

Introductory Fisheries Science

Robert T. Lackey

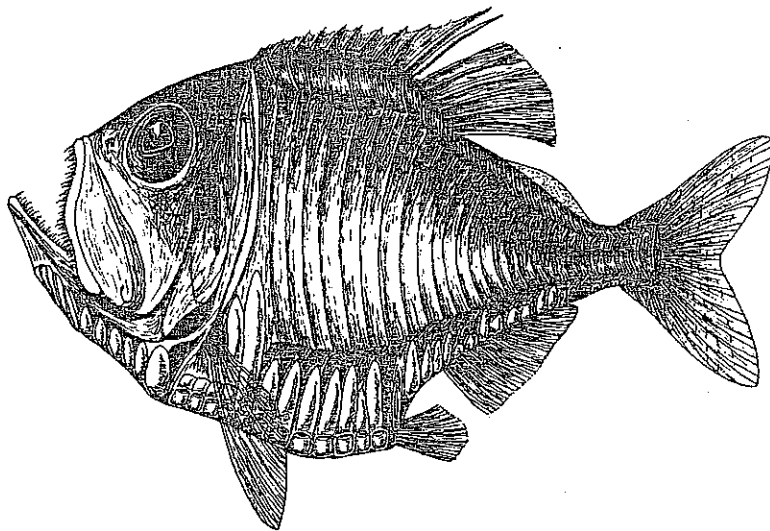
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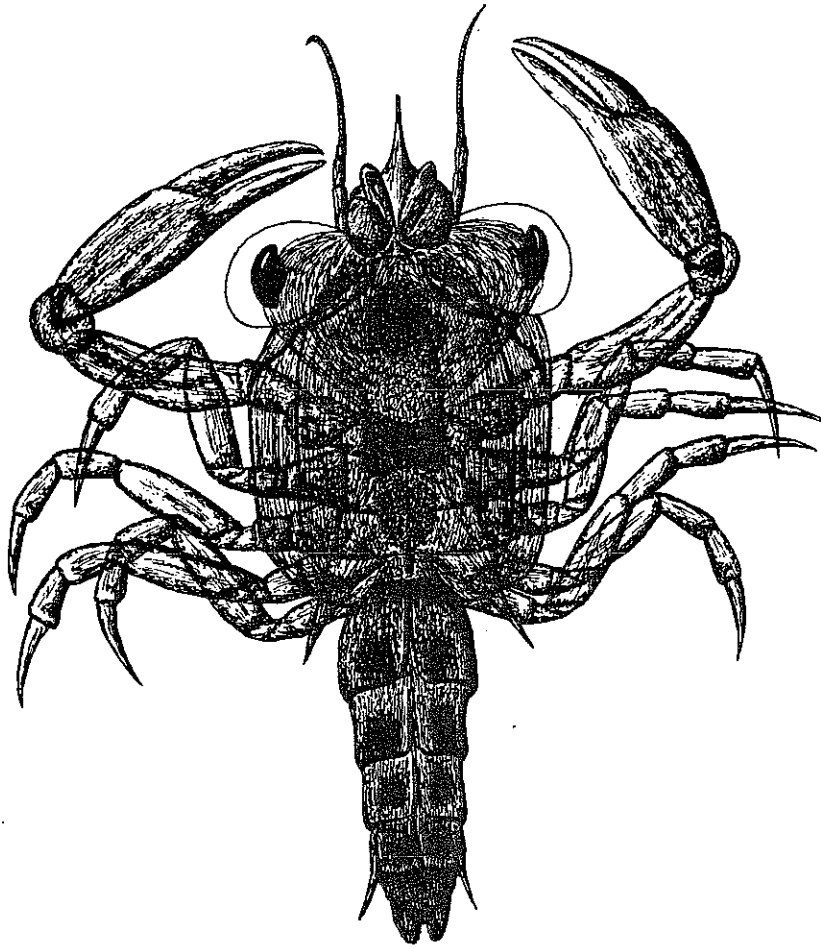
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Introductory Fisheries Science



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TABLE OF CONTENTS

	<u>Page</u>
Preface	v
<u>INTRODUCTION</u>	
1. Perspective	3
2. Aquatic Ecosystems	15
<u>POPULATION ANALYSIS</u>	
3. Stock Identification	23
4. Abundance	33
5. Mortality	57
6. Growth	65
7. Recruitment	71
8. Multi-stock Fisheries	75
<u>SYSTEMS SCIENCE</u>	
9. Systems Analysis	81
10. Modeling	93
<u>MANAGEMENT TECHNIQUES</u>	
11. General Management Techniques.....	103
12. Aquaculture	115
13. Computer Technology	133
<u>MANAGEMENT PRINCIPLES</u>	
14. Management Objectives	139
15. Strategy Analysis	143
16. Simulation	155
17. Planning	171
<u>RECREATIONAL FISHERIES MANAGEMENT</u>	
18. General Principles - Recreational Fisheries	181
19. Warmwater Management	187
20. Farm Pond Management	195
21. Stream Fisheries	201
22. Salmon Fisheries (SALMON)	219
23. Trout Fisheries (TROUT)	223
<u>COMMERCIAL FISHERIES MANAGEMENT</u>	
24. General Principles - Commercial Fisheries	229
25. World Fisheries.....	241

MULTIPLE-USE MANAGEMENT

26. Macro-level Management	257
27. Conflict Resolution (DAM)	263

RESEARCH

28. Analysis of Research	269
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PREFACE

Fisheries science is the study of the structure, dynamics, and interactions of habitat, aquatic animal populations, and man, and the achievement of specific human goals and objectives through the aquatic resource. Fisheries science is a tremendously broad discipline that encompasses many, superficially unrelated aspects. Some fisheries scientists, for example, may be only indirectly concerned with fish; Others may be addressing fisheries with the aid of an electron microscope.

The purpose of this text is to provide an introduction to fisheries science from a broad, principle-oriented approach. The major disciplines of fisheries science (management, biology, theory, population dynamics, aquaculture, technology, planning, and economics) are considered as an overview of aquatic renewable natural resources and to provide the necessary foundation for further coursework in fisheries science.

Much of this book has been written in collaboration with my students, both past and present. Specifically, John L. Boaze, William T. Bryson, Richard D. Clark, Vaughn M. Douglass, Dennis E. Hammond, Ed L. Hampton, Gary F. Martel, Joseph E. Powers, Thomas L. Schulte, Franklin B. Titlow, and James R. Zuboy contributed materially.

INTRODUCTION

PERSPECTIVE

Dramatic technological advances in our society in the last several decades have often produced equally dramatic changes in natural resource management. Resource managers have witnessed the advent of modern computers, the widespread adoption of management sciences techniques, the development of a dynamic social structure, as well as the myriad psychological problems associated with rapidly expanding technologies. But technological advances have also allowed the resource manager to deal with some of the complexities of natural resource systems.

Computer technology is one obvious and widely cited example of the rapid development in technology. Modern computers can perform routine computational tasks, but this blessing is mixed with the uncompromising demand for sound models in order for the information generated to be meaningful. As processed data become readily available to the decision-maker, more demands are placed upon the individual to make rational use of this increased information. Far from replacing man, computers have made certain types of individuals desirable, if not indispensable, to a modern society.

Originally these individuals 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. Optimization strategies now appear regularly in the ecological literature and "planning" in resource management has been stressed as being of paramount importance.

But, as is true of many of the "improvements" in life, advances in technology have produced many drawbacks. Most drawbacks can be directly or indirectly associated with "future shock" as defined by Toffler. Many people fear the impersonality of computers and consciously, or subconsciously, fear that technological change is too rapid to be socially or professionally assimilated. According to Toffler, technological change is reflected in the fact that 90 percent of all scientists who ever lived are now alive and that worldwide output of technical literature increases 60,000,000 pages per year. Such rapid change has made it increasingly difficult for the professional resource manager to deal with resource problems in the most effective manner.

Tangible proof of technological changes are increasingly self-evident. Computers have become the core of business, government, and universities. Other proof may be seen in almost any university curriculum. Many diverse departments have a systems analysis and "planning" course, but still many resource management students have not been introduced to these changing technologies. Perhaps management science majors may be best trained for many fisheries management positions.

Through the years recreational fisheries management, as all natural resources management, has remained a relatively qualitative field. Statistical methods are common, but many problem solving tools such as linear programming, dynamic programming, and decision analysis under risk and uncertainty are neglected. Currently, the newly-graduated 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 commitments at such a low level that exploration of non-crises situations are infeasible.

The Decision Model

The decision-making process in fisheries management is a complex system, but it can be pared to the bare essentials to facilitate discussion (Fig. 1). The conceptual model (as illustrated in Fig. 1) is an old idea which is often followed implicitly, but is rarely clearly defined. Admittedly the model is simple, but it is of value if it can help solve the problem for which it is intended. The attitude or philosophy behind decision-making in resource management is an adaptation of the classical scientific method applied to problem solving in a dynamic and complex matrix.

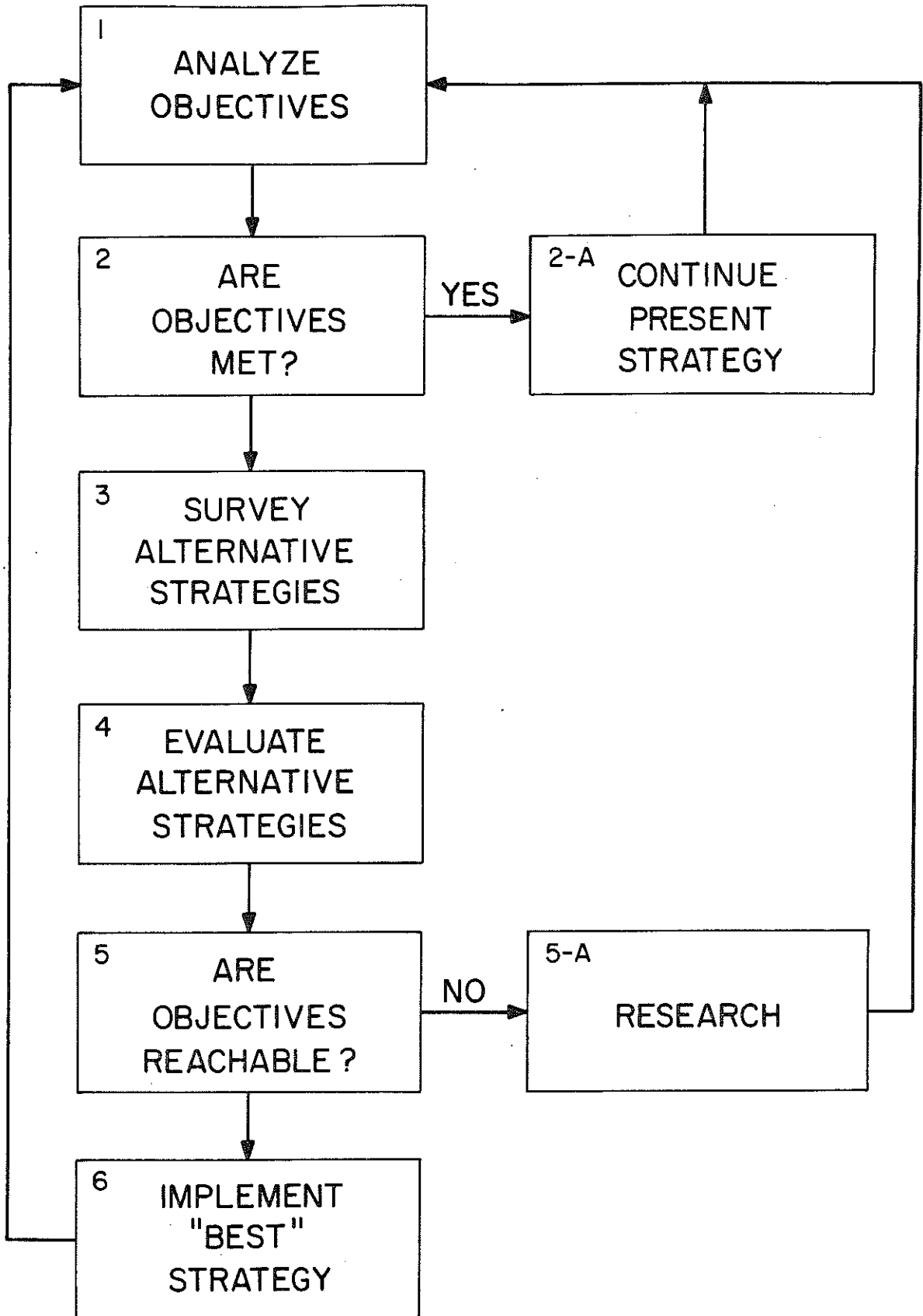


Figure 1. Flow chart of the decision-making process in fisheries management.

Selecting Objectives - Step 1

The first question any decision-maker must ask is: What are the objectives? Most objectives in 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. Quantifiable objectives which may be subjective in origin should be defined at all levels of the organization from the local manager to the head of the organization.

Secondly, the decision-maker must ask if the management objective is achievable. If the "objective" is merely a general direction, there may be no way to evaluate the relative success of management activities, other than by comparative numbers of complaints. The achievability of a management objective is contingent upon its measurability, among other things. How do we measure recreational "benefits?" Historically we have attempted to maximize yield, primarily because it is easy to measure. But in recreational fisheries such an objective neglects other important aspects in the fishing experience, such as species and size preferences.

Then how can we select objectives? The public should supply input by choosing preferences within existing constraints of the resource bio-socio-economic system. Ranking procedures have been employed on similar problems to determine some public preferences concerning a hunting resource. Such techniques involve ordinal scales of preference that quantify relative preference while minimizing sampling bias. Other measures of value or utility to consumers have been developed and/or used and may allow the decision-maker to maximize individual utility rather than dollar income or total poundage of fish removed.

In developing usable measures of management objectives, some basic tenets must be evaluated. Is maximum yield desirable? To an angler, catching fish may be of secondary importance. The quality of the surrounding environment and of the aesthetic experience may be more important. Therefore, our present research needs include development of a management benefit unit which will integrate some or all of the components of yield, species and size desirability, and environmental qualities into a common denominator.

Selection and quantification of management objectives is one of the most difficult problems facing fisheries managers. We need a specific objective toward which we can work. Without a feasible objective, we are subject to random wandering, are easily diverted, and our management lacks continuity.

Are Objectives Met - Fisheries Assessment - Step 2

Initially there must be recognition that a problem exists in a fishery (Fig. 1). Sources for problem recognition and identification traditionally have come from field surveys, receipt of complaints, and prior experience. From these sources the "key" statistics must be identified as indicators of system response and then must be monitored.

If fishery output coincides with the management objective, then management effort should be allocated in other areas (Step 2-A). If the objective is not being met, the manager must decide how much money to spend in order to alleviate the problem. In other words, the manager must (within his fixed budget) move the total program toward the objective.

An excellent means of assessing the fishery is through monitoring. The importance of monitoring cannot be overemphasized. An example of monitoring is that of the Virginia Commission of Game and Inland Fisheries in which creel census are performed on state-owned lakes. The census system is computerized for quick tabulation. Using such a system, potential problems may be identified before they become insurmountable. Identification of the key statistics requires adequate financial support, i.e., the monitoring system costs money, but it is necessary for proper management of the fishery.

Survey Alternative Strategies - Step 3

What are the possible ways to meet management objectives? This step involves identification of the decision possibilities, i.e., the available alternatives. These can be enumerated by relating past experience, discussion with other managers, and a review of relevant literature. It must be reiterated that in order to systematically list the alternative decisions, a clear objective is needed. Without an objective alternative strategies are meaningless.

Evaluation of Alternative Strategies - Step 4

Initial evaluation should eliminate those decision alternatives which are technology infeasible. Many such alternatives can be discarded immediately. For example, it may be infeasible to establish selective harvest between two species because the available harvest methods cannot differentiate between the two. Other alternatives that may be disregarded are those that will obviously exceed a budgetary constraint.

The next step in lowering the number of decision alternatives is in using experience and the literature. What has been the most common procedure? Given similar problems, what was done before? But, it may be dangerous to accept these decision alternatives in all cases because it causes perpetuation of the "conventional wisdom" that may have caused the problem. If the manager analyzes the alternatives obtained from experience and chooses none as the "best" alternative, then he has made a decision. In essence, the manager must make a decision and he must not simply accept the status quo.

Methods of simple analysis to choose from remaining decision alternatives include simple conceptual models. Such models do little more than force the decision-maker to organize the decision-making process, but this in itself can be valuable. With the advent of programmable calculators, these simple models can be applied to more complicated decision problems.

More complex analytical systems can be developed to evaluate management alternatives. These methods employ mathematical and computer models to evaluate relative success of decisions upon the aquatic resource. One example is the Catchable TROUT Fishery Simulator (CATS). CATS asks the manager to provide inputs relevant to his particular catchable trout fishery and to apply the management decisions. The stocking and fishery statistics are then computed and tabulated for the user. Many computer models are too expensive in time and money for most managers, but time-sharing systems are available to the manager and these may be financially feasible for a management agency. Time-sharing systems could bring the field manager in contact with more complicated analysis and the expense (in relation to the costs of experimentation with the real system) is small.

Other evaluation tools involve the large scale problems associated with diverse resources of a state agency. The agency must allocate its funds to provide the public with the amount and kind of desired recreational experience within bio-socio-economic constraints.

Are Objectives Reachable - Step 5

At this point the program should be re-evaluated. Are the objectives reasonable? Perhaps none of the alternative decisions are capable of meeting the management objectives. In this case the objectives should be restructured. Program re-evaluation is a continual process that is allied with monitoring, as discussed before.

If the alternatives produce unsatisfactory results the process can revert back to step 1 to recycle through the model again. Perhaps, no feasible solution exists and it would be better to spend time and money on some other activity. Perhaps, doing nothing is the best alternative. Note that this is a positive action, a decision, and very much different from the passive action of not making a decision.

It is important to see where research fits into the conceptual model (Step 5-A). Research may be used to develop or evaluate a potential management solution. Basic research is needed, but it should be within a broader decision-making framework. Management-oriented research should be methodical and problem-oriented (i.e., seeking answers to specific questions). Also, research is needed to develop effective prediction models in the fishery. Prediction (illumination of cause and effect) is the essence of all science and integral to effective management.

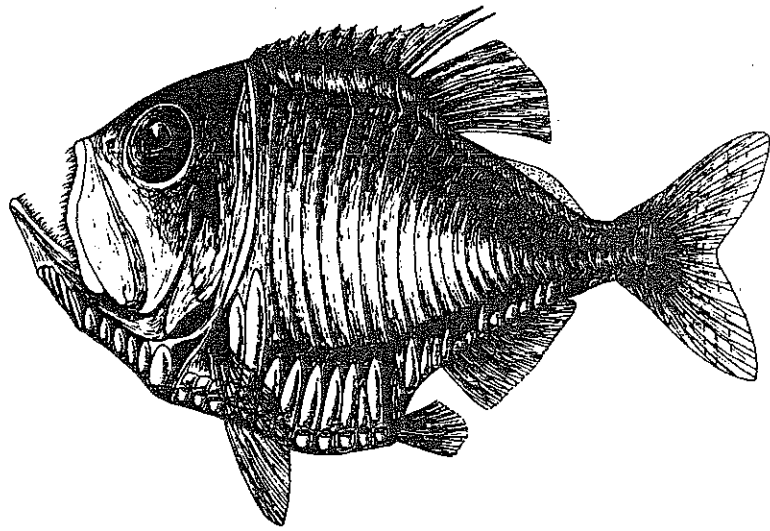
Such a viewpoint does not preclude nondirected research, but it should be identified as such. Basic research may be found in management agencies, but the agency will have to justify the expense in terms of its objectives.

Implement the Best Strategy - Step 6

When the "best" strategy has been identified, it must be implemented, i.e., it must be put into use on the fishery. For example, creel limits may be set or a certain stocking regime implemented. Decisions have been made and the fishery will in part be a product of those decisions, but the decision process does not stop here. The system must be monitored to see if the management strategy is effective and the entire decision-making process must be continually re-evaluated. Objectives may change (i.e., people may change their preferences for species) and the fishery itself may be influenced by external factors (subdivisions, road buildings, etc.)

The value of this decision-making model is that it puts a complex process into a describable system, so that areas of weakness may be identified. The process is then broken down into its solvable components. The key point in this process is the first step: formulating objectives. Most management decisions fail because the first step is not included.

This model and the more complicated analyses mentioned previously are signs of the evolution of fisheries management from development of techniques to development of strategies. By having organized decision processes, the "information overload" and subsequent "decision stress" of future shock may be avoided.



AQUATIC ECOSYSTEMS



Fisheries Science is usually, either directly or indirectly, concerned with producing the best possible fishing experience, whether for fun or profit. To achieve such a worthwhile goal, the fisheries manager must often work directly with fish, but he must also consider other parts of the aquatic environment, as well as man.

Life within a lake is as diverse as life on land. Plants and animals grow, reproduce, and die; most are rarely noticed by man. Just as the forest and wildlife manager must understand and manipulate the terrestrial environment to achieve optimal harvest, the fisheries manager must, in a similar manner, work with the aquatic environment.

Plants

Aquatic life can be divided into two classes: the plants and the animals. Phytoplankters, tiny plants that float in the surface layer of lakes, are usually the most important plants to the fisheries manager. Like most plants, they carry on photosynthesis to store part of the energy of sunlight. This is the first level of life in lakes, the level at which energy is stored to power the living lake. To fish, phytoplankters are the first part of a food web. Small animals eat phytoplankton and are in turn eaten by larger animals which are then eaten by fish.

Fisheries managers can have problems when phytoplankton abundance is too high or too low. If for some reason the phytoplankton population becomes very large, a bloom develops. During a bloom, green scum is usually present and the water has a soupy consistency. When these plants die, they decompose and, in the process, use oxygen required by fish. A fish die-off may be caused under these circumstances, and is called a summerkill. One solution to this problem is for the fisheries manager to chemically treat before phytoplankton populations explode.

Low phytoplankton levels can also cause problems for the fisheries manager. If the phytoplankton level is low, the lake cannot support as many fish as it might at higher phytoplankton levels. One solution is to fertilize just as a farmer fertilizes his crops. By increasing the initial link of the food chain, we may ultimately increase the final link - fish.

Rooted aquatic plants are also important in a lake. These plants flourish in coves and shallow water where their roots can get a good hold. Rooted plants, like phytoplankters, carry on photosynthesis which adds energy to the lake.

Rooted plants are often important in providing good fishing. First, weed beds are good habitat for young game fish and small forage species. Game fish can cruise these weedy areas in search of prey. Secondly, weed beds provide some fish with protection from predators during the reproductive season. Perhaps most important, rooted aquatic plants shelter a rich assortment of invertebrate animals, prime fish food.

Rooted aquatic plants can also cause the fisheries manager problems. Overabundance of weeds makes angling a frustrating chore. Rooted aquatic plants also compete with phytoplankton for sunlight and nutrients. Since phytoplankton are more important in the aquatic food chain, this competition is detrimental to fish production. Overabundance of rooted plants is often associated with super-rich (eutrophic) lakes that predominately support rough fish like suckers and bullheads.

Control of rooted aquatics can be achieved by chemicals or water level manipulation. Chemical control is usually limited to smaller lakes and ponds because of the high cost involved. Water level manipulation can be used to retard plant growth, but is not always possible.

Underabundance of rooted aquatic plants is often a less common fisheries management problem. Providing additional habitat is usually the solution here. Brush piles are sometimes added to heavily fished lakes to concentrate fish. Artificial reefs of old tires, commonly used in saltwater fisheries management, also show some promise for improving lake habitat.

Animals

Zooplankters, tiny organisms that drift with the currents, are the most abundant animals in lakes. They feed on phytoplankters and smaller zooplankters. The importance of zooplankton is their role of transferring the solar energy phytoplankton have captured to the animal community. Young fish are dependent on zooplankton for their food supply, but managing zooplankton to improve fishing is very difficult. The best approach is to maintain good water quality and adequate food.

Bottom animals, termed benthos, live in and on the floor of lakes. Benthos include worms, crayfish, sowbugs, and a large variety of insect larvae. Most common of the benthos are the larval stages of midge flies. Benthic organisms eat a variety of foods, including bacteria, phytoplankton, zooplankton, and decaying organic material.

Most fish prey heavily on benthic animals. In fact, many adult game fish are totally dependent on these animals. Benthos perform another important function in a lake, that of recycling organic materials by eating dead plants and animals. This activity also prevents excess accumulation of biological debris in lakes.

Even though benthic animals are important to fish, there is little specific management that can be implemented. Occasionally exotic species such as aquatic sowbugs have been introduced to increase available fish food, but this is not a common approach.

Of all the animals inhabiting lakes, fish are the largest and most important. They have been pursued by man for food and sport for at least 7,000 years. Yet only a relatively small number of fishes are actively sought by man. Fishes are the most common of all vertebrates, in fact, there are probably more fishes than of all other vertebrate species combined.

Within a lake each species of fish lives in a manner and location that suits its particular requirements. These requirements vary from species to species and over the lifetime of an individual fish. Some species prefer the quiet of weed beds, while others thrive in deep, clear water.

Food to a fish may be nearly anything that can be swallowed. Some fishes, like the shad and alewife, are mainly plankton feeders. At the other extreme are the northern pike and muskellunge, which prey almost exclusively on other fish.

Management

Management can be conveniently divided into that dealing with warmwater and coldwater fisheries. Warmwater lakes are typically inhabited by species such as bass, bluegill, and other sunfish. Most lakes in the southeastern United States fall into this category. Coldwater lakes generally support trout and similar species.

Coldwater fisheries present several management problems. First of all, trout have a much lower reproductive potential than warmwater fishes and secondly, cold water is also less productive than warm water. Together, these two factors make trout fisheries very susceptible to overfishing. Under heavy fishing pressure some form of stocking and restrictive regulation is usually required.

The management of warmwater fisheries is somewhat different and centers around the high reproductive potential of the fishes. If surplus reproduction is unchecked and harvest isn't adequate, game fish tend to stunt. Small fish have little appeal to anglers and, consequently, less fishing takes place. Stunting then tends to get progressively worse. Stocking fish in warmwater environments has limited use because most warmwater fishes have a high reproductive potential. If for some reason a species has a poor reproductive season, supplemental stocking of fingerlings may be appropriate. Stocking adults is very expensive and usually improves fishing for only short periods.

One of the most promising approaches to management of all fisheries involves the study of population dynamics. This means controlling fish yield by knowing and manipulating population levels and the harvest rate of each population present. The theoretical maximum fish harvest possible from a lake is achieved by keeping various species at a level which will produce the most fish on a sustained basis. This approach is difficult in practice, but in the future it may be one of our most powerful management tools.

***POPULATION
ANALYSIS***

STOCK IDENTIFICATION

The unit stock is one of the most fundamental, yet elusive, concepts in fisheries management. Generally, by unit stock, we mean a group of fish or other aquatic animals that can be treated as a single unit for management purposes. Superficially, it may seem a simple task to identify a unit stock, but it is actually quite difficult, especially in multispecies fisheries. The problem of the definition of the unit stock is common to all studies of natural populations. Some of the apparent inconsistencies of population dynamics studies of animals seem to have arisen because the group of animals being studied did not form, to a sufficiently close approximation, a unit stock.

One other question that we might address at this point is: why do we need to delineate a unit stock? The answer lies in the fisheries theory upon which is based modern management strategy. Population dynamics models have been developed, generally with the aim of deriving the maximum sustainable yield from a fishery. To realistically apply these models, a unit stock with definable characteristics must be delineated.

Concepts

Most of the work on population dynamics models has been done on single species marine fisheries, e.g., the tuna fishery. Consequently, reference to the unit stock usually has a marine orientation. A unit stock has been defined as "a self-contained and self-perpetuating group, with no mixture from the outside, and within which biological characteristics and impact of fishing are uniform." Careful analysis of this definition reveals that the ideal unit stock (as defined) would be the exception rather than the rule in nature. The choice of what is to be considered a unit stock must usually be made empirically, depending on requirements set forth by the investigator regarding accuracy and detail in analysis.

The unit stock has also been commonly defined as one in which the adult fish return to the same fixed spawning ground each year, and in which the vital statistics of recruitment, growth, and mortality are homogeneous. Comparison with the previous definition reveals that they are essentially congruent.

Royce gives a somewhat more liberal interpretation of the unit stock: the ideal definition of stock is that of a single, interbreeding population, but this condition is so rarely demonstrable, either because of scanty data or the rarity of isolated interbreeding populations, that stock must be more or less arbitrarily defined. It is a unit capable of independent exploitation or management and containing as much of an interbreeding unit or as few reproductively isolated units as possible. Royce's concept allows more flexibility in delineating a unit stock than either of the two previous definitions. His concept would allow several different groups, under certain circumstances, to be classified as one unit stock.

The above concepts of a unit stock have been formulated in terms of marine commercial fisheries. How do we apply them to multispecies, freshwater, recreational fisheries?

Applications.

One basic problem in applying most population dynamics models to freshwater fisheries is defining the appropriate management unit, i.e., the unit stock. In a fishery with several distinct species there are many possible unit stocks.

For purposes of illustration, we will consider a small (50 hectare) warmwater lake fishery with four reproducing fish species of importance to the angler. The species are largemouth bass, bluegill, channel catfish, and pickerel.

Individual Species Unit Stocks

A possible choice of unit stocks would be to designate each species as a separate stock. Thus, bass would be one stock, bluegill another, and so forth. One problem would be that data would either have to be collected separately for each stock or subdivided over each stock if the data were collected on the fishery as a whole. It is usually most convenient to treat as large a group as possible as a unit stock. This is especially true in freshwater fisheries where data are often scanty. The corollary is that if data are collected separately on all stocks, statistical analysis will take considerably more time and effort, and a separate model would have to be constructed for each stock.

Although individual species unit stocks would conform most closely to the ideal definition of a unit stock, there might still be some difficulties. There is a possibility that the impact of fishing might not be uniform on a particular stock. An example would be where half of the lake is unavailable for shore fishing due to vegetative growth. The stocks would be subject to different fishing pressures on the fishable and unfishable shores. In addition, the interaction between species could act to alter the biological characteristics of the stocks in different parts of the lake. Predation and competition might both play a role here. Hopefully though, the vital statistics of recruitment, growth, and natural mortality would be homogeneous within each stock.

The Aggregate

Suppose we lump the four species under consideration together for management purposes and call the aggregate the unit stock. Obviously, we violate any rigid definition of unit stock, but possibly in this case we can consider the aggregate as a unit stock under the more liberal definition of Royce (lumping as few reproductively isolated units as possible). If we can assume that the values of the statistics of growth, mortality, and recruitment do not vary substantially between the different species, we probably would not have serious errors in our analysis. However, this would be a very gross assumption to make, but perhaps a necessary one.

Graham applied a population dynamics model to the aggregate of the demersal fishes of the North Sea. He made the assumption that a unit biomass of one species was equal to that of any other species in this area, an assumption which is generally not true. Graham was working with a commercial marine fishery and species of similar habit. The assumption of homogeneity is likely to be more realistic in his case than for lakes. However, in some situations (e.g., lack of data on individual species) perhaps the only way we can evaluate the total fishery will be to make this assumption and call the aggregate of all species present the unit stock.

Pairs as a Unit Stock

In simple population dynamics models we are primarily interested in the effects of fishing on a stock. If we can assume growth and recruitment of two species are similar and we think they are exploited at like rates, we might be able to designate the pair of species as a unit stock. For example, consider bluegill and crappie. It is possible in a given situation that they could have similar vital statistics. If we are exploiting them at near equal rates, we might possibly consider the two species together as a unit stock. We might apply the same idea to a bass-channel catfish stock.

Ecological Unit Stocks

Pursuing the idea of similar exploitation rates and the assumption of like vital statistics, another possibility for unit stock would be based on the general ecological behavior of species. For example, we might consider our lake to have three unit stocks. The demersal stock (catfish), the littoral stock (bass, bluegill), and the pelagic stock (crappie). Or we might even lump crappie into the littoral stock and say we have only demersal and littoral stocks.

Here we might use as justification for our choice of stocks the assumptions that fishing pressure is more likely to be uniform over like ecological groups than unlike, and also that vital statistics are probably more similar within ecological groups than between them. Again we must make some gross assumptions.

At this point you must begin to realize that there are many possible combinations which we might designate as unit stocks - the choice being limited only by imagination.

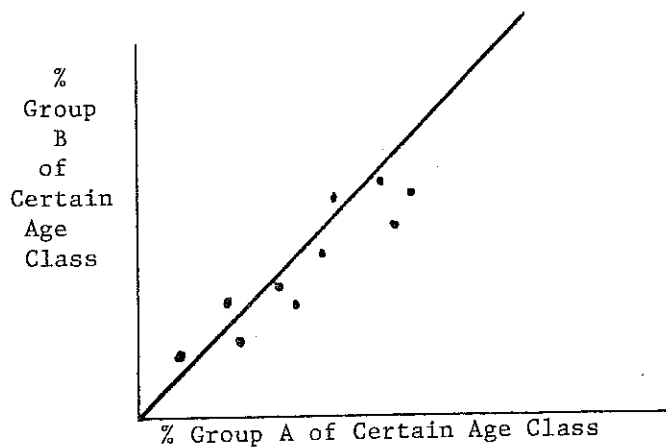
Delineation

The most obvious approach to delineating a stock is by geographical analysis. The maximum range that members of a species might cover is determined. Geographical analysis is usually a first-pass approach in poorly studied fisheries.

Another method of delineating a stock is by spawning area analysis. Do all members of a group use the same spawning area? If the answer is yes, then there is cause to treat these fish as a homogeneous group or stock.

Catch and effort analysis can also delineate a stock. How does C/f compare in adjacent areas? Do populations in adjacent areas respond in the same way to fishing?

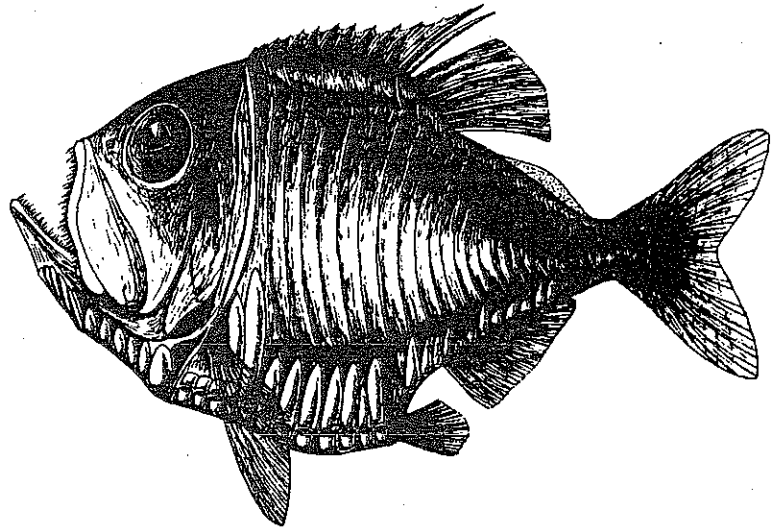
A fourth method to delineate a stock is age composition analysis. Since the vital statistics of a stock are (by definition) homogeneous, you would assume that a given age class would constitute the same percentage of the population throughout the fishery.



If the fitted line significantly deviates from the 45° line, it is likely that you are dealing with two or more stocks.

Tagging is a fairly straightforward approach for delineating stocks. Fish may be tagged in the fishery and then all possible areas sampled for recaptures. The opposite approach is to tag fish on the spawning grounds and sample in the fishery for recaptures.

Morphological and physiological analysis is useful in some situations to delineate stocks. Similarities and differences in vertebrate counts, fin ray counts, and blood chemistry are factors that have been successfully employed.



ABUNDANCE

Estimating stock abundance or relative abundance in a fishery is of importance in fisheries management as an intermediate step to estimating other vital parameters. The manager must determine the status of various stocks, however rough these estimates are, as the first step in population analysis. The most important use of estimates of abundance is in estimating mortality rates, which in turn are reduced to exploitation rates. In all cases the manager should carefully decide exactly why he wants to estimate abundance and then use the simplest method to satisfy his needs.

Indices of Abundance

Standard Gear Unit

In most situations, the manager only needs to know the relative abundance of various stocks. Catch from a standard gear unit is one approach that is often used in this situation. A standardized seine haul, a fixed length and mesh size gill net, and electrofishing over a standard course are examples. Coves are sometimes treated with rotenone and this method can be considered a standard gear unit. Advantages of these methods are simplicity and ease. Disadvantages are questionable representativeness of the sample, variability of the index, and weakness of statistical analyses (replicates are needed to estimate variance, but are difficult to obtain with this method).

Catch Per Unit Fishing Effort

The basic assumption is that C/f is in some constant way related to stock size, N . The difference between this approach and the standard gear unit is that C/f can be calculated on any gear, as long as f is in the same units. Creel data can be used in many ways to express C/f . This method is most commonly used for making year to year comparisons as part of a monitoring program. The same advantages and disadvantages of the standard gear unit also apply to this method.

Direct Enumeration Methods

Direct enumeration is one of the simplest methods of estimating abundance. This method depends on counting all or a selected portion of the population. Whenever this method can be used, it is preferred because it is usually cheaper and relatively accurate. However, these methods are usually of limited value because they can only be utilized when the total population may be confined sufficiently to make an actual count of individuals.

FISHERIES SYMBOLS

(Internationally Standard)

<u>Symbol</u>	<u>Term</u>
A	* Mortality rate (fraction) (often 1-S)
B	Biomass (general)
C	Catch of fish (number)
D	* Natural death rate (fraction)
E	* Exploitation rate (fraction)
F	* Fishing mortality rate (instantaneous)
G	* Growth rate (general)
K	* Growth rate (von Bertalanffy equation)
M	* Natural mortality rate (instantaneous)
N	Number of individuals in a stock (or population)
P	Biomass of fish in a stock
R	* Number of recruits (annual recruitment)
S	* Survival rate (fraction)
V	Virtual population estimate
Y	Yield (catch of fish in weight)
Z	* Total mortality rate (instantaneous)
e	Natural base
f	Fishing effort
l	Length of individual fish
l_c	Length at first capture
m	Number of fish marked
n	Sample size
q	Catchability coefficient (F/f)
r	Number of fish recaptured
t	Time
t_c	Time at first capture
w	Weight of individual fish
w_c	Weight at first capture

* Rate estimators

Total Count

Total count of a fish population can be accomplished in various ways. Salmon and trout on their spawning runs can be guided into a weir or trap. Salmon usually follow current patterns along the banks of spawning streams and fisheries scientists have taken advantage of this type of behavior by erecting counting towers along stream banks. Observation is often improved by providing a light colored stream bottom background. Where fishways have been constructed, salmon can be easily counted at the exit, or a T.V. camera and video-tape equipment can be installed in the fishway. Sophisticated equipment such as this can reduce counting error substantially. Small ponds can sometimes be drained adequately to permit the recovery of the total population with seines. Since total counts require enumeration of all individuals in the population there is no statistical analysis involved.

Partial Count

Partial counts using direct enumeration may also be practical in some fisheries. A portion of the population is counted then the total population is projected from these data. Towers on the banks of salmon streams are usually not manned continuously, rather, counting periods of 10 minutes per hour can be randomized and then expanded for a complete migration period. A stream or lake bottom can be stratified then the results of sampling these stratified areas can be projected to the total population. Cove sampling may be considered a type of partial count. In this method, coves of a reservoir or lake are sampled and these results projected to the population of the entire reservoir.

The statistics involved are fairly straight forward. Assuming the abundance of the fish remains the same and is uniform throughout the fishery, arbitrarily divide the population space into A equal unit spaces and select a of these to enumerate completely. This yields error free numbers $N_1, N_2, N_3, \dots, N_a$ corresponding to subspaces 1, 2, 3 ... a. Then:

$$\hat{N} = \frac{A}{a} \sum_{i=1}^a N_i$$

and

$$\text{var}(\hat{N}) = \frac{A^2 - aA}{a} = \text{var}(N_1)$$

where

$$\text{var}(\hat{N}_i) = \frac{a \sum_{i=1}^a N_i^2 - \left(\sum_{i=1}^a N_i \right)^2}{a(a-1)}$$

For example, suppose you mark off a shallow 25 acre lake into 25 one acre grids. Five grids are randomly designated as sampling units and the fish counted by aerial photographs. The results are:

$$a_1 = 30$$

$$a_2 = 40$$

$$a_3 = 25$$

$$a_4 = 15$$

$$a_5 = 35$$

then

$$\hat{N} = (25/5) (30 + 40 + 25 + 25 + 15 + 35)$$

$$\hat{N} = 725$$

The estimated variance of N is calculated as follows:

$$\hat{\text{var}} (N_i) = \frac{5[30^2 + 40^2 + 25^2 + 15^2 + 35^2] - [30 + 40 + 25 + 15 + 35]^2}{5(4)}$$

$$\hat{\text{var}} (N_i) = 91.2$$

then

$$\hat{\text{var}} (\hat{N}) = \frac{(25)^2}{5} (91.2)$$

$$\hat{\text{var}} (\hat{N}) = 9120$$

Correlated Methods

Often the life history of a fish may be such that some closely related (correlated) sub-adult population may be estimated more readily than the adult population. For example, the number of adults may be related to egg production or the number of nests or redds. In fisheries, estimation of adult population size from eggs has been attempted for a few marine species that have pelagic eggs. In addition the nests of certain fishes, such as the salmonids and basses, may be used as an estimate of the number of spawning adults.

Fisheries scientists in Alaska often forecast the size of salmon runs using a correlated method or index. Sometimes this method is only able to give an index of population size because sampling of all areas during all time periods is difficult. Forecasts are not only important in determining population size, but are also used for planning and regulatory decision-making. Pink salmon forecasts, for example, are based on the relationship between pre-emergent fry abundance and subsequent adult return. The forecast of the expected number of returning adult pink salmon is obtained by relating past fry indices to corresponding returns of adult pink salmon. Data acquired over past years is analyzed using simple linear regression.

The following is an example of the procedure to forecast pink salmon runs in Alaska. Let,

X = pre-emergent fry density (fry per m²)

Y = subsequent total return of adult pink salmon (millions
2 years later)

Brood Year	X	Y (Year)
1968	72.6	2.2 (1970)
1969	111.3	20.6 (1971)
1970	85.2	3.2 (1972)
1971	124.8	9.7 (1973)
1972	121.3	11.0 (1974)

$$\bar{X} = 113.04$$

$$\bar{Y} = 9.34$$

$$\beta = \frac{\sum XY - \frac{(\sum X)(\sum Y)}{n}}{[\sum X^2 - \frac{(\sum X)^2}{n}]^2}$$

$$\alpha = \bar{Y} - \beta \bar{X}$$

$$\alpha = 9.34$$

$$\alpha = -14.40$$

Thus

$$\hat{Y} = -14.40 + 0.21X$$

Current incomplete data include:

Brood Year	X	[Forecast] Y (year)
1973	133.9	[13.7] (1975)
1974	101.5	[6.9] (1976)

Pre-emergent fry density (X) in 1973 was found to be 133.9. The estimate of adult pink salmon (Y) returning in 1975 (two year life cycle)

$$\hat{Y} = \alpha + \beta X$$

$$\hat{Y} = -14.40 + 0.21 (133.9)$$

$$\hat{Y} = 13.7$$

The standard deviation of this estimate is calculated from that point on the regression line:

$$s^2 = \frac{\Sigma(Y - Y_1)^2 - \beta \Sigma(X - X_1)(Y - Y_1)}{n-2}$$

$$= 1.15$$

Pre-emergent fry density in 1974 was to be 101.5/m². The run forecast for 1976 can be made in the same manner (6.9).

Mark-Recapture Methods

Marked fish may provide information on abundance. These methods are well adapted for use on small, discrete freshwater stocks that support recreational fishing and for which catch statistics are difficult to obtain. The basic estimators are the single census, multiple census, and multiple recapture method.

Single Census

One of the simplest mark-recapture methods is the single census estimator using marked individuals and their recovery. The general method was developed by LePlace (1783) to estimate the human population of France (registered births were the "marks"). Peterson (1896) used mark-recapture to estimate exploitation rate. Dahl (1919) applied the method to a lake to estimate N. Lincoln (1930) applied it to wildlife and Jackson (1933) to entomology. In fisheries the actual estimate of N in mark-recapture is often incidental to estimating exploitation.

For a single census estimator, marked fish are released and then, at a subsequent time, a total catch is made including marked and unmarked individuals. This method is based on the principle that the proportion of marked fish recovered is to the total catch as the total number of marked fish released is to the total population.

Basic assumptions to be satisfied are: (1) marked fish have no more mortality than unmarked; (2) marked fish are caught at same rate as unmarked; (3) marks are not lost; (4) marked fish are randomly distributed or the sampling effort is random; and (5) recruitment is negligible or can be estimated.

The simplest estimator is

$$\hat{N} = \frac{mC}{r}$$

where m = number of fish marked

C = the catch taken for census (total marked and unmarked)

r = the number of recaptured individuals (marked fish) in the census

For example, say 550 fish are captured by fyke net and marked. Over the next two weeks, 8720 fish are taken by sportsmen of these creeled fish, 157 were marked.

$$m = 550$$

$$C = 8,720$$

$$r = 157$$

$$\hat{N} = \frac{(550)(8,720)}{157} = 30,547$$

One method of calculating the confidence interval depends on adjusting the recapture of marked fish from a Poisson to a normal distribution with the following formula:

$$r + 1.92 \pm 1.96 \sqrt{r + 1}$$

Thus,

$$157 + 1.92 \pm 1.96 \sqrt{158} = 134 \text{ and } 183$$

then substituting into the estimation formula,

$$\frac{(8,720)(550)}{134} = 35,791$$

and

$$\frac{8,720 \times 550}{183} = 26,214.$$

Finally the approximate confidence interval at $\alpha = 0.05$ is

$$26,200 < \hat{N} < 35,800$$

Exploitation rate (E) can be estimated by

$$\hat{E} = \frac{r}{m}$$

with a small r (binomial distribution),

$$V(\hat{E}) = \frac{C}{mN} \left(1 - \frac{m}{r}\right).$$

With a large r ($\frac{r}{C}$ approximates $\frac{m}{N}$),

$$V(\hat{E}) = \frac{r(C-r)}{m^2C}.$$

Multiple Census

The multiple census estimator is simply a modification of the single census estimator. The ideas behind the method were developed by Thompson (Illinois) and Juday (Wisconsin). Schnabel (1938) and Schumacher-Eshmeyer (1943) provided the mathematical basis. In this case marked fish are repeatedly added to the population while those removed are recorded by time period to yield an estimate of the population size. As the number of marked fish increases, the variance of the estimate decreases. The assumptions for this estimator are similar to the single census estimator.

As an example, assume we sample fish by fyke net daily. Each sampling time we mark any unmarked fish. Let

m_t = total number of marked fish at large at the start of the t th day,

Σm_t = total number marked to day t ,

C_t = total sample taken on day t ,

r_t = number of recaptures in the sample C_t , and

Σr_t = total recaptures during the experiment to day t .

C_t	Σm_t	$C_t \Sigma m_t$	r_t	Σr_t	\hat{N}
80	0	0	0	0	-
100	80	8,000	5	5	1600
60	175	10,500	9	14	1321
90	226	20,340	15	29	1340

N for each time period is estimated by

$$\hat{N} = \frac{\sum C_t m_t}{\sum r_t} \quad \text{or} \quad \hat{N} = \frac{\sum (C_t m_t)}{\sum r_t + 1}$$

With "low" r treat r as a poisson variable to calculate variance.

With "high" r, use a normal approximation. DeLury (1958) reviews the mathematical basis for variance estimation in multiple census estimation.

In the previous example, N has been estimated by

$$\hat{N} = \frac{\sum C_t m_t}{\sum r_t}$$

In practice the worker would continue sampling until the confidence interval is narrow enough for the purposes at hand.

Multiple Recapture

The multiple recapture method (Jolly-Seber Method) can be used in situations similar to these used in a single or multiple census, but in which a closed population cannot be assumed. However, it is best suited to small lakes where each marked fish can be recognized every time it is recaptured. Remarking and giving double weight to an already captured individual may introduce some bias if the individual is capture-prone. Fortunately, in most cases fish are not capture-prone and tend to avoid any type of sampling gear.

The multiple recapture procedure is as follows: On the first occasion ($t = 1$) the fish are marked, at $t = 2$, recaptures are noted and returned, and unmarked fish are given a different mark; at $t = 3$, the previous marks of both categories are recorded as well as unmarked individuals.

The data obtained maybe set up in tabular form:

Time Period	Fish Newly Marked	Fish Examined for Marks	Recaptures from 1st Marking	Recaptures from 2nd Marking
t	m_t	C_t	r_{1t}	r_{2t}
1	m_1	-	-	-
2	m_2	C_2	r_{12}	-
3	-	C_3	r_{14}	r_{23}

A direct estimate of the population at N_2 can be found by

$$\hat{N}_2 = \frac{m_2(C_2 + 1) r_{13}}{(r_{12} + 1) (r_{23} + 1)}$$

The variance of \hat{N}_2 is found by approximation techniques described by Seber (1973).

As an example, a small lake containing brook trout was sampled.

The data are as follows:

Time Period	Fish Newly Marked	Fish Examined for Marks	Recaptures from 1st Marking	Recaptures from 2nd Marking
1	500 (m_1)	-	-	-
2	400 (m_2)	480 (C_2)	120 (r_{12})	-
3	-	1000 (C_3)	163 (r_{13})	174 (r_{23})

$$\hat{N}_2 = \frac{(400)(481)(163)}{(121)(175)} = 1481$$

Catch Composition Methods

Change in Ratio

Population estimates can sometimes be made by taking the composition of the catch into consideration. The change in ratio (survey-removal) estimate is of this type. In using this estimator, (1) the relative abundance of two or more kinds of individuals in a population at $t=1$ is determined, (2) changes in the relative abundances are made by removing or adding known numbers of known kinds at some time later than $t=1$, and (3) estimates of the new relative abundances are made at $t=2$.

The assumptions for this estimator are as follows: (1) the kinds of individuals into which the population is divided must remain constant, i.e. male or female, marked or unmarked; (2) mortality and recruitment between $t=1$, and $t=2$ must be negligible or at least non selective with respect to the kinds of individuals into which the population is divided; and (3) mortality and recruitment must not occur while additions or removals are in progress.

The basic estimating equation is found by solving a series of simultaneous equations. The symbols used can be defined as follows:

N_1 = total number of fish (brook and brown trout, for example) in the population at $t=1$.

X = number (brook trout) added or removed between $t=1$ and $t=2$

Y = number of the other kind of fish added or removed (brown trout)

p_1 = decimal fraction of population N_1 which consists of one kind (brook trout) at $t=1$.

p_2 = new decimal fraction (or brook trout) among the N_2 individuals in the population at $t=2$

N_2 = total number of fish (brook and brown trout) in the population at $t=2$

The two necessary simultaneous equations can be formed as follows:

$$p_2 N_2 = p_1 N_1 + X$$

$$N_2 = N_1 + X + Y$$

solving

$$\hat{N}_1 = \frac{X - p_2 (X + Y)}{p_2 - p_1}$$

There are many possible applications of this method. One possibility likely to occur arises whenever a creel census is conducted on a fishery with more than one species present. For example a trout population is shown by sampling to consist of 70% brook trout and 30% brown trout. If anglers remove 200 brook trout and 30 brown trout and a second sampling shows that the removal of fish changed the brook to brown trout ratios to 55% brooks and 45% browns N_1 is found as follows:

$$\hat{N}_1 = \frac{-200 - 0.55 (-230)}{0.55 - 0.70} = \frac{-73.5}{-0.15} = 490$$

$$\hat{N}_1 \text{ (brook trout)} = 343$$

$$\hat{N}_1 \text{ (brown trout)} = 147$$

Virtual Population

An estimate of the actual population can be made from knowing the virtual population, but this method can be applied only when there are extensive creel census data on the fishery. A yearly age census of the catch and the allocation of the catch among year-classes must be carried out. The virtual population can be defined as the minimum estimate of catchable fish present in one year which is the total of the minimum number of fish in existence of each year class. To estimate the actual population from the virtual population a number of fish must be marked and the number of recaptures of these fish in following years must be recorded.

The assumptions include (1) complete recruitment of the recruiting age class and older; (2) the same rate of exploitation for all age classes; (3) negligible natural mortality at all ages greater than the recruited age; and (4) constant recruitment of the recruiting class from year to year.

To find the virtual population estimate with a variable survival rate, a table of the minimum number of survivors of each brood year is constructed.

Year Class	III	IV	V	VI	Total Virtual Population	Year
1961	-	-	-	1665	5553	1967
1962	-	-	1371	1243	4764	1968
1963	-	1294	1199	1165	4650	1969
1964	1223	1193	1180	1062	4774	1970
1965	1129	1122	1059	939	4711	1971
1966	1277	1265	1229	1147	-	-
1967	1388	1349	1265	1121	-	-
1968	1194	1174	1095	1049	-	-

The total virtual population is found by summing the entries diagonally from lower left to upper right. Thus at the start of the 1967 fishing season there were at least 5553 fish of age III or older in the lake, 4764 in 1968, 4650 in 1969, etc. Exploitation rate can be calculated by

$$E_t(\max) = \frac{C_t}{\bar{V}_t}$$

The actual population can be found by combining the results of a marking experiment with the virtual population. The total recoveries from m fish marked at the start of year 1 (1967 in this case) in successive years of their appearance in the fishery is $r_1 + r_2 + r_3 + \dots$

then

$$\hat{N} = \frac{mV}{r_1 + r_2 + r_3 + \dots + r_{t+n}}$$

For example, the virtual population in 1967 is 5553. During that year 500 fish were marked and $r_1 = 53$, $r_2 = 45$, $r_3 = 75$, then

$$\hat{N}_{1967} = \frac{(5553)(500)}{53 + 45 + 75} = 16,049.$$

If we assume a constant age composition in the stock and let $X =$ fraction of age i , then

$$V = \sum_{i=1}^{\infty} C_t (1 - X_1 - X_2 \dots - X_{i-1}),$$

when

$V =$ Virtual estimate of N .

Depletion Methods

The depletion method (regression, Delury, Leslie methods) is based on the principle that a decrease in catch per unit of effort (C/f) as the population is depleted bears a direct relationship to the extent of the depletion. This estimator can only be used where at least 50% of the population can be removed as it depends on the ability to estimate the slope of the regression of C/f on either cumulative catch or effort. Catches from most sport fisheries are unsatisfactory for using this method because of variation in catch. However, this can be overcome by simulating fishing effort and catch by electro-fishing. In a valuable sport or commercial fishery, captured fish can be marked and subsequently ignored instead of removing them.

The assumptions are (1) catchability of the fish remains constant; (2) the population is totally available to the fishery, (3) there is no natural mortality or recruitment; and (4) the fishing effort applied is constant.

The number of fish in the population is found by sampling the population a number of times (using a constant fishing pressure), and plotting a regression line of C/f on cumulative catch (ΣC_t) for each time period. The regression line is then projected to the intercept of the X axis, the initial population size. The initial population size can be directly found without plotting by mathematically deriving the intercept using the least squares method.

By definition the C_t/f during time t is equal to the catchability (q) multiplied by the population present at the beginning of that time.

$$C_t/f_t = qN_t \quad (1)$$

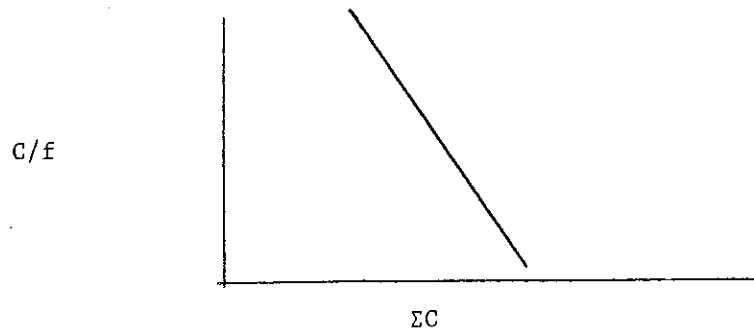
The population at the start of time t is equal to the original population less the cumulative catch ΣC .

$$N_t = N_o - \Sigma C \quad (2)$$

substituting into (1)

$$C_t/f = q(N_o - \Sigma C) \quad (3)$$

Equation 3 indicates that C/f plotted against ΣC has a slope of q . Also, the X axis intercept is an estimate of the original population N_o , since it represents ΣC if C/f and the population were hypothetically reduced to zero by fishing. N_o can now be found using the least squares methods to obtain the X axis intercept.



A hypothetical example follows showing table set up and calculations:

Time Period	$\Sigma C(X)$	$C_t/F_t (Y)$
1	0	131
2	131	69
3	200	99
4	299	78
5	377	56
6	433	76
7	509	49
8	558	42
9	600	63
10	663	47
Total	3,700	710

$$\Sigma x^2 = 1,846,194 - 3770^2/10 = 424,904$$

$$\Sigma y^2 = 57,062 - 710/10 - 6652$$

$$\Sigma xy = 223,519 - 3770 \times 710/10 = -44,151$$

$$\beta = \text{slope} = -44151/424904 = -0.103908$$

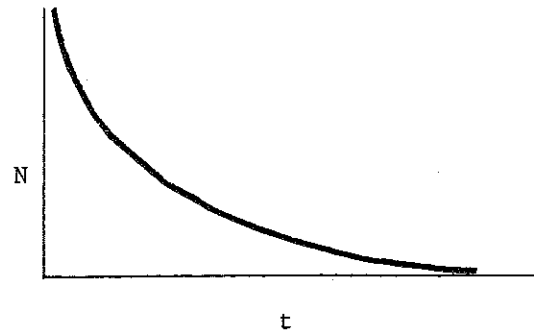
$$\alpha = \text{Intercept} = \frac{710 - (-0.103908 \times 3770)}{10} = 110.73$$

$$q = \text{catchability} = +0.103908$$

$$\hat{N}_0 = 1060$$

MORTALITY

Mortality in populations can be expressed in a number of ways. For example, the general decline in abundance of a particular year class often follows a rate proportional to the abundance level at any point in time.



The above graphical model can be described by

$$\frac{dN}{dt} = -ZN.$$

By integrating, it can be shown that

$$N_t = N_0 e^{-Zt}.$$

By rearranging terms,

$$\frac{N_t}{N_0} = e^{-Zt}.$$

The term $\frac{N_t}{N_0}$ is simply a ratio of the number of fish alive at the end of time t to the number alive at the beginning of time 0, or survival (S). Therefore,

$$S = e^{-Zt}$$

By taking the natural logarithm of both sides,

$$Z = -\ln S.$$

Z is defined as the instantaneous total mortality rate (or force of total mortality).

Total mortality is made up of two components: fishing mortality and natural mortality. Mathematically,

$$Z = F + M$$

where

F = instantaneous fishing mortality rate, and

M = instantaneous natural mortality rate.

Then, using a previously developed equation,

$$N_t = N_0 e^{-Zt}$$

$$N_t = N_0 e^{-(F + M)t}$$

Estimating Total Mortality

Successive Ages

If fishes can be easily aged (or placed in size classes), then

$$\hat{S} = \frac{N_{t+1}}{N_t}$$

and

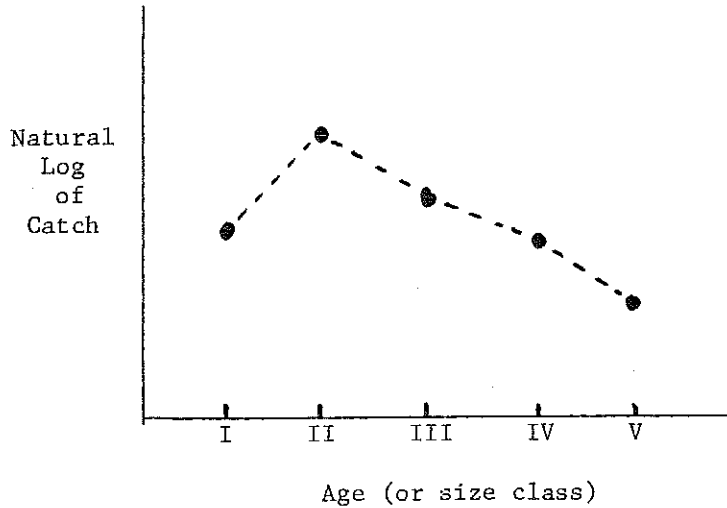
$$\hat{Z} = -\ln \hat{S}$$

can be used to estimate Z. This procedure is simple to use in practice, utilizing either population estimates or indices of abundances. There are also many variations to the basic method that can be useful in providing improved estimates in certain situations.

Disadvantages with the method of successive ages are: (1) highly variable year class strength; (2) variable mortality due to random environmental changes; and (3) bias in sampling.

Catch Curves

A second approach to estimating total mortality is by the use of catch curves. The basic principle is similar to that of successive ages, except that catch data are used. Catch data may be plotted as:



The left side of the curve represents incompletely captured ages, and speculation on mortality rates for these age classes is risky. The constant slope on the right side indicates mortality is probably constant.

To calculate total instantaneous mortality, the differences between abundance of two age classes is determined. Since catches are expressed as natural logs, a difference is actually a division. In other words, the slope of the right side is equal to Z .

Estimating Fishing Mortality

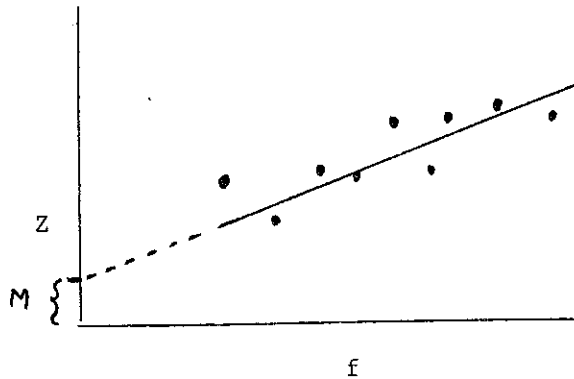
Exploitation rate (E) is the probability that a given fish will die during the year when all other causes of death are operating on the population. The simplest way to estimate E is by using catch and abundance data

$$E = \frac{\hat{C}}{\hat{N}}$$

Since \hat{C} and \hat{N} are estimates themselves, the resulting estimate may not be very precise and/or accurate.

Another approach is to use tag data. The principle is very closely related to single census estimation (see chapter on Abundance). Tagged fish are released and the total recovery over a specified time period (usually a fishing season) relative to the number released provide an estimate of E.

A third approach to estimating fishing mortality, is to use changes in total mortality. Fisheries with long histories of data are amenable to this approach.



If the regression line is extended to $f = 0$, the only mortality operating on the population would be due to natural causes. Fishing mortality would then be estimated by the mortality rate above the natural mortality rate.

Estimating Natural Mortality

Natural mortality is nearly always estimated by the difference between total and fishing mortality,

$$M = Z - F.$$

In a few situations (virgin fisheries or closed fisheries) it may be possible to estimate natural mortality directly, but this is the rare case.

Exploitation Rate

Manipulating exploitation rate (fishing pressure) is one of the most useful tools in fisheries management. Since

$$F = \left[\frac{E}{1-S} \right] Z,$$

the manager could conceivably adjust E and then predict the effect on F. If E is increased by 25%, the above equation could be solved to determine the effect on F. And since,

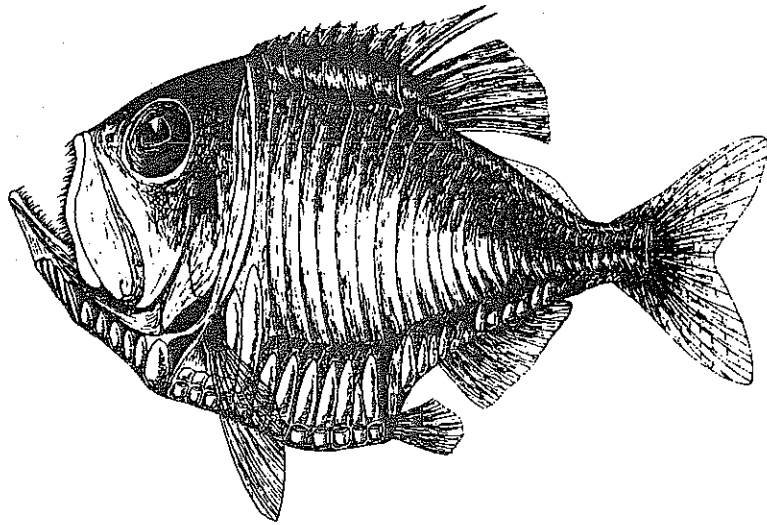
$$F = qf$$

where,

q = catchability coefficient

f = fishing intensity

then, f could be adjusted to provide the desired level of F.





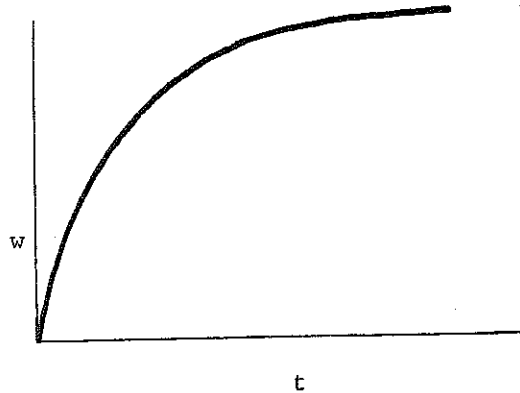
GROWTH

Growth can be defined as change in length or weight of an animal over time. Changes in numbers over time are considered under "mortality" and are covered in Chapter 5. Analysis of growth in fisheries management is usually designed for (1) predicting average fish size at some point in time, and (2) comparing "well-being" of fish in different systems or under different management strategies.

An equation describing growth of fishes should possess a number of characteristics to be useful in fisheries work. The equation should be relatively easily fitted to data. Second, growth characteristics should be reasonably well described over the desired range of time. Third, the number of assumptions should be as few as possible and reasonable. A final characteristic for a useful growth equation is the ease with which it can be integrated with other population dynamics models.

Exponential Growth

There are two growth models used extensively in fisheries. The first, exponential growth, can be graphically illustrated by



Mathematically, the model is

$$w_t = w_0 e^{Gt}$$

where

w_t = Weight of individual fish at time t

G = Growth rate

The exponential model is usually used over relatively short time periods because growth rate changes over the life of a fish. The exponential model is easy to use analytically in calculating short-term yield, but cannot be easily used for long-term prediction.

In practice, G can be estimated by

$$w_t = w_0 e^{Gt}$$

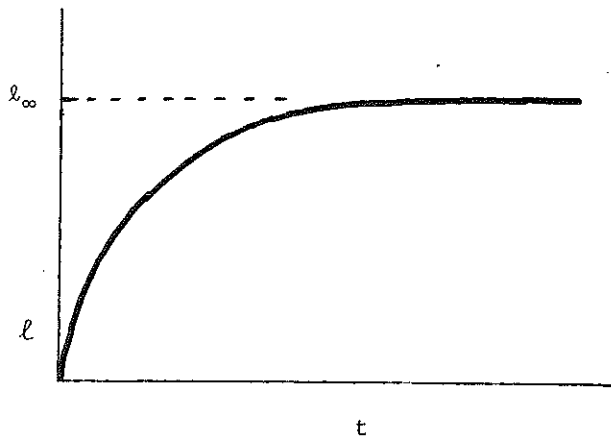
$$e^{Gt} = \frac{w_t}{w_0}$$

at $t = 1$

$$\hat{G} = \ln w_t - \ln w_0$$

Von Bertalanffy Model

The second growth model is the von Bertalanffy equation. If the rate of growth in fish length is linearly related to length, then:



Mathematically,

$$\frac{dl}{dt} = K(l_{\infty} - l)$$

$$\frac{dl}{dt} = K(l_{\infty} - l)$$

$$l_t = l_{\infty} - ce^{-Kt}$$

where

c = constant of integration

At

$$l = 0 \text{ and } t = 0,$$

$$0 = l_{\infty} - ce^{-Kt}$$

$$l_{\infty} = ce^{-Kt}$$

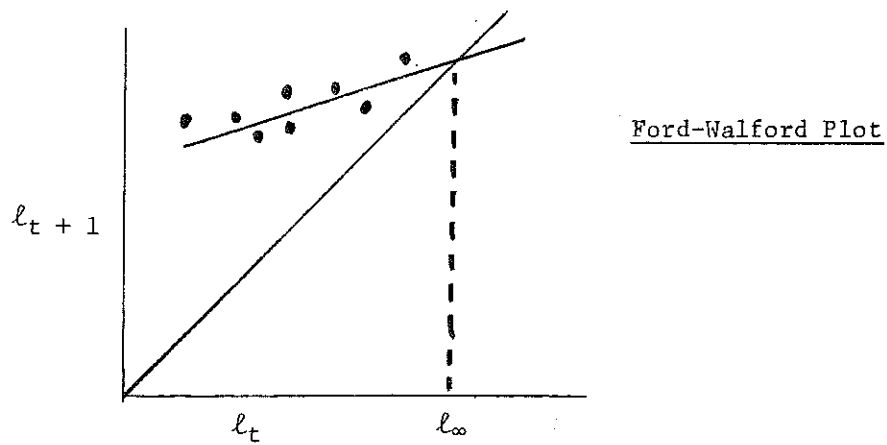
$$c = l_{\infty}e^{Kt}$$

then

$$l_t = l_{\infty} [1 - e^{-K(t-t_0)}] .$$

In practice, we must estimate l_{∞} (maximum fish length), K (growth coefficient), and t_0 (time when length would theoretically be zero). Maximum fish length can be easily estimated by observation, as well as by analytical techniques. The other two coefficients must be solved analytically.

If length at one age class is plotted against length at the next older age class, it is possible to estimate K and l_{∞} .



The slope (β) of the line fitted to the data is e^{-K} . The following manipulation provides an estimate of K .

$$\beta = e^{-K}$$

$$\ln \beta = -K$$

$$K = \ln \beta$$

The Ford-Walford plot may also be used to estimate l_{∞} . The 45° line represents a "no growth" relationship and its intercept with the plotted line estimates l_{∞} .

An estimate of t_0 can be made by substituting in the growth equation estimates of K and l_{∞} at a particular l_t and t .

Length-Weight Conversion

The weight of a fish is generally proportional to the cube of its length. Von Bertalanffy's equation can thus be changed to

$$w_t = w_\infty [1 - e^{-K(t-t_0)}]^\beta$$

Usually, β will be about 3 since

$$w = \alpha l^\beta$$

RECRUITMENT

Predicting recruitment, the addition of new individuals to a population or stock, is one of the truly challenging problems in fisheries management. The amount of effort expended to improve recruitment prediction is substantial, but success has been limited.

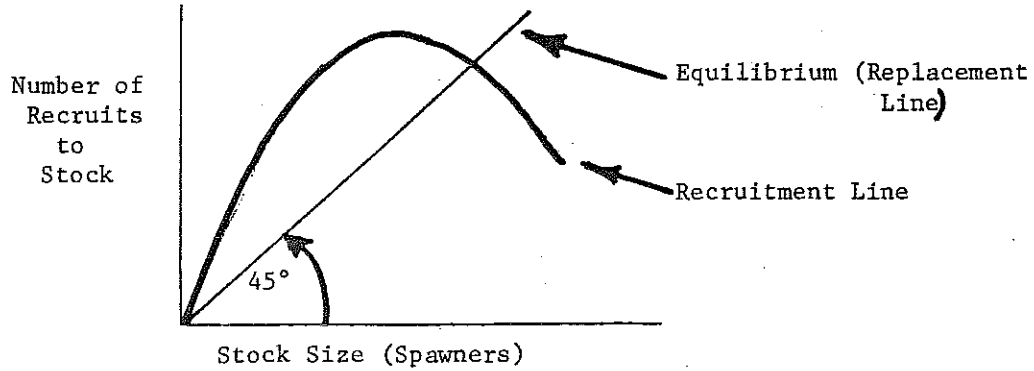
A number of factors can affect recruitment, including spawning stock size, environmental factors, predation, and competition. These factors can be categorized as either density-independent or density-dependent.

Density-independent factors act in a manner unrelated to population level. Pollution, floods, and water temperature act independent of population level. A fisheries manager must often handle these probalistic or stochastic events.

Density-dependent factors are related to population level or ecological interrelationships. Competition, predation, and disease may be in part or in total, related to population level and can be consider density dependent factors.

Ricker Stock-Recruitment Model

If we assume that density dependent factors play the dominant role in determining recruitment, then such a model may be graphed as



Mathematically,

$$R = N e^{-\alpha (N_r - N)/N_{\max}}$$

where

R = Recruitment from N

N_r = Replacement stock (exactly replaces itself)

N_{\max} = Stock size which produced maximum recruitment

If

$$\alpha = N_r/N_{\max}$$

Then

$$R = N e^{-\alpha (1 - N/N_{\max})}$$

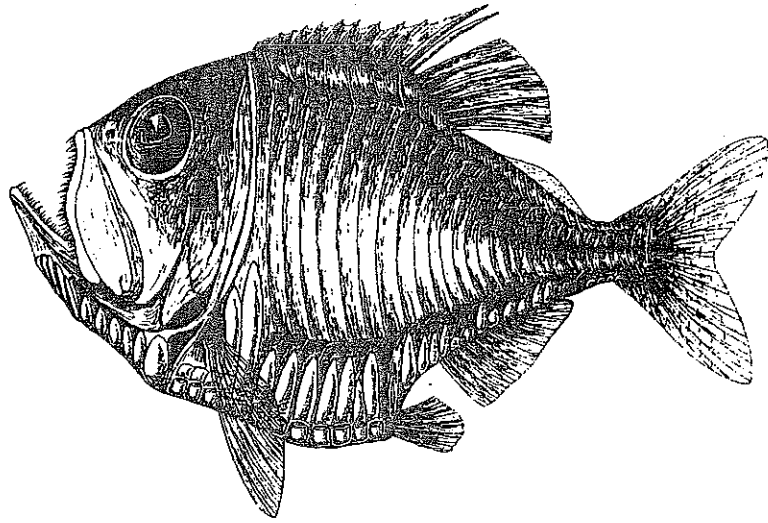
The Ricker stock-recruitment model is well studied, especially as related to Pacific salmon fisheries. The largest predictive problem is accounting for variations due to density-independent factors.

Recruitment Regression Models

A number of workers have combined density-dependent and density-independent factors into multiple regression models. The general case is

$$R = f(N, \text{Environmental Factors})$$

Recruitment is predicted as a function of population level and any number of environmental factors, such as water temperature and weather conditions.





MULTI-STOCK FISHERIES

Effectively managing multi-stock fisheries is a perpetual engima in fisheries management. Successfully managing a single species is difficult at best, but managing a fishery with two, three, or more competing species is a formidable, if not impossible task. To enhance understanding of fisheries and thereby increase management capabilities, mathematical models have been formulated which attempt to describe how fisheries function. Some of these models have become classical tools in fisheries management. Unfortunately, none of the models is particularly applicable in multispecies situations which are characteristic of freshwater fisheries. The classical models best apply to single species fisheries as found in the marine commercial situation. For example, the Ricker (1954) stock-recruitment model applies to a fishery where fish spawn once and die, as in the Pacific salmon fisheries.

The two best known single stock models are the dynamic pool model (Beverton and Holt) and the logistic model (Schaefer). The dynamic pool model describes a fishery in terms of the vital statistics of recruitment, growth, and mortality. Implementing this model requires a large amount of data and can generally be successful only after substantial information has been collected on a fishery. The logistic model, also called the surplus-yield model, combines the effects of recruitment, growth, and natural mortality into a single-valued function of population biomass. The logistic model is usually employed when information on a fishery is relatively scanty, requiring only catch and effort data for a series of years.

Both the dynamic pool and the logistic model 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. The logistic model has been useful in managing the Eastern Tropical Pacific yellowfin tuna fishery. Neither, however, has been applied with much success in freshwater sport fisheries. Watt (1959) did an extensive study of the smallmouth bass population of South Bay, Lake Huron. He applied four different population models to the fishery, including the logistic and dynamic pool models, and found that all models were deficient in one or more respects. He attributed the weakness of the models to lack of adequate input data. He had "relatively small amounts of information collected over only a ten year period" (emphasis added). In comparison to data available on most freshwater sport fisheries, Watt had an abundance of information. Watt's conclusion illustrates one of the main problems with classical fisheries models: they simply require more data than are available on most sport fisheries to be accurate predictive tools.

An additional problem with all commonly used fisheries models is the deterministic description of stochastic population phenomena. Models that incorporate stochastic processes may provide better descriptions of fisheries dynamics. An example of deterministic versus stochastic processes should illustrate why the latter is to be preferred for sport fisheries. A deterministic model predicts that for a given value of the independent variable, X , we can expect the dependent variable to have a corresponding value, Y . A stochastic model predicts that for a given value of X we can expect any one of a number of Y_i values, with a probability of P_i attached to the occurrence of each Y_i . The stochastic approach is appropriate where a steady state situation cannot be safely assumed, which is the case in most fisheries.

There are many computer-implemented stochastic fisheries models described in the literature. A simulation model has been developed to investigate economic and biological consequences of various strategies for restricting entry of gear into the salmon net fisheries. A computer simulator has been used to synthesize the main features of the population biology of sockeye salmon of the Skeena River. A large-scale simulation model has been used to study three management strategies for limiting halibut catch in the north-eastern Pacific. Others developed a simulator to determine potential economic benefits to the canning industry of varying degrees of forecast reliability of the size of sockeye salmon runs to Bristol Bay, Alaska.

Analysis and modeling of complex fisheries is difficult and there are few examples in the literature. A stochastic model has been constructed of interpopulation dynamics based on energy flow through an ecological system composed of the Pacific sardine, the northern anchovy, and their competitors, predators, and prey. Large-scale models of marine commercial fisheries are not easily applicable to a freshwater sport fishery. Walters (1969) developed a general computer simulation model which may have application in sport fisheries, but the basic model structure is deterministic. Also, this model is designed to describe a single species fishery and therefore, its predictive value in most freshwater fisheries is limited. Zuboy and Lackey (1974) developed a computer simulator, STOCKS, to test alternative management strategies in a three species warmwater lake fishery.

SYSTEMS

SCIENCE



SYSTEMS ANALYSIS

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

Systems analysis is a process of translating concepts about a system into a set of mathematical relationships and manipulating the model thus derived. This definition is quite comprehensive and its full impact may not be easily recognized.

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, has 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 clearly 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 organism can exist by itself. It is dependent on other organisms 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 behavior 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 FORTRAN 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 procedure 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 are 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. Remember that 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, as will be discussed shortly, 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. The 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 initially estimated, quantification must be accomplished. Statistical tools used in quantification procedures include multiple regression analysis. Multiple regression analysis relates simultaneous changes in several independent variables to changes in a dependent variable. Correlation analysis differs from regression analysis in that the functional relationship on one variable to another is not considered. 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 (illustrative) 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, are 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, represent 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.

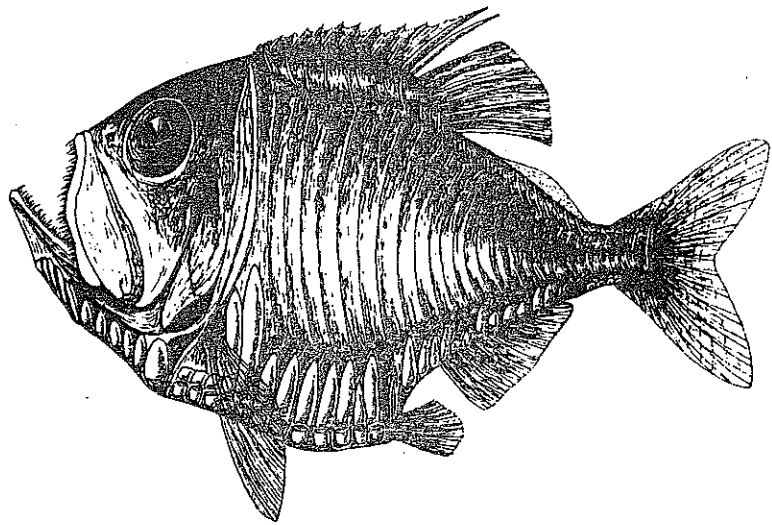
The basic mathematical tools used in model development are set theory and transformations, matrix algebra, and differential equations. Set theory is used with change of state models. A set consists of a group of equations which represent a particular state of the ecosystem as defined by the system variables. 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 a 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 large-mouth bass population.

After an initial working model has been developed, it must be refined until it satisfactorily mimics the real situation 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. Using a fishery model, the effects of increased primary production due to fertilization could be determined by changing the value of a forcing function so as to represent this fertilization. Weaknesses of a model, which are due to a 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 three basic goals of model building: (1) realism; (2) precision; and (3) generality. Realism describes the amount of correlation between the mathematical equations of the model and the expression. Precision is a measure of the model's ability to mimic new data from the ecosystem on which it is based. Generality refers to the number of different situations to which the model is applicable. If the model successfully accomplishes the objectives for which it was developed, then the model is a success. If a model has been developed from an analysis based on insufficient or inaccurate information, or has not been properly validated, then it is of more limited use. A major constraint on ecosystem analysis lies in the area of data acquisition. Many of the field methods of obtaining and handling data are of limited use in meeting data requirements for some models.

There are a variety of uses for ecosystem models. Models may be used to guide research efforts, by simplifying and facilitating understanding of the ecosystem 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

Fisheries modeling, specifically fish population modeling, has experienced a rapid increase in popularity in the last twenty years. Older mathematical characterizations of populations were expressed as a single differential equation with one or two parameters, such as in the Malthusian growth equation or the logistic function. More recent models have tended to include systems of equations describing several populations and the effects of abiotic factors. Such models require many parameters for quantification. Several contemporary models have also included probability aspects by incorporating stochastic processes as random variability.

State of the Art

Mathematical models of populations largely started with the birth process model of Malthus (exponential growth) and developed later into the logistic model of Verhulst and Pearl. Both models assume a constant rate of population increase with the logistic carrying an extra parameter governing the maximum attainable population size. Lotka, Volterra, and Gause expanded these models by incorporating two species into a differential equation. These two-species models were instrumental to the development of general ecological concepts, but were too gross for direct use in fisheries management.

Later modeling approaches tended to follow one of the two general paths: (1) those describing populations at discrete points in time; and (2) those describing populations continuously through time by instantaneous rates. Functional differences between these approaches are minimized as the discrete time intervals are reduced.

One of the most important discrete models is Leslie's age dependent birth and death rate model. Birth and death parameters for each age class comprise a single matrix. The structure of the entire population is described by this single matrix and it can be easily computer-implemented. One major deficiency in Leslie's model is that the birth and death rates in a time interval are usually not constant, but are a product of the system (i.e., the population size, abundance of forage, etc). Without a functional relationship for birth and death rates, application of Leslie's model is of limited use in most fisheries management situations. Other researchers, however, have added such a functional relationship which more closely approximates the structure of real systems.

Continuous time models, developed from differential equations, are also used to describe population dynamics. One of the first continuous time models used with success in fisheries management was the classical Ricker stock-recruitment model. This model only accounts for the effect of population abundance on recruitment. Even though growth effects were not included, it was one of the first models directly oriented toward management objectives and was a precursor for more complex approaches, that resulted in yield models.

Yield models achieved popularity with fisheries managers for two reasons: (1) they were oriented toward predicting yield from fisheries; and (2) most of the required information can be obtained from catch or creel data. Yield models can be conveniently divided into surplus production models and dynamic pool models.

The surplus production model of Schaefer assumes that: (1) the rate of natural population increase responds immediately to changes in population abundance; and (2) the rate of natural increase at a given population biomass is independent of any age-structure deviation from the steady state age-structure of that population biomass. The best success with this model has been achieved with tropical fisheries where age determinations are difficult.

The dynamic pool model (Beverton and Holt) assumes constant recruitment and mortality rates and a growth rate independent of population size. The model also distinguishes between the number of fish in a new year class and the time that they recruit to the fishery, which facilitates evaluation of fishing impact. The Beverton-Holt model has been applied to many fisheries with success.

Other workers have modified the dynamic pool approach to include n species in equilibrium by starting with a single species model of the Beverton and Holt type, except that yearly recruitment occurs at an instantaneous point in time, rather than over a time interval. A second species is added to include interspecific interaction. The generalized model includes n species. The coefficients of the interaction (both intra- and inter-specific) are expressed in a single matrix to evaluate equilibrium dynamics (i.e. fishing pressure required to bring the population back to steady state). The problem with such a model lies in two areas: (1) the steady state assumptions of a constant environment are seldom if ever met; and (2) since the interactive coefficients have no physical significance, there is a great deal of difficulty in their estimation.

Another approach, which developed simultaneously with the yield models, was stochastic modeling which described the random effects of nature. Stochastic processes using Beverton and Holt's dynamic pool framework were formulated to provide a philosophical interconnection between deterministic modeling and their stochastic counterparts. Also, a stochastic multi-species model of population dynamics in a marine environment has been developed. As components are incorporated into a stochastic process, the analytical complexity increases disproportionately, so other methods of including randomness had to be developed.

These methods to account for randomness were Monte Carlo techniques whereby random variables are generated for input into a deterministic model and the output can be tested statistically. These techniques have been employed using a derivation of the surplus production model and conceivably, they may be used with any deterministic model, thereby increasing realism.

A somewhat different approach to modeling has been taken by many investigators concerned with individual ecological phenomena. Models of random dispersal, stability and diversity, effects of temperature on biological rate processes, time lags, density effects on reproduction, predation, and growth have been developed. These models may be incorporated into larger population dynamic models (as was done with the von Bertalanffy growth equation appearing in dynamic pool models). The predator-prey model (Holling) is especially promising because it stresses the importance of biological time, i.e., the time it takes for an event to occur in the organism's life cycle. Others use energy flow concepts in growth and predation and they partition the available energy according to metabolic needs. These concepts may also be used in larger models.

Another area of particular promise is the theory of optimization and control of systems. Ricker's stock-recruitment curve, from which maximum sustainable yield for some fisheries may be estimated, could be considered a form of optimal control, but it in no way reflects the mathematical techniques available today. Linear programming has been used for economic analysis of salmon fisheries, but the assumption of linearity does not conform to many biological problems. Dynamic programming has been used extensively in water resource management models. The only biological application of dynamic programming to date is the evaluation of management strategies on a pest species. Another mathematical programming approach which employs the continuous maximum principle has been suggested for fisheries. These last two methods (dynamic programming and the continuous maximum principle) appear to be especially good because they assume no linearity of the models and they are structured so that they may be used in multi-stage decision processes, where a decision at one point in time will affect the system's state at some later date.

This brings us to the ecosystem models. In these, systems of difference or differential equations describe the important components of an entire ecosystem. Choice between differential or difference equations is generally a minor point, since computer solutions of the differential equations are approximate. Interactive feedback loops, reflecting both abiotic and biotic factors and their effects, are used extensively. These models have been far-reaching steps toward understanding the complexities of an ecosystem, but currently they have not been employed in management problems.

Modeling - The Future

Fisheries management modeling in the future will probably include the major components of an ecosystem as well as feedbacks. In order to characterize these feedback loops, models of ecological phenomena such as abundance-reproduction relationships and predator-prey relationships will probably be employed. Monte Carlo generation of random variables will be a necessity and may include more than simple generation of random variation around an expected quantity of objects such as numbers of eggs or numbers of prey eaten. Random variable generation may be used to obtain the time of an important event in an organism's life.

Most importantly, a fisheries management model must use concepts of optimization. If a fishery is to be managed effectively, the best decisions must be made from the available alternatives. Optimizing a fishery implies that effective measures of the fishery's performance have been developed, i.e., the management objectives have been formally defined, but in most systems this is far from true. Therefore, criteria functions for a fishery must be developed. In a general use model these criteria may be many, so that a manager may select the ones that apply to his situation, e.g., optimizing for dollar yield rather than maximum sustainable yield in pounds of fish.

***MANAGEMENT
TECHNIQUES***

GENERAL MANAGEMENT TECHNIQUES

Habitat Improvement

The ecological justification of habitat management is based on Liebig's Law of the Minimum. The premise is that for all animal populations, there is one environmental factor, biotic or abiotic, that is present in the least relative quantity (the greatest relative quantity in the case of predation and competition) which prevents the population from increasing beyond its present level. When a fisheries manager decides to improve habitat, whether it be adding fish cover, adding spawning areas, or fertilizing nutrient-poor waters, he is acting as if he has identified the limiting factor for the particular population whose yield he is trying to increase. By changing the habitat factor that is limiting, the inflection point of the sigmoid growth curve may increase.

Many habitat improvement procedures attempt to increase spawning areas for game fishes in order to increase recruitment. This approach implies that increasing recruitment is desirable (often not true) and that density dependent mortality factors are not the prime reasons for limited recruitment. Successful attempts have been made to construct spawning channels for anadromous fishes. Efforts have been particularly rewarding where spawning areas have been destroyed. The technique includes providing proper gravel, water level, and stream flow in the artificial channel.

Natural sloughs have been used for rearing steelhead fry. Fry are allowed to mature for one year prior to seaward migration. They are given protection from predation, food supplements, and controlled water levels. The goal of this procedure is to increase fish catch on their return migration from the ocean.

Boxes of gravel or graveling large areas have been utilized in warmwater lakes for nest building fishes. This technique is especially useful for smallmouth bass reproduction since these fish will not spawn successfully over silty or mud bottoms. Quantities of large rocks (baseball to bushel basket size) have been dumped in lakes in Maine to increase lake trout reproduction.

In areas where northern pike are important game fish, the practice of lakeside marsh drainage has reduced much of the pike spawning habitat. The management practice of water level control on once-drained marshes can provide spawning habitat. Mature pike are caught and put in the controlled marshes, 2 males and 1 female per acre of marsh. Young pike are released from the marsh when 2 inches long, when they start eating each other.

Habitat improvement in streams may include many practices other than spawning improvement. Current deflectors designed to increase the number and depth of pools in trout streams are sometimes employed. Studies on Hunt Creek, Michigan, showed that current deflectors caused material to be swept from pool floors, thereby uncovering previously silted gravel and increasing the number of food organisms available to trout.

Much has been done to facilitate fish migration on streams and rivers. Construction of fishways on dammed rivers of the Pacific Northwest has been especially important for anadromous salmon and trout management. Fishways on small dams on inlet streams to lakes can be important for fish that make spawning runs up these streams. Fishways should allow for the following principles of operation: (1) suitable for passage for all migratory species in the area; (2) operate at all water levels in the forebay and tailrace of the dam; (3) operate at all volumes of flow; (4) fish should be able to ascend without injury or extreme exertion; and (5) fish should be able to find the entrance, enter quickly, and pass through the fishway without delay. Obstructions, other than man-made dams, may retard fish migration. Logs, sandbars, and beaver dams may have to be removed from streams.

Stream siltation can be detrimental for fish spawning and on fish food production. Fencing stream banks from livestock can cut down erosion and consequent siltation by preventing bank breakdown and by allowing a buffer zone for vegetation.

In certain instances it has been speculated that lack of cover in streams may be limiting trout or smallmouth bass production rate. Stumps of trees anchored to the bank and pointing down stream and boulder filled cribs are two of the many techniques for increasing stream cover.

There is considerable speculation among fisheries scientists whether creation of artificial shelters in lakes actually affects lake production or merely serves to concentrate fish in known areas for anglers. The latter effect would be helpful for achieving maximum equilibrium yield of warmwater species whose populations are too great. Shelters of logs, brush, or tires have been used principally in waters relatively barren of natural cover.

Much effort has been expended to rid lakes of extensive plant growth, be they algae or higher aquatic plants. Extensive aquatic plant growth is instrumental in causing summer- and winterkills, decreased dissolved oxygen in the hypolimnion, and reduced angling opportunities. Dense aquatic weed patches may allow trash or pan fish to overpopulate a lake by providing too much protection from predators. Techniques for reducing aquatic plants include: (1) herbicides like copper sulfate; (2) harvesting vascular plants by machine; (3) eliminating excessive nutrient additions from sewage and agricultural run-off; and (4) fertilizing ponds to cause algal blooms, which block sunlight penetration and prevent rooted aquatic plants from growing.

Many recent attempts have been made to artificially destratify lakes. During the summer when well defined epi-, meta-, and hypolimnions occur and top to bottom water circulation is prevented, the hypolimnion may have insufficient dissolved oxygen and the epilimnion may become nutrient poor. Different types of aerators can be employed to bubble air from bottom waters in an attempt to mix bottom and surface water, thus disrupting stratification.

In northern lakes where algal blooms may occur in the winter, dissolved oxygen may drop to lethal levels when sunlight cannot penetrate snow-covered ice. Attempts have been made to remove snow by plowing, thus allowing a more favorable ratio of algal photosynthesis to respiration.

In waters where low phosphorous or nitrogen concentrations limit algal productivity, game fish production may be limited due to food chain relationships. Game fish production may possibly be increased by adding these nutrients to the system. Generally, fertility of the water is related to fertility of the land over which the water flows. Thus, in areas of the midwest where soils are very fertile, the water is fertile. Therefore artificial fertilization is generally not practiced and, in fact, probably would be harmful due to accelerated eutrophication and the concomittant problems stemming from excessive blue-green algal blooms. However, in the southeastern states where soils tend to be less fertile, artificial addition of phosphorous or nitrogen is often recommended to increase game fish production. This practice is most suitable in small, shallow lakes where control of the lake outlet to prevent loss of fertilized water can be achieved.

Stocking

With the exception of trout, salmon, and other coldwater fishes, yield to fishermen generally can be maximized within the context of natural reproduction. Factors other than reproduction, such as overpopulation, competition, habitat destruction or alteration, and pollution, are generally much more important in determining yield.

Stocking can be beneficial in several circumstances: (1) in new or reclaimed waters or in waters where occurrences such as winterkill, drainage, or pollution have eliminated a desired species; (2) introduction of a new species; (3) restoration of population balance by introducing large numbers of predatory fish to prey on a forage fish population; (4) replacement of deficient spawning where there has been year class failures in otherwise suitable habitat; (5) stocking catchable-size trout to provide fishing in ponds, lakes, or streams that lack habitat for reproduction or fingerling survival in order to maintain short-term yields at higher levels the waters will naturally supply; (6) increase salmon yields by planting fry in streams where salmon normally breed, but dams or spawning habitat destruction prevent spawning; and (7) introduction of forage fish into an aquatic system where significant unused phyto- or zooplankton biomass may be transferred through forage fish to game fish. Alewives, smelt, and gizzard shad are often introduced into reservoirs to provide increased food for largemouth, white, and striped bass.

Control of Undesirable Fish

Fisheries management is replete with instances where control of undesirable fish is required. Undesirable fish, by competition, predation, or parasitism, increase environmental resistance acting on game fish populations, and thus suppress maximum equilibrium yield.

The following are situations where control of undesirable fish is often practiced:

- (1) In instances characterized by the bass-bluegill relationship where a less desirable fish, whose population is normally suppressed, may dominate a body of water due to heavy angling pressure on the desirable predator;
- (2) In instances where a desirable game fish population has become stunted due to their overabundance, producing few legal or desirable sized fish;
- (3) In instances where feeding habits of certain fishes (carp, gizzard shad, various suckers) in shallow lakes with soft bottoms may so increase water turbidity as to reduce photosynthesis and ultimately game fish production. If large populations of rough fish are present, clouds of silt can keep water permanently turbid. Not only will photosynthesis be reduced, but feeding by fish that depend on sight can be reduced. Turbid waters can also interfere with bass reproduction as well as aid sunfish and catfish reproduction, causing population explosions of stunted forage fish;
- (4) In instances where large populations of undesirable predatory fish, e.g. gars or squawfish, may be limiting desirable fishes; and
- (5) In instances where parasitic lampreys may be severely suppressing desirable games fishes.

There are many management techniques available for attempting to control undesirable fish populations. Among the more important techniques are:

(1) Complete lake rehabilitation where all fish are killed by lake drainage or by a toxicant. The system is then restocked with desired game and/or food fishes. Certain problems may be incurred in lake rehabilitation. When a toxicant is used, most often rotenone, an incomplete kill may result due to the chemical not reaching all areas or large springs may reduce the concentration to harmless levels. Some fish may escape into untreated lake outlets or inlets only to return later. Overhangs of vegetation may also prevent the thorough distribution of the toxicant.

(2) Selective removal of undesirable fishes may be warranted in certain situations. Undesirable gizzard shad or yellow perch may be selectively eliminated by dilute rotenone solutions. Thermal stratification, acting as a barrier to rotenone below certain depths, permits treatment of warmwater fishes while deeper, coldwater species remain unaffected. Treating pond margins at midday affects large numbers of intermediate size bluegills, but few bass. The chemical Squoxin is selective for squawfish and may be used where squawfish are severely reducing salmon fry populations in the tail waters of large dams. Dowlap is selective for spawning adult lampreys and stream dwelling larvae.

(3) Fluctuating water level at the proper time may achieve some degree of control over the abundance of certain species. Dropping the water level during the spawning season for shallow water spawning fish may be practical for controlling sunfish, minnows, suckers, perch, pike, pickerel, and carp.

(4) Various netting techniques have been used to catch large numbers of undesirable fish at different times of the year, but varying degrees of success have been reported. Attempts to control carp in large northcentral lakes generally have not been effective. A year or so after netting, the population bounces back to pre-netting levels. However, in some instances, large scale netting of freshwater drum and netting of exploding crappie populations, have resulted in increases in game fish harvest.

Regulations

It is sometimes desirable to protect fish during the spawning season. If the spawning stock is below that which will provide maximum equilibrium yield or if they are exceptionally vulnerable to fishing while spawning, this justification for the regulation may be true. However, it is probably not true for most warmwater game fishes.

Limiting the catch can be achieved by reducing the efficiency of an individual fishing unit through regulations on gear type, vessel size or horsepower, bag limits, restrictions on gear in certain areas, and by restricting the size units of gear, e.g. net or hook size. Secondly, limiting the catch can also be achieved by limiting the number of fishing units through regulations on number of rods, number of tip-ups, number of nets, weirs, etc. Finally, limiting the catch can be achieved by limiting the number of fish taken from the stock by all fishermen for the entire season, i.e. establishing a quota.

There are many regulations designed to restrict catch to particular segments of a stock. Regulations protecting small fish may be justified where the combination of natural and fishing mortality would reduce the yield below the maximum. To restrict catches of particular segments of a fish stock, regulations may be used to close areas to fishing. Examples include protecting fish on spawning grounds, protecting fish migrating through a limited area where they are exceptionally vulnerable, and by protecting young fish on nursery grounds.

Restriction of fishing to certain seasons is another way to promote or prevent particular parts of a stock from being caught. Closed fishing seasons may be used to protect adults during spawning, permit taking fish at the end of the growing season when considerably more poundage is available, permit anadromous fishes to escape through zones of intensive fishing, and to restrict efficiency of individual gear.

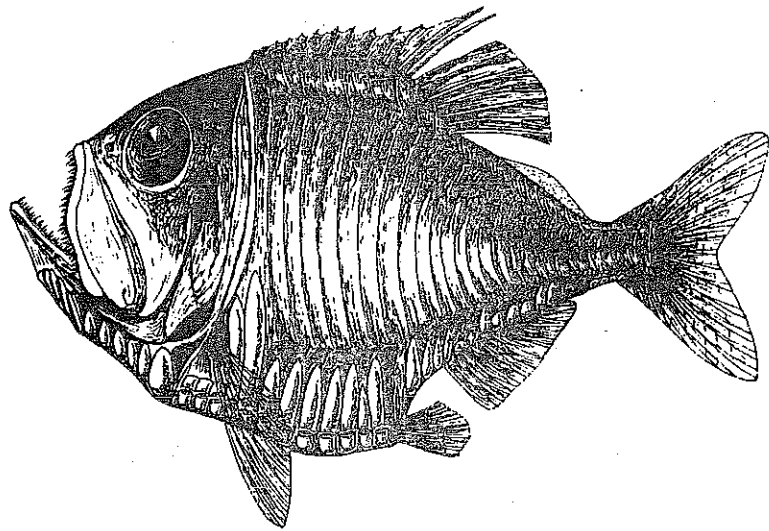
A trend in fisheries management has been to eliminate regulations that have little biological significance. Over the last two or three decades there has been a general trend toward liberal regulations, especially in warmwater fisheries. The realization that natural mortality is taking many of the fish that could be harvested by anglers has prompted such regulations. As an example, by 1960 at least 34 states had developed liberalized fishing seasons (including spring or year around fishing) and did not impose length limits. The tendency to maintain fairly strict harvest regulations is biologically justified for salmon and trout where fishing can and often does suppress populations below the optimum level on the stock-recruitment curve, i.e. below the level of maximum equilibrium yield.

Pollution Control

Various forms of water pollution can seriously affect yield. For 1967, 12 million fish were reported killed by identifiable pollution in 40 states. Since this annual census began in 1960, a total of 88 million fish have been reported killed in 2,500 individual cases. Many kills are not seen while others go unrecorded.

Far more important in reducing game fish harvest is the pollution that degrades aquatic systems for desirable fishes rather than pollution that causes acute kills. The thousands of miles of acid streams, streams toxic due to anaerobic conditions or toxic substances, streams silted from highway, industrial, and domestic construction, all destroy habitat for game fish production.

Game fish can be killed by pollutants in many different ways: (1) increase in osmotic pressure; (2) increase in acidity; (3) decrease in dissolved oxygen; (4) specific toxic ingredients; (5) destruction of food organisms; (6) destruction of spawning grounds; (7) mechanical injury to gills from silt or suspended materials; (8) blocking of migration channels; (9) accelerated aging of lakes and ponds; (10) thermal alteration; and (11) changing the environment to favor a competitor, predator, or parasite.



AQUACULTURE

Aquaculture had its inception with the ancient Chinese who farmed carp. Aquaculture is a very diverse aspect of fisheries science considering the range of organisms cultured today. Many fin-fishes, mollusks, and crustaceans are now routinely cultured and research is constantly in progress to perfect culture methods for other species.

Aquaculture is practiced in two very diverse aquatic environments, fresh- and saltwater. Fin-fishes, crustaceans, mollusks, and algae are cultured in saltwater, while freshwater is generally limited to growing fin-fishes, but there are many exceptions.

Saltwater farming (mariculture) is still relatively new and under careful study by scientists. As human population expands, conventional terrestrial farming will be unable to meet protein demands on an economical basis. Mariculture offers potential and should lead to the production of much needed protein-rich seafoods.

Like mariculture, freshwater culture ultimately leads to the harvest of protein-rich food. However, there is another very important use: live fish are often used to provide better fishing. This is evidenced by the ever-increasing numbers of state and federal fish hatcheries in the U.S.A. Unlike mariculture, freshwater culture is a very old practice. It was started by the Chinese around 2,000 B.C. or earlier. Since then methods have become much better developed and the techniques usually adequately studied, especially in the area of trout, salmon, and carp culture.

The most obvious benefit of aquaculture is the production of a high-protein food. However, there are many other indirect benefits. The tangible food product of aquaculture has certain favorable characteristics: (1) quality and quantity can be controlled; (2) fish and shellfish have excellent flavor and a variety of preparations; (3) and they convert feed economically. The flesh of the commonly cultured fish is high in protein, vitamins, and minerals, but low in saturated fats, carbohydrates, and cholesterol. These considerations may become even more important to the diet-conscious consumer of the future.

The per capita consumption of fish and shellfish in the U.S.A. for the past ten years has remained comparatively static, varying only from a low of 10.3 pounds per person in 1960 to a high of 10.9 pounds in 1965. Five billion pounds of fish and shellfish were used for human consumption in 1967 and U.S. fisheries could only supply 2.4 billion pounds. The total imports of all fishery products into the U.S. has increased from 25 percent of the total products consumed in 1950 to 76 percent in 1968. The U.S. market will need around three billion pounds of additional fish and shellfish for food markets over the next 15 years. There is great opportunity for aquaculture to fill some of these demands.

Mariculture

Most maricultural activities take place in estuaries. One of the most prominent characteristics of an estuary is the dynamic nature of the physical, chemical, and biological processes taking place. Temperatures, salinity, and pH may change rapidly depending on the position of the tide and flow of freshwater into the estuary. Aside from these difficulties, mariculture is practiced in estuaries because they are the most fertile natural areas in the world, and generally high fertility yields high productivity.

The location of sea ponds depends on the method to be used to obtain the young animals for cultivation. If the farmer wishes to obtain his stock directly from the sea, he must locate his pond where the tide and currents can sweep directly into it and naturally stock the pond with young animals. Another method involves buying young stock from fishermen. In this case, the pond can be located further from the sea. A third method of obtaining young stock involves placing brood in ponds to spawn naturally or artificially.

The most commonly cultured crustaceans are shrimp, lobster, crab, and crayfish. Of the four, shrimp farming is the most important, though only because the culture of the other three is not as well developed. The techniques for shrimp farming have been well developed in Southeast Asia. Shrimp are cultured in ponds in shallow brackish estuarine areas where they occur naturally. Ponds are excavated and separated by dikes into nursery ponds, rearing ponds, and a catch pond. Such a system may cover about 25 acres.

The pond is prepared for stocking shrimp by draining to eliminate most predators and encourage growth of a complex mass of small bottom-dwelling plant and animal material, a prime source of food for young shrimp. After a good growth of this material has been established, the water level is permitted to rise to about 12 inches, and seed shrimp are introduced. During their stay in the nursery, they feed on the material grown during the draining of the pond. After several weeks, they are transferred to a rearing pond where they forage for natural food or are fed artificially. Depending on growth, shrimp may be held in the rearing ponds from three months to a year. They are then harvested by seining, trapping, or draining. The rate of production of shrimp varies depending on local practices and biological conditions. However, annual yields of more than 600 pounds of shrimp per acre have been reported.

The future of lobster culture is uncertain. Commercial farming at the present time is not feasible because it takes five years for most species to reach market size. Attempts at farming lobsters have been made. For instance in 1905 in New England, lobster hatcheries were built. Eggs were collected from ripe females, hatched, and put in floating screened cages to grow. They were held for about four months and then released to take up residence on the floor of the ocean for further growth. These attempts at aiding nature were largely unsuccessful because of high mortality of the young larvae and high production costs. The best solution to this problem now seems to be short retention. Undersize lobsters are taken from the fishery and held until they reach marketable size. As inefficient as it may seem, this method is the closest to being profitable.

The future of crab culture seems to be about the same as for that of the lobster. Stone and blue crabs, however, show real promise. Some culturists hold many adult stone crabs and remove their claws periodically. This becomes practical only when the claws regenerate fast enough. Profitable short-term farming is being carried out with blue crabs in the Middle Atlantic States, which consists of holding the molting crab. The crab is sold just as soon as it sheds, because soft-shelled crabs are more valuable. However, long-term farming of crabs is not yet practical because of slow growth.

Oysters, clams, and mussels are commonly farmed in the sea. Unlike crustaceans and fin-fishes, they are sessile organisms and, therefore, do not need to be impounded.

Oyster farming is the most popular form of mariculture because of their relatively high economic value of the product and ease of culture. Culture of these organisms can be closely compared to that of the production of agricultural crops because the cultivation procedure only involves preparing a bed for the oysters, letting them grow, and then harvest. The most suitable grounds for planting oysters are muddy shelly, or stiff mud-sand bottoms. Other more unstable bottoms are less satisfactory because the oysters may sink into the soft mud or be smothered with sand. Any hard substance to which the larval oysters may attach, such as crushed oyster shells, is spread on the bottom. Oysters are purchased and spread over the substrate at the rate of 500 bushels per acre. These oysters produce young which in the larval form are mobile, eventually sink and attach themselves. They can be raised there or transferred to other beds where growth might be better. Eventually, they are harvested by dredging.

Clams and mussels are important species to the sea farmer. They are not cultured as commonly as oysters, but are well suited to mariculture because they are sessile, feed low on the food web, and are in demand by consumers.

Clam culture is similar to oyster culture with the exception that the substrate is not necessary since clams burrow into mud, where they eventually grow to market size in about five years. Clams usually grow best in tidal flats where the bottom is between 60 to 80 percent sand. Clams are harvested by dredging or simply digging with a hoe when the tidal flats are exposed.

The common mussel is cultivated in Spain, The Netherlands, France, and Italy; but not in the U.S., where the demand is insufficient to warrant culture operations. Mussels are discouraged on the American oyster beds because they compete with and crowd out oysters. Mussel culture is also similar to oysters. Poles may be sunk vertically into the floor of the estuaries to provide attachment surfaces. Mussels rapidly grow to marketable size. When grown from seed in The Netherlands, they require about three years to reach the marketable size of 2 1/2 inches. Further south the growing time is only one year. Harvest is usually accomplished by dredging or simply scraping the mussels off the sunken poles with a hoe.

Of the various fin-fishes, the milkfish is probably the most common species cultured in brackish water. In the Philippines, milkfish farming is a highly-developed industry. During monsoons and prevailing periods of inclement weather, in which no offshore fishing for marketable adult milkfish can be done, pond production supplies fresh fish to the market.

Since milkfish have never reproduced in captivity, fry (1-2" young fish) are caught in traps near shore and planted in rearing ponds which are about 3 feet deep. There they feed on a natural growth of algae and grow to marketable size of one pound in six to nine months. They are then harvested by seining and the ponds are drained to eliminate parasites and predatory fish. Ponds are refilled, and after a new growth of algae has formed, fry are again stocked. This procedure permits three crops of fish to be reared to marketable size in two years. Annual production rates of 300 pounds per acre are typical with 600 pounds per acre frequently reported.

The pompano, a hardy, fast-growing fish, is currently being cultured in Florida and other areas along the Gulf Coast. These fish at the present time demand a high market price, and their economic future appears to be excellent. Experimental results show that it is possible to produce a market-size fish in about six months. Production may exceed 5,600 kg per hectare with good management. As with milkfish, pompano do not reproduce in captivity; they can be spawned with hormones, but a complete hatching process has not yet been developed.

Pompano are stocked as fry in brackish water ponds and fed a commercial trout food. Growth rates are rapid, and it is possible to obtain an average monthly growth of 2.5 to 3 cm and an increase in weight of 60 to 80 grams. In about six months, they reach a length of about 8 inches and a weight of about one pound, and are harvested. Pompano can also be raised with success in floating cages. This permits raising of other fishes, mollusks, or crustaceans simultaneously, so the culturist can utilize the entire water column and insure harvesting on a year-round basis.

Freshwater Culture

Only fin fish with the exception of one crustacean, the crayfish, are commonly grown in freshwater culture. Freshwater culture is subdivided into cold- and warmwater culture according to temperature requirements of various species. As a rule of thumb, fishes grown at a temperature above 70°F are warmwater species and those below that temperature are classified as coldwater fishes. Warm- and coldwater culture can be further divided into categories which relate to the use of the product. The most prevalent use for the cultured trout is stocking to provide better fishing for ever-increasing numbers of anglers. Coldwater fishes, because of their relatively low fecundity, often need supplemental stocking to keep their population levels high enough. Warmwater culture is usually used to stock farm ponds or lakes that have been reclaimed. Both cold- and warmwater species are grown for consumptive use. The rainbow trout and channel catfish are examples of this; however, the channel catfish is beginning to be cultured much more extensively for this because of its rapid growth rate, ability to withstand crowded conditions, and its low food into flesh conversion rate. In addition, the production of small shiners, chubs, and goldfish is very common, and the species are used as baitfish.

There are five basic steps in freshwater culture: (1) obtaining brood stock; (2) spawning, artificial or natural; (3) fertilization of the eggs; (4) hatching - the fertilized eggs are always removed to special incubators or wire baskets placed in the rearing troughs; and (5) rearing - the fry are removed from the incubators and placed in rearing troughs or simply swim out of the wire basket.

Coldwater species most commonly cultured are trout and salmon. The trouts propagated artificially include the rainbow trout (including the steelhead trout), cutthroat trout, brook trout, lake trout, and brown trout. They are all propagated by essentially the same methods.

In locating a trout hatchery, the most important single consideration is water supply. It must be continuous with an adequate flow for future expansion of the hatchery. In addition, one must consider water quality. Factors influencing the suitability of water for trout culture include: temperature, gas content, turbidity, mineral content, and freedom from pollution, and possible disease-causing organisms. Generally, springs and wells are considered the best sources because they provide a constant flow, the water temperature does not vary, turbidity is low, and there is usually no pollution or disease organisms present. However, they can be low in oxygen and high in other dissolved gases, such as nitrogen or hydrogen sulfide. The water must be then aerated to increase the oxygen content and reduce unwanted gases.

Today most hatcheries maintain their own brood fish rather than capturing wild stock. With the approach of the spawning season, brood trout are separated by sex and placed in different ponds. When they become "ripe," eggs are stripped into a pan and milt from the male is stripped over the eggs. The mixture is stirred with a feather to insure fertilization. There are two methods of handling the eggs during fertilization: the wet and dry methods. In the wet method the eggs are placed into a pan of water and in the dry method the pan is dumped by rinsing and then turning the water out of the pan. The dry method seems to give the best fertilization because the sperm are not diluted by the water. Eggs are then put into baskets placed in hatchery troughs or incubators. After about 30 days at a temperature of 50°F the eggs hatch (rainbow trout) and the sac fry move out of the baskets into the troughs or must be transferred from the incubator into the rearing troughs. When the sac of the fry is absorbed, the fry are then started on a commercial trout food. Soon they are removed from the hatchery troughs to raceways to complete growth to stocking size.

Pacific salmon are cultured extensively on the west coast of the United States and Canada. Culture is similar to that of trout with the exception of egg collection. The typical goal of a salmon hatchery is to supplement natural propagation and rarely are they transplanted from their natural river to stock others.

Mature salmon are collected as they ascend spawning streams. Since they die after spawning, captured fish are killed to facilitate handling, and eggs are taken and fertilized. Propagation now continues using similar methods as those for trout. After the young salmon reach fingerling size, they are released into the stream to augment the downstream migrating population. The number of hatchery-reared salmon thus released is usually more than 75 percent of the eggs initially fertilized.

Coldwater Hatcheries

Immigrants from Europe started the first hatcheries in the United States in the mid-1800's. They did a fine job of convincing the public that hatchery-reared fish were needed in nearly all our lakes, rivers, and streams. The selling point was that stocking was necessary to prevent depletion of existing fisheries by advancing civilization. So well did these early conservationists accomplish their mission, that their philosophy was deeply ingrained in public thought for many years.

Use of hatcheries in fisheries management has changed considerably since these first efforts. Today, the main purpose of public hatcheries is to help state and federal agencies meet the immediate management objective of providing maximum recreational enjoyment to all types of anglers.

The most well-known use of hatchery fish in the United States is stocking catchable-sized trout. To satisfy intense angling pressure, stocking programs maintain fishable populations in streams and lakes incapable of satisfying angling demands with natural populations. Catchable trout programs are an integral part of most coldwater recreational fisheries management programs and annually supply millions of people with a satisfying recreational experience.

In many aquatic environments, conditions are quite favorable for good fish growth, but spawning grounds or nursery areas are not available. In this situation, fingerlings can be stocked, instead of catchables, to offset poor reproduction. Thus, the stocking agency is relieved of the cost of growing fish to catchable size. These fisheries have been appropriately named "put, grow, and take."

Hatchery fish are often used for restocking waters after some natural or man-made catastrophe has reduced or eliminated existing populations. The terms winterkill and summerkill describe sudden mortalities of fish due to winter or summer oxygen deficiencies in lakes or ponds. Accidental spills of toxic chemicals can cause large-scale fish mortality. Often, when such catastrophies occur, stocking hatchery fish is the only way to restore fishable populations.

An often overlooked use of hatcheries is the production of eggs for exchange with other hatcheries on a world-wide basis. Eggs may be fertilized in the United States and shipped to other countries to be incubated. Because of rapid transport, low space requirement, and low mortality during shipment, eggs can be transported more conveniently and cheaply than hatched fish.

Many times hatcheries are called upon to supply fish for experimental projects. By studying how the physiology and behavior of fish are affected by different environmental conditions, fisheries scientists are gaining insight into many longstanding management problems. Hatchery-reared fish help accomplish some of these studies geared to the wise use of our fisheries resources.

The word hatchery is often synonymous with trout propagation, but this is an inaccurate assumption. Hatcheries produce other coldwater species besides trouts (especially salmon and whitefish), and many efforts have been made to artificially propagate certain warmwater species. The development of artificial diets for the very popular large- and smallmouth bass will certainly increase availability of these species. Walleye, northern pike, chain pickerel, and muskellunge are now being stocked as predators to control large populations of stunted sunfish. Catfish are enjoying a new reputation as delicious food fish and are being cultured in the southeastern United States on a large scale.

Some species such as northern pike, walleye, muskellunge, and catfish may be spawned and raised under artificial conditions similar to trout culture. However, most warmwater fish are generally propagated by the extensive method in ponds under near natural conditions. After adult fish have spawned and the eggs hatch, young are placed in rearing ponds until they are large enough for distribution. Here the hatchery staff must develop and maintain an adequate food supply of forage fish to reduce cannibalism, a major problem in the culture of warmwater game fish, and assure rapid growth among young fish.

Catfish Culture

The channel catfish is becoming to be an extremely important warmwater species from a commercial standpoint. There is an ever-increasing demand for this fish for distribution to restaurants and grocery stores. Until recently, catfish culture was an infant industry, but by 1980 the market could grow to over 1 billion pounds necessitating 200,000 acres of ponds.

Anglers in many parts of the United States consider channel catfish to be a highly desirable game fish. Although often classified as a commercial species, catfish are highly esteemed for their fighting characteristics. In many streams, rivers, and lakes, the channel catfish is often one of the most popular game fish present. In addition, they will take a wide variety of baits such as worms, shiners, insects, doughballs, and artificial lures.

On the other hand, catfish, especially the channel, are valuable commercial species. Catfish farming is one of America's newest and most promising agricultural industries. Many farmers, confronted with poor crop markets, are looking to catfish as an additional cash crop. Catfish now command a good market and sale price. Compared to other farm animals, catfish convert feed into meat much more efficiently.

Catfish raised in farm ponds can be sold on the live fish market (stocking) or the food market. Live fish are in demand by private operators of fee fishing ponds. Fee fishing ponds are especially attractive near population centers and will become very popular in the future. But most catfish are sold to processing plants where they are dressed and distributed to grocery stores and restaurants.

Farming catfish sometimes includes collecting brooding stock, spawning and fertilizing eggs, hatching eggs, and rearing fingerlings to a marketable size. However, most farmers are only interested in growing catfish to marketable size (about one pound) and are not concerned with spawning. Commonly used culture methods include ponds and cages. Pond farming is usually by far the most common and practical method available to most farmers, although cage culture shows much promise.

Pond culture is the most popular, best developed, and most reliable method of fish farming. Fingerlings are stocked from commercial breeding hatcheries at the beginning of the growing season (March or April) and fed daily with a scientifically prepared ration. Harvest takes place at the end of the growing season (November).

The characteristics of a pond are very important factors in fish farming. The pond should be at least four feet deep and free from other fish. Flood hazards should be minimal. Dissolved oxygen in the pond water should always be at a high level. Harvest is an important consideration with pond culture. The pond should have a drain or be easy to seine.

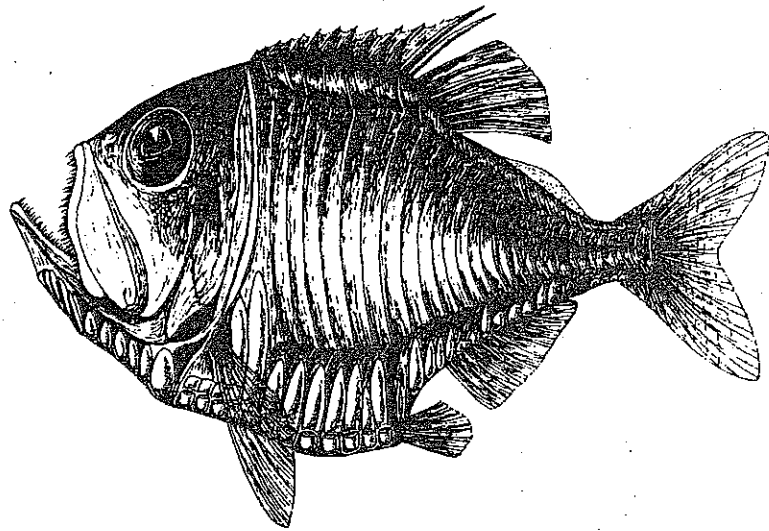
Cage culture is similar to pond culture but involves rearing fingerlings to market size in a box of hardware cloth or netting. Cages have floats and are placed in ponds with anchors to keep them from drifting to shore. About as many pounds of fish per acre can be grown in cages as can be grown free in the pond.

The cage culture method has several advantages: (1) it may be used in farm ponds, mining pits, irrigation canals, and other water environments which are not suitable for pond culture; (2) it allows for a combination of cultures in ponds, such as catfish in cages and largemouth bass and bluegill in open water; (3) it permits easy and complete harvest by simply lifting the cages from the water; and (4) it allows observation of the fish for diseases. Disadvantages are: (1) relatively high cost of cages; (2) fish in cages require a nutritionally complete feed which is expensive; (3) fishkills caused by low dissolved oxygen due to poor water circulation; and (4) easier transfer of disease due to crowded conditions.

Miscellaneous Freshwater Culture

Preliminary studies are being conducted in the southeastern United States on an exotic fish from the Orient, Tilapia mossambica. The quest of fisheries scientists in various countries for a fish exhibiting rapid growth rate, large reproductive capabilities, and suitable for human consumption has apparently been satisfied to a great extent by this species. Tilapia is a desirable fish because under natural conditions, plankton makes up the bulk of its diet. Therefore, one would not be troubled with the expense of artificial food if he could get a suitable crop of algae to grow in the pond by fertilizing. The major problem is that the fish cannot tolerate temperatures below 60°F and will suffer total mortality when the temperature reaches 47° to 49°F. Preliminary experiments have shown that Tilapia culture may be worthwhile as they appear to be very efficient feeders on plankton. If extensively cultured in the United States, their propagation probably would be similar to catfish, and one might even expect faster growth rate at a cheaper cost of production.

A generation ago minnows for bait were easily seined from lakes and streams. Now, because of a tremendous increase in the number of anglers, these natural waters often cannot supply angling needs. Bait-fish culture, the propagation of species such as the golden shiner, fathead minnow, white sucker, and others have arisen out of this demand.



COMPUTER TECHNOLOGY

Few technological developments have affected twentieth century society as has ready availability of high-speed digital computers. Computer usage has permeated nearly all phases of modern technologically-oriented society and, although it is difficult to distinguish cause from effect, computers have been either heralded as servants of man, or damned as heartless masters. Whatever conclusion one draws, the fact remains that computers are integral to contemporary society.

The computer age, as some are inclined to describe the present period in the U.S.A., has resulted in harnessing a tremendous and relatively inexpensive analytical capability for man's use. This situation appears inherently desirable, but it has not been without cost, both real and imagined. There are reasons why universities offer courses such as Computers and Society, Man and the Computer, Computers in the Modern World, and Socio-Technological Problems. Part or all of the potential benefit from technological advance is lost if potential users are unable or unwilling to use the tool.

Resource managers, either directly or indirectly, have been influenced by the ready availability of high-speed computers. The issue is not whether computer use is inherently good or bad, but when and how can we use this tool effectively. To what degree computers will improve resource management effectiveness cannot be ascertained at this point, but the use of computers in many situations is very promising.

The most common application of computers in natural resource management is data tabulation, processing, and analysis. The potential advantages in terms of quantity and speed of data handling are obvious, but less apparent is the problem of determining when to implement a computer approach. There is no simple solution to the problem. Thorough familiarization with computer capability allows a potential user to make "good" decisions on a case by case basis, but there are presently few generalizations to assist professionals without such backgrounds.

A second common application of computers deals with automated and semi-automated monitoring systems. This could range from a completely automated system, such as environmental sensing connected directly to a computer facility, to using creel clerks to record data on forms that can be processed directly by computer. In the correct circumstances use of computer support in this manner can be highly efficient in fisheries management.

A third category of computer usage are applications to enhance natural resource education, especially at the university level. Since resource management problems are very complex and dynamic, it is difficult to transmit to students a realistic appreciation of management problems. Computer simulations of particular resources can be used as case studies for students to practice management.

Computer-implemented simulation has become quite popular in ecology and resource management in the last few years. The rationale for this approach is that most resource systems are very complex and, although a particular part of the system may be relatively easily understood, the total system cannot be comprehended without substantial assistance with computational and bookkeeping aspects. Computers can handle large volumes of numerical manipulations at relatively low cost and allow the user to manipulate the simulated system rather than the real system to test hypotheses.

There are two general approaches to simulation commonly used in fisheries management: simulation to evaluate management strategies; and simulation to learn basic system properties, especially ecological properties. These two approaches are not mutually exclusive, but rather reflect a general orientation of a particular simulator.

Evaluation of management strategies with the aid of computer-implemented simulators may be considered a fourth category and is a very promising application of computers. Simulation allows the user to cope with the large number of variables inherent in a complex system and manipulate decision variables to ascertain likely results of a particular set of decisions. Management of reservoir fisheries, one of the most formidable problems facing our profession, has been approached with the aid of computer simulations.

The fifth category of computer application involves improving understanding of ecological interrelationships by employing computer simulation. The continual interactive refinement between modeling and data acquisition, and modelers and field personnel, is in itself a vehicle to improve understanding of ecological systems. The biggest problem with this approach, as with many new tools and techniques, is knowing when to use it and in what format.

A sixth and final class of computer applications involves facilitating numerical analysis. One of the perpetual difficulties in fisheries management is developing best strategies. The problem of maximizing (or minimizing) the objective function by manipulating control (decision) variables, subject to system constraints, is the core of resource management. Computers can be useful in handling these types of problems.

MANAGEMENT
PRINCIPLES

MANAGEMENT OBJECTIVES

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. How can agencies, both public and private, formulate objectives? What methods and channels should the organization use to accomplish this? What are the important factors involved in a fishing experience? These are important questions that need to be answered.

Most managers have recognized the inherent difficulties with using "soft" 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. The main undesirable property is that most anglers regard catch as only one of several measures of output from a fishery. Most anglers admit that their interest is not solely in the fish they catch but in fishing itself. A survey of Ohio fishermen revealed that over half enjoyed fishing even if no fish were caught. Other aspects important to the angler are the outdoor experience, environmental aesthetics, and the sporting challenge. Additional considerations are the species caught, sizes of fish, settings in which they are found, and the method by which they are sought.

The public receives benefits of a psychic or convenience nature which might in total amount be larger than the more tangible benefits received. The social product of sport fishing is the aggregate of value which accrues to the participants from an enriching use of their leisure time. Fishing may be an escape to solitude, a social enterprise, a vigorous physical challenge, or an occasion of relaxation. The sporting experience is composed of two basic factors: the quest—an adventure in angling methodology; and the attainment of a tangible reward, such as a fish. However, this basic core may be enjoyed in a variety of natural and social environments and consequently, the sport means different things to different people.

Among more recent efforts to replace soft objectives have been attempts to measure quantities such as man-days of use. The assumption is that measuring the number of man-days of recreation on a particular resource is a valid index of system output. Some may also go further and assume that the approach could be used to maximize recreational benefit. However, maximizing man-days may result in an amusement park situation. For example, a trophy trout project in Pennsylvania sustained shoulder-to-shoulder angling with a second tier of anglers on crowded days. Neither potential yield nor intolerance of crowding by anglers apparently constitute foreseeable limits on sport fishing intensity in freshwaters.

Another potential objective is maximizing aesthetics. This is a very altruistic approach, but not readily quantifiable. Due to lack of a pricing system, the market survey is not readily applicable to the heterogenous angling public. Aesthetics can never be accurately measured according to many researchers, however, by defining the variables associated with an object and a subject's perception of it, a reasonable understanding of aesthetics may be attained.

Since satisfying its clientele is a major function of a natural resource organization, management objectives which address this requirement would be of tremendous benefit. Historically, natural resource decisions have been arrived at by the consultation of professionals in institutional roles and positions, an elitist planning process. The strategy being that elitism allows those who are best qualified and most knowledgeable to make decisions. A planning process involving the public is more nearly a democratic process and may have a higher probability for success because it provides representation from those who are affected.

The administrative expertise type of decision-making is characterized by a complex division of labor around functional specialties and recruitment of trained personnel capable of responding to narrow problems efficiently and competently. 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 clearly defined, pertinent data collected, and alternatives surveyed and selected. 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 that scientifically trained personnel are no more qualified than the general public to make these value-based decisions.

Public involvement is a basic cultural value which is not compatible with efficiency through technological expertise, another basic cultural value. Natural resource agencies in the past have not been concerned with this incompatibility. A prominent view among natural resource personnel is that environmental decisions must be entrusted to experts. However, a trend toward participatory democracy exists. Citizen participation is a part of our democratic heritage and has been proclaimed by some as a means to perfect the democratic process. Recently, water resource agencies have come under pressure to incorporate citizen input into the planning process. 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.

Interviews of anglers to determine the relative importance of selected factors related to success of a one-day fishing trip showed that environmental factors, such as water quality, natural beauty, and privacy while fishing, to be relatively more important than catch. Many recommendations for fisheries managers to include environmental management in the scope of fisheries management have been made.

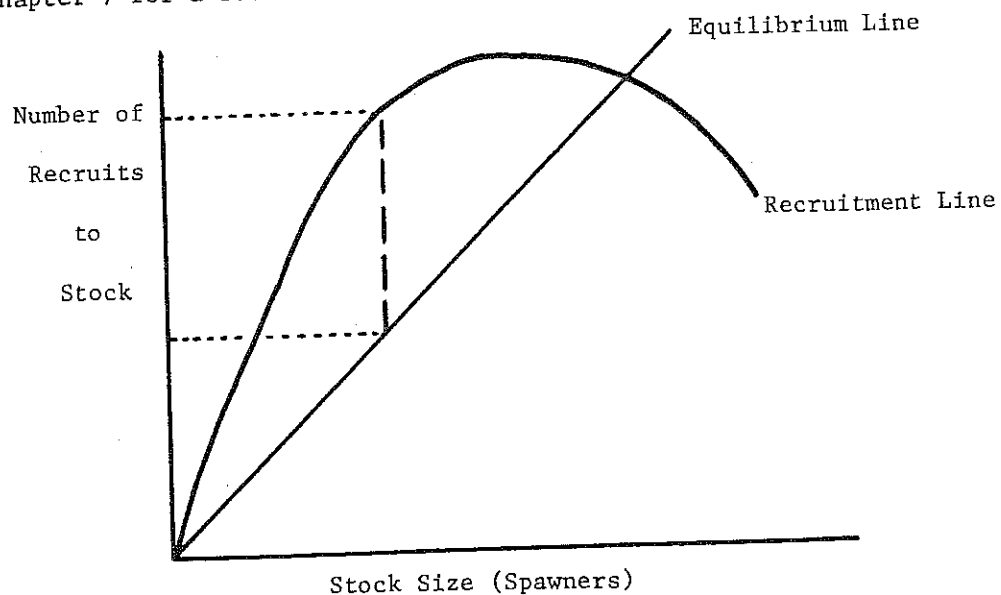
STRATEGY ANALYSIS

Strategy analysis is at the very core of fisheries management. Given that an end-point (objective) is defined and accepted, the job of the manager is to meet that objective within specified constraints. Strategies are the various routes to meet the management objective.

There are few generalizations available in reviewing various management strategies. Any management problem should, however, be systematically attacked from a systems analysis standpoint.

Stock-Recruitment Strategy

Assume that our management objective is MAX Y (maximum equilibrium yield) and stock. Such conditions are most closely met in the Pacific salmon fisheries and, to a lesser extent, with other anadromous or adfluvial species. If we can reasonably accept that the number of spawners determines the number of progeny that recruit, a stock-recruitment model may form the basis of a management strategy (See Chapter 7 for a review of the model).



By maximizing the difference between the recruitment population level and the equilibrium population level, the maximum equilibrium yield can be maintained.

The stock-recruitment strategy has several advantages in practice: (1) only data on adult fishes are necessary; (2) the model is well studied and there is much published literature on its use; (3) the model may be a good approximation of a complex ecological system; and (4) the effectiveness of management efforts are relatively easily measured since the unit of system output is the captured fish.

Disadvantages of the stock-recruitment strategy include: (1) the assumption that the relationship is solely due to density-dependent factors; (2) the assumption that the adult stock is homogeneous (no fluctuation in age structure); and (3) the assumption that MAX Y is the desired management objective.

Regression Prediction Strategy

Most management situations do not warrant use of the stock-recruitment model, but rather some other, more complex, approach. Regression prediction is an approach in which key factors are used to predict maximum equilibrium yield.

For example, we may wish to predict the catch of lake trout in a particular fishery. Catch in a particular year is hypothesized to be a function of last year's catch, the fishing effort last year, and the fishing effort in the particular year. Therefore,

$$C_t = \alpha + \beta C_{t-1} + \nu f_{t-1} + \delta f_t + \varepsilon$$

where,

C_t = Catch in year t

C_{t-1} = Catch in year t-1

f_t = Fishing effort in year t

f_{t-1} = Fishing effort in year t-1

ε = Unaccounted for variation

α , β , ν , and δ are regression coefficients calculated from data

In practice data for a number of years are used to solve the above mathematical model. Then, by manipulating decision variables (such as angling pressure through season regulations), the manager can determine maximum yield or the yield under a potential management decision.

Selection of the independent factors (C_t , C_{t-1} , f , and f_{t-1}) is often difficult in practice. Such parameters as total dissolved solids, water temperature, barometric pressure, and average lake depth have been used.

Advantages to using a regression prediction strategy include: (1) relative ease of mathematical analysis; (2) data are often available; (3) extreme flexibility in model structure; and (4) density-dependent and density-independent factors can be mixed, although analytical difficulty increases rapidly.

Disadvantages to the regression prediction strategy are: (1) a stable environment must generally be assumed; (2) a stable age class structure must usually be assumed; (3) selecting initial independent variables may be difficult; and (4) the error term (ϵ) may always, even with a highly complex model, account for most of the variation.

Constant Environment Strategy

Usually the general principle underlying strategies that assume a constant environment is an effort at manipulating population statistics to achieve MAX Y. This type of strategy is often considered to be classical population dynamics. Most of the variation in fish abundance, growth, and mortality is assumed to be predictable based on certain population statistics and their interrelationships.

(1) For example, if we consider total mortality:

Since,

$$\frac{dN}{dt} = -ZN_t$$

And, t_{∞}

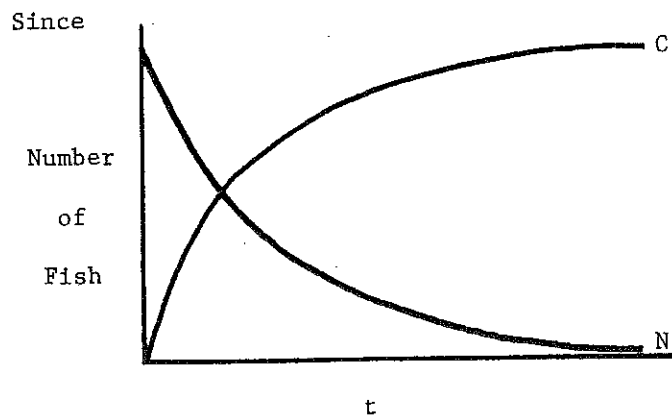
$$\int_{t_c}^{\infty} dN = \int_{t_c}^{\infty} -ZN_t dt$$

$$N_t = N_0 e^{-Z\Delta t}$$

(2) But, since we are primarily interested in fish after they recruit

$$N_t = R e^{-Z\Delta t}$$

Using the same reasoning for fishing mortality:



Then,

$$\frac{dC}{dt} = FN_t$$

And,

$$\int_{t_c}^{t_\infty} dC = \int_{t_c}^{t_\infty} FN_t dt$$

$$C_t = \int_{t_c}^{t_\infty} FN_t dt$$

But, according to section #1:

$$N_t = N_0 e^{-Zt} \quad (\text{if } \Delta t = 1)$$

Then,

$$C = \int_{t_c}^{t_\infty} F [R e^{-Zt}] dt$$

Finally, by integrating over the time an age class will be in the fishery

$$C = R [1 - e^{-Zt}] \frac{F}{Z}$$

(3) When growth was considered in Chapter 6, it was shown that

$$\frac{dl}{dt} = K (l_\infty - l)$$

can be reduced to

$$w_t = w_\infty [1 - e^{-K(t-t_0)}]^\beta$$

By adding the expression for w_t , C becomes Y and

$$Y = R[1 - e^{-Zt}] \frac{F}{Z} \int_{t_c}^{t_\infty} K (w_\infty - w_t) dt$$

This equation for estimating Y is called a yield equation and is a mathematical statement of the theory of fishing.

The advantages of classical population dynamics as a strategy are: (1) the relatively simple conceptual basis; (2) there are often large quantities of available data, especially in commercial fisheries; (3) the vital statistics can be controlled (at least somewhat) by practical decisions; and (4) the models can easily be computer-implemented.

Disadvantages include: (1) rate statistics are assumed to be constant (this may be adjusted for, but it is difficult); (2) constants are difficult to accurately estimate; (3) extrinsic factors may be very important to the system; (4) the model may not adequately reflect the fishery.

Variable Environment Strategy

If environmental factors act in a variable manner to such a degree that relatively simple strategies are inappropriate, the manager may be found to use a "big model" approach.

For example, assume we can control largemouth bass survival at various stages in the life cycle (selective chemical treatment, stocking, regulations, predator control, etc). We then wish to manipulate these various controls (survivals) to maximize catch.

Then

$$N_{ij} = N_{i0} S_{i1} S_{i2} S_{i3} \cdots S_{ij}$$

where

N_{ij} = Number of bass in the i th year class surviving
to the j th birthday

S_{in} = Probability of survival of individual bass in the
 i th year class from the $n - 1$ to the n th age

N_{i0} = Number of bass in the i th year class that hatched

Since

$E = f$ (angling pressure, f)

where

E = Exploitation rate

then

$C_{ij} = E N_{ij}$

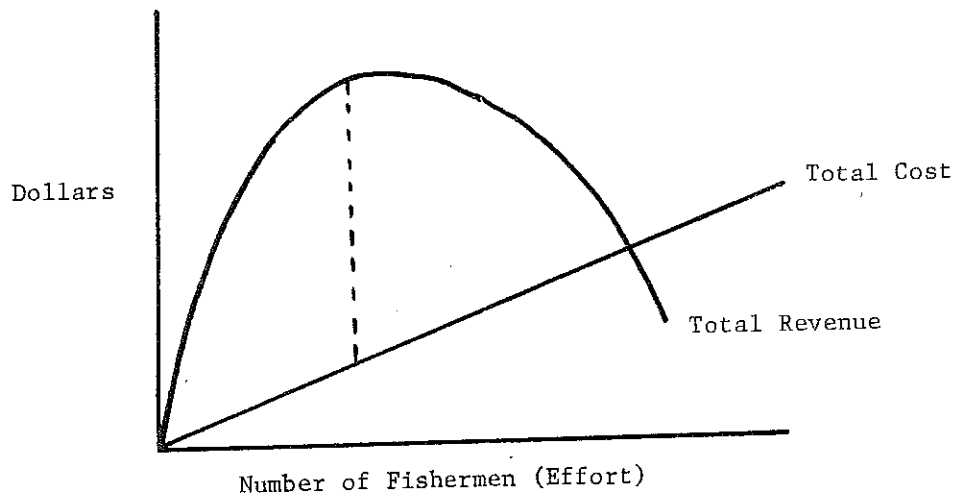
The advantages of this approach are: (1) any system can be described, at least conceptually; and (2) the model structure bears a close relationship to biological mechanisms.

Disadvantages include: (1) bookkeeping and analytical problems may be tremendous - one needs computer support; (2) model quantification results in a relatively large data requirement; (3) modeling detail may obscure management objectives; (4) cost of this strategy may exceed benefits.

Strategy to Maximize Profit

In commercial fisheries the participants wish to maximize their personal profit or net income. Yield is important only as it affects profit.

It is reasonable to assume that for the total fishery:



The "total cost" line may be linear or bend up with time, but in any case it must rise with additional fishing effort. Total revenue from the catch will increase rapidly with additional fishing effort at lower levels. With heavier fishing pressure, total revenue will stabilize and then decrease.

To maximize total profit, fishing effort should be held at a point that results in maximum deflection between total cost and total revenue. In practice fishing effort tends to stabilize around the intersection of total cost and total revenue. This point is, of

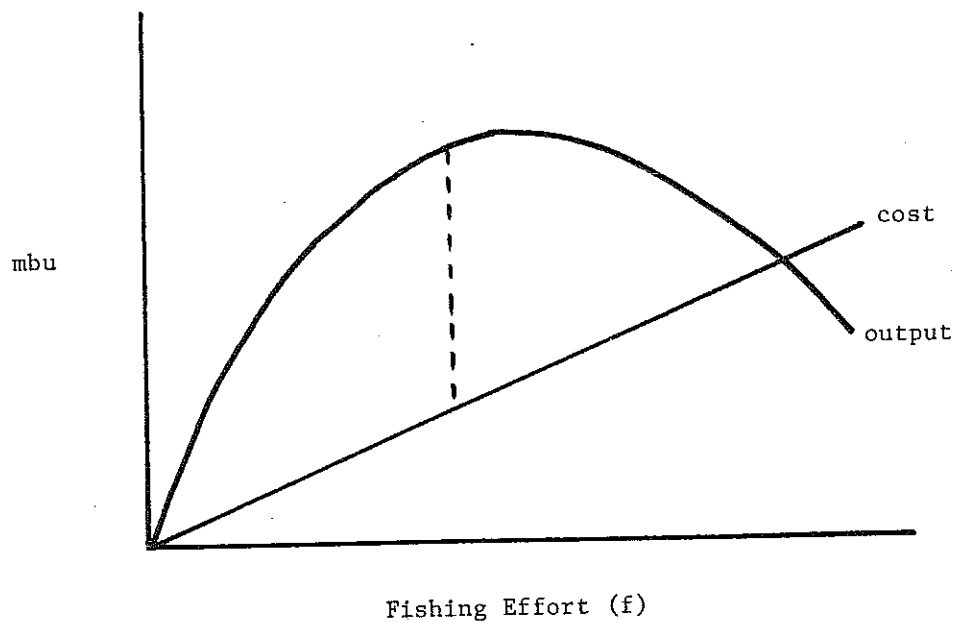
course, zero profit for the total fishery, although some individuals will show a profit while others lose money.

This strategy is intuitively acceptable from a social standpoint, but are fisheries managed for the benefit of the participants or society as a whole? In practice it is difficult to control fishing effort without reducing the fishing to a zero profit level.

Management Benefit Unit Strategy

In all the previously discussed strategies, we measured fishery output in pounds, numbers, or dollars. In recreational fisheries these measures of output have been criticized as being poor measures of true benefits. Aesthetic and other intangible factors are important in recreational fisheries, but they are difficult to measure.

Assume that we develop a scale of benefit measure produced from a fishery (management benefit unit or mbu). The output from a fishery, as measured in mbu's may be composed of factors such as yield, water quality, crowding, user conveniences, and others. The following relationship can be developed:



The shape of output line may be highly irregular, but should rise rapidly, level off, and then decline. The cost line may be equally irregular, but should at least continuously rise.

A strategy to maximize the net mbu's (maximum deflection between cost and output) seems reasonable. However, people will still participate or enter the fishery as long as he shows a net profit. The total profit will thus, without management, tend toward zero. The problems with quantifying the mbu are covered in other chapters.

SIMULATION

Fisheries management is the science of making and implementing decisions to maintain or alter the structure, dynamics, and interactions of habitat, aquatic animal populations, and man to achieve specific 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 anglers, and directly supporting commercial activities), the true complexity becomes apparent (Figure 2). In fisheries management, a slight change in one part of the fishery may result in substantial change in another superficially unrelated part.

Warmwater fisheries are especially complex. There are usually many game fish populations to consider: typically bass, bluegill, crappie, catfish, and miscellaneous sunfishes. Angler diversity is also large. Some anglers exclusively pursue a single fish species, while others exhibit little preference. Management strategies for a trophy bass fishery may be very much different than those of a crappie 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.

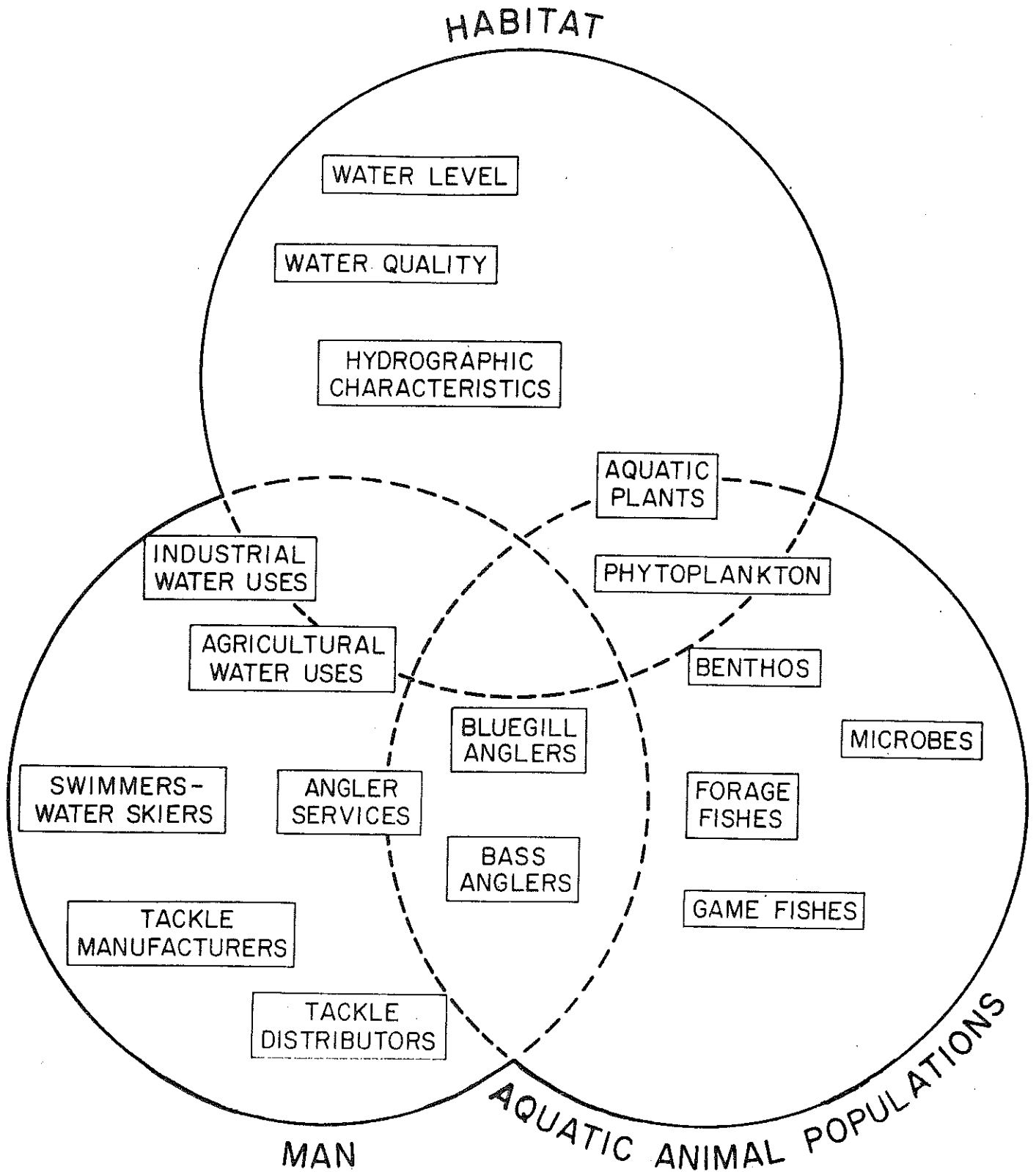


Figure 2. Graphical model of a generalized freshwater recreational fishery. Only major system components are included.

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 make accurate prediction difficult. The dynamic aspects of a fishery are also important because rates of change are as important as the components themselves.

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 that can improve decision analysis in fisheries management would be highly useful, especially if additional funding was not required.

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. Models may be simply a verbal abstraction: "A population tends to increase most rapidly at low levels." Fisheries may also be described via graphical models (Figure 3). The importance of verbal and graphical models in fisheries lies in their initial description of complex phenomena. With these models the process of breaking a complex fishery into its components is begun. 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, 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 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 those 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 study is still a physical model of the ecosystem.

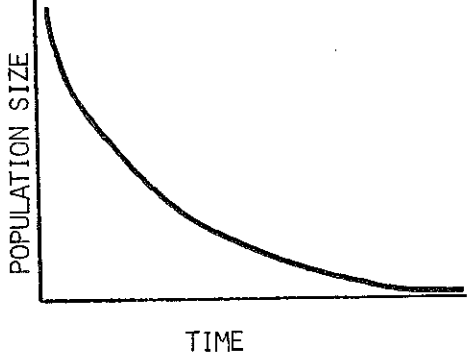
MODEL TYPE	EXAMPLE
VERBAL	"ONCE FISH REACH A CERTAIN SIZE, THAT AGE CLASS WILL DIE AT A FAIRLY CONSTANT RATE."
GRAPHICAL	
MATHEMATICAL	$N_t = N_0 e^{-Zt}$ <p>WHERE,</p> <p>N_t = Population size at time = t</p> <p>N_0 = Population size at time = 0</p> <p>e = Natural base</p> <p>Z = Total mortality rate</p> <p>t = Time (greater than 0)</p>

Figure 3. Verbal, graphical, and mathematical models of population change over time. Each model can be useful, depending on the purpose at hand.

The most rigorous type of model is that utilizing mathematical descriptions (Figure 3). Mathematical models, until very recently, have been relatively simple because analytical tools have not been available to solve complex systems of equations. For example using one older method of solving 19 simultaneous equations (Cramer's Rule) would require approximately 38 hours of calculation on a computer. Hand calculation would clearly be impossible.

Arithmetic calculation has been a major problem with using mathematical models in fisheries management. This problem has been solved to some degree by "simulating" fisheries. This 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 ten 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 and arithmetic analysis. For example, on a computer you may hypothesize: IF we fertilize this lake, THEN the growth of large-mouth bass will be according to the following relationship. . . IF not, THEN the relationship will be this. In this way 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 and ultimately enhance decision analysis. 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.

Each component of a bass fishery is in itself "relatively" simple. For example, changes in individual populations can be studied. Age class abundance by species may be monitored with relative ease. It may be shown that 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 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 test the probable impact of changing size limits.

One of the least appreciated aspects of modeling and simulation is its relation to raw data. A difficult decision in management or research is deciding on 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 simulator will make one painfully aware of data gaps and how useful various pieces of data are. Simulation can thus serve to identify data to be collected.

Modeling and simulation is very definitely a learning experience. A modeler must state his perhaps hazy thought in a very exact manner. Relationships that the modeler had never considered must now be addressed and his best estimates provided.

Fisheries Simulation

STOCKS, an example of the application of computer simulation in fisheries management, is based on a 3-species freshwater lake sport fishery. Much of the basis for the model was derived from 10 years of creel census data from Lake Brittle, Virginia. Each species is considered to be a single stock (a manageable unit in itself). The three stocks used in the model are black crappie, largemouth bass, and bluegill. Recruitment acts to increase the total number of fish in the fishery (N_j). Total annual natural mortality rate and fishing exploitation rate act to decrease N_j . Environmental effects either increase or decrease N_j through actions on recruitment and mortality.

Since 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 resources 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, 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. 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 N_j , which affects spawning success of all three stocks.

Growth in biomass per individual is not considered explicitly in STOCKS, only increase in numbers. 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 should consider the model to be operating under the average conditions of the particular fishery he is dealing with and assume 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.

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 results 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 yield; and (4) the graphical analysis showing that STOCKS may be capable of mimicing a multispecies fishery (Figure 4).

The average catch of a stock was found to be about 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 estimates for the simulator along with his best intuitive estimates for recruitment and initial population 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 interating 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.

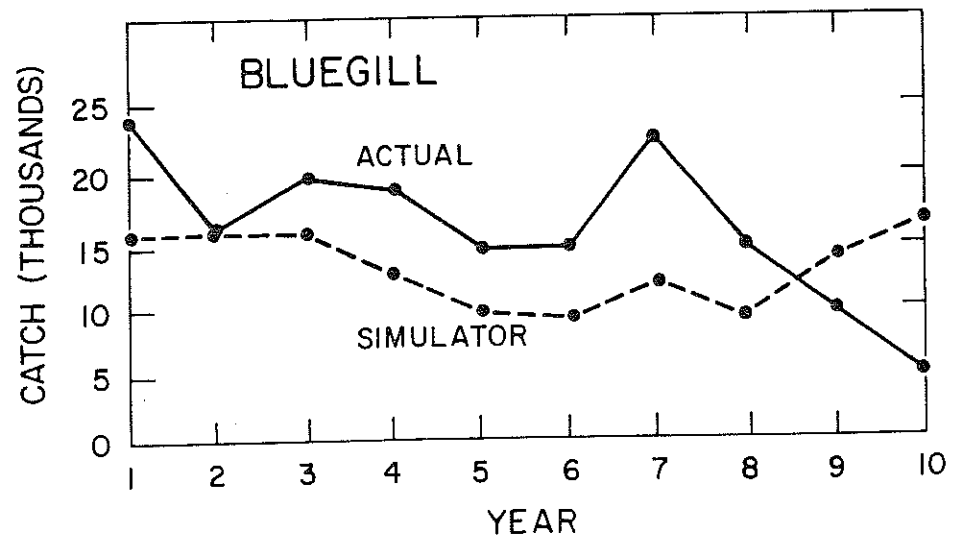
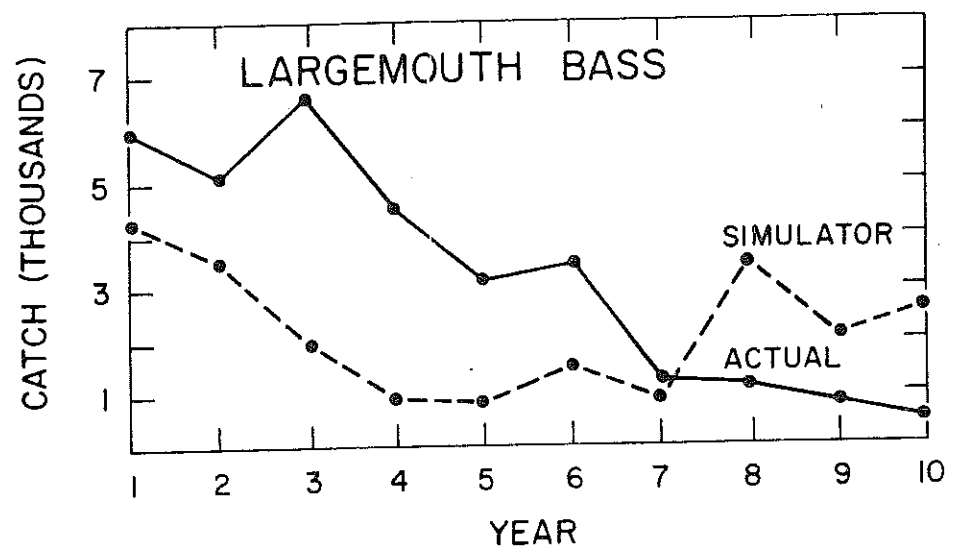
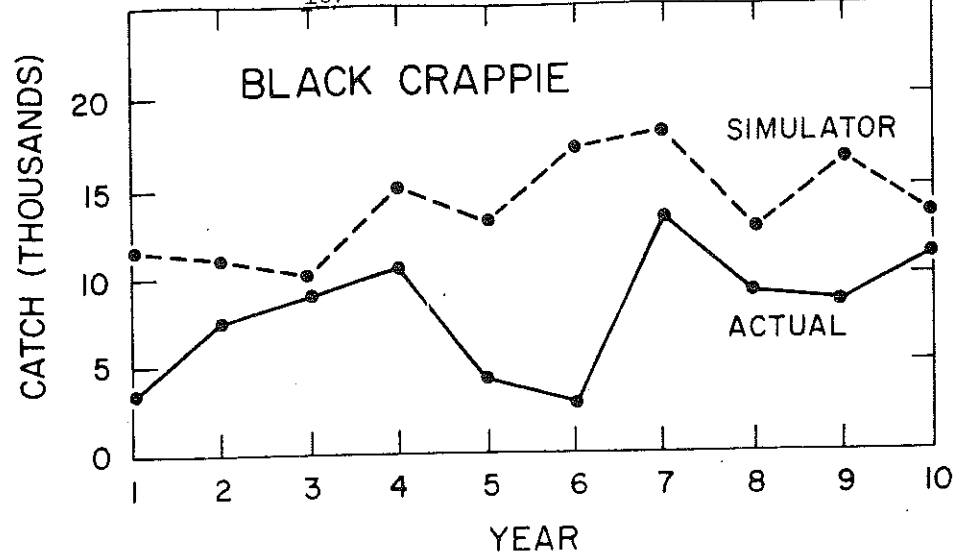


Figure 4. Plots of STOCKS-generated catches vs. Lake Brittle catches of black crappie, largemouth bass, and bluegill.

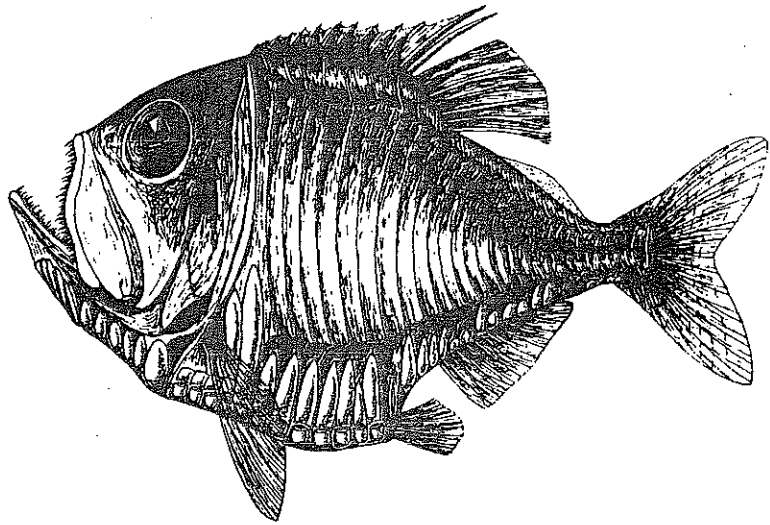
The response of STOCKS to varying exploitation rate for one stock, while holding the others constant, appears to verify interaction effects. When a stock was increasingly exploited, average catch of that stock increased until overexploitation was achieved, and then the catch took a drastic decline. Concurrently, 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 in all disciplines. Any model can be made to deliver desired 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 is of little value in management unless it addresses the 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 in terms of decisions or identifying weaknesses in existing knowledge.

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 a 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 (learning) 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 in the real world and evaluate if the fishery responds as the simulator predicts. The heuristic value to the fisheries manager is limited only by his imagination.



Use of sport fishing resources is intensifying. Out of necessity, fisheries managers are becoming more involved with people management. This trend has added to the number and magnified the complexity of management problems. With increased demand, the need for effective management has increased. Fisheries managers must develop improved management tools and concepts if they intend to achieve effectiveness under such circumstances.

Managers are, by definition, planners, but as management systems vary in complexity, management plans vary in effectiveness. The complexity of natural resource systems is staggering. Natural resource planning is a sophisticated family of processes involving a number of well defined steps. The theme which underlies each planning approach is a commitment to objective definition and quantitative analysis of the system involved.

Planning in fisheries management may permit the manager to direct trends in resource consumption, but the state of planning in fisheries management leaves much to be desired. Many decisions made by fisheries managers are forced upon them by crisis situations. As a result, trends in freshwater sport fisheries are largely out of control. Most agencies view such trends as extrinsic phenomena, and design fisheries management programs to run along behind these trends, trying, but inevitably failing to keep up. Management must be viewed as a generator of new trends rather than the response to trends of the past.

Computers and Fisheries Management

Computers have many uses in fisheries management ranging from education to facilitating numerical analysis. Ultimately, the most exciting applications of computers to fisheries will probably be in the planning and decision-making areas.

There are two major benefits to be gained from the use of computers to aid planning. First, computer use forces formal problem definition. The problem of recreational fisheries management can be made clearer by attempting to set it forth formally. Even primitive efforts in formal problem statement will raise questions which, for lack of answers, cast grave doubt on the effectiveness of management plans.

A second benefit is that the computer stores and manipulates great masses of information flawlessly according to detailed instructions. This facilitates comprehension of a complex management system. These computer instructions, or models, tend to contain many variables and require large amounts of input data because fisheries systems are complex. Fisheries managers will have to accept and use large models.

Some scientists have predicted the computerization of perhaps most human managerial activities during the seventies and eighties is inevitable. It is certainly safe to conclude that fisheries science professionals are participating actively in the computer revolution.

Computer Simulation

A simulation model is a special kind of model, and a model is a special way of expressing a theory. A theory is a set of statements about some aspect of reality, such as past reality, present reality, or predicted reality. A theory attempts to describe the components of that reality and to specify the nature of the relationship among those components. In our case reality is the fisheries management system and we describe our theory through mathematical relationships. The resulting simulation model answers IF..., THEN... type questions about the management system.

The best reasons for using computer simulation are economic. First, it is usually cheaper to experiment with the simulated system than the real system. The computer compresses the time element of the experiment and provides a method of synthetic data collection. Second, costly mistakes are often avoided in the real system if management strategies are tested in the simulation. And finally, the simulation can set forth new and revise old data collecting procedures, thus assuring maximum payoff for data collecting efforts.

Probably, the most important benefit of simulation for aiding planning is the improvement of the planner's predictive capabilities. Computer simulation models put together knowledge of the system in such a way as to enhance the accuracy of predictions about a system. Thus, computer simulation can be a potent methodology for predicting consequences of alternative management strategies. They produce quantitative information that can serve as performance measures of each strategy.

PISCES - A Computer Simulation

PISCES is a computer simulation model of a state 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 objective 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 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 fishery. 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 acquisition; and (3) water losses as from pollution or inundation.

PISCES is divided, internally, into five types of fisheries which are typical of many states: (1) warm streams; (2) marginal trout streams; (3) natural trout streams; (4) ponds and lakes; and (5) reservoirs.

The choice of angler-days as the common measure of output for PISCES was based on the importance of people management in fisheries management. An angler-day is defined as any part of a day one person spends angling. The effect 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 types of fisheries previously mentioned. Thus, an angler-day of bass fishing can be weighed equal to, more than, or less than an angler-day of trout fishing.

The real world fisheries management system is complex and contains many random components. Even if the system is organized into a simulator, random variables remain. Many of these random variables describe events which never occurred in the past or have very little or no recorded data. Assignment of an objective probability distribution to such variables is not possible. It is a difficult task to obtain reliable predictions under such circumstances, but management decisions must be made regardless.

PISCES uses a technique of subjective probability assignment. It is a method of fitting Weibull probability functions by utilizing the best available subjective and objective information about variables. Low, most likely, and high estimates are used to develop the Weibull probability distributions.

PISCES is a Monte Carlo simulator. A random value is selected from the probability distribution for each input variable and substituted into the model to yield one value of the output function. Repeating this procedure fifty times produces a distribution on the output. The expected value (mean) and standard deviation of the output distribution is printed. These printed values can be interpreted as predictions of the performance of management strategies under alternative future conditions. For example:

$$\text{bad conditions} = E(X) - S.D.$$

$$\text{average conditions} = E(X)$$

$$\text{good conditions} = E(X) + S.D.$$

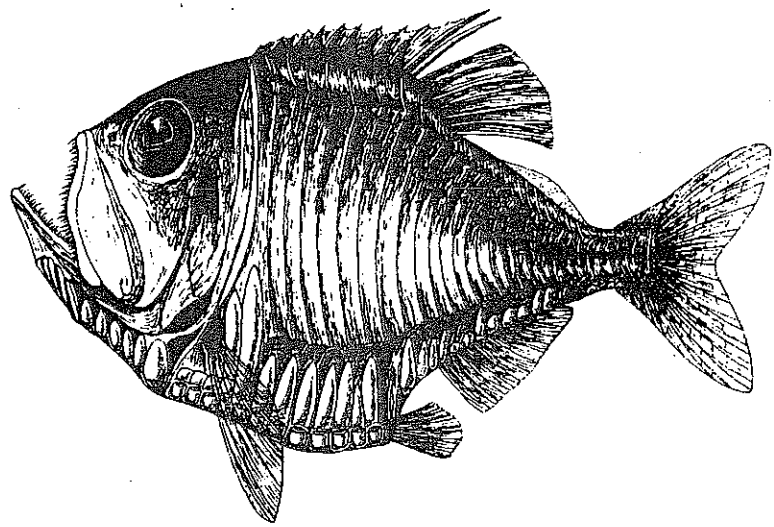
Where $E(X)$ is the expected value of the output (angler-days), and $S.D.$ is the standard deviation. Predictions from such an approach should lead to the development of management plans designed to cope with alternative conditions.

As is typical of simulators, no statement of management objectives is required by PISCES. This should not be construed as belittling the importance of clearly stated objectives, but should be understood to be a scheme for allowing the use of different objectives. For example, PISCES can be used to devise budget allocation plans for either maximizing or minimizing the number of angler-days in the state. A more rational

use for PISCES would be to give fisheries managers an additional, subtle means of control of angling effort via budget allocation. This added control would be useful because many other management strategies are based on the assumption that management has control over effort.

Use of computer simulation, as illustrated by PISCES, as a planning aid is not without problems. Simulators are large, complex models, and managers must trust model builders to incorporate the important components of the system in a valid fashion. Also, while understanding how to use a simulation is relatively simple, obtaining the best results requires a degree of skill. Thus, management expertise must take on a new form.

Fisheries managers should seriously question the validity of models, but there is no need to wait until the nature of the components of the management system are certain before constructing models. Models which tentatively postulate the nature of the system can be constructed. By watching the behavior of the operation of the tentative model, it can be checked and refined. Thus, even an uncertain and partially erroneous framework may be a way of generating a complete and well validated model.



***RECREATIONAL
FISHERIES
MANAGEMENT***

GENERAL PRINCIPLES - RECREATIONAL FISHERIES

Whether a population increases, remains stable, or decreases over time depends on the balance of input (births and immigration) vs. output (deaths and emigration). When births and immigration are greater than deaths and immigration, the population increases. If the opposite is true, the population declines. Population change depends on environmental resistance (food availability, spawning habitat, predation, competition, etc.) suppressing the innate or biotic potential of a species to increase.

When a species is introduced into suitable habitat, its population sometimes increases in the manner expressed by the sigmoid growth curve. Immediately after introduction, population increase is often relatively slow (lag phase), probably due to the difficulty of finding mates. The population growth rate then increases and approaches geometric or logarithmic growth. During this phase, environmental resistance is still minimal and the biotic potential comes close to being fully realized. When the population reaches its maximum rate of change, the inflection point, growth begins to slow. Eventually, the population reaches an asymptote (sometimes called the carrying capacity). Here population growth rate is zero, births are balanced by deaths, and factors of environmental resistance balance any potential for increase.

A virgin (unfished) population usually exists at the asymptotic level on the population growth curve, although population size does fluctuate above and below the asymptotic level. During some periods, environmental resistances may diminish, thus allowing the population to temporarily increase, while at other times, environmental resistance may increase, thus causing the population to decline below the asymptotic level. Exploited (fished) populations almost always exist below the asymptotic level.

In classical ecological theory, managing game fish populations may revolve around deciding at what point on the growth curve the population should be to produce maximum equilibrium yield and then trying to manipulate the factors of environmental resistance (including fishing) to maintain the population at the desired level. Although many forms of environmental resistance act together to suppress population increase, quite often one or a few factors have much greater effect than others. By identifying the more important determinants of environmental resistance and minimizing them, the fisheries manager can alter the fish growth curve and increase harvest. The manager must recognize that management almost always revolves around rates rather than static estimators, such as numbers of fish.

The forms of environmental resistance are usually divided into biotic and abiotic factors. Abiotic factors that influence the size of game fish populations are classified as physical, chemical, or organic. Examples of important physical factors might include the nature of the spawning substrate, water depth, temperature, or velocity, stream gradient, and physical obstacles to migration. Examples of chemical factors include dissolved oxygen, pH, and concentrations of nutrients and toxicants. Among factors of the organic type may be included vegetation used for spawning, shelter, or food organism habitat. Biotic forms of environmental resistance include competition, predation (natural or fishing), parasitism, and disease.

Stock-Recruitment Theory

To manage fish populations for maximum equilibrium yield in certain fisheries (salmon and trout), the manager must understand the relationship of spawning stock size to recruitment stock. This relationship has been best developed for commercial fisheries, but does have application in recreational fisheries (Chapters 7 and 15). In essence, for a given weight of adult spawners, the weight of recruited mature progeny at the 45° equilibrium line is the weight of recruited mature progeny needed to just replace the spawning adults. The weight of mature progeny above the 45° line are surplus and can be completely harvested without changing the future spawning stock size and produce an equilibrium yield.

Near maximum stock abundance reduces efficiency of reproduction. Food supply is limited and is less efficiently converted to fish flesh. Unfished stocks tend to contain excessive numbers of older individuals. Larger fish eat larger food so an extra step may be inserted into the food chain with concomittant energy loss due to trophic transfer.

The fisheries manager may desire to maintain fish populations at a level that will give maximum equilibrium yields and this population is below the level that gives maximum total recruitment and very much below the virgin population size (often 25 to 40% of the virgin population size). However, this is not to say that a virgin stock exploited on a non-sustained and temporary basis cannot give a much greater yield than the sustained yield from the same fishery.

The spawning adult population producing the largest yield of recruited progeny of the stock-recruitment curve closely corresponds to the inflection population size of the sigmoid growth curve. In order to achieve maximum equilibrium yield, the fisheries manager must keep the population well below the asymptotic level and harvest the population at the point where it is growing at its maximum rate.

Surplus Production Theory

It often occurs that the combination of commercial and recreational fishing on salmon and trout over-harvests these species so that the biomass of spawning adults is less than adequate to produce maximum sustained yield. In warmwater fisheries the opposite is often true: there is a surplus production relative to harvest. Recreational fishing almost always tends to under-harvest warmwater species so that populations of adult spawners remain in excess of the biomass necessary to produce maximum equilibrium yield. On the other hand, coldwater recreational fisheries management techniques are often designed to lower fishing or natural mortality and to increase recruitment so that adult populations may attain the level where maximum equilibrium yield can occur. In warmwater fisheries management, techniques are usually designed to increase fishing or natural mortality of adult spawners in order to lower their biomass.

Theory of Fishing

It is important that the fisheries manager understand the theory of fishing and how various vital statistics of stock size, recruitment, growth, total mortality, fishing mortality, and natural mortality relate to yield of a fish stock. It is intuitive that

$$P_2 = P_1 + g + R - z$$

where, P = biomass of stock at $t = 1$ or $t = 2$

g = growth between $t = 1$ and $t = 2$

R = weight of recruited stock between $t = 1$ and $t = 2$

z = weight of fish dying between $t = 1$ and $t = 2$

[The change in harvestable biomass of a fish stock between time 1 and 2 equals the biomass of harvestable fish stock at $t = 1$ plus the addition of weight to P_1 by growth, plus the weight of the recruited stock over the time interval $t = 1, t = 2$, minus the loss of weight due to mortality, either fishing or natural.] Thus, the fisheries manager can affect the biomass of fish available for harvest by applying techniques that affect growth, recruitment, fishing mortality, or natural mortality.

The theory of fishing is mathematically stated (in simplified form) that:

$$Y \cong (N_0 + R) \cdot (1 - e^{-Z_t} + G_t) \cdot \frac{F}{Z}$$

Further elaboration is provided in Chapter 15.

WARMWATER MANAGEMENT

Standing water may be classified into two broad categories, natural and artificial. The most common natural lakes are in glacial basins formed by continental glaciers scouring already-formed stream valleys. Another type of natural lake, the tectonic basin, is common in Florida and is formed by the movement of the earth's crust. One of the most impressive lakes formed by stream action is the oxbow lake. As a stream erodes its banks, a lake is formed. This type of impoundment is often found along the Mississippi River. Swamps and marshes are natural pond and lake basins that are formed from flooding low ground or siltation of a pond or lake. Swamps are characterized by the presence of large trees and shrubs, while marshes support grasses and sedges.

Artificial ponds and lakes may be divided into two groups: (1) water basins for some definite purpose, such as farm ponds or flood control basins; and (2) water-filled depressions from which surface materials or mineral deposits have been removed, for example, gravel or borrow pits.

One of the most common types of artificial ponds is the farm pond. Usually ranging in size from a quarter to ten acres, these are multi-purpose structures for water supply, livestock, and recreational use.

The primary function of most artificial lakes is to provide water for consumption. A secondary function is recreation. Many restrictions are placed on their use for recreation, thus, limiting flexibility in fisheries management. Lakes built for flood control, navigation, hydroelectric power, and water-based recreation provide us with the largest artificial lakes. These lakes range in size from only a few thousand acres up to seventy thousand acres. Due to their size and multiple use function, these are the most difficult lakes to manage.

Similar to the natural ponds and lakes are the water basins from which surface material or minerals have been removed. The most common of these basins are the gravel pit ponds and the strip mine ponds. Gravel pits are characterized by steep sides, clear water, and low productivity, while strip mine ponds are characterized by high pH and brownish tint to the water. Strip mine pits have been used in catfish culture in the mid-west. Phosphate mining in Florida has created water basins ranging in size from 1/2 to 17 acres. These ponds are quite fertile, but the control of aquatic vegetation in them is very difficult. Another artificial water basin, the borrow pit, is created by the removal of soil for the grading of highways. These pits fill to the level of the ground water and, when stocked, provide excellent ponds for recreational use.

Stocking

Each lake or pond has to be considered on its own merits before stocking is undertaken. Stocking programs may be broken down into three categories: (1) introductory stocking where there are no fish, such as barren waters, new ponds or lakes, and reclaimed waters; (2) improvement to enhance a population, as in the case of a spawning failure; and (3) exotic stocking to improve the food chain, for example, the introduction of a plankton feeder to serve as a forage fish. Only those species for which management is planned should be used in introductory stockings. Before stocking is undertaken, careful consideration should be given to the combination of fish to be used.

Introduction to improve the food chain has become a common technique, especially in large lakes, over the last fifteen years. Threadfin shad have been planted in several southern lakes. Their presence often improves growth rates of such species as white bass and walleye. Other forage fishes used for this purpose are the landlocked alewife, smelt, and herring.

Introductions of new fishes into existing ecosystems has long been common in fisheries management. In the past, fish were stocked on a trial and error basis. Now, more emphasis is being placed on the life history of the fish and whether or not a niche will be available in the new waters.

Management Approaches

Surveying and stocking new lakes are initial steps in a fisheries management program. Periodic sampling of the fish populations is required to evaluate the stocking program. There are five general ways to sample a population in a large lake. Each has a certain species and size selectivity. In order to adequately sample a large population, two or more of the following should normally be employed: (1) rotenone (cove sampling); (2) nets; (3) seines; (4) electrofishing; and (5) trawls.

Cove sampling with rotenone involves blocking off a section of the lake of known acreage with a net, then completely eradicating all the fish in the enclosed cove. From species numbers and weights of the fish collected, a rough estimate of the species composition and abundance in the lake can be obtained. To have statistically valid results, a large number of coves must be sampled. Under most field conditions, obtaining highly reliable data is nearly impossible.

Nets can be used to secure a cross section of the fish population. All nets, gill nets, trap nets, etc. are selective in that they depend on fish movement. Seines on the other hand do not require fish movement. The use of seines to sample reproductive success in ponds and small lakes is a widely accepted practice. Several seine hauls should be made, with each haul covering a different location.

Electro-fishing can be used to collect young and adult fish. The main restriction with electro-fishing is its ineffectiveness in deep and/or turbid water.

For sampling pelagic fishes, the trawl is very effective. By regulating towing depth, young fish and old fish can be selectively captured. With this method pelagic fishes may be sampled, but for fishes utilizing shoreline areas, other methods have to be employed.

When a fish population is not able to support high yields or species such as suckers invade the lake, complete removal of the population may be warranted. The complete removal process is only practical for small lakes, 250 acres or less, because lakes or larger size are usually multi-purpose structures with fishing a secondary function.

When draining a pond is impossible, use of a fish toxicant, such as rotenone, may be substituted. In many cases complete eradication is not secured, particularly if freshwater inflow is great, if there are dense weed patches, or if the pond is shallow and turbid. Undesirable fishes may return so quickly that the efforts were wasted.

In larger ponds the technique of selective chemical treatment has been used. The pond can be treated around the shoreline or sectionally treated. The timing of partial eradication is important because you want to eradicate only the target fish such as bluegill, while not harming the bass population. With sectional treatment a sufficient amount of toxicant is applied to remove all the fish from the given section of water. The disadvantage of sectional treatment is that the more desirable species are killed along with the undesirable fishes.

When only a single species or two is the object of eradication, chemical treatment at a given concentration may be used. For example, 2 mg/l copper sulfate has been used to remove bullheads and golden shiners. To remove unwanted fishes in a catfish fishery, guthion, an organo-phosphate insecticide, at the rate of 1 mg/l will remove the unwanted species within forty-eight hours.

A rotenone concentration of 0.05 mg/l has been used to attempt control of gizzard shad in southeastern lakes. Although a high percentage of the population was removed, within three years the shad population returned to the pre-treatment level. By treating the nest of bluegill and other sun-fishes with sodium hydroxide pellets or copper sulfate crystals, the eggs or fry are killed. These chemicals not only kill the eggs or fry, but also discourage reneating.

By fluctuating the water level of a pond or lake, small fish will be drawn from the shoreline cover into open water and be easy prey for the predatory fish. When water level is held at a low stage, the resulting population will adjust to the smaller body of water. In late winter or early spring, when the water basin is again filled to capacity, all fish that have survived the crowding begin to grow rapidly due to an increased supply of food and space.

Drawdown operations have been used to regulate spawning success. By lowering water level following carp spawning, a carp population has been temporarily reduced. The flooding of recently established vegetation has resulted improved conditions for pike spawning.

Regulations

Although regulations usually have little impact on warmwater fisheries, a few really large fish are sometimes more important than maximum poundage. If such a situation exists, it may be desirable to limit fishing intensity so that the total mortality rate is low enough to permit a certain number of fish to reach advanced age and size. There are several ways this may be attempted. The first is by closed seasons in an effort to protect fish during the spawning season. Loss of some recruitment is usually not important unless reproduction rates are so low that the resulting recruitment to catchable size is controlled by reproduction rather than competition prior to recruitment size. If the brood stock is critical, it may be wise to prohibit fishing just before the spawning season, but this situation is rare. In a shorter season, fishermen may fish more. Therefore, a closed season may really increase fishing effort.

A second method is to close an area. In general, closed areas are not effective, but occasionally certain areas of concentration of spawning, or areas with largely small fish, may be closed.

Gear limitations are mainly restricted to either coldwater fisheries or commercial fisheries. Warmwater management seldom involves over-fished populations. But if this case should arise, restrictions on the size of hooks, bait, or pieces of fishing tackle in use may be employed to reduce catch.

A fourth type of regulation used in management is the creel and possession limits. These are generally applied to restrict the total catch and to distribute effort among a greater number of anglers. Since the number of anglers may increase, creel limits are probably not very effective in controlling total catch. Where fishing is very heavy, creel limits may force fishermen to quit fishing before they normally would, thereby releasing fishing sites to others. Too high a limit tends to bring out greed and the individual will stay out just to try to reach the legal limit, often at the expense of the "recreational" aspect. The daily limit becomes a goal, a measure of success. A limit of fish may imply to some anglers that he is as skilled an angler as the next fellow and that he could have caught more, but the law would not allow it.

The last type of regulation to be discussed is that of size limits. Size limits may be used to protect fish until they spawn in an effort to maintain adequate brood stock. However, size limits may result in undue protection and accumulation of slow growing, under-sized fish.

FARM POND MANAGEMENT

Ponds have many beneficial uses for landowners and fishing is one that is especially enjoyable. Many farmers stock their ponds with bass and bluegill to provide leisurely hours of fishing. They also have the added benefit of a private area to swim, camp, and picnic. Others invest on a commercial basis in their ponds by having them stocked with fingerling bass, bluegill, or catfish, raise them to catchable size, and allow people the use of their ponds for a fee.

In most cases well managed southeastern ponds can produce 100 pounds of fish per acre per year, but with exceptionally good management they may yield several hundred pounds of fish per acre per year. What is more important, though, are the many hours of healthful recreation provided.

Farm ponds range in size from a quarter to several acres. Many farm ponds, even when designed for other purposes, are adequate to support good fishing, and often those which are unsuitable can support fish populations after only slight modification.

The following conditions can be used as a guide when deciding to build a farm pond: (1) six to ten acres of watershed are desirable to maintain each acre of pond; (2) a four-inch or larger drain pipe should be installed to allow water level to be lowered or the pond drained for weed control or fish population adjustments; (3) dam specifications and spillway size should be tailored to pond size and expected runoff; and (4) the slope of the pond edges should be at least 60 degrees to eliminate weed-growing shallow water areas. Proper pond construction requires some engineering skills. To prevent construction mistakes, one should always seek advice from a county extension agent or the Soil Conservation Service.

Ponds used for fishing do best when stocked with the right species and in the right amount. Warmwater ponds are suitable for largemouth bass, bluegill, redear sunfish, and catfish. All unwanted fish should be removed before stocking.

Warmwater ponds are usually stocked with largemouth bass and bluegill, or a combination of bluegill and redear sunfish with bass. These species can reproduce in ponds and fishing is usually good unless bluegill overpopulate. The best stocking rates are 50 young bass and 500 young bluegill per acre for ponds of natural fertility and 150 young bass and 1,500 young bluegill per acre in water that has a high level of fertility. Redear may be substituted for one-third of the bluegills.

The three major species of catfish (channel, blue, and white) can be grown successfully in farm ponds. They do best when they are the principal fish stocked. From the angler's point of view, the channel catfish is probably the best of the three to stock for a game fish because it can be regularly caught. Blue and white catfish are more difficult to catch, but in some cases provide good fishing. Channel catfish are also popular as food fish as they grow rapidly and have excellent flavor. The three species may be stocked separately or in combination at the rate of 1,500 - 2,000 per acre. Combining these fish usually results in an enhanced angling opportunity for most fishermen. When stocking at high rates however, supplemental feeding with a commercially prepared catfish feed is usually necessary.

Fish for the initial stocking of farm ponds are often available from the U.S. Fish and Wildlife Service through the local county extension agent. County extension agents can also provide a list of private fish suppliers.

To provide high quality fishing one must maintain a balance between the fish species in the pond. Balance is defined as a favorable ratio between predatory fish (bass) and forage fish (bluegill). Balance is first reached by using correct stocking rates, and then maintained by keeping the pond in good physical condition (few weeds, no wild fish, and adequate fertility), and by using a sensible fishing rate.

Each species serves a special purpose in a farm pond. Bass provide an occasional large fish and prevent the bluegill from overcrowding. Bluegill provide most of the fisherman's catch and provide bass with food.

Bass should be removed at a much lower rate than bluegill, since they must always be present in adequate numbers to control bluegill. At least four to five pounds of bluegill should be removed for each pound of bass. A pond out of balance may be helped by heavy harvest of the overabundant species or, as a last resort, removal of all fish by draining or chemical treatment, then starting over with the correct ratios.

Besides stocking and maintaining balance, one must manage the physical aspects of the pond to produce quality fishing. Shallow areas can become choked with weeds. To prevent this, pond edges should be fairly steep, the pond fertilized, and rooted plants removed if they get started. Once weeds have a good start, it is often difficult to control or remove them. There are numerous mechanical and chemical controls in use today which give good, but temporary results.

Excessive weeds and decomposing material can cause a problem known as summerkill. This occurs when living plants and decaying material use all or most of the oxygen in the pond. The result is a partial or complete fishkill. This can sometimes be remedied by aerating the water (forced turbulence to replenish oxygen), but it is much better to prevent excessive weed growth in the first place.

The poundage of fish that a pond supports ultimately depends upon the amount of phytoplankton in the water. Phytoplankton utilize energy from the sun and this energy is then transferred through the food chain by larger organisms consuming smaller organisms (microscopic animals → insects → bluegills → bass).

Phytoplankton require sunlight, water, and nutrients to grow. All three are provided by nature, but man can often supplement nutrients to increase phytoplankton abundance and available energy. This is accomplished by fertilizing the water just as one fertilizes cropland. Pond fertility should be built up early in the spring and maintained throughout the summer. This enables fish to grow well through spring, summer, and fall, and will also prevent growth of rooted weeds, which rob water of dissolved oxygen, and add little to the food chain.

A mineral fertilizer is best for fish ponds. A commonly used formulation is 20-20-5 (ratio of nitrate, phosphate, and potassium) applied at the rate of 40 pounds per acre. Fertilizer is usually applied once every two weeks by distribution over the entire pond or by spreading it on platforms placed a few inches below the water surface. Wind action will then disperse the fertilizer. Applications should be continued at this rate until a bright object lowered in the water cannot be seen deeper than 18 inches, then the amount of fertilizer can be reduced by 50 percent.

Disease is rarely a primary cause of a fish dieoff in a well-managed pond, but wild fish may carry disease into a pond. To minimize chances of a disease outbreak, eliminate wild fish and watch for abnormal behavior and sores on fish. If disease should occur, have the disease checked by the county extension agent and then initiate the recommended treatment.

Farm ponds in many states are now being used for commercial purposes. Channel catfish are grown under very intensive conditions to be sold as a marketable product. They grow fast, command a good sale price, and easily adapt to artificial feed. Compared to other farm animals, catfish convert feed into meat very efficiently. One hundred pounds of catfish feed will produce 70 to 80 pounds of catfish.

Channel catfish raised in ponds can be sold in the live fish market (for stocking) or the food market. Live fish are in demand by private operators of fee fishing ponds. Fee fishing ponds are increasing in number to fill a much needed recreational demand. The bulk of farm-raised catfish are sold to processing plants where they are dressed and distributed to grocery stores and restaurants.

Pond culture is well developed and is the most reliable method of catfish farming. Fingerlings are obtained from commercial breeding hatcheries at the beginning of the growing season (spring) and fed daily with a prepared ration. At the end of the growing season (October to November), they are harvested at marketable size (3/4 to 1 pound).

The characteristics of the pond are especially important in fish farming. The pond should be structured such that: (1) it is free from other fish; (2) flood hazards are minimal; (3) dissolved oxygen level will always be high; (4) the pond will be at least four feet deep; (5) and have a drain.

STREAM FISHERIES

A stream is a mass of water (brook, creek, and rivers) with its load moving in a more or less definite pattern and following the course of least resistance toward a lower elevation. For fisheries management purposes, streams are typically classified as warmwater or coldwater, depending on the fish fauna present. The true complexity and variability in streams has been described by contrasting physical, biological, and political aspects.

Physically, streams may be long or short, fast- or slow-moving steep or flat, slow- or fast-growing in size, rocky- or soft-bottomed, clear or turbid, widely variable in temperature, both seasonally and along its course, free-flowing or cluttered with obstacles, sparsely or heavily pooled, relatively uncluttered or dammed, channeled or diverted, and clean or polluted with industrial, agricultural, and municipal wastes. Biologically, a stream is fertile or infertile, poor or rich in fauna, and weedless or choked with vegetation.

Politically, a stream usually passes through private, commercial, and public jurisdictions covering city, county, state, and national boundaries. Streams serve multiple uses, including recreational, agricultural, municipal, and industrial purposes. A good management plan will include the implications and effects of all these factors.

The living portion of the stream - from the smallest bacteria to the largest fish - usually command the largest portion of the manager's attention, both from the length of time required for proper sampling and from the concern of the public which utilize fisheries resources. Stream organisms must be able to survive twenty-four hours per day, throughout the year in a stream. For this reason, measurements of biological parameters throughout the year generally provide better estimates than do random chemical measurements which reflect the situation only at the time they were taken.

In streams, as in all ecosystems, sunlight is the initial energy source. Basic nutrients enter by substrate erosion, leachates from soil, which enter as runoff, from man-caused sources (agriculture, municipal sewage, industry) and from entering vegetation such as falling leaves. Most primary production is not from the phytoplankton as in lakes and oceans, but mainly from attached algae, mosses, and higher plants.

The majority of fish-food organisms for smaller fish are included in the benthos. Included in the benthos are attached forms, such as plants, and the free-living forms, such as the invertebrates. Higher aquatic plants are usually confined to the shore of pool areas, especially in swifter streams. Attached forms of algae may flourish in the riffle areas.

Fishes in streams are as varied as the physical and chemical characteristics. Warmwater streams generally support a greater biomass and a greater species diversity. Headwater streams, usually geologically recent, may have relatively few fishes, such as trout and several minnow species, while the older warmwater streams support an abundance of sunfishes, suckers, and minnows. Unlike lakes, streams are open systems without precise boundaries, although several zones are often recognized.

Management

Three basic management alternatives are available--managing the fish, the habitat, or the fisherman. The manager must first define his objectives. Is he striving for maximum yield of fish? Should the yield be expressed merely as pounds or as size? Will the stream be managed for a single species, several similar species, or several grossly different species? The manager must know if the habitat will provide for natural reproduction or provide only a seasonal fishery like a put-and-take trout fishery. And consider the fisherman--will he want fish, regardless of size? Or is he only interested in a trophy fish? Generally, managers work to produce a population which will give the maximum equilibrium yield. However, state governments set regulations and managers must work within this context.

Before evaluating various potential manipulations of a fishery, the manager must identify and quantify populations. Various population estimators will be briefly described here as they specifically relate to stream fisheries (See Chapter 4 for greater detail). Before a management study is attempted, a definite plan must be outlined. The study should be designed so that all data gathered contribute to the ultimate goal and are collected in such a manner that will allow statistical analysis.

Sampling techniques often depend on stream size and desired data. If a complete population estimate is attempted, much more extensive sampling is necessary than if only a few fish are to be captured for use as brood stock or to estimate relative year class strength. Gear selectivity should also be considered in sampling. All nets are selective for a particular size or species.

Set nets commonly used in stream sampling include fyke, hoop, trap, and gill nets. Nets are often impractical for use in streams containing substantial floating debris. Fish often avoid nets in clear streams, necessitating overnight sets. Many nets are set for a twenty-four hour period, but actually catch fish only at night and thus may select against fish active during the day. Gill nets are size-selective according to mesh size. The practice of setting nets in pool areas and avoiding rapids may also be size and species selective.

Actively-fished nets include seines, small trawls, and drift gillnets. The seine is probably the most used net although it is practical only in small streams or shallower areas of large streams, and larger fish can easily avoid the seine. Trawls are occasionally used in large, deep, slow-moving rivers. Drift gill nets are generally fished at night, where the net is allowed to drift freely with the current over a stream section.

Various traps and weirs are used for population studies, especially on rivers having economically important runs of salmon. These weirs are often permanent devices installed at great cost which would be prohibitive on small stream studies. Weirs funnel fish through a small restricted area where they are counted visually. Electronic counters are gaining increasing favor as the techniques become more highly sophisticated and refined.

Probably the most widely used method for small stream sampling, as well as for reclamation, is treatment with toxicants. The most commonly used toxicant is rotenone usually in a 5% emulsifiable formulation. Toxicants will give a complete population distribution in a stream section, but the fish are not returnable to the population.

Electrofishing, which came into usage in the 1950's has gained wide acceptance on all sizes of streams. Units range in size from the small one-man "backpack" units to boat-mounted models. The smaller models are easily carried into remote areas for sampling small headwaters. The larger units are confined to rivers.

Species differ in their susceptibility to electrofishing, and larger fish of a given species are more easily stunned than smaller fish because of the larger surface area exposed to the electric field. Efficiency of the gear is governed by water conditions as well as by the experience of the workers. Softwater streams (usually less than 200 micromhos conductivity) are difficult to sample because of the poor electrical fields set up in the water. In smaller streams, blocks of salt can be set in the stream to increase the conductivity in the sampling area. In larger streams where boat shockers are used, sampling is often done at night when fish are more active. High turbidity will also hinder sampling, as fish are hard to see. The major advantage of electrofishing is that fish can be returned unharmed to the water.

As with other sampling methods, stream sampling must be standardized if any statistical analyses are to be run. Commonly used expressions of catch are numbers or pounds of fish relative to time shocked or stream distance covered.

Creel censuses are also used to estimate various population parameters, and if properly conducted give estimations of population size, age-class distribution, fishing pressure, total catch, catch per unit effort, mortality, growth, movement, results of population or environmental manipulation, and effectiveness of regulations.

The creel census, properly taken and used, is a measure of the ultimate success or failure of the manager's work because it measures changes in angler success. On controlled-access areas, a creel census can be complete. However, in most situations, access is open, funds limit personnel or time, or other circumstances demand a partial census. This census should be stratified, so that allowances are made for weekends and holidays, which receive greatest pressure.

All of the above procedures are used for population estimation and the related parameters of recruitment, total mortality, fishing mortality, and ultimately, yield.

Stream Improvement

The common methods of stream improvement attempt to improve yield by increasing survival, growth, and recruitment of fish. Stream improvement usually consists of physical alterations of the stream or its banks. Improvements are necessary because of naturally poor conditions, or as a result of destructive practices of logging, agriculture, channelization, highway construction, etc. Bank improvement consists of soil stabilization in areas disrupted by poor cultivation methods, overgrazing, excessive logging, or poor road construction. Severe siltation results in decreased light penetration, destruction of benthic organisms, and decreased success of fish (poorer growth and reproduction and perhaps fewer numbers). Bank improvements include introduction of streamside vegetation to provide cover, as well as shade to keep down water temperatures.

Instream improvements include various forms of dams, weirs, and deflectors. These may be constructed of wood, wire, and rocks and are designed to form pools, prevent erosion, and direct water flow to the most suitable channel. Dams are also used to prevent reinfestation of reclaimed streams with undesirable fishes.

Other stream improvements include creating or improving spawning areas by new channels parallel to the main channel, removing silt from gravel, loosening packed gravel, and removal of barriers to spawning areas.

Stream improvement has been used mostly on trout streams, although it is being used on warmwater streams where construction, agriculture, or other land use practices have damaged streams. The question is often asked whether the high cost of improvement is equivalent to the benefits of catching more and/or wild trout, more efficient utilization of inherent stream productivity, more larger fish, increased production, and enhancement of water quality and stream aesthetics. There is no universally accepted answer to this question. Each proposed stream improvement project must be judged individually.

Fertilization, although very successful in ponds, is virtually worthless in streams, where phytoplankton production is low and fertilizer would be swept away without continuous addition. A somewhat similar technique has been used on a small West Virginia stream receiving acid-mine drainage. The stream had no fish life, with the low pH being the limiting factor. Large steel drums were placed on the stream and filled with limestone chunks. The current rotates the drums and crushes the limestone which raises the pH to a near-neutral level, in which trout can survive. Drums must be refilled frequently and the procedure is expensive and infeasible on a large scale.

Reclamation

Stream reclamation with toxicants has met with varying degrees of success. Most successful have been smaller stream projects, where a greater degree of control can be exercised, both with treatment and prevention of reinfestation. Problems in stream reclamation include stream classification (public or private, navigable or non-navigable, wild or multi-purpose), political boundaries (city, county, state, or national), and water conditions (temperature, depth, current, tributaries).

Toxicants offer the only practical means for completely controlling fish populations in streams. Properly applied, toxicants will reach all areas of the stream and eliminate all fish. Control has proved particularly successful in salmonid streams, where elimination of competing species has resulted in significantly higher game fish populations.

Stream reclamation with toxicants developed slowly until 1956, when the first efficient method for detoxifying a fish eradicator was developed. Early toxicants tended to repel fish, driving them ahead of toxic water into springs or tributaries. Most early treatment work was done to clean all fish out of hatchery water supplies to prevent disease spread.

The Bureau of Sport Fisheries and Wildlife reported that in the first five years of the Federal Aid in Fish Restoration Act, 1952-1956, more than one thousand miles of streams were reclaimed. In a ten year review of the program, the Bureau (1962) reported that biologists in 34 states had chemicals to restore fishing in about 2,500 miles of streams. The Sport Fishing Institute indicates that from 1963 through 1967, 5,825 miles of streams in the United States were reclaimed with toxicants, principally rotenone and toxaphene.

Steps involved in a stream reclamation include the following:

- (1) Conduct an initial biological survey.
- (2) Conduct a public relations program.
- (3) Obtain written approvals from the necessary landowners and interest groups.
- (4) Prepare an outline map including all access points, tributaries, backwaters, and toxicant stations.
- (5) Establish volume at each station.
- (6) Conduct water chemical tests at each station.
- (7) Calculate toxicant requirements for each station.
- (8) Establish a detoxification station, if required.
- (9) Establish stations for cages of live test fish.
- (10) Establish post-treatment survey procedures.

Although most reclamation projects have been on small streams, several ambitious projects have been undertaken. One of the largest was in the early 1960's on the Green River in Utah and Wyoming. Approximately 450 miles of the river and its tributaries were treated with 21,500 gallons of 5% rotenone.

Commonly-used toxicants include rotenone, toxaphene, Fintrol (Antimycin), and cresol. Rotenone is most widely used and is sold under a variety of commercial names. Concentrations vary, with most being between 1 and 5 mg/l, with exposure times up to one to six hours. An advantage of rotenone is that it is easily detoxified with potassium permanganate so that a specific area can be treated.

Reclamation has been used largely in small streams to remove competing trash fish. To prevent reinfestation by these rough fish, barriers are constructed at the lower end of the reclaimed stretch before any reclamation is attempted. The falls thus created prevent upstream migration of trash fish from the untreated portion of the stream. Many early reclamations were failures because of the almost immediate reinfestation by undesirable fishes. Incomplete eradication of undesirable fishes is also the major failing point of reclaiming larger streams. The large volumes of water in both the main stream and tributaries and the large amount of toxicant required usually make treatment impractical. A second potential source of reinfestation is the introduction of undesirable fish by the angler. Often bait minnows are small suckers, carp, stonerollers, and the like. Releasing bait fish after a day's fishing may prove disastrous. For this reason, regulations are often enacted on reclaimed streams prohibiting use of minnows as bait.

Stocking

Stocking of fish, while practiced little in warmwater streams, is becoming increasingly important in trout streams. The following are uses for hatchery-reared fish:

- (1) Maintaining fishable populations in streams incapable of producing sufficient natural populations to satisfy demand.
- (2) Restocking streams after some natural or man-made catastrophe.
- (3) Restocking waters following pollution abatement.
- (4) Stocking streams without adequate spawning areas.
- (5) Restocking streams after chemical rehabilitation programs.

Maintenance stocking of warmwater species is unnecessary in most situations. Notable success has been achieved in some areas, however, by the introduction of exotics such as the striped bass in warmwater streams, and the rainbow and brown trout in coldwater streams. Conversely, the most outstanding failure as viewed by most fisheries scientists, was the introduction of the carp.

Stocking of trout in coldwater streams takes various forms. In streams which support fair numbers of native trout, hatchery fish may be stocked to relieve some of the angling pressure on native populations. This is usually a poor practice since native fish out-compete hatchery fish. Many streams of marginal quality, where no natural reproduction occurs, are stocked with catchable-sized trout to provide a put-and-take fishery. These streams now make up the bulk of the trout fisheries in many states.

The size of fish to be stocked is often debated among sportsmen and managers. Sizes stocked range from egg stage to catchable-size for trout, whereas cost usually prohibits raising warmwater fish larger than fingerling size. Sportsmen often request that fry be stocked, in the hope that more "native" fish will result. However, several studies throughout the country have shown a survival rate averaging around 2 percent for trout stocked as fry.

Problems have arisen with the practice of "truck-following" by over-eager anglers. Several methods have been devised to discourage this practice, such as closing the stocked section for a short period or stocking in small closed sections of a larger open stream so that the fish gradually disperse into the open water. Mean return of catchable size trout from 13 streams was 73 percent. The time required to catch 50 percent ranged from two to nine days with a mean of 3.6 days. The mean harvest time for 75 percent of the catch was 6.5 days.

Reasons for low survival of hatchery-reared fish include artificial diet, overfeeding to hasten growth, uniform environment, lack of exercise, no foraging for food, and others. Many people, again hoping for a more "native" fish advocate fall stockings, but for the above reasons, heavy mortality occurs immediately after stocking, and the rigors of overwintering leads to low survival.

The scope of hatchery programs is shown by the fact that states spend about 23 percent of their management budgets on fish cultural programs. By weight, 94 percent of the fish raised to be stocked in the United States are coldwater species. This accounts for 82 percent of the expenditures. To help cover these costs, most states have required anglers to purchase a trout stamp in addition to the regular fishing license.

One area where stocking has been highly successful is the tail-water trout fisheries created by high dams. These dams, usually constructed for flood control and hydroelectric power production, discharge coldwater drawn from the depths of the lakes and provide year-round trout habitat for many miles in the river below. Food supply is abundant and growth rates are much better than in most natural streams. Since no spawning areas are present, the trout population must be maintained by stocking. These tailwater fisheries have introduced trout fishing in many areas where they do not naturally occur.

Regulations

Fishing regulations are designed to establish ownership of fish by the people of the individual states and to provide for licenses permitting the individual to acquire ownership. Restrictions include: (1) using legally described methods; (2) fishing in open areas; (3) fishing at legal times; and (4) fishing for only certain kinds, sizes, and numbers of fish.

Many regulations are a direct result of public pressure and may or may not reflect sound management principles. Warmwater fisheries have very liberal regulations, especially concerning the prolific panfish. These often have no closed season, no size limit, and high or no creel limits. Bass, including largemouth, smallmouth, and spotted, often have minimum size limits of eight to twelve inches as well as creel limits. Larger game fish such as muskelunge and northern pike may have minimum size limits over twenty-four inches.

Trout fisheries are the most closely regulated. Seasons are usually closed from around September or October until April or May to protect the spawners. Both creel and size limits may apply. Gear is restricted so that fishermen may use only one rod, a limited number of hooks, or artificial lures or flies only. These regulations are based on the following (questionable) assumptions:

- (1) The fewer fish caught now, the more that will be available in the future.
- (2) A fairly large number of older fish are needed for spawning stock.
- (3) Smaller fish should be protected as the majority will grow into larger fish.
- (4) It is essential to protect fish during spawning season.

None of these is always correct. The first is not true in unexploited fisheries which are stabilized at the maximum yield well below virgin stock size. The second and fourth statements generally do not apply to sunfish populations. The third statement is untrue if a population has become stunted by overpopulation, as in some sunfish or underexploited fisheries.

Research on Lawrence Creek, Wisconsin, revealed the effects of regulations on a brook trout fishery. Three sets of regulations were evaluated over a six-year period. These included the following:

(1) a six-inch minimum size limit and creel limit of ten; (2) no size limit and no creel limit; and (3) a nine-inch minimum size limit and a creel limit of five. The first two sets had similar effects in that few anglers were skillful enough to catch ten wild trout and few trout less than six inches were kept even when it was legal to do so. The authors concluded that regulations as liberal as these had little effect on the harvest rates. The third set of regulations caused a sharp decline in catch, in angling success indices, and in fishing pressure. At the same time, growth rate declined and natural mortality increased, both in summer and winter. This may result in a stockpiling effect which could decrease yield. The nine-inch limit did increase the reproductive capacity of the brook trout.

The Future

Since streams are open systems and are not confined by political boundaries, and must be shared by all users, fisheries managers must be aware of all potential and real effects of the fishery on other uses of the stream, such as water supplies. Fisheries managers are becoming increasingly aware of the need for total systems management. Increasing knowledge in fisheries-related fields has pointed out new concepts and variables which should be considered, such as the subtle effects pollutants have. Whereas toxic levels for many pollutants have been determined, the sub-lethal effects are largely unknown or unquantified. Streams have and are still used as sewage and other waste disposal mechanisms. As the outcry over this destruction grows, research has increasingly been slanted toward pollution abatement through studies of the effects of various substances on the biological diversity of polluted streams, the stream assimilative capacity, and the recovery zone.

Fisheries management is an extraordinarily inexact science, particularly insofar as quantification of the various parameters. Organisms are acted upon by countless variables and isolating a single factor for a cause-effect relationship is difficult, if not impossible. Sociological aspects are even more difficult to control or predict.

SALMON FISHERIES

22

There are six species of Pacific salmon: sockeye, pink, chum, chinook, coho, and cherry. The cherry salmon is found only on the Asian side of the North Pacific. Fisheries for the Pacific salmon developed rapidly in the last third of the 19th century and extended from California to Alaska. The largest fisheries are now located from Washington to Alaska.

Management efforts center upon that observation that (1) salmon return to their home stream to spawn, and (2) the rate of harvest of the population of each river must be limited. In practice, hatcheries have been used to supplement runs, although such programs are often not successful. Escapement, those fish allowed to pass through the fishery, is usually controlled to provide for optimal yield. Catch is also highly regulated.

Selecting optimal catch and escapement is difficult. Environmental variables obscure population dynamics relationships upon which the manager bases his decisions. Unexplained phenomena, such as oceanic currents, often alter population dynamics relationships, making accurate prediction difficult.

Management Exercise

A salmon fishery has been computer programmed (SALMON) and is available for management practice.

The Salmon River is intensely fished for a one-year life cycle salmon, Oncorhynchus simplex. Catch (commercial drift-net fishery) and escapement (adults that escape fishing to actually enter the spawning run) are usually the two most important factors determining run size (total number of adults returning to the fishery). Many other factors affect run size, but usually to a lesser degree.

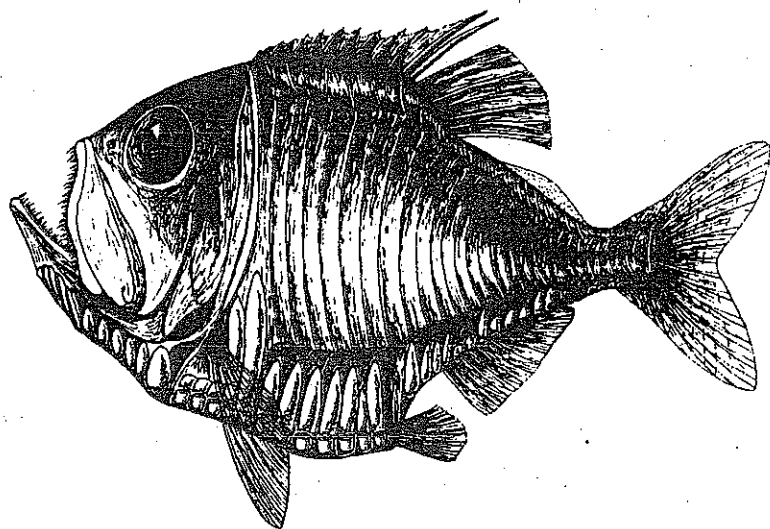
In proposing a management plan, it is only practical to control catch or escapement. Fortunately, scientists have developed a computer program (SALMON) that calculates the effect of changing catch or escapement on the fishery. You can use SALMON to develop your management plan.

Fishing on the Salmon River (between the United States and Canada) has fallen on bad times. Each country blames the other for poor management practices. The political and social situation is tense. You must develop a fisheries management plan that will maximize catch. There will be no single right answer and there is a high premium on interpreting general trends in the fishery.

Instructions for use of SALMON are available at the computer terminal.

In your final management plan, consider the following points (among others):

- (1) Did you manage for catch or escapement? Why?
- (2) What was your optimal level of catch or escapement for the fishery? (include graphs, if you wish).
- (3) Consider other factors that could have an effect on run size in a salmon fishery? How could these factors produce variability in run size from year to year?
- (4) Could you do better if you varied your management each year to build up the stock? Explain why?
- (5) Discuss other characteristics of this fishery you learned in developing your management plan.



TROUT FISHERIES

23

A trout fishery has been computer programmed and is available to practice fisheries management. The purpose of TROUT, the computer management game, is to allow the user to develop a management plan that will provide the best fishing year after year.

Trout Lake is located on property recently purchased by the State Department of Fish and Game. The only past information available indicates the lake supported a fairly good rainbow trout fishery. Preliminary field surveys show the lake covers 100 acres. Some natural reproduction might take place, as there is a fairly good inlet stream. The local conservation officer remembered that the owners used to plant fingerlings and catchables every few years. General field observations indicate that the lake is fertile and supports abundant fish food organisms.

Decision Alternatives

Stocking Catchable Rainbow Trout

Hatchery-reared rainbow trout (4-5/lb) can be stocked in Trout Lake. They cost the department \$1.00/lb to raise and stock. Stocking catchables provides immediate angling, but may or may not improve fishing over the long term. Also, the impact of catchables on the fishery will depend, in part, on your other management alternatives.

Stocking Fingerling Rainbow Trout

Hatchery-reared rainbow trout fingerlings (300/lb) can be stocked in Trout Lake. Recruitment will take place at some later time, depending on a number of factors. As a manager you would want to know when these fish would enter the fishery.

Spawning Ground Improvement

Various amounts of stream may be cleaned up and graveled to improve spawning conditions. In some ways this is similar to stocking fingerlings, but differs in several respects. The length of useful life of an improved stream is also important.

Artificial Destratification

Trout Lake may be aerated to eliminate thermal stratification in an attempt to improve habitat. This may improve the fishery in a number of ways. Dissolved oxygen may increase at certain times of the year. Water temperature may be more favorable for trout during summer. Lake productivity may also be affected.

Population Estimation

As one measure of the rainbow trout fishery, you may run a multiple census estimation in September. In addition to a rough estimate of the number of catchable trout in the lake, a subjective appraisal of fish growth rate is provided.

Creel Regulations

Creel regulations are often quite controversial. The manager must often select regulations for social reasons, rather than for achieving maximum catch. Maximum catch per day and minimum size are two examples of creel regulations.

Bait Regulation

Selecting bait regulations is often difficult. Special interest groups (i.e. fly fishermen) may pressure the manager to implement their preferences. Often the effects of bait regulations on population dynamics are obscure.

Season Regulations

Regulation when anglers can use the resource is most often a social decision. The impact of a particular season length is often obscure due to complex social customs and obscure population dynamics.

The Management Plan

Management of the Trout Lake fishery involves deciding on the optimal mix of decisions in the eight categories. The computer program TROUT allows you to manage the fishery for many years to develop the required level of understanding to recommend an optimal management plan. TROUT can be used to study each potential decision to clarify its function in achieving your management objective.

***COMMERCIAL
FISHERIES
MANAGEMENT***

GENERAL PRINCIPLES - COMMERCIAL FISHERIES

A commercial fishery includes any aquatic animals or plants taken for utilitarian purposes. Commercial fisheries include anadromous species, cultured species, non-fish groups, such as shellfish and aquatic mammals, and various plants.

The earliest known commercial fisheries began in the Indus Valley, India, and Egypt between 5,000 and 6,000 years ago. Fish were preserved by salting, drying, or smoking. These techniques remained the sole means of fish preservation until the 15th century. The nations around the Mediterranean began to exploit the aquatic resources of that sea early, and by 1,000 B.C. there was an extensive trade of dried, salted, and smoked fish in Greece.

Prior to the Middle Ages, the major European fisheries were located in the Mediterranean Sea, but by 950 A.D. the major source of supply had become the North Sea. The causes of this change of source were probably a combination of diminishing stocks, a shift in population centers, and Arabian control of the Mediterranean. Fishing vessels required a shore-based camp to salt and dry the catch, thus fishing could be drastically curtailed without adequate naval protection. By 1440 A.D. another means of preserving fish was developed - brine pickling. Unlike drying and salting or smoking, this technique allowed the fisherman to preserve the catch at sea, thus extending the range of fishing.

The major source of fish for Europe shifted after 1497, when Cabot reported that the seas off Newfoundland were swarming with fish. By 1583, competition for the Newfoundland fishing grounds was intense. The English occupied Newfoundland and forced the French, Spanish, and Portuguese to fish elsewhere. This action may have resulted in the discovery (1587) and rapid exploitation of the Grand Banks.

As fishing grounds became more distant and competition increased, catching and preserving techniques were modified to increase efficiency and improve the quality of the catch. Another breakthrough was made in preservation techniques in 1810, when fish and lobster were preserved by a canning process. Within a few years salmon and sardines were being packed in cans.

By 1860, steam powered vessels became available and ice was being used to preserve fish. Ice-making machines were installed at various ports and by 1900, fishing vessels could return to Europe with iced fresh fish from Iceland, Greenland, and the Barents Sea. The advent of powered vessels made use of large purse seines possible; these appeared around 1900, increasing catch efficiency of pelagic fish to the same degree that trawling had done for demersal species.

Large processing plants were developed in the 1920's at many fishing ports. The by-products thus produced led to the collection of fish remains for use as supplements in agricultural feeds. Flash-freezing and very low storage temperatures were introduced in 1945. These developments resulted in an increase of product-quality, storage life, and created an even larger market potential for fish products.

By the late 1950's echo-locators became readily available for fishing vessels. The fishing fleets of the Soviet Union and Japan began to develop sea-going factory ships, allowing them to extend their fishing range over the entire globe. Since 1960 there have been further improvements in fishing vessels and gear, including stern trawlers, echo-location, and increased range. Many of the new vessels were capable of processing and freezing the entire catch at sea. The resulting product can be landed at any port (not just fish processing ports) and rapidly shipped inland. Another important advance made in the last decade is the development of an acceptable fish flour (fish protein concentrate or FPC) at an economically feasible cost of 8 to 10 cents per pound. This process allows utilization of many species previously considered undesirable for economic or cultural reasons.

Improvements made in fishing and processing techniques prior to 1950 were usually not sufficient to endanger most stocks. Since the development of the trawl, however, the annual marine catch has increased fantastically; to the point that it has become possible, using advanced technology, to overfish most stocks. Unfortunately, the management techniques necessary to prevent overfishing have not, as yet, been adequately developed.

Migration and Homing

The commercial fisheries manager is particularly faced with the problem of highly mobile species. Migration is characteristic of many fishes, particularly oceanic species. Perhaps the best known examples are those of the Pacific salmon. Pink salmon from southeastern Alaska and British Columbia have been known to travel over 4,000 miles per year. Chinook salmon cover even greater distances when returning to the Columbia River from south of the Aleutian Islands. One of the longest distances traveled by a fish was recorded for a tagged bluefin tuna which traveled from Cat Cay (Bahamas) to the Norwegian coast, a distance of over 5,000 miles. Other extensive travelers include albacore, white marlin, swordfish, sailfish, tuna, eels, and dogfish. In addition, numerous species of marine mammals and turtles migrate extensively at sea.

Theories as to the direction finding mechanism employed by fishes include: (1) passive drift; (2) random search; (3) sun orientation; (4) odor orientation; (5) orientation to visual landmarks; (6) orientation to electrical field; (7) orientation to water currents; and (8) orientation to physical and chemical gradients. Evidence has been found to both support and cast doubt on each theory.

Can fishes migrate simply by passively drifting with currents?

Migrational patterns, from spawning grounds to rearing areas to feeding grounds, of herring in the North Sea appear to be controlled by ocean currents. The seasonal direction of movement of herring parallels prevailing current direction in each locality. However, the passive drift theory fails to explain salmon migrational speeds of over thirty miles per day in the North Pacific Ocean. Current velocities in the North Pacific average only 1-4 miles per day. Also, upstream migration cannot possibly be the result of passive drift.

Do fishes find their way by searching for their destination in a random fashion? Tagged largemouth bass have been observed to move at random when released in the center of a lake. Recaptures indicated that over 50% of these tagged bass returned to the area of original capture. In similar studies over 95% of the tagged brown and cutthroat trout returned to their homestream. It is doubtful that random search procedures alone could account for extremely high homing percentages.

Can fishes use the sun to guide them? Both field and laboratory studies have provided evidence that fish can use the sun for direction finding. The theory is that fish possess an internal compass-like mechanism which is controlled by the position of the sun. However, migrational movements of fish have been observed at night and on extremely overcast days. Sun orientation fails to explain fish migration during periods when the sun is not visible.

Can fishes smell their home area? This theory proposes that each home area possesses a unique odor which fish learn in the early weeks of life. Adult fish use this learned odor to guide their return to the home area. Research has shown that many fish do rely on their sense of smell to detect their home area, but experiments with cutthroat trout provide evidence against the absolute necessity of smell in homing. In these studies, trout with nose plugs were able to home as successfully as trout without nose plugs.

Do fishes follow a series of visual landmarks during migration? Several studies in Yellowstone Lake, Wyoming, suggest that cutthroat trout are able to follow the lake shoreline to the entrance of their homestream, but experimentally blinded cutthroat trout were able to find their homestream as easily as normal trout.

Can fishes detect and follow differences in electrical voltage in the aquatic environment? Water is an electrical conductor which produced voltages by moving through the earth's magnetic field. Sturgeon swimming in the Snake River in Idaho avoid passing directly under a high voltage power line. Sharks and rays can detect weak electrical stimuli in the ocean, but most migrating fishes do not possess electrical sensory devices which would allow orientation to electrical fields.

Can fishes follow the boundaries of currents in a body of water? The migrational patterns of some oceanic fishes are probably governed by currents, but direct detection of current boundaries by migrating fish seems unlikely because of the immense volume of water that would have to be traversed.

Are fishes able to detect and follow physical and chemical gradients? Slight variations in the amount of dissolved gases, solids, acidity, and temperature exist within any body of water. However, the differences between points miles apart are usually not great enough to be detected by sensory organs.

Some scientists have hypothesized that fishes possess a distinct homing sense which controls migration without the aid of any environmental stimuli. Others believe that navigational ability in fishes is genetically controlled and passed from generation to generation.

Management Principles

The earliest reference that deals with commercial fisheries management was a paper by J. Hjort published in 1910. Hjort discussed the differences in year class abundance in North sea herring, suggesting an awareness of the influence of catch on stock size began in the late 1800's. The concept of a unit stock also appeared at this time (see Chapter 3). The unit stock usually is defined as a population in which the vital statistics of recruitment, growth, and mortality are homogeneous. Recruitment can be described as that of the stock which is added to the stock over a given period of time (usually a year).

The purpose of a commercial fisheries management program is to provide a desirable yield without damaging the replenishment capability of the resource. By calculating the size of the unit stock, the rate of natural mortality, and the rate of recruitment, the fisheries manager can predict how many fish will be available for harvest with reasonable accuracy.

Unfortunately, many population estimation methods that can be applied successfully to freshwater fisheries fail when applied to marine situations. The first problem presented by a marine fishery is that of unit stock range. Often the area occupied by a stock is very large and the boundaries may not be well delimited. Consequently, population estimation methods based on tag-recapture may be of questionable value. The method traditionally used to estimate population size and the harvestable portion is based on commercial catch record statistics, but such a technique can lead to numerous management problems.

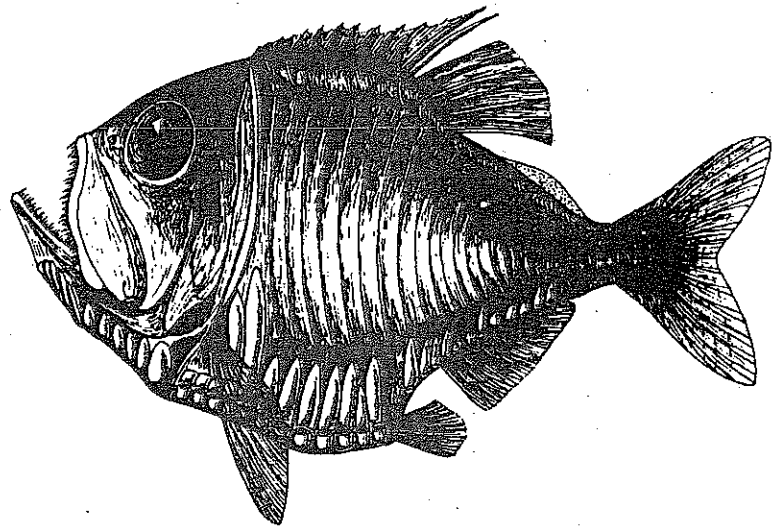
First, there is a considerable time lag between fishing and publication of catch statistics. Often the most recent material available may be one or two years old. Second, when an international fishery is involved, different methods of statistical tabulation may be used by fishermen of different nations. Some fishermen may report false catch statistics or may refuse to report any catch statistics at all. This demonstrates another problem encountered in commercial fisheries management, that of international cooperation. Different nations have different management goals and most would rather sacrifice the resource than relinquish what they consider to be their fair share.

The concept of economic optimization is particularly difficult to implement if different goals are set by participating nations. Economic optimization consists of obtaining the greatest amount of a resource for the smallest possible investment of equipment, manpower, and capital, per resource unit acquired. Under certain circumstances, however, a nation may find it desirable to obtain as much of the resource as possible. When this occurs, the amount of effort required to capture each additional resource unit beyond the point of economic optimization increases in accordance with the law of diminishing returns. As the number of fish available for harvest decreases, it becomes increasingly more difficult (expensive) to harvest them. Unfortunately, this additional harvest expense is shared by the fishermen of other nations who are also using the resource. They, in turn, must increase the price of their product in order to survive.

The question of international cooperation becomes more difficult when the problem of stock ownership arises. With anadromous fishes the situation becomes particularly acute as each country of origin insists on getting its share (usually that percentage of the stock that originated in its waters). Fortunately, the record for international cooperation appears to be considerably better than might be expected, especially in the case of Pacific salmon management.

A further source of difficulty may occur when a country declares a territorial limit of sufficient distance to include a fishery that was previously international. An increasing rate of fisheries exploitation result in nations following the example of Peru, Chile, and Iceland, either as a political act or as an attempt to reduce excessive exploitation. Unfortunately, if all major fishing grounds were nationalized, the effects would be disastrous for countries such as Japan, the Soviet Union, Portugal, and Britain, which have come to rely heavily upon international fishing grounds.

Enforcement of management regulations for an international commercial fishery is difficult, if not impossible. Often fisheries legislation is ignored by individuals of the participating nations in order to acquire the largest possible share of the resource. Enforcement of international fisheries is often claimed to be too expensive to warrant serious consideration; that is, the costs of effective enforcement would exceed the value of most fisheries. With the recent advances in technology and the increase in competition for marine fish stocks, this concept may no longer be valid. For example, it should be possible to regulate the number of commercial fishermen on a given fishing ground via satellite, as well as monitor the activities of various fishing vessels - especially if the identification numbers are painted on the upper surfaces with a special paint - obtainable only with a license.



WORLD FISHERIES

Many people view the world's oceans as vast, uniformly productive waters. In reality, highly productive zones comprise only a small percentage of the total oceanic area. As in all food webs, biomass production is initially dependent upon favorable light and appropriate plant nutrients. In the oceans, release of these nutrients from decaying matter takes place at depths where photosynthesis does not occur because of low light. Thus, the major fisheries will occur in areas where necessary nutrients are made available to the primary producers (phytoplankton), which are then utilized by other components of the food web (zooplankton, fish).

Suitable conditions of light and nutrient result from different causes. In estuarine areas much of the nutrients are carried by entering freshwater streams. Relatively shallow continental shelves may extend many miles offshore and contain some of the major marine fisheries. Major fisheries are not restricted to these areas, however. Actions of winds, winter cooling, the earth's rotation, and turbulence at current interfaces, all serve to mix the ocean's waters, bringing nutrient rich bottom waters to the surface. Areas where surface water is moved away, allowing deeper water to replace it, are known as upwellings.

Total Fisheries Catch by Country (Thousand Metric Tons)

Country	1938	1948	1955	1960	1965	1967	1969
1. Peru	23	84	235	3,569	7,462	10,134	9,224
2. Japan	3,678	2,518	4,908	6,913	6,908	7,852	8,623
3. USSR	1,523	1,485	2,495	3,051	5,100	5,777	6,498
4. China	--	--	--	5,600	--	--	--
5. Norway	1,128	1,422	1,813	1,543	2,307	3,269	2,481
6. USA	2,260	2,417	2,790	2,813	2,724	2,430	2,495
7. South Africa	67	184	600	864	1,368	1,696	2,130
8. India	--	--	480	593	1,331	1,400	1,605
9. Spain	480	547	770	970	1,341	1,438	1,486
10. Canada	837	1,053	965	934	1,262	1,296	1,408
11. Denmark	97	226	425	581	841	1,070	1,275
12. Chile	32	65	214	340	708	1,053	1,077
13. Indonesia	476	--	673	761	1,067	1,180	1,209
14. Thailand	161	161	213	221	615	847	1,270
15. UK	1,198	1,206	1,100	924	1,047	1,083	1,083
World Total	21,100	19,600	23,900	40,000	53,700	61,100	63,100

Pacific Salmon Fisheries

The six species of Pacific salmon support many large fisheries in the North Pacific Ocean. Development of these fisheries generally took place in the last 30 years of the 19th century. The value of the annual United States salmon catch of over 100,000 metric tons is over 50 million dollars, ranking only behind shrimp as the single most valuable catch. Fisheries management has centered around the homing instincts of salmon, whereby they return to their natal stream to spawn (See Chapter 24). Without regulating gear and fishing time, it would be relatively easy to capture very nearly 100% of the returning salmon in many streams. Thus, the fishing potential is much more powerful than is necessary for optimal harvest.

In the ocean, salmon range over wide areas and support an international fishery. The Japanese fishery has expanded especially rapidly from its beginning in the early 1950's. Most of the Japanese catch comes from the high seas of the North Pacific. The Soviet Union also has a major salmon fleet, but the majority of their effort is in coastal waters.

Many methods have been used to capture salmon. Open ocean fishermen use longlines, trolling gear, and nets (prohibited in the United States and Canada). Coastal fishermen use traps, seines, weirs, and gillnets. Control of salmon fishing is administered by the International Pacific Salmon Fisheries Commission and the International North Pacific Fisheries Commission.

Because the fisheries are still surviving after 100 years of exploitation, management can be considered successful, if only in a defensive way. Protection must be continued for spawning areas, which are threatened with the side effects of human population increase.

World Catch by Species (Thousand Metric Tons)

Species	1938	1948	1961	1965	1967	1969
1. Anchoveta	1	1	5,270	9,681	10,530	9,709
2. Atlantic cod	2,085	2,085	2,955	2,766	3,181	3,654
3. Alaska pollack	191	192	465	1,042	1,735	2,552
4. Mackerel	370	322	657	1,159	2,058	2,407
5. Herring	1,752	2,233	2,473	4,002	3,877	2,358
6. S. African pilchard	1	69	804	1,119	1,198	1,613
7. Haddock	375	406	462	747	484	963
8. Capelin	17	16	224	281	513	855
9. Yellowfin tuna	50	99	278	247	239	345
10. Pacific halibut	27	33	42	42	---	---

Herring Fisheries (North America)

In the Pacific, the herring fishery ranges from California to Alaska, with Canada accounting for most of the 134,000 metric tons landed in 1966. The landings on the Pacific coast have declined, whereas on the Atlantic coast they have risen markedly. Fisheries on the two coasts are managed differently and the catch is utilized for different products. The Pacific fishery is largely coastal (i.e., inside territorial waters) and more restrictive, with regulations including catch quotas, closed seasons and/or areas, gear restrictions, and method of utilization in some areas. This fishery has been heavily exploited and catches have greatly declined from previous high years of 250,000 metric tons. Pacific herring have been utilized mainly for reduction to oil and meal in Alaska and British Columbia, and for bait fish in Washington, Oregon, and California.

Atlantic herring are fished commercially from Virginia through the Canadian Maritime Provinces. With the decline of the Pacific fisheries, Atlantic fisheries expanded and are still expanding (over 585,000 metric tons taken in 1967). Although Atlantic herring are used mainly for reduction, other uses include canning as sardines, smoking, and bait. Herring scales are also used in paints, plastics, jewelry, and cosmetics.

Problems in the herring fisheries of both coasts include lack of success with regulations, many of which are based on social and political consideration. A major problem is the lack of data on stock abundance, recruitment, and mortality. Much of the catch fluctuation is due to poorly understood variations in natural mortality.

Halibut Fishery

The halibut is the largest of the flatfish, averaging 30-35 pounds, with a maximum weight of 500 pounds. In 1970, nearly 12,000 metric tons were landed in the USA and over 13,000 metric tons were landed in Canada. The fishery began as a joint American-Canadian venture in about 1890 and since 1923 has been regulated by the International Pacific Halibut Commission, with the sole objective being maximum sustained yield. The halibut fishery is intensively managed with fishing control achieved by catch limits and time restrictions. Juvenile mortality was reduced by closing nursery grounds and by size limits. By restricting the commercial fishery to hook-and-line gear, the large numbers of juveniles taken in trawls were eliminated from the catch.

With the continued expansion of foreign fishing using both trawling and setlining, this well-managed fishery may be in jeopardy. The North Pacific Fisheries Commission initiated a catch limit much in excess of that previously taken and the stocks were decimated. In addition, a low priced Atlantic flounder was marketed as "Greenland halibut" and caused a drastic price decline for Pacific halibut. Whether or not the fishery can recover is still open to question.

Cod Fisheries (North America)

North American cod fisheries are relatively old and have established regulatory agencies. The cod fisheries in the northwest Atlantic are regulated by the International Commission for the Northwest Atlantic Fisheries (ICNAF) and the fisheries for Icelandic stocks are managed by the International Council for the Exploration of the Sea. In the Atlantic, separate stocks have been identified off New England, the North Sea, the Baltic Sea, and off Newfoundland, Labrador, and Greenland.

Cod are exploited by many countries (over 3.6 million tons were taken in 1969). Many problems have arisen because of this international aspect. No country feels it should be compelled to obey regulations until all others do. To control over-exploitation, a great deal of research has been conducted on the most suitable mesh size in trawls to optimize sustained production. Newer cod boats include large freezer trawlers that can process, fillet, and freeze the catch at sea. The old boats, dories with handlines, and other inefficient equipment are forced to compete. The major problem of the cod fisheries is not so much one of mesh size, but of the imbalance between existing fishing pressure and the amount needed for optimal stock harvest. This is indeed difficult in that it involves telling some or all of these multinationality fishermen that, for all or part of the season, they may not fish. By beginning with mesh-size regulation, which are non-discriminatory among nations, the ICNAF hopes eventually to be able to decrease pressure on the fishery.

Tuna Fishery

Tuna management is the responsibility of the Tropical Tuna Commission (Eastern Pacific), the International Commission for the Conservation of Atlantic Tuna (Atlantic), and two FAO agencies, the Indian Ocean Fisheries Commission and the Indo-Pacific Fisheries Council (Southeast Asia and West Pacific). Major tuna species and their percentage of the total catch are yellowfin (39%), skipjack (25%), albacore (20%), bluefin (13%), and Bigeye (12%). The annual catch for 1969 was over 1,600,000 metric tons. The Pacific Ocean supplies around 60-70% of the catch, the Atlantic around 20%, and the Indian Ocean about 10%. Japanese fishermen using longlines fish in all oceans and account for around 2/3 of the world catch. Most other countries use purse seines.

Since tuna are largely warm water fishes, the Atlantic stocks have restricted movement, whereas the less limited movement of Pacific stocks could cause additional management problems among the various agencies involved. Most tuna fisheries are now probably near maximum sustainable yield.

South American Anchovey Fishery

The anchovy fishery off the coast of Peru and northern Chile is the world's largest fishery with highest annual catches being in the ten million metric ton range. There has, however, been a dramatic drop in catch in the last few years. The fishery developed rapidly, increasing from only a few thousand tons in 1955 to the level of near maximum yield, about 10 million metric tons. This is somewhat misleading, however, since this is not a valuable fish and is used only for reduction to meal and oil.

Anchovy are small pelagic fish that are captured by purse seine. As the fishery developed, two major problems have been observed: (1) the necessity of understanding more about population stability which comes from the stock-recruitment relationship; and (2) the economic efficiency of the industry. Rapid expansion led to a large overcapacity of boats and processing plants compared to possible fish yield. Regulations, including closed seasons and limited fishing days during the week, are used to reduce the efficiency of the industry.

Whale Fisheries

Today whale species of major importance are the sperm, blue, fin, humpback, and sei. All these species are depleted, especially the blue whale. The formally commercially important right and gray whales were fished nearly to extinction in the late 1800's and the right whale still has not recovered. Historically whaling was international, but today Japan and the Soviet Union are the only major participating nations and the North Pacific and Antarctic are the major fishing grounds. International commissions were established as early as 1931 to control harvest, but have been generally unsatisfactory.

Whales are harvested by catcher boats using harpoons. The carcass is then taken into the factory ship and processed at sea. Blubber and bones are processed into oil and the meat refrigerated for human consumption as well as for use in pet food, meal, and oil. The liver is used for vitamin production with most of the remaining viscera discarded. Sperm whale meat is of low quality and not generally used for food.

Whales have been grossly overexploited and only recently have reasonably accurate estimates of sustained yield been calculated. The range of estimates leaves doubt as to whether the stocks are slowly rebuilding or slowly depleting, so even better estimates are necessary.

Fur Seal Fishery

The fur seal fishery is an outstanding example of the recovery of a depleted stock through cooperation and proper regulation. The fur seal industry is mainly centered around the Pribilof Islands, Alaska, which contain over 80% of the world's fur seals. Fur seals breed on these islands and are extremely vulnerable during the mating season. Indiscriminate slaughter on land and in the seas reduced their numbers to less than 150,000 in the early 1900's. By restricting open ocean harvest and allowing only males to be taken, the population has increased to present levels of about 1.5 million. A sustained annual yield of about 69,000 animals has been taken since 1939.

Efforts have been made to utilize the carcass of the seal, which was usually discarded after skinning. Attempts have been made to use the meat as food, or reduce it to oil and meal. The meat has been used in fish hatcheries and poultry farms, but the most promising market is the sale of the frozen ground meat for use as mink food.

Molluscan Fisheries

Oysters, clams, and scallops support major fisheries. The leading oyster producing countries are Japan, USA, Korea, and France. Clams are distributed worldwide, with the more important species including the soft-shell, surf, hard, and Japanese clams. Japan and the USA are the major harvesters. Bay and sea scallops are important commercially, with the major fishery along the New England coast. The world mollusk harvest in 1968 was nearly 7.5 billion pounds. To the American fishermen, this amounted to over \$60,000,000.

Harvest of mollusks is mainly by dredges and tongs. Oysters and clams are marketed alive in the shell, shucked, or canned, and are graded by size. Only the adductor muscle of the scallop is marketed in the United States, whereas in Europe the entire scallop is eaten.

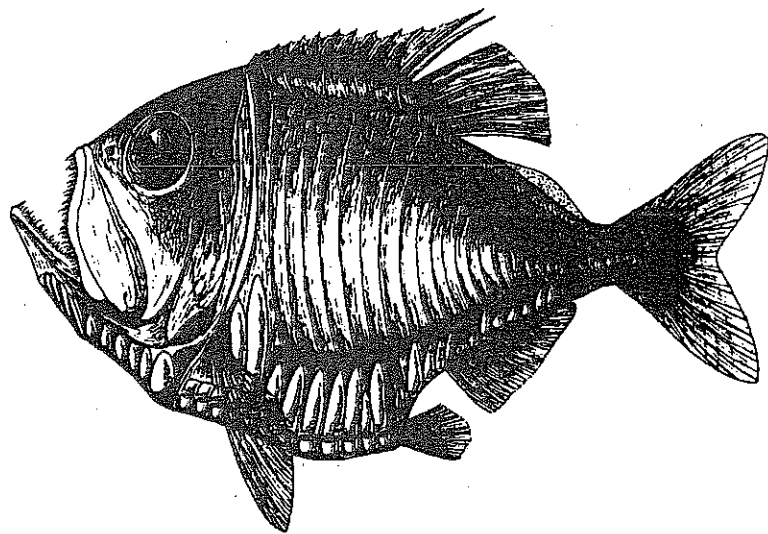
Management has consisted largely of the preparation of beds and seeding with larvae. As with many other fisheries, regulations usually have a political and sociological basis rather than a biological one. Many improvements in the industry, such as rock culture and mechanical shucking devices, have been countered by increased losses of habitat through dredging and pollution.

Crustacean Fisheries

Crabs, lobsters, and shrimp are the major commercially important crustaceans. Shrimp fisheries yield about 60,000 metric tons annually, which is only about 1% of the weight of seafood landed, but represents about 5% of the value of the catch. Various commercial shrimp species are taken along the coastlines, mainly in the USA, India, Japan, and Mexico. Shrimp are generally taken by trawl.

All commercial species of lobsters totaled more than 120,000 metric tons of 1966, with the spiny lobsters accounted for over 57,000 metric tons of this. Lobsters are taken in pots and, in increasing numbers, offshore with bottom trawls.

Important crab species include the king, queen, Dungeness, rock, and tanner crabs on the Pacific coast and the blue and rock crabs on the Pacific coast. The various methods for harvesting crabs include pots, ring nets, trawls, and tangle nets. Management includes limits on size, and season, and restrictions on taking females with eggs. Fishing has been done primarily by the U.S. and Canada, but both Japan and the Soviet Union have exploited the king crab. Crabs are sold alive, canned, freshly cooked, and cooked and frozen.



***MULTIPLE - USE
MANAGEMENT***

MACRO-LEVEL MANAGEMENT

A problem facing all fisheries management agencies is evaluating how best to allocate limited financial resources to meet particular agency objectives. Given a measure of output (such as the angler-day) from a fisheries management program, how can an agency allocate its resources to increase output within a relatively fixed budget? For example, how many angler-days accrue from investments in the following: (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 manipulation; (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 all resource management disciplines. Evaluating decision alternatives requires a system model (conceptual and quantified) in which to make an allocation analysis. Since resource allocation decisions are made in a very complex matrix, including uncertainty, time lag, poorly understood and quantified variables, and obscure interrelationships, decision-makers must interact in formulating model structure. One example of methodology to predict outputs accruing to state fish and game agency activities and expenditures is a deer hunter participation simulator (DEHPAS) developed at VPI & SU. DEHPAS is designed to allow state wildlife administrators to analyze the interaction between factors (season length, budget allocation, etc.) that go into operation of a regulated deer population.

Other examples of resource management plans developed through simulation modeling also involve deer management. One simulator was aimed at evaluating alternative paths of action and estimating consequences in complex management situations. This same simulation approach has been applied in a number of other cases. A general computer mode, FARMS, was developed to look at land use and big game populations in British Columbia. 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 trees; (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. As another approach to evaluating resource allocation strategies, linear programming, has been used. Salmon management problems have been studied extensively by linear programming and simulation procedures. 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 remaining fish to 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, such as 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 also been advanced as one solution to meeting management decisions. 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 fishes and management activity affects each to a varying degree. Modeling at this level is quite difficult, but some success has been achieved using energy flow in projecting trends in a fishery. Sub-systems 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 natural resource management. 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. 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.

Management Example

An essential problem of allocating fisheries management funds with optimal efficiency is determining output (i.e., the number of angler-days) resulting from specific input. More specifically,

$$Q = f(X_1, X_2, \dots, X_n \mid Y_1, Y_2, \dots, Y_m)$$

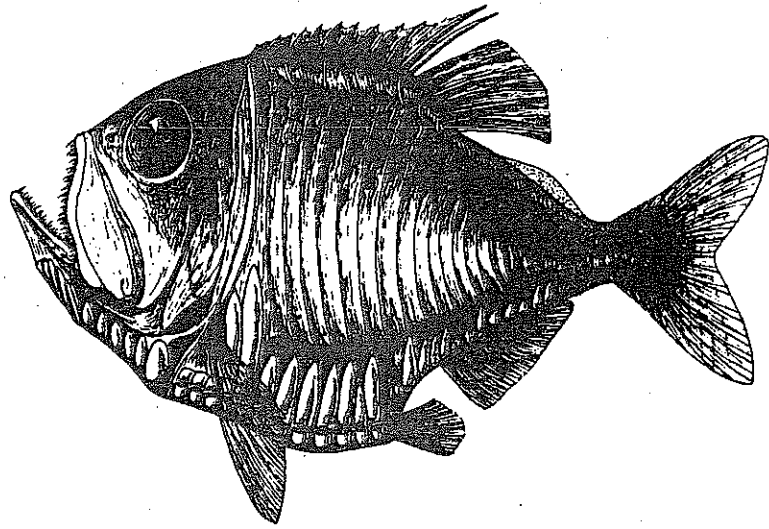
where,

Q = Number of angler-days

X_n = Input variables which are at best partially controlled
by agency activity.

Y_m = Input variables which are not controlled by agency
activity.

Controlled or partially controlled variables (X's) are those regarded as management activities (stocking, habitat improvement, etc.). Non-controlled variables (Y's) are random or dependent on other factors (weather, highway development, recreational attitudes, etc.). Variables may overlap both categories. Computer simulation procedure would involve quantification of the above expression.



CONFLICT RESOLUTION

Complex management situations are created by impounding large multiple-use (e.g., hydroelectric power, recreation, and flood control) reservoirs. Due primarily to rapidly increasing demands for electrical energy and flood control, the number of large reservoirs in the United States increases significantly every year. Large reservoir systems are exceedingly difficult to manage because of: (1) speed of development around the reservoir; (2) nature of developmental controls; (3) strength and influence of local governments; (4) amount and allocation of financial assistance; (5) extent of public sewage treatment and water supply facilities; (6) type of secondary road systems; (7) quality of recreational facilities; (8) effects of river pollution; and (9) range of local public services (e.g., police and fire protection, refuse collection).

To effectively manage a newly impounded reservoir system, participating management personnel must appreciate the total system. The complexity of interactions between a variety of system demands (e.g., physical, chemical, biological, economic, political, and sociological) makes cooperation and compromise an integral part of successful reservoir system management.

As renewable natural resources come under increased utilization, conflicts between resource users become more severe. DAM, a computer-implemented learning exercise provides students an opportunity to manage a multiple-use renewable natural resource, a reservoir. Rather than having to wait for years for the results of your management decisions, a computer will provide rapid answers to what would probably have happened.

There are four basic principles associated with DAM. First, resource users interests inevitably conflict. Second, there is no simple, prescribed system for resolving user conflicts. Third, no matter what decision is made, users will consider it inappropriate or wrong. Fourth, a resource manager always starts with limited knowledge of the system at hand, but must make decisions based on the best available information.

DAM: Background Information

Franklin Lake was impounded by the Intermontane Electrical Power Company (IEPCO) to provide hydroelectric power. Filling was recently completed. Surface area of the lake is 20,000 acres at maximum pool elevation and the mean depth is 70 feet. The drainage basin covers 1,000 square miles. Most of the surrounding land is privately owned, being used primarily for farming and grazing. IEPCO owns 2,500 acres of shoreline property. The climate is moderate with an average annual rainfall of 45 inches. Soil and rock composition has been generally declared suitable for septic systems and there is a plentiful supply of pure groundwater.

Franklin Lake is located in a geographical area of medium population density. There are several small cities (i.e. population 25,000 to 100,000) within a 50-mile radius. There are no other large bodies of water (i.e., over 5,000 acres) within a 100-mile radius. The lake is bordered by land in four counties. A Regional Planning Commission, composed of two representatives from each county, was formed to coordinate development in the area. Each county government makes an annual allotment of \$5,000 to the Commission.

Franklin Lake is inhabited by native warmwater fish species. Fishes present include largemouth bass, smallmouth bass, crappie, sunfish, channel catfish, flathead catfish, bullheads, carp, suckers, threadfin shad, and golden shiners. The State Department of Fish and Game has allocated \$35,000 for reservoir fisheries research during the next 5 years.

The State Department of Fish and Game has recommended that minimum flow for the river below the Franklin Lake dam be set at 650 cubic feet per second (cfs). According to the local Coast Guard Auxiliary, a guaranteed minimum flow of 6,000 cfs is needed to permit navigation of the river. A consultant from the Army Corps of Engineers has recommended that at least 3 vertical feet (60,000 acre-feet) of storage be maintained for flood control. According to Federal Power Commission guidelines, a minimum of \$150,000 per year should be spent on equipment maintenance at the Franklin Lake dam.

The State Department of Outdoor Recreation and Department of Fish and Game both receive state and federal funds for the financing of activities in the Franklin Lake area. The State Highway Department provides funds for road construction and maintenance. There are currently ninety miles of secondary roads in the reservoir area.

The city of Sparkle (population 100,000) is located 40 miles upstream on the Rancid River, the main tributary to Franklin Lake. During the past ten years the sewage treatment plant in Sparkle has become increasingly overloaded. This overloading has resulted mainly from extensive development in rival population centers in the surrounding county. Tremendous amounts of raw sewage (up to 7 1/2 million gallons per day) must bypass treatment during rainy periods. Complaints about rising pollutant levels, especially phosphates and sludge, are becoming more numerous. The State Water Control Board has delegated the responsibility for improving the situation to the city government. However, the citizens of Sparkle believe that residents in the surrounding county should be responsible. The planning budget allocation of the Sparkle city government averages \$100,000 per year.

The objective of this exercise is to provide your instructor with a summary and justification of your recommended management strategy. Your final management plan should be summarized (3-4 pages) and then systematically justified (5-6 pages). You will undoubtedly have to manage DAM many times to improve your management plans.

RESEARCH

ANALYSIS OF RESEARCH

The purpose of this chapter is to speculate on research that will likely provide maximum payoff to enhance decision-making in fisheries management. These ideas were formulated by: (1) skimming through Transactions of the American Fisheries Society over the last 25 years; (2) talking with a number of state and federal fisheries scientists; and (3) discussions with the staff in fisheries sciences at VPI & SU. This input was combined with the results of applying a basic decision-making model to several realistic decision situations encountered in fisheries management (See Chapter 1 for model). The major hindrances in decision-making seem to be: (1) the need for formal objectives (this is the first thing taught in resource management, and it's very important); (2) the need to understand the decision-making process as a process; (3) methodology to evaluate management decisions; and (4) better models of fisheries (better understanding of the structure of fisheries).

The first research area, the formalization of objectives in management, is very important. Perhaps it is the most important of the areas covered in this chapter. Formalizing objectives may seem simple at first, but it is exceedingly complex. For example, toward what end are we managing? When we will be there? In business we manage for profit within certain social and legal constraints. This is a fairly straightforward approach. Fisheries, on the other hand, are normally managed on soft objectives. A soft objective is something like wise use or best use. This may be great for public consumption, but you cannot evaluate management effectiveness with soft objectives. And more important, you cannot use the optimization approaches that are now available.

Perhaps an illustration of the situation will clarify it. Many managers have tried to get away from soft objectives. The most common approach has been to maximize something like pounds or numbers of fish. This is the historic approach in both recreational and commercial fisheries. It's also used in most fisheries models. Data are simple to handle and are easy to understand. Variants of this approach are to maximize yield of a certain species such as bass over bluegill and to maximize the catch of a certain size, like a trophy fishery. The desirable properties of this type of objective are: (1) it is easily quantifiable; and (2) it's conceptually very simple. The undesirable property is: it's not realistic from many viewpoints.

Among more recent efforts to get away from soft objectives have been approaches like trying to maximize angler use. In other words, maximizing the number of anglers or the number of angler-days in a particular fishery. We often assume that this is equal to maximizing recreational benefit. However, it may result in an "amusement park situation." There are all kinds of variants to this objective.

Other objectives are maximizing aesthetics. This is a very altruistic approach, but how do you quantify it? Also there is maximizing economic output, especially in commercial fisheries. But are we maximizing average, total, or rent? These are only some of the problems that we have to face with this objective.

Now the conclusions from this are: (1) decision-making problems will keep recurring with soft objectives; and (2) we have to look at the critical needs and answer the question: how can we solve this problem? How can we get away from the soft objective toward something that will allow us to use some of the contemporary management strategies.

First, we need clear definition of the objectives. We need philosophical research to determine what are we trying to do. How can objectives be defined? We need to get these kinds of ideas in the literature and get professionals thinking in terms of objectives. The benefits from this of course are great. First, a problem clearly defined is half solved. And more importantly though, this is the first step in a decision-making process. This will be very important in later management efforts.

The second aspect that we have to consider, after we have defined the objective, is to quantify the objective. This is a very difficult avenue from a research standpoint, but it is very important. For example, in business we say: how will this particular decision help us make money? In fisheries we are more likely to say: how will this particular decision improve the fishery? How do we quantify improvement? It is a very difficult question. As a possible solution we might consider something like the management benefit unit. This would put the output from a fishery in a common denominator much like economics is a common denominator in a commercial fishery.

The third aspect, setting a value or level to be achieved, is really more of a policy decision than a research problem. Also, once we've defined the problem and quantified it, setting a level to be attained is relatively simple. So much for formalization of objectives - a very difficult, yet very important problem.

The next area mentioned for investigation was the decision-making process as a process. Two examples will suffice here to illustrate the type of research needed. The first is to study the decision-making model as a model. We need such a model to frame all fisheries decision-making activities. How are management problems identified, studied, and solved. The process should be formally stated regardless of how simple it seems.

A second example of the type of research needed is to study decision-making from a personnel aspect. For example most professionals in fisheries are not trained in decision-making. How do they differ from other decision-makers? Is fisheries the best training? Perhaps agencies should recruit from management science departments? How do fisheries managers perceive resource problems and solutions? What type of people are attracted to fisheries? What is their orientation? The essence of this approach is to incorporate personnel aspects into this type of research.

The third area to consider is methodology to evaluate management decisions. The specific question we're faced with is how well does a particular decision or management strategy meet an objective? Again success here is premised on a good objective. We must then have ways to evaluate our decisions.

One example of this type of potential research is that dealing with creel census. The creel census is commonly used by most agencies to collect large volumes of creel data to evaluate particular management decisions. The questions fisheries managers have to face are: How much data are needed? What are the important statistics? What degree of accuracy is required? The theme here is to develop methodology to make managers accountable. How can a manager go back and see how well his decisions have done? Again decision evaluation is very difficult and very painful, but it is exceedingly important.

The fourth research area, developing sound fisheries models, is very important. A sound conceptual base is needed to develop efficient and realistic management plans. In spite of the piles of data that have been gathered, most fisheries are very poorly understood. For example, most models that we do have are single species, very simple, and lack the degree of realism we would like. What we really need in this area are some significant breakthroughs.

It is very difficult to select a critical research area, but one example will be considered. A key problem we face in decision-making analysis is to predict output from a fishery, being defined in the same units of measure as the objective. In general, this methodology is not available. Although there have been many specific studies, very few general models have been developed.

The key problem is integrating population dynamics models, environmental factors, and fishermen. Models of this type would be of tremendous decision-making interest because if we could predict output from a fishery, this implies that we can test independent variables and can optimize. In other words, we could do more drawing-board research to evaluate what would happen if we did so and so. This may ultimately lead to total decision-making models that would integrate social, economic, and biological factors.

In conclusion, the key areas are: (1) the formalization of objectives in fisheries management, which is a very critical problem to solve before you can do very much; (2) a better understanding of the decision-making process as a process including workable models in decision-making and people involved in the decision-making process; (3) methodology to evaluate decisions to see how well decisions are working; and (4) good fisheries models with a strong conceptual base that could have a big payoff in terms of evaluating decision alternatives.

