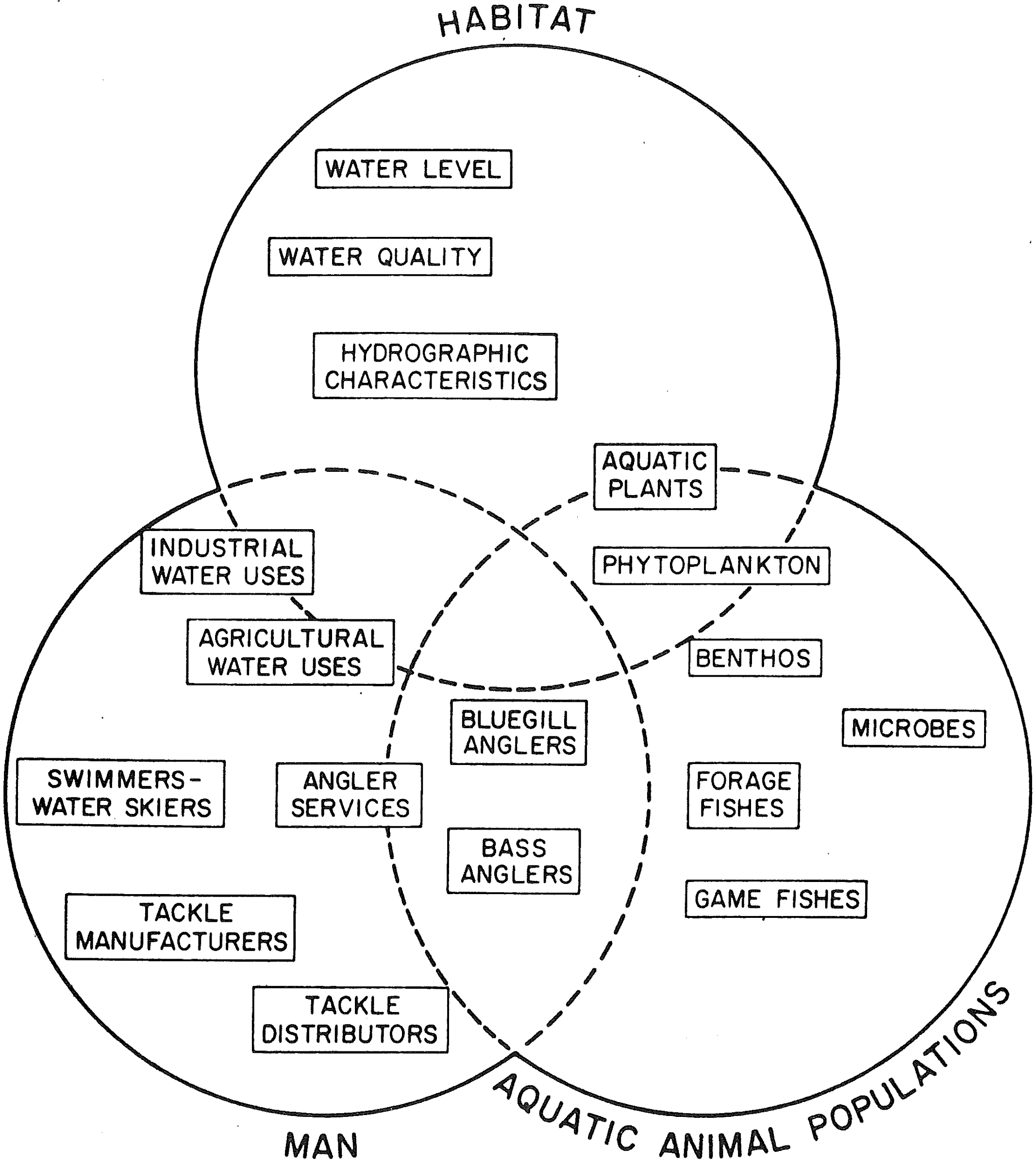


Fig. 1. Graphical model showing major components of a bass fishery. Only major system components and interrelationships are included.

tion. For example, a laboratory model of a reservoir may be built to test water flow 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 are physical models of ecosystems. In these models, many variables are controlled so 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 system.

The most rigorous type of model is that utilizing mathematics to describe a system (Figure 2). Mathematical models, until the

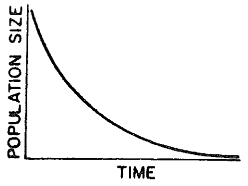
MODEL TYPE	EXAMPLE
VERBAL	"ONCE FISH REACH A CERTAIN SIZE, THAT AGE CLASS WILL DIE AT A FAIRLY CONSTANT RATE."
GRAPHICAL	
MATHEMATICAL	$N_t = N_0 e^{-Zt}$ WHERE, N_t = POPULATION SIZE AT TIME = t N_0 = POPULATION SIZE AT TIME = 0 e = NATURAL BASE Z = TOTAL MORTALITY RATE t = TIME (GREATER THAN 0)

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

past 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 that could be done by many workers over several months using calculators can be accomplished on a computer in a few minutes. Hand calculation is often impossible in modeling work.

Arithmetical calculation has been the major problem with using mathematical models in fisheries management. This problem has been partially solved by "simulating" fisheries, which is done by coding mathematical relationships in computer language for 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.

Closely related to analytical capability of computers is the option to use logic statements in arithmetical analysis. For example, on a computer 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 this. Thus we can approximate relationships over the range of the variables with which we are concerned.

Computer Simulation

The purpose of computer simulation in fisheries is to improve understanding of the system, enhance decision analysis, and, in turn, benefit fisheries management. Computer simulation (1) provides a framework for describing complex systems; (2) allows rapid and inexpensive evaluation of alternative management strategies; (3) identifies gaps in available data; and (4) forces the modeler to organize his thoughts into formal statements.

Each component of a bass 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. Rapidly, however, the model becomes extremely complex. The relationships must be systematically written in logical and arithmetic statements for bookkeeping by computer.

A manager is continuously faced with the question: "What will happen *if* I follow this management strategy?" Often computer simulation is the tool best suited to address this question. For example, if we had constructed a simulation of a fishery, we could easily examine the probable impact of changing size limits.

One of the least appreciated aspects of modeling and simulation is its relation to raw data. Perhaps the most difficult decision 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 of data to be collected and its location and frequency of collection.

Modeling and simulation are definitely learning experiences. A modeler must state his perhaps hazy thoughts in an exact manner. Relationships that the modeler had never considered must now be addressed and his best estimates provided.

Simulating Bass Populations

STOCKS, an example of the application of computer simulation in fisheries management, is based on a three-species freshwater sport fishery. Much of the basis for the model was derived from 10 years of creel census data from Lake Brittle, Virginia. (Appreciation is extended to the Virginia Commission of Game and Inland Fisheries for assistance throughout this research effort.)

Each species is considered to be a single stock (a manageable unit in itself). The three stocks used in the model are largemouth bass, black crappie, and bluegill (Figure 3). Total population size of the combined three stocks is represented by the outer line in Figure 3. Recruitment acts to increase the total number of catchable size fish. Total annual natural mortality rate and fishing exploitation rate act to decrease total population size, whereas environmental effects either increase or decrease total population size through actions on recruitment and mortality.

Inasmuch as the model includes three stocks, there must be a mechanism to account for interspecific competition. Competition is the demand, typically at the same time, of more than one organism for the same environmental resource in excess of immediate supply. Interspecific competition in STOCKS is based on spawning sequence and predicated on the theory that density-dependent factors control animal populations. Bass and bluegill, although not strong competitors, may each curtail the population of the other.

An assumption in STOCKS is that the population which first produces a strong year-class will have a competitive advantage over other species. Crappie spawn first (by water temperature), largemouth bass second,

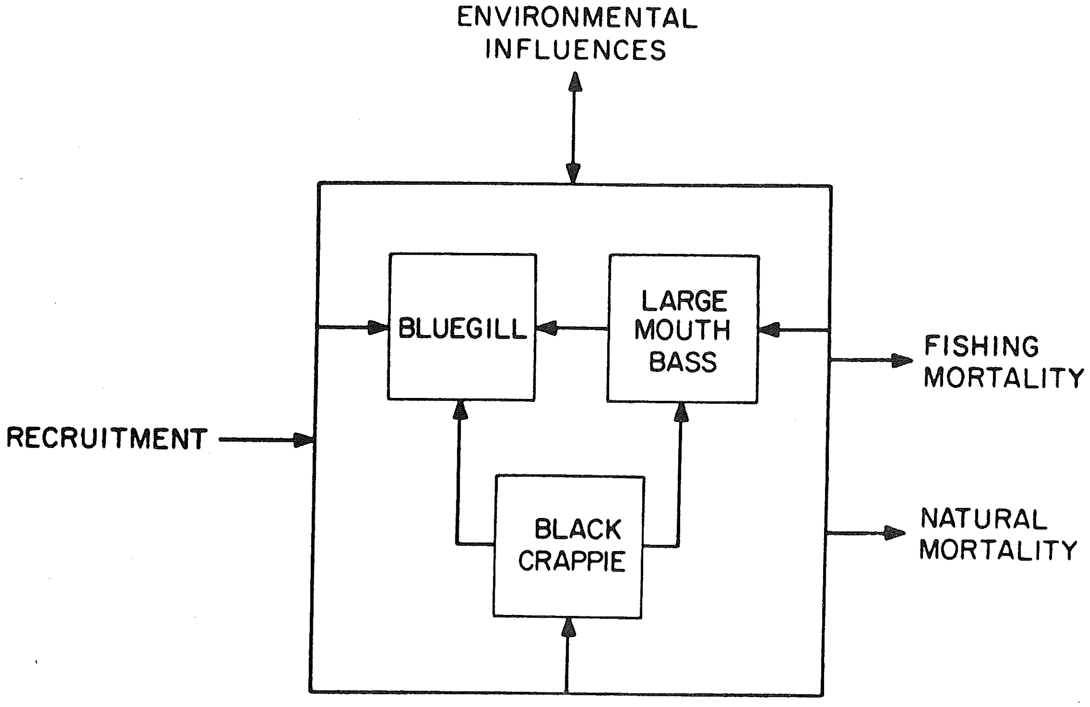


Fig. 3. Graphical model of a three-species fishery simulated by STOCKS.

and bluegill last. There is some overlap (i.e., crappie are still spawning when largemouth bass begin spawning) but spawning times are distinct enough to consider the sequence discrete. If crappie exhibit high spawning success, they will exert a controlling effect over the spawning success of largemouth bass and bluegill (Figure 3). In turn, the spawning success of largemouth bass affects the spawning success of bluegill. The spawning success of bluegill does not directly affect spawning of either crappie or largemouth bass, but does have an indirect effect in that it contributes to total population size, which affects spawning success of all three stocks.

Growth in biomass (weight) per individual is not considered explicitly in STOCKS, only increase in numbers of individuals. For a general application simulator, it is more practical to deal with numbers of fish rather than growth rates. Average sizes for each species vary substantially from fishery to fishery, and few realistic growth relationships could be easily incorporated into a simulator. Rather, the user would consider the model to be operating under the average conditions of the particular fishery he is dealing with and assume that results reflect these conditions. For example, the catch of bluegill predicted by STOCKS for a given year should be considered as being comprised of the average size bluegill found in that body of water in an average year. If stunting occurs, STOCKS provides a statement to this effect in the output. In practice, the occurrence of stunting (as shown by STOCKS) is rare, and generally happens only when the initial population estimates are very high.

STOCKS is coded in FORTRAN IV for an IBM System 370. A fully documented program listing and user's guide is available from the authors. The simulator is comprised of a main program and five subroutines. The main program serves to read in data, call various subroutines, and write out yearly results. The program iterates on a daily basis for a simulation of 10 years.

The key predictions from exercising STOCKS are: (1) the proportional relationship of recruitment and catch in the model; (2) the effect that varying exploitation of one stock has on the catch of the other stocks; (3) an indication of the exploitation level which produces the maximum sustainable catch; and (4) the graphical analysis showing that STOCKS may be capable of mimicking a multispecies fishery (Figure 4).

The average catch of a stock was found to be approximately proportional to the recruitment values specified for that stock as input data. This relationship may prove useful for discovering what the average recruitment levels really are since it is difficult to get accurate population estimates, much less good estimates of recruitment. Perhaps we can address the problem in a different manner. For example, the manager designs a strategy to obtain good mortality estimates in the simulator along with his best intuitive estimates for recruitment and initial popula-

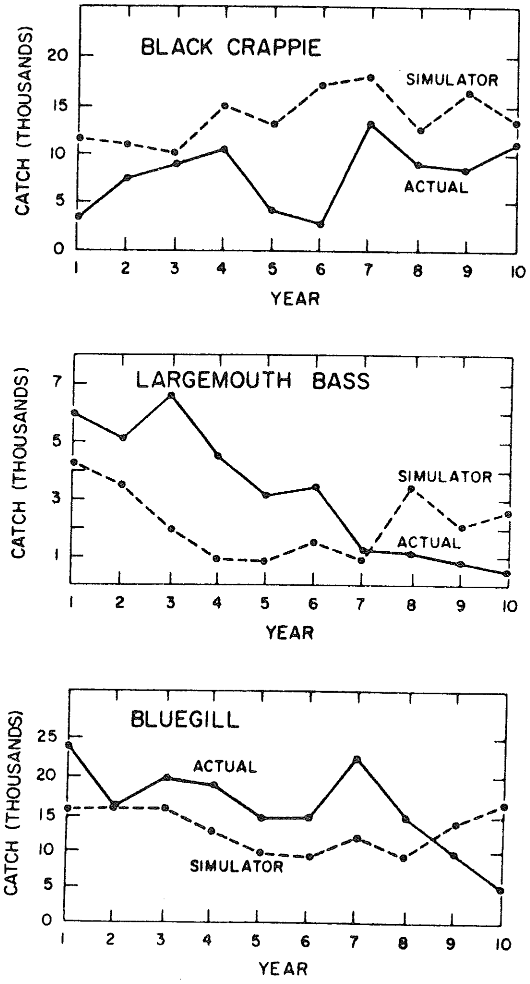


Fig. 4. Plots of STOCKS-generated catches vs. Lake Brittle catches of black crappie, largemouth bass, and bluegill.

tion levels. He runs the simulation to estimate catches in the fishery. If the simulated catches are low compared to actual catches he would increase input recruitment values and rerun the simulator. He would continue iterating until the simulated catch approximated the real catch level. He should finally arrive at a reasonable approximation to the recruitment values. Once he has recruitment values, he can then begin to experiment with the simulator by varying exploitation rate.

The response of STOCKS to varying exploitation rate for one stock, while holding the others constant, appears to verify interaction effects. When a stock was increasingly exploited, average catch of that stock increased until overexploitation was achieved, and then the catch drastically declined. Concurrently, the catches of the other two stocks were not significantly affected until the stock which was being increasingly exploited reached an overexploitation level. Catches from one of the two other stocks would increase sharply and act to exert control over the third stock.

Validation of computer simulation models is of concern to all disciplines. Any model can be made to deliver desired or undesired results by appropriate manipulation of its parameters. The key question is whether we are utilizing the model to best advantage to meet management objectives. Although we can show graphically that a model may mimic the real system, this mimicry is of little value in management unless it addresses or provides information to relevant decision alternatives. Whenever a simulator is used in management the ultimate objective should not be output that just looks good, but output that has management significance.

Conclusion

STOCKS is not presented as the solution to multispecies management problems, but rather to provide a foundation on which to build. STOCKS demonstrates one approach that may be used to address these problems. STOCKS currently simulates a small sport fishery, but this application can be expanded and refined as better data concerning various population dynamics parameters are collected. The model can be expanded, or consolidated, and continually reshaped depending on the situation at hand. STOCKS provides one way to put new data to immediate use and in the process should help guide research efforts in the collection of appropriate data.

STOCKS and similar simulators provide a heuristic device by which the fisheries manager may gain insight into the workings of a fishery. By manipulating input parameters he can observe how the fishery may respond and perhaps test a "best" simulator strategy under field conditions and determine if the fishery responds as the simulator predicts. The self-teaching value to the fisheries manager is limited only by his imagination.

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