Technical Report Series

Technical Report No. 1

"A Microcomputer-Based Decision Support System For Multispecies Fishery Management

by

Bruce L. Golden, Brian J. Rothschild,
and Arjang Assad
The University of Maryland

May, 1987

Fisheries Stock Assessment
Title XII
Collaborative Research Support Program

The Fisheries Stock Assessment CRSP (sponsored in part by USAID Grant No. DAN-4146-G-SS-5071-00) is intended to support collaborative research between U.S. and developing countries' universities and institutions on fisheries stock assessment and management strategies.

This Working Paper has been produced by the collaborative efforts of The University of Maryland-Center for Environmental and Estuarine Studies and The University of Costa Rica-Centro de Investigacion en Ciencias del Mar y Limnologia (CIMAR) in association with The University of Delaware and the University of Miami. Additional copies are available from the CRSP Management Office and from:

Chesapeake Biological Laboratory
Center for Environmental & Estuarine Studies
The University of Maryland
P.O. Box 38
Solomons, Maryland 20688

A MICROCOMPUTER-BASED DECISION SUPPORT SYSTEM FOR MULTI-SPECIES FISHERY MANAGEMENT

Bruce L. Golden, College of BMGT, University of Maryland, College Park, MD 20742
Brian Rothschild, Chesapeake Biological Laboratory, University of Maryland, Solomons, MD 20688
Arjang A. Assad, College of BMGT, University of Maryland, College Park, MD 20742

In the past year, we have worked to design an improved tool kit for stock assessment and decision-making in small-scale fisheries. The tool kit is structured as a microcomputer-based decision support system that automates multiple-species stock assessment, maintains a current and accurate database of fisheries statistics, monitors the data for outliers, simulates the ecosystem upon command, and advises the user on a variety of multiple-species-related issues. An overview of the system will be sketched in this paper.

1. THE PROBLEM SETTING

Informed observers are concerned about the performance of contemporary fisheries management. A large part of this concern relates to the adequacy of the traditional fishery models--the yield-per-recruit model, the production model, and the stock-and-recruitment model. A major difficulty with these models is that they have been designed for large-scale, industrialized fisheries and, as a consequence, they are not always applicable to small-scale fisheries.

The reason for this incompatibility stems from the differences between large and small-scale fisheries. Large-scale fisheries generally employ a relatively small number of landing units which land fish at relatively few ports. Hence, effort, and population size or age structure statistics, the primary inputs into traditional models, are relatively easy to monitor. In addition, the large-scale fisheries land only a few species of fish and, hence, the stock-assessment analyst is typically faced with something close to a single-species estimation problem. Widely-used stock-assessment procedures assume a single-species environment. In contrast, small-scale fisheries can consist of thousands of independent or semi-independent fishermen with widely scattered landing sites. In addition, many small-scale fisheries generally market a much larger number of species than the large-scale fisheries. This observation focuses attention on the important issue of the complex biological and fishing interactions amongst species. In light of these issues, one can easily see that the setting for small-scale fisheries is much more complicated than that for large-scale fisheries and, of course, the assessment and analysis of large-scale fisheries is already a complex task.

The problem of small-scale fisheries management is exacerbated by the fact that a significant portion of the world's fish catch is taken by small-scale fisheries. It is sometimes thought that small-scale fisheries are found predominantly in the developing countries. While it is true that many fisheries in the developing world are small-scale fisheries, it is also true that a large number of fisheries in the developed world have the same characteristics. Examples include many shrimp fisheries in the U.S. portion of the Gulf of

Mexico or the coastal fisheries along the northern shores of the Mediterranean Sea and the shellfish fisheries in France.

There has been a tendency in the literature to view the small-scale fishery management problem simplistically, as a domain for unsophisticated methods and solution techniques. This is unfortunate, since small-scale fishery management presents very complex problems that are at least as difficult as those encountered in large-scale fisheries. It is very hard to think of managing the complex multi-species systems of small-scale fisheries without recourse to techniques of equal or greater sophistication as those used in industrial fisheries. The cost of opting for simpler techniques would be a classic example of suboptimization since certain crucial facets of the interacting system, such as interactions among species, would be ignored to avoid complications. Unfortunately, the ignored relationships may be pivotal for good system performance.

While it may be clearly preferable to address, rather than suppress, the multicomponent nature of a complex system as described above, the most obvious obstacle is the high dimensionality of the full system. Nevertheless, the goal envisioned in this paper involves the articulation of a much-improved toolkit for stock assessment and decision-making in small-scale fisheries that allows for a more realistic and faithful stock assessment and modeling capability. A major component of this toolkit is a microcomputer-based decision support system that automates stock assessment, maintains a current and accurate data base of fisheries statistics, monitors the data for outliers, simulates the ecosystem upon command, and advises the user on multiple-species stock assessment. The broad outlines of such a system are sketched in the remainder of this paper.

It will take several years of effort to build a fully-functional prototype of this toolkit. While the component modules will be "fleshed out" one at a time, the overall structure will basically be in place from the outset. Naturally as new mathematical models for the multi-species problem are proposed and elaborated upon, their place within the overall structure will become clearer and will be defined in greater detail. An initial blueprint for the decision-support system structure follows.

2. OVERALL STRUCTURE OF THE DECISION SUPPORT SYSTEM

The concept of a decision support system (DSS) dates back to work done by Scott Morton [3] in the early 1970's. A DSS may be characterized as a highly interactive computer-based system that enables decision makers to effectively utilize data and models to solve unstructured problems.

We now describe the basic structure of our proposed DSS for multi-species fishery management. The system comprises four basic interacting modules as shown in Figure 1. The modules are called MONITOR, OPTIMIZER, SIMULATOR, and ADVISOR and are briefly described below.

MONITOR is designed to accept stock-assessment data collected on a weekly or monthly basis. Data can be collected for the entire fishery or by town or fishing ground. These data include measures of numbers caught, size-by-age distributions, types of fishing gear used, water temperatures, cost of fishing effort, etc. MONITOR should be enriched with a variety of data-manipulation capabilities that would allow it to transform the available data in a specified manner or to calculate derived measures (such as weighted averages). In addition, MONITOR should be able to detect outliers. Thus, when certain data dependent measures fall outside preset or computed allowable ranges, MONITOR would generate an appropriate signal to alert another interacting module. While MONITOR can start out with straightforward data analysis and exception reporting capabilities, it may, in its fully-developed form, include a variety

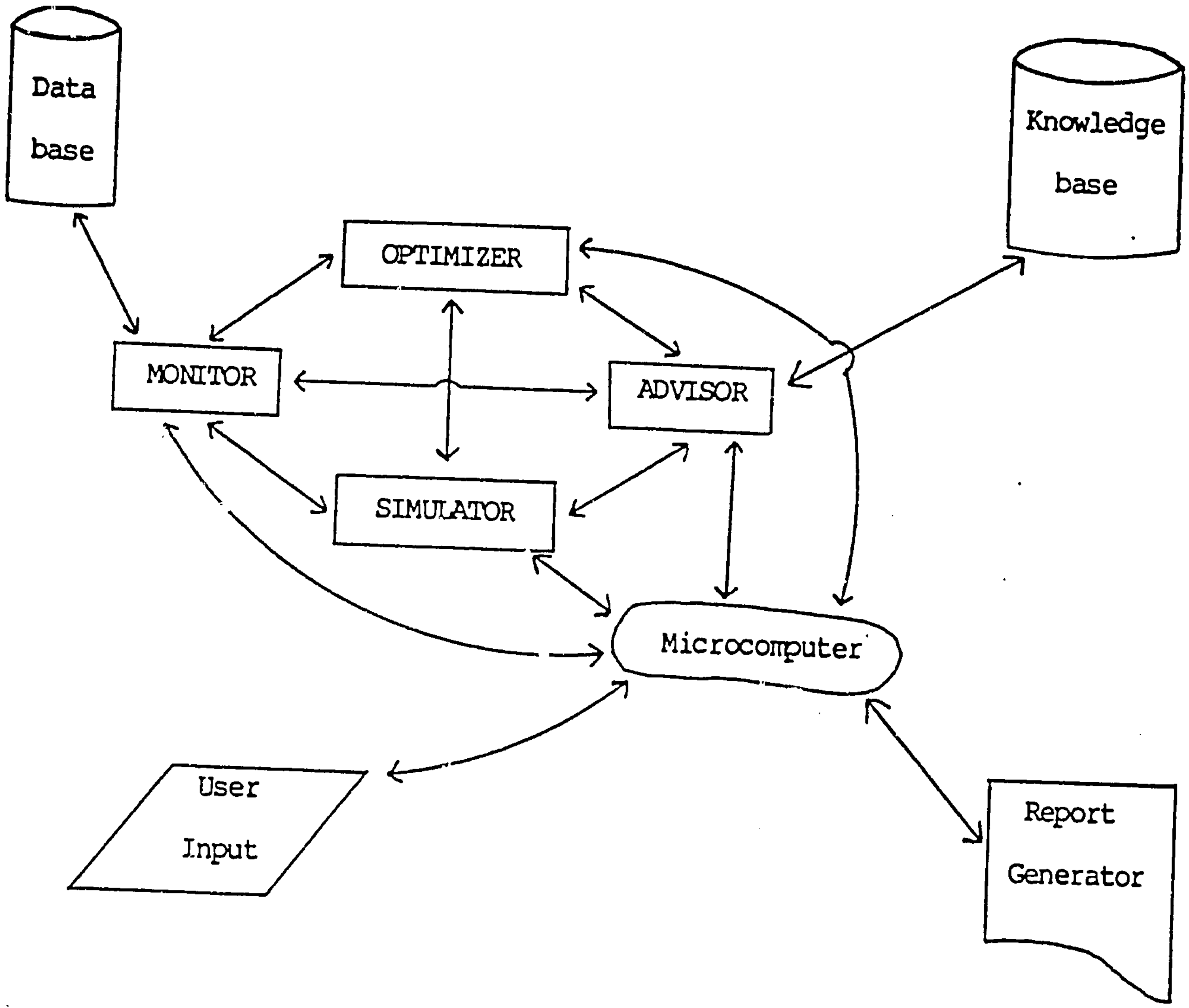

FIGURE 1
Overview of DSS for Fishery Management.

of well-known statistical tools (e.g., statistical estimator procedures, statistical quality control, or exploratory data analysis) as subroutines.

OPTIMIZER is the module containing standard optimization programs for stock assessment. Many of the techniques described by Ricker [4] for a single species, as well as those in more recent papers, would reside in this module. General-purpose procedures, such as linear and nonlinear programming, may also be available to OPTIMIZER as subroutines. The use of these techniques in fisheries management has been proposed by Rothschild and Balsiger [6] and Granic [2], for example. Beyond existing tools and techniques, OPTIMIZER could house new solution approaches specific to the multi-species aspect of fisheries.

SIMULATOR is a module that provides an evolutionary representation of the "state" of the real world. Since the time-evolution of this state may be viewed as a dynamical system governed by differential equations, one of the functions of SIMULATOR is simply to solve a system of differential equations. Here, systems dynamics provides a well-known and much-used technique. In systems dynamics, the interactions of various components of the simulated system are studied by means of a causal loop diagram (see Figure 2 for an example of a causal loop diagram for a simple system). An arrow between two nodes, A and B, of this network diagram indicates that an increase in the level of A causes an increase in B if a plus sign appears at the arrowhead. A minus sign at the tip of the arrow indicates that B will decrease if A increases. Loops in the diagram exhibit either positive or negative feedback, depending on the number of negative labels on the arrows in the loop (see Roberts et al. [5]

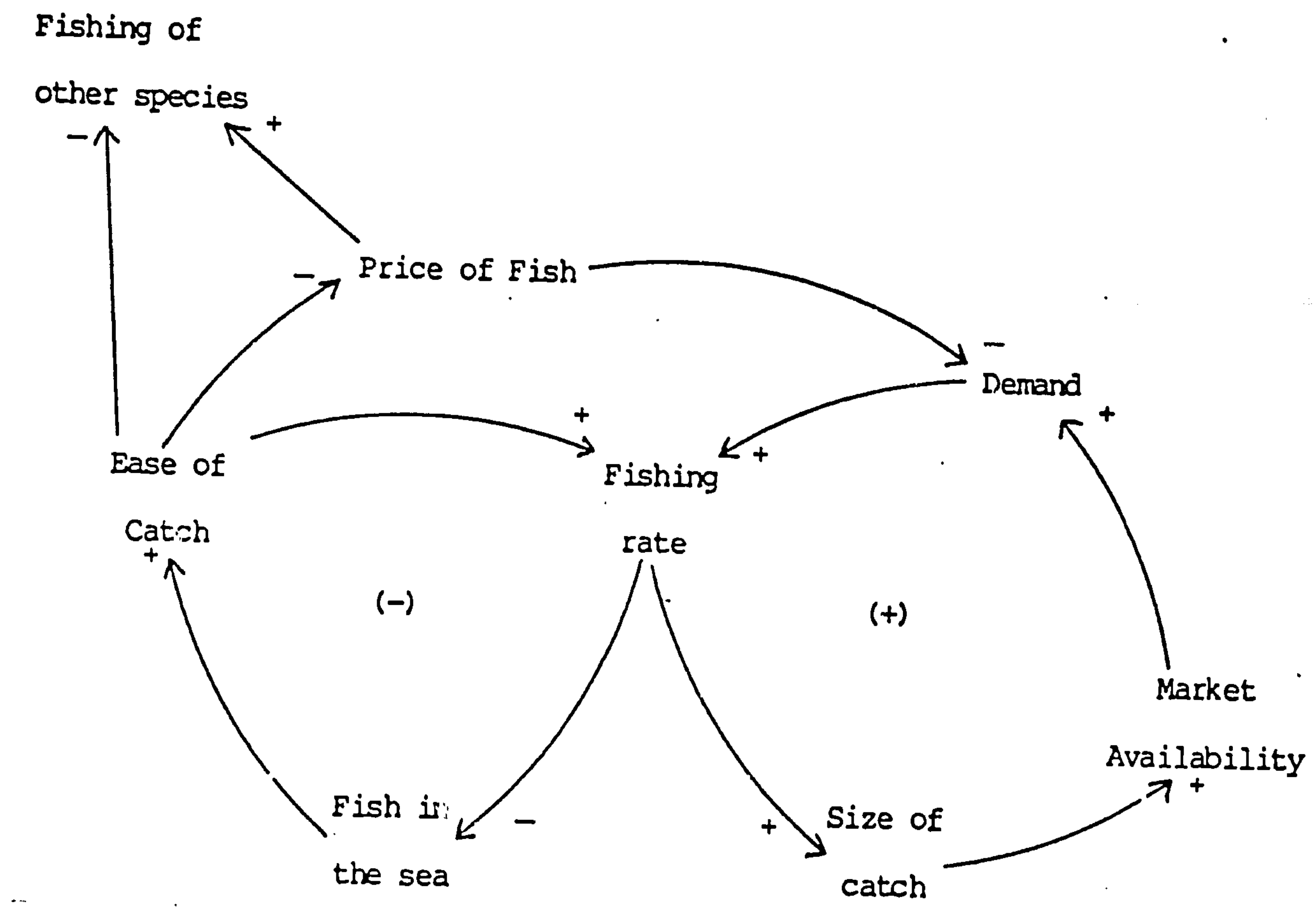

FIGURE 2
Causal Loop Diagram.

for further details). In short, systems dynamics provides an easy mechanism for modeling and simulating interacting systems.

We envision SIMULATOR starting out as an implementation of the systems dynamics methodology. As such, it will prove valuable for studying population dynamics and tracking key features of complex systems over time. The module might be called upon to give the manager a feel for the stability, persistence, or health of the ecosystem under present conditions, or it may be used to anticipate the impact of certain policy changes. Later in its evolution, the SIMULATOR module may be amplified with additional capabilities to address some of the issues raised in the next section of this paper.

The fourth module, ADVISOR, is an expert system for multi-species fisheries management. This module is at the heart of the decision support system, as we envision it, since it drives and coordinates the interactions between the various modules of the DSS, as well as the interface with the user.

Simply stated, an expert system is a software system with an associated base of information that utilizes the specialized knowledge of experts to achieve high performance in a specific (narrow) problem domain. The field of expert systems, a sub-field of artificial intelligence, investigates methods and techniques for constructing man-machine systems with domain-specific problem-solving expertise (see Assad and Golden [1] for an overview).

Functionally, the expert system in ADVISOR attempts to emulate a consultant with specific knowledge of fisheries management. The consultation paradigm implies that ADVISOR can query or probe the user and ask appropriate questions about the environment of interest to the user. In addition to this, ADVISOR should be capable of accepting information from and guiding the operation of other modules of the DSS directly. More specifically, ADVISOR's capabilities should include the following:

1. Given a set of outlier measurements from MONITOR, ADVISOR will either generate advice directly or request that OPTIMIZER or SIMULATOR perform tests that will enable ADVISOR to recommend a course of action.

2. Given catch quotas from OPTIMIZER, ADVISOR will advise the user as to possible interactions among species that were ignored, their implications, and strategies for overcoming these limitations based on experience.

3. Given output from MONITOR and/or OPTIMIZER, ADVISOR may set "birth and death rate" parameters and ask SIMULATOR to examine economic and ecological system behavior over time in order to avert potential catastrophes.

4. Given output from MONITOR, ADVISOR may recommend that certain fishing grounds be sampled. In other words, ADVISOR can request specific types of data or additional data from the user.

5. Given a description of the fishery's main characteristics, ADVISOR may recommend a strategy for using OPTIMIZER and SIMULATOR to study the system. This may involve specifying "regimes" under which the simulations are to be performed. ADVISOR may also recommend that the user consider specific "submodels" that address a component of the full system.

6. Given situations which are outside its domain of expertise, ADVISOR should explain why this is the case and decline offering a recommendation.

We should remark that although ADVISOR is referred to as a single expert system for convenience, it will likely be structured as a number of communicating expert systems, each with a specific, but different, domain of expertise. Fortunately, expert system development tools such as TIMM-PC and RULEMASTER easily allow such a modular organization.

3. CONTRIBUTIONS OF THE PROPOSED DECISION SUPPORT SYSTEM

This section summarizes the main contributions we envision the decision support system outlined in the preceding sections can make to fisheries management.

First, data collection will be better organized as a result of MONITOR's easy-to-use features with the intent of increasing cost effectiveness. Moreover, data will be collected much more frequently than in current practice. Instead of aggregate (yearly) data, MONITOR will process data on a daily, weekly, or monthly basis. More detailed data should reveal seasonality effects such as migration, and we fully expect that it will result in better decision making.

Second, MONITOR will be responsible for identifying measurement values that fall outside of a normal range. These ranges will either be prespecified by the user or by ADVISOR. Some limited degree of learning may even be present so that the ranges may vary slightly over time. The key point here is that outliers cannot be ignored or overlooked. MONITOR will call upon ADVISOR and the user to explain outliers.

Third, OPTIMIZER will provide the user with a number of powerful and easy-to-use routines. Classical single-species stock-assessment models, as well as linear and nonlinear programming capabilities, will be readily accessible to the decision maker. Moreover, OPTIMIZER includes special multi-species optimization models, studied in the literature or developed over the course of our work, within its inventory of models. The selection of appropriate "advanced" models to include will be a key decision in itself.

Fourth, SIMULATOR will provide the user with the capability of performing simulation studies conveniently. Its role within the DSS, however, recognizes that an inherent problem in large simulation studies has always been the difficulty in interpreting results; i.e., the simulation turns out to be "almost" as complex as the real-world system. Our use of simulation will, therefore, be considerably more selective. The complexity of using simulation as the basic tool to understand the entire system is reduced by focusing only on specific questions asked by ADVISOR. In this way, the interpretation of the simulation results is guided by the expert system.

Fifth, the approach of using an expert system to capture usable knowledge on multi-species fisheries management has the advantage of formalizing our rules-of-thumb into a working system. On the other hand, since these rules themselves are expected to evolve over time (as we gain deeper insights into the structure of the multi-species problem), the knowledge-base of the expert system can be refined, updated, and enriched with new rules. In short, the expert system provides a convenient mechanism for mirroring our knowledge of the system's key features.

Finally, opting for a microcomputer-based implementation of the DSS should provide a friendlier user interface and also enhance the availability of the system at different geographic locations.

We have now been at work on the decision support system for about one year. We view the system as <u>canonical</u> in the sense that it is applicable to both small and large-scale fisheries involving one or more than one species. With this in mind, we refer to the system as CANOFISH. A prototype version of CANOFISH is up and running on an IBM AT look-alike at the Chesapeake Biological Laboratory.

Three key tasks still remain before us. First, we need to begin to work from real-world data as soon as possible. Within several months, we expect to receive a detailed data set from the Gulf of Nicoya in Costa Rica. In the meantime, we are utilizing a fishery data generator which can "mimic" the behavior of a wide variety of real-world fisheries. Second, whereas the other modules are nearly fully operational, ADVISOR remains limited in its capabilities. This module is now the major focus of our attention. Finally, we remark that the modules are currently linked in a somewhat ad hoc manner. We are in the process of designing more elegant module linkages. Naturally, these will be installed in the next version of CANOFISH.

Obviously, the development of a decision support system along the lines proposed in this paper involves a considerable effort spanning a considerable length of time. Moreover, in contrast to, say, financial planning decision support systems where the underlying metholology is well-understood, the domain of our DSS itself requires much further exploration. As the peculiarities of multi-species fishery management, as opposed to single-species fisheries management become more evident during the course of this research, the DSS must evolve accordingly. The design of the DSS must be modified to exhibit special sensitivity to these issues. Notwithstanding the magnitude of the proposed effort, we hope that our enthusiasm for the inherent worth and tractability of the undertaking is not unjustified.

ACKNOWLEDGEMENTS

We thank Cluney Stagg and Hiren Trivedi for their helpful comments and the U.S. Agency for International Development for its support.

REFERENCES

[1] Assad, A. and Golden, B., Computers & Operations Research, 13, 301-321 (1986).

[2] Granic, B., The Problem of Optimization of Saltwater Fish in Demersal Community or The Problem of Optimization of the Exploitation of Demersal Resources, Unpublished Report, Faculty of Economics, Radovanova 13, 58000 Split, Yugoslavia (1986).

[3] Morton, M. S. Scott, Management Decision Systems: Computer Based Support for Decision Making (Harvard Univ., Cambridge, Mass., 1971).

[4] Ricker, W. E., Bulletin of the Fisheries Research Board of Canada, 191, 382 pages (1975).

[5] Roberts, N., Anderson, D., Deal, R., Garet, M., and Schaffer, W., Introduction to Computer Simulation: The Systems Dynamics Approach (Addison-Wesley, Reading, Mass., 1983).

[6] Rothschild, B. J. and Balsiger, J. W., Fisheries Bulletin, 69, 117-140 (1971).