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Stock Assessment for Tropical Small-Scale Fisheries

Stock Assessment for Tropical Small-Scale Fisheries

Proceedings of an International Workshop Held September 19-21, 1979, at the University of Rhode Island, Kingston, R.I.

Conveners and Cochairmen

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Preface

The U.S. Agency for International Development (AID), through the authority contained in the Foreign Assistance Act of 1961, awarded the University of Rhode Island a grant to sponsor a workshop on stock assessment for tropical small-scale fisheries. The Fisheries Division of AID, as well as agencies that are involved in the evaluation of its programs, had expressed the need for such a workshop.

The Fisheries Division organized a small steering committee, consisting of Philip Roedel, chairman, and Donald Bevan, Elmer Kiehl, Brian Rothschild, Saul Saila, and Robert Wildman. The role of the steering committee was to draft the terms of reference for the workshop, to provide guidance, and to formulate final recommendations from the proceedings. A series of background papers and experience papers combined with active discussions was planned as the basis for the workshop.

The objective, as written in the proposal to AID, was "to encourage dialogue between LDC fishery administrators, who must make the most of whatever information is available to them, and theoreticians, who can more effectively propose new approaches to assessment if they are more aware of the practical problems which inhibit data collection and analysis in the less developed countries (LDCs)."

John A. Gulland, a distinguished name among fishery scientists, who has an international reputation in the field of population dynamics and a deep understanding of the real problems faced by developing nations, agreed to participate in the workshop. The steering committee and URI administrators decided that it was an opportunity to bestow upon Dr. Gulland an honor he richly deserved, the award of an honorary degree, which was presented to him on the opening day of the workshop, September 19, 1979.

The tribute by URI President Frank Newman reads as follows:

> Your global view together with your pioneering studies in fishery science have made you a leader in international efforts to provide more food for the hungry millions of this world. As Chief of the Fish Stock Evaluation Branch of the Food and Agriculture Organization of the United Nations, you organized the first comprehensive review of the marine fishery resources of the world. You have successfully combined your early mathematics background with your understanding of fish populations to produce scores of important scientific papers culminating in a highly regarded manual on fish stock assessment.
>
> You have served as a marine resource adviser to developing nations, to the fishing industry of the developed nations, and to several international organizations and scientific bodies. You have participated as lecturer at major universities of the world and have directed fishery training centers in the third world.
>
> Your unique ability to understand and communicate your findings on a host of major fishery resource problems has gained you worldwide recognition as a leader in fishery science. It is a privilege to confer upon you the honorary degree of Doctor of Marine Resource Development.

Report of the Steering Committee

Introduction

The Steering Committee of the International Workshop on Stock Assessment for Tropical Small-Scale Fisheries herein presents an integrated set of recommendations for future research to the Joint Research Committee. These recommendations are based on the priorities identified by the workshop drafting committee and discussed and approved by the participants.

At the outset, the committee wishes to make clear that these recommendations relate to the problems of small-scale fisheries, as differentiated from those of capital-intensive, commercial, large-scale fisheries. We recognize that stock assessment problems exist for the pelagic and demersal fisheries of developing nations which are worked by modern industrial fleets or by both large and small-scale fleets. There are also problems of allocation of resources under the new regimes of extended economic zones (EEZs) which require the continued attention of national and international development assistance agencies. The committee recognizes the valuable work being done in these areas by the Food and Agriculture Organization (FAO) and the Development Program (UNDP) of the United Nations and by other national and regional bodies. Although the workshop was concerned with the problems of small-scale fisheries, it is believed that some of the approaches suggested in these recommendations will have utility far beyond tropical small-scale fishery systems.

As the developing nations turn more and more to the sea for food supplies and export products, expansion of the coastal artisanal fisheries increases the threat of resource depletion. Resource assessment is a basic element of sound management policies which will permit sustained catches of fish at highest possible levels over time.

Only recently has the role of artisan fisheries and fishermen received attention. These fisheries supply much of the domestically consumed protein in many of the less developed countires (LDCs). Yet it is true that fishermen often represent the poorest of the poor in these countries. The problems of stock assessment within tropical small-scale fisheries are numerous and complex. The number of species harvested is very high. There are complicated interactions between species. There are no predictable growing seasons. Many of the tropical ecosystems are sensitive to perturbations. Management data collection is hindered by the numerous remote landing points and by the many diversified gears in operation. And while development assistance in this sector would appear to be a significant positive intervention both for the fishermen and for the consumers of their products, the information vital to management decisions does not exist, and there is no appropriate set of assessment methodologies. The scientific capital developed in relation to industrial, temperate, or cold water fisheries needs considerable adaptation and modification to be relevant and usable in multispecies tropical fisheries.

We feel that the recommendations included here represent the most promising approach to the development of new methods for stock identification and assessment, catch and effort measurement, optimal biological and economic sustainable yield estimation, and overall management of tropical small-scale fisheries.

Methodology

During the workshop, the participants divided into groups to consider the various aspects of stock assessment problems. These groups focused on data collection and analyses, information dissemination, survey techniques, decision processes, and productivity estimates. Specific topics were identified and developed for consideration by the workshop as a whole. They were subsequently drafted and presented to the assembly for discussion and approval. The Steering Committee integrated and categorized these topics. All of these activities are, in a sense, priority activities, since they were selected from numerous suggested solutions.

Some items are clearly topics for "collaborative research"—i.e., research that is either basic, applied, or adaptive—and are of sufficient scope to require multi-institutional involvement. These topics are suggested as candidates for collaborative research support programs, since they would benefit from and be properly pursued under arrangements between the research and development institutions of the United States and the developing country. Recognizing the particular relevance of these topics to the Joint Research Committee, the Steering Committee has set priorities for this group.

There are research areas which are better pursued in other than a collaborative mode. Inasmuch as they are directed at the same basic problems and because they can be carried out simultaneously and benefit the collaborative research, they are termed "supportive research."

Activities which had merits recognized by the workshop but which are not strictly research have been termed "supportive development activities." Indeed, the supportive research and development activities will be found to be in some instances preconditions for the application of research results.

It is the feeling of the Steering Committee that the candidates for collaborative research have merit in any of a number of other research arrangements, but that the group would most appropriately be conducted in a collaborative mode.

The Steering Committee has rated the collaborative research topics on several bases. This evaluation relates specifically to the potential of the research itself and to the utility of the end products; that is, models, methodologies, techniques, etc. The committee examined the following:

1. Payoff. The anticipated benefits to accrue to developing nations given the success of the research and its implementation in the LDCs. This is a subjective estimate of the numbers of people, of countries, and of fisheries to which the research is relevant.

2. Transferability of Research Results. How easy or difficult it will be for the LDC to apply the methodologies developed by the research. It also considers the degree to which these methodologies can be generalized over environments.

3. Probability of Success. Whether the research is likely to produce usable results within a reasonable time frame and whether the resultant methodology

being applied will be successful.

4. Implementation Cost. The cost of utilizing the research results in terms of both labor and capital.

5. Technical Support and Scientific Personnel Necessary. The scientific infrastructure necessary for the prosecution of the research both within the U.S. and in the LDCs and for the implementation of the research product.

The committee considered other factors in assigning priorities. The duration of the research was examined as well as the estimated total funding. The committee was also cognizant of the fact that certain research areas, while having some relevance to tropical small-scale fisheries problems, have been primarily and/or are potentially recipients of funding from other sources on the basis of their general merits rather than on their relation to foreign assistance.

The Steering Committee recognizes the limitations and problems in applying subjective criteria in ranking the potential of research. However, this method was helpful in providing the required priorities.

Summary of Recommendations by Activity

I. General

Future appointments to BIFAD, JRC, and JCAD reflect AID's interest in and concern for fisheries and aquaculture (Topic 1)

II. Collaborative Research, First Priority (no ranking within priorities)

A. Comparative Studies—Productivity. Development of methods for predicting productivity from comparative studies of environmental indices (Topic 2a)

B. Comparative Studies—Catch. Development of assessment techniques from comparisons of data from experimental fishing, varying artisanal gears, areas, and intensities (Topic 2b)

C. Comparative Assessment Models. Evaluations of mathematical properties and limitations of alternative assessment models, and testing these in LDCs (Topic 3)

D. Policy and Decision-making Structures. Development and testing research methodologies to examine existing policy formulation and decision-making structure (Topic 4a)

E. Biosocioeconomic Models. Construction, implementation, and validation of biosocioeconomic models applicable to policy formulation and decision-making (Topic 4b)

III. Collaborative Research, Second Priority

A. Data Analysis Systems. Development of algorithms and computer techniques for data analysis and transfer of these analysis systems to developing countries (Topic 5a)

B. Surveys—Direct Census. Research to determine environments where counting procedures (observation, use of transects) can be standardized (Topic 6)

C. Surveys—Acoustics. Development and adaptation of acoustic survey techniques for relative biomass estimation in selected environments (Topic 7)

IV. Collaborative Research, Third Priority

A. Age and Growth Studies. Further research in microstructure analysis of tropical fish hard parts (Topic 8)

B. Surveys—Remote Sensing. Photographic, radiometric, and thermal infrared sensing of environmental phenomena coupled with capture or direct census surveys (Topic 9)

C. Surveys—Capture. Marking (or tagging), release, and recapture studies to determine optimum methodology (Topic 10)

D. Surveys—Eggs and Larvae. Appraisal of spawning biomass by sampling eggs and larvae (Topic 11)

V. Supportive Research Activities

A. Inventory of Exploited Resources. A compilation of resources exploited by tropical small-scale fisheries by habitat (Topic 12)

B. Inventory of Human and Institutional Resources. A compilation of human and institutional resources in developing countries available for research in fisheries and aquaculture (Topic 12)

C. Inventory of Ecosystem Response. A compilation of existing materials on various ecosystem responses to habitat modifications (Topic 12)

D. Inventory of Life Histories. A compilation of information on vital statistics and life histories of major species exploited in tropical small-scale fisheries (Topic 12)

E. Surveys—Effort. The development and evaluation of techniques and training methods for aerial surveys of fishing effort (Topic 5c)

VI. Supportive Development Activities

A. Information Dissemination. Development of cost-effective methods for greater dissemination of scientific information; e.g., library materials (Topic 13)

B. Training—Data. Development of suitable training progbrams for LDC personnel in data gathering and analysis methods (Topic 5b)

Recommendations by Topic

1. *General*

Recognizing that the United States Agency for International Development (AID) through the Title XII amendment to the Foreign Assistance Act now includes aquaculture and fisheries research and development in its terms of reference, and further recognizing that the Title XII program is directed by a Board of International Food and Agriculture Development (BIFAD) and Joint Research Committee (JRC) as well as a Joint Committee on Agricultural Development (JCAD), whose functions are to provide guidance and advice, the workshop participants respectfully suggest that the membership in these bodies (BIFAD, JRC, and JCAD) reflect AID's interest and concern for fisheries and aquaculture in future appointments to these bodies.

2. *Comparative Studies*

Traditional resource assessment procedures which are used in developed, temperate-zone countries such as the U.S. are aimed at estimating the biomass of individual stocks of fish which are available for harvest and/or the maximum quantities which may be harvested from these stocks while maintaining the resource and achieving the optimum economic and social benefits from it. There have been very few successful applications of these methods to tropical small-scale fisheries in the LDCs, given the great variety of species which are harvested and the general inadequacy of historical fishery statistics and biological information which is available. In many cases it is simply not feasible to collect, analyze, and interpret all the data required by conventional assessment techniques for species which are regularly harvested in tropical fisheries.

One alternative approach is to compare the yields obtained by different gears and with different fishing intensity in different unit fisheries in order to form development and management strategies based on the relative degree of resource exploitation in a range of situations. A second alternative is to conduct studies of yields obtained from different unit fisheries and the environmental features associated with each. This could lead to the development of empirical models for predicting potential yields from some set of environmental variables. Such models have been successfully applied to predicting yields from inland lakes and rivers in North America and Africa. Either approach might best be applied to species assemblages rather than to individual species.

a. It is recommended that research to develop methods for rapid assessment of stocks based on comparative studies of environmental indices be initiated. Such studies should involve a careful review of limnological studies, a careful description and classification of the environments of tropical small-scale fisheries in diverse locations, and a careful analysis of independent variables such as tidal amplitude, substrate composition, wave energy, temperature, salinity, tidal flushing, bottom topography, etc., in relation to some response variables; say, fish yields or standing stock estimates based on direct census techniques. Data would first be examined for postulated associations among variables. Then empirical prediction equations, modeling techniques, or classification techniques would be applied so that the environments could be grouped into categories which have relatively similar yields. Confirmation and refinements of indices and the stock potential estimates derived therefrom would require further tests in the field. However, it should be recognized that this research would involve a diversity of environments as well as a number of disciplines. Further, it would be logically carried out in two stages: 1) data collection and analysis, and 2) field testing, estimation, and modeling.

The Steering Committee recommends this as Collaborative Research, First Priority.

b. It is recommended that studies comparing the performance of various small-scale fishing gear (traps, handlines, longlines, nets) be initiated. Such studies would be aimed at defining the fishing power of these gears in much the same way that characteristics relative to the effectiveness of bottom trawls have been evaluated in temperate-zone fisheries. Gear studies would have several objectives: 1) to select a standardized reference gear which could be fished in a uniform fashion in different locations to estimate stock densities directly, 2) to establish a basis for combining catch per unit effort data obtained from different gears fished in the same location, 3) to establish a correction factor which could be applied to historical catch and effort data to account for changes in gear efficiency. All three alternatives would facilitate the use of catch records for stock evaluations. Information on the cost-effectiveness of each gear type would also be useful in optimizing small-scale fishing practices. Gear performance studies will require a carefully programmed series of experimental fishing surveys aboard a research vessel in a selected tropical developing country.

Once the performance characteristics of different gear types used in tropical small-scale fisheries are defined, catch and effort data can be assembled from relatively discrete but otherwise comparable fishing areas which are subject to gradations of fishing intensity and the data standardized. With such information, a relatively simple surplus yield model could be applied to estimating optimum levels of yield and effort. It should be quite practical to apply this method to existing data at relatively little cost and obtain results within a year or two.

Another recommended comparative approach to stock assessment involves experimental fishing in an area that has not been fished or where fishing is minimal and where there are discrete replicate environments. By fishing such replicate environments with different intensities, an empirical model could be constructed which would directly relate yield capacity to effort. In addition, an experimental fishing program of this kind would provide valuable information concerning the biological response of fish populations to fishing.

The Steering Committee recommends this as Collaborative Research, First Priority.

3. *Comparative Assessment Models*

Fisheries models are attempts to provide quantitative descriptions of fisheries. The models to date have been used to help interpret data from a fishery and to test the effect of possible management policies. The conventional models are quantitative analyses of the assertion that population growth is the sum of recruitment and individual growth minus death. These models range from the simple logistic model stating that the rate of population increase is a quadratic function of stock size to complex, age-structured models. These have recently been expanded to multispecies versions.

Conventional models require either a fairly extensive historical record of catch and effort data or comprehensive biometrical data on which to base growth and mortality rate estimates. They also require a number of simplifying assumptions, have traditionally been applied to single-species populations, and usually do not account for variations in recruitment. Their application to the assessment of resources exploited by tropical small-scale fisheries needs to be critically evaluated. More specifically, the common mathematical properties and possible limitations imposed on the utility of different conventional yield models in the tropical LDCs should be carefully analyzed.

There is a critical need to design alternative assessment models which are not subject to the same restrictive data requirements or assumptions, models which could be applied to existing information or which would require the collection of a minimum amount of new information. Suitable methodologies should be analyzed and empirically tested in selected LDCs. Ideally, these models would be conceptually simple and rapidly applicable to the assessment of multispecies tropical fisheries, which utilize a variety of gear types. As a result, some loss of precision would be expected. New approaches might include the use of structural models involving graph theory, network analysis, a restructuring of stock production models, or a rigorous analysis of size-frequency data to estimate growth and mortality. The objective of this work would be to provide first-approximation solutions to multispecies fishery estimation problems.

The Steering Committee recommends this as Collaborative Research, First Priority.

4. *Policy Formulation and Decision-making*

The main purpose of stock assessment is to provide information that will assist in determining the optimal utilization of fishery resources. However, the raw output of stock assessment will not be directly useful in and of itself; it is only an input to the decision-making process. To ensure that the data is used to its best advantage, it is necessary to understand the decision-making process in which it is used. Furthermore, it is necessary to provide models to assist the decision-makers in understanding the full implication of their decisions on a wide range of issues. The main goal of research in this area should be to provide policy analysis studies of management and development options for small-scale fisheries. Research in this area should focus on developing and testing methodologies to examine existing policy formulation and decision-making structures.

Management and development objectives and the strategies to achieve them are not determined in a vacuum. The existing political, cultural, and economic institutions, as well as the state of the fish stocks, the extent of current utilization, and the level of harvest and processing technologies, play a very important role in determining these objectives. These features vary from country to country. Therefore, before practical advice on which types of management and development regimes should be considered and before evaluation of the effects of these regimes can take place, it will be necessary to understand the background information.

a. Research should be initiated to analyze the process of policy formulation, tracing the policy process from formulation through implementation in selected LDCs. This will require the identification of key information inputs in the policy formulation and implementation process (e g , yields, income distributions, technology levels, price structures, cultural attributes, management and development objectives). It will also be necessary to explore the full implications of alternative decision-making processes (modes) for use by policy-makers of 1) stock assessment information, and 2) fisheries development and management strategies. Each should be examined for fisheries that are not exploited, are lightly exploited, and are heavily exploited.

The Steering Committee recommends this as Collaborative Research, First Priority.

b. It is further recommended that research be pursued to construct, operationalize, and validate biosocioeconomic models of fisheries that are directly applicable to the particular nature of the policy formulation and decision-making structure of LDCs.

A general model should be developed that would be adaptable to various structures. Bioeconomic models for fisheries currently exist. The research here will necessitate improving and extending them, where necessary, to fit the particular problems of LDCs—especially to include social and cultural factors. The challenge will be to make the models operational, i e , to define the critical elements so that they can be fairly easily measured. Before the models can be a useful tool they must be validated. The models should be capable of describing the operation of the fishery within the policy formulation and decision-making structure and to provide information on how management and development strategies will affect such things as the economic efficiency of the fleet and the processing sector, the distribution of income from the fishery, the size and the distribution of enforcement costs, existing social relationships, cultural values, job satisfaction, and other such related items deemed important by the LDC.

The Steering Committee recommends this as Collaborative Research, First Priority.

5. *Data Collection, Analyses, and Interpretations*

The conventional method for analyzing changes in fish stocks has been the use of catch and effort statistics from the fishery. It is a relatively cheap method, and if based on a large number of fishing units, the sample variance may be small. In tropical small-scale fisheries, there may be several problems gathering and applying catch and effort data such as those associated with a variety of gear, poor communications, diverse landing sites, and an absence of data analysis methodologies. The need for certain standardized methodologies for data collection and analysis is recognized.

a. The development of suitable algorithms and/or computer programs for routine analyses of fishery data, and the development and transfer of entire data analysis systems, including both hardware and software to developing nations through collaborative educational programs involving suitable personnel from the developing areas at institutions in the United States, are recommended. Later, monitoring of the operations of the data analysis systems in the developing areas is vital until major difficulties in routine applications to assessment problems have been resolved.

The Steering Committee recommends this as Collaborative Research, Second Priority.

b. In addition, there is a need to train local fisheries officers in the collection and analysis of diverse data necessary for effective management decisions. To this end, it is recommended that a series of local or regional workshops which train fisheries officers in such techniques be established. Minimum data requirements include: 1) biological data on age, growth rate, weight, or morphological features associated with sexual maturity; 2) catch-effort data including landings evaluation, gear types, hours fished, number of fishermen, effects of weather on effort, etc.; 3) historical data on changes in fishing patterns over time based upon interview techniques; 4) social data on time devoted to fishing, willingness to organize and cooperate, response to innovations, etc.; and 5) economic data on prices, costs, and earnings.

The Steering Committee recommends this as an important Supportive Development Activity.

c. Surveys of fishing effort or intensity by aerial reconnaissance of fishing areas may prove to be a low-cost sampling technique. Aerial photos can distinguish small fishing crafts and describe the distribution of fixed gears by showing the numbers and location of floats. Training films could be developed to train surveyors in gear-type identification. An analysis of the benefits and costs of this method is worthy of investigation.

The Steering Committee recommends this as an important Supportive Research Activity.

6 *Direct Census Survey Techniques*

Except for some unique situations, such as in the case of anadromous fish and in some small aquatic environments, it is not feasible to count all individuals in a population of fish. It should be recognized, however, that precise direct counts of salmon and other migrating fishes have been made in some instances in large riverine systems when diurnal and other influences have been suitably corrected.

Underwater counting of fishes can be done by searching long narrow strips (transects) in which it is assumed that all fishes present are counted. It appears that the strips must be narrow and that the speed of the observer over the area must be slow. The exact values of these parameters—to be used by divers, for example—are not known. Some of the possible research areas for this kind of work include repeated series of transects in which some of the parameters are varied and systematically studied.

Although it may seem somewhat esoteric as a direct census method, it should be recognized that radio-equipped fish have been successfully tracked by surface vessels and detailed daily, and other short-term movements have been successfully recorded. The technology for this methodology is already well developed. It remains to determine if or under what conditions it might be cost-effective for small-scale fisheries assessments.

It appears that many of the transect census methods (line transects, belt transects, strip transects) applied previously to plant, mammal, and avian populations hold considerable promise for small-scale fisheries assessment. A careful review of these methodologies, and suitable modifications to permit application to tropical small-scale fisheries, seem desirable. This could then be followed by a limited field program in suitable environments and with empirical testing of relevant methodologies.

The Steering Committee recommends this as Collaborative Research, Second Priority.

7. *Acoustic Survey Techniques*

The application of acoustic techniques for abundance estimation of single-species pelagic marine fish and multispecies lake fish has been underway for approximately ten years. As a consequence, there is a wide variety of acoustic equipment and associated electronic devices available. Typically, acoustic techniques cannot be used to identify species directly. Thus, active capture must supplement acoustic data.

In a multispecies environment, acoustic techniques may be used to provide relative biomass estimates. The potential of this method in the environmental regimes of tropical small-scale fisheries in coastal areas and noncoastline shelf areas is considered to be high enough to justify collaborative research efforts.

Success of this research program will require a carefully structured group of U.S. and LDC institutions, since acoustic stock estimation techniques involve a complete integration of physical and biological factors.

The first item in the program would be an examination of the various tropical small-scale fisheries to maximize the probability of success of this application of acoustic techniques. Following this identification of the most likely environments, experiments employing minimal equipment sufficient to demonstrate the feasibility of specific acoustic techniques are suggested. These would be followed by more operational-sized assessments, which would ultimately be taken over by the developing countries involved in the project.

The Steering Committee recommends this as Collaborative Research, Second Priority.

8. *Age and Growth Studies*

The need for continued research support to develop further understanding of the microstructure of hard parts (otoliths, scales) as a valuable tool in the critical determination of age and growth in tropical fishes is clear. To this end, a combined laboratory and field approach to consider various problems in the interpretation of growth records and the factors influencing them is desirable. The specific sequence of activities suggested for the project includes: a) a series of workshops to train technicians in the interpretation and use of the method and in providing needed instrumentation; b) an international research program to deal with all phases of the life history of fishes, but particularly with the younger stages (an effort should be made to integrate resultant age and growth data into a form applicable to standard stock assessment methodology); and c) the development of a manual outlining methods, interpretation, and application of microstructure analysis.

The Steering Committee recommends this as Collaborative Research, Third Priority.

9. *Remote-Sensing Survey Techniques*

Remote sensing provides relative measurements of selected environmental phenomena. These data may be used to indicate the probable presence of various fishes in all environmental regimes. "Remote sensing" means that the sensor, and the human instrument, are above the air-water interface. The most readily available instrument sensors are photographic, radiometric, and thermal infrared. Earth-orbiting vehicles or geostationary satellites may be useful, but more investigation is required to confirm performance over small areas. Remote sensors are generally most effective when airborne. Multispectral photography is useful to penetrate seawater (nine meters) and for investigating bottom features: coral reefs, benthic flora, and sediment transport. Radiometric and thermal measurements may be useful for examining upwelling. Optimum conditions for aircraft remote sensing are clear and calm weather. Simultaneous observations of the fish populations of interest and quantitative direct measurements of specific environmental parameters are necessary to normalize relative remote-sensing data.

It is important to recognize the exploratory nature of future research, since many of the technological tools available for the job are still being improved and their utility in detecting relatively small-scale biological and physical phenomena needs to be demonstrated. This approach also requires reasonably accurate, short-term estimates of fish population size in areas where small-scale fisheries are actively pursued. Appropriate methods for obtaining these estimates need to be developed. Once they have been developed, however, the costs of implementation would not be very high. There is sufficient potential in the use of remote-sensing data for resource assessment of tropical small-scale fisheries to warrant further attention.

The Steering Committee recommends this as Collaborative Research, Third Priority.

10. *Capture Methods: Marking Studies*

It is suggested that the use of tags or marks by mutilating some part of the body of captured fish and the subsequent recapture of these animals by various means can provide valuable information for stock assessment in all of the environments of tropical small-scale fisheries. However, there are a number of specific problems involved in mark and recapture methods which are not as yet fully resolved. The recovery rate of tagged or marked fish in tropical environments appears to be quite low on the basis of available evidence. Whether this is due to differential mortality, differential vulnerability of marked animals, loss of marks or tags, incomplete recovery or reporting, significant recruitment into catchable populations during the time recoveries are made, or some combination of the above is generally not known. Indeed, detailed studies on the types of tags or marks most suitable for these environments are still lacking. Research could be undertaken to resolve some of these questions. For example, a critical comparison of various available tag types for some of the important tropical species by suitable holding pen, aquarium, and limited field studies seems appropriate. Following this initial work, detailed experiments designed to estimate population size, growth rates, survival rates, and movements of selected species in representative environments could be undertaken. The information obtained from such studies would provide complementary information for other stock assessment techniques which might be examined.

The Steering Committee recommends this as Collaborative Research, Third Priority.

11. *Eggs and Larvae Surveys*

These methods have been applied primarily to large fisheries, and the sampling effort required for successful estimates of spawning biomass is formidable. Indeed, the use of egg and larvae surveys in small-scale fisheries might best be applied to the detection and preliminary appraisal of fishery resources rather than for population dynamics studies. Positive aspects of surveys designed to estimate spawning biomass include the fact that samples contain not only eggs and larvae but also part of the prey and predators of the eggs and larvae. When simultaneous measurements of the physical and chemical environment are made, trends of water movement can be estimated. Spatial and temporal isolation over wide areas can be detected and can help define unit stocks. Spawning distributions tell when and where fish will be concentrated for efficient capture. Results can be used to monitor changes in species composition. Data can be used to forecast stock size into the next season and the year class strength of a species. Information on new stocks with commercial potential can also be provided.

Major problems with successful execution of surveys stem from underestimation of necessary technical effort and from imprecise survey objectives. In fact, all the factors necessary to estimate spawning biomass from ichthyoplankton surveys are not known for most stocks at present to allow for any better than a preliminary estimate, and the cost of such surveys is high. The collaborative possibilities are numerous, but the costs very probably would be prohibitive.

The Steering Committee classifies this as Collaborative Research, Third Priority.

12. *Inventories for Stock Assessment*

The need to prepare certain types of inventories of resources in tropical environments as a framework for later collaborative research projects is recognized. Such inventories include but are not restricted to: a) an inventory of fishery resources by habitat for the developing nations with small-scale fisheries; b) an inventory of human and institutional resources present in the developing countries which would be available for collaborative research; c) an inventory of the responses of various ecosystems to habitat modification; and d) an inventory of the vital statistics and other data (e.g., life histories) of the major fish species which are a component of small-scale fisheries. The Steering Committee recognizes the important work being done in this area by regional and international bodies, and recommends further encouragement of this Supportive Research Activity.

13. *Information Dissemination*

The inadequacy of existing library reference materials and the great value of timely published reports and information on fishery science and other disciplines related to stock assessment in many parts of the developing world are recognized. It is therefore recommended that AID and other agencies concerned with aquatic science in developing areas assist in an analysis of methods for augmenting the supply and timely dissemination of suitable materials. Some suggestions include initial collaboration with fishery scientists from developing nations to establish the nature of the information requirements, the form of the library materials required, and the means for cost-effective distribution on a broad scale. The workshop recognized that while this is not collaborative research, the magnitude of the problem is great and suggests cooperation with international agencies such as FAO and UNESCO in alleviating it.

The Steering Committee recommends this important Supportive Development Activity.

January 7, 1980

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The Workshop on Stock Assessment in Tropical Waters: Its Genesis, Rationale, and Objectives

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Genesis

The genesis of this workshop lies in two initially unconnected chains of events concerning technical assistance which came together a year or two ago. One of these chains began in international fisheries circles, the other in U.S. government circles, and at first the latter had nothing whatsoever to do with fisheries.

The fisheries events came about in part as the result of a shift in emphasis in FAO and various other donors from large-scale fisheries development that was generally capital-intensive to small-scale, labor-intensive fisheries projects designed to have a more significant and direct impact on poverty-stricken areas. This shift was coupled with the impact of zones of extended fisheries jurisdiction on developed and underdeveloped nations alike, and particularly with the often expressed needs of the lesser developed for managerial and scientific assistance in coping with these problems.

The broad problem of fisheries development, especially small-scale fisheries in the LDCs, has, of course, received a lot of attention from fishery scientists and administrators for years, and there has been a growing emphasis on and interest in stock assessment for small-scale fisheries in the tropical environment. Recent work done by the FAO Advisory Committee of Experts on Marine Resources Research (ACMRR) is a case in point. There are other endeavors, some by participants in this workshop, and their experiences will be of particular value to these deliberations.

As for the other chain, the workshop is a fourth- or fifth-generation product of an amendment to the U.S. International Development and Food Assistance Act of 1975. This amendment added a new section, Title XII—Famine Prevention and Freedom from Hunger, to the act, which was signed into law on December 20, 1975, as Public Law 94-161. The chief objective of the amendment was to bring about a substantial expansion of U.S. academic involvement to help solve food and nutritional problems in the developing world. As originally written, Title XII did not mention fisheries, but it was amended to do so before passage. The pertinent language in the act as passed reads, "The term agriculture shall be considered to include aquaculture and fisheries," and, "The term farmers shall be considered to include fishermen."

Title XII established a Board of International Food and Agriculture Development (BIFAD), and one of its tasks was to give AID guidance with respect to the use of research funds, particularly for collaborative efforts involving joint operations by certain U.S. universities and by appropriate research institutes in the developing world. On the U.S. side, all Land Grant and Sea Grant universities are included, and there are provisions under which others can participate. There was established as well a Joint Research Committee (JRC) with the function of advising BIFAD and AID on appropriate fields for collaborative research.*

In 1975, AID decided, quite independently of Title XII, to revive its virtually dormant fisheries program (Roedel, 1976), and fisheries was well enough reestablished in the agency to get the attention of the JRC when it was casting about for suitable sectors to consider for collaborative research support programs (CRSPs). AID had continued its support of URI in fisheries during the "dry years," from about 1970 to 1975; this was the agency's only significant non-aquaculture fisheries project during that time.

"Fisheries and aquaculture" was designated a high-priority area by the JRC, and a California firm, Resources Development Associates (RDA), was contracted late in 1977 "to coordinate an initial review and analysis of LDC problem areas, inventory research capabilities and interests of United States universities, identify LDC institutions with current or potential capability to participate in collaborative research support programs (CRSPs), outline suggested research programs, develop funding estimates and a priority plan for accomplishment." The final report, from which the foregoing is quoted, was issued in August 1978 (Craib and Ketler, 1978). It is this report, with its identification of stock assessment as a key research area, that is directly responsible for the organization of this workshop. It is the latest product of the interaction of a global interest in tropical small-scale fisheries and AID's interest in collaborative research.

The Steering Committee recommends this as an important Supportive Research Activity.

Rationale

Given the background recited above, why the decision on the part of AID to go ahead with fisheries stock assessment as a potential subject for collaborative research? Are there not sectors other than fisheries with greater claim on AID's funds, and within fisheries are there not researchable areas of greater significance and potential payoff than stock assessment?

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*The pertinent section from the first BIFAD Report (1977) reads:

> The Joint Research Committee was instructed by the BIFAD to give initial priority to the development and implementation of the new collaborative research program authorized by Title XII. Conceptually, this program rests on the facts that (a) there exist a number of agricultural and related problems which are common to the United States, other developed countries and the developing countries and (b) collaborative research involving US universities investigating such problems and, as appropriate, research institutions in the developing countries, other more developed countries and the international agricultural research centers would result in the discovery of knowledge and information of great benefit to both the United States and the developing nations.
>
> The JRC has worked intensively on the conceptualization, elaboration and implementation of this new program. It constructed a working model for the program to be known as the Collaborative Research Support Program (CRSPs). The guidelines have been accepted and approved by both the BIFAD and AID.

The question regarding fisheries vis-à-vis other sectors was decided in general terms prior to the RDA study, and it seemed to reflect a growing awareness on the part of the Congress and the Executive Branch of the useful role fisheries might play in foreign assistance. The answer to the second question lies in the RDA report's emphasis on the views of the developing countries, some 20 of which were visited during the course of the study. RDA's charter was basically to identify problems with solutions which would benefit small-scale fishermen and fish culturists and which might be attained through collaborative research support programs.

The RDA report lists stock assessment as the top-priority subject for the fisheries people in the nations visited. It says, "The most frequently expressed and highest priority need was for assistance in the general area of capture fisheries stock and resource assessment, followed by fresh/brackish water aquaculture and fisheries administration/management" (page 12).

A priority problem area in this sense does not necessarily have as high a rating when analyzed as a candidate for collaborative research. Thus, stock and resource assessment *as a topic for collaborative research* received a relative priority of class 2 because many of the perceived needs were for training and direct technical assistance rather than for research per se. "Principles and mechanisms of pond culture" was the only subject in relative priority 1, and it has already been selected to be the subject of a CRSP. Whether stock assessment will become an additional subject rests in large degree on the recommendations of this workshop.

Observations made by the author during the RDA study of African nations, including Guinea Bissau, Ivory Coast, Ghana, Kenya, and Sudan, bore out and contributed to RDA's identification of stock assessment and population dynamics methodologies appropriate to small-scale fisheries in the developing world as a high-priority research topic. Comments were frequently made to the effect that, whatever the country, it had been studied to death and it was high time something practical was done. There is enough truth in this for it to be kept in mind as needs for more research are considered.

The RDA report, which is the most pertinent background document for this workshop, has this to say regarding research needs generally:

> One of the most critical needs expressed by the LDCs engaged in capture fisheries was for assessment of their fisheries resources. Although these countries are generally aware of the extent and composition of their fisheries, there is a need for more precise and accurate information regarding the identification of the fish stocks, the numbers of species involved, their distribution in time and space and population dynamics.
>
> Within the field of stock assessment, research is required in the following areas:
>
> • development of rapid, simple methods of assessment to be used either initially or as a means of monitoring the status of stocks under the impact of fishing;
>
> • development of methods for assessment of multi-species fisheries (e.g., in the Gulf of Thailand a single trawl haul may include 50 or more species of a total of about 200 demersal species which may enter the catch. Many inland lake fisheries are similarly concerned with a large assemblage of species),
>
> • development of methods to assess stocks which do not lend themselves to trawl surveys (e.g., those coral reefs or hook-and-line fisheries);
>
> • development of stock assessment techniques for use in large rivers (particularly important in Africa and South America);

> - development of methods to define the biological potential of inland water, using environmental parameters.
>
> In addition to needs for resource stock assessment, the development of suitable techniques for obtaining basic catch data was given high priority by the LDCs. While a few of these countries compile catch and effort statistics, the greater majority do not, usually because they lack the necessary infrastructures or trained personnel or both. A very basic need exists for unsophisticated techniques or methods to obtain basic catch statistics as applicable to small-scale fisheries. Accurate fisheries data is essential to the LDCs if they are to implement effective management and control of their fisheries. [pages 60-61]

In its discussion of topics for collaborative research, the RDA report goes on to say:

> The ultimate objective of this research subject is to develop methods for assessing the condition of the fishery resources and the effects of fishing on it. This is a fundamental area of research which is a necessary prerequisite to the solution of nearly every other problem of capture fisheries. It is essential to know what stock are present, in what quantity, what is being caught and whether or not the catch is commensurate with the stock available.
>
> Effective methods for doing this in LDCs do not now exist or are not directly applicable. To restrict the scope to manageable proportions, it might be necessary to confine the effort to a few species which are common to the LDCs of major interest.
>
> The research area which needs to be addressed consists of four related subsets or projects.
>
> 1. Stock Assessment Methods. This involves the development of means for identifying stock, determining quantities, and migratory habits, and may include natural mortality rates, growth rates, reproductive potential and other characteristics useful in analyzing and evaluating the potential of the fishery.
>
> 2. Catch and Effort Statistics. Methods for estimating the landings and fishing effort which can be applied to LDC conditions and artisanal fishermen have to be devised.
>
> 3. Determination of the Effects of Fishing on the Resource. This concerns the development of techniques for evaluating the impact of fishing efforts on the condition of the fishery.
>
> 4. Determination of Sustainable Yield. Methods suitable to LDC application need to be developed which will provide a basis for management of the fishery. [pages 99-100]

The RDA report was received by the JRC, which appointed a Fisheries and Aquaculture Task Force to analyze it and make recommendations for a course of action. In its December 27, 1978, report to the chairman of JRC, the task force said, in part:

> The Task Force you appointed on Fisheries and Aquaculture to recommend follow-up to the RDA report has met four times and presented reports at three JRC meetings for discussion. We have proposed three activities in this area to help develop a collaborative research program.
>
> *1. Fishery Stock Assessment*
>
> More simplified methodologies are needed to enable LDCs to evaluate their resource base, particularly in response to the new 200-mile Extended Jurisdiction Zone. Current techniques used in the U.S. are time consuming and expensive. Perhaps more appropriate technologies exist on the shelf or could be developed.
>
> We propose that a workshop be convened on this topic which would include approximately twelve to fifteen U.S. and six to twelve foreign participants. Background papers and literature reviews could be prepared in advance.

The group would address the development of new, or modification of existing, technology for identifying and assessing coastal fish stocks which can be harvested by fishermen in developing countries. These methods should provide a basis for increased harvest of existing wild populations of both freshwater and marine fish and shellfish, while at the same time accumulating baseline information for management and the development of a system for maintaining a sustainable harvest. Significant modification of techniques developed for U.S. domestic needs and some new research for this specific need will be required.

The RDA report and the subsequent recommendation of the JRC task force stimulated the University of Rhode Island to submit a proposal to AID for a workshop on stock assessment for tropical artisanal fisheries. The JRC endorsed the concept at its April 1979 meeting and gave its tacit approval to URI as the logical institution to sponsor the workshop.

Objectives

This workshop represents the agency's response to the constantly recurring theme in the RDA report that a major requirement in the developing world is for resource assessment methodologies that can be applied to tropical small-scale fisheries. These nations need to answer fundamental questions about fisheries management such as: What is the nature and extent of each nation's living aquatic resources? Are some or all of the resources peculiar to a given nation or are they common to several? Do they range beyond zones of extended fisheries jurisdiction? What is their species composition, their sustainable yield, their optimum yield? What is the current rate of exploitation and how does it relate to biological and economic potentials and limits?

The agency recognized that the good methodologies available for assessment of large-scale fisheries—e.g., the trawl fisheries of the Northern Hemisphere, the tuna fishery of the eastern tropical Pacific—are not suitable for direct transfer to artisanal tropical operations where the fisheries are usually based on a multiplicity of species and are prosecuted by large fleets of small craft operating out of a number of shore bases.

What is needed is a workable system or systems that developing countries can either apply with their existing scientific complements or, barring the existence of such complements, train people to apply within a reasonable time. This may at first be nothing more than a quick and dirty means of getting first approximations of population size and dynamics, based upon data of at least some statistical validity. The methodologies may be simple adaptations of existing techniques or they may represent totally new concepts.

The workshop, in essence, is being asked to address these questions:

- What do the developing countries need to know, and how do they get the information required, to harvest and manage the living aquatic resources available to them at an optimal level?
- What studies can be instituted within the framework of collaborative research in Title XII to help these nations carry out their management responsibilities with particular respect to small-scale fisheries in both salt water and fresh?

The workshop should use the term "stock assessment" broadly to include inter alia the identification and delineation of species and stocks, the measurement of stock abundance, the determination of the effects of fishing in multispecies fisheries, the collection of biological and economic information necessary for wise management, and the analysis and interpretation of the data to permit formulation of management plans

The agency expects the group to explore and emphasize the innovative in considering

- new methods for stock identification, stock delineation, and determination of stock size,
- development of new methods for measurement of catch and catch per unit effort,
- new methods for determination of maximum biologically sustainable yields;
- new methods for translation of maximum sustainable yields to optimum yields; and
- use of new technologies in formulating management procedures

The workshop in reaching its conclusions must take due regard of

- pertinent activities under way or under consideration in other bodies;
- the amount of information that is really necessary,
- the costs of increasing accuracy, remembering that the perfect solution is useless if one cannot afford to apply it,
- the energy demands of alternative courses of action,
- three questions posed in the draft report of the ACMRR committee that met in December 1978: 1 Are the administrators' concern for information adequately communicated to scientists and technicians? 2. Does the information produced by scientists match the needs of the administrators? 3. Is the science that is required for decision-making produced on a reasonably cost-effective basis?
- the mores and the economics of the fishing societies which are affected;
- the absorptive capacity for new programs in U.S. universities and in developing countries—are there people to do the job?
- the short-, medium- and long-term prognosis for any research programs proposed, and educated estimates of their cost

In summary, the agency expects the workshop to do the following:

- Primarily, define and describe the principal problems facing the developing world in obtaining, analyzing, and applying the basic data needed for stock assessment; and delineate specific topics for collaborative research in the context of Title XII which would have the best chance of providing the LDCs with stock assessment methodologies suitable to their needs;
- Secondarily, identify problems requiring research in other than a collaborative mode for their resolution; and note problems not requiring research for their resolution that are identified during the course of the workshop;
- Finally, recommend a course of action to AID and BIFAD regarding collaborative research on stock assessment; and make any appropriate recommendations concerning AID's course of action regarding stock assessment in other than a mode of collaborative research.

This is a large order, but one with which the group participating in this workshop is well prepared to cope. Its collective wisdom can have a lasting impact on programs of technical assistance in fisheries, whether sponsored by the United States or by others. AID awaits its advice and counsel.

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Keynote Address

Arporna Sribhibhadh, *Deputy Minister of Agriculture, Thailand*

The economic and social development of the rural fishing and agricultural sectors has become a major concern of most developing countries in recent years. This concern is shared by many donor countries and international agencies, and they are ready to assist in national efforts to raise the living standards of rural populations. Until recently, however, most development programs in the fisheries sector have focused more on industrial level activities, with sizable investments going to offshore fishing boats, harbors, cold-storage installations, marketing networks, and training facilities. Industrial development is relatively straightforward, since its goal, increased production, gives reasonable return on investment and can be more clearly defined than can those of rural development projects. The development process in the small-scale fisheries sector is infinitely more complex as a result of social and cultural considerations.

Until recent years, the small-scale fishermen enjoyed a rather idyllic existence. Virtually all their economic needs were met very simply by bartering surplus fish catch for the basic staples they found necessary for life. They were adept at the skills of their trade, such as boatbuilding, fishing gear repairs, and traditional methods of fish preservation. They had no competition in their exploitation of abundant fisheries resources. The social services that their urban cousins needed they neither required nor desired. Their simple life-style had remained unchanged for generations.

During the past two decades, however, this scenario has fast disappeared. Urban population growth has accelerated rapidly, necessitating that large quantities of food stocks including fishery products be transported to urban markets daily. To meet these demands, large commercial fisheries have been developed, which in many instances compete with small-scale fishing operations for the same resources. Fish buyers have established themselves as the only marketing outlet for small-scale fishermen and have replaced the barter system with cash purchases. In an effort to compete for the resources, the small-scale fishermen have had to adopt more sophisticated catching techniques which require capital investment in boat motors and fishing gear. Moreover, basic social services and modern living comforts are becoming available in many rural fishing communities. In other words, the small-scale fishermen in their communities have been caught in the plight of progress.

It is generally recognized at present that the small-scale fishermen and their communities are at the bottom of the socioeconomic ladder in most countries. An acute need to improve their standard of living and quality of life is expressed and discussed in many meetings concerned with fishery development programs around the world. Although everyone agrees that it is desirable to give assistance to this sector and to raise their living standards, little actual assistance has been evident and very few of such programs are successfully applied and achieve their stated goals.

In the Southeast Asian countries that border the Bay of Bengal and the South China Sea, where some small-scale fisheries development projects have been implemented, there are an estimated 3 million fishermen and their dependents, about 15 million people in all, who depend mainly upon fisheries for their livelihood. While this large number of fishermen live at subsistence levels, their total production of fish is very considerable and their contribution to society is of great significance. Nevertheless their per capita production is much less than it could be. This low production results in reduced income to fishermen. The situation is further aggravated by post-harvest losses due to inefficient handling of catch on board, and inadequate processing, preservation, storage, distribution, transport, and communications facilities. All these result in avoidable loss of animal protein food, which is in short supply in these countries.

In spite of several measures already introduced by governments in the region to improve the social and economic conditions of the small-scale fishermen, in some areas and in varying degrees they still suffer from low levels of real income, indebtedness, substandard housing, malnutrition, and poor health. In many cases, this situation is also attributable to a combination of economic and technological considerations such as the remoteness of many rural villages, the lack of basic infrastructure facilities, the lack of alternative employment, the unavailability of credit, and in most cases the complete lack of base line data upon which estimates of fishery resource potential can be based. Although the conditions characterizing the small-scale fisheries vary from country to country in degree and emphasis, they are largely similar throughout the area, and thus the problems and constraints of their development programs are also similar.

Dr. Roedel mentioned earlier that assistance in the general area of fish stock and resource assessment was identified as the highest priority need of the developing countries. This is true in the context of fishery development and management, but other priority needs prevail when the overall scheme to better the livelihood of the small-scale fisherman is considered. Experience gained from some small-scale fishery development projects in Southeast Asia indicates clearly that projects "based more on optimism than on realism are doomed to failure," because of the simple fact that in some areas there are not enough fish to develop a better fishery. On the other hand, how successful have our stock assessments been in connection with small-scale fishery development? In my opinion, we are yet to succeed.

The nature of the subsistence fishery and fish stocks in the coastal tropical waters in which these fishermen operate make it very difficult, if not impossible, to obtain the conventionally required information on captures as well as effort by traditional means. The initial failure is due to the lack of appropriate data and methodology at all levels. Attempts to estimate even the preliminary standing stocks have not succeeded, resulting in a total absence of guidelines for conservation measures in most national policies for fishery development. Perhaps one can search for and try some unconventional and untraditional alternatives. On the other hand, lack of stock assessment in many areas has proved to be no obstacle for development in fisheries. My region is a case in point. The scientists and administrators there are drifting farther apart. The scientists seem not able to convince the administrators of the vital role that stock assessment plays in the essential understanding of the rational development of fisheries. The answer is that the estimates and the degree of expectation of the administrators are both high enough to counter the scientists' requests for increased allocation in terms of manpower and budget for an effective assessment program. Moreover ample evidence shows that the weakness in analysis is due to the lack of objectively designed programs and the cost-effectiveness of information required, as well as the difficulty in obtaining cooperative informants among the rural fishermen. The proposed stock assessment programs presented to the administrators are also, in most cases, unacceptable in terms of the time frame needed. A post-mortem analysis of the status of fish stocks and fisheries is unproductive, as the recommendations for management are usually not adopted. The usually prevailing mode is to move development forward even though donor institutions or countries would require having such information on resources for their feasibility evaluations.

What are the original sources of the communications gap that presently exists? In general, the administrators, in accordance with their national policy, aim to expand fish production and increase the productivity of their fisheries with the reduction of cost per kilo of fish involved. The planning scientists must not fail to relate these objectives to the activities of the administrators, since they cannot afford to separate themselves from such requirements. Furthermore, all the capture fisheries are at a disadvantage when compared to agricultural sectors such as crops, livestock, and forestry funded at a comparable level. Fishery scientists must be able to compete for support in their development programs. The above observations are not intended to rule out coastal stock assessments. On the contrary, it is obvious that practical and effective solutions to the problems and constraints facing developing countries, such as obtaining, analyzing, and applying the basic data needed for stock assessments, must be found if rational development of small-scale fisheries is to be effective. A means of bridging the communications gap between scientists and administrators must also be realized in order to put stock assessment in fishery development and management in a proper perspective vis-à-vis other agricultural sectors. The search for these solutions should be based on the essential understanding that fishery development is but one aspect in the overall development of the rural small-scale fishing community. It involves biological as well as economic considerations in the exploitation of the fish stocks concerned. Development of the rural fishing community necessarily consists of many aspects: social, cultural, and political, as well as biological.

The concern of fishery scientists should not be limited to fish stocks. They must be constantly aware and not lose sight of the eventual goal, which is to see that these small-scale fishermen and their families gain a better livelihood and that they are able to live with dignity and without hunger.

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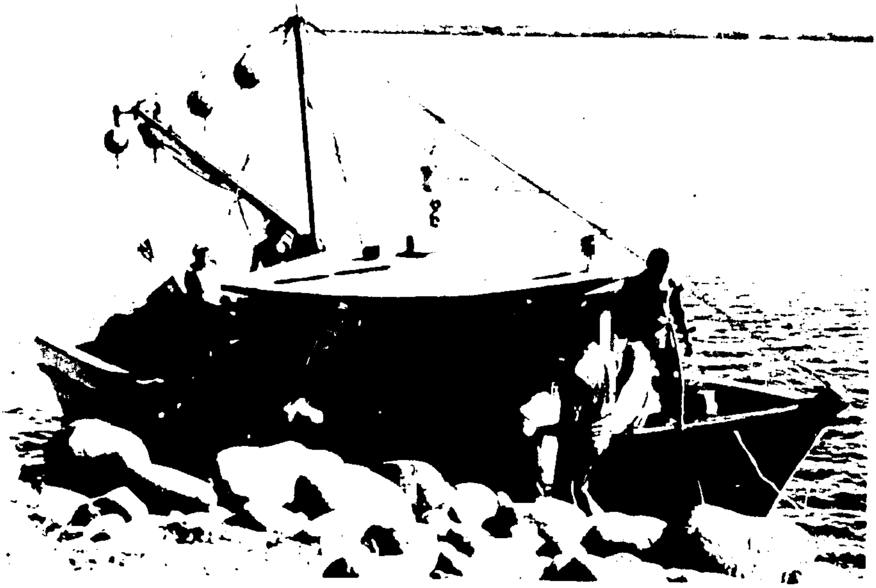

Perspective Papers

Stock Assessment in Tropical Fisheries: Past and Present Practices in Developing Countries

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Introduction

Stock assessment has been perceived by many developing countries as one of their priority needs. In setting this priority, the emphasis has been on the output from stock assessment studies as they are used in making decisions concerning the management—and, more particularly, the rational development—of their small-scale fisheries. The actual detailed processes of stock assessment, as generally understood by fishery scientists, especially those in the academic communities of both the developing and developed worlds—i.e., calculation of growth patterns, mortality rates of different species of fish, etc.—are in themselves of rather less priority except in so far as they are an essential part of the production of advice to policy makers.

In discussing past and present practices, it is therefore convenient to distinguish four stages in the provision of advice: the collection of basic statistical and similar data; biological studies (growth or migration, for example); stock assessment *sensu strictu* (that is, evaluation of yield curves, sustainable yields, etc.); and the provision of advice to the policy makers, such as investment planners.

Statistics

Collection of statistics from scattered small-scale fisheries is not easy. In many cases, the procedures used are similar to those used in industrial fisheries—a flow of information, purporting to represent the total catch, on a daily or weekly basis, from small landing places to provincial centers and so on to the central authority, which subsequently arrives at a figure for the annual catches of the country. This system is recognized to be far from reliable. Most sources of error—false reporting to avoid the attention of the tax authorities, omission of many catches because they do not pass through even the smallest of formal landing places or fish markets—will result in an underestimate of the total catch. To correct for this, some authorities, as in the Philippines in respect to the so-called municipal fisheries (from vessels of under 3 gross tons), use a factor deduced from a review of the likely sources of error to multiply the number obtained to arrive at a more reasonable figure.

Apart from being unreliable, this approach is also expensive. An alternative is to use sampling procedures (Bazigos, 1974). This requires first a careful frame survey (which needs to be repeated at intervals) to obtain a complete enumeration of all the landing places. These are then sampled, usually through stratified and multistage sampling processes, so that only a small proportion of the total is actually recorded. This is used in India, and has also been introduced, with FAO assistance, to a number of African and South American inland fisheries. It does require careful planning and proper training and supervision of the staff involved, but with these provisos can provide good results. Further, provided the work is properly carried out, it is possible to determine confidence limits within which the true values—say, of the total catch—probably lie. This is valuable, because for most purposes quite rough estimates, possibly within ± 10 percent, are quite adequate, but it is seldom known whether the figures available in the usual official statistics are as close as this to the real figure.

Little attention is paid in general to the collection of effort statistics in the conventional stock assessment sense. Records, usually on an annual basis, often consist of the numbers of fishermen and the number of vessels (powered or unpowered, classed according to type of gear used). This information is collected at the local level and normally summarized using the same channels as the catch data. While not the most useful information on fishing effort, in many small-scale fisheries in the developing world the fishing practices (type and size of gear used, amount of fishing done per year) do not in general change much from year to year. There are exceptions; for example, in river and river-floodplain fisheries the effort is largely governed by water level and the ability of fishermen to cope with high water levels. Thus, with few exceptions, the catch per fisherman, or similar simple index, can be used as a satisfactory index of year-to-year changes in stock abundance, at least within the range of operations of the fishermen. Changes in availability—e.g., the extent to which the fish migrate inshore—may mean, however, that the local abundance may bear quite a variable relation to the abundance of the stock as a whole.

Biological Research

This has generally been patterned on biological research in developed countries. Indeed, in many countries, notably in Africa, most of the research in the past has been carried out by expatriate staff, who have tended to have a background of academic scientific training in marine or freshwater biology rather than in fisheries per se. Similarly, much of the graduate or post-graduate training received by local scientists outside their country (and many countries do not yet have adequate facilities within the country) has tended to be in "pure" science—for example, in fish biology rather than in fishery biology.

There have been notable exceptions and the situation is improving. Nevertheless, the work in fish biology, both marine and fresh water, in developing countries has not on the whole been closely directed to obtaining the sort of information required for stock assessment purposes. This seems to be particularly true in some of the countries that have large research staffs engaged in fisheries problems; in such countries there may be an impressive bulk of information and scientific publications on classical aspects of the biology of numerous fish species (not always those of major economic importance), but not much that can be immediately used to help advise the authorities as to whether or not catches can be increased.

One problem is that it is not clear what biological information is required to assess the multispecies stocks of tropical waters. Certainly to follow for each species the classical procedures adopted for the major species (cod, salmon, etc.) of temperate waters—to estimate growth, mortality, etc.—would be hopelessly time-consuming and prohibitively expensive if applied to all species, even if this were not in many cases impracticable because of the difficulty of telling the age of most tropical species. Some analytical, specific work of this kind is needed to understand and quantify the population characteristics and biomass turnover of tropical finfish or other species groups still poorly investigated even in higher latitudes (cephalopods, penaeids, shellfishes, etc.)

The problem of what data should be collected and what lines of study pursued is discussed further in the next section. It may be noted here that two possible approaches to assessing the stocks are: 1) the estimation of the general level of biological production (and hence of the proportion that could be available for regular sustained harvest), and 2) the establishment of some relation between the amount of fishing and certain characteristics of the stocks.

The first could demand a variety of different types of observation, ranging from the physical and chemical characteristics of the water body, through examination of the phytoplankton (and other plants in fresh waters) and zooplankton, to the detailed biology of the fish themselves. The second approach traditionally involves looking at either catch per unit effort (or some other measure of abundance) or the size or length composition data, and hence deriving some measure of total mortality. In addition, in the multispecies situations typical of most tropical fisheries, including those of interest to small-scale fisheries, monitoring of the species composition (as far as possible of the stock rather than of the catches) is likely to be valuable.

Stock Assessment and the Provision of Advice

These two stages can well be treated together at present. The level of both activities in most areas has been relatively low, and the lack of progress in one field discourages activity in the other. Because there is no good assessment of the state of the fisheries and of the possibilities for increasing catches, fishery administrators charged with developing national policy toward small-scale fisheries are not in the habit of turning to biologists for advice. (The fact that fishery administrators in developing countries are now placing high priority on stock assessment work, as shown by the arrangements for the present workshop, does not mean that they have been using stock assessment data or that they know where to get such advice.) Conversely, because until very recently there has been little clear demand for or use of stock assessment data, scientists have not paid much attention to carrying out assessments.

Fishery scientists have not been encouraged to pay more attention to making assessments by the typical career structure of the discipline. As elsewhere, success in developing countries within the scientific community largely depends on published papers. Stock assessment, except where there is a long series of detailed data—which is the case in few, if any, small-scale fisheries—does not lend itself to scientific papers of the traditional kind. Most assessments—and, still more, the advice coming from them concerning tropical small-scale fisheries—will normally be a series of "best guesses" and attempts at a balance of probabilities. These, if phrased properly, can be extremely useful to policy makers, but they are not the stuff on which scientific reputations are normally built.

Another problem is that, even when a formal research institute exists, it will be small in developing countries. This means that each individual scientist has to handle many research topics, as well as administrative tasks, and has little time to work on any one problem for an adequate time.

Here it is worth noting the past practice of stock assessment in developed countries. The factors mentioned in the previous paragraph, which act against the involvement of scientists in stock assessment studies, used to be equally applicable in these countries. Apart from a number of original studies of a few individual stocks (notably, Beverton and Holt's study of North Sea plaice), set out as much to demonstrate the new methodologies as to provide current advice on the state of the fisheries, stock assessment as part of national programs tended to be neglected. Two things have changed this. First, the need for the growing number of regional commissions to have up-to-date advice available at their annual meetings provided a great spur to assessment activity, whether by the commission staff itself (I-ATTC, for instance) or by national scientists whose activities were coordinated by a commission (ICNAF, ICCAT, etc.). Even though it is only recently—and then to a large extent as a result of the extension of jurisdiction which took most of the management responsibilities away from the commissions—that these assessments were used to implement effective management measures, the results of the assessment studies themselves have been of a high quality, and should be a cause of satisfaction to those responsible for setting up and running these bodies.

The other impetus for increased assessment work has been the growing requirement at the national level for explicit statements concerning fishery resources as part of the development of national management plans. These often arise (the United States Fishery Conservation and Management Act is a good example) as a result of the changes in jurisdiction resulting from the new law of the sea.

The first of these factors does not affect small-scale fisheries. CECAF (the FAO Commission for the Eastern Central Atlantic Fisheries) and, to a lesser extent, some of the other FAO regional fishery bodies, which between them cover most of the developing world, are becoming fully engaged in the range of stock assessment work (compilation of regional statistics, meetings of working parties, preparation of reports to the commission and member governments, etc.) typical of the longer established bodies. This work has mostly been done for the large-scale industrial fisheries (mainly, those carried out by long-range vessels from outside the region), rather than for the small-scale fisheries and the resources which support them.

There are good reasons for this. Each of the big resources may be exploited by two or more coastal states as well as by ships from a dozen nonlocal countries. They are therefore a direct international responsibility. The resources of interest to small-scale fisheries are of interest to only one country, and often only of localized interest even within that country. Further, the large-scale fisheries involve large-scale decisions—investments of tens of millions of dollars in new vessels; international licensing agreements, etc.—which are likely to require a fairly formal and detailed decision-making process, with a review of what is known about the resource an important element in this process. (However, this does not necessarily have to be the case; a surprising number of important decisions have been taken without a careful examination of resource data Subsequent history suggests that this is often not a very sensible procedure.)

The development of small-scale fisheries, on the other hand, has seldom involved big decisions Growth is normally a slow, organic process, with the traditional methods gradually modified to take advantage of, for example, modern synthetic materials The most abrupt changes have often come from outside decisions to build a new road, say, thus giving access to new markets for the produce from small-scale fisheries in the big cities Such formal decisions seldom call for explicit information on the state of the resources An exception has been the construction of big hydroelectric or irrigation dams with associated man-made lakes behind them These, and some other large-scale modifications in the environment, have provided the impetus for careful reviews of the fishery situation, including the assessment of existing stocks in the pre-impoundment or early post-impoundment stages in African man made lakes.

This situation is now changing It is becoming more widely recognized that, if the benefits of development are not to be concentrated in the better-off sections of the community, and if some of the harmful effects of development (for example, ever greater drift to the large cities and their surrounding slums) are to be avoided, greater and more explicit attention needs to be paid to the poorer people, including the small-scale fishermen This recognition is partly reflected in well-meaning resolutions at appropriate international conferences. It is also resulting in the formulation of large-scale projects, financed by various international and national agencies, for developing small-scale fisheries These require advice about the resources before a decision on the details of the projects can be made—for example, it would be worse than useless to encourage the increased catching power of a group of fishermen by financing the purchase of outboard motors if the resources are already fully exploited Those responsible for such projects are finding, however, that information on the resources is not readily available in most cases.

This rather black picture of the state of stock assessment work in many small-scale fisheries should not detract from the very real progress that has been made in some areas, particularly in the inland fisheries of Africa. Some of this work has used the traditional stock assessment techniques (analysis of CPUE data, calculation of yield per recruit from growth and mortality estimates), but fresh approaches have been developed, including the ultimate in simplification proposed by Graham (1958).

Improvement in technology has allowed the use of acoustic methods to become almost routine for surveying pelagic fish, and these are widely used in FAO projects. While they are mainly concerned with large industrial-scale fisheries, they can be used to assess some resources of interest to small-scale fishermen or to both small-scale and industrial fisheries.

Of wider interest have been the attempts to establish general formulas relating potential yield to simple characteristics of the body of water concerned. The original concepts developed from lakes in North America have been extended to lakes and river basins in Africa (Henderson et al., 1973; Welcomme, 1974 and 1975). Also, the simple estimation of potential yield has been expanded, by a study of the number of fishermen per unit area, to provide an assessment of the likely level of exploitation. For African lakes it seems that when the intensity of fishing rises to one fisherman per square kilometer of lake, the lake becomes fully exploited, and no further increase in catch can be expected by increasing the intensity beyond 1 to 1.5 fisherman/km² (see Henderson and Welcomme, 1974, Fig. 2, p. 8).

This approach has been less widely used in the sea, partly because the sea does not offer such neat and clearly defined replications of approximately similar situations as lakes do. The yield per unit area of reef fisheries in the Caribbean has already been examined. These tend to an asymptote in areas which seem to be heavily fished. A broadly similar figure of a maximum yield of around 5 tons/km² of reef was found, using the same approach, for the reef fisheries in the western Indian Ocean (Mauritius, Seychelles, Kenya, and Tanzania). Off West Africa (the CECAF area), though greater attention has been paid to the large offshore stocks exploited mainly by long-range vessels, progress has also been made in assessing inshore stocks. Apart from the use of traditional methods (e.g., CPUE), examination of ecological indices, especially the intensity and duration of upwelling and the nature of the bottom, has proved useful.

Considerable progress has been achieved in the Far East, largely through the initiative of the FAO/UNDP South China Sea project. This project has organized a number of workshops to assess different groups of resources. These assessments have largely consisted of detailed catch and effort data, which is available at various local and provincial offices.

The general experience of FAO has been to confirm the need for a combination of different approaches. Both the analysis of catch and effort data and the interpretation based on ecological indices need to be supported by some examination of more detailed aspects of the populaton dynamics of at least a representative sample of the species involved. The ecological approach and the estimation of yield from information on unexploited biomass require some idea of turnover rate or longevity of the various species of fish. Similarly, it would be unwise to rely on a decrease of CPUE (or an absence of such a decrease) as an indication of the presence (or absence) of heavy fishing unless there was other evidence of changes in the population structure—e.g., a decrease (or not) in the proportion of larger animals or, better, an increase in total mortality rate.

Discussion

This brief review of past and current practices of stock assessment of the small-scale fisheries of developing countries suggests that the supposition on which the workshop is based is correct. On the whole, the people making decisions on the development of these fisheries (using the term "development" in a general sense to denote any improvement in the fisheries and in the benefits received by the fishermen, rather than in the narrower sense of just increasing the total catch) do not have sufficient information on the resources, their potential and their state of exploitation, to make rational plans for such development.

The reasons for this are many, but they can, for the purposes of this workshop, be divided into three groups:

1. Appropriate techniques do not exist to assess many of the stocks, especially when many species occur.
2. Techniques exist, but the countries concerned are not able to apply them.

3. There is no structure within the country to ensure that the results of stock assessment, even when the relevant studies have been carried out, are made available to, and are used by, those making decisions.

Development of new stock assessment techniques, as well as the adaptation of existing techniques used for large-scale, temperate-water fisheries to the different conditions of small-scale tropical fisheries (many species, short life span, lack of age data, etc.) are discussed by other contributors to the workshop, and need not be expanded upon here.

Similarly, the transfer of knowledge is a problem that has been discussed before at length. The advantages and disadvantages of different approaches—sending expatriate "experts" to developing countries for shorter or longer periods; fellowships or similar medium-term or long-term training in developed countries; training courses in the recipient countries; provision of manuals, textbooks, and other written material—have often been talked about. Though the matter may not have been resolved by these discussions, it seems unlikely that much can be added here. However, it may be useful to distinguish two different situations. At one extreme are the large countries (Brazil, India, possibly Nigeria) whose small-scale fisheries, and the actual or potential supply of scientists, are important enough to expect that eventually they will establish their own self-sufficient program of assessment. At the other extreme are the small countries (the Caribbean island states, most countries in the Gulf of Guinea, the small Arab states in the Gulfs, etc.), which cannot be expected to command the expertise to make their own assessments within any reasonable time. Their fishery departments are very small, and in the smallest countries there may be only a couple of men to handle all fishery problems, from economics to the improvement of net design. For the latter class—which, in the short run, may include a majority of developing countries—improving the application of existing assessment methods will encompass arrangements for continuing assistance (possibly through regional or subregional cooperation) in the actual work of assessment, as well as the transfer of knowledge of how such work can be done.

Possibly, the most important reason for poor assessment studies, and poor use of any results of studies that are in fact carried out—and this is a reason that is often overlooked—is the absence of a structure or of administrative arrangements within a country (or external agencies, purporting to provide aid to the country) linking those responsible for scientific studies with those making decisions about development and management. Assessments, however precise, accurate, and detailed, are of no practical value unless they are actually taken into account in reaching decisions of some kind (subsidizing the import of outboard motors, prohibiting mechanized fishery within two miles of the shore, and so on). Conversely, even poor assessments if used properly can improve decisions that might otherwise be reached on a blind guess--or, more often, assumptions about the resources that are favorable to the action being considered. Further, using assessments can provide the best possible incentive for improving them.

A structure that would link the scientist with the decision-maker would also help overcome the biggest obstacle to better assessments. This is lack of resources, particularly in the collection of basic data (catch statistics, etc.). Even with the most efficient statistical design, collection of data is not cheap, and administrators will not be willing to allocate the necessary funds unless they clearly understand how important it is for their own work.

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Stock Assessment Models: Applicability and Utility in Tropical Small-Scale Fisheries

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Abstract

Problems of applying conventional stock assessment models to multispecies tropical small-scale fisheries are outlined. It is concluded that at the present time empirical Schaefer-type biomass production models are the only means available for assessing such fisheries but that there are strict limitations to the usefulness of such models.

The enormous problems of parameter estimation and the unknown effects of complex community interactions limit the utility of the Beverton and Holt type of models. Nevertheless, such models provide valuable insights into the dynamics of the constituent species.

Parameter estimations based upon simple measurements such as length frequencies, mean lengths or weights, and upon generalized interrelationships of basic parameters are advocated. They should be more closely investigated in order to test the degrees of accuracy which are attainable.

The effects of selective and nonselective exploitation patterns upon community structures are considered, and the effects upon harvests are described.

A set of carefully planned and executed research programs on selected small-scale fisheries could provide solutions to many of the problems which have been identified.

Introduction

The problems of stock assessment in tropical small-scale fisheries mostly relate to the fact that such fisheries are based upon a multitude of species, many of which are exploited by a variety of techniques to which the various species are differentially vulnerable. Instances in which a single species is overwhelmingly dominant in a tropical small-scale fishery are exceedingly rare (e.g., the Barbadian flying fish fishery) and need not claim further attention here.

A number of recent reviews (FAO, 1978; Stevenson and Saila, 1977) have been made of the models which are presently available for assessing multispecies stocks, and Pope (1979) has most recently formulated a multispecies model founded upon the basic logistic model of Schaefer (1954, 1957). Multispecies versions of the Beverton and Holt (1957) model, such as that of Andersen and Ursin (1977), have also been developed, but the feasibility of actually applying such complex models to the fisheries is not yet apparent.

This paper is an attempt to evaluate the relative utility of the available models when applied to tropical small-scale fisheries, and to identify specific factors which might limit their usefulness, including problems of parameter estimation. For the purposes of this discussion, tropical small-scale fisheries are defined as those fisheries which operate without the assistance of *unified* or integrated distribution and marketing organizations, and in which the fisherman most often retains a portion of his catch for his own use and sells the remainder directly to the consumer or to an individual vendor. Fishing methods can be extremely diverse and the landings may be dispersed over a great length of shoreline.

Conventional biological and statistical exercises therefore become extremely difficult to implement. For example, landings made at a village beach after an overnight trip in a Western Pacific reef fishery might include handline, gill net, spear or spear gun, and troll catches. Several sizes of hooks and/or mesh might be employed, and all fish from all sources are stored in a single icebox (if such a luxury is available).

Additionally, artisanal and subsistence fishermen often have a fund of knowledge of fish behavior, migrations, and general ecology which enables them to switch their attention from one habitat to the next in order to capture the most readily available species. This will result in the sudden absence of a species from the landings—not because the species is unavailable but because a different species is more readily available.

In other situations, fishing might cease entirely, despite favorable conditions, because abundant supplies of some terrestrial crop have become available and rendered fishing uneconomical. Alternatively, fishing might simply cease because the fisherman's labor is required elsewhere. Where fishermen have become indebted to middlemen or traders, large portions of the landings might be concealed in order to avoid demands for debt repayment.

In all instances where biological or statistical sampling is done at a village level it is necessary to have local agents or to get to know the fishermen on a personal level in order to gain their confidence. This is a time-consuming process—often prohibitively so.

One other feature of such fisheries which is not always recognized is that the conventional economic restraints on overexploitation might be absent or become operative only long after the largest (and often the most valuable) organisms, which mature at relatively large sizes, have reached a severe state of biological overfishing. This eventually results in reductions in recruitment and a decline in volume, quality and value of the catch. Under such circumstances, it is entirely possible to render extinct the most sought-after or most vulnerable species.

The foregoing remarks apply to the fisheries prosecuted by the overwhelming majority of individual fishermen and fisherwomen in the world and to fisheries which probably produce much more than half the world harvest of marine products for direct human consumption. The amount of scientific attention directed toward these tropical fisheries (with the notable exception of African freshwater fisheries) has been negligible.

Models

Only two basic models exist for the assessment of fish stocks; viz., the empirical Schaefer production model (1954, 1957) and the analytic constant-recruitment Beverton and Holt model (1957). All other models are merely permutations, variations, simplifications and/or improvements of the basic material. With very few exceptions, application of the models has been directed toward stocks of individual species and it is only comparatively recently that serious attention has been directed to multispecies fisheries.

The FAO Expert Consultation on Management of Multispecies Fisheries (1978) considered some aspects of multispecies stock assessment using the Gulf of Thailand trawl fishery and the trawl fishery of the Georges Bank-Cape Hatteras part of the International Commission for Northwest Atlantic Fisheries area as prime examples. Neither of these is a "small-scale" fishery, but they differ in regard to numbers of species, diversity of fishing methods, and the difficulties involved in assembling catch and effort statistics.

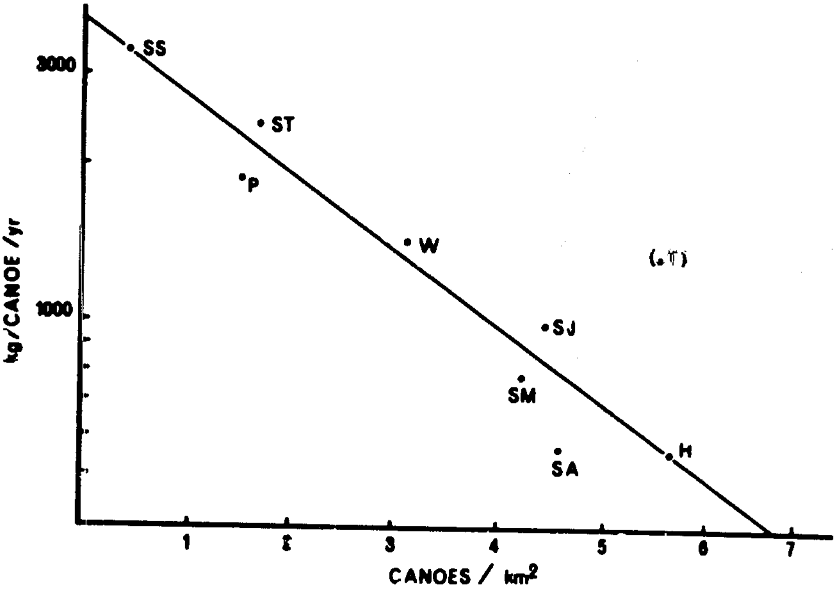
In cases where catch statistics exist, the simplest assessments of multispecies fisheries have been based upon the combination of the available catch statistics and treatment of the entire community as a single stock. This has worked surprisingly well, and FAO (1978) cites examples from the trawl fisheries on Georges Bank, in the northeastern Pacific, and in the Gulf of Thailand. Either linear or semilogarithmic regressions of catch per unit effort against effort have been employed.

Munro and Thompson (1973) applied a semilogarithmic regression to catch statistics for the canoe-based Jamaican near-shore fishery (Fig. 1). In this particular case, no annual statistics were available, and the analysis was based upon a sample survey conducted by the Jamaican government during 1968. Catch rates expressed as kg/canoe/year were regressed semilogarithmically against fishing *intensity* (canoes/unit area) for various sectors of the island shelf which were subjected to different fishing efforts. The inherent assumption in this "model" is that the different areas are ecologically similar and originally supported fish communities of similar composition and biomass.

These biomass-production "models" are purely empirical, and the yield curve is obtained by simply multiplying values along the x and y axes. The FAO Expert Consultation on Management of Multispecies Fisheries (1978) speculated on possible reasons for the relatively good fit of such "models" and, while not reaching any definite conclusions, suggested that "total biomass does react in a simpler way to overall fishing effort than does the biomass of individual stocks" and pointed out that species interactions must be implicit in such a response to fishing.

Pope (1979) has expanded upon earlier considerations of interspecific interactions in exploited communities and has described a new multispecies model which is founded upon the basic premises of the simple parabolic Schaefer model but allows for the effects of predation and competition on all the component species. There is, apparently, no theoretical limit to the number of species which can be treated by the model, provided that the necessary parameters can be estimated. However, parameter estimation for individual species may not be necessary, because the model shows that the yield will be at a maximum when the combined catch per unit of effort of all component species is reduced to one half of the initial catch per unit of effort, provided that no stock becomes zero.

In the latter context it is also most important to note that Beddington and May (1977) have shown that, as a result of chance environmental fluctuations, the variability in population size will increase as harvesting effort increases, particularly at levels of exploitation beyond that which will produce maximum sustainable yields. The right-hand arm of any yield curve therefore becomes pro-



gressively less reliable as effort increases, and there is a danger of extinction of species which are at a temporarily low level of abundance. Beddington and May (1977) point out that the effects are more pronounced under a constant yield strategy (i.e., a quota system) than under a constant effort strategy, and it is, perhaps, fortunate that quotas are one of the management tools which are least likely to be used in tropical small-scale fisheries.

An additional point that is made clear by Pope's model is that the sum of yields from two interacting stocks which are simultaneously exploited is always less than the sum which might be obtained from the stocks if they did not interact. Similarly, Shirakihara and Tanaka (1978) concluded that in the case of competing species such as *Scomber japonicus* and *Cololabis saira*, 'the MSY level for each species based on the single species theory could be quite erroneous."

The only alternative to models of the Schaefer type appears to be that of making estimates of the population parameters of the component species (or at least of the dominant species) in a fishery, applying the Beverton and Holt model (1957, 1964) or one of its successors (Gulland, 1969) and summing the resulting yield curves. The calculations present very few practical problems provided there is access to minimal computer facilities.

However, a simple summing of component yield curves must largely ignore the possibility of changes in the parameters in response to community interactions, because such changes cannot be calculated at the present time. The theoretical basis for detailed analysis of multispecies analytic models already exists (e.g., Andersen and Ursin, 1977), as does the computing technology. All that is lacking are estimates of the parameters.

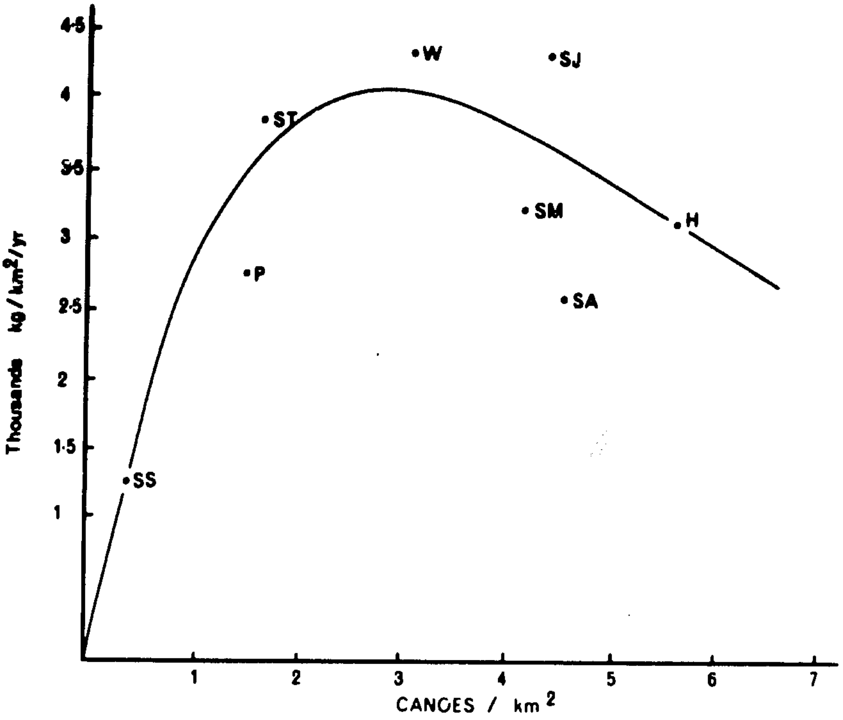


Figure 1. (A) Semilogarithmic plot of relationship between catch in 1968 of demersal and neritic pelagic species per unit of effort (kg/canoe/yr) and fishing intensity (canoes/km^2) for shelf areas adjacent to the Jamaican parishes of St. James (SJ), St. Mary (SM), St. Ann (SA), Trelawney (T), and Hanover (H) on the north coast; St. Thomas (ST) and Portland (P) at the eastern end of the island, Westmoreland (W) at the western end; and for the South Jamaica Shelf (SS). Trelawney is excluded from the regression. (B) Regression line of Figure 1A translated to terms of annual yield per unit area (thousands of kg/km^2/yr) relative to fishing intensity (canoes/km^2). Actual yields and fishing intensities (1968 statistics) for shelf areas adjacent to Jamaican parishes and for the South Jamaica Shelf are also included (abbreviations as given for Figure 1A). (From Munro and Thompson, 1973.)

Applicability of the Models to Tropical Small-Scale Fisheries

In applying either the Schaefer or the Beverton and Holt models, it is necessary to make certain bland assumptions even when the models are applied to single-species stocks. In applying the models to multispecies stocks, very serious problems can arise. For example, Pope (1979) shows that there are no serious objections to the empirical Schaefer-type multispecies assessments which have been done for the fisheries of the Gulf of Thailand and the Jamaican shelf. However, both assessments will become inapplicable if any species is extinguished or if there is any major change in fishing technique or in the mesh sizes used. This is because the composition of the exploited community is a function of its original composition, of the lengths or ages at first capture, and of the catchability of each of the component species. To take an extreme example, a very large increase in mesh size at a given level of effort would result in a drop to zero of the fishing mortality of all small species, while the abundances of those species would rise to some equilibrium level. The large species would continue to be harvested, but the recruitment rate of each of them might change radically. For example, some of the small predators previously held in check by large predators or by fishing might now increase in abundance and prey heavily upon juveniles of large species and adversely affect recruitment. Alternatively, recruitment of large species might be enhanced as a result of maturing and spawning before recruitment. The permutations are clearly endless, but the point remains clear: the only management measure which can be effected on the basis of a Schaefer-type assessment of a multispecies stock is an adjustment of fishing effort. The effect of any other alteration of fishery parameters must be separately assessed by means of an analytic model.

The analytic Beverton and Holt model assumes that recruitment is unaffected by fishing effort, something which is patently untrue at high levels of exploitation. In conventional single-species assessments, this problem, and the problem of fluctuations in recruitment, are circumvented by expressing yield estimates in terms of yield/recruit. However, this *cannot* be done if the Beverton and Holt model is applied to a multispecies fishery in which the yield curves of individual species are summed.

In such a case, recruitment (R) must be incorporated into the calculations, because it is the *proportion* of recruits of each species which determines the magnitude of the yields. Absolute estimates of recruitment are not essential, and an index of recruitment can be used instead (Munro, 1974). However, evidence is accumulating that coral reef fish communities which are reputedly "stable" can have substantial variations in annual recruitment of individual species (Russell et al., 1977). There is not yet any information on the degree to which tropical food fish stocks may be subject to variations in recruitment, but there is every likelihood that the same variability will be encountered.

If analytic models of any sort are to be used for the assessment of small-scale multispecies fisheries, it is vitally important that a better understanding of the biology of the constituent species, and of the factors which affect the basic biological and fishery parameters, be achieved. Most important of all, we need to know how the exploitative process affects the composition and productivity of the exploited community. The parameters which might be affected include the natural mortality rate (M) and the recruitment rate (R). It is also conceivable that catchability (q), length and/or age at recruitment (l_r, t_r) length and/or age at maturity (l_m, t_m), fecundity (e), and condition factor (a) could be affected. Clearly, the growth parameters of the von Betalanffy growth formula (k,L_∞ and/or W_∞, t_0) could be affected if selective fishing induced changes in the composition of the community and changed the amount of food available to a competitor or predator.

In the latter context, attention should be drawn to the work of Pauly (1978a, 1979), who argues very cogently that growth rates in aquatic animals are primarily a function of relative gill-surface area and of temperature, and that it is the availability of oxygen to the tissues which imposes the primary limitation on the growth of aquatic animals. An important corollary of Pauly's theory is that food is seldom a limiting factor in the natural aquatic environment. However, this does not mean that food might not become limiting in an altered community or environment, or that growth rates might not improve under reduced population densities as a result of reduced intra- or interspecific aggression and increased feeding on available foods. Nevertheless, if true, this contention means that numerous cherished ecological concepts will have to be discarded.

Natural mortality rates (M) are affected by changes in the abundance of major predators. Munro (1974a, 1974b) found some evidence of reduced natural mortality rates in exploited communities and found very high mortality rates of most species in unexploited communities. Indeed, the total mortality rates in some species appeared to be *lower* in the exploited areas than in unexploited areas (Fig. 2). Munro (1974a, 1974b) therefore calculated mortality rates in exploited areas to be $M = M_X + g P$, in which M_X is mortality from causes other than predation, P is the relative biomass of predators, and g is the amount of mortality generated in the prey population by one unit of biomass of predators. Pauly (1978b) has argued that natural mortality is a function of K, L_∞, or W_∞ and temperature for a large variety of fishes. However, this would imply that mortality is independent of the abundance of predators, and it is not clear how the two above-mentioned cases can be reconciled.

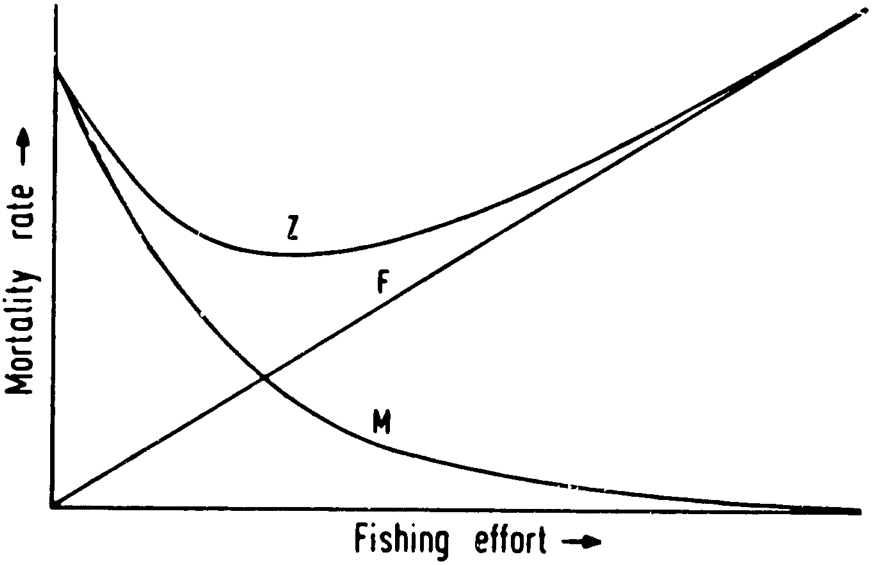


Figure 2. Theoretical interrelationships between natural mortality rate (M), fishing mortality rates (F), and total mortality rate (Z) which will exist if natural mortality rates in an exploited community decline as a result of concurrent exploitation of predatory species. (From Munro and Thompson, 1973.)

Recruitment is the parameter in which the causes of changes are most difficult to identify. In the absence of good biological information, it is also difficult to ascertain whether changes in the composition of catches are a result of enhanced recruitment or of simple increases in biomass as a result of changes in the longevity of prey species. For example, in both the Georges Bank area and the Gulf of Thailand the relative abundance of squids has increased with increased fishing effort (FAO, 1978; Pope, 1979). Has this increase been brought about because of decreased predation upon prerecruit squid or has recruitment remained constant and the biomass increased as a result of improved longevity (decreased predation upon adults) and/or reduced competition for food?

Additionally, it is important to note that the ecological effects of exploitation upon a community are determined by the method(s) of exploitation and the selectivity of the method(s). For example, in the Jamaican fishery it has been argued (Munro, 1974a) that the exploited reef fish community contains a complete spectrum of species, ranging from predators such as sharks, mainly piscivorous species such as groupers, snappers, and jacks, invertebrate feeders such as grunts, squirrel fish, and trigger fish, to herbivorous species such as surgeon fish and parrot fish. Most species are resident on the reef from a very small size and are liable to predation by larger fishes throughout their lives, but the likelihood of death by predation decreases with increasing size. Predatory species are themselves liable to predation throughout their lives, the only likely exceptions being the largest sharks. The position of a fish in the trophic structure is therefore largely determined by its size. The same argument could be applied to almost any other tropical aquatic community. Most species contribute to the biomass of predators in accordance with their numbers, average size, and proclivity to piscivory. All species form part of the pool of prey in accordance with their numbers and average size.

If the foregoing arguments are accepted, it follows that the effects of exploitation must depend upon the selectivity of the fishing techniques. For example, Antillean fish traps are the predominant gear in the Jamaican fishery, followed by handlines. Nets of various types are relatively unimportant. Both the traps and the handlines tend to select the piscivorous species, such species being most prone to taking a baited hook or entering a trap to feed upon previously captured prey species. The groupers, for example, thus suffer a relatively greater catchability (q) in the overall fishery than do, say, the surgeon fishes. The biomasses of both groupers and surgeon fishes will therefore decline in response to increases in fishing effort, but the numbers of surgeon fishes will not decline as rapidly as those of the groupers. The predators will be of smaller average size, and the survival of the largest members of the prey population may be differentially improved. If the size at recruitment to the fishery (l_r) is less than the size at first maturity (l_m), significant effects upon recruitment may result. This pattern of exploitation may eventually result in the elimination of the predatory species as significant components of the catches.

In contrast, a fishery which is selective for the smaller members of the community will have very different effects. Examples might be the Gulf of Thailand trawl fishery (Pauly, personal communication) or the subsistence fisheries in some areas on the south coast of Papau New Guinea. In the Gulf of Thailand trawl fishery, the small-meshed trawls may be avoided to some degree by the larger, swifter, predatory species. In certain Papuan fisheries, small-meshed (6.35 cm) monofilament floating gill nets are the most favored gear, and are fished day or night by setting the nets over seagrass beds or close to reefs and driving fish into the nets. The nets are highly selective for the smaller invertebrate-consuming members of the reef community, such as mullids, nemipterids, and small lethrinids, and for small neritic pelagic species. The larger pelagic species (Spanish mackerel, tuna) and benthic predators (snappers, groupers, jacks) are not often captured. Under the circumstances outlined above, the small-sized species are subjected to their normal, high, natural mortality rate plus fishing mortality, and the stock biomass declines rapidly. The predators suffer reduced food supplies and reduced growth rates and might even enjoy enhanced recruitment as a result of decreased predation on their early life stages. Selective exploitation of this sort can result in a seriously reduced harvest.

For example, Marten (1979) has shown that there is an inverse relationship between the abundance of *Tilapia* spp. and of *Bagrus domac* in various parts of Lake Victoria. Munro (1967) showed a similar relationship between the annual abundances of *Tilapia* and *Sarotherodon* spp. and the abundance of predatory *Hydrocyonus vittatus* (tiger fish) in each preceding year in an African reservoir fishery. Order-of-magnitude differences result in each case.

Saila and Parrish (1972) have used graph theory to demonstrate that high-level predators contribute more to community stability than do low-level predators. This is because high-level predators will "elect" (Ivlev, 1961) to consume the most abundant prey, and thus tend to flatten out chance variability of populations. Selective exploitation of high-level predators (e.g., the Jamaican fishery) will therefore lead to high yields but greater instability. Selective fishing for prey species in the Gulf of Thailand may well account for the stability of the composition of the stocks (e.g., FAO, 1978, Fig. 5), but this may be achieved at the cost of lower total production.

There is no method whereby the factors discussed in the preceding pages can all be incorporated into present analytic models. While the analytic models remain useful in achieving an understanding of single-species fisheries, they do not at the present time provide accurate assessments for multispecies fisheries in temperate regions, let alone those of the tropics.

Data Acquisition

The most basic deficiency of the Schaefer-type production models lies in the very sparse statistical data upon which any conclusions must be based. Detailed annual catch and effort statistics are probably prohibitively expensive, and thus unwarranted for most tropical small-scale fisheries. However, well-designed sample surveys administered periodically by trained teams might do much to remedy the situation and provide a data base upon which fishing intensity surplus yield curves (Munro, 1974b) might be based.

Pope (1979) has advocated the use of research vessels to provide standardized catch per unit effort data, and there appears to be every reason to encourage fisheries agencies to undertake routine test fishing in order to accumulate such basic information. Standardized fishing programs conducted in conjunction with periodic sample surveys of tropical small-scale fisheries could provide a wealth of information. However, a major problem in some small-scale fisheries may be the stability of the fishing effort. In such cases, recourse to the method of Munro and Thompson (1973) in seeking ecologically similar areas with differing fishing intensities may be the only solution.

In the case of analytic models, there are a number of opportunities for parameter estimation which have not yet been fully utilized and which might assist in some measure in compensating for the dearth of estimates available for the species comprising the tropical multispecies stocks. Possibly the most significant of these is the Beverton and Holt (1956) formulation

$$Z = K\,(L_\infty - \bar{l})/\bar{l} - l_c \text{ or } \frac{Z}{K} = (L_\infty - \bar{l}(/(\bar{l} - \bar{l}_c)$$

in which Z is the coefficient of total mortality, K is the coefficient of growth, L_∞ is the asymptotic length, $\bar{l}$ is the mean length of all fishes which are fully recruited to the fishery, and l_c is the length at which full recruitment is attained. The parameters $\bar{l}$ and l_c are easily derived from any reasonably based representation of the annual average length composition of a stock. The growth parameters, K and L_∞, can be derived from separate growth studies, or if such estimates are not available, reasonable estimates of L_∞ can be deduced from records of the largest fishes captured (Taylor, 1958). Thus, given a reasonable set of length-frequency data, total mortality, Z, can be estimated. If no estimate of K is available, at least an estimate of Z/K can be obtained. If different levels of fishing effort, f, have prevailed in two or more years or in two or more areas, estimates of M/K can be derived.

In unexploited areas, fishing mortality is zero and Z/K = M/K. This procedure was followed in assessing the mortality rates in Jamaican reef fisheries (Munro, ed., 1973-78). This immensely useful formulation warranted only a brief note in the early edition of Ricker (1958) and is omitted entirely from the latest version (Ricker, 1975). It has been utilized by only a handful of investigators (Kipling and Frost, 1970; Le Guen, 1971; Munro and Thompson, 1973). Ssentongo and Larking (1973) have more recently derived a very similar formulation.

Pope (1979) examined the possibility of deriving mortality estimates from the length distributions of various species taken by research trawlers in the Gulf of Thailand and concluded that it was not possible. However, it is not clear whether the length distributors shown were representative of the annual average length distributions or why, in some cases, it was not possible to estimate mortality rates.

A second approach, which appears not to have been utilized by anyone other than myself, is to derive estimates of mortality rates from the mean weight of individuals in the catch. The formulation (Gulland, 1969)

$$\overline{W}_c = W_\infty \sum_0^3 \frac{U_n Z e^{-nK(t_c - t_o)}}{Z + nK}$$

shows that the mean weight ($\overline{W}_c$) is a function of the asymptotic weight (W_∞), the growth rate (K), the total mortality rate (Z), and the relative age at entry to the exploited phase ($t_c - t_o$).

If the growth parameters (K, W_∞, and t_o) and the age of first capture (t_c) are known, then curves or tabulations showing the relationship between $\overline{W}_c$ and Z can be prepared and estimates of Z can be derived from the observed mean weights of individuals in the catch. If data on mean weights is systematically collected over a full year, this must surely be a most accurate statistic. Nevertheless, it never appears to be utilized for any fishery assessment. Why not?

Finally, Pauly (1978a, 1978b, 1979) has used multiple regression techniques to derive a set of empirical formulas which interrelate mortality rate to growth parameters (K, L_∞, or W_∞) and water temperatures in one instance, and in another relate growth rates to relative gill size and water temperatures. The theories put forward are bound to generate much discussion, but it is clear that certain fundamental generalizations underlie many of the parameters which fishery biologists seek and that these generalizations could easily be utilized at least to set bounds for unknown parameters and permit trial assessments to be made for numerous stocks.

Alternatively, Marten (1978) has proposed a yield per recruit model which circumvents the problems of age and growth rate estimation by assuming linear growth of the exploited phase and a growth span of unity. Such radical departures from conventional techniques must be examined to ascertain their general utility and to determine whether they can be adapted for multispecies stock assessment.

Research Requirements

The greatest obstacle to small-scale fishery assessments is the remarkable lack of reliable estimates of fishery and biological parameters with which the population modelers can test their theories. The reasons for this state of affairs are obvious. Few of the third world countries have or can afford to purchase the expertise which is necessary to investigate the immense complexities of their small-scale fisheries, and until recently international organizations and granting agencies have preferred to direct their attention and funds elsewhere. It is perhaps opportune to note here that, at the present time, about 95% of all fisheries funding in the tropical Western Pacific is devoted to tuna. The impact of the tuna fisheries upon the indigenous people of the region can be described as trifling, at best. More money and more effort are essential if we are to understand the problems of small-scale fisheries.

One of the stated objectives of this workshop is to "delineate specific topics for collaborative research ... which would have the best chance of providing the less developed countries with stock assessment methodologies suitable to their needs." A long-term commitment to a study of harvesting strategies and assessment techniques directed at the most complex and extensive of all fish communities, those of the coral reefs of the Indo-Pacific region, would lead to the greatest insight into the complexities of multispecies stock assessment techniques.

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Economic, Social, and Cultural Aspects of Stock Assessment for Tropical Small-Scale Fisheries

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Introduction

In his paper, Dr. Roedel presented a set of issues related to stock assessment for consideration during this workshop. The aim of this paper is to help define, from a social science perspective, the nature of those issues.

First and foremost, under Title XII the ultimate test of any research and development program for tropical small-scale fisheries is the extent to which it improves the well-being of small-scale fishermen and increases fish consumption among the malnourished segments of the population. It follows, therefore, that stock assessment involves a number of economic, social, and cultural considerations as well as the conventional biological and ecological ones.

This paper is divided into two major sections. The first presents an economist's perspective on the issues, while the second concentrates on social and cultural aspects of stock assessment issues.

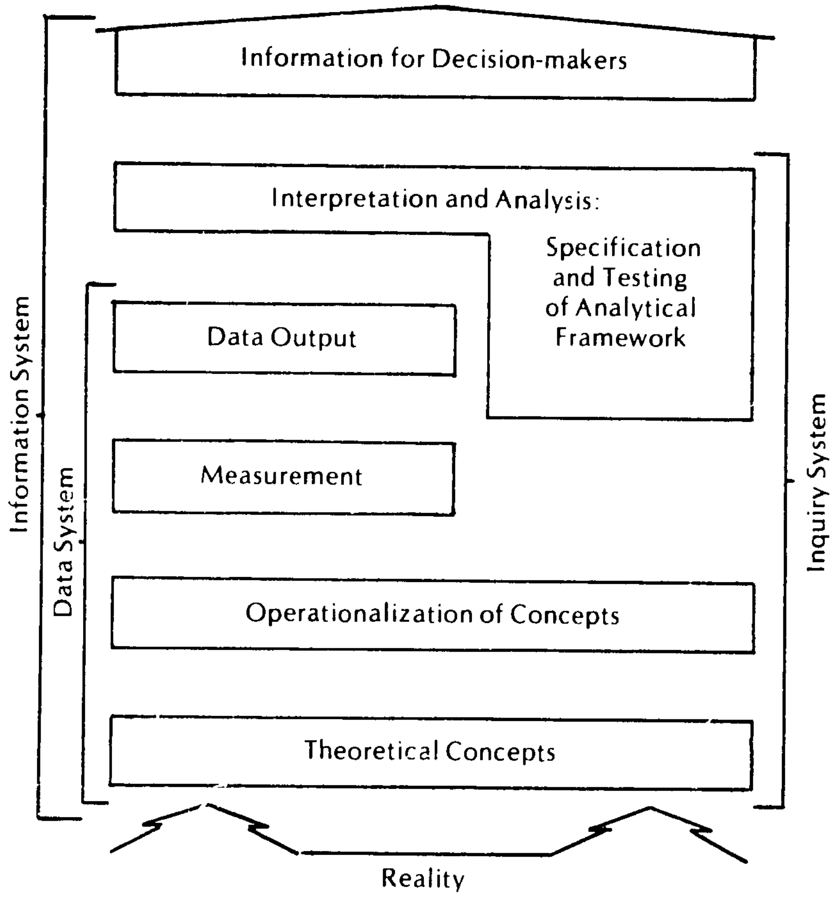
Economic Aspects

The Information Systems Paradigm

The information systems paradigm developed by Bonnen (1975) addresses an analogous set of issues in agricultural economics. According to this paradigm, the problem of small-scale fisheries development can be viewed as a fundamental problem of information processing. Before it can be solved, there must be a solution to the associated problem of an implicit information system. That is, solving the problem of fisheries development requires making decisions, and making decisions requires information. Providing information depends upon devising a system in which data are collected, analyzed, and acted upon by decision-makers.

Every decision requires an understanding of some part of reality (see Fig. 1). Since reality is too complex for a complete understanding, a set of *theoretical concepts* is typically developed to explain reality in a manner that is appropriate for the problem at hand and capable of being grasped by the human mind. Since concepts cannot be measured directly, they are *operationalized* by devising a set of variables (empirically observable phenomena) which correspond to that part of reality under study. The identified phenomena are then observed and the variables *measured*. The resulting set of measured variables represents the *data output*. At this point, there is a "data system," since data are not information (see Fig. 1).

Figure 1



To generate information, the data are subjected to *analysis and interpretation* for a particular decision-making context. That is, data must be given form and meaning in order to become information useful for decision-making.

Establishment of such an information system, of course, must be preceded by a process of *analytical inquiry*. That is, a body of theory is operationalized, matched with data, and the resulting analytical framework is tested, refined,and retested. Through repetition of both the analytical and the empirical processes, reliability is enhanced. In fact, three types of reliability can be identified: measurement reliability, operational reliability, and conceptual reliability.

For present purposes, there should be an assessment of the measurement, operational, and conceptual reliability of the approach used to generate information on stock assessment. An inadequacy at any one stage can cause a breakdown in the information process. The following questions should be asked:

1. Where are the gaps; where is the information system breaking down?

2. Is the theory inadequate?
3. Are operationalized concepts lacking?
4. Is measurement poor?
5. Has the analytical framework been suitably tested and refined?
6. What is the nature of the information to be provided decision-makers?

The information system can also be viewed as a producing system, one that supplies information to decision-makers. The worth of any information system, of course, is properly judged by its contribution to the decision-making process that it is supposed to serve.

At the abstract level, the nature of the data desired by decision-makers is derived from 1) the nature of the problem of fisheries development which they face, and 2) the nature of the decision-making process actually in effect. If the exact nature of the problems of fisheries development and of the decision-making process were known, the needed set of information could be "derived."

Decision-making and Fisheries Development

Rationality as used in the social sciences is the process of selecting the best possible alternative, given relevant preferences and constraints. A rational decision-making process for fisheries development would proceed as follows:

First, an inventory is taken to identify all salient facts and constraints that are expected to govern the selection of means to achieve an identified set of objectives.

Second, the development potential of the fishery is assessed and a variety of actions which can achieve the development objectives is identified.

Third, a set of possible projects is designed and evaluated for their expected social benefits (in terms of the objectives) and costs.

Fourth, the project or set of projects with highest net benefits is selected for implementation.

Fifth, the project is monitored and evaluated during implementation for the actual net social benefits realized from the project(s).

To the extent that this process is followed, one could derive a set of "information demands" at each stage. Quite clearly, it appears that information on stock assessment would be involved at almost every stage.

To some extent, this process is followed in practice. However, those who have studied decision-making behavior in other contexts have found that rational decision-making is rarely used (Simon, 1979; Kinreuther, 1974; and Day, 1971). In the real world of incomplete and imperfect information, of severe time constraints and conflicting objectives and interests, it becomes impossible to behave in a fully rational manner. Thus, the decision-making process is only partially rational. In order to derive the information demands needed, the actual decision-making process used in fisheries development must be learned.

Here is a set of possible decision-making modes that may apply to fisheries development, each of which could imply different information characteristics and most certainly would imply a different analytical framework:

1. *Safety principals*
   a. Decision-makers seek to minimize the probability that some set of variables (e.g., catch and employment) will not fall below some given

"disaster" level over time.

b. Decision-makers seek an "optimum" yield, but it is subject to the constraint that the probability of disaster (e.g., overexploitation) is below a certain level (e.g., 15%).

2. *Maximin*

Decision-makers select the best of all possible worst cases. More precisely, they maximize minimum benefits that can be obtained with some given level of probability.

3. *Satisficing*

Decision-makers set an arbitrary level to be attained (e.g., of catch or income).

4. *Cautious Suboptimizing*

Decision-makers move in the right direction, but no further than some distance perceived as "safe."

These are some of the partially rational decision-making modes. The point is that each mode demands different informational input, the fully rational mode being the most demanding. Until the actual decision processes are known, social scientists cannot supply information that effectively serves fisheries development.

Some Characteristics of a Stock Assessment Information System for Fisheries Development

What should the nature of a stock assessment information system for fisheries development and management be? What would an appropriate analytical framework for it be? What part or parts of reality need explanation?

The reality of the fishery and related sectors is vast and complex. The fishery is composed of several components and is interconnected with other, nonfishery sectors (see Appendix). Constructing a metamodel of this larger system, if not infeasible, is surely impractical. It seems more reasonable, instead, to focus on the closely related resource and capture subsectors of the small-scale fishery—to think in terms of an analytical framework that provides decision-makers with information on these subsectors alone.

The part of reality focused on involves both the fishery resource and its habitat, as well as man's exploitation of the resource. Like the fishery resource, man's behavior is conditioned by his environment, an environment that consists of social, cultural, economic, and related elements. It seems clear, therefore, that in order to provide useful, reliable information to decision-makers, a stock assessment information system should take into account all of these elements of reality as well as the nature of the decision-making process used.

The implications of such a biosocioeconomic approach may be quite significant for the study of stock assessment issues. Among other things, this implies 1) an integrated, interdisciplinary conceptual framework; 2) a joint effort to systematize the collection and analysis of data on the behavior of the fishery resource and the human sectors; and 3) a study and evaluation of the decision-making environment that exists. These seem to be some of the conditions necessary for an effective information system.

Social and Cultural Aspects

Beyond the economic and information system aspects, however, there are other social and cultural variables which impinge upon and can affect the relative effectiveness of stock assessment models. For example, many techniques rely on catch and effort statistics or return of tagged fish. Both of these types of data are practically impossible to obtain without the cooperation of the fishermen. It is important to note that the need for this basic type of catch data was stressed in a report by Resources Development Associates (Craib and Ketler, 1978). Further, even information concerning the types of fish caught and utilized is so minimal in some regions that research preliminary to actual stock assessment could be rather costly. The biologist should use the rather considerable knowledge of local fishermen to provide guidelines to facilitate acquisition of data concerning identification of fish stocks, the number of species involved, and aspects of their distribution and numbers.

Obtaining Data from Fishermen

The importance of using the proper approach for obtaining data from fishermen can be illustrated by an experience of one of the authors. In a recent fisheries research project, the fisherman himself was a crucial link in obtaining data about the small-scale fishery. The fisherman is often the only person who can supply certain information, since much of his work is conducted away from shore and not easily observed. This separation from land-based society has given him a worldwide reputation for secrecy and deception. His cooperation in providing data is essential. It was therefore necessary in this project to determine the attitudes, beliefs, and values that fishermen held concerning some of the questions that they were being asked. Attention was focused on an economic questionnaire which included catch and effort questions, since data concerning income is often the most difficult to elicit.

Experience indicated that the most effective situation for obtaining attitudes of fishermen was in small, natural, interacting groups, when fishermen gather together to discuss football games, women, etc. In such small groups, fishermen feel they have the support of companions and are more likely to speak their minds. When spoken to individually, they may acquiesce to what they think the interviewer wants to hear.

The anthropologist and his research assistant were rather familiar faces among the fishermen. They became part of such a group and gradually turned the conversation around to the economic and biological research which was being conducted. They asked the fishermen what they thought about the catch and effort questions, and invariably the fishermen said they didn't like them. They were afraid that the information was going to be used 1) for taxes, 2) to close the gulf or areas of the gulf to fishing, and 3) to prohibit the use of nets in the gulf. When asked if anyone had told them why the data were being gathered, they said no. When the potential benefits of the research program were explained to them, the attitude of the entire group changed. The fishermen said that since they had been afraid the data were to be used against them, they had not always told the truth when responding to questions. The fact that they admitted lying indicated that the interviewing technique along with a full explanation of the purpose of the data gathering was an important element in gaining their cooperation. The fishermen themselves even went on to suggest that there should be some way of informing all the fishermen of the potential benefits of the research. They said they had simply been questioned with little or no explanation, and that they were reluctant to cooperate in research they didn't understand.

The inspectors who had been interviewing the fishermen were also interviewed, and it was discovered that they had a limited understanding of the reasons for gathering the data. After being read a list of potential uses of the data, they said they wished that they had known them beforehand. They went on to say that when fishermen would press them for an explanation, they would fabricate some sort of reason, not knowing if it were true or false.

Neither fishermen nor inspectors had problems in understanding various goals of the research. This indicates that full explanations of programs should be provided to fishermen and all inspectors.

This example indicates that proper communication of purpose can play an important role in obtaining data from small-scale fishermen. It also shows that several aspects of the communication process have an effect on the evaluation and acceptance of a data-gathering effort.

The communication event entails several important components (Hymes, 1964a): 1) the participants—senders, receivers, interpreters, spokesmen, etc.; 2) the channels—the spoken word, newspapers, pamphlets, wall posters, etc.; 3) the codes—the language (national, local dialects, etc.), or a combination of language and illustrations; 4) the setting—formal meeting, on the beach, etc.; 5) the message form—salesman's pitch, sermon, informal chat, etc.; and, finally, 6) the topic—here, information concerning the need for data collection from small-scale fishermen. It is important to note that the above components of a communication event form an interrelated whole, a system. For example, the relative social status and familiarity of the sender and receiver dictate message form and code in many societies. Familiar message forms or codes may be taken as insulting when used by strangers. The characteristics of the receiver may also dictate the channel and code. It is obvious that written messages or the national language cannot be used with people who have only a rudimentary grasp of reading or the national tongue. One must become sensitive to the structure of communication events within the local groups of fishermen, either through extensive exposure or through the use of a good local-level assistant.

Turning to the participants in the communication event, let us focus first on the sender of the message. Rogers and Shoemaker's (1971) extensive review of the literature concerning communication and the transfer of innovations suggests that individuals most likely to communicate effectively with small-scale fishermen will be those who have empathy with the fishermen and can identify with them and who are credible in their eyes. This suggests that reasons for data gathering should be transferred through local opinion leaders.

Barnett (1953), however, cautions that prestige is not a good means of identifying opinion leaders who will be effective within specific domains, because the prestige rating of a person may vary from context to context. For example, an opinion leader with regard to net fishing may not be an opinion leader for trap fishing.

Rogers and Shoemaker (1971) present a number of attributes associated with opinion leaders Nevertheless, even within a specific domain it is difficult to identify an opinion leader with only the use of identifying characteristics such as social status, degree of social participation, mass media exposure, etc It is often necessary to rely on sociometric techniques (Menzel and Katz, 1956; Lionberger and Copus, 1972) If for some reason (e g , the presence of opinion leaders with a vested interest in the status quo) it is not advisable to work through opinion leaders, the change agent should try to inform as many concerned individuals as possible

Turning to communication channels, those most likely to result in effective, credible message delivery to the small-scale fishermen should be used. Knowledgeable individuals within the society can be consulted (e g , marketing specialists), or opinion surveys of attitudes, beliefs, and values concerning the various channels can be conducted Sometimes this must be done on a trial and error basis Nevertheless, even when an effective medium has been isolated, its success often depends on other factors For example, Sinha and Mehta (1972) note that the success of instructional television in India often depends on the farmer's motivation to change Rogers and Shoemaker (1971) cite numerous studies which indicate that although the mass media (e g , radio, newspapers, television) are important for imparting information, interpersonal channels are important for persuasion They indicate that the mass-media channels are more effective among peasants in lesser developed countries when used in combination with interpersonal channels in organized small groups of individuals who regularly meet to attend and discuss mass-media programs

Although it is obvious, it must be noted that the degree of functional literacy must be determined before written mass-media channels can be considered a viable alternative Additionally, and less obviously, if pictures form an important part of the communicative event, target group familiarity with the interpretation of two-dimensional pictorial material should be taken into consideration (Hudson, 1967)

Use of proper code is also an important consideration, and it is not as simple as merely selecting a language with which the target group is familiar In bilingual contexts, one language may have more prestige than another (Lambert et al., 1960, Rubin, 1968) or usage may be situationally dependent. For example, Rubin (1968) reports that use of Guarani or Spanish in Paraguay depends on the location, degree of formality, intimacy, seriousness of the situation, and sex of participants Even when only one language is spoken, there may be different codes which signify degree of respect, social class, and other variables Brown and Ford (1961) clarified the extent to which degree of intimacy and status affect direct address usage in American English Further, Geertz (1960) indicates that Javanese has three levels of speech, including honorifics which are related to the participants' age, sex, kinship relation, occupation, wealth, education, religious commitment, family background, social setting, the content of the conversation, the background of social interaction between the speakers, and the presence of a third person The foregoing are not isolated examples Such variance in language usage occurs in many societies around the world (Burling, 1970; Hymes, 1964b), and failure to adhere to these usually unwritten rules may lessen the credibility of a message

It should be noted that strict adherence to the foregoing precautions will not necessarily guarantee adequate communication. As one sensitive change agent noted, "We spoke the same language, but we didn't communicate" (Weller, 1965). Recent psycholinguistic research (Pollnac, 1975a, 1975b; Szalay et al., 1972) has shown a significant degree of variability in semantic structure which could impede effective communication. Wallman (1965) indicates that in Basutoland the failure of a number of development schemes can be attributed to semantic problems in the communication of measurement. Catch and effort statistics rely heavily on communication of measurement (amounts caught, time spent, etc.), hence, efforts must be made to understand the meaning of measurement and the different systems of quantification used by the local fishermen. Pollnac (1974) demonstrates a fair amount of semantic variability with respect to food plants among the Baganda, and argues that agricultural change agents must become sensitive to variability in the semantics of agriculture if they are to communicate effectively with various sectors of the population. Names for fish sometimes vary from one area of the coast to another. Additionally, some fish have different names at various stages of the growth cycle in some regions (Pollnac, 1979); therefore, attempts to question a fisherman concerning species X may result in responses of different types in different regions. Data gathered without an understanding of this linguistic phenomenon would surely result in unusual size distributions for the fishery biologist to analyze.

The setting of the communication, like the channel, depends upon determining the most effective technique among the small-scale fishermen. As was noted above, however, the setting may affect the code used as well as the message form. In our society, a sermon is not the proper message form to be used between friends at a party. Situational constraints such as these operate in other societies in contexts which the investigator may not be aware of without previous research. For example, in much of the world schooling is associated with children. If communication of reasons for data collection is held in a schoolroom setting with a student-teacher message form, adults in such societies may be reluctant to attend (Foster, 1973).

Examination of aspects of obtaining information from fishermen has identified three areas where prior planning could be of great aid in increasing the reliability of data collected directly from small-scale fishermen. First, communications must be developed to obtain the cooperation of the fishermen. Second, since systems of quantification may vary greatly from society to society (Reed and Lave, 1979; Zaslavsky, 1973; Guy and Cole, 1967), local systems must be determined and understood to insure proper question form and interpretation of responses concerning quantities. Finally, systems for naming fish vary not only between languages but within languages. Sometimes a given name will refer to a specific species only during a certain stage of the growth cycle or will be applicable only along certain regions of the coast; hence, great care must be taken to determine the exact referent for all fish names used in data collection schemes.

Data That Can Be Provided by Fishermen

Most local fishermen have been interacting with the sea for a long time. In their attempts to wrest a living from it, they have made inferences from their observations, and constructed taxonomies and theories concerning the marine environment and its flora and fauna. Although some of the conclusions they have drawn regarding explanations for observed phenomena may not be adequate, their observations of correlations and variability within the sea are usually accurate, since their livelihood depends on the ability to locate fish of specific types. Anthropologists have been investigating this type of "folk science" for a number of years (Tyler, 1969), and their findings indicate that taxonomies and beliefs concerning flora and fauna in the immediate environment of primitive and peasant farmers and fishermen are exceptionally complex and detailed. This "folk science," or ethnoichthyology, can save the fishery biologist a great deal of preliminary work in his attempts to census the fish populations in various parts of the world.

All fishermen have names for the types of organisms they capture. What is surprising is the number of marine organisms which are recognized and named by local fishermen. For example, Anderson (1967) reports over 400 marine organisms named and recognized by Hong Kong boat people. Cordell (1972) lists over 140 fish named by estuarine canoe fishermen in northeastern Brazil; Morrill (1967) has found 51 named varieties among small-scale fishermen of the Virgin Islands; and Pollnac (1979) reports 122 different categories of fish named by the small-scale fishermen of the Gulf of Nicoya, Costa Rica. All of these taxonomies are relatively complex and hierarchically organized. The elicitation of adequate taxonomies is not a simple matter (Tyler, 1969), but, once obtained, they can be used in further research to: 1) determine the number of types harvested and utilized; 2) obtain specimens for scientific investigation; and 3) collect further data concerning distribution and behavior.

Since a fisherman's livelihood depends on his ability to find fish, fishing communities have observed fish behavior and developed locally appropriate systems for locating fish according to physical features in the marine environment, the moon position and phase, the tides, the time of day and year, and various meteorological phenomena. Once again, anthropologists have provided illustrations of these folk scientific systems (Cordell, 1972, 1974; Forman, 1967). This type of information can be of use to fishery biologists in the structuring of sampling techniques for maximum efficiency. For example, information regarding the location, behavior, and temporal variability of stocks will permit the use of sampling techniques (e.g., stratified cluster sampling), which will save both time and effort and will result in more reliable data. Additionally, the scientist's knowledge at least of what the fishermen know and believe will enhance his credibility in their eyes and probably result in their being more likely to cooperate in the future.

Finally, in many societies longitudinal data on fish stocks are not available. In these communities, oral histories concerning catch and effort should be obtained from local fishermen. A sampling of such histories can be obtained and compared to assess their reliability (Young, 1966). The general trends which can be derived from such data, although not as detailed as one would like, are better than no historical data at all and, if care is taken, can be quite reliable.

The fishermen possess a system of knowledge concerning local species of fish that can be of considerable use to fishery biologists in identifying stocks, framing questions concerning the stocks, deriving general historical trends of catch and effort, and designing sampling frames for stock assessment. The intelligent use of this information can save a great deal of time and effort on the part of the fishery biologist and, in the process, result in enhancing his credibility in the eyes of the local fishermen.

Conclusions

The interrelationships between stock assessment and selected aspects of economic and anthropological information, and data collection and analysis techniques, have been examined. Several of the speakers who proceeded us noted the importance of these interrelationships, and we hope that our observations will stimulate further discussion and research on these matters.

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Appendix

The Fishery and Related Sectors

In most LDCs, the fishery typically consists of two sectors: 1) a small-scale fishery sector that uses low-level technology generating low incomes and producing fish for local human consumption; and 2) an industrial fishery that is capital-intensive, producing higher incomes for a relatively small number of people, and products for export or industrial use. The small-scale fishery can be separated into four levels, or subsectors: 1) the resource and its habitat; 2) capture or harvesting; 3) processing, distribution, and marketing; and 4) consumption. These levels are convenient divisions for a variety of analyses.

The industrial fishery sector is related to development of the small-scale fishery in a number of ways. The industrial fishery may dominate and negatively affect the small-scale fishery. Conflicts can arise over exploitation of the same or interdependent fish stocks (as in the South China Sea), or where the by-catch of the industrial fleet dominates the local fresh fish market (as in Central America).

The agricultural sector influences small-scale fisheries development as well. Many, if not most, fishing families also raise crops and livestock. In some areas, fishing is viewed as the employment of last resort, where people fish only when farming is not feasible (e.g., East Africa). The agricultural sector may dominate the regional distribution and marketing network, and thereby define the possibilities for expanding the distribution and marketing of fish.

Similarly, the existing infrastructure defines the possibilities for expanding the small-scale fishery. If port facilities and harbors have not been developed to support the general economy, it is unlikely that small-scale fishery needs will justify their construction. The same is true for roads and other major components of the physical infrastructure.

Institutions and laws can also be critical to the realization of the potential for fisheries development. Since implementation of development projects typically rests with LDC institutions, the structure, organization, and legal power of fisheries administration and related agencies determine the efficacy of any development program. Other institutional and legal aspects which condition the process of fisheries development include interagency conflict and coordination, credit, and subsidy and training programs (see Doucet et al., 1974; Crutchfield et al., 1974; Woodland, 1976).

To be effective, development planning must account for all aspects of the fishery and related sectors. If the problem of fisheries development is not addressed in this holistic manner, links necessary for successful development can be overlooked. Such oversights account for a large proportion of the failures in fisheries development efforts.

For stock assessment purposes, however, one may wish to focus exclusively on the resource and capture sectors of the small-scale fishery.

Some Environmental Considerations for Stock Assessment of Small-Scale Fisheries

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Introduction

Definition

What are small-scale fisheries? It seems that a clear and universally accepted definition is not yet at hand. However, Sutinen (1976) has defined a small-scale fishery system as consisting of two segments: 1) the resource and its environment, and 2) man and his environment. He further indicated that the resource consists of a very large number of species, usually found in shallow tropical or subtropical waters (estuaries, reefs, shelf areas, lagoons, etc.). Man's relationship to the resource consists of harvesting, processing and marketing, and/or consuming it. Harvesting usually takes place from small boats (often non-motorized) which have been built from indigenous materials and designs. The fishing gear is often simple, consisting of fixed nets or traps, hook and line, and simple towed gear. The processing and marketing is variable, with most fishermen selling their catch on the beach or in port for cash. The above concept of a small-scale fisheries system is in keeping with the FAO (COFI/74/9) objective and definitions, which suggest that small-scale fisheries in developing areas must be treated as part of the overall rural development. However, development in the sense of increased production of fish could well not be a primary objective of this development. The Committee for Inland Fisheries of Africa (CIFA) has also stressed the concept of an integrated FAO approach to the development of artisanal fisheries, which explicitly considers the social and economic aspects of the fishing community. Rothschild (1973) has outlined certain broad questions of strategy in fishery management and development into which the above concepts seem to fit rather well.

If we accept, for the present, the above-mentioned broad concepts and objectives of small-scale fisheries, then it seems apparent that the traditional methodologies of fisheries stock assessment are only a part of this system, and, furthermore, some of the traditional objectives and methods of stock assessment may be open to question as applied to small-scale fisheries.

Conventional stock assessment is concerned with problems of estimating the important parameters (growth, mortality, recruitment) of fish populations and using these estimates to determine the total catch, and how the catch and catch per unit of effort vary with changes in the pattern of fishing. Before population theory can be applied to a particular fishery, it is necessary to determine to what extent the population and the fishery based on it can be treated as a unit system. The usual models of stock assessment work (either the dynamic pool model or the stock production model) are single-species models based on the concept of a unit stock. Pauly (1977) has recently reviewed tropical multispecies stocks and managerial models with emphasis on demersal fisheries. In material which follows, it will be demonstrated that tropical small-scale fisheries consist of a very large number of species, that many tropical fisheries (especially reef and lagoon fisheries) exploit relatively local stocks in relatively fragile environments, and that the nature of recruitment and other parameter estimates are sufficiently unique in the tropics to raise serious questions about the direct application of conventional stock assessment methodology for management purposes in tropical small-scale fisheries located in reef and coastal areas.

The definitions of Clark and Lackey (1974) are recommended as useful in forming a basis for considering small-scale fisheries. Fisheries are defined as systems consisting of aquatic biota, the aquatic environment, and man, interacting through time and space. Fisheries management, of which stock assessment is a part, is the science of making and implementing decisions to maintain or alter the structure, dynamics, and interactions of fisheries components to achieve specific human objectives. More recently, Lackey (1979) has proposed an equation as a basic theory of fisheries, stated as

$$Q_{max} = f(X_1, X_2, \ldots, X_m \mid Y_1, Y_2, \ldots, Y_n)$$

where

Q is some measure of societal benefit,
X is a management decision variable, and
Y is a management constraint variable.

The vertical line reads "given that." The theory states that the greatest societal benefit (Q) from a fishery can be realized by manipulating a series of decision variables (X's) given a set of constraints (Y's). Controlled or partially controlled decision variables (X's) include management techniques (such as size or gear limits, environmental stabilization or improvement, etc.). Noncontrolled decision variables are random, or dependent on other factors. These include weather effects or industrial development. It is clear from the above that Q is not simply a measure of yield but may involve many additional components. The objectives of fisheries stock assessment must be clearly stated, be specific, and be quantifiable by some means to be effectively evaluated.

The complexity of small-scale fisheries as systems to be managed seems clear from the above material. How to model and quantify the activities associated with management in the context of small-scale fisheries remains to be further resolved.

Objectives

The objectives of this report are to consider some aspects of the management of small-scale fisheries as defined above, by briefly reviewing some features of the physical environment and biology of small-scale fisheries (especially as related to reefs and adjacent areas), and providing some suggestions for future studies which take environmental considerations into account. Much of the material which follows relates primarily to reef and estuarine environments, rather than to tropical continental shelf environments and their fisheries, which Pauly (1979) has recently described and which have somewhat different management requirements.

Environments of Small-Scale Fisheries

General

Most small-scale fisheries are located in tropical or subtropical regions. However, much of the available limnological and oceanographic information concerning the environments of fisheries is from temperate regions. The temperate region of the oceans corresponds to a band of westerlies where there are strong winter storms. These strong winds induce a major current, the West Wind Drift. Extensive mixing occurs, and a marine food chain which includes large fish populations is supported in this region. In contrast, there is a monsoon circulation, which is especially well developed over Southeast Asia and India, which results from warming and cooling of the Asian land mass. The effect of the monsoon climate on fisheries is not as well understood. It appears that there are some fundamental differences, in both marine and freshwater environments and their living resources, between tropical and temperate regions. These should be carefully considered in attempting to assess fish production and in developing management strategies. Some of these environmental conditions have been analyzed by Weber (1976), who demonstrated that the major spawning activity of tropical fishes in monsoon climates can be induced 1) by strong wind and heavy rainfall, and 2) by low values of water temperature and salinity. However, not all species are affected similarly. Furthermore, details concerning the physical environment of many tropical fisheries are still lacking. Some of these environments and their properties will be briefly mentioned in the context of fisheries assessments.

Diversity and the Environment

The high diversity of tropical fish communities has been of considerable ecological interest for some time. The current ecological concensus is that any community is an equilibrium community of numerous species whose coexistence is explained in the theory based on Lotka-Volterra competition and predation equations (Goel et al., 1971). Recently, Sale (1977) has questioned this and proposed a new concept of the dynamics of reef fish communities which emphasizes environmental changes and patch structure of the reefs. He makes two predictions concerning reef fish communities which are considered very important to any stock assessment or management scheme for small-scale fisheries in these areas. The first of these is that, at the level of the species, reef fish communities have an unstable structure; i.e., the species composition of the fish at a given site will not tend to recover following a disturbance (removal or addition of fish). His reasoning is that the relative abundance of the species of a guild (those species having similar environmental requirements) is largely the result of chance recruitment of young which will change from time to time. Thus, the selective removal (by fishing, for example) of one or more species of a guild may not be followed by recovery of the original species composition of that site. Sale's second prediction is that the diversity of reef fish communities is directly correlated with the rate of small-scale unpredictable disturbances to the supply of living space.

Both hypotheses lend themselves to empirical testing. The first can be tested by carefully monitoring selective fishing activity over a reef area and comparing the original species composition with that which follows the cessation of fishing activity. The second hypothesis can be tested by comparing diversity in sheltered and exposed areas, or by manipulating natural or artificial habitats.

If the stochastic nature of recruitment and replacement of species within guilds were adequately demonstrated for tropical reef fish communities, this would have profound effects upon stock assessment models and management methods. For example, data on species guilds, rather than on individual species, might be used in models which treat interacting groups. This would immediately bring parsimony into the models. Second, the concept of species diversity as an index of exploitation or perturbation effects would have to be re-examined. Third, controlling and manipulating fish communities by habitat modification would have a high probability of success in these areas.

In summary, the hypothesis put forth by Sale should be tested adequately. If shown to be correct, it would be important to recognize the stochastic nature of the tropical fisheries system (the chance interactions of predators, prey, and the environment). It would then become necessary to describe the dynamics of populations living in randomly fluctuating environments. Reed (1978) has contributed to this possible solution by developing a stochastic harvesting model based on a discrete-time Markov population model. Further work in this area is clearly required if the stochastic nature of tropical fish communities is demonstrated by future empirical studies. Also, the accepted concepts of diversity and stability would need to be revised in this event.

It should be recognized, however, that Sale's hypotheses are based on data consisting of relatively small species, and the utility of the hypothesis for harvested species of larger size remains to be tested as well.

Tropical Estuaries

Rodriquez (1975) stated that tropical climatic conditions reflected in estuarine hydrodynamics create situations that clearly differentiate tropical from temperate estuaries. Unfortunately, there is considerably less information available on tropical than on temperate estuaries. Saila (1975) has summarized some aspects of fish production and cropping in estuarine systems; his review was restricted primarily to temperate regions but had some reference to tropical lagoons.

It is apparent that tropical estuaries can be characterized by their peculiar hydrographic regime: dominated by the seasonality of river flow with a concomitant salinity regime and with uniformly high temperatures. Tropical estuarine biotic characteristics include a significant effect from organic matter derived from bordering vegetation, including mangroves, and from certain regular migratory events by some biota.

From a fisheries point of view, it should be recognized that a substantial part of the fisheries (especially crustacea) is dependent upon the migratory movements of populations between the sea and tropical estuarine waters. This estuarine dependence has been demonstrated for the white shrimp *(Penaeus setiferus)* in Texas estuaries by Weymouth et al. (1933) and by others (Baxter and Renfro, 1967; Christmas et al., 1966) for U.S. Gulf Coast areas. It is important to note that similar behavior has been described for other penaeids, such as

Peneaus schmitti in Venezuela and *Penaeus duoderum* in Dahomey, West Africa, as cited by Rodriquez (1975).

It has also been demonstrated that a substantial proportion of the estuarine waters of many large tropical rivers is located outside the mouth of the estuary. Since tropical oceanic waters are low in productivity, it is worth noting that future fisheries developments of various kinds (including small-scale fisheries) might be considered in the relatively richer estuarine areas.

In general, the fishes and important invertebrates of tropical estuaries are nearer their tolerance limits of high temperature than those in more temperate areas. This suggests that organisms in tropical estuaries may be considerably less tolerant of thermal loadings than temperate estuarine forms. In addition, it appears that physical modification of tropical estuaries may have serious consequences to fisheries which are estuarine-dependent in some life history stage, since the uniformly high temperatures and the salinity associated with river flow would be altered by such modifications.

Coral Reefs

The diversity of fish on tropical coral reefs is probably higher than that of any other marine ecosystem. The total number of species for a coral reef is variable, and the range has been estimated from about 320 species for a small island like Barbados in the West Indies to about 600 to 800 for a Caribbean continental fauna to over 2,000 species for a large island or continental barrier reef in the Pacific (Emery, 1978).

Topographic relief on coral reefs is very high. There appear to be differences in the growth of coral reefs, typified by the atoll and continental barrier forms, but the elements of construction are essentially similar. Reef topography may be an important determinant of fish communities and needs further study.

Because of the large variety of habitats, the problem of describing the nature of reef fish populations by depth regions is not straightforward. However, Emery (1978) has attempted this, and the following is adapted from his analysis:

Zone 1. Shallow, Wave-Torn Area

Presence of two fish types: those which utilize obstructions to water movement and take cover in areas of reduced flow (typical families include blennids, clinids, gobies, scorpaenids, gobiesocids), and those which are highly active and utilize waves and lateral flow to move over the reef top (these free swimmers include kyphosids, acanthurids, and some pomacentrids; also, some carangids and sharks forage in the bubble zones).

Zone 2. Depths from 2 to 30 Meters

a. There is a large variety of fish taxa, mostly large species groups, schooling or aggregated.
b. The richness of fauna reaches a peak at 5 to 20 meters and is significantly reduced at depths of much more than 30 meters.
c. Diversity is lower by night than by day.
d. Representative families include a anthaids, labrids, chaetodontids, pomacentrids, and scarids.

In reef areas, the free-ranging individuals are often predatory and of large size.

The significant features of the life history of coral reef fishes have been summarized by Sale (1978). They suggest that reef fishes are limited by suitable living space; are sedentary as adults; produce frequent clutches of pelagic larvae over extended breeding seasons; and are widely dispersed as larvae, which opportunistically colonize vacant patches of habitat. Stock assessment models of reef fisheries should take these characteristics into account.

There seems to be a relatively close coupling between physical oceanographic processes near reefs and the biota of reefs. Since the larvae of reef-dwelling fishes appear to be advected to the reef area after spawning, which takes place outside the reef, the presence of gyres and the nature of water circulation are important considerations in the management of reef communities. For example, artificial reefs might be optimally sited if proper data on physical oceanographic processes were available. In addition, the coral reef environment is considered to be fairly vulnerable to degradation and change by man. Some evidence for destruction of coral areas by silting is available in the literature, and the recovery of damaged coral areas appear to be very slow, ranging from a decade to more than 30 years.

Inland Waters

Welcomme and Henderson (1976) and Henderson (1976) have summarized the state of assessment of fish resources of inland waters in developing areas. Their summary statements indicate that these food fisheries (primarily in tropical and subtropical regions) are extremely diverse in species and that production in these environments is highly variable. The fisheries appear to be considerably more changeable than had been previously supposed. Comparative studies among diverse fisheries and performance monitoring as means for developing rational management plans are suggested.

It has been recognized for some time that measuring the performance of inland food fisheries is difficult because of the dispersal of fishing units and the methods of marketing and disposal of the catch. A demographic approach has been adopted by FAO, based on frame surveys of fishermen and their equipment and a stratified random sampling of catches at known intervals. This approach is considered reliable and of widespread applicability to small-scale fisheries throughout the world. The methodology is clearly described by Bazigos (1974).

The use of morphoedaphic indexes, based on limnological parameters of lakes, has been summarized by Ryder et al. (1974). Good correlations between index values and lake productivity have been demonstrated for a wide latitudinal range, merely by adjusting a proportionality coefficient in the index term. For comparative purposes, in small-scale fisheries of reefs, lagoons, estuaries, and shallow inland areas, it seems that an approach somewhat analogous to the above for estimating fishery potentials for those areas may be of considerable utility. The possibilities for developing such index terms should receive further study.

Henderson and Welcomme (1974) have utilized the number of fishermen per unit area as an index of fishing intensity, and they have made inferences from this material to indicate how close the observed yields are to estimated potentials Again, this approach seems to have utility, and some work similar to this has been initiated regarding tropical island fisheries by Munro

Yields of river fisheries have also been studied by means of certain morphoedaphic features One of the best postulated associations appears to be that between river drainage area and annual catches from relatively large river systems (Welcomme, 1978) A recent summary of the European method of fish harvest prediction in fluvial systems has been given by Köbling (1978) It seems that this method, with some further elaborations, has the potential utility of the lake morphoedaphic index described previously

Welcomme and Henderson (1976) have reviewed many aspects of inland water management for fisheries A brief summary of their work suggests that

1 Water use requirements (other than fisheries) must be considered with fisheries needs This implies that models of these systems must be broad enough to embrace these alternatives

2 There appears to be a general response of fish communities to fishing or significant environmental manipulation This is manifested by a displacement toward smaller, faster-growing, short-lived species

3 The decision-making processes in inland fisheries often involve questions of policy and alternative allocation of resources Such questions can only be examined in a management context which includes socioeconomic as well as biological variables

Habitat Modification

Tropical freshwater and marine habitats and ecosystems may possibly be manipulated as part of a management strategy for small-scale fisheries of which stock assessment forms a part In traditional marine fisheries, it is rarely possible to exert any significant influence on the habitat or the unexploited biota The only estimated parameters which are manipulated in these fisheries are size at first capture (size limits or mesh regulations) and fishing effort In view of the fact that certain tropical fisheries are pursued over relatively small geographic areas which contain indigenous fauna, it seems desirable to know more about the aquatic environments and trophic webs in tropical latitudes, especially exploitation effects and effects of environmental changes.

It should be recognized that habitats of tropical fisheries can often be enhanced. Artificial reefs and other man-made structures have been used for centuries to enhance fishing. Ino (1974) has provided a historical review of artificial reef activities in Japan using a diversity of materials. In general, the installation of artificial reefs is recognized as an important step in the development of coastal fisheries Their role includes providing habitat for certain organisms, nursery areas, and fishing grounds. In the same artificial reef conference, Fast and Pagán (1974) have indicated that the biomass of artificial reefs in Puerto Rico was substantially higher than that of natural reefs, although the number of species was slightly smaller. There is a real need for further work on habitat manipulation to maintain and/or improve small-scale fisheries by enhancing desired species or total fish production.

Some interesting initial developments relating to the colonization of defaunated natural reefs and the factors affecting species assemblages on reefs have been described by Nolan (1975).

Tropical Fishery Resource Characteristics

General

Johannes (1978) has recently reviewed some reproductive strategies of marine fishes in the tropics. His major conclusion is that temperate zone models of reproductive strategy are inapplicable in the tropics. He indicates that intense predation exerts heavy selection pressure on fishes living in coral reef, mangrove, or seagrass communities. These fishes spawn at times and locations which favor offshore transport of pelagic eggs and larvae to reduce predation. However, there is a requirement for larvae to return to shallow areas when ready to colonize postlarval habitats. This is done by concentrating spawning at times when prevailing winds and currents are weakest, thereby reducing transport losses. In addition, spawning appears to be concentrated in areas of gyres, which favor return to the natal location. Lunar and monsoon-related reproductive activity appears to be common. From the above, it is concluded that there is a relatively close coupling of meteorological and physical oceanographic phenomena with the breeding biology of tropical fishes. This has been indicated by Weber (1976), who suggested specific temperature and salinity influences of monsoon conditions. Erdman (1976) has provided an extensive review of the spawning patterns of Caribbean fishes, and concludes that individuals of many marine species spawn year round, with seasonal peaks once or twice a year. The year-round spawning activity of East African reef fishes has been recently documented by Njioka (1979), who draws conclusions very similar to those of Erdman.

Summary

1. A small-scale fishery has been operationally defined as a system consisting of the biota, the aquatic environment, and man, interacting through time and space. Management in this context consists of maximizing societal benefits subject to certain decision variables and constraints, including environmental constraints. This implies a broad operational definition, of which stock assessment forms a part.
2. The apparent coupling between physical environmental conditions and the reproductive activity of tropical fish seems to be strong, and should be recognized in assessment methodologies.
3. There is some evidence that the nature of species replacement within species guilds in tropical fisheries is stochastic. This implies that changes in indices of species diversity may be of limited value, and that vital statistics and assessment methods might be applied to species groups (guilds) rather than at an individual species level.
4. Tropical estuaries have been shown to be different from temperate estuaries, with possibly more significant consequences resulting from perturbations to tropical fisheries which are estuarine-dependent.
5. Coral reefs and coral reef fisheries are uniquely characterized by op-

portunistic colonization of a limited habitat by almost continuous input from dispersed early life history stages.

6. The concept of morphoedaphic indices, adapted from inland fisheries, is suggested as having utility for stock assessments in small-scale marine fisheries in coastal areas.

7. Habitat modification seems feasible for some tropical small-scale fisheries as a management and assessment tool and needs further empirical study.

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Predictive Stock and Catch Assessment for Decision-making in the Management of Tropical Small-Scale Fisheries

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Although fishery scientists generally agree that knowledge of stock size is a basic predictor of potential catch, "stock assessment" means different things to different fishery scientists. The meanings and applications range from theoretical and dynamic to empirical and practical.

In North America and in developing countries of Africa and Southeast Asia, the time frame of investigation and the need for immediate prediction have led to the use of standing crop as the basis for the prediction of yield, or vice versa. At least loosely, "standing crop" is an expression of potential for annual production of finfish and, within limits of accuracy that are often determinable, is something that can be learned with reasonable rapidity for many habitats. In many of the situations in which the need for prediction has arisen, there are no catch, biological, or population data on which to base a dynamic, conventional model approach. An empirical estimate or one based on an existing index (even though it may need to be adapted for use) has proven to be the quickest, even if not perhaps the best, means to an end.

In one early study (Lagler and Ricker, 1943), a mark and recapture method was used to estimate standing crop by species in an oxbow lake in southwestern Indiana. It was a sport fishery, and the parallel catch data were obtained by a complete creel census at the sole point of fishing access to the lake. In order to relate catch to standing crop by species, estimates of stock size required to provide different levels of yield in terms of quality of angling success were derived.

Allowing that stock size is a determinant of yield and, further, allowing that to obtain a given yield a predictable size of stock should be maintained as a management objective, Lagler and deRoth (1953) undertook to determine minimum stock of largemouth bass required to provide one legal-sized (ten-inch) individual for each hour of angling. This study was done on two artificial ponds of about 4 ha each in size and drainable by gravity. The standing crops of bass in each of the ponds were determined by draining the ponds through inclined-plane screen traps (Wolf, 1951) and returning the bass to the ponds. Separate, complete sport fishing catch statistics were kept for each pond. These indicated that about 100 legal-sized bass per hectare would enable realization of the one-keeper-per-sportfisherman-hour objective.

In Southeast Asia in 1964, the absence of catch statistics frustrated attempts to relate standing crop (as determined by chemofishing) to catch in swamps of central Thailand. By 1966, the government was gathering catch and standing crop statistics on a number of swamps and reservoirs. On one of the reservoirs, shallow 410 km^2 Nam Pong in the northeast, standing crops as determined by quadrat chemofishing have ranged around 300 kg/ha, and have yielded some 2,000 mt/annum. It is interesting that the reported harvest of this multispecies fishery has remained relatively constant for the past decade, while the number of artisanal fishermen has increased from some 1,000 to 8,000! It is also interesting that the annual catch has fluctuated only little in spite of some change in species composition of the catch. Inasmuch as stock and catch determine carrying capacity in terms of the number of fishermen at any prescribed level of earnings, the foregoing data enable planning and management based on desired income level for the fishermen. In the 1979 economy, this body of water might support only about 2,000 fishermen, or about one-fourth of the present number. Sociopolitical conditions have prevented management of the resource on the basis of a desired income level.

Stock (standing crop) assessment in various inland, estuarine, and coastal habitats was performed by a variety of means throughout the Lower Basin of the Mekong River in Laos, Thailand, Cambodia, and Viet Nam (Lagler, 1976). Employed principally were measured trawlings, beach seinings, and chemofishing quadrats. Bottom trawls were used in the mainstream Mekong at various water levels and in inshore waters to depths of some 30 m of the South China Sea, including the area of the seasonally differing plume of the Mekong River. Riverine otter trawling was by shrimp try-net, and in the South China Sea by commercial otter gear. Coupled with existing reported values for catch, human consumption, and population, and adjusted by application of the FINS model of the U.S. Fish and Wildlife Service, estimates of standing stock gave catch estimates of 500,000 metric tons (mt) for the Lower Mekong Basin, the upstream zone contributing 95,000 mt; the existing reservoirs, 13,000 mt; the downstream freshwater, 236,000 mt; and the brackish water, estuarine, and inshore coastal waters, 156,000 mt. These values were used to predict an overall loss of between 32,000 and 48,000 mt, with a 1975 value of between $5 and $6 million, when the planned extensive water resource development and management plans for the basin are implemented. These losses could, of course, be more than offset by effective fishery management and the development of additional aquaculture. The social costs of the losses in catch and of the shift of the concentrated areas of fish production in the basin to future reservoirs upstream were of course pointed out.

In Africa, mostly in the years spanning 1966-71, prediction of fishery yield potential of new man-made lakes was repeatedly required by governments for decision-making on investments for research, development, and management. In the early part of this period, it became the responsibility of FAO to provide future catch estimates to such governments as Egypt for Lake Nasser, Nigeria for Lake Kainji, Ghana for Lake Volta, Ivory Coast for Lake Kossou, and, later, Zambia for the Kafue Gorge Dam Reservoir. Of the foregoing, except for the Kafue lake, all were desk-top estimates drawing on general knowledge and, for Lake Nasser, on the recorded catch from the reservoir itself, which was already one-third filled by its coffer dam. For Lake Kossou, the estimate was based on experience with another, smaller impoundment in the country. All of the estimates served their purpose in predicting the approximate scale of the fisheries and in helping the governments to obtain UNDP research and development support for them. It is interesting that none of these estimates has really been proven wrong, except for Lake Volta. On this lake (and, subsequently, on other African lakes), FAO's fishery statistician George Bazigos developed a frame survey and sampling program. His system estimated the annual catch to be some 40,000 mt, in contrast to a 20,000 mt prior estimate. Later, colleagues in FAO (Henderson and

Welcomme, 1974) improved the precision of yield estimates and fisherman carrying capacities (effort) by adaptation of existing catch data and temperate-water morphoedaphic indices of Ryder (1965) and others.

Predictions of the effects of the Kafue Gorge Dam on fish stocks and catch in the reservoir area, including the historically productive upstream Kafue River Flats, were based on detailed field studies from 1969-71 (Lagler et al., 1971). In this effort, the multispecies standing crop of fish was determined by chemofishing and beach seining of measured areas at floodwater to be some 96,000 mt, and at low water some 57,000 mt. The catch from this stock in the same year was only 7,850 mt, accounting for only a small fraction of the difference between the stocks of the two periods; the remainder went to natural mortality. The catch in any year proved to be predictable from the previous year's extent of area flooded (extent of floodwaters over the floodplain) or of the flood storage volume. The potential catch was shown to approximate three times the recorded harvest and was predicted to be little affected by future operation of the Kafue Gorge Dam. With the dam in operation, the fishery, as in the past, could harvest annually on a sustainable basis at least a third of the exploitable standing stock as measured at the time of its high-water maximum.

Practical working predictions of potential catch can be derived from the behavior of comparable ecosystems, and indices such as those developed for certain freshwater systems need adaptation or development for rapid evaluation of small-scale fisheries of coral reefs, lagoons, bays, and other inshore tropical (and temperate) waters. Practical, simplistic methodologies have provided information adequate for decisions on management, not unlike the predictive indices of a patient's well-being that exist in the components of a routine human medical examination. Prior catch statistics continue to be most valuable in fishery predictions, quite like the question "How have you been feeling?" in a medical history. Expansion and improvement of systems for fishery catch statistics must be encouraged. For newborn fisheries, as in new man-made lakes and in unexploited habitats, there is no "medical history," and comparable water areas, existing or newly developed indices, and/or experimental fishing will have to be used as models. Working catch/stock models should continue to find primary application to fisheries in various stages of development where population, catch, and effort data are available or can be deduced. As such, they are akin to the special tests that a medical practitioner may call for when a component of the routine physical exam turns up an "abnormal" condition. Special problems exist, of course, for stocks that are highly migratory, strongly multispecies (including species flocks for which eyeball identification of the individual species is not possible), or extremely slow-growing.

The foregoing perspective suggests that alternative, viable routines can be prescribed for predictive purposes adequate to basic fisheries management decisions.

Alternative and/or Complementary Stock Assessment Routines for Tropical Small-Scale Fisheries

The following outline is a brief compilation of possible methodologies:

*1. Static Procedures**

a. Estimate catch potential from behavior of similar ecosystems for which data are available and simultaneously estimate the effort (or numbers of fishermen) that the stock can support.

b. Estimate potential catch from measurement of standing crop (with variations perhaps allowing 30 to 50% of the stock to be available for annual harvest).

c. Estimate potential catch by application of existing, adapted, or newly developed indices—morphoedaphic for lakes, inundation zone extent or floodwater volume in large rivers, etc.

*2. Dynamic Procedures**

Use, adapt, or develop new models for maximum sustainable yield (e.g., Schaeffer, Beverton and Holt) when catch, effort, and supporting biological data are available or obtainable, as in ongoing fisheries.

Initially, the use of static procedures is recommended. Later, dynamic methods requiring more extensive data bases may be utilized.

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*The "static" procedures are primarily applicable to estimating future yields in incipient fisheries. The "dynamic" procedures are mostly for ongoing fisheries or for newly created fisheries where adequate catch, effort, and biological data exist or are obtainable.

Small-Scale Fisheries— Politics and Unfulfilled Promise

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Background

Traditional large-scale commercial fisheries have received the attention of governments and private industry for a long time. Such fisheries have been variously studied, managed, and abused. Mechanisms exist to encourage the search for new resources and the development of new products. The fishery literature abounds with reports concerning all aspects of the field. Interest in small-scale and other supplemental fisheries has lagged, and development of such fisheries has been slow, often seemingly thwarted by groups who should be most supportive of them.

The purpose of this paper is to analyze some problems associated with supplemental fisheries based on experiences in nations bordering the tropical Atlantic. What is related below is not new. Each member of this conference will be aware of most or all of the points raised. Were it not for the fact that the problems remain, that progress is slow, and that attempts by fishery scientists to aid in research and education are uncoordinated and unsupported by political bodies, this report would be unnecessary.

Small-scale fisheries are important to the developing nations in that they enable the poorer people not only to catch food for their own table but to sell the excess catch and thus earn some income. They are labor-intensive, and this is important in lesser developed countries where unemployment is high, at least seasonally, and pay scales very low. The economic impact of small-scale fisheries is much higher than would be surmised from the size or value of the catch alone. The small-scale fisheries are also important in that they make additional food available. The products, both fresh and processed, can be used for domestic consumption, including the serving of tourists' desires, and they can be exported. If the catch is to serve more than family or local needs, it must be handled properly, transported to a plant, and processed.

The key problem is to develop fish-processing plants that are equipped to handle a wide variety of fish species and produce a considerable array of fishery products. At the Vikingos plant in Colombia, the mainstay of the plant is shrimp, but they routinely handle many fish species (including gobies, cusk-eels, eels, goatfishes, and many small species of seabasses, snappers, and porgies), and produce fillets, steaks, fish sticks, cakes, and meal in a variety of packages. Although Vikingos is based on a fleet of commercial trawlers, it utilizes the bycatch of the trawling fleet. Thus, the plant is a good example of what is needed if the produce from artisanal fisheries is to supplement in any meaningful way the nation's total yield in fish products both for domestic consumption and for export. In my view, too many plants are inadequately equipped and many are dependent on a single fishery and product, such as conch, lobster, or shrimp. Many are marginal operations, and upgrading or renovation is based only on past operating experience. Each product seems to be cost-accounted independently. There is little effort to integrate the fisheries either at the catch or product end.

The real promise of artisanal fisheries lies in combining the yield with that of traditional commercial fisheries and, by doing so, reducing costs while producing a useful product.

It does little good to train and equip the family fisherman or to encourage any type of small-scale fishery if the fisherman has no place to sell his catch at prices that are meaningful to him in terms of the local economy. As a fishery scientist interested in resource identification and in training programs, I am thwarted because, without some cooperative arrangement to finance a proper fish-processing plant, the proposals that I make are incapable of producing anything but frustration.

Perhaps the problem has been that we have tried to treat small-scale fisheries as different from other fisheries. How different are they? They are small scale, they involve smaller investments in boats and fishing gear or other equipment. The catch (or culture) methods may be primitive and expensive; they involve a low yield-to-man-hour ratio. But they involve identification and harvesting of an aquatic resource, transporting it and handling it to insure a safe and useful product, and marketing or distributing that product—all familiar topics to the fishery scientist.

In identifying targets for small-scale fisheries, the fishery scientist should review all fishery resources, not just those that the local people have previously exported. Does it matter that Bahamians seem not to like octopus or squid? They could be trained to catch these cephalopods, and a good product could find a ready market abroad and in their own international hotels. Education may teach Bahamians to enjoy these products. Squid and octopus are sold in many Miami restaurants, where 20 years ago none was to be had. Nor is it just the Latin Americans who are buying them, though they did produce the market.

A second problem area that I see is the lack of integration of target species. Evaluation of a deepline fishery in the Bahamas is done independently of other fisheries. Why cannot a fisherman set his lobster traps and then proceed to the drop-off for deepline fishing instead of deadheading back to port or anchoring near the traps? In evaluating boat design for the lobster fisherman, no thought seems to have been given to dual or multipurpose boats. Many fishes that cannot be harvested profitably in their own right can provide added incentives and added profit margin when added to a more secure base such as lobster or conch. With rising fuel costs, such combined programs could be important in terms of yield per trip or per gallon of fuel. It could mean the difference between a losing, a self-supporting, or a profitable fishery.

Small-scale fisheries need economic protection. A small bay or gulf (like Uraba in Colombia) may harbor sufficient populations of shrimp and groundfish to sustain 3 to 5 small trawlers of the type used in Biscayne Bay, Florida, indefinitely. Yet one visit by a large commercial trawler could wipe out the fishery in a few nights. If a small-scale fishery is developed in areas like Uraba and support is given to local fishermen for boats and small trawls, then such areas must be excluded from fishing by others or the fishery will fail and the investment be lost. Just as riparian rights have been divided along European salmon streams, certain coastal areas deserve zoning.

Much of what has been said of small-scale fisheries applies to the catch from recreational fisheries. Each year in the Bahamas, tons of tuna and billfishes rot and are dragged back to sea because there is no way to utilize the catch. Elsewhere, in Kenya, for example, the anglers' catches are utilized and are a significant addition to the fish landings in that country.

Since most or all of the points being made are well known in fisheries circles, there is little point in pursuing details. Clearly, a major problem is one of communication. Those that can make these fisheries work are the heads of government, the ministers, the leaders of the legislature. When I have had the opportunity to talk to such persons, I have found interest but no real knowledge of the detailed problems of small-scale fisheries.

A final problem that deserves discussion is the need to integrate development in coastal countries. Tourism, agriculture, industry, and fisheries are all subjects of intensive effort in the developing nations, usually by different agencies, and although the effort varies from nation to nation, the first three are being pursued on a larger scale than fisheries. These programs are often not compatible. It does little good to develop coastal aquaculture or to encourage small-scale or large-scale fisheries if changing agricultural or industrial activities in the drainage basin pour chemicals, nutrients, and silt into the coastal waters, ruining fisheries or rendering the fish products unmarketable because of chemicals taken up by the fish or shellfish. The coastal zone cannot be separated from the estuaries, the upstream drainage, and man's effect on them, since it is the coastal zone that is the recipient of runoff and its entrained materials. Hotels are built to attract tourists to places where the waste from expanding urban centers soon pollutes the waters. Coastal zone management has been a hollow concept in the developing world.

Also to be considered are riverine fisheries and freshwater aquaculture. Knowledge of fishes of the large rivers is elementary at best. Few large rivers have been surveyed in any systematic fashion. Preliminary analysis of catches in such areas is by category (e.g., catfishes, sharks) rather than by species. Little effort has been devoted toward identification of local culturable species. Rather, tilapias have been introduced everywhere, often to the detriment of the indigenous fauna. Diseases of man and of fishes have been transported to other continents. Expansion of fish ponds in Puerto Rico in the 1950s exacerbated the already serious blood fluke problem. The fisheries for freshwater and marine tropicals are seldom recognized as true small-scale fisheries. Well over 100,000,000 fishes are imported to the United States annually. Large numbers go to Western Europe. These fisheries, their impact on the local economy, and their effect on fish stocks are largely unassessed and unmanaged. When one can sell a four-inch fish for $50, one has a commercial species of the highest order.

Education and training are part of the package in the development of small-scale fisheries. Yet it must be recognized that when you train someone to repair outboard motors, etc., you provide him with a ticket to a job in industry or in another more lucrative government service such as transportation. Until the number of technicians is increased in an important way, the training of technicians in fisheries in developing nations is likely to be a continuing process.

In this overview, problem areas have been identified in order to broaden the view of this workshop. At some point, it is necessary to depart from specific discussions of fisheries problems and to work with political leaders to assist not only in developing a small-scale fisheries plan for each nation but to participate in an integrated approach to coastal zone development and management.

Conclusions

1. Small-scale fisheries are bona fide fisheries involving the need for resource identification, harvesting, processing, marketing, and management.

2. If small-scale fisheries are to yield products that serve more than the local population, they must emphasize proper handling of catches, and provide refrigeration at local collection sites and transportation to processing plants.

3. Since small-scale fisheries can scarcely be expected to support processing plants, they will succeed when they can be tied to other fisheries, preferably with a lead product. In such cases, they will provide a diversity in products, a hedge against seasonal surges in the principal catch, and added economic benefits.

4. In each country, special attention should be given to combined fishing effort in which a boat sets its lobster traps or fish pots and then proceeds to fish in nearby deeper waters for fishes or squid during the night.

5. Recreational fisheries and small-scale aquaculture are an integral part of small-scale fisheries in terms of storing, transporting, processing, and marketing catches.

6. Integration of programs for fisheries development with those for industry, agriculture, and tourism is important if serious conflicts are to be avoided. Proper coastal zone management requires integrated planning.

7. The aquarium fish industry is an important small-scale fisheries, although it is fundamentally different, since it involves the catching and transportation of live animals.

Perspectives on Minimal Data Requirements for Aquatic Resource Management in Developing Countries

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Abstract

The central thrust of this paper is that most fishery planning and management is carried out on a piecemeal or fragmented basis, with the consequence that the data collected often are inadequate for the overall purpose of managing the resource. Further, the data collected are ineffectively communicated. Minimal data requirements which might facilitate effective management, as well as a number of suggested areas of research, training, and cooperation, are suggested for the use of the international aid community.

Introduction

It has been argued that in the case of most aquatic resources sufficient data are not available for effective management, which in turn results in the non-management (and, occasionally, mismanagement) of resources. A wide variety of causes have been cited to explain this state of affairs. The object of this presentation is to suggest that obtaining adequate data for resource management depends on an overall approach to the requirements of management instead of the piecemeal or partial approach to the problem so prevalent today. Further, areas in which minimal information could substantially improve management of small-scale fisheries are recommended. Some of the following material was developed with the aid of an award from the Izaak Walton Killam Fund for Advanced Studies, which I wish to acknowledge with gratitude.

Some Basic Precepts

In meeting management goals it is apparent that the existing small-scale and artisanal fisheries must be upgraded but, insofar as possible, not enlarged. To avoid further hardship to the artisanal fisherman, any industrial fishery should evolve from the existing fishery and not be superimposed on it.

Management may be defined as the function of planning, organizing, coordinating, directing, controlling, and supervising to reach a given result. It must be recognized at the outset that in fishery management value to society in the broad sense is the overall goal. This means that the short-term policy objectives should be consistent with the long-range societal goals, whether these be the acquisition of capital, maintenance of a protein base, raising of living standards, or some combination of these elements. Usually conservation, as manifested through the long-range maintenance of sufficient stock size of the aquatic resource, is inherent in any such principle.

Given policy goals and the strategic objectives which follow from them, management is essentially a decision-making task The information, knowledge, and wisdom applied to decision-making are based on available data It should be recognized that data are no more than a representation of facts, and until processed, interpreted, and *communicated*, they do not represent information upon which decisions can be based The manner in which information is conveyed to the user essentially and effectively controls the degree to which one receives, understands, and accepts the information as knowledge The ability to use or apply knowledge in an intelligent manner through the use of judgment, insight, and experience, collectively termed wisdom, is not the subject of this paper

My definitions of these terms follow their usual use in the information science community

Management is perceived as a wide variety of activities, depending on the client or user It is fundamental and essential that management and planning proceed in a hierarchical fashion, defining the information requirements if the data are to meet the criteria of scope and relevance, timeliness, accuracy, and precision As an example, because the degree of uncertainty of each input element is additive, if several elements contribute to a final decision which should be correct to ten percent, then each element must be collected with substantially less than ten percent error If the data are dependent upon a variety of sources which can only be collected at some gross level of measurement, the result will be accordingly affected The failure to look at the cost and benefit of incremental improvement of varying levels of accuracy on overall need results in programs in which some data are collected to several decimal places and then combined with other data comprised only of gross guesses Unhappily, this is the usual case It is to be emphasized that these same statements relate to timeliness with equal if not more validity However appropriate, knowledge unavailable for decision-making because it is still in the process of analysis is for all purposes useless

The essence of the foregoing is that effective management requires an overall view of the information needed for decision-making, combined with a statement of acceptable levels of accuracy, precision, and timeliness for data acquisition Failure to do this can only result in incomplete, inadequate information, at costs which are not justifiable Such planning and management cannot take place in the vacuum of a single discipline. The development of a fishery from assessment of stock, catch, processing, and transport to marketing must be coordinated or there can be negative consequences, perhaps irreversible ones, for the fisherman and for national goals.

There is an urgent need for the application of sequential and other appropriate sampling techniques, whereby when the given level of precision is reached the program can be stopped. Some information is required on a continuing basis, but in many other cases, through failure to express a desired level of accuracy and precision, data collection goes on "forever." The professed need for more study and data has contributed to the frequently existing credibility gap between the fishery scientist and the senior managers. It is important to know when to terminate a program in terms of return-on-data improvement.

Four categories of management information can be recognized (examples given are from the biological area and could be expanded to any of the management components):

1. Immediate Management. The monitoring of the *activity* against the objective or goal. Primarily, this comprises the measurement of rates of removal by measuring effort and catch. It is to be emphasized that the operative word here is "catch" and not "landings." This information requirement has a continuing need for data on an up-to-date basis.

2. Safe-Fail Information. The ability to determine the *state* of the resource; when rapid cessation of an activity should be enforced and alternative or contingency plans implemented. The data required to monitor the state of the resource may include information such as stock size and extent of spawning, recruitment, mortaliy rates, and/or environmental factors such as pollution. Data acquisition usually requires some form of standardized survey approach. I distinguish between safe-fail and fail-safe in that the former allows one to recover to the original state, whereas the latter only assures that one does not get further into trouble. Their differing data requirements are substantial. Both involve continuous data acquisition programs.

3. Remedial, Improvement, and Enhancement Activities. Data which involve a wide variety of environmental technical information. Data needs are usually intermittent and not required for an extended basis.

4. Research and Development. Data acquisition which covers the broad range of fundamental and applied research in fisheries, designed to solve problems existing within the previous three categories.

The appropriateness of these categories becomes clear when the requirements of data in terms of relevance, timeliness, accuracy, and precision to information needs are considered. From a statistical viewpoint, the selection of data needs is particularly revealing in the manner in which these categories reflect a breakdown into enumerative and analytical components. As the statistician Deming stresses, the confounding of these two data types in terms of predictive accuracy continues to elude many statistical texts.

The key element of effective management is communication; i.e., implementing the decision action, the ability to bring about change in a readily acceptable fashion. This may be translated as the authority to act, the ability to act, the desire to act.

Even under adverse conditions there is an overwhelming tendency to maintain the status quo rather than to make a decision for change. This frequent response is directly traceable to ineffectual communication of information and/or to the upgrading of knowledge to a point where the action is recognized as desirable. The issues involve clarity, ease of comprehension, and acceptability and *credibility* of the results. Ignoring these factors has often led to the collection of too many data in the context of need, which are frequently unorganized, inconsistent, and have no hope of reduction or interpretation. The inevitable consequence is that no use of them is possible in decision-making. It is a sad fact that many policy makers do not rely on their own organization's output to help with the requirements of decision-making and management.

Communication of resource and monitoring information to the senior executive poses special problems. Relevancy, acceptability, and cost of uncertainty all need attention. Chernov, while at Stanford, suggested a novel approach to multidimensional data with which we have been experimenting. His development makes use of the ability common to most humans of recognizing subtle differences in the human face. This technique permits recognition of changes in the monitored information on environment and catch before they can be detected and demonstrated in a more conventional manner. More important, it allows an administrator to see in a single picture the overall weighted estimates rather than a single factor. A number of formats including fish and invertebrates have been used in the hope that prompt information added to a time series of past performance would alert a manager to the state of any resource change.

The essence of the foregoing is that communication in a reliable and acceptable fashion is an inherent part of the data problem and that in general we have failed to demonstrate the cost of uncertainty in decision-making effectively. In particular, there should be more attention given to the feasibility of using natural and man-induced fluctuations in adaptive or experimental management. Only in fishery science is practical field implementation and testing of theory approached with such trepidation.

Opportunities for the International Aid Community in Assisting the Management of the Small-Scale Fisheries

Conversion of these principles to practical implementation is possible in a number of ways. Information needs in fisheries can be grouped into three broad classes: 1) biological, 2) technological, and 3) institutional. Examples from each suggest the basic data requirements.

Approaches to Some Biological Questions

In the first category of information, a measure of fishing activity is the goal: i.e., effort, catching power, and catch are the minimal data elements to be obtained to determine extraction rate. Estimates of the number of units of most small-scale gear can be obtained through aerial reconnaissance. This is a cost-effective method, permitting rapid acquisition of this information with high levels of accuracy. The role of the international aid community could be to provide training films and simulations in enumeration and recognition techniques, thus saving the time ordinarily needed by new observers to gain experience in recognizing and counting gear type when using aircraft as a platform.

The catch effectiveness of different gear types needs to be established regionally. Information on small-scale and/or artisanal fishing power is extremely poor. The estimates of catching power of some canoes and lift nets vary by more than two orders of magnitude. Single or infrequently repeated studies would meet initial requirements. These data applied to samples of the catch could be extrapolated to provide an estimate of total catch.

Effective sampling of catch poses a somewhat more difficult but not intractable problem involving the frame, frequency of sampling, and identification of catch both to species groups and to weight.

While a long way from developing formalized models of tropical multispecies fisheries, it is clear that included in the information needed are data on composition of catch by species groups in relation to total effort. This requires knowledge of fish types, not necessarily to species but to general groupings. FAO and other agencies have made laudable efforts in terms of identification and sampling manuals, but the presence of these guides in field stations is far too rare to make their use common. The international aid community could contribute significantly by developing training programs in improved sampling techniques, in identification of species groups, in weight and number estimation, as well as in the processing of basic sample data. This processing can be carried out intelligently by persons who have had no advanced training in mathematics or ichthyology; they only have to be aware of the meaning of each phase of the task. It would appear that there is ample skill at many regional headquarters to design the sampling programs but inadequate numbers of trained personnel to carry them out.

In many areas, much greater use can be made of the catch of small fishes by processing them instead of disposing of them as trash. Implementation of new processing procedures depends on understanding the composition and relative abundance of the various types over the seasons. The primary information is obtainable on a one-time basis. As it is a common problem, a series of workshops with representatives from many regions might serve to facilitate analyses and collection of such data.

Unfortunately, unlike many sampling programs, monitoring of the catch must be carried out on a continuing basis. Convincing bankers, administrators, and planners of the importance and fundamental need for programs to obtain such information in competition with more "visible" projects is one of the most challenging tasks facing the fishery manager today. Yet, thus far, there appears to have been no truly effective way to include data acquisition programs among the shopping lists so dear to some planners and some aid agencies.

Approaches to Some Technological Questions

Bettering catches requires development of a stable outlet for harvest. Processing and preparation relate directly to landing sites and physical facilities, particularly sanitation and icing. These in turn involve water and power. The final stage of distribution to markets involves transportation. The difficult task of integration is often made even more intractable by problems of local geography. Nevertheless, there are challenging and exciting opportunities for the development of small, maintenance-free, refrigerated trucks, and ice plants of three to five tons for use in this capacity. The typical introduction of large industrial-scale plants, refrigeration units, and transportation systems is inappropriate to most small-scale fisheries.

Programs for improving basic fish processing often involve the installation of relatively complex fish dryers. Instead of this superimposition of technology, staged upgrading might be a better mode of progression. Plastic, two-layer Dibbs dryers, which only require the sun for energy, are low-cost, virtually maintenance-free, and would make available a means of upgrading dry fish products to all fishermen. In some areas, mechanical dryers have been proposed, and to cope with oil shortages, conversion to wood has been suggested. Yet, in many parts of the world wood is in limited supply and needed for cooking fuel. One might get the impression that the fishery scientist fails to communicate with the forestry scientist.

Approaches to Some Institutional Questions

The Development of Regional, Provincial, and Interprovincial Fishery Plans. There is an urgent need for integrated fishery planning and management. To assist in the development of such plans, a series of workshops and training sessions might be held for provincial fishery officials and responsible planners to improve their skills in these areas. Emphasis should be placed on developing a dialogue among various provincial planning groups while preparing a workable, cost-effective strategic plan.

Effective Organization of Fishery Services. Many improvements might be accomplished through the organization of fishery services on an operational basis. The need to provide incentives for senior staff to work in distant and difficult areas is paramount. A clear opportunity exists for the upgrading of fishery personnel in management skill and data analysis. An efficient means of training and avoiding national and institutional barriers would be to make use of a mobile training base paralleling the concept of the hospital ship *Hope*. This would provide for the greatest possible flexibility, but would be more expensive than holding localized training sessions. The value of such programs and the advantage of demonstrating techniques with modern gaming procedures were illustrated in a management workshop recently sponsored by the Southeast Asia Fisheries Development and Economic Commission (SEAFDEC) in the Philippines.

Implementation of management decisions requires the strategic need of recognition and delegation of authority at the requisite political level. This implies adequate compensation for the fishery worker, who in many countries today must seek outside employment to make financial ends meet. Critical mass funding for a few well-chosen projects in lieu of inadequate funding for a broad variety of programs is the hard solution necessary. The concept of critical mass cannot be overemphasized. If adequate personnel and funding over sufficient time are not made available to carry out a given task effectively, there is no point in its inauguration. Further lack of authoritative management can only result in jurisdictional competition and operational confusion. The leadership and necessary authority for such projects can only be developed on a regional basis.

New ways of communicating management concerns to the fishermen and the public should be explored. The misapprehension over the use of ice in many tropical countries is an area of communication in which the international aid community could play a fundamental role. Extension techniques such as the use of animated posters, an adult comic book approach, and similar media techniques might bridge the gap where local dialects prove a barrier to more usual but less effective communication.

The yield of many net fisheries could be improved by changing lift frequency and mesh size. Implementing any such modifications will require considerable extension and demonstration effort.

There is an urgent need to demonstrate publicly the detrimental effect of using fine-mesh material or "blue cloth" on the young of commercially important species. The feasibility of an exchange and/or subsidy program for replacing such gear should be examined.

The apparent limitation on the dissemination of results of research, statistics, and raw data can be observed throughout the developing world. Both governments and universities must take responsibility. No doubt this is often a consequence of the lack of funds for printing and insufficient copies available, but in many instances stocks of supplies remain uncirculated while obtaining copies through normal channels is almost impossible. An open stance should be taken so that publications are widely disseminated throughout the region as well as "outside" to stimulate the exchange of information, criticism, and credit, and to test the veracity of results. The effect on staff morale would be striking.

Village Extension Programs. There is considerable scope for research on effective ways of training people, ranging from fishermen to distributors, in methods of gear improvement, fish handling, quality control, and the elements of practical economics and finance. In spite of the success of terrestrial agricultural extension programs, fishery extension has remained relatively weak in terms of effectiveness. A notable exception is the approach being taken by the Bureau of Fisheries in the Philippines, whose techniques deserve careful attention.

It is important to re-emphasize that aid can be effective only in a participatory mode. "Upgrading" should be the key word, not "superimposition." Involvement and participation in planning and in decision-making programs by people who are in authority to act is essential to any international aid activity. In the broadest possible context, there is a need to stress the maintenance features of data acquisition programs, whether they are statistical or mechanical. This implies that the transfer of technology must involve understanding as well as operation. A fish dryer standing idle because of some minor mechanical flaw is no gift at all but a glaring demonstration of the ineffectiveness of a training program. Less obvious but more serious are the unrecoverable errors resulting from perpetuation of avoidable lapses in data acquisition.

Special attention should be placed on the problems of size of financial assistance. As FAO studies show, the minimum loan to fishermen is often too large to make it generally accessible to those who need it the most. Provision should be made for operating loan funds, as distinct from capital funds. Loan programs should be directly facilitated at all stages by the responsible agency to prevent unfair advantage being taken of the fishermen. Until training programs become effective, this will require that the bank negotiations, application forms, and transfer of funds be done for the fishermen. For those living at the subsistence level, incremental loan payment is often a new concept.

Improving Fish Distribution and Quality. Computer simulation, econometric analysis, and field trials should be made of a collector boat system to develop means of improving the quality of fish supply and income to primary fishermen. The adopted system might include regular radio broadcasts and market posting of price information. This would contribute to better distribution of fish supplies and price stabilization, as well as directly contributing to the welfare of the primary fishermen. The argument that communications are inadequate is not valid; one can go to the most distant village in Asia and learn the price of gold posted in London that morning. Until comparative data are available so that there is a choice among alternatives, waste in small-scale fisheries is likely to remain high.

Provision for Regional Resource Libraries. The state of library reference services and materials in outlying areas is deplorable. Methods of bringing notice of pertinent literature to the field investigator is crucial. Regional bibliographic facilities and their means of distribution need improvement urgently. With a one-time effort, a substantial basic reference library collection could be prepared in microform. For the cost of a microform reader (battery-operated), the most distant field station could have the facilities of a central library. Because of the substantial, but one-time, task involved, it might be desirable for several international aid organizations to mount a cooperative effort to support a contract with a firm which has access to large libraries for the micro-carding of a fishery library base.

Development of Data-Processing Computer Programs. Because of the parallel nature of data reduction and analysis, it would be feasible for the international aid community to support the development of a set of programs to handle common types of fishery data. These programs should be independent of computer type, thoroughly tested, and written so that any future updates can be made and be completely transparent to the user. At a minimum, there is an urgent need for regional agreement on a series of editing and verification procedures to assure quality of input data. However surprising, a co-equal need is to provide a series of test data so that those constructing their own analytical systems can be sure of consistent and comparable results. This is a nontrivial matter.

Basic Understanding of Fishermen. While all the foregoing may perhaps be a useful start, there is a fundamental lack of understanding in the fishery management community of the nature of the participants of most fisheries. It is hardly possible to manage for societal long-term needs when so little is known about the innate behavior of the primary unit. Understanding is basic to communication. Both developed and developing nations have a poor record of success in convincing fishermen of the value of management measures. Some exciting work is being done by groups working at the University of Tokyo, and more recently at the Universities of Oregon and Rhode Island, on the acquisition of what is generally called in fishery anthropology an "ethnographic profile." (Better, more expressive terms, perhaps like those used in the field of ergonomics, are needed.) Knowing more of the behavior, perceptions, and desires of the fishermen could lead, or substantially contribute, to the elimination of this major gap in communication.

In many small-scale and artisanal fisheries, fishermen occupy a low position in the society of the region. Their perceived existence is in poorer terms than are other trades or professions, perhaps in part explaining their dependence on middlemen for a wide range of social support. A number of countries are developing programs which promote fisheries as a reputable occupation and emphasize the important role fishermen play in society. This is another area of anthropological research with significant practical potential. While the role of the middleman will never be eliminated, which is suggested as desirable by some national policies, increasing the earnings of fishermen while maintaining reasonably stable consumer prices will require a fundamental change in market infrastructure. This can only come about when small-scale fishermen reach an appropriate stage of sophistication and self-esteem; again, a problem of effective communication.

The Utility of Isolated Data Sets

The literature of the optical industry implies and suggests the existence of a helicopter-borne high-power laser developed for the military which is capable of penetrating the sea to considerable depth. Let us assume that a helicopter equipped with such a laser is available to the fishery manager and that he covers the sea area of interest in the brief time needed to fly over it—searching, apparently, can take place at high rates of speed. Knowing the distribution of the fish stocks and having a measure of mean density would allow the application of the usual familiar methods of aerial stock assessment.

If the stock assessment data for any artisanal fishery of your choice were available, what would be the best way to handle it? How would management of small-scale fisheries differ from what is being done now? Is there any rational framework to form a basis for clear action and its implementation? Would the action be acceptable to the local people?

Fishery scientists may be seeking the wrong information or only part of the information needed. If stock information is wanted, infrequent aerial surveys of gear, a series of measures of catching power, and a program of adequate sampling are all that are required for most small-scale fisheries and these are achievable today. Would this information be sufficient to improve fisheries management significantly?

Probably not. While important in itself, stock assessment is only part of the answer; all the components of aquatic resource management need to be considered and upgraded more or less simultaneously.

Experience Papers

Approaches to Some Problem Areas in Tropical Small-Scale Fisheries

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The problems facing development and management of tropical small-scale fisheries are many and varied. Often these include infrastructure, matters political and financial (especially relating to sources of capital and marketing options), and cultural attitudes. This paper will be concerned only with the considerable biological problems in such a fishery. These tend to fall into two classes: those related to life history information (and the scarcity thereof) and those related to population and community dynamics.

Life History

A problem encountered continuously in tropical small-scale fisheries is a serious lack of the type of basic life history information that is well known for almost every species of any commercial importance in developed temperate fisheries. This information gap persists despite the fact that most of the tropical species in question have been fished locally for hundreds of years. It is fostered by 1) the multiplicity of species taken together in the fishery, 2) the historic shortage of trained fishery workers in the areas, and 3) the relatively small financial resources involved in the fishery.

In some cases, the very identification of the species as a recognizable, reproducing unit is so doubtful that it seriously hinders fishery analysis. This is particularly true among some of the scarids and carangids, both important food fishes in much of the tropics. For example, in Hawaii fishermen almost never attempt to distinguish among any of the scarids caught, and some basic taxonomic questions remain to be resolved among the economically important genera *Caranx* and *Carangoides*. Worse yet, even where good taxonomic distinctions permit relatively easy field identification, catch reports often lump related species grossly. In Hawaii, all species of scarids are reported together as "uhu," and 11 species of carangids are reported under the heading of "ulua." Neither the population parameters of individual stocks nor the nature of species interactions can be properly determined without better separation of biological entities. Both aspects of this problem should be responsive to vigorous application of existing capabilities, using standard methods.

Until recently, the problem of aging tropical species has been the source of more complaint than effort. Within the last few years, however, efforts on several fronts have produced encouraging results. Efforts have been made to collect adequate series of important species for length-frequency analysis. There are several somewhat successful examples in the extensive Jamaican work of Munro (e.g., 1974). Recent successful efforts include Muller's (1977) work on the anchovy, *Stolephorus heterolobus*, in Palau, and McMahon's (1975) work on the silversides, *Pranesus insularum*, in Hawaii. There has been renewed, serious work on the effective use of hard parts; e.g., Munro (1974) on scales and otoliths of a variety of Caribbean species, Sylvester (1969) on scales of several Hawaiian species, Stevens (1979) and Taylor (unpublished) on vertebrate of sharks, and Nagelkerken (1976) on scales of the grouper *Petrometopon cruentatum*.

One of the most recent and promising aging techniques with hard parts is the reading of daily rings. Impressive success was shown by Ralston (1977) with the Hawaiian butterfly fish, *Chaetodon miliaris*, and by Brothers et al. (1976) with several tropical species. The NMFS Honolulu lab has been operating a systematic program of this sort for several years. One result was to corroborate McMahon's (1975) length-frequency results while aging a Central Pacific sardine and silversides (Hida and Uchiyama, 1977). Another was Struhsaker and Uchiyama's (1976) work on the Hawaiian nehu, *Stolephorus purpureus*. A recently completed study provided a growth curve for the goatfish *Parupeneus porphyreus* (Moffitt, 1979). Aging is well along on the deep snapper *Pristipomoides filamentosus*, and all the other Hawaiian commercial snappers appear to have readable otoliths. Other species currently in the program for aging include the carangids *Seriola dumerili* and four local *Decapterus* species, *Caranx ignobilis* and *Carangoides ferdau*, the dolphin, *Coryphaena hippurus*, and the goatfish *Parupeneus pleurostigma*. Williams (personal communication) is currently working on aging the Marquesan sardine, *Sardinella marquesensis*, in Hawaii. In few cases has it been possible to corroborate results of daily rings with an independent method, but the otolith results in most cases are convincing, at least up to some maximum readable age. For many species such a maximum limitation may have to be accepted. Although daily ring reading is slow and laborious, it appears to offer prospects for aging many tropical species.

Because of the recent rapid progress made in scattered locations and the present pace of development, it seems important that an information exchange system be implemented so that fishery workers might be aware of recent results on species of interest and become knowledgeable enough in the techniques to concentrate effectively on local species not previously analyzed.

The growth curves and estimates of growth parameters, including L_∞, that these age estimates will permit are extremely important in all fishery analysis and management. They also permit converting size-at-recruitment and size-at-maturity data to age data. In a few cases (e.g., the extensive Jamaican studies of Munro, 1974), size-at-maturity is well known. Very often it is not known even for important commercial species. For example, in Ralston's (1979) analysis of the Hawaiian commercial bottom fishery, of 13 species treated individually, information on size-at-maturity could be found for only three. Since a reasonable estimate is usually obtainable from sampling the catch, this important piece of management information should be collected in studies of all commercial species. Size information is generally poorly reported in catch statistics. Catch reports often require only the weight of catch of a species. Even where the number of individuals is reported every fishery program should include sampling the catch for size distribution. Among other uses, this will ultimately provide a historical trend in the size of catch which may be important in assessing the effect of fishing. Even where a small-scale fishery has operated in an area for many years, often no better historical data on trends in fish size exist than qualitative comments of fishermen ("They used to be bigger").

Fecundity is usually poorly known for most important species in tropical small-scale fisheries. (Munro's 1974 results are a refreshing exception.) Its determination is complicated in many cases by extended or multiple spawning seasons. Nevertheless, useful data can be taken from catch sampling or experimental fishing over a period of a year or more, and this should be included in studies of those fisheries.

Reproductive timing has historically been very poorly known in tropical fishery circles. The large number of species, diminished seasonal cues, and predominance of more or less pelagic eggs and larvae have created a complex and bewildering picture. The larval stages of most species are entirely unknown in terms of their identity or life history. Larval taxonomy and ecology are certainly major areas for further study, and a key emphasis for that study should be on survival and recruitment of the young to the adult habitat. For habitats of hard substrate (e.g., coral reefs) evidence appears to be accumulating that for many demersal species the habitat has a spatial carrying capacity, in terms of physical niches, that is normally fully occupied. Recruitment occurs as individual niches are vacated. This type of larval ecological study will require long and sustained effort to yield practical results.

A more immediate goal is a reasonable understanding of the timing of reproduction in important species. Important progress has recently been made for several fish groups (Munro, 1974; Munro et al., 1973; Erdman, 1967, 1976; Johannes, 1978a). These data are based mostly on gonad examinations and occurrence of concentrations of eggs and young larvae in the water. Johannes (1978a) has emphasized the local fisherman as an additional information source. Spawning season for some species may be well known to fishermen because it produces aggregation or other changes in fish behavior that are important to the fisherman's catch. Johannes (1978b) has discussed a number of inexpensive approaches to small-scale fishery management based on predictable periodic spawning aggregations.

Population and Community Dynamics

One approach to stock assessment that seems to hold promise in many tropical areas (much more so than in conventional, temperate situations) is direct, visual enumeration. The basic method was perhaps first published by Brock (1954) and has subsequently been modified and used by many investigators for individual site studies, usually with ecological orientation. Results depend upon divers spending fixed times or covering fixed transect distances underwater and recording the number (and sometimes size) of each fish species of interest seen. The utility of the method is limited to shallow depths (practically speaking, < 100 feet) and reasonably clear waters, to largely demersal, day-visible species, and to substrate that is conducive to a reasonably uniform distribution of fishes at the meso scale. Fortunately, this combination of environmental conditions and economically important species occurs rather commonly in tropical coastal situations. Also, temperatures and sea conditions in tropical coastal areas are often reasonably benign for this man-in-the-sea approach.

If the method is to be effective for stock assessment, personnel must be highly experienced in the use of SCUBA and in rapid sight identification of many species in the water Error due to individual observer bias cannot be eliminated or quantified entirely, but careful studies (e g , Nolan and Taylor, in press) suggest that such bias does not negate the results of well-executed transect censuses

Procedures must be well standardized A field evaluation study of visual census techniques was recently conducted by the Hawaii Cooperative Fishery Research Unit (Nolan and Taylor, in press) It stressed the lack of standardization among studies to date (Even within the local scientific community of Hawaii, transects swum for direct abundance-per-unit-area counts vary from 25 m x 10 m to 500 yd x 40 ft, and there are many other variations in technique with effects that are largely unstudied) The Unit study suggested a most efficient length of about 50 m for the completely rocky substrate area In this length, 75% of all species present and vulnerable to visual census were identified, the density of total individuals was as great as that found by census of the entire area, and the number of uncommon species (< 5 individuals in the sampling "universe") was as large as that found by census of the entire area Censuses which recorded only certain selected species took less than half the underwater time of all-species censuses, but were no more accurate in estimating population density of those species No significant difference was noted between population density or species composition when doing hand recording versus tape recording of data

The location of census sites must be carefully selected so as to be representative of all the different important habitat types present The method appears to be appropriate for most species of interest only where the bottom offers reasonably frequent elements of cover (e g , coral, rock, grass beds) Over featureless, open bottoms, fish density is so low and the probability of occurrence of fish as infrequent groups is such that transects of reasonable size or length of time do not sample the distribution of fish occurrence well Within areas of frequent bottom cover, the habitat must still be carefully assessed and census sites located appropriately A statistically adequate sample size is necessary Little study has been done in this area, but the Nolan and Taylor (in press) study indicated that at least two replicates of the 50 m transects were necessary to estimate 85% of the species present An additional replicate added few species, if any

In view of the uncontrollable variables in visual census work, there has been real concern over its accuracy; e g., the size of change in real abundance that is detectable In the Nolan and Taylor study, when a portion (25-30%) of the population of certain species was removed by spearing, observers using standard census techniques (and having no knowledge of the manipulation) were able to detect the changes in population consistently This result gave credence to seasonal variations in population estimates made on the same transect lines—and sounds a note of caution that even on tropical coral reefs, temporal (seasonal?) variation may have to be assessed before effects of exploitation can be well determined

Methods that rank fish species observed as a function of time rather than estimating numbers of individuals within a transect area have recently received attention (e.g., Jones and Thompson, 1978) Nolan and Taylor (in press) evaluated such a species/time method versus their species/area (fixed transect) method simultaneously They found that the species/time method detected 60%

more species (probably due primarily to the diver's freedom to cover a larger area). The species/time method produced only a ranking of species by apparent abundance—no estimate of absolute abundance. Several of the top-ranked (most abundant) species by the species/time method were also among the most abundant species in area transects, but others were not; i.e., some species that probably were widely different in abundance had equal rank by the species/time method.

There are a number of rather intensive current survey programs active in Hawaii using visual underwater techniques to estimate relative and absolute abundance (population density). A project of the University of Hawaii Marine Option Program has completed field survey, by both area transect and species/time methods, of several sites on Molokai Island and is analyzing the data (Sanderson et al., in preparation). The results should also be valuable in comparing the characteristics of the two methods. Hobson (1977, 1979) is in the midst of a several-year study of Hawaii's uninhabited Leeward Islands, which consists of swimming area transects at several locations on each of several islands and reefs/shoals in this group and using the results to describe community structure. The author and Dr. Taylor are doing some area transect and species/time census work in a few selected Leeward Islands sites to provide the necessary information on species populations to go with our trophic research. An environmental consulting firm, AECOS, is implementing an extended series of transects located systematically around the various major Hawaiian islands as part of a Corps of Engineers statewide coral reef inventory (AECOS, 1979a, 1979b). The Hawaii Division of Fish and Game has done fish census work on a site-specific basis for many years. The most extensive effort at present is in the Leeward Islands and is specifically directed at assessing unknown potential fishery resources in these unexploited areas (Hawaii Division of Fish and Game, 1978).

All these major census efforts, like all that have gone before them, are apparently limited in their present scope to determining fish areal density. In the Division of Fish and Game surveys, data include estimates of fish length, and weight is estimated by the use of a formula of the form

$$\text{weight} = A\,(\text{length})^{B}.$$

Average values of the constants have been calculated from collections over the years, and data are converted to pounds/acre of a species. The final step to making visual transect data meaningful in an assessment program to manage stocks would be to determine the extent of the bottom areas of each habitat type censused and use these areas to extrapolate the sample census results and thus estimate stock size. Even good-quality charts are probably inadequate for this purpose unless most of the coastal hard bottom area is extraordinarily well known to the researchers by sight. However, high-quality aerial imagery, together with reasonable ground-truth diving observations, should be adequate. The Corps of Engineers project in Hawaii (AECOS, 1979a, 1979b) is producing imagery that appears to be satisfactory. The fish census data in the project are not sufficiently quantitative nor sufficiently extensive for rigorous stock assessment, but some further field work might make such an assessment feasible. Perhaps the closest approach to full application of this technique so far is in the U.S. Peace

Corps-aided coastal fisheries stock assessment program (Biña et al., 1979; Carpenter, personal communication).

However well the work is done, assessment based on visual census will be biased in favor of demersal, substrate-oriented species, and will estimate pelagic species, especially the more surface-oriented types, poorly. It will also be poorer for schooling species and will be inadequate for species that are highly cryptic by day. As stated earlier, the method is limited to clear, shallow waters and gives poor results on featureless bottoms. Nevertheless, it seems to have considerable potential for estimating sizes of some important tropical coastal stocks and has the significant advantage that stocks of a number of important, potentially interacting species in a community can be estimated together. The Nolan and Taylor (in press) results indicate that successive censuses are capable of indicating changes in stock size.

Obviously, a major research effort is required to estimate the size of a stock, even for a relatively small island. However, good aerial imagery is becoming increasingly available in many areas. If it must be generated from scratch, a one-time aerial survey is usually adequate and can often be done with relatively low-cost equipment (e.g., light aircraft). The field work has two advantages. One is that workers gain a good first-hand idea of the quality of their data and the nature of the environment, giving the program better real-time feedback than a surface sampling program usually receives. Second, the nature of the field work is such that high-quality, low-cost labor may be attracted to it. The participation in state census work by highly competent University of Hawaii undergraduates from the Marine Option Program is a case in point.

At greater depths, stock size must be estimated by other, more conventional means. Although a continuum of depths occurs, in many tropical areas, particularly islands, the species of economic interest that commonly occur in water shallow enough for visual census are heavily concentrated in these shallower waters. Similarly, species that support a deep handline fishery are largely restricted to depths below practical visual census limits. Thus, for purposes of stock size assessment, adults of the two depth groups may be considered to have reasonably discrete distributions. The deeper fisheries, it appears, contain species with less commercial potential; thus, conventional methods using catch statistics may be more appropriate. Traps and handlines are the major gear types used in nearly all small-scale deeper fishing operations. Space and hauling power requirements plus distance from shore typically result in larger, more expensive—thus, fewer—vessels. It is therefore more feasible to get catch and effort statistics from this deeper fishery. In most small-scale developing fisheries, catch statistics range from nonexistent to mediocre. Probably all need substantial improvement, especially in the area of effort. Where a deep-water commercial fishery does not exist, there is no alternative to an exploratory fishing program. Recent examples in areas that have long had heavy shallow, inshore fishing include the surveys by 1) the Commercial Fisheries Laboratory, Department of Agriculture of Puerto Rico (continuing); 2) the Office of Marine Resources, Government of American Samoa (1967-70; Swerdloff, 1972); 3) the Aquatic and Wildlife Resources Division, Department of Agriculture of Guam (1967-70; Ikehara et al., 1970); 4) the Honolulu Laboratory, National Marine Fisheries Service, in the Leeward Hawaiian Islands (continuing).

For fisheries employing relatively fewer and larger vessels in somewhat deeper water, semiconventional methods of population and yield analysis may be appropriate. There are still serious problems hindering reliable analysis. The nature of some of these and a measure of the success now obtainable are illustrated by the recent analysis of certain Pacific bottom fisheries by Ralston (1979).

The best data for this study came from Hawaii, where over half a million monthly catch reports from individual fishermen were available through State Division of Fish and Game records. Fishermen legally required to report catch include full-time commercial bottom fishermen, full-time commercial fishermen who sometimes bottom fish, part-time commercial fishermen, and "sport" fishermen for any incidental catch they sell. It is generally believed that catches are grossly underreported (a common situation in tropical small-scale fisheries). Since the fishing groups mentioned fish and probably report differently, this makes the catch statistics problematical even as relative indicators. The numerous purely recreational fishermen do not report their catches, and their unquantified impact is probably very substantial. Such a large recreational fishery is atypical in tropical small-scale systems, but this catch may be analogous to true subsistence fishing in less developed economies. Fishing effort data were so poor that the best measure of effort* used in yield analyses was number of fisherman months for the species; i.e., the total number of monthly catch reports in which the species occurred.

Species analyzed included eight deep-water snappers, one deep-water grouper, two goatfishes, *Seriola dumerili* (Carangidae), and eleven other lumped species of carangids. Data extracted and summarized for all species included total annual catch, seasonal catch trends, areas of major catches, and principal gear types (dominated by handlines). For all species (or species groups), correlations were run on catch per unit effort versus effort. In four cases, the correlation was significant at least in some geographical area. A standard Schaeffer stock production model produced a credible MSY estimate for only two species (or groups) in only part of the state.

In an effort to improve the realism of representing a multispecies fishery, six major species of broad distribution and high vulnerability to handling were treated as being fished for simultaneously; i.e., fishing effort expended on any one of these species during any month was considered imposed on the remaining five of these species. All except one, a minor species, produced credible correlations of CPUE versus effort. Fox's exponential surplus yield model was applied, and the resulting yield curves predicted MSY for five of the species. In the five cases, present fishing effort varied from slightly above to far above MSY.

Ralston (1979) also examined the results of the new Samoan offshore fishery resulting from the recent fishery development project based on introduction of powered dories. The catch consisted mainly of snappers from six genera, two genera of groupers, and two genera of jacks.

Economically, the modernization program followed a sad but common pat-

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*The measure that gave best correlation of catch per unit effort with effort.

tern: six years after the first dory was built, only one was still actively fishing. All measures of effort (number of vessels in existence, number reporting, number of recorded vessel trips, and number of recorded bottom fish trips) showed an increase from 1971 to a peak and then a decline to a 1977 low. However, some measure of fishing impact was possible. Over a 17-month period, an estimated total of 136,000 kg of bottom fish were landed. Recorded catch rate dropped from 310 lb/trip to 254 lb/trip.* Fishermen reported catch rates reduced as much as half and generally reported a decrease in the size of fish taken. The data were inadequate for yield analysis, but clearly the stock was significantly affected by the level of effort applied.

In Guam there was no commercial bottom fishing. Reasonably good data on catch quantity and gear type were available on a considerable sport fishery, with data well standardized for the period 1969-78. Nearly half the catch consisted of snapper species. The bigeye scad, *Trachurops crumenophthalmus*, comprised an average 12% of the catch and other carangids 9%, but both were highly variable between years. Squirrel fishes (8.5%) and groupers (7.2%) were present every year. Over the nine years, catch showed some increase with effort, but not consistently. CPUE showed no consistent trend with time nor with effort. There was no indication of an effect of fishing on stock size. However, a separate experimental fishing program was implemented using a larger vessel both in coastal waters and on offshore banks. The results at one small, isolated, submerged, oceanic pinnacle demonstrated a consistent and drastic decrease in CPUE over the 16-month term of the study for data on all species combined. The major species were four deep-water snappers, one grouper (*Epinephelus* sp.), and the jack *Caranx lugubris*.

Where a truly diverse fishery occurs with strong interactions among species, adaptations of conventional unit stock methods have limited value. A number of theoretical models of interacting species have been devised (e.g., Laevastu and Favorite, 1978a, 1978b; Menshutkin, 1968, Parrish, 1975; Andersen et al., 1973). Although these models have considerable versatility in representing ecological processes and can handle rather large groups of species, a common problem is the large and detailed data base required. Some much cruder models that require less detailed data can give insights into the general behavior of multispecies systems (May et al., 1979, contains a recent discussion). However, it is not clear what sort of analytical approach provides useful realism at the proper cost in data requirements for small-scale fisheries.

There are two related research approaches that will provide important support for system models and data that are useful in more intuitive management methods. One is basic trophic investigation of systems; i.e., determination (at least for important species at various life stages) of who eats whom and how commonly. Such studies will reveal whether predation exerts important effects on population control and, if so, how this is influenced by exploitation. For example, if wrasses eat goatfish eggs and man fishes goatfish but not wrasses, what is the effect on goatfish stocks? This approach will also reveal the identity of

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*Most of the available catch data are in pounds of combined bottom fish species.

limiting food resources if they exist and help predict how the food competition between species responds to exploitation of one or more competitors. Work in Puerto Rican coastal waters (Parrish and Zimmerman, 1977 and in preparation) comprised a pilot study of reef fish community trophics, including assessment of invertebrate food supply. This work is being continued and expanded in Hawaii (Parrish and Taylor, 1978).

The other potentially valuable approach is direct, experimental manipulation of virgin fish communities in the field. Replicate communities in discrete habitat patches of manageable size could be studied in the pristine state and then fished for various species and at various levels of effort (including controls with no fishing). The population structure and trophic structure would be monitored at intervals. Among other advantages, this would provide opportunities of two kinds that almost never occur in commercial fisheries: 1) the opportunity to observe the baseline, pristine condition so as to assess clearly the effects of fishing, and 2) the opportunity to control the type as well as the intensity of fishing (e.g., experiments with top predator removal versus herbivore removal, etc.). Admittedly, the extrapolation of the small patch habitats to more extensive areas holds some uncertainty, but most fishery areas studied are in fact a part of some larger range of the species involved. Some suitable sites with adequate logistics still exist for this kind of field experimentation; e.g., in the Pacific, Enewetak Atoll and a number of the Leeward Hawaiian Islands. Some work of this sort is planned in the latter area on a small scale (Parrish and Taylor, 1978).

Other Problem Areas

Ciguatera

The incidence of ciguatera poisoning from eating tropical food fishes (especially certain upper-level carnivores) is a major deterrent to further fishery development in many areas. Some examples are: 1) the exploratory fishing program conducted in the U.S. Virgin Islands by the Caribbean Research Institute in the late 1960s (Caribbean Research Institute, 1969, 1970), in which the high occurrence of toxic fish presented a problem which "makes all others academic"; 2) the offshore dory fishery development in American Samoa, described above (Ralston, 1979), in which, for example, *Lutjanus bohar* was one of the most abundant species caught but was not marketed because it is frequently toxic; 3) the current exploratory fishing program in the almost virgin Leeward Hawaiian Islands fishery. In the latter program, from a wide spectrum of species tested for toxicity, results ranged from 0 to 100% (moray eels) of specimens toxic. A number of valuable food species had fairly high incidence of toxicity; e.g., the jack, "*Caranx ignobilis,*" 11%; the amberjack, *Seriola dumerili,* 16%. Some large wrasses such as *Cheilinus* species and even some herbivores (surgeonfish and parrot fish) tested positive.

Furthermore, outbreaks of ciguatera occur sporadically in long-established fisheries, producing economic depression concurrent with the public health problem. A recent case was the outbreak in the inhabited Hawaiian Islands in 1978-79 (at least 30 documented cases as of May 1979). Several species were involved, especially *Seriola dumerili.* This species grows to 57 kg, but the reputation for toxicity of fish over about 10 kg makes them hard to market. Recently the Honolulu NMFS laboratory has been operating a program of testing for toxicity samples which fishermen voluntarily supply from the market. The problem is much more serious in some less developed, remote, oceanic islands, where endemic ciguatera seriously reduces consumption of the major available supply of protein.

Although ciguatera research has been done irregularly over a number of years, two recent developments suggest that the time is right for another concerted effort to understand the origins and transmission of ciguatoxin well enough so that control—or at least detection prediction—will be possible in a way that will have practical benefits to fisheries. The work of Hokama et al. (1977) provides a method for measurement of toxicity levels in fish flesh without the inconvenience and uncertainties of the classical crude bioassays (cat, mouse, and mongoose tests). While the current Hokama radioimmunoassay is hardly a field technique, there is continuing progress toward a modification that is relatively portable and simpler to apply. The other key development is the discovery of a source organism for the toxin at the base of the food chain (Yasumoto et al., 1979). With the knowledge of at least one source of toxin and the tools for effective detection in hand, a program of research to tie together the trophic ecology of ciguatera is certainly appropriate and timely. This is particularly fitting, since some of the trophic relationships among fish species that are involved are likely to be important in understanding community dynamics from a fish production perspective.

Introduction of Exotic Species

Exotic fishes have been introduced into many areas of the world. Often the purpose is improvement of sport fishing or some nonfishery objective (e.g., insect control, aquatic plant control, decorative value). Freshwater introductions are most common, and there have been many such attempts for aquaculture or wild fishery enhancement. Introductions to augment wild marine fisheries are much less common, perhaps least of all into the diverse marine fish faunas of the tropics. However, exotic introduction is a management tool—one that will be considered where local stocks are depleted—and its effects merit consideration.

The experience of Hawaii is instructive. Its isolation by distance and prevailing current systems from the West Pacific faunal sources appears to have produced a relatively depauperate coastal fish fauna, with high endemism and a conspicuous lack of shallow-water groupers and snappers. There is also a shortage of suitable baitfish to support the pole-and-line tuna fishery. For over 100 years, there have been attempts to fill Hawaii's perceived needs for additional aquatic animals by introduction of exotics—at least 70 species released to the wild as of 1968 (Kanayama, 1968). The success rate, in terms of number of exotic species maintaining wild reproducing populations of any size, has been high—at least 51%, according to Kanayama.

Fully marine species have been introduced only since 1955, largely for food and sport, but also as tuna bait. The success rate has been lower—4 of 15 (27%). The successful species, now regularly seen in Hawaiian waters, are the Marquesan sardine, *Sardinella marquesensis* (a baitfish); the grouper *Cephalopholis* *argus;* and the snappers *Lutjanus vaigiensis* and *Lutjanus kasmira*. Another baitfish (California anchovy), five other groupers, and one other snapper were introduced during the same period. Results varied from no apparent reproduction to small populations that produce negligible catches. The Marquesan sardine has so far not become sufficiently abundant to be a reliable bait, but it appears to be on the increase. *Cephalopholis argus* and *Lutjanus vaigiensis* appear regularly in commercial catches and are well regarded, but they are not abundant enough to be important commercially. *Lutjanus kasmira* (popularly called "blueline snapper," or "taape") had been singularly successful ecologically. Its population has grown explosively, and it has spread rapidly throughout all the high islands of Hawaii. It has moved up the Leeward chain as far as Laysan Island (personal observation, June 1979). Catches have increased exponentially over the 11 years during which statistics have been kept, despite the fact that effort is rather desultory. The market still appears to be unready to absorb nearly all that can be caught. This may be partly due to the relatively small size of most fish landed but probably mostly due to the common, illogical market resistance to an unfamiliar species (this snapper is highly regarded at the source locations in French Polynesia).

The population success of the taape is obvious. The problems for the fishery manager are: 1) the low success rate of introduced species in terms of effort to introduce, 2) the highly dynamic status of the successful population that makes any kind of conventional production/yield analysis very difficult, 3) the market acceptance prohlem and resulting uncertainty of fishing effort, 4) the lack of any capability to control range extension (if this were desirable), 5) a dearth of life history or ecological information or any sort of fishery parameters from the source location, and 6) considerable uncertainty about the interaction developing with native species. Many of these problems would be common to most introductions in tropical coastal waters. It seems likely that the success rate would be lower in areas with more diverse native faunas.

The question of interaction with native species is a critical one for any introduction. If the exotic is a potentially important prey or an inferior competitor to local species, it will not succeed in significant numbers. If it is a potentially important predator or a superior competitor of local fishery species, its success is likely to be at the cost of existing native fishery resources. There appears to be a narrow range of situations in which a successful introduction can significantly increase fishery yields; namely, those situations in which the exotic can use largely unused local resources or use resources much more efficiently in terms of fish flesh productivity and does not have critical trophic or habitat interactions with native fishery species.

In the case of *Lutjanus kasmira,* a current research project (Parrish and Oda, in preparation) is a beginning toward the analysis of trophic requirements and interactions. A broader study of life history, ecology, and the fishery is envisioned (Parris and Shang, 1978). Careful studies of this sort should always be done when any introduction is considered, to reduce the impact of problems (1), (3), (4), (5), and (6) above.

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Fishery Yields of Coral Reefs and Adjacent Shallow-Water Environments

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Recently, S.V. Smith (1978) estimated that the fisheries potential of reef and adjacent shallow-water environments is about 6 x 10 kg/yr, or about 9% of the present annual commercial ocean fish landings. The percentage would be considerably higher if one were to restrict the estimate to latitudes where reefs occur and still greater for regions of reefs exclusively.

Also, although none of the yield information and appraisals thereof (for example, Gulland, 1972; Stevenson and Marshall, 1974; FAO, 1978; and Munro, 1978a) suggest that the coralline areas can sustain yields comparable to those of the great fishing grounds of the temperate regions, these very extensive tropical environments are generally accessible to the small-scale fisherman (whose well-being is of special concern in this workshop) and occur in areas where the need for food is greatest. Furthermore, because many of these environments cannot be fished readily with large-scale gear, particularly trawls, they are often the exclusive domain of small operators.

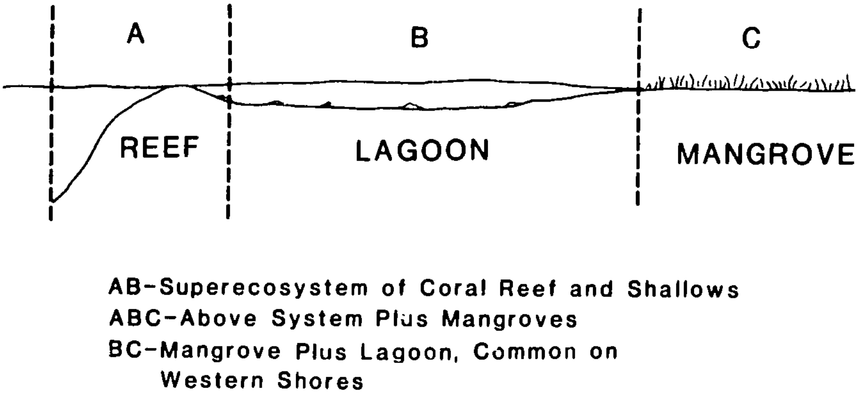

Figure 1. Composite of coral reefs, adjacent shallows, and slope as a superecosystem.

This paper focuses on coral reefs, the adjacent shallows, plus the immediate slope beyond the reef, a composite which may function as a superecosystem (see Fig. 1). This is the environment Smith (1978) is apparently emphasizing; it is the environment Stevenson and Marshall (1974) had in mind; it is the environment involved in Gulland's (1972) estimates for shelf areas of the Bahamas and the Caribbean; and much of Munro's work applies to such a composite system. Some confusion may arise in trying to exclude from this shallow-water environment the deep fishing banks not contiguous with coral coasts, since exploratory fishing and the literature reporting thereon often refer to such banks, where large groupers and snappers are to be found. However, since some of these lie far beyond the outer reef slope, Smith's (1978) assumption that deep-shelf demersal fishes derive much of their nutrition from the reefs does not seem altogether tenable. Fishing many of the deeper banks may be a bit beyond the operating capabilities of small-scale fishermen, and, thus, beyond the concern of this workshop.

The superecosystem of the reef and adjacent shallows is a feature amounting to considerably more than the reef per se, and in many locales coastal mangroves are a major interlocking component of this system. Further, there are many tropical areas in which the mangrove input may overshadow that of the reef, and perhaps such areas are more akin to noncoralline shallows than to the environments where reefs are featured. In arbitrarily referring to the reef and adjacent shallows superecosystem, it is recognized that a further step in an exercise of this sort should be to differentiate between the potentials of environments with and those without a mangrove influence.

At one stage in exploring the reef-associated fisheries potential it was hoped that workers might agree upon a standardized classification of habitat categories and could seek thereby to acquire comparable information. A habitat scheme was suggested by the present author, but other workers promptly destroyed this attempt at an ecological taxonomy. They riddled it with exceptions, they suggested modifications so varied that common denominators were impossible. No doubt some of them will even be reluctant to accept a discussion of the supposed overall average conditions as developed in this paper.

Turning to the fisheries potential of this generalized superecosystem, it is immediately evident that, with the prevailing species diversity, single-species models do not apply. The next thing to try is the modeling of interacting species, then a consideration of the yields of multiple, interacting species. Actually, multiple interactions must be involved in almost every demersal fishery, but, practically speaking, this has been conveniently ignored where the harvest is focused on relatively few forms. On the other hand, in tropical areas, where the gear commonly used may take as many as 25 important species and several times as many more incidental, interacting forms, any approach failing to assess the overall potential would be very inadequate.

Thinking of the overall potential, a simple first step is to blend the prospective yields into biomass and to consider an integrated harvestable yield or sustainable biomass harvest from the superecosystem. For a first approximation of this integrated harvestable yield or potential sustained biomass of the reef/lagoon/mangrove (where it applies) superecosystem, interpretations based on basic ecology, on abundance observations, on catch data, and on catch observations have been considered.

Abundance data are generally of little or no use for this purpose and can even mislead the unwary. Fish cluster in spectacular concentrations, and can exceed 300 g/m^2 in these environments (Stevenson and Marshall, 1974). Though such concentrations have been the focus of many significant studies of fish assemblages (not reviewed here), much of the work of this sort provides very little information on the overall adjacent areas required for the support of the biomass observed. Also, abundance or standing stock figures never provide direct production information, even though some fair guesses might be ventured, particularly if abundance information is available for the adjacent shallows as well as for the reef. For example, one might attempt to calculate yields by assuming that the growth and life span of the species of concern approximate those known for related forms or, as Bayliss-Smith (unpublished ms.) has done, generalizations might be attempted from other work as to the yield level that is to be expected from a given fish biomass. Finally, note must be taken of the frequent interest in using artificial reefs, sometimes rather elaborate in design, to increase the abundance of fish. While one cannot deny some net increments from such practices, particularly since adequate space and cover are important for reef fish communities (Sale, 1977), the basic supporting potential of the areas in question may be limiting, which means that artificial reefs may serve largely as attractants rather than as production systems.

Attempts to apply a basic ecological approach to ascertaining the prospective biomass yield seek the answer to a simple ecological question; namely, what is the excess of production over respiration for the environments in question? For reef systems, this approach has attracted considerable attention, since the gross productivity of coral reefs and the grass flats in adjacent lagoons is about as high as any found in natural systems. A pioneering quantitative evaluation of reefs by Odum and Odum (1955) was followed somewhat later by the more comprehensive Symbios Expedition (Johannes et al., 1972), which showed one reef tract at Enewetak to be a slight net consumer, whereas another produced twice its respiratory demands.

As it stands, it is clear that data on net basic production will have to be far more extensive, with a consideration of influences not well understood as yet, before such information is used for fishery evaluations. For example, ecological studies of this sort are not taking into account the response of the ecosystem to harvesting practices. In a table in E. P. Odum's (1971) ecology text showing entries both for the production inputs in Long Island Sound and for the respiration demands, there is very little or no net production. If one were to consider the Long Island Sound fisheries potential from such a tabulation, one would conclude that no harvests would be possible, yet the Sound is an area from which great quantities, particularly of shellfish, are harvested annually. Marshall (1970) went through a rather similar tally in making rough estimates of production and demand for four estuaries in southern New England, and arrived at demand figures that required all the production estimated. Knowing that these estuaries are harvested intensively and continue to sustain good yields of scallops and other shellfish, as well as flounder, striped bass, and other finfish, he concluded that, when not harvested, any such system operates as a closed cycle and tends to consume its production, whereas harvests can often short-circuit such a closed cycle of production and respiration. In essence, this means that a system must be harvested if one is to make an appraisal of its yield potential.

Finally, there is the consideration of catch data. Information now available adds considerably to the summary of such data provided by Stevenson and Marshall (1974). Yields of finfish approaching or in some places even exceeding 2 tons km^2 yr are on the high end of the spectrum, while yields far below this may represent either underutilization or overfishing. Perhaps the best summary of catches is in Table 1 of Munro's (1978a) paper, which lists the greatest reported annual catches from Caribbean and Bahamas sites in the period 1964-73. Another source is the summary for the same areas offered in the report of an FAO workshop (1978).

More important than the catch per se are the insights such information may give regarding yield potential (see Table 1) Munro (1978a), using a surplus yield model based on extrapolations in which the number of canoes in the fishery differed from area to area, gives a figure of 4.1 tons/km²/yr as the maximum to be expected in managing present fishery practices off the south coast of Jamaica In the Report of the FAO/IOP Workshop on the Fishery Resources of the Western Indian Ocean South of the Equator (1979), catches from Indian Ocean sites are calculated against trap fishing intensity to suggest a potential harvest of 5 tons/km²/yr Though the latter appraisal is based on sketchy information, the two approaches reinforce each other. They about equal the maximum yields Stevenson and Marshall (1974) had noted in reviewing the literature; they are roughly in accord with Gulland's (1971) maxima, calculated from the tabulations presented, of 2 4 tons/km²/yr and 4 tons for the Bahamas and Caribbean shelf areas, respectively; and they are similar to the maximum reported by Bayliss-Smith in a comparison of four atolls and reef-bordered islands with Lakeba, Fiji, yielding about 4.4 tons/km²/yr (unpublished ms.).

Table 1. Estimates of potential fisheries yield of coral reefs and adjacent shallow water environments

Munro (1978) South of Jamaica	4 1 tons/km²/yr—surplus yield model from concurrent trap fishing intensities with some recognition of seine and gill net catches, i e , demersal plus neritic pelagic fishes taken
FAO (1978) Western Indian Ocean	5 tons/km²/yr—extrapolating from trap catch data, different areas
Stevenson and Marshall (1973) Worldwide	4 7 tons/km²/yr—highest yield found, presumably diverse gear and for both demersal and neritic pelagic finfish
Gulland (1971) Caribbean	2 5 tons/km²/yr for Bahamas, 4 tons for Caribbean—presumably involves diverse gear; about 80% neritic pelagic, the balance demersal
Bayliss-Smith (Unpublished) Pacific	4 4 tons/km²/yr—maximum yield from four atolls and reef-bordered islands

The canoe fishery analyzed by Munro was largely a trap effort, but other gear, including seines and gill nets, were involved in the fishery, and he referred to the potential as including demersal plus pelagic neritic fishes. The FAO projection was for traps only. The maxima mentioned by Stevenson and Marshall and Bayliss-Smith presumably included all fishes and Gulland referred both to demersal and to a component of pelagic neritic amounting to about 80% of the total. Apparently these projections generally do not include living resources other than fishes. One should add the potential in lobsters shellfish, bêche-de-mer, turtles, etc., plus miscellaneous gleanings from off the reef, which Hill (1978) notes, in a study on American Samoa, can be both high and relatively noncompetitive with other production.

The consistency just reported is disrupted by the observations of A.C. Alcala, who recorded yields approaching 15 tons/km^2/yr for two successive years on the Sumilon Island Reserve in the Philippines (unpublished presentation at the recent Pacific Science Congress*). Seeking to reconcile Alcala's observations, taken with considerable care, with the general yield levels apparent from other reports, three possibilities come to mind: 1) a yield of 15 tons may represent a highly localized situation not adequately averaged out with due consideration of the total support area involved, 2) it would be a mistake to assume that interpretations from data available prior to Alcala's work can be used to suggest a generalization of the potential of reefs and adjacent shallows, and 3) the suggestion of 4 to 5 tons/km^2/yr may be upheld as a generalization for the yield potential, but one must be aware of the extreme variability that might reflect different environmental situations. Since almost all other reported catch records fall below the suggested potential of 4 to 5 tons, and since the reef and reef flat areas of Sumilon Island are small and thus concentration effects might be expected, Alcala's observations should probably be regarded as unique rather than as an indicator of harvest prospects in general.

Though the data base is sketchy, the potential suggested in Table 1 is impressive, i.e., it is not far below the yields of some of the better temperate latitude fishing grounds. This suggests that advisory appraisals of the living marine resources of reef and adjacent shallows can now be made with added confidence. By blending area measurements, a generalized value for potential, and a sound on-site review of specific local conditions, one could offer a reasonable first appraisal for almost any area. Certainly one should be cautious before advising the local people to count on harvests as high as 4 tons/km^2/yr of finfish alone, but along with such caution, the possibility of supplementary catches from other categories should be considered.

Accepting that a finfish harvest of 3 to 5 tons per km^2 can be expected annually from the superecosystem discussed, an obvious follow-up question is "How does this relate to the standing stock?" Since, as noted, abundance surveys have usually been carried out with a focus on the reef habitat, and have generally failed to relate population levels to the overall area of support, this question is not answerable at present. Actually one might instead deal with the subject somewhat in reverse. That is, by using data from elsewhere in which yields and standing stock have been compared, one might attempt a first-order appraisal of the standing stocks of the reefs and adjacent shallows.

After a first appraisal, as suggested above, more thorough evaluations should be undertaken. It is likely that reef habitats may be unusually sensitive to fishing pressures (see Huntsman and Manooch, 1978, for a discussion of this). Obviously, one of the needs for ongoing management is to acquire more catch record data. To the extent that good catch data become available, one can progress beyond verifying or modifying estimates of the overall potential made thus far and can turn to a consideration of the catch components. As with temperate latitude fisheries, the average size in the catch is bound to decrease with ex-

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*Also at the Pacific Science Congress, S.S. Amesbury reported on fishing yields for areas in the Mariana Islands, but he had not at that time converted catch data to biomass yields.

panded fishing, but a pattern not as common to temperate regions is likely to unfold; namely, a shift in species composition. Thus, the management issues must focus not only on optimum yields but also on preferred species and size groupings. In fact, the shift in species may be sufficiently disadvantageous as to suggest abstaining from fishing certain areas to enable preferred species to repopulate. Several observers, including Johannes (1978), have noted situations in which native inhabitants have, under village rulings, traditionally closed off sections of reefs to realize recovery of populations. In comments not altogether facetious, C. Lavett Smith has suggested (personal communication) rather drastic measures to decimate a fish population that is biased unfavorably and thereby to allow for the recovery of desired species. The point to be made is that complex management problems are involved in taking the important next steps beyond appraising the integrated harvest potential.

To improve the first-order estimates of the overall potential, better and additional catch observations, plus more experimental fishing such as Munro (1978a and other reports) undertook south of Jamaica, would be very useful. There is also a need for greater clarity in gathering and reporting catch data in order to remove ambiguities as to what catches are referred to, what areas are fished, what environments are involved, etc. Admittedly, in practice there are many obstacles to achieving this objective. Finally, special projects comparing the fishing impact on specified areas should be undertaken. One might run comparison experiments at Enewetak, for example, where there are multiple, replicate coral knolls that have been unfished since the atoll was used as a bomb test range a quarter of a century ago. Munro (1978b) has pointed out that, since Pacific reefs and lagoons are generally environmentally discrete entities, an exponential surplus yield model could be derived if suitable catch records were obtained for a minimum of 30 such areas.

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The Application of Hydroacoustics to Stock Assessment for Tropical Small-Scale Fisheries

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Abstract

Hydroacoustic techniques have potential application to stock assessment for tropical small-scale fisheries. The advantages of hydroacoustic techniques include independence from fishery catch statistics, favorable time scale, and high sampling power. A major disadvantage is poor species discrimination. An approach used in a similar mixed-species assessment problem in the near-shore Southern California Bight is presented. Hydroacoustics was the primary sampling technique. Subsampling for species identification was done by lampara seine. The advantages of this complementary technique approach to assessment problems are discussed.

Introduction

The great variety and number of species which characterize tropical ecosystems appear to dictate a fishery management approach which differs from the classic single-species methodology used for resource assessment in higher latitudes. In fisheries which exploit a large number of species together in the same fishing areas, the data collection and analysis tasks involved in assessing each species separately would be beyond the capacity of the limited financial and manpower resources available (FAO, 1978).

Hydroacoustic techniques for resource assessment are relatively recent, and their use in resource surveys has increased considerably in the last decade (Thorne, 1977; Mathisen, 1975). Although most applications to date have been in predominately single-species environments, hydroacoustic techniques have favorable potential for assessment problems in tropical fisheries. The advantages and limitations of hydroacoustic techniques and an example of an approach developed for a similar assessment problem are presented in this paper.

Principles of Hydroacoustic Assessment

About 1930, it was discovered that the ultrasonic depth sounder could also be used to detect fish, and subsequently it became widely used for fish detection and quantification. Although special research echo sounders and sonars and several types of automatic signal-processing systems have been developed for fisheries investigations, the basic part of most systems for acoustic surveys is still a standard depth sounder or a sonar (horizontally ranging echo sounder). Acoustic energy at a given ultrasonic frequency (usually 20 to 200 kHz) is transmitted into the water in a cone-shaped beam. Echoes from discontinuities such as fish or the bottom are received by the transducer, amplified and displayed in some fashion.

Acoustic techniques are based on the fact that the amount of sound reflected from fish targets is a function of their abundance. The speed of sound propagation through water varies with temperature, salinity, and depth, but is usually between 1,400 and 1,500 m/sec. As sound propagates, the sound *intensity*—that is, the energy per unit area in the sound wave—decreases because of geometric spreading and absorption. Thus, the sound intensity (I_r) at some range (R) can be described by the relationship

$$I_r = \frac{I_1 \; 10^{-aR}}{R^2} \qquad (1)$$

where I_1 is the intensity at a unit range from the transducer (sound source), and -a is the attenuation coefficient, which is a function of the sound frequency and the water temperature and salinity.

When sound strikes a target, the intensity of the reflected sound is proportional to the intensity of the incident sound; that is,

$$I_r = kI_i \qquad (2)$$

where I_r is the reflected sound intensity a unit distance from the target, I_i is the incident sound intensity, and k is a constant dependent upon the reflective properties of the target.

As the reflected sound returns to the transducer, it is further reduced by geometric spreading and absorption. The generalized expression for the echo intensity I_e measured at the transducer is therefore

$$I_e = \frac{kI_1 \; 10^{-2aR} \; b^2(\theta,\phi)}{R^4} \qquad (3)$$

where $b^2 (\theta, \phi)$ is a factor for the transducer directivity pattern and the other symbols are as defined above. The factor for transducer directivity is equal to 1.0 on the acoustic axis and to less than 1.0 at all other angles. The equation is often expressed in decibel units, which measure ten times the ratio of intensities in logarithmic units; i.e.,

$$10 \log_{10} (I_e / I_1).$$

In decibel (dB) units, the sonar equation is:

$$EL = SL + TS - 40 \log R - 2aR + 20 \log b (\theta,\phi) \qquad (4)$$

where EL is the echo level, SL is the source level ($10 \log I_1$), and TS is the target strength (10 log k).

The target strength depends on the size of the target and on its reflective characteristics. The target strength of fish is generally a function of size, but it varies between species (especially between those with and without a swim bladder) and is very dependent upon the aspect (orientation) of the fish.

There are basically two types of acoustic data-processing: 1) counting, and 2) amplitude measuring. Counting techniques depend on resolving and enumerating individual targets. Amplitude-measuring techniques are based on the principle that the reflected sound intensity (amplitude-squared) is, for a given size and species of fish, directly proportional to the fish abundance (assuming appropriate range corrections are made). The proportionality constant includes the acoustic system parameters and the mean fish target strength. Within these two basic types, the analysis technique may utilize echograms, oscilloscopes, or more sophisticated, automatic signal-processing equipment.

Advantages of Hydroacoustic Techniques

The advantages of hydroacoustics relative to other resource assessment techniques are: 1) independence from fishery catch statistics, 2) favorable time scale, 3) relatively low operational costs, 4) low variance, and 5) capability for absolute population estimation.

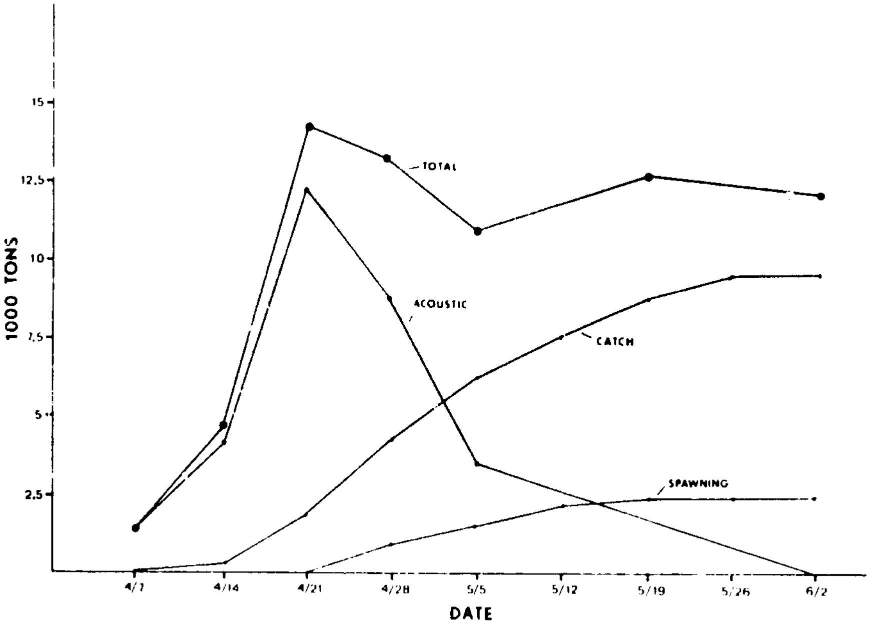

Figure 1. Estimates of herring prespawners, spawning biomass, catch, and total stock biomass for the Gulf of Georgia sac-roe herring fishery at weekly intervals during 1976.

Independence from fishery catch statistics allows application to unexploited or poorly exploited stocks. It also frees acoustics from the long lag times associated with catch statistics, leading to the second advantage. Unlike fishery catch statistics which are obtained only after the fishery harvest, hydroacoustic techniques can be applied prior to harvest. This feature is exploited in the management of herring stocks in Alaska and Washington. In these cases, acoustic surveys are conducted immediately before a fishery, and harvest quotas are established on the basis of them. The time scale for the management of the Gulf of Georgia herring stock in Washington is particularly impressive. Management is conducted on a week-by-week basis during the period of the fishery. An acoustic survey is conducted the first night of the week, the results are analyzed the next day, including establishment of a quota for the week, and the fishery is opened the following day. Figure 1 illustrates the acoustic data, plus the weekly catch and spawning data which input to the management decisions.

The short time scale is necessary for the Gulf of Georgia herring, an intense fishery on a migrating, spawning population. Such a time scale is not necessary for tropical small-scale fisheries. However, the scale is indicative of the minimal time and effort required for hydroacoustic assessment and the lack of lag time compared to other techniques.

As a result of the high sampling power and efficiency of hydroacoustic techniques, operational costs are relatively low. The major operational costs are associated with ship time and manpower for data collection and analysis. In all three categories, the costs are usually much lower than those associated with exploratory fishing.

The low variance associated with acoustic techniques is also the result of the high sampling capability. The sampling power of hydroacoustics is at least an order of magnitude higher than that of exploratory fishing.

The last advantage is the capability for absolute population size estimation. This advantage is not paramount, since most techniques for fishery management are based on relative indices such as CPUE. However, the capability for absolute estimates allows reasonably precise management without a historical data base, and ultimately leads to a much better understanding of production processes (Thorne, 1978).

Limitations of Hydroacoustics

The limitations of acoustic assessment techniques are: 1) poor species discrimination, 2) little or no sampling capability near the bottom and the surface, 3) relatively high complexity, 4) high initial investment, and 5) lack of biological samples.

The partition of acoustically derived biomass estimates into various species requires auxiliary information, which is usually obtained by subsampling with nets. There are possibilities for hydroacoustic identification of species, or at least minimizing uncertainty so reliance on costly direct capture techniques is reduced. Such identification depends on establishing species-specific distributional patterns. Unfortunately, this establishment requires comparison of acoustically measured distributional patterns with net catches. Thus, as noted in Thorne (1976), "Species information must ultimately come from capture techniques—ironically, the same techniques whose glaring deficiencies made the potential of hydroacoustics so attractive in the first place."

Echo-sounding techniques are limited in their ability to survey near the surface and bottom of the water column and cannot resolve on bottom targets. The limitations near surface and bottom are a function of several parameters, especially pulse length. Boat avoidance is an additional complication for near-surface fish. An example of this problem is illustrated by the echogram from a concentration of herring and juvenile pollock in southeastern Alaska (Fig. 2A). Even though those fish are supposedly "pelagic," they are distributed on and just above the bottom with an unknown portion acoustically indistinguishable from the bottom. Often this problem can be solved or minimized by taking advantage of diel vertical changes in distribution. Figure 2B shows the same concentration of fish at night. It is now completely pelagic and accessible to the hydroacoustic gear. Other approaches which can minimize this limitation include deep-towed transducers for better near-bottom resolution, sonars, and up-looking transducers for near-surface distributions.

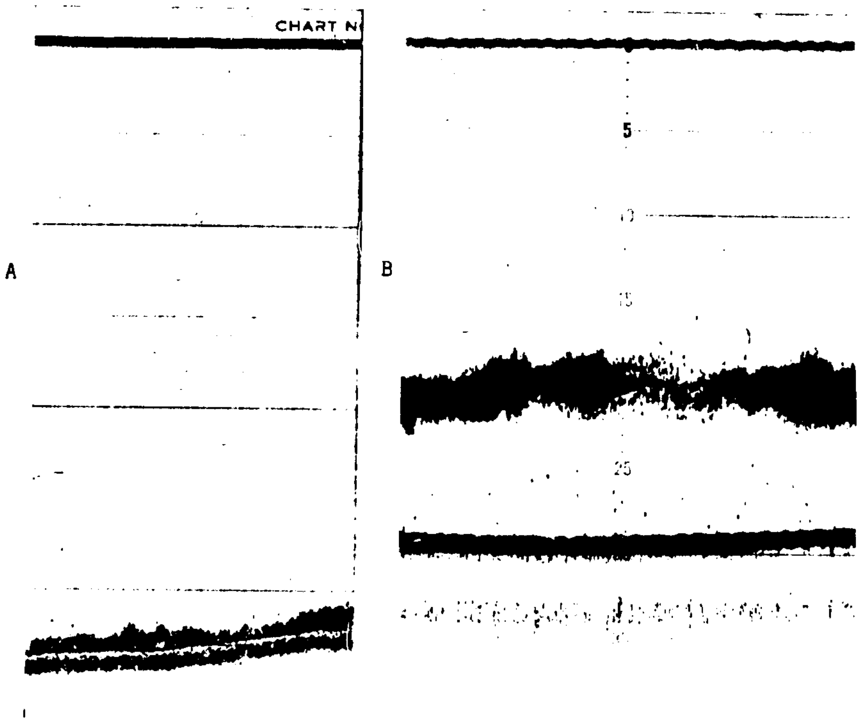

Figure 2. Echograms showing mixed layer of herring and juvenile pollock in Auke Bay, Alaska, January 14, 1975, during afternoon (A) and evening (B), depth scale in fathoms.

A third disadvantage of hydroacoustic techniques is their relative complexity. Fishery management is generally the realm of biologists, who typically have difficulty with the mathematical, electronic, and physical concepts of hydroacoustic techniques. Also, since acoustic techniques are highly specialized and comparatively recent, training in these concepts is not usually included in the education of fishery scientists. In addition, since knowledge of the hydroacoustic system parameters is critical for successful application, users of hydroacoustic techniques should have good access to hydroacoustic calibration facilities. As a result of this complexity and lack of understanding, there have been many misapplications of hydroacoustic techniques, prompting the statement in Thorne (1978) that "historically the biggest source of error is the result of biologists applying acoustic techniques without having the slightest understanding of them.

The problem is aggravated in developing countries where fishery managers often do not have access to either the training or the support facilities. The author has taught at several one-month FAO NORAD training centers in acoustic techniques (Argentina, 1971, India, 1973, Philippines, 1975, and Morocco, 1978) as well as special two-week short courses at the University of Washington. The general conclusion from this experience is that hydroacoustic techniques require considerably more training than can be obtained in these short time frames. Successful adoption of hydroacoustic techniques has been generally limited to situations where an FAO project or regional center has provided an opportunity for considerable experience.

Although operational costs are low, initial investment is relatively high. A wide variety of echo sounders are commercially available and could be used in some applications. However, since they are not designed for scientific applications, they must be used with caution and considerable understanding (Thorne, 1977b). Scientific quality research echo sounders are commercially available at reasonable cost. However, data processing equipment for techniques such as echo integration are limited and expensive, although their availability is increasing. The cost of acquiring a minimal system for scientific quality data collection and echo integration analysis is on the order of $50,000.

The last limitation is lack of biological samples. In general, this is a minor concern, since complementary direct capture techniques are needed for species identification in most cases.

An Approach to a Multispecies Assessment Problem

The problems associated with environmental impact studies at offshore cooling water intake systems off southern California are surprisingly relevant to those in stock assessment for tropical small scale fisheries, despite the seeming differences in objectives. One of the objectives of the environmental impact studies is to determine water intake design, location, and operational procedures which minimize fish entrapment. This objective requires information on the offshore fish density and distribution (Thomas, 1979).

Like tropical ecosystems, the near-shore area of the Southern California Bight has high species diversity. However, the primary impact of the cooling systems is limited to a few species. The assessment conditions are unfavorable in several other aspects, including shallow water, wide variety of behavior patterns, near-surface schooling fishes, and mixed-size classes.

Research was conducted during 1976-79 to develop an optimal set of techniques for use in the fish entrapment studies. Techniques which were evaluated included commercial CPUE, various direct capture techniques, including lampara seine, horizontal and vertical gill nets, bottom and midwater trawls, acoustic techniques, and optical techniques. CPUE was rejected because of lack of synopticity, variable selectivity, and large variance. All direct capture techniques were similarly rejected as the primary sampling tool because of variable selectivity and large variance. Optical methods were rejected because of limited and variable sampling power.

The need for high sampling power and detailed distributional information dictated the use of hydroacoustic techniques. However, since identification of echoes to a species level was required, a net sampling program was developed to subsample a portion of the targets. This complementary technique approach minimized the major limitation of hydroacoustic techniques: poor species discrimination. The second limitation, poor near-surface and bottom resolution, was minimized by surveying at night with a relatively small vessel and towing a near-surface transducer ahead of the boat from a boom projected from the bow. Relegation of net capture techniques to a secondary sampling role limited the problems caused by low sampling power. Considerably fewer samples were required for species composition than for density estimation. In addition, simultaneous deployment of hydroacoustic and net sampling techniques provides information from which some aspects of net selectivity and efficiency can be evaluated.

The research area is characterized by shallow water in which numerous size classes of each species are present. Each of the primary species is characterized by schooling habits. Several species are known or thought to exhibit movements daily or seasonally. Most of the species exhibit marked diel shifts in behavior, generally schooling tightly during daylight and dispersing during periods of feeding at night. Several of the species are found throughout the water column, while others are oriented primarily to the bottom. They differ in size range. In consideration of these behavioral and life history observations for the species of primary concern, optimal net sampling techniques were chosen to identify acoustic targets on the basis of the following characteristics: 1) to be able to fish the entire water column at the location of an observed acoustic target in the shortest period of time with the highest efficiency; 2) to have the ability to capture and retain the largest-size range of fishes with a similar catchability; 3) to have the ability to capture the largest variety of species with the least difference in catchability; 4) to be able to fish effectively over the widest variety of habitats; 5) to fish with similar power throughout various diel and seasonal periods; and 6) to be cost-effective. Clearly, no existing single net sampling method possesses all these characteristics. However, the particular characteristics of the research area led to the choice of a lampara seine as the primary net capture technique. Selectivity was a major factor in the choice. In general, the least selective of fishing gear used in marine waters is the surrounding nets; i.e., purse ring and lampara seines. Their low selectivity results primarily from small mesh size. They are also relatively efficient for a large variety of species. The lampara seine probably requires the least amount of time of all the surrounding nets from deployment to closing on an observed fish target.

The lampara net was selected as a gear type to subsample acoustic targets in the offshore study area for the above reasons. When fished properly, the lampara seine probably has the ability to capture a larger variety of species (highest relative efficiency) and a larger size range of individual species (lowest relative selectivity) than any other single net which could be deployed to capture acoustic targets located throughout the entire water column.

The complexity of the lampara seine makes description a difficult task. However, the following data are pertinent to the net used in 1978. The net used for sampling the acoustic targets consisted of a 35 m corkline at the bunt of the net. The bag of the net measured 12 m deep and was constructed of approximately 1 cm stretched mesh. The thread of the net (the section around the bag which represents the initial pursing sections) was constructed of heavy material with an approximate mesh size of 2.5 cm. Attached to the sides of the bag (partially by the throat) were two 85 m corkline wings which tapered into 100 ft. rope leads. A large float was attached to the primary lead rope and the secondary lead rope was fixed to the boat. The retrieval of the rope leads and wings was made with a dual-hydraulic drive system.

Obviously, the choice of complementary capture gear depends on the particular characteristics and requirements of the study. The lampara seine met most of the needs of the fish entrapment studies, but it was necessary to complement it with gill nets, since the seine could not be deployed safely within 60 m of an intake structure and because information on the vertical distribution of species was needed. These particular requirements are not relevant to fishery management problems. However, depending on the depth and vertical distribution, trawling techniques might be required either as primary or complementary capture techniques.

Discussion and Conclusions

Far too often, fishery managers tend to evaluate management techniques in the framework of selecting the single best one. All management techniques have both advantages and limitations, and the relative weight of these varies with the specific circumstances. Often the critical limitations can be minimized by using complementary techniques. As hydroacoustic techniques develop and become better understood, their advantages relative to other techniques are becoming more widely appreciated, with corresponding increase in their use. All fisheries have specific management problems, and a best technique or set of techniques needs to be tailored to those specific needs. The same is true of hydroacoustics as an assessment technique. Considerable flexibility in the procedures is available to best suit the characteristics of the fish stock. This flexibility includes the use of complementary techniques in order to minimize specific limitations. Often the greatest limitation of hydroacoustics is the poor species discrimination, and any application of hydroacoustics to stock assessment in tropical small-scale fisheries must account for this limitation either by management on a total biomass basis or by developing suitable complementary techniques.

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Age and Growth Studies on Tropical Fishes

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Abstract

Reliable age and growth data are necessary for the scientific management of fisheries. Common biological characteristics of tropical fishes, such as weakly expressed annual or seasonal cycles of growth and reproduction and their population structure consequences, have made age and growth rate determination difficult for many species. Knowledge and experience gained from studies on temperate fishes utilizing anatomical and statistical techniques can be successfully adapted to the tropics. However, due to the complexity of interpreting the significance of time markers in calcareous structures, or of unraveling population dynamics, this has proven to be a challenging and sometimes imprecise science. The advantages and disadvantages of different traditional aging methods are discussed, with particular reference to problems encountered in the tropics. Further improvements in the success rate of these approaches will depend primarily upon the careful execution of already established procedures. A new technique which relies upon the existence of daily growth units (marks) in otoliths offers a substantial advantage because of its suitability for accurately aging at least the early stages of all marine and freshwater fishes. Under the proper circumstances, adult ages and growth rates can also be determined. Further research may help to increase its usefulness for the adults of more species. The importance of this technique is illustrated by examples of potential and realized applications of otolith microstructure data to studies of tropical fishes.

Introduction

Information on the age and growth of fishes is a central element in fishery management analysis. Growth rate data are essential for production estimates. Even preliminary studies may be useful in first identifying exploitable species. Age-specific parameters such as mortality and fecundity are the basis for fishery analysis using dynamic population models. Other types of information that can be obtained from detailed age and growth studies include description of the population structure, determination of the timing and frequency of spawning, individual and population growth responses to environmental changes such as population density or habitat alteration, and annual or short-term variation in recruitment success. These data, whether of a basic life history nature or directly applicable to fishery statistics, all greatly contribute to our understanding of the biology of fishes. Furthermore, in a more applied sense, we can extend this age and growth information to examine past responses and predict future changes in relation to a variety of exploitation schemes.

The utility and importance of age and growth studies are beyond question; unfortunately, the means to effect them are far from standardized, and serious difficulties arise when one attempts to attain the higher levels of precision and accuracy needed for more detailed studies. In the case of small-scale fisheries in tropical waters, the problems are greater, even for relatively gross estimates of age and growth. This is due to two factors: the biological properties of tropical fishes (or, more appropriately, fishes in the tropics, to indicate the role of environment) and the greater difficulty in obtaining large representative samples and statistics for these fisheries.

It is not intended that this contribution serve as a manual for aging tropical fishes; rather, it is a review of the current status of our knowledge and methodology for the aging of fishes in general, with special reference to the tropics. This discussion emphasizes the assumptions basic to each method and then considers some of the significant advantages and disadvantages of the different approaches. A relatively recent development in aging studies is the analysis of otolith microstructure to obtain extremely detailed growth history information. It is this method which offers the only true breakthrough in the study of tropical fishes. Appropriately, this technique is reviewed and discussed in greater detail, with some brief examples of both realized and potential studies. Finally, there is a short section on important areas for future research.

There is a vast literature on age and growth determination for fishes. Basically, the methodology falls into three types: 1) direct measurement of growth in certain individuals and extrapolation to the population—e.g., mark-recapture studies or growth in confinement, 2) statistical approaches based on measurements of large samples—e.g., modal progression in a time series of length-frequency histograms, and 3) aging individuals on the basis of regular periodic markers in hard structures (usually calcified), such as scales, otoliths, and bones (anatomical method). Good reviews of approaches to aging fishes can be found in Graham (1929), Menon (1950), Chugnova (1959), Tesch (1971), Weatherley (1972), and Ricker (1979). Several authors have dealt specifically with tropical fishes (Menon, 1953; DeBont, 1967; Fryer and Iles, 1972; and Lowe-McConnell, 1975). The major subjects of discussion in most of these reviews can be classified into the following topics: 1) manual-style instructions on the mechanics of aging studies, 2) criteria for validating the temporal significance of age markers, 3) exogenous and endogenous causes for the appearance of these marks, 4) statistical treatment and mathematical models for data, and 5) numerous examples. Examination of these papers as well as of a great many specific publications on both tropical and temperate species reveals that there have not been any truly substantial or generally applicable improvements in the anatomical methods since their discovery at the end of the last century. Second, critical testing of the validity of annual or seasonal marks, particularly in tropical fishes, has often been ignored or only weakly attempted because of the success of these techniques in fishes of higher latitudes. Many workers seem to be satisfied with an assumption of analogy, or a sometimes biased view of less than convincing "corroborating" length-frequency analysis. Finally, the weak or complex expression of age marks in many tropical species makes what in temperate fish is a subjective discrimination problem an even worse situation.

Compared to temperate species, tropical fishes, both freshwater and marine, live in environments which on the average show less seasonal variation in such abiotic and biotic factors as temperature and productivity. To the extent that recognizable zones on scales or otoliths are reflections of variations in growth rate in response to such factors, it is natural to expect that the marks would be less well developed or even absent in the tropics. Many authors report that no easily observable or interpretable marks occur in the hard parts of a number of tropical species. Nevertheless, critical analysis not only of environmental parameters but also of fish growth, ecology, and behavior has demonstrated that seasonal variation, sometimes substantial, exists in many tropical habitats and that periodic marks do occur on calcareous structures. Obvious examples include the predictably cool monsoon rain periods alternating with hotter and drier weather. The effects of resultant changes in temperature, salinity, turbidity, and food availability are discussed by a number of authors including Chevey (1933), Menon (1953), and Sarojini (1957). Small differences in temperature (5°C or less) may be correlated with changes in growth and otolith composition (Poinsard and Troadec, 1966, LeGuen, 1976), and spawning rhythm (Munro et al., 1973). The fact that these are just apparent correlations should be emphasized, since the mechanisms involved have not been demonstrated. Reproductive processes in fish involve substantial shifts in nutritional and metabolic pathways (Weatherley, 1972, Iles, 1974) which usually have resultant effects on somatic growth. Thus, spawning activity, and particularly the preceding gonad maturation, may be expected to result in discernible marks on scales, bones, and otoliths. This has been an expected observation in temperate species with restricted breeding seasons (see Blacker, 1974, for otolith examples), but the supposed greatly extended or even aseasonal spawning pattern of tropical fishes led many workers to believe that such effects would not be seen in these fishes. However, seasonal patterns of reproduction are now very well documented in a wide variety of marine and freshwater species (e.g., Sarojini, 1957, Hopson, 1965, Randall, 1961, Fryer and Iles, 1972, Lowe-McConnell, 1975; and Talbot et al., 1978). The occurrence of scale or otolith marks has at least been closely correlated to reproductive activity in some tropical fishes (Holden, 1955, Garrod, 1959, Hopson, 1965, Krishnayya, 1963, Poinsard and Troadec, 1966, and Pantulu, 1962). Even if an aseasonal pattern exists for the population as a whole, it is possible that individual fish may show a regular cycle, which, if determined from gonad studies and reflected in calcified structures, could also be used for aging.

Thus, the major difficulty in directly aging tropical fishes is the evenness of growth processes throughout the year, a generalization with more exceptions emerging, and one which may only be valid in comparison to certain high-latitude species. Regular seasonal variability in reproduction, growth rate, feeding intensity, and movements is readily observable in the tropics. More detailed analysis of hard structures is needed to determine whether the fish are recording such changes. Otoliths of many of the species have an overabundance of potentially decipherable marks; determining their significance is a major challenge for the future.

The perplexing nature of marks in the otoliths, scales, and bones of tropical fishes is exacerbated by the equally great problems encountered in statistical approaches used either as verifying criteria or as alternate aging methods. The most significant of these complicating circumstances is that recruitment is typically extended over a long period in the year in many species. As noted above, this is made more problematical by the often irregular and incomplete sampling programs available to small-scale fisheries. Thus, the value of a major method of analysis, the examination of length-frequency histograms, can be decreased because of the broad overlap of age classes, even in the youngest categories. Further discussion of these statistical approaches is included in the following section.

Review and Discussion of Methods

Time Markers in Calcified Structures

For information on this well-established and widely practiced method, see the general reviews referred to earlier, as well as those on otoliths by Blacker (1974) and Williams and Bedford (1974), and on bones by Menon (1950). Time markers of very short periodicity—e.g., daily marks in otoliths—will be discussed separately below. A wide variety of structures is involved in this method, typically scales, otoliths, and various bones such as fin spines, vertebral centra, cleithra, hypurals, and skull bones. The basic premise of this approach is that periodic changes in the growth rate of these structures (both in form—e.g., circuli spacing on scales—and or in composition—e.g., hyaline and opaque zones of bones and otoliths) are reflections of changes in growth of the fish. More specifically, the fish may be experiencing endogenous and or exogenously induced cycles of somatic growth rate, or perhaps just protein and calcium metabolism (protein and calcium being the major constituents of these structures). The nature of the causative relationship between the ecology, behavior, and physiology of the fish and the observed marks is an important and continuing area of investigation. Potentially, experimental approaches combined with detailed structural and chemical analyses should yield the greatest insights (e.g., references in Blacker, 1974, Simkiss, 1974, Bilton, 1974).

In spite of a number of contradictory results in the literature (only some of which are artifacts of terminology and methods), there still are generally observable patterns in the calcified structures of temperate fishes. To summarize briefly, in bones and otoliths, fast or accelerating growth zones usually appear as broad, opaque (optically dense) zones, while slow growth zones are narrower and hyaline (more translucent). As pointed out by Mina (1968) and others, the terms "hyaline" and "opaque" are relative terms which refer to optical comparisons of adjacent material. Even under relatively low magnifications, these "major" zones, which are often demonstrated to be seasonal in occurrence (i.e., one or two each per year), are seen to consist of a gradient of optical densities and are composed of a number of less distinct discontinuities defining "minor" hyaline or opaque areas. The significance of these minor zones is being elucidated in microstructural studies (see below). In scales, slow growth zones are represented by more closely spaced circuli or sclerites or, in some cases, by irregular circuli and evidence of resorption.

The highly seasonal nature of growth and reproduction is accepted to be related in some way to the appearance of these marks. In many cases, this has been clearly demonstrated, and the marks are confidently used for age determination (well-executed recent studies involving subtropical or temperate families having representatives in the tropics include McErlean, 1963; Moe, 1969; Tong and Vooren, 1972; Johnson, 1972; Van der Waal, 1975; Warner, 1975;

Cambell and Collins, 1975; Powell, 1975; Gregory and Jow, 1976; and Davis, 1977).

There are a number of advantages to this widely used method. It affords a relatively simple way to determine age of individual fish, thereby gaining information on intrapopulational variation as well as establishing population parameters from representative samples. A powerful application is the ability to retrieve historical data from the growth records of individuals by back calculation (see below). This enables investigators to extend their growth studies into periods when population and environmental conditions may have been different, allowing, for example, for the analysis of growth trends with respect to different fishing pressure. Finally, this method of age and growth determination is not as dependent upon extensive representative sampling as some of the techniques that follow.

Age determination by time markers on calcareous structures is clearly the preferred method, the only substantial disadvantage is the difficulty of its application and the extreme care and extensive study that may be necessary to establish its validity in a particular situation. Once established, the amount of technical skill and elaborate equipment necessary can usually be kept to a minimum. In many species, marks are observed which are referred to as false annuli or accessory checks. These are features which may be mistaken for true annual or other periodic marks unless carefully scrutinized. They correspond to the "minor" hyaline and opaque zones referred to above. These accessory marks may or may not be useful for determining age, but this can only be determined once causative factors or patterns are established. In many temperate and tropical fishes it is noted that one of the hard parts, either bones, scales, or otoliths, is the most readable. It is not uncommon to find inconsistencies between counts from different structures, particularly concerning the first few annual or seasonal marks. Often even the best of these structures requires painstaking preparation in order to enhance the visibility of the marks. Finally, there can be a substantial amount of subjectivity involved in discriminating what are considered to be the "true" time markers. For a number of reasons mentioned in the introduction, these problems are exaggerated in most tropical fishes. Many authors simply note that calcareous structures either have no discernible marks or do not show any decipherable pattern. Therefore, it becomes extremely important to take great care to validate the periodicity of observed marks. Graham (1929) and van Oosten (1929) were the first to clearly state a procedure for validating age marks. These criteria have been further elaborated and used by many researchers. However, too many studies, particularly in the tropics, have not followed or have been unable to follow the criteria in a rigorous manner.

A revised list and brief discussion of types of validating criteria follows. Not all are applicable in every case, and some are better than others. Several of them are, in fact, alternate aging methods (*) with which scale, bone, or otolith derived ages and growth rates can be compared. These will be discussed separately below.

1.* Length-frequency analysis of a population sample, Peterson method.

2.* Modal-progression analysis in a time series of population samples.

3.* Comparison with growth rates derived from tag-recapture data or growth in captivity.

4. Determination of the period and timing of mark formation. This is usually carried out by a qualitative and quantitative examination of the margin of the scales, bones, or otoliths in samples taken at different times of the year. This may require special collecting efforts.

5. Determination of the proportionality of growth of the aging structure and the length or weight of the fish. Once a relationship is established and mathematically or graphically described, measurements to earlier formed time marks can be used to back-calculate the growth history of individuals. A growth curve constructed from these data should approximately conform to the curve derived from ages of fish at the time of capture.

6. Comparison of ages derived from different structures; e.g., scales vs otoliths.

7. Tag and recapture studies where the calcified structure itself is also marked, using chemicals such as ^{45}Ca (Irie, 1960), lead (Ickikawa and Hiyama, 1954), or tetracycline (Weber and Ridgeway, 1967; Jones and Bedford, 1968). Here the number of marks between the chemical tag and the margin is compared to the known elapsed time period. This is a powerful tool, but it requires a large effort in time, energy, and money. An easier but related method simply compares the number of annual or seasonal zones on fish of known age. This may be accomplished by tag and release where age is known (e.g., for young of the year) or by holding fish in captivity of some sort. All of these techniques require relatively long periods of time before results are meaningful, and they are also subject to the various biases introduced by tagging and/or artificial confinement. Williams and Bedford (1974) and Poinsard and Troadec (1966) point out an analogous validating technique which relies upon recognition of unusual zones formed in particular years. These marks may be used as a reference point for subsequent counts.

8. Comparison of the empirically derived growth curve to mathematical formulations such as the von Bertalanffy growth curve. This is only one of several possible comparisons (Ricker, 1979). All have different biological and nonbiological assumptions, and a particular one will usually fit the data better than others. However, wildly deviant empirical patterns should be suspect.

9. Correlation of the time of mark formation with various exogenous and endogenous cycles such as temperature, salinity, rainfall, feeding intensity, condition, or reproductive activity. Correlation will not establish a causative relation, but this method will at least help to establish a biological basis for the observed periodically marked structures.

10. Establishment of objective criteria to discriminate marks; avoidance of bias by aging fish without knowing their size; and comparison between readers for consistency.

Criterion 4 is very important, quite straightforward, and gives unambiguous results when it can be properly applied. Complications arise when the marks are found to be formed over a large part of the year or when different age or size classes form them at different times (e.g., Moe, 1969; Williams and Bedford, 1974). The apparent extended period of mark formation in tropical fishes can lead to ambiguous results, especially with small samples. Negative results by this test—i.e., determining that marks may be formed at any time of the year—do not necessarily eliminate the possibility of their being regular periodic markers.

If it can be shown that the presence of the marks is related to some regular event in the life of an individual fish, such as spawning every four months, then these marks can be used for aging almost as well as if all fish in the population were synchronized.

The studies on subtropical fishes referred to earlier provide excellent examples of the practical application of many of the above criteria. A few case studies involving tropical fishes include those by LeRoux (1961), Pantulu (1962), Krishnayya (1963), and Kutty (1971).

Length-Frequency Analysis

Under this heading are included at least three closely related methods which depend upon large, relatively representative population samples as their data base. As the size structure of a sample is plotted as a length (or weight) frequency histogram, various peaks usually emerge which are taken to represent modal lengths of age classes. There are statistical and computer techniques to help discriminate the modes by assuming that the total distribution is composed of a series of overlapping normal distributions (Harding, 1949; Cassie, 1954; McNew and Summerfelt, 1978; examples in Mathews, 1974; Skillman and Yong, 1976). When a single or combined sample is used, the technique is usually called the Peterson method. Here assumptions are made on the time interval which separates different peaks assumed to represent age groups (Pauly, 1978). A modification involves sampling the same population serially (a problem discussed below) and then noting the growth of fishes as reflected in modal class progression with respect to time. Assumptions in this method involve decisions on which peaks should be interconnected; that is, which represent the same age class. Finally, in species where modes are not well developed, occasionally a dominant or scarce year class may act as a marker which can then be followed as the fish grow with time. Here one has to be concerned with the possibility that this age class may also exhibit somewhat abnormally fast or slow growth.

There are a number of assumptions and conditions which generally affect the usefulness of the above method. It works best when recruitment is restricted in time and when growth is relatively rapid throughout life, with a minimum of variability between individuals and age classes. Samples must be representative and unbiased with respect to the population in question; gear selectivity and fish movements altering availability will strongly affect the results.

The major advantage of length-frequency analysis is that it can be a relatively simple matter to obtain size data from many fisheries. Thus, the catch statistics themselves can, under the right circumstances, form the basis for the age and growth analysis. This makes it easy and cheap, requiring no highly skilled technical personnel. There are several limitations, however, which arise when the fish biology and sampling schemes do not conform to the assumptions and conditions stated above. This is particularly true for tropical species.

1. Breeding seasons tend to be prolonged over several months or more; thus, even the youngest age classes may not be easily separable from one another. Short life cycles complicate and telescope the distributions even further.

2. Older age classes tend to crowd and overlap as growth typically decelerates and variability within classes increases.

3. Individual variation, especially differences between the sexes, may obscure modes if not taken into account.

4. Dominant or variable age classes may introduce statistical problems.

5. The lower number of older fishes available (due to mortality) makes discrimination of their modes more difficult.

6. Due to environmental or population changes, current age or size—specific growth rates determined from length-frequency analysis may not conform with back-calculated lengths from anatomically based aging.

7. The method only allows a statistical characterization of a large sample; it does not work for individuals or small samples.

8. Samples are easily biased by gear and site selectivity and fish movements which may cause size or age classes to appear and disappear, as, for example, in reproductive migrations.

Despite all of these potentially complicating factors, these methods are widely applied, commonly with good results. However, the inferences made have not always been substantiated by other methods. A few examples of the use of these techniques for tropical fishes include studies by Sarojini (1957), Bennett (1961), Pantulu (1962), Longhurst (1965), Fryer and Iles (1972), and LeGuen and Sakagawa (1973). Olsen (1954) used length-frequency analysis and tagging data to age subtropical sharks, for which no direct aging methods worked. Many fishes, particularly in the tropics, are demonstrated to have a lunar or semilunar spawning and juvenile recruitment periodicity (Johannes, 1978). Thus, the minor peaks in recruitment may be followed to gain information at least on early growth. These cycles are probably the cause for at least some of the "minor modes" noted by several researchers (e.g., Randall, 1961; Feddern, 1965).

Tag-Recapture Studies

Fish can be marked in a variety of ways such as fin clipping, tattooing, attaching a variety of external and internal tags, and chemical exposure (usually injection), which causes a mark to form on calcareous structures (see above). The measurement of fish length and/or weight at the time of release and then at recapture can provide direct information on the growth rate of individuals. These can later be applied to a mathematical growth description to provide estimates of age as well. The most important assumption in the method is that the presence of the tag or perhaps the tagging and capture procedures themselves do not affect growth rate. This may or may not be true, depending on the species, type of tag, and other circumstances (e.g., Fryer and Iles, 1972; Bardach and Menzel, 1957). In some cases, the method of capture, such as trapping, may bias results because of the amount of time certain fish spend in traps and because some fish cannot feed while enclosed (Randall, 1962). Some other examples of tag-recapture studies on the growth of tropical or subtropical fishes include Olsen (1954), Randall (1961), and Joseph and Calkins (1969). As mentioned earlier, tagging studies incorporating a chemical marker on scales, bones, or otoliths are very valuable for verifying the time periods of natural mark formation.

There are a number of significant disadvantages to tag-recapture studies. These include the uncertainty of the effect of tagging on growth; the common occurrence of large measurement errors, especially due to the difficult and usually different measuring conditions at release and recapture, resulting in "negative growth"; the need to mark large numbers of fish in order to have sufficient returns (more necessary and more difficult for older fish); the need for intensive efforts, usually at great expense, the possibility that long-term returns may be necessary to show measurable growth, and the difficulty of individually tagging small and delicate fishes, including young of the year of larger species. In some cases, this latter problem has been circumvented by direct diver observation and measurement of sedentary fish (Allen, 1975). Gunderman and Popper (1975) took advantage of an accidental fish kill which destroyed the fish fauna of a small reef in the Gulf of Aqaba. Natural resettlement occurred soon afterward during the normal seasonal spawning peak. Censusing over the following year established early growth rates for several of the more sedentary species. Similar experimental studies may be carried out on natural or artificial reefs. Although no tagging is necessary in such methods, there is still a strong possibility of "abnormal" growth rates in these altered environments.

Fragmentary data from tagging studies or other growth studies can be used to establish more complete growth curves and age estimates. Growth data such as length at t and t + 1 are fit to a theoretical growth formula such as the von Bertalanffy using Walford plots (Weatherley, 1974). In this case, a straight line is usually fitted to the points and the growth parameters are calculated. The method forces a particular form of growth curve on the data, which may or may not be realistic.

Rearing Experiment (Laboratory and Field)

It is practically possible to rear some species under seminatural conditions, either in the laboratory or in some sort of enclosure in the field. The introduction of fish to natural or man-made bodies of water also falls into this category. In this manner, fishes of known age can be monitored to establish growth rates and to look for marks on calcareous structures. As in the case stated above, there is an almost certain departure from growth exhibited by fish in their natural, undisturbed environment.

In Vitro Determination of Relative "Instantaneous" Growth Rates

Ottaway and Simkiss (1977) and Ottaway (1978) describe a radically different method which measures the rate of ^{14}C glycine incorporation by cells associated with isolated fish scales. This is a new technique which requires rather sophisticated procedures and equipment. Furthermore, this method appears to offer a way to determine only relative growth rate as yet, and is perhaps applicable solely within a species. There has not been any attempt to transform results into absolute growth rates. This work is mentioned here not only because of the promise it holds for determining growth rates but, more importantly, because of its potential usefulness in experimentation on the factors controlling scale growth.

Otolith Microstructure

In 1971, Giorgio Pannella published a paper in which he re-examined the microstructure of fish otoliths and came to the remarkable conclusion that the finest lamellae of which they are composed are formed with daily periodicity The structures he described had been seen by a number of earlier workers (mos notably, Hickling, 1931); however, Pannella's careful analysis of recurrent groupings or patterns of the fine growth increments strongly suggested their true temporal significance A number of papers have since followed, reconfirming the presence of daily growth units by a variety of other means in a wide sampling of species from many different habitats (Pannella, 1974, Ralston, 1976, LeGuen, 1976, Brothers et al , 1976, Struhsaker and Uchiyama, 1976, Taubert and Coble, 1977; Brothers and McFarland, 1979, and Brothers, unpublished observation). Many of the fish studied were larvae and juveniles of tropical species The reason for the interest in these types of fishes is simple; the analysis of otolith microstructure offers the only way to determine directly the age of individuals in these categories, since they usually offer no other type of readily visible time marker in their otoliths or other calcareous structures.

The method of preparation for viewing daily growth units varies with the size of the otolith and its structural peculiarities Unlike traditional otolith studies, which almost always utilize the sagitta or saccular otolith, microstructure studies may often best be carried out on the other otoliths, particularly the utricular pair, or lapilli (Brothers, unpublished observation; Brothers and McFarland, 1979) Specimens may be viewed whole, ground and polished, or etched (for acetate replication and SEM) The basic and most generally useful technique involves direct viewing of ground otoliths with a high-quality compound light microscope at magnifications of about 250 to 1500x Very helpful accessories are television viewing systems and polarizing filters These can greatly enhance image quality to make otherwise non-discernible features visible Semi-automated counting and measuring systems are also currently being developed (Methot, 1979).

Fundamental research on the occurrence and mechanism of daily growth unit formation has revealed that they are usually present in the otoliths of all bony fishes, at least during the early life history (i.e., through the juvenile phase). In ontogeny, daily growth units may begin to form as early as the pre-hatching "embryonic" phase, or as late as yolk absorption, depending upon the species The daily growth units themselves are usually simple bipartite structures (measuring from 0.25 to well over 25 μm thick), each composed of a protein-rich and a protein-poor layer. Research in the laboratory at Cornell indicates that in temperate stream fishes the protein-rich layer is deposited at night, under the direct influence of falling water temperatures. Daily growth units are more complex in some species or life stages, being composed of two to several subdaily growth increments formed over a 24-hour period. In temperate stream fishes, temperature is the predominant factor in determining the time of formation, thickness, and overall protein content of growth increments, with food and light cycles having subordinate roles. Taubert and Coble (1977) have also implicated the importance of endogenous rhythms.

Two classes of information are available from the study of otolith microstructure: one is based on counts of daily growth units, the other depends upon detailed examination of the characteristics of each unit (Brothers, 1979). Count data yield ages in days. This method is based upon validating the existence of daily growth units, knowing the age at which growth units begin to form, and determining that a complete time record is preserved in the otolith. The latter condition appears to hold for the larvae and juveniles of most fishes, and may include the adults of some. In the majority of fishes, however, once growth rates (both of the fish and of the otolith) begin to decelerate, daily growth units become proportionately thinner and also seem to be interspersed between growth interruptions of varying duration (see Pannella, 1971, 1974). Only under special conditions can the duration of the interruptions be determined. The presence of growth interruptions therefore poses a serious problem to age determination by daily growth unit counts. For fishes which have strongly periodic growth, the growth interruptions are usually clustered in the slow growth (hyaline) zones of the otolith; however, clear exceptions to this occur (Brothers, personal observation). As a generalization, complete daily growth records in tropical fishes are usually present for at least the first 150 to 200 days; thereafter, the completeness and readability of the record depends upon the physical properties of the otolith and the biological characteristics of the species. In some tropical fishes, apparently continuous daily growth records of two or more years are present. Beyond this point, other types of longer-period otolith growth rhythms, which may also be apparent in the microstructure, such as lunar or spawning cycles, perhaps could be used for aging (Pannella, 1974); however, more research is required to evaluate the potential here.

The second type of microstructure study involves the thickness, protein content, and subdaily structure of individual daily growth units. Such analysis yields additional information on the day-to-day ("instantaneous") growth, environmental conditions, and changes in the life history experienced by a fish. Daily growth rates and back-calculations of growth history can be determined in a manner analogous to back-calculations using the traditional annual or semiannual zones.

Validation of correct identification of daily growth units and demonstration of the existence of complete records are necessary because of the presence of complicating factors such as subdaily growth increments and growth interruptions. Another assumption inherent in calculating instantaneous growth and back-calculations is that there is a precisely definable fish growth/otolith growth relationship, not only on a relatively coarse time and size scale, as in traditional otolith studies, but also on a daily basis. The following procedures are useful in increasing the reliability of microstructure studies:

1. Determining the age at which daily growth unit formation commences is usually accomplished by laboratory rearing of eggs and larvae under close to natural conditions. Such studies are not essential for most applications, since the majority of tropical fishes have fairly rapid development times and daily growth units probably first appear within a week of fertilization. Thus, errors that may be introduced by not knowing the absolute age are small relative to the total counts of juveniles or adults.

2. Validation of the daily nature of the increments or units and the completeness of the record can be ascertained by a variety of approaches analogous to those used for validating seasonal or annual marks. Any other method that can be used to approximate age and growth—e.g., length-frequency analysis of new recruits, mark-recapture, lab rearing, known time of spawning, etc.—can be

helpful. Modifications of several methods presented earlier require additional discussion:

a. Marginal Increment. Under optimal circumstances of rapid growth, large, easily visible growth increments, and availability of fish, specimens can be collected over a 24-hour period, and the condition of the margin can be noted—i.e., whether the protein-rich or protein-poor layer is being formed—and quantified. Although this has been accomplished for a few tropical and temperate species (Brothers, personal observation), it is very difficult, and not possible or worthwhile for a routine aging study.

b. Otoliths can be marked in vivo in various ways, typically, by chemical injection such as with tetracycline. The fish are then either held in the laboratory or externally tagged and released in the wild. Subsequent examination of the otoliths after a known period can be compared to increment counts.

c. In some cases, "natural" marks appear in the otoliths, usually as a result of physical variation in the environment; e.g., sharp temperature fluctuations or tidal cycles. Counting back from the margin to such marks can confirm the daily nature of growth units. This technique works if the date of the "disturbance" is known. Otherwise, one can simply look for consistency between individuals, which would be evidence for regularity of growth unit formation but not necessarily for the period or the completeness of the record. Pannella (1971) used a modification of this method by counting increments between periodic marks (actually patterns of increment intensity and spacing) and then relating these counts to the duration of expected environmental cycles; e.g., lunar, seasonal, and annual.

d. Struhsaker and Uchiyama (1976) utilized a statistical approach by sampling a population, calculating a mean otolith age, and then resampling the same population to determine whether the mean otolith age increase agreed with the known elapsed time period. This method requires that there be no significant changes in the population composition between samples.

Potential of the Microstructural Method and Some Examples. In the course of the author's studies on tropical fishes, otoliths of approximately 200 species from over 65 families (see Appendix) have been examined. Most of these were juveniles; however, many were adults. Validation was not rigorous for most of the species in this preliminary survey, but there is very good evidence that confirmed daily growth units were present and correctly discriminated in several species. The otoliths of all species had analogous microstructural elements assumed to be daily, pending further investigation. Given this assumption, a general conclusion of the survey is that tropical fishes, both marine and freshwater, can be accurately aged by means of counts of daily growth units, from the larval at least through part of the juvenile stage. On the average, aging beyond 200 days is difficult; success is dependent upon the species involved, and further development or preparation techniques is required for many. Pannella (1974) has suggested the use of higher-order patterns (e.g., lunar rhythms) to help in age determination of adults. Although such patterns are sometimes visible, their appearance is often very irregular, inconsistent, and difficult to demonstrate critically. Thus they have very limited usefulness for aging the majority of tropical species. Of course, this is especially true for freshwater forms.

A recent study by Brothers and McFarland (1979) illustrates the potential power of microstructure analysis. Juvenile French grunts *(Haemulon flavolineatum)* were aged and a growth curve was established for the first 100 days (other studies have extended it to over 300 days). Furthermore, examination of daily growth unit spacing and structure revealed discontinuities at certain ages that, when back-calculated to fish length, were found to correspond to observed size ranges undergoing ecobehavioral transitions in habitat, social behavior, feeding ecology, and diet. Work continues on back-calculating spawning and settlement dates for new recruits, establishing evidence for a lunar periodicity in these activities.

Thus far,the most extensive completed or nearly completed studies on tropical species by other workers have centered on the families Cichlidae (Fagade, 1976; Taubert and Coble, 1977); Scombridae (A. Wild, I.A.T.T.C., unpublished manuscript); Engraulidae (Struhsaker and Uchiyama, 1976); Chaetodontidae (Ralston, 1976); Lutjanidae, Centropomidae, Carangidae, Haemulidae, and Holocentridae (Pannella, 1974); and Sciaenidae (Pannella, 1974; LeGuen, 1976). A number of other laboratories around the world have initiated otolith microstructure investigations as a routine procedure. There should be many studies on tropical fishes forthcoming in the near future.

Applications of Otolith Microstructure Data. The data are most easily applied to the accurate determination of age and growth rates of young fishes. Only fish size and daily growth unit counts are required. As mentioned earlier, given the proper validation precautions, the method can be extended to older individuals in a number of species. Where fisheries utilize juvenile fishes, these data are of direct interest to production estimates, however, most fishery analysis requires age and growth information on the entire life history of a species. Even when a complete adult microstructure (i.e., daily) record is not obtainable, growth patterns up to the point when the record becomes unreliable may be useful to project an expected adult growth rate and longevity. Observations on maximum sizes of individuals in combination with early growth curves and such tools as Walford plots may be useful to obtain a first approximation of the needed fishery statistics.

Complete, detailed age data may be used to determine spawning times and to reveal the presence of seasonality or periodicity in recruitment. With the proper sampling scheme, and knowledge of microstructural patterns corresponding to life history changes, the duration of the larval, planktonic, and/or pelagic phase of near-shore tropical fishes can be determined. This is of great importance in understanding the recruitment dynamics of reef fishes, and particularly in evaluating whether local stocks are potentially self-sustaining or perhaps receiving substantial input from other areas due to larval drift and water movements. Island fisheries would be especially interested in such information. Given a sufficient knowledge of local current patterns, information on the ages of newly settling larvae could even help to locate sites of spawning activity if this is unknown for certain species (especially migratory ones).

Back-calculations of growth history and instantaneous growth rates from daily growth unit measurements can contribute substantial information on the ecology, behavior, and physiology of tropical fishes. The certain identification o spawning marks is also a potentially valuable tool. Published accounts of such marks have not been rigorously verified (Pannella, 1974; Fagade, 1976). Once we have a clear understanding of the exogenous and endogenous factors involved in determining otolith microstructure, we should have a remarkably sensitive method for reconstructing the growth history of individual fish as well as for detecting environmental changes. For example, work on temperate stream fishes has demonstrated that the otoliths of some species act as daily, even subdaily, recorders of water temperature and are responsive in different ways to mean daily temperature, rate of change, and range (Brothers, personal observation).

Recommendations for Future Research

In order to increase our information on the age and growth of tropica fishes, several lines of research should be followed. There is still a serious need for well-controlled experimental laboratory and field manipulations of fishes to determine the causative factors involved in the formation of all marks, subdaily to seasonal, in different calcareous structures. These studies should be correlated to anatomical, physiological, and biochemical investigations of calcification processes in fish.

Rigid adherence to careful analysis and validation of all aging techniques is an absolute necessity. General patterns can emerge only when misinformation and incompletely substantiated conclusions too prevalent in the literature are eliminated. For example, at the present time it is extremely difficult to distinguish a true difference in the timing of mark formation from a procedural artifact.

Understanding of the management of tropical fisheries will ultimately depend not only upon traditional fishery statistics but also upon a more complete appreciation of the biology of the species, particularly of their recruitment dynamics and the complexity of community interactions. The biology of the early life history of fish is now recognized as being of considerable significance to our understanding of the population biology of fishes (Hunter, 1976; also see Ehrlich, 1975, for coral reef fishes). We need to gain a better understanding of the ecology of these life stages. For example, to what local oceanographic conditions are the larvae subject? Otolith microstructure studies will be of major importance in answering many of the above questions; however, intensive physical and biological oceanographic research, as well as basic investigations on community ecology, are also required.

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Appendix

Families of tropical fishes in which otolith microstructure has been examined and found to be suitable for aging investigations.

Acanthuridae
Anablepidae
Anguillidae
Antennariidae
Apogonidae
Atherinidae
Aulostomidae
Balistidae
Batrachoididae
Blenniidae
Bothidae
Carangidae
Carapidae
Centropomidae
Chaetodontidae
Characidae
Cichlidae
Clariidae
Clinidae
Clupeidae
Congridae
Congrogadidae
Coryphaenidae
Cyprinidae
Cyprinodontidae
Diodontidae
Engraulidae
Exocoetidae
Gasteropelecidae
Gobiidae
Haemulidae
Holocentridae
Labridae
Leiognathidae
Lophiidae
Lutjanidae
Merlucciidae
Mormyridae
Mullidae
Nandidae
Nemipteridae
Nomeidae
Notopteridae
Ophichthidae
Oryziatidae
Opistognathidae
Ostraciontidae
Pempheridae
Pantodontidae
Percichthyidae
Plotosidae
Pleuronectidae
Poeciliidae
Polynemidae
Pomacentridae
Pomatomidae
Scaridae
Scombridae
Serranidae
Sciaenidae
Scorpaenidae
Siganidae
Syngnathidae
Synodontidae
Tetraodontidae
Xiphiidae
Zeidae

Use of Length-Frequency Data to Estimate Growth and Mortality Rates for Species Exploited by Tropical Small-Scale Fisheries in Puerto Rico and Costa Rica

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Abstract

Length-frequency data collected aboard commercial fish trap vessels on the west coast of Puerto Rico during 1973-74 and from landings of a mixed-gear fishery in Costa Rica during 1976-77 were used to estimate growth and mortality rates required for the determination of maximum yield per recruit for individual species harvested by both fisheries according to a modified version of the Beverton and Holt yield model of particular relevance to the assessment of tropical fish populations. In both cases, growth rate estimation was based on modal size progressions and was impeded by 1) low sample size, 2) the "simple" size composition of observed polymodal frequency distributions, and 3) the overlapping of adjacent size groups in individual samples. Component size groups were separated by mathematical and visual means. Total mortality was estimated from growth parameters and observed length data. Natural mortality rates could not be determined from available data in either study. Yield assessments were performed, however, using published natural mortality estimates.

Introduction

The dynamics of exploited marine fish populations have historically been evaluated by means of theoretically derived mathematical yield models in order to determine the maximum biomass of fish which can be extracted from a unit stock on a continual basis without depleting the population. Although recent developments in fishery science favor the use of the more versatile management objective "optimum yield" (Larkin, 1977; Roedel, 1975), an estimation of maximum sustainable yield (MSY) is still an important first step in designing effective management strategies for individual stocks.*

Historically, most of the basic fishery research and development of yield models has taken place in northern temperate waters and has been applied to relatively slow-growing, long-lived species. The widely used Beverton and Holt "analytic" model (1957) is no exception. This model is more powerful than other

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*Given the high species diversity of tropical marine ecosystems and the degree of ecological interaction among species, however, it is questionable whether unit stock models adequately predict maximum yields for multispecies tropical fisheries. In fact, the unit stock concept itself may not apply to tropical species with highly restricted distributions (those species that inhabit coral reefs, for instance).

models in the sense that it permits a more effective approach to management. When size-selective gear is used, fishing effort and gear may be regulated independently to achieve MSY. At the same time, this model has more rigorous data requirements and is limited by assumptions such as constant mortality and growth, and the fact that the rate of recruitment to the exploited population is seldom known.

The original Beverton and Holt yield model has been modified (Holt, 1962; Kutty, 1970) for use with tropical fish populations by the substitution of size-dependent terms for age-dependent terms, and the use of exploitation rates and mortality/growth ratios rather than individual estimates of growth, natural mortality, and fishing mortality. Beverton and Holt (1964) published a set of yield tables which permit the determination of yield per recruit relative to maximum yield per recruit* for known values of three parameters: 1) the ratio of natural mortality to growth (M/K); 2) the exploitation rate, or the ratio of fishing mortality to total mortality (F/Z); 3) the ratio of the length-at-first-capture to the theoretical maximum length attained by each individual in the population (l_c/L_∞).

For tropical species which do not exhibit marked seasonal fluctuations in growth and therefore cannot be reliably aged by conventional techniques commonly applied to temperate species (e.g., scale annuli), parameter estimation techniques and yield calculations based on size information represent an important step forward.

Procedures have been developed for estimating instantaneous growth rates from modal progressions of individual size groups over time and for estimating total mortality from length data with known growth rates. In the studies reported on in this paper, growth was assumed to conform to the model proposed by Bertalanffy (1934):

$$l_t = L_\infty(1 - e^{-k(t-t_0)}) \qquad (1)$$

where l_t = the length of any fish at time (age) t,
L_∞ = the theoretical maximum length attained by each fish in the population,
k = the average instantaneous rate of growth,
t_0 = the theoretical time (age) at which growth begins

transformed to its linear regression form:

$$\log_e(L_\infty - l_t) = \log_e L_\infty + kt_0 - kt \qquad (2)$$

where l_t = the mean or modal length of a given size group at time t

as derived by Ricker (1975). In this procedure, the parameter L_∞ can be derived by repeated trial-and-error regressions until the best least-squares fit is obtained, or it may simply be assumed to equal the length of the largest fish observed in the

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*Yield is expressed on a "per recruit" basis when recruitment (the number of individuals entering the exploitable population per unit time) is unknown.

catch as long as the larger fish in the population are retained by the sampling gear and as long as fishing pressure is not so intense that the largest fish have been selectively removed from the population. If the largest fish are not represented in the catch, theoretical maximum lengths can sometimes be obtained from the literature.

The total mortality rate Z as expressed by the negative exponential equation

$$N_t = N_o e^{-Zt} \tag{3}$$

where N_o = the number of fish in a given cohort born at time zero,

N_t = the number of fish in the same cohort alive at a later time t,

Z = the annual instantaneous rate of total mortality derived from an equation derived by Beverton and Holt (1956), in which

$$Z = \frac{K(L_\infty - \bar{l})}{\bar{l} - l_c} \tag{4}$$

where l_c = the mean length at first capture,

$\bar{l}$ = the average length of fish captured larger than l_c.

For both growth and total mortality rate estimation, length data may be obtained directly from samples of commercial landings.

In addition to the limitations imposed on the estimation of model parameters by tropical ecosystems and the unique features of many tropical fishery resources (e.g., a multiplicity of species, less predictable growth cycles, prolonged and/or multiple spawning seasons, short life cycles, high growth and mortality rates), the assessment of populations harvested by tropical small-scale fisheries is complicated by the difficulties involved in collecting reliable data from a fishery which operates from many remote shore bases and which may market only a proportion of the catch through normal channels, thus bypassing the usual data-recording system.

Research conducted in Puerto Rico during 1973-74 and in Costa Rica during 1976-78 was designed to test systems of data collection and analysis useful for the assessment of stocks harvested by tropical small-scale fisheries. The management objective was the determination of MSY by means of the modified version of the Beverton and Holt yield model. Parameter estimation techniques were primarily aimed at estimating the vital statistics (growth and mortality rates) required by the model from length-frequency data. In addition, a modest tag and recapture study was carried out in Costa Rica. Research was funded by the Agency for International Development through the International Center for Marine Resource Development of the University of Rhode Island. This paper briefly presents the results of these two studies and offers a critique of the methods used to collect and analyze the data.

Methods and Results

Puerto Rico

Growth and total mortality rates were estimated from length-frequency data collected aboard commercial fish trap vessels which operated on coralline offshore grounds on the west coast of Puerto Rico during 39 fishing trips made during three sampling periods in 1973 and 1974. Over 10,000 length measurements were collected (from two different mesh sizes) for ten species of reef fish which accounted for approximately 80% of the weight landed during the study period (fintish only). Instantaneous growth estimates were obtained for seven species from the length increments of individual size groups with the aid of a computerized maximum-likelihood estimation technique, which estimates the mean length of component size groups in a polymodal frequency distribution (Hasselblad, 1966; Tomlinson, 1971). Total mortality rates were estimated from observed length data and a priori growth estimates for eight species captured in both mesh sizes. For six of these species, natural mortality rates were estimated by the same procedure for lightly exploited populations on Pedro Bank, an offshore fishing ground located southwest of Jamaica, by Munro and co-workers (see Munro, 1974) under the assumption that all mortality was due to natural causes.

Yield evaluations were performed with the modified Beverton-Holt model (Beverton and Holt, 1964) for seven species captured in the Puerto Rican trap fishery (Stevenson, 1978). The results showed that two species were slightly overexploited and five were underexploited, some of them significantly. Mesh size regulations which would theoretically increase the biomass yield of these species were not recommended, however, since the capture of a greater proportion of immature fish would significantly reduce recruitment.

Costa Rica

The growth and total mortality estimation procedures tested in Costa Rica were essentially the same as in Puerto Rico. There were, however, some important differences between the two studies. Length data were collected from commercial landings of the small-scale fleet which operates in the Gulf of Nicoya, a tropical estuary on the Pacific coast of Costa Rica. The most important species in the catch belonged to the family Scianidae (croakers or corvina). Over 40,000 length measurements were collected on a continual basis for one year (July 1976 to June 1977); five sciaenids and one species of mackerel accounted for 85% of the length data. An improved version of the computerized mathematical procedure for separating polymodal frequency distributions into component size groups (Yong and Skillman, 1975) was tested. Total mortality estimates were derived from the Beverton and Holt equation, but it was not possible to estimate natural and/or fishing mortality from the length data. No estimates of natural mortality were available from other sources for any of the species represented in this study, only for other species of the same genera.

Approximate growth estimates were derived for two sciaenid species from length data. Total mortality rates were estimated for both sciaenids. A preliminary yield evaluation was performed for one species, using natural mortality estimates for two other species of the same genus. It suggested that a 50% reduction in fishing effort or an increase of 20 cm in the size-at-first-capture would increase biomass yield by 9%.

The resource assessment study conducted in Costa Rica was part of an interdisciplinary study which included analyses of the costs and earnings of the small-scale fleet, marketing efficiency, the quality and nutritive value of fish at different stages in the marketing process, anthropological and sociological aspects of the fishery, and the institutional policy-making framework of the country.

Discussion

Growth Rate Estimates

Efforts to estimate growth were based on the increments in the mean or modal lengths of individual size groups in length-frequency distributions compiled during defined sampling periods for given gear types and fishing locations (Fig. 1). Mean lengths were estimated mathematically by means of computerized maximum-likelihood techniques, and modal lengths were estimated directly from visual inspections of length-frequency distributions. The mathematical procedure programmed by Yong and Skillman (1975) is more objective, since it does not require any judgments about the number of cohorts in the data. Furthermore, this technique can be applied to shorter time series of length data: mean length estimation for each individual data set is more precise than visual estimation *as long as sample sizes are sufficiently large and the overlap between adjacent groups is not extreme*. As a general guideline, Cohen (1966) has reported that a minimum sample size of 400 was necessary for the separation of two groups in a single size-frequency distribution. For more than two groups, an even larger sample size is required.

Growth rates based on visual modal length estimates have been successfully estimated by a number of authors (Ommanney, 1949; Jhingran and Natarajan, 1969; Thompson and Munro, 1974; Chapman and van Well, 1978). Since small sample size and overlap also create problems for visual modal length estimation, the use of longer time series permits the omission of poorly defined peaks during certain sampling periods and the estimation of growth rates even when the size increments during certain time intervals are negative. The establishment of guidelines for the estimation of "acceptable" modal lengths often removes some of the subjectivity associated with this procedure.

Once mean or modal lengths have been estimated, cohort sequences must be identified. This process is much riskier when there are large time gaps between length samples.

Finally, to estimate growth, "best guess" estimates of L_∞ must be obtained from catch data or from published sources and Equation (2) solved repeatedly by trial-and-error fits to the data using refined L_∞ estimates until the best fit is obtained. Experience has shown, however, that unless a relatively long time series of length data is available, the iterative solution does not converge to a single L_∞ estimate.

Most of the problems which hindered the estimation of growth rates from length data collected in Puerto Rico and Costa Rica involved the determination of reliable mean and modal lengths. In most cases, these problems were caused by some biological feature of the exploited populations. A brief discussion of three of the major problems follows.

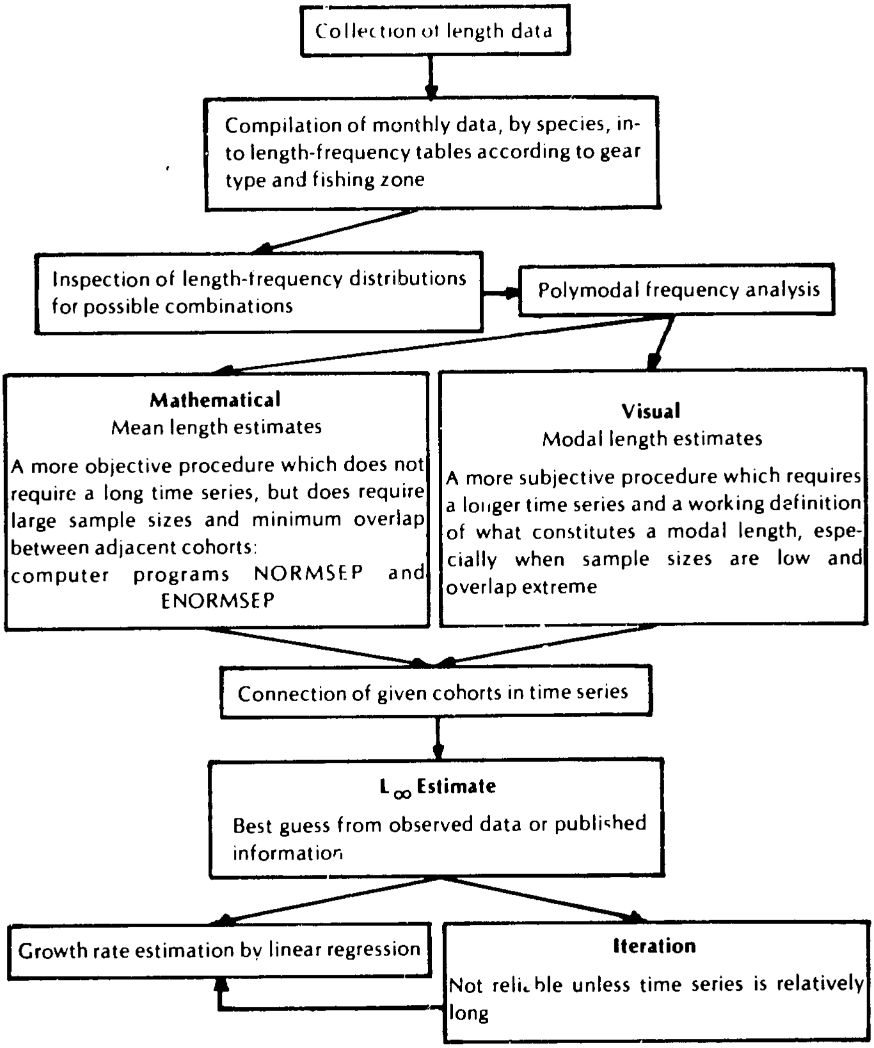

Figure 1. Schematic diagram showing series of steps leading to estimation of instantaneous growth rates from length-frequency data.

Reduction of Sample Size by Gear and Location Effects. The number of modes and the approximate size range represented by each often varied in samples collected at the same time in different locations or with different gears, thus eliminating the possibility of combining length data obtained from different sources and reducing sample sizes to such low levels for the less frequently sampled species that mean or modal lengths could not be reliably estimated.

This problem was expected for fish captured with size-selective gear (e.g., gill nets and wire mesh traps), but less so for fish captured in different locations.

The effect of locations was not limited to depth differences. Length data for three reef species captured in 30 m with the same gear and over the same time period in Puerto Rico varied considerably over a distance of only five kilometers. The movements of reef fish have been reported by several authors to be very limited (Randall, 1962; Moe, 1972; Springer and McErlean, 1962), suggesting that small populations in separate locations may respond independently to variable fishing pressure in the separate locations. In the Gulf of Nicoya, annual length data for several species captured in contiguous zones with the same gear also varied considerably (Figs. 2 and 3), suggesting that even in estuarine waters with strong tidal currents fish do not move around a great deal and are therefore differentially vulnerable to variable fishing effort. In this example, *Micropogon altipinnis* were harvested by the small-scale fleet in both Zones 2 and 3, but also by shrimp trawlers in Zone 3.

In order to use length-frequency data for growth rate estimation, one must differentiate fish captured in different zones and with different gear types. Accurate data collection calls for a working definition of fishing zones based on lengths-at-capture by a given gear type. There is evidence that some demersal tropical fish populations may be composed of a number of site-specific subgroups. For these species, growth rate estimation based on increments of individual size groups over time requires either a large amount of data collected from different locations or sufficient data from a very specific location. Only the former alternative is acceptable in the case of species being sampled for the first time, since the range of site-specific size variations will be unknown.

"Simple" Size Composition. Length data collected for many tropical species in Puerto Rico and Costa Rica frequently revealed the presence of only a few well-defined size groups. Data collected over a size range of 30-120 cm for *Cynoscion albus*, for example, revealed only two or three dominant size groups, suggesting that the entire population in the gulf may be composed of less than four year classes (Fig. 4). Length data for smaller species exploited by small-scale fisheries in Puerto Rico and Costa Rica over a more reduced size range typically revealed even fewer size groups, often one or two. In cases where three or four size groups were sampled in a short size range, size variations were most probably caused by multiple spawning periods and/or differential growth of male and female fish of the same year class.

The continual presence of a single size group in length-frequency data collected at different times during the year suggested that recruitment of young fish to the exploited population was constant as a result either of continual spawning or of immigration of young fish to the fishing grounds. Constant recruitment was not implied for any of the reef species captured in the Puerto Rican trap fishery, but was observed for at least one of the principal species captured in the Gulf of Nicoya (Fig. 5). Growth could not be estimated from length data, which revealed no progression of modal lengths over time.

The use of size-selective gear contributed to the "simple" size composition of many length-frequency samples. If possible, gear such as gill nets or wire fish traps should not be relied on for length data. Since size-selective gear is common

Figure 2. Map of Gulf of Nicoya showing three fishing zones.

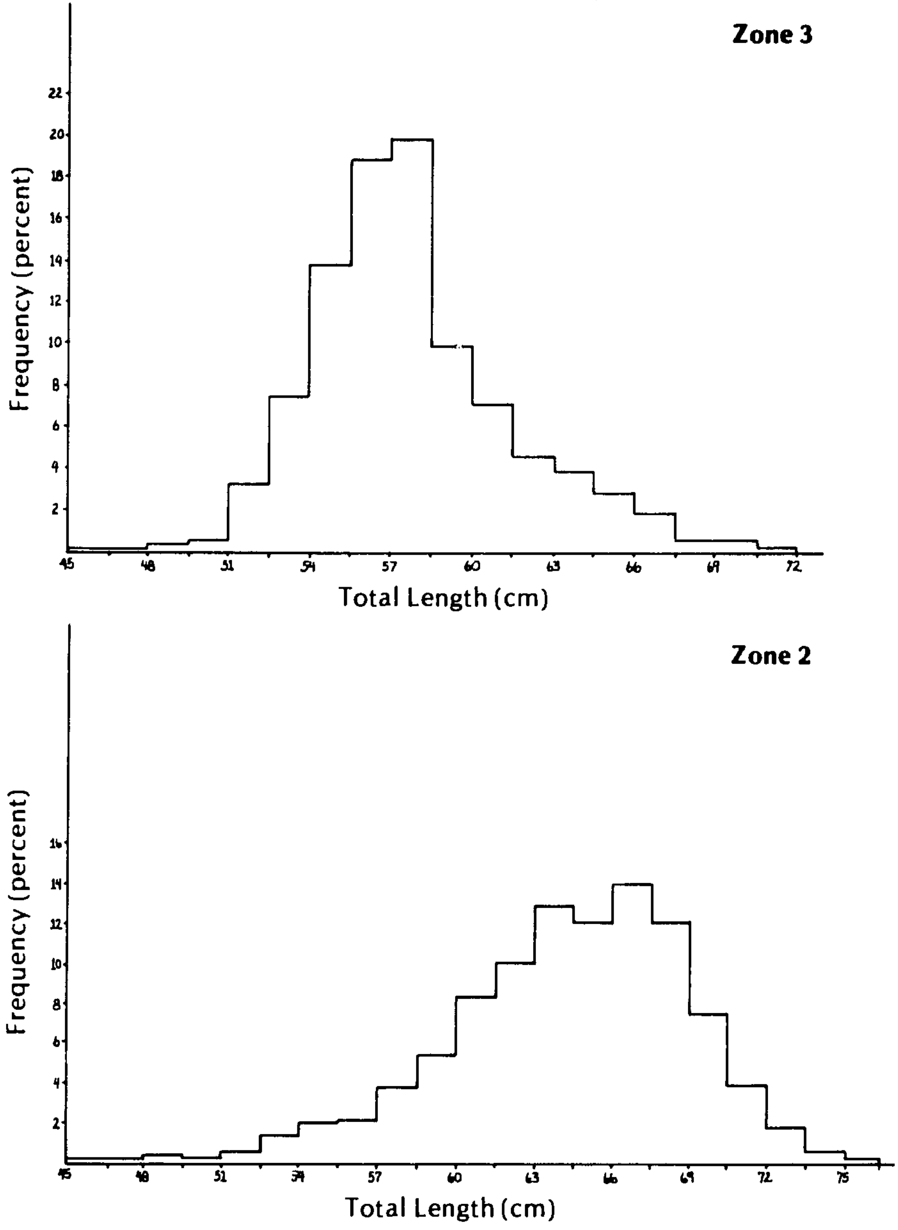

Figure 3. Average annual length-frequency distributions for *Micropogon altipinnis* collected in 12.5-15.0 cm mesh gill nets, Zones 2 and 3 in the Gulf of Nicoya, during the period July 1976-June 1977.

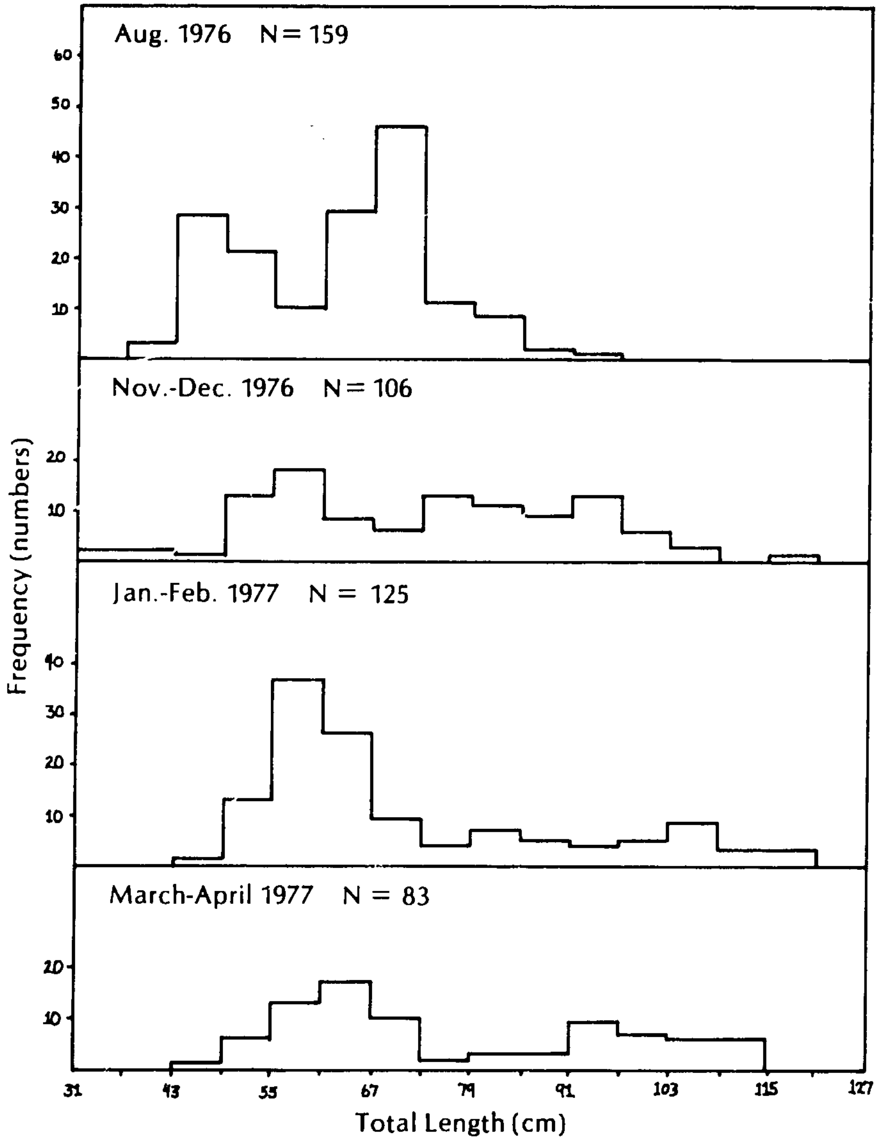

Figure 4 Monthly and bimonthly length-frequency distributions for *Cynoscion albus* collected with hooks, Zone 2 in the Gulf of Nicoya, during the period August-April 1977.

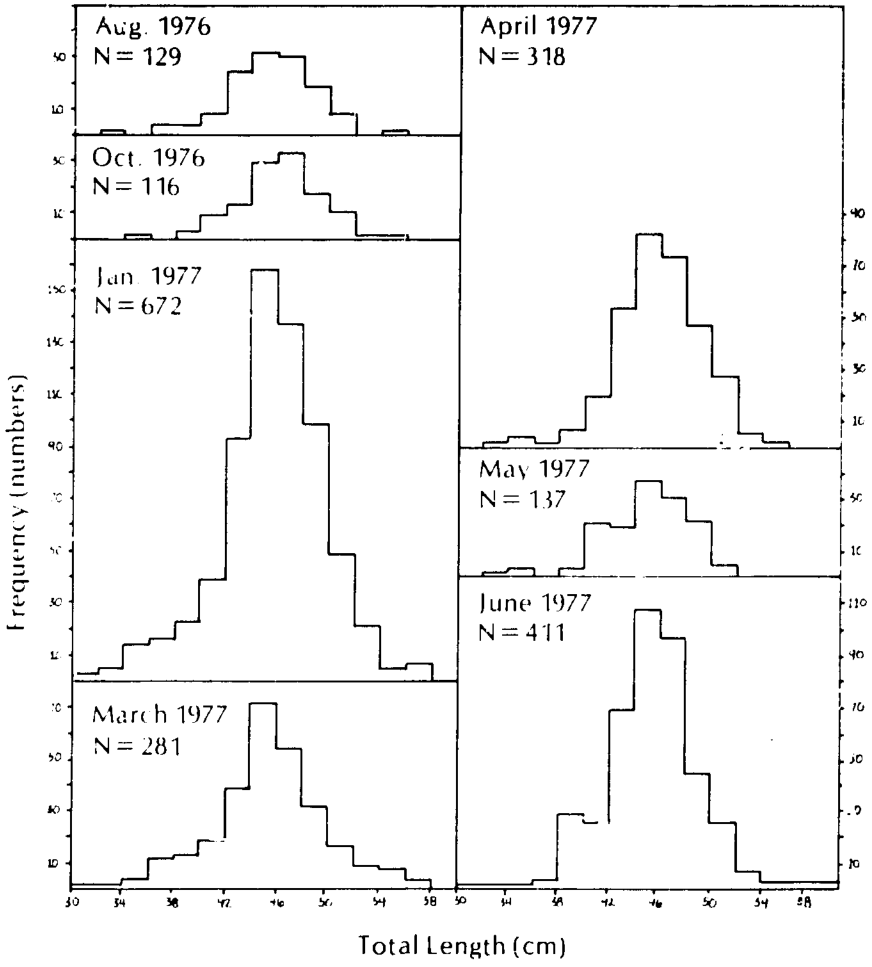

Figure 5. Monthly length-frequency distributions for *Cynoscion squamipinnis* collected in 7.5-8.75 cm mesh gill nets, Zone 2 in the Gulf of Nicoya, during the period August 1976-June 1977

in tropical small-scale fisheries, however, it seems impractical to avoid sampling commercial catches made with these gear types.

Even when reliable mean or modal length estimates can be obtained from size-frequency data collected over time, the presence of only a few size groups reduces the number of data sets from which an overall growth estimate is averaged for a given species. At the same time, if growth is relatively rapid, each size group may be represented in the data for only a few months; thus, growth rates will be based on a number of short-term modal progressions rather than on a few progressions which are based on a large number of length-at-time data. Growth estimates based on short-term data are less reliable if there is any seasonal variation in growth. Moreover, data collected from size-selective gear which captures fish only at lengths near their theoretical limiting length (L_{∞}) will also produce unreliable growth estimates.

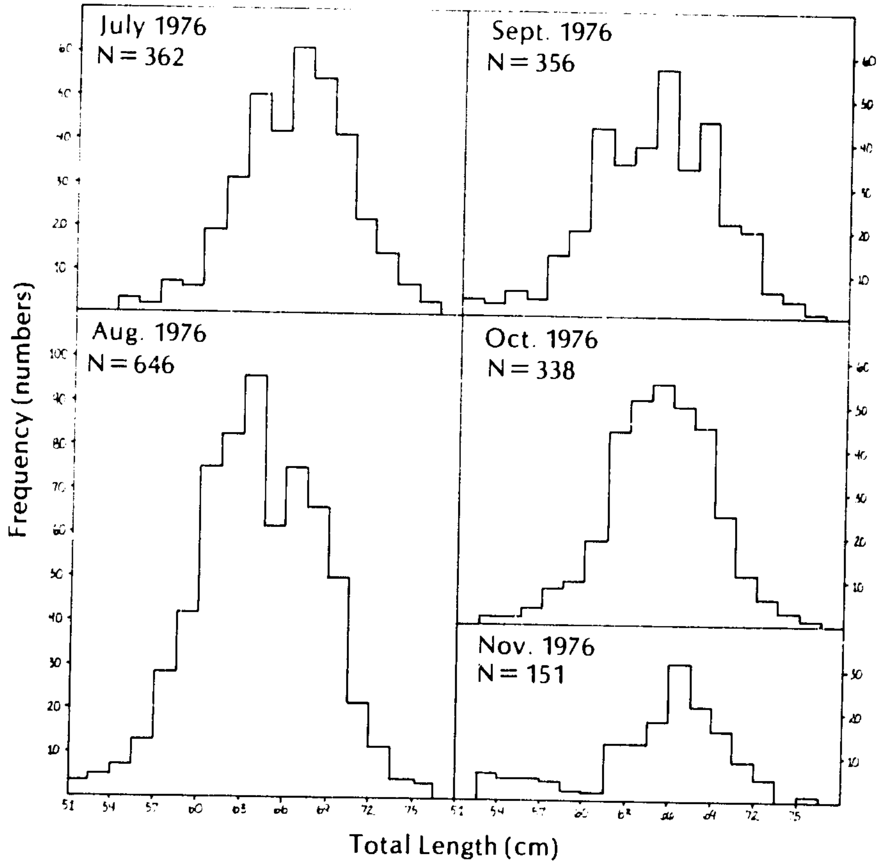

Figure 6. Monthly length-frequency distributions for *Micropogon altipinnis* collected in 12.5-15.0 cm mesh gill nets, Zone 2 in the Gulf of Nicoya, during the period July-November 1976.

"Overlapping" Size Groups. As was the case with low sample size, the greater the degree to which adjacent size groups in polymodal length-frequency distributions overlapped each other, the greater the error with which component mean or modal lengths were calculated, even for species which were sampled in abundance. For example, for mathematical mean length calculations performed with the computer from 1,853 length measurements of *Micropogon altipinnis* taken over a five-month period (Fig. 6), adjacent size groups overlapped to such a degree that the variances for individual mean length estimates were often ex-

cessive, producing unacceptable interval estimates of mean length (Table 1). Moreover, the high chi-square values indicated very little agreement between observed and predicted length frequencies. For some sampling intervals (July, in this example), use of Hasselblad's method led to more than one set of possible mean length estimates and no justifiable basis for selecting one set over the other.

Month	XL_1		XL_2		XL_3		X^2	P
July	567.2	± 10.4	640.2	± 4.4	683.7	± 4.2	7.12	0.20
	631.7	4.7	675.6	3.3	719.8	6.6	11.06	< 0.10
Aug	446.7	13.0	642.1	3.4	—	—	22.91	< 0.25
Sept	532.1	10.0	610.3	4.6	667.4	4.3	14.77	< 0.05
Oct	586.3	11.0	642.7	3.7	678.0	5.0	3.51	< 0.75
Nov	543.4	16.0	670.2	5.4	—	—	10.55	0.48

Table 1. Point and interval mean lengths for *Micropogon altipinnis* estimated from length-frequency data collected in 12.5-15.0 cm mesh gill nets, Zone 2 in the Gulf of Nicoya, Costa Rica, during the period July-November 1976 and analyzed by a maximum-likelihood procedure (ENORMSEP).

In fact, mathematical analyses of length data collected in Costa Rica were abandoned completely in favor of visual modal length determinations. Visual determinations of modal lengths were also hindered by the overlap problem, however, since two intersecting size groups can produce "false" length-frequency maxima. As a result, modal lengths were estimated only for those species with clearly defined size groups.

Mean length estimates by means of computerized maximum-likelihood estimation were more successful in Puerto Rico. Although low sample sizes and overlap often produced wide interval estimates, the greater delay between samples (eight months and four months) resulted in size increments which in most cases produced mean lengths which were significantly different. Only in the case of relatively slow growing species could growth be estimated from such widely separated sampling periods: instantaneous growth for six of the seven species studied in Puerto Rico was between 0.20 and 0.30. Even in cases where mean lengths were mathematically determined, however, overlap frequently caused the "disappearance" of certain size groups at certain sampling times and reduced the data available for growth rate estimation.

Mortality Rate Estimates

A method for estimating total mortality which does not require a priori growth rate estimates relies on estimates of the relative abundance of at least two size groups in a given size-frequency distribution. Although the absolute age of these size groups need not be known, the time which is required for fish in group A to attain the size of fish in group B must be known. Furthermore, both size groups must be captured beyond the selection range of the gear being used.

This parameter estimation procedure required the use of the same computerized polymodal frequency analysis procedure used to estimate mean lengths for growth rate estimation, and was hindered by the same problems. Moreover, McNew and Summerfelt (1978) have reported that the maximum-likelihood estimation of relative abundance for individual size groups in a polymodal length-frequency distribution with the ENORMSEP program is subject to greater error than mean length estimation. Also, since the "transition time" between size groups A and B must be known, this method is severely limited by the fact that male and female fish may grow at different rates and that some species may spawn more than once a year (Weber, 1976; Munro et al., 1973).

Total mortality rates were estimated from average annual length-frequency data for eight species captured in Puerto Rico and for two species captured in Costa Rica by means of the Beverton and Holt Equation (4), using a priori L_∞ and K estimates and observed l_c and $\bar{l}$ estimates. The parameter l_c was defined as the lower boundary of the first length class that was 100% retained by the gear; i.e., the first distinct frequency maximum in the annual length-frequency distribution. In those cases where the first mode was not very distinct, Z estimates were repeated using two l_c values.

Beverton and Holt (1956) outlined a number of theoretical bases for estimating fishing (F) and/or natural mortality (M) rates from catch samples in the absence of absolute age information. These methods do require information on fishing effort. The three essential requirements for obtaining these estimates are: 1) there must be changes in fishing intensity, either with time or in relation to the stock as a whole, or with the age of the fish; 2) these changes must be large enough to produce measurable changes in total mortality; and 3) the different fishing intensities must be known and expressed in standardized units so that they are proportional to the values of F that they generate. Estimates of F and M can be obtained under any of the following situations: 1) when fishing effort is stabilized at two different levels; 2) when fishing effort varies continuously with time; 3) when fishing effort varies with the age of the fish.

Martén (1978) derived an equation for estimating total mortality implicitly from length parameters without requiring an a priori estimate of growth, and provided an example of how the natural mortality of the population can be estimated from differences in the total mortality rates of fish caught with variable fishing intensity in two different fishing zones. This approach requires that natural mortality and growth remain constant in both locations.

No estimates of natural or fishing mortality were obtained from length-frequency data collected in Puerto Rico or Costa Rica. The first two alternatives listed above require a longer time series of catch (weight or length) and effort estimates than were available in these studies and are complicated in situations where different gears are used to harvest the same species. The last alternative requires fishing effort to vary according to the age of fish captured by two different gears—e.g., as a result of gear selectivity—and was tested with length-frequency data collected with gill nets of variable mesh size in the Gulf of Nicoya with unsatisfactory results. For a gill net fishery, the method requires that: 1) two size groups be exploited selectively by one mesh size, while a third is exploited with 100% efficiency (i.e., probability of retention) by the same mesh; 2) the same three size groups be exploited concurrently in a smaller-meshed net or by some reference gear (e.g., a trawl) with 100% efficiency; and 3) two of these groups remain in the exploitable size range for three months or more.

Due to the extremely simple size compositions of the species samples in the gulf, these requirements were not met by any of the species studied. In fact, this method has very little application to any short-lived, rapidly growing tropical species, especially those captured with selective gear which may impose a lower and an upper limit to sizes-at-capture. Also, the use of trawls as reference gears is severely restricted in areas of coral growth.

Natural mortality rates which were used to determine maximum relative yield per recruit in Puerto Rico (Stevenson, 1978) were obtained from M/K estimates for presumably unexploited populations of the same species on Pedro Bank (see Munro, 1974) after some adjustments in the original estimates had been made. The probability, however, that unexploited populations can still be found is so low and the costs of obtaining sufficient data from them are so high that this alternative would seem to hold very little future promise.

Conclusions and Recommendations

The use of maximum-likelihood estimation techniques with length-frequency data collected from small-scale fisheries in Puerto Rico and Costa Rica met with mixed success. Growth rates were estimated for six reef species in Puerto Rico sampled during only three sampling periods, and with intervals between samples of eight and four months. In Costa Rica, data were collected continuously over an entire year, but in very few cases were obvious modal progressions detected. For the Costa Rican data, separation of individual size groups in polymodal length-frequency distributions with the ENORMSEP program was abandoned in favor of visual analyses, due to low sample sizes and extreme overlap between adjacent size groups. A promising recent contribution, which recognizes the need to make some initial judgments when analyzing mixed size-frequency distributions, is an interactive computer program developed by MacDonald and Pitcher (1979).

Tropical fish pose special problems for growth estimation from modal size progressions, since spawning may be continuous or extended over several months, sometimes more than once a year. Reliable growth estimation is also more difficult for short-lived, rapidly growing tropical species, which may remain in the exploitable size range for only a few months at a time. This problem is magnified when length data are collected from size-selective gear.

The lack of reliable length-at-age data also limits the estimation of total mortality to species with known growth estimates, unless wider use is made of Martén's equation. The most promising simple way to estimate natural mortality may be to collect information on spatial or seasonal fishing effort variations and relate it to changes in total mortality. The fact that many tropical demersal species apparently move around so little means that greater attention must be devoted to collecting accurate information from a few carefully selected sites.

Despite the problems involved in the interpretation of size-frequency data, it is readily available, and fishery biologists will continue to make use of this source of information for determining growth and mortality rates of species exploited by tropical small-scale fisheries.

It is important to understand what the risks involved in using size-frequency data are, so that maximum effort can be devoted to the collection and analysis of data for only those species which show some promise. Preliminary, short-term surveys of commercial landings are called for before major commitments of time, manpower, and money are made. Landings surveys to collect length-frequency data should be combined with estimates of catch and effort information, thus increasing the overall chances of eventually estimating MSY. Landings surveys need to be complemented with basic life history studies, since so little is known about the biology of most species exploited by tropical small-scale fisheries.

Finally, there is the question of whether unit stock models that require a great deal of information are useful for assessing multispecies tropical fisheries. The future of stock assessment for these fisheries clearly demands either simpler models, which do not require so much or such high-quality information, or more comprehensive models, which will account for interspecies interactions and which will undoubtedly be even more data-intensive than unit stock models.

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A New Methodology for Rapidly Acquiring Basic Information on Tropical Fish Stocks: Growth, Mortality, and Stock Recruitment Relationships

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Abstract

Comparative methods are presented which allow for quick and relatively reliable growth parameter estimates when growth data are not at hand. One of these methods involves the use of a newly developed "auximetric grid."

An empirical equation for the estimation of natural mortality of any fish stock, given a set of growth parameters, is briefly reviewed.

The methods are applied to data from the Gulf of Thailand trawl fishery, and the mortality caused by this fishery is estimated.

The equations and data needed to derive stock recruitment relationships given catch, effort, and fishing mortality data are stated, and stock recruitment relationships are given as examples which pertain to the false trevally *Lactarius lactarius* and to the Indian halibut *Psettodes erumei*. In the latter fish, the demonstration is made that both recruitment and prerecruitment mortality, from 1960 to 1972, have been closely related to the size of the total demersal standing stock in the Gulf of Thailand.

These various exercises are presented in order to demonstrate that an exhaustive analysis of the data available to date from tropical stocks and fisheries would contribute greatly to our understanding of the dynamics of tropical multispecies stocks.

Introduction

The fishery biologist working in the tropics, except when working on pelagic fishes, such as the scombroids and some clupeoids, will generally be faced with several, if not all, of the following problems:

1. The fishery under investigation catches and lands a large number of species, and relatively few specimens of one single species.
2. There are no reliable catch, landing, and effort data available to assess the fishery, and especially no time series of such data.
3. There exists no suitable theoretical model into which these data could be plugged, even if primary data are available.
4. There are no funds, no scientists, no time available even to apply standard methods and to use standard models of stock assessment.

The irony is that whoever is facing these problems is still expected to generate figures for the various departments of fisheries. (See Marr, 1976, or Pauly, 1979c, for a review of problems occurring in tropical multispecies fisheries.)

The following are two temporary solutions to some of these problems:

1. Better use can be made of the available data on the biology of tropical and other fishes.

2. There is a need to use the data on the biology of tropical fishes (especially growth and mortality rates, as described herein) and the available catch per effort data generated by the fisheries in conjunction with the most sophisticated concepts now available for the investigation of temperate fisheries.

Both of these points have been conspicuously ignored in the literature, with the result that the analysis of stock recruitment relationships in the tropics is still in its infancy, although data are available which can be used for this purpose (Pauly, 1979b). Only when such concepts are routinely applied will it become possible to develop and successfully apply the sophisticated multispecies interaction models which are actually required and which have been, possibly prematurely, proposed (e.g., Pope, 1979) for the management of tropical multispecies stocks.

The present contribution, therefore, has two aims: 1) to describe "short-cut" methods by which certain important parameter values can be generated, even when the commonly used primary data are lacking (this should illustrate Solution 1, above); and 2) to use the parameter values generated in (1) to demonstrate the existence of stock recruitment relationships in selected tropical stocks (this is meant to illustrate Solution 2, above).

The Analysis of Growth

For stock assessment purposes, growth is best expressed in terms of the von Bertalanffy growth formula (VBGF), which has the following form for length:

$$L_t = L_\infty (1 - e^{-K(t-t_0)}) \qquad (1)$$

and for weight:

$$W_t = W_\infty (1 - e^{-K(t-t_0)})^3 \, . \qquad (2)$$

Actually, Equation (2) is the one that is most useful, since it expresses weight growth, and it is the weight of the catch we are interested in. Therefore, we need values of

W_∞, the asymptotic weight,
K, the stress factor,

and t_0, the origin of the growth curve, for each species of fish that we want to include in our stock assessments.

Values for the parameters can be obtained as follows:

1. Growth parameter values may have been published which pertain to the stock in question, or to a closely related one. Sources for such values are scientific journals, textbooks, and review papers, or lists of growth parameters that have been compiled especially for the purpose of assisting fishery biologists working in the field (e.g., Pauly, 1978a, which covers more than 1,500 different stocks distributed over 500 species, over 100 of which occur in the tropics).

2. Another source of growth parameters is obviously the fishery biologist's

own work with length frequencies, scales, otoliths, and the like. This method is most often time-consuming, and will have its limits when a multispecies stock composed of several dozens or even hundreds of species is investigated.

3. Another method is to use what is presently known of the growth of fish in general to make reasonable estimates (or educated guesses) of the growth parameters of little-investigated stocks.

It is the last method which will be discussed here. Two approaches, adapted from Pauly (1979a), are:

1. to use the relationship between K and asymptotic size, and
2. to use an auximetric grid.

It has been noted by many authors that in a given fish species K increases as asymptotic size decreases, and vice versa; there has been, however, no attempt to quantify this effect. Using data from 126 species, distributed over 978 stocks, I have shown that, on the average,

$$\log K = a - \tfrac{2}{3} \log W_{\infty} \qquad (3)$$

or

$$\log K = a' - \tfrac{2}{3} \log L^3_{\infty} . \qquad (4)$$

The data used for the derivation of these relationships are given in Pauly (1979a), together with an interpretation of this result. While the interpretation need not concern us here, an example may be presented as to how this relationship may be used.

Chomjurai and Bunag (1970) presented tagging data on *Scolopis cancellatus* from which, using the method of Gulland and Holt (1959), I have extracted the following growth parameters:

$L_{\infty} = 20$ cm and $K = 1.33$.

This provides us with an estimate of the intercept in Equation (4) of $a' = 2.725$. As will be seen below, an estimate of L_{∞} and K in *Scolopis taeniopterus* is required. As the latter species in the Gulf of Thailand reaches a size of about 28 cm (Boonyubol and Hongskul, 1978), an estimate of the asymptotic length may be obtained by means of the relationship

$$L_{(\infty)} \approx \frac{Lmax}{0.95} \qquad (5)$$

which applies to fishes which reach a length of about 50 cm (see Pauly, 1979a, for reasons). Note also the coding of $L_{(\infty)}$, to distinguish it from an estimate of L_{∞} as obtained from growth data; e.g., by means of a Ford-Walford plot. The use of Equation (5) and $L_{max} = 28$ cm provides us with an estimate of $L_{(\infty)} = 29.5$ cm, which, when used in conjunction with $a' = 2.725$ and Equation (4), gives an estimate of $K = 0.6$, if it can be assumed that *Scolopis cancellatus* and *Scolopis taeniopterus* have similar growth patterns. This technique, which strictly speaking can be applied only within species, may be applied between species, if they are congeneric and ecologically similar, as is probably the case in the example here.

The second method—i.e., the auximetric grid—is related to the first method in that the relationship between K and asymptotic size is used, although in a slightly different manner. When the VBGF describes the weight growth of a fish (stock) adequately, the growth rate $\left(\frac{dw}{dt}\right)$ at the point of inflexion of the growth curve is given by

$$\frac{d\,wi}{dt} = \frac{4 \cdot K \cdot W_\infty}{9} \qquad (6)$$

(Hohendorf, 1966; Pauly, 1979a).

I have defined

$$P \doteqdot \log_{10}(K \cdot W_\infty) \qquad (7)$$

and shown that, if W_∞ is expressed in grams, and K in years, the value of P ranges in marine fishes between about -0.70 for small Myctophidae to 5.79 for the basking shark *Cetorhinus maximus* and about 6.20 in the largest of all fishes, the whale shark *Rhincodon typus* (Table 1). The interesting point is, however, that the value of P is within species relatively constant, with values, for instance, of 3.4 to 3.5 in the cod *Gadus morhua*, 2.2 to 2.3 in the croaker *Pseudotolithus elongatus*, or 4.0 to 4.2 in the skipjack *Katsuwonus pelamis*. The character of P, which is in fact an index of growth performance, is best demonstrated by transposition of the concept into a special grid called the "auximetric grid" (from the Greek *auxein*, "to grow," and *metron*, "to measure"). The absissa scale of an auximetric grid consists of values of log K (on a yearly basis), with the range covered by both scales chosen in such a way that normal-sized commercial fishes appear near the center of the grid (Fig. 1).

Table 1. Growth parameters and values of P in representative marine fishes (from Pauly, 1979a).

Family	Species	W	K	P
1. Myctophidae	*Notolychnus valdiviae*	0.14	1.411	-0.70
2. Gasterosteidae	*Apeltes quadracus*	1.23	1.174	0.16
3. Cyprinodontidae	*Cyprinodon macularius*	0.538	3.391	0.26
4. "	" "	0.703	2.995	0.32
5. Myctophidae	*Myctophum punctatum*	6.56	0.323	0.33
6. Cyprinodontidae	*Cyprinodon macularius*	0.710	3.223	0.36
7. Myctophidae	*Benthosoma glaciale*	5.72	0.45	0.41
8. Syngnathidae	*Siphonosoma typhle*	6.2	0.558	0.54
9. Gasterosteidae	*Gasterosteus aculeatus*	1.97	1.788	0.55
10. Myctophidae	*Myctophium affine*	9.0	0.42	0.58
11. Syngnathidae	*Nerophris ophidion*	5.46	1.052	0.76
12. Myctophidae	*Scopelopsis multipunctatus*	5.4	1.118	0.78
13. Macrorhamphosidae	*Macrorhamphosus scolopax*	21.7	0.36	0.89
14. Blennidae	*Blennius pholis*	54	0.30	1.21
15. Cottidae	*Taurulus bubalis*	102	0.230	1.37
16. "	*Cottus kessleri*	118	0.197	1.37
17. Maenidae	*Maena smaris*	117	0.218	1.41
18. Callyonimidae	*Callyonymus lyra*	52.5	0.49	1.41
19. Gadidae	*Trisopterus esmarkii*	47.7	0.59	1.45
20. Pomadasydae	*Rhonciscus striatus*	142	0.229	1.51
21. [illegible]lossidae	*Cynoglossus macrolepidus*	170	0.239	1.61
22. [illegible]ulidae	*Engraulis anchoita*	212	0.230	1.69
23. Labridae	*Symphodus melops*	190	0.359	1.83

24. Nototheniidae	*Trematomus bernachii*	309	0.29	1.95
25. Carangidae	*Selaroides leptolepis*	85	1.155	1.99
26. Polynemidae	*Polynemus heptadactylus*	718	0.157	2.05
27. Sparidae	*Dentex macrophtalmus*	941	0.162	2.18
28. Scorpaenidae	*Scorpaena porcus*	869	0.177	2.19
29. Zoarcidae	*Zoarces viviparus*	965	0.203	2.29
30. Sciaenidae	*Pseudotolithus elongatus*	715	0.274	2.29
31. Scyliorhinidae	*Scyliorhinus canicula*	550	0.53	2.46
32. Leiognathidae	*Leiognathus equulus*	197	1.884	2.57
33. Labridae	*Labrus berggylta*	3830	0.107	2.61
34. "	*Tautoga onitis*	2845	0.165	2.67
35. Scombridae	*Rastrelliger kanagurta*	117	5.16	2.78
36. Serranidae	*Epinephelus guttatus*	2089	0.243	2.71
37. Mugilidae	*Mugil cephalus*	2078	0.435	2.96
38. Pomatomidae	*Pomatomus saltatrix*	5808	0.197	3.06
39. Trichiuridae	*Trichiurus lepturus*	4663	0.296	3.14
40. Gadidae	*Pollachius virens*	11331	0.141	3.20
41. Scombridae	*Sarda sarda*	3434	0.693	3.38
42. Gadidae	*Gadus morhua*	16350	0.181	3.47
43. Acipenseridae	*Acipenser stellatus*	15675	0.192	3.48
44. Lophiidae	*Lophius piscatorius*	53952	0.060	3.51
45. Serranidae	*Roccus lineatus*	17543	0.186	3.51
46. Scombridae	*Auxis thazard*	4394	0.829	3.56
47. Acipenseridae	*Acipenser güldenstädti*	97200	0.045	3.64
48. Scombridae	*Euthynnus alliteratus*	44869	0.164	3.87
49. "	*Katsuwonus pelamis*	55200	0.179	3.99
50. Acipenseridae	*Huso huso*	149100	0.097	4.16
51. Scombridae	*Katsuwonus pelamis*	16000	0.949	4.18
52. Istiophoridae	*Tetrapterus albidus*	861500	0.026	4.35
53. Scombridae	*Thunnus obesus*	234961	0.114	4.43
54. "	" "	165108	0.167	4.44
55. Istiophoridae	*Istiophorus platypterus*	36740	0.754	4.44
56. Carcharhinidae	*Prionace glauca*	447750	0.091	4.61
57. "	" "	738000	0.072	4.73
58. "	*Eulemia milberti*	89190	0.610	4.74
59. "	" "	99740	0.580	4.76
60. Scombridae	*Thunnus thynnus*	987388	0.067	4.82
61. "	" "	504835	0.308	5.19
62. Lamnidae	*Cetorhinus maximus*	13820000	0.045	5.75
63. Rhineodontidae	*Rhincodon typus*	60000000	0.025	6.20

Also, lines connecting same P values are drawn at regular intervals of P, and a base line selected (at $P = 0$). On such a grid, the distance from a point representing a pair of growth parameters (W_∞, K) to the base line thus directly expresses P (see Fig. 1). Figure 2 gives a representation of the range of P (and W_∞ and K) values occurring in marine fishes (see Table 1). The grid may now be used to define taxa, such as families. Figure 3 gives an example of the definition in terms of growth parameters of the families Scombridae (= Thunninae and Scombrinae) and Cyprinidontidae.

Figure 4, finally, shows the best use to which the auximetric grid can be put; namely, the definition of species by means of their growth parameters. As may

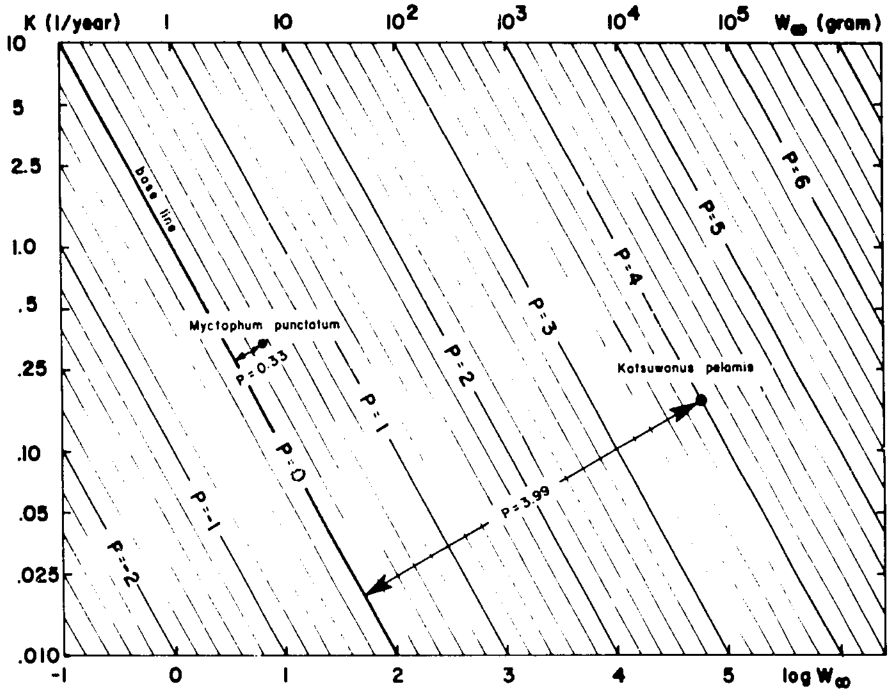

Figure 1. An auximetric grid. Plotted are the following parameter values: W_∞ = 55,200 (g) and K = 0.179 for *Katsuwonus pelamis*, and W_∞ = 6.56 and K = 0.323 for *Myctophum punctatum*. (From Table 1.)

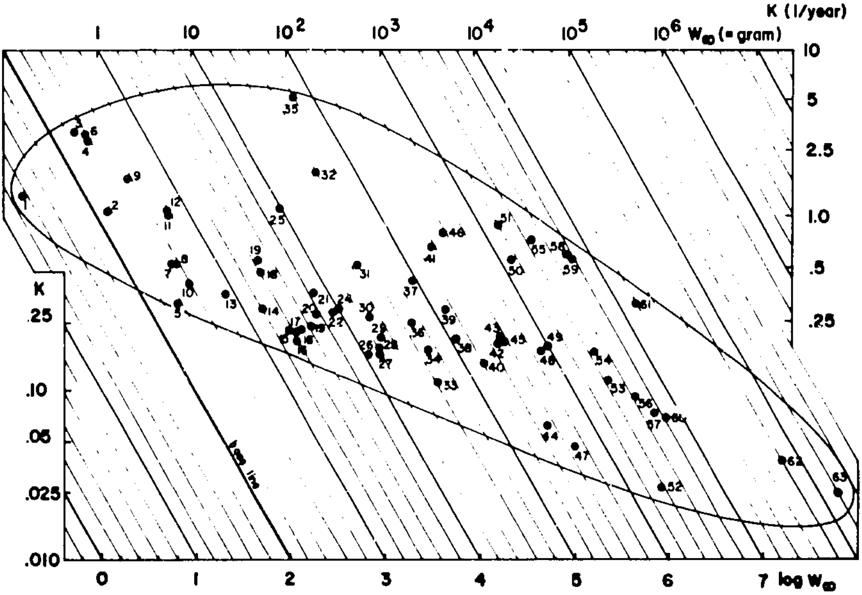

Figure 2. Definition of the area of the auximetric grid that is covered by a representative selection of marine fishes. (Based on data of Table 1.)

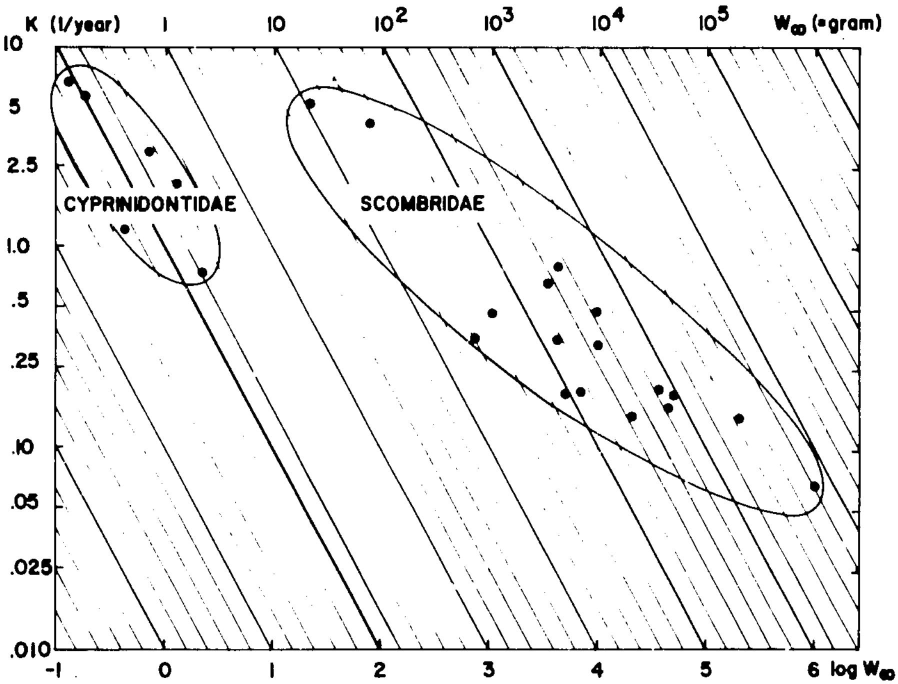

Figure 3. Definition of two families of fishes (Cyprinidontidae and Scombridae) by means of the auximetric grid. Each dot represents one species. (Based on data in Pauly, 1978a.)

be seen from this figure, there is only a limited range of values that P can take in a given species. This results in an equally limited range of possible W_∞ and K combinations. Thus, given the growth parameters of a series of fishes more or less closely related to those one is investigating, it is possible to select a most likely value of K from a reasonable estimate of asymptotic weight.

There are other uses to which the auximetric grid can be put (Pauly, 1979a), but its property of allowing for reasonable estimates of K given W_∞ is certainly the most interesting one as far as stock assessment in the tropics is concerned.

The methods outlined above to "guesstimate" the asymptotic size and the value of K in fish stock do not generate estimates of t_0; that is, of the "age" at the origin of the growth curves. There are cases, however, where an estimate of t_0, even a rough one, may be needed. In such cases, it may be helpful to use the empirical relationship

$$\log = (-t_0) = 0.3922 - 0.2752 \cdot \log L_\infty - 1.038 \cdot \log K \qquad (8)$$

which yields rough estimates of t_0, for any fish, given a value of L_∞ (in cm) and a value of K (on a yearly basis), and which was derived by Pauly (1979a) on the basis of 153 triplets of t_0, L_∞, and K values selected from a compilation of growth parameters (Pauly, 1978a).

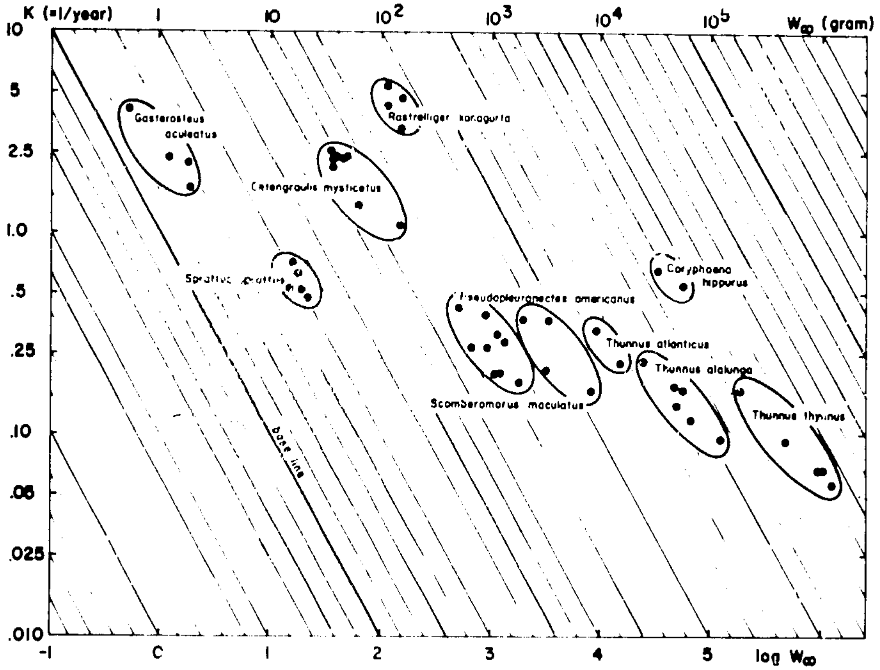

Figure 4. Definition of some species of fishes by means of the auximetric grid. Note that the W_∞, K combinations fit into ellipses, whose main axis should have a slope equal to -⅔. (Growth parameters from Pauly, 1978a.)

Natural Mortality

Estimating the natural mortality of a given fish stock is generally extremely difficult (unless the stock is unexploited) and the lack of reliable estimates of this all-important parameter is one of the major stumbling blocks for fishery biologists attempting to perform stock assessments. This applies especially to the situation in the tropics where statistical data generated by the fishery cannot be used to estimate this parameter. Luckily, it appears that M, the exponential rate of natural mortality, closely correlates with the growth parameters and to the mean habitat temperature of a given stock, to the extent that a knowledge of the asymptotic size of a stock, of its stress factor K, and of its mean habitat temperature is sufficient to obtain reliable estimates of M for any species of fish. The empirical relationship linking all these variables is, for length:

$$\log M = 0.1228 - 0.1912 \cdot \log L_\infty + 0.7485 \cdot \log K + 0.2391 \cdot \log T \quad (9)$$

and for weight:

$$\log M = 0.1091 - 0.1017 \cdot \log W_\infty + 0.5912 \cdot \log K + 0.3598 \cdot \log T \quad (10)$$

where T is the mean environmental temperature, in °C (e.g., as read from an oceanographic atlas), while L_∞ is expressed in cm (Lt) and W_∞ in g (live weight). These relationships were derived from 122 independent sets of L_∞ (W_∞), K, T, and M values which had been compiled and/or calculated from literature data. Both relationships have coefficients of multiple correlation of R = 0.8, and slopes all significantly $\neq$ 0 (Pauly, 1978b). The relatively high value of the coefficients of multiple correlation (with 118 dF and p = 0.01, a value of R = 0.303 would still be significant) suggests, in fact, that the estimates of M obtained by means of Equation (9) or (10) should be very reliable, especially since values of M completely off the mark are virtually impossible (as opposed to the situations, often arising, when Z is plotted on f, where impossible values of M, including negative ones, can easily occur, as shown by Ricker [1975, pp. 172-174]). A biological interpretation of the empirically established relationships between M and the growth parameters and the habitat temperature is attempted in Pauly (1978b) and Pauly (in press).

An important feature of the fact that reliable values of M can be obtained independently of estimates of Z is that it becomes possible to estimate F by subtraction (from Z) and or to estimate the catchability coefficient q of a gear from a single value of Z with contemporary value of effort. Say, for example, we know in 1978 the fleet of artisanal crafts of country A consists of 520 units (similar canoes, all operating similarly) totaling 520 x 220 fishing days per year = 114,400 fishing days in that year. Say, also, that the mean value of Z for the stock exploited by this fleet in 1978 was 0.80. Say, finally, that we know the growth parameter of the fish of this stock, and that they produce, when combined with the mean annual temperature at the fishing grounds, a value of M = 0.35, then F = 0.80 - 0.35. With F = 0.45, it follows that

$$q = \frac{0.45}{114{,}400} = 0.000004 \qquad (11)$$

This method for estimating q is not new. Ricker (1975) discussed its application to the arcto-Norwegian cod (pp. 172-174). The point is that it can now be used as a routine method, since it is easier to estimate M than to estimate q.

An application of this method may be demonstrated here. Table 2 gives values of L_∞, K, and M for six species of fishes occurring in the Gulf of Thailand, M being calculated from the L_∞ and K values, a value of T = 28°C and Equation (9). Also given is the selection factor (SF) of these six fishes, as given in Sinoda et al. (1979), and the mean length at first capture (L_c) resulting from a 4 cm mesh size.

Boonyubol and Hongskul (1978, Table 8) give for these six species of fishes

Table 2. Values of constants used for computing values of F. (Based on data from Pauly, 1978a and 1978b.) L_c refers to the 4.0 cm meshes used by R/V *Pramong 2*.

Species	L_∞	K	M	SF[a]	L_c
Nemipterus pernoii	28.9	0.46	0.87	3.0	12
Nemipterus japonicus	28.9	0.47	0.88	2.4	9.6
Scolopsis taeniopterus[b]	29.5	0.6	1.05	2.4	9.6
Selaroides leptolepis	20.0	1.16	1.85	2.5	10
Saurida undosquamis	40.0	1.00	1.45	3.6	14.4
Priacanthus tayenus	29.0	1.2	1.77	1.9	7.6

a. From Tables 1 and 2 in Sinoda et al. (1979).

b. See text for growth parameter estimates.

the mean length ($\bar{L}$) in the catch of R/V *Pramong 2* (which uses 4 cm meshes) in the years 1966 to 1976 (see Table 3). From the data in Tables 2 and 3, values of F, by year and species, can be obtained through the relationship

$$F = \frac{K(L_\infty - \bar{L})}{(\bar{L} - L_c)} - M \qquad (12)$$

based on Beverton and Holt (1956). The resulting fishing mortality values are given in Table 4. Since we have fairly accurate effort data (SCS, 1978) for the Gulf of Thailand demersal trawl fishery, we may also estimate the value of q, by species, and a mean value of $\bar{q}$ pertaining to the whole fishery. We obtain in this manner a mean value of $\bar{q} = 0.31$, when effort is expressed in millions of trawling hours (Table 4).

Table 3. Mean length of fishes ($\bar{L}$) caught by R/V *Pramong 2* in the Gulf of Thailand (from Boonyubol and Hongskul, 1978, Table 8)

Species	**1966**	**1967**	**1968**	**1969**	**1970**	**1972**	**1973**	**1974**	**1976**
Nemipterus peronii	16.4	16.9	15.9	16.9	16.1	10.2	14.1	13.4	—
Nemipterus japonicus	14.8	14.9	14.2	13.2	12.6	—	12.1	11.5	12.1
Scolopsis taeniopterus	14.6	15.8	15.1	14.2	15.5	12.8	11.0	11.0	12.4
Selaroides leptolepis	13.2	13.0	13.0	13.1	12.4	12.3	12.0	12.6	10.9
Saurida undosquamis	21.3	20.2	20.0	21.4	21.4	14.6	18.7	17.5	17.2
Priacanthus tayenus	15.7	15.5	16.1	14.9	14.4	16.6	12.8	12.8	14.2

Table 4. Fishing mortality, by year and species, with estimation of a mean value for the catchability coefficient (q).

Species	**1966**	**1967**	**1968**	**1969**	**1970**	**1972**	**1973**	**1974**	**1976**	**q**
Nemipterus peronii	0.44	0.26	0.68	0.27	0.58	--	2.32	4.30	—	0.28
Nemipterus japonicus	0.39	0.36	0.62	1.17	1.67	--	2.28	3.42	2.28	0.29
Scolopsis taeniopterus	0.74	0.28	0.52	0.95	0.37	2.08	6.88	—	2.61	0.34
Selaroides leptolepis	0.62	0.86	0.86	0.73	1.82	2.03	2.79	1.45	—	0.29
Saurida undosquamis	0.86	1.56	1.72	0.81	0.81	—	3.10	5.41	6.29	0.50
Priacanthus tayenus	0.20	0.28	0.05	0.55	0.81	—	1.97	1.57	0.92	0.17
Total Effort (f), million hours	2.08	2.80	3.50	3.60	3.80	7.19	9.94	6.06	(9)[a]	—
Fishing Mortality[b]	0.64	0.87	1.09	1.12	1.18	2.23	3.08	1.88	2.79	—

[a] Effort for 1976 is an estimate, other values from SCS (1978)

[b] $F = \bar{q} \cdot f$, with $\bar{q} = 0.31$

That this estimate of $\bar{q}$ is not unreasonable may be briefly assessed. SCS (1978) reports that a surface area of 0.0667 km^2 is swept during one trawling hour. Hence, one million trawling hours sweep 66,700 km^2, or 62% of the 106,800 km^2 of inshore waters (<50 m depth) in the Gulf of Thailand. If there were no escapement, the value of 0.62 would correspond to our value of $\bar{q}$. The value of

$$\frac{\bar{q} \cdot 106{,}800}{66{,}700} = \frac{0.31}{0.62} = 0.50 \text{ or } 50\% \qquad (13)$$

is thus an estimate of escapement. It will be noted that this value happens to be exactly the one commonly assumed for this kind of gear (SCS, 1978; Isarankura, 1971; Pauly, 1979c).

Stock Recruitment Relationships and Stock Interactions in Tropical Fishes

The estimation of $\bar{q}$ given above, hence the availability of a set of fishing mortality data, in combination with the excellent catch per effort data given by the R/V *Pramong 2* from the same area, make it possible to derive stock recruitment curves and to obtain evidence of species interactions of a very interesting kind. Pending a more comprehensive account (Pauly, in preparation), the method by which such relationships may be made visible is outlined here, in the hope that it may encourage colleagues to have a second look at what may at first sight appear to be inappropriate data. I have selected for this exercise the catch per effort data of R/V *Pramong 2* given in Ritragsa (1976) for the total demersal stock, for the false trevally *Lactarius lactarius*, and the Indian halibut *Psettodes erumei* (Tables 5-7).

Table 5. Estimation of the total demersal standing stock size, per year, Gulf of Thailand, Thai inshore waters

	Virgin Stock	**1963**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**
Catch per Effort (kg/h)[a]	—	249	131	115	106	103	97 4	66 3	63 1
Effort (in million hours)[b]	0	0 698	2 078	2 800	3 500	3 600	3 800	6 200	7 188
Total Catch (in thousand tons)[c]	0	278	436	515	594	593	592	658	726
Fishing Mortality[d]	0	0 22	0 64	0 87	1 09	1 12	1 18	1 92	2 23
Standing Stock (in thousand tons)	(1978)[e]	1.264	681	592	545	530	502	343	325

a As given in Ritragsa (1976, Table 4)

b As given in SCS (1978)

c = (c/f) • f • (1 6), the latter factor correcting for the different mesh sizes used by the commercial fleet (2 5 cm) and R. V *Pramong 2* (4 0 cm) (from Boonyubol and Hongskul, 1978)

d With q = 0 31, as estimated in Table 4

e Estimated by extrapolating to f = 0 the natural logarithms of the 1963 and 1966 standing stock values plotted on effort

The catch per effort (c/f) values were first converted to estimates of annual catch (Y) by means of the relationship

$$Y = (c/f).f.(1.6) \qquad (14)$$

where f is the effort as given in Table 5, and 1.6 is a factor correcting for the fact that the commercial fleet, by using smaller meshes than R/V *Pramong 2*, catches more per unit of effort (the area swept, however, is equal). The 1.6 correction factor is taken from Boonyubol and Hongskul (1978).

These estimates of annual catch were then used to estimate stock (B) for any given year by

$$B = \frac{Y}{F.} \qquad (15)$$

The results are given in Tables 5 through 7. However, stock recruitment analysis relates recruit numbers to parent stock size, not to overall stock size. It is thus necessary to reduce, in the cases of *Lactarius lactarius* and *Psettodes erumei*, the overall stock size to the size of the standing stock of those fishes that have reached or are above the age at first maturity (t_m). The relationship between the total standing stock and the standing stock of (potential) parents is, for any fish species,

$$B_p = B \cdot m \qquad (16)$$

where B_p is the parent stock, B the total stock, and m a correction factor which is, among other things, a function of fishing mortality. The value of m for any value of F may be computed from

$$m = \frac{e^{-Zr_3}\left(\frac{1}{Z} - \frac{3e^{-Kr_2}}{Z+K} + \frac{3e^{-2Kr_2}}{Z+2K} - \frac{e^{-3Kr_2}}{Z+3K}\right)}{\left(\frac{1}{Z} - \frac{3e^{-Kr_1}}{Z+K} + \frac{3e^{-2Kr_1}}{Z+2K} - \frac{e^{-3Kr_1}}{Z+3K}\right)} \qquad (17)$$

where $r_1 = (t_c - t_o)$,
$r_2 = (t_m - t_o)$,
and $r_3 = (t_m - t_c)$.

The values of m computed by means of Equation (17) are given in Table 6 for *Lactarius lactarius* and Table 7 for *Psettodes erumei*. Both tables also give the parent stock size obtained by means of these values of m.

Finally, the number of recruits is computed by estimating the yield per recruit for each year and its corresponding level of F, and by dividing the yield per recruit into the catch, or

$$R = \frac{\text{annual catch}}{\text{yield per recruit}} \qquad (18)$$

Table 6. Data for the derivation of stock recruitment curve in *Lactarius lactarius* in the Gulf of Thailand, Thai inshore waters.

	Virgin Stock	**1963**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**
Catch per Effort (kg/h)[a]	–	0.700	0.510	0.191	0.227	0.099	0.016	0.031	0.004
Catch (Y) (in tons)[b]	–	782	1,696	855	1,271	570	97	308	46
Y/R (in g)[c]	–	3.27	5.81	6.21	6.29	6.28	6.27	5.55	5.17
R (in millions)	–	239	292	138	202	90.8	15.5	55.5	8.90
Standing Stock (in thousand tons)	4,125[d]	3,555	2,650	983	1,166	509	82.2	160	20.6
m[e]	0.645	0.587	0.482	0.429	0.381	0.375	0.363	0.236	0.194
Spawning Stock (in thousand tons)	2,660	2,087	1,277	422	444	191	29.8	37.8	4.0

a Recalculated from Tables 5 through 13 in Ritragsa (1976), which give catch rates of R/V *Pramong 2*.

b = (c/f) • f • (1.6), the latter factor correcting for the different mesh sizes used by the commercial fleet (2.5 cm) and R/V *Pramong 2* (4.0 cm) (from Boonyubol and Hongskul, 1978).

c Using the following parameter values: W_∞ = 193 g, K = 1.0, t_o = -0.1, t_c = 0.2, and M = 1.59. Values based on Apparao, 1971, and Pauly, 1978a and 1979a.

d Estimated by extrapolating to f = 0 the natural logarithms of the 1963 and 1966 standing stock values plotted on effort.

e With t_m = 1 year.

Table 7. Data for the derivation of stock and recruitment data in *Psettodes erumei*, in the Gulf of Thailand, Thai inshore waters.

	Virgin Stock	**1963**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**
Catch per Effort (kg/h)[a]	—	0.211	0.992	0.594	0.580	0.653	0.558	0.711	0.504
Catch (Y) (in tons)[b]	—	236	3298	2661	3248	3761	3392	7053	5796
Y/R (in g)[c]	—	30.1	32.6	29.5	26.5	26.1	25.4	18.7	16.8
R (in millions)	(1.10)[e]	7.84	101	90.2	123	144	134	377	345
$\log_e R$	0.09	2.06	4.62	4.50	4.81	4.97	4.90	5.93	5.84
Standing Stock (in tons)	485[d]	1073	5153	3059	2980	3358	2846	3673	2599
m[f]	0.808	0.691	0.469	0.365	0.282	0.271	0.252	0.093	0.059
Spawning Stock (in tons)	392	741	2147	1117	840	910	717	342	153

[a] Recalculated from Tables 5 through 13 in Ritragsa (1976), which give catch rates of R/V *Pramong* 2.

[b] $= (c/f) \cdot f \cdot (1.6)$, the latter factor correcting for the different mesh sizes used by the commercial fleet (2.5 cm) and R/V *Pramong 2* (4.0 cm) (from Boonyubol and Hongskul, 1978).

[c] Using the following parameter values: $W_\infty = 1100$ g; $K = 0.3$; $t_0 = -0.4$; $t_c = 0.2$; and $M = 0.58$ (based on Kühlmorgen-Hille, 1976, and Pauly, 1978a, 1979a).

[d] Estimated by extrapolating to $f = 0$ the natural logarithms of the 1963 and 1966 standing stock values plotted on effort.

[e] Based on Equation (20) and the virgin stock estimate of 485 mt.

[f] With $t_m = 2$ years.

The yield per recruit itself being estimated from

$$\frac{Y}{R} = F \cdot W_\infty \cdot \left(\frac{1}{Z} - \frac{3e^{-Kr_1}}{Z + K} + \frac{3e^{-2Kr_1}}{Z + 2K} - \frac{e^{-3Kr_1}}{Z + 3K} \right) \qquad (19)$$

with r_1 defined as above, the model being a simplified version (Jones, 1957) of the equation presented by Beverton and Holt (1957). The parameter values used for these computations are given in Tables 6 and 7, which also give the number of recruits estimated in this manner.

In the case of *Lactarius lactarius*, plotting R on parent stock size results in a typical "Ricker curve" (Ricker, 1975); the freehand version seems slightly more realistic than the calculated curve (Fig. 5). (The curves differ somewhat from the one previously published [Pauly, 1979b], mainly because different catch data were used to estimate the numbers of recruits.) Quite clearly, the dramatic decline of *Lactarius lactarius* in the Gulf of Thailand, to a virtual disappearance from the catch (Hongskul, personal communication), is due to recruitment overfishing.

In the case of *Psettodes erumei*, on the other hand, there is obviously no relationship between R and parent stock size (Fig. 6). This fish is one of the few whose catch did not decrease as fishing pressure increased. (See Pauly, 1979c, for a preliminary discussion of this feature.) However, plotting the natural logarithm of the number of recruits produced each year by *P. erumei* against the size of the total demersal standing stock (that is, all fishes and invertebrates with which *P. erumei* potentially interacts) provides a surprisingly linear relationship (Fig. 7), which may be described by the regression

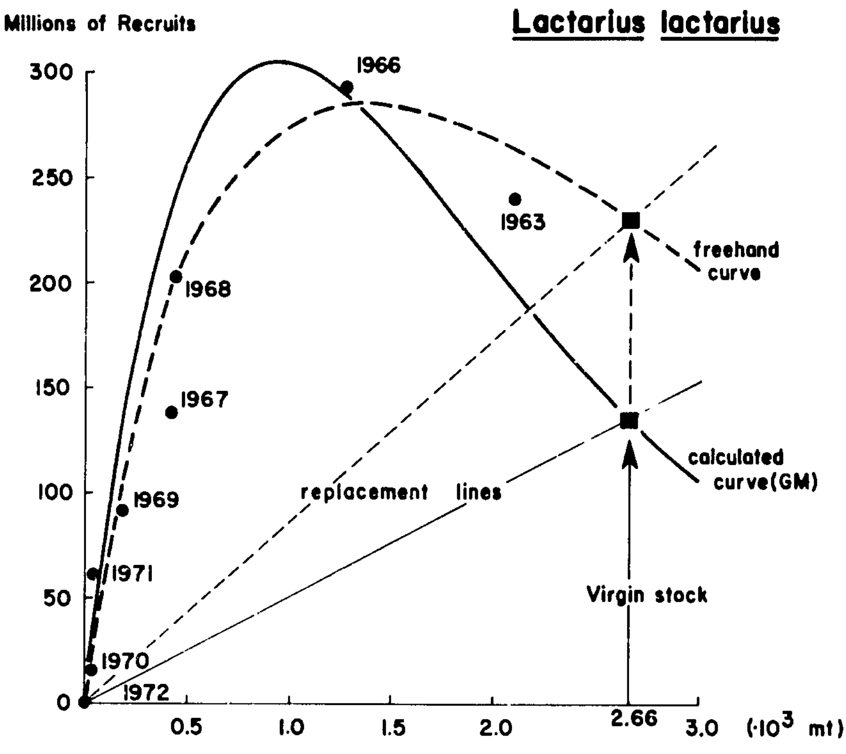

Figure 5. Stock recruitment relationships in *Lactarius lactarius* from the Gulf of Thailand. (Based on data of Table 6.)

$$\log_e R = 7.10 - 4.01\ B_T,\ r = 0.990 \qquad (20)$$

where R is the number of *P. erumei* and B_T is the biomass of the total demersal standing stock in millions of metric tons. Equation (20), in fact, expresses a "stock recruitment relationship," except that the stock in question is not the parent stock but the overall stock of potential competitors and predators. We may therefore call this type of relationship an *interspecific* stock recruitment relationship, as opposed to the normal *intraspecific* stock recruitment curve where the interactions occur within a single-species stock.

The interspecific stock recruitment relationship in Figure 7 suggests that the extraordinary resilience of this flatfish against a strong fishing pressure is due to the fact that *P. erumei* is an r-selected species, whose biomass was being kept at low levels in the virgin stock. As its predator diminished, however, recruitment to the stock of *P. erumei* increased rapidly, which allowed this fish to sustain the heavy fishing pressure. This confirms the pattern of stock interactions suggested in Pauly (1979c). The actual decrease in mortality of the prerecruits of *P. erumei* as the total demersal stock declined can even be demonstrated directly.

For the age t = 0 (at which the eggs are shed) and the age $t_c = 0.2$ years (=

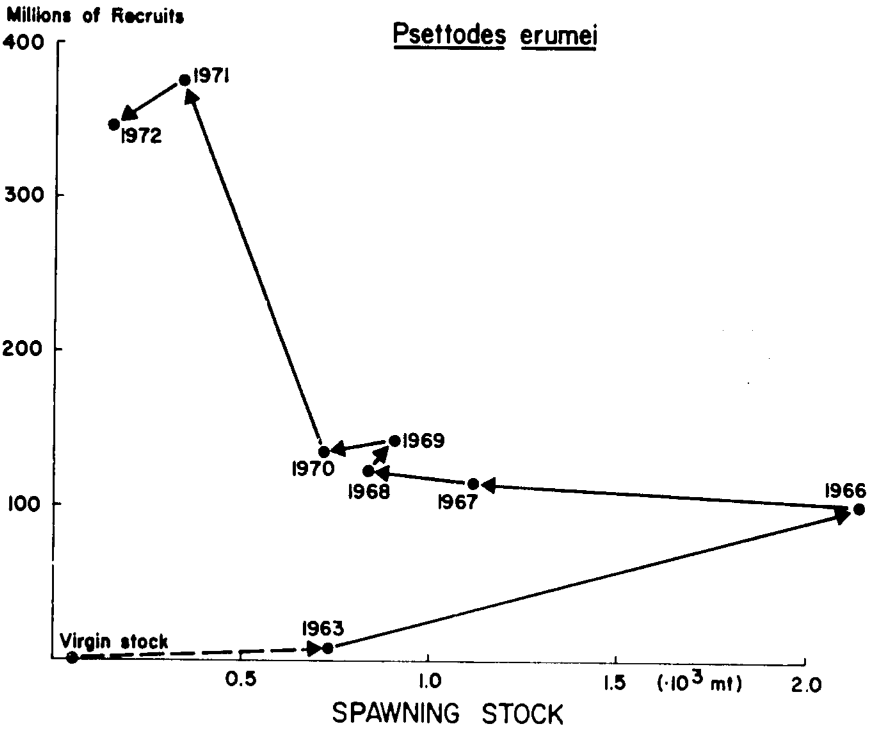

Figure 6. Demonstration of the lack of a stock recruitment relationship in *Psettodes erumei* from the Gulf of Thailand. (Based on data of Table 7.)

73 days, the mean age at first capture and recruitment), the natural mortality can be estimated for each year through

$$M_d = \frac{\log_e \left(\frac{\text{recruits}}{\text{eggs produced}}\right)}{-73} \qquad (21)$$

which provides the mortality estimates of Table 8. These estimates can be transformed to estimates of the percentage of prerecruit dying per day through the relationship

$$\%\ \text{dying per day} = 1 - e^{-M_d} \qquad (22)$$

(see Table 8). The values of M_d that were obtained range from 0.144 in the virgin stock to 0.052 in the exploited 1972 stock (Fig. 8). These values, incidentally, compare quite well with those given by Cushing (1976) for plaice (0.05) and haddock (0.10).

What is most striking, however, is the relationship of these computed mortality values to the biomass of the total demersal standing stock (Fig. 8). The points for eight different years (plus the point derived indirectly for the virgin stock) suggest a continuously decreasing prerecruit mortality as the total stock decreased, with the intriguing possibility that the prerecruit mortality of *P.*

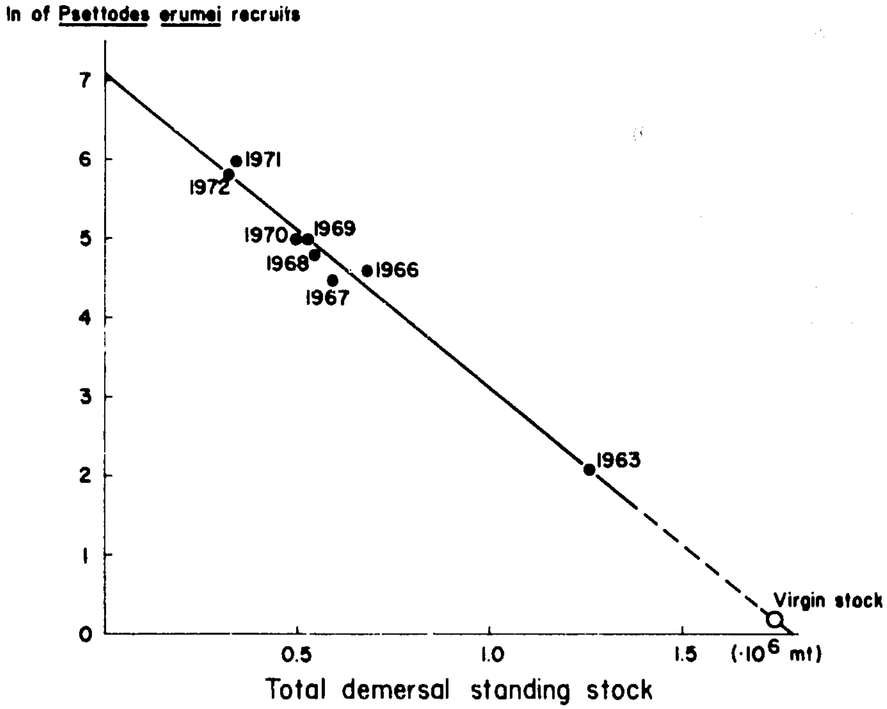

Figure 7. The relationship between recruitment in *Psettodes erumei* and the size of the total demersal stock. (Based on data of Tables 5 and 7.)

Table 8. Data for the estimation of prerecruit mortality in *Psettodes erumei*.

	Virgin Stock	**1963**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**
Number of Recruits (10^6)[a]	1.10	7.84	101	90.2	123	144	134	377	345
♀♀ Spawning Stock (in tons)[b]	196	370.5	1,073.5	558.5	420	455	358.5	171	76.5
Eggs Produced (10^8)[c]	392	741	2,147	1,117	840	910	717	342	153
Exp Rate of Mortality (per day)[d]	0.144	0.125	0.105	0.098	0.089	0.088	0.086	0.062	0.052
Percent Dying (per day)[e]	13.4	11.8	10.0	0.3	8.5	8.4	8.2	6.0	5.1

a. From Table 7

b. 50% of parent stock size in Table 7.

c. With 200 eggs per g of adult female, an assumed value based on plaice data (based on Table 59 of Bagenal, 1973).

d. From Equation (21)

e. From Equation (22)

erumei may be reduced to a negligible amount when all other fishes are removed (Fig. 8). Indeed, what may be occurring here is one of the first demonstrations of "density-dependent" mortality in the prerecruits of any tropical stock, along with one of the first demonstrations of stock interactions of this type.

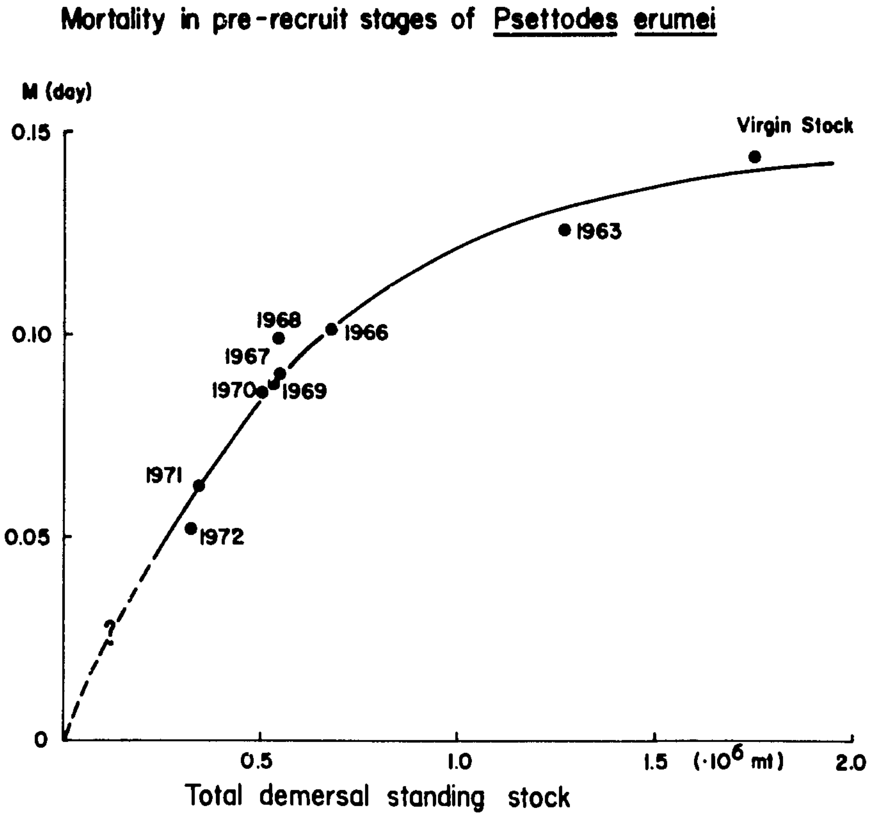

Figure 8. The relationship between prerecruit mortality in *Psettodes erumei* and the biomass of its potential predators. (Based on data of Tables 5 and 8.)

Conclusions

In the introduction, mention was made of the need for more thorough use of the data on the biology of tropical fish presently available. Also, it was contended that the combination of such biological data with the data generated by the fisheries themselves would allow, at very little cost, for a greatly improved understanding of the dynamics of tropical multispecies stocks. The present exercise may be seen as an illustration of these two points.

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Report on the Studies of Multispecies Systems in Fisheries

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Introduction

Classical studies of fisheries dynamics deal mostly with single populations treated as if they existed independently. Fishery biologists have come to recognize, however, that in many situations the fish stock cannot be so treated. To a steadily increasing extent, modern fisheries are concerned with harvesting a wide range of species living in the same body of water. The exploited populations of interest are interdependent with others (which may be either exploited or unexploited) through competition or predator-prey relationships. Any effect of exploitation on one stock may produce a reaction in another, resulting in readjustments in both populations, and invalidating the expected response to exploitation based on single-species dynamics.

The management problems arising from multispecies fisheries have been recognized. Since yields of different species are maximized at different effort levels and it is impossible to adjust the fishing effort to each level to maximize the sustainable yield of all, some populations will be overfished and some underfished. In fact, it is likely that, in multispecies fisheries, species of lower productivity are progressively eliminated or pushed close to extinction as the fisheries harvest the more productive species to the level of their supposed maximum yield, as pointed out by Larkin (1977). The results of such changes on the stability of the fish community are virtually unknown at present, although the effects of the exploitation on species succession such as those in the Great Lakes (Smith, 1968) are expected.

The extension of coastal state jurisdiction up to 200 miles added a further dimension to this complex problem. This action brought virtually all fish stocks within coastal state jurisdiction. The first paragraph of Article 61 of the Informal Composite Negotiating Text assigns the responsibility to the coastal states for determining the allowable catch of living resources in their exclusive economic zones. The problem of the principles that should be used in determining these allowable catches immediately arises. The uncertainty of the general applicability of the single-species models, the interactions among species, and also the influence of environmental fluctuations are making it difficult, even for the developed coastal states, to estimate the sustainable yields from the multistock, multispecies, and multigear fisheries. Needless to say, the developing countries with less capacity in fishery science have greater difficulties.

Therefore, a study of the dynamics of the multispecies system becomes important to the developing countries, while at the same time being of considerable

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value to fishery science in general. An André Mayer Fellowship was granted to the author by FAO with the objective "to study and develop models which would provide the basis for a good understanding of events in a multispecies community that occur under exploitation and for deeper and more fundamental study of the subject." This objective should be met by: 1) identifying the required statistics and other data necessary to undertake such studies; 2) identifying information on feeding habits and other behavior factors required to study the species within the system; and 3) developing suitable theoretical models which will take account of the direct effects of fishing on each species, and the interaction between species.

This report presents a critical review of the existing multispecies models, problems, and proposed program of field study that should be carried out in accordance with the terms of the assignment.

Multispecies Models

Despite the general concern, effort toward solution of what has been called the multispecies problem has been diffused and uncoordinated. While considerable work has been done on the single-species system, very little work of value has been undertaken on the effects of fishing on multispecies systems. In fact, there is little evidence of a generally recognized concept as indicated by recent meetings on the multispecies fisheries problems (Hobson and Lenarz, 1977; FAO, 1978). It may be because there are so many variations of the problems. A large amount of recent literature on modeling abundantly demonstrates that a wide variety of unexpected consequences can flow from what seem to be simple management strategies for these fisheries.

The first attempt was made on the multistock problem by Ricker (1958) and later by Paulik et al. (1967) for salmon management where escapements were known and could be regulated. The application of their work to other species elsewhere is therefore limited. On the other hand, Rothschild (1967) and Pella (1969) suggested stochastic models for multispecies fisheries in which there is competition for fishing gear rather than among the species concerned, called the "technological interaction" by Pope (in press).

For the interspecific interaction which is the crux of this problem, Larkin (1956, 1963, 1966) pioneered the mathematical examination of the interactive relationships for two species, in the form of Lotkva-Volterra equations. Silliman (1969, 1975) employed these equations to investigate the interactions among species and the resulting yields from analog computer simulations. He suggested that the competition theory may account for a substantial proportion of the variation in the Pacific anchovy biomass. Pope and Harris (1975) also explained the effect of interspecific competition between the South African pilchard and anchovy stock complex based on a similar formulation. Many other attempts were made along these lines, although few were applied to the actual fishery situations. For example, Lord (1971) formulated a general multiple-species production model with interspecific interaction terms and performed some mathematical analysis of the logistic form. However, there has been no attempt to apply the model to an actual fishery. Nevertheless, one important feature of such interacting population models emerged from these studies, as shown by

Pope (1973, 1976), Silliman (1975), and Horwood (1976). It is when two species are interacting that the total yield from an interactive system would be lower than the sum of the individual species MSYs. The maximum attainable yield, however, lies within a parabolic dome whose sides are defined by the loci of species mortality rates generated by the fisheries. For highly interactive fisheries, the yield region is rather narrow and the total yield is not much greater than that which would be achieved by the fishery for either species separately.

The third approach for the multispecies problem was taken by expanding the basic interactive model into the "whole system" or trophic-dynamic models. By identifying the appropriate trophic assemblages (e.g., indirect indices of the degree of interaction and organization within fish assemblages, indices of feeding success, growth and feeding relationships, metabolism, etc.), food intake, and biomass, the models of the energetics of the natural populations were constructed to predict the reactions of the system to changes in the structure of the populations and their environment. Among these groups are those of Riffenburgh (1961, 1969), Garfinkel (1967), Patten (1969), Parrish and Saila (1970), Paloheimo and Dickie (1970), Saila and Parrish (1972), Regier and Henderson (1973), Timin (1973), Stewart and Levin (1973), Hackney and Minns (1974), Parrish (1975), Jones (1976), Andersen and Ursin (1977), and more to come. It is interesting to note that, while emphasis on the ecological approach is made and generally accepted, nearly all of these models are still in the experimental stages with no applicability for the actual management or conservation of the species under study. It is apparent that attempts have been made to deal with the problems of energy flow and species diversity in natural communities. However, the problem of major concern to marine ecologists, as well as to marine fishery biologists, is how to quantify and analyze the complex patterns of passage of energy among fishes and other trophic levels in the marine environment. Testing such theories in a natural setting is also extremely difficult and suffers from lack of control on other exogenous factors. This stage can be summarized by a quote from Patten (1969):

> A definitive rationale for ecological modelling has not been invented yet. There is little agreement about what constitutes a valid model since all modelling is abstraction and biologists are inclined to be concerned with realities. Models having predictive and analytical capabilities with real world relevance are an ultimate goal, but until technical problems relating to the abstraction process are resolved the greatest value of dynamic ecological modelling is likely to remain what it is at the present time—heuristic.

Nevertheless, in the author's point of view, these attempts are encouraging evidence that the multispecies problem is increasingly well recognized and is already receiving much attention.

As a series of multispecies models were constructed and presented in the past decade, certain questions arose: What do we expect from these models? What would be the criteria for good models, academic as well as practical, for management purposes? It would be better to concentrate on the following questions to be asked of multispecies fisheries models:

1. Can an interdependent or interactive model be made to fit reality reasonably well?
2. If the fit is adequate, what are the extrapolations for abundance and

catches of species concerned?

3. What would be the mix of fishing efforts in these interactive fisheries that would, without upsetting the ecological balance, optimize a) the target species catch, and b) the combined species catch?

4. For the possible mixes of fishing effort, what are the projected catches of the species concerned?

5. Can we affect population abundance generally by the control of fishing intensities?

6. If so, how delicate must this control be? For example, can we optimize catch while maintaining ecological balance or are we likely to upset the ecological balance with the slightest change in fishing intensity?

The closest model that can answer some of these questions is that of Andersen and Ursin (1977), which was used for multispecies fish stock assessment in the North Sea (Ursin, 1977). Regrettably, the great number of predetermined parameters required, as well as many that have to be obtained from simulations, make it less applicable to other fisheries, which have a short history of fisheries and fishery research.

It is apparent that the success of multispecies models depends critically upon the quality of the data set on which they are based. The available data therefore dictate the choice and also the outcome of the models to be employed for a particular purpose. Lack of appropriate data at a number of levels of specificity and of temporal and spatial scope, for both strategic and tactical purposes, was pointed out as the main hindrance to progress in this field at both expert meetings on multispecies fisheries problems (Hobson and Lenarz, 1977; FAO, 1978).

With this fact in mind, the author views the development of the multispecies models as five levels of progression, which are outlined in Table 1. At the most basic level, Level 1, only some exploratory work has been done, with little fishing, but crude estimates of the abundance and nature of the existing communities in the area, as well as of basic production, could be made to guide the fishery development schemes. When the fisheries have been in existence for some time and catch and effort data become available from properly designed fishery statistic systems,the fishery scientists could progress to the second level, and estimate overall fish production and the optimum fishing effort required for management. Most of the fisheries of the world are still at this stage, with a greater or lesser degree of satisfaction. The use of surplus production models has been generally adopted for multispecies fisheries, with some adaptations to the catch-effort analysis to suit the particular characteristics of the fisheries under study (see Chikuni, 1976; Clark and Brown, 1975; Hongskul, 1975; Brown et al., 1976; Pinhorn, 1976; Halliday and Doubleday, 1976; Boonyubol and Hongskul, 1978). Of course, the validity of the use of this model without a specific study of the interactions among the species presented in the area has been criticized. Nevertheless, as pointed out by Gulland (1976), the immediate day-to-day management needs are to determine what is happening; i.e., what the net effects of changes in the amount of fishing (including the indirect effects through interactions between species) are, rather than why and how these effects take place. The main problem lies in the refinement of catch per unit of effort analysis, particularly when the catchability coefficients change with the abundance of stocks, as suggested by Fox (1974), Garrod (1976), and Ulltang (1976, 1978).

Table 1. The development of multispecies models and their expectations at each progressive level.

Level	Progression	Data required	Expectation
1	Exploratory	Standing crops Primary production	Virgin biomass Potential yield Fish communities
2	Production models	Catch/effort Fishing strategies	Overall MSY Optimum effort
3	Biomass models	Mortality rates Catchability coefficient Biological parameters	Species TACs Mesh regulations Effort regulations
4	Interactive models	Food web analysis Plankton analysis Life history	Management options Effort control
5	Ecological models	All-level productivity Ecological coefficients Energy transfer	Overall production Conservation

Among fisheries in temperate waters where aging of fish is possible, the use of Virtual Population Analysis (VPA) opens the door for the investigations on variations of fishing mortality rates with age, as well as on the catchability coefficients mentioned above. These additional types of information lead to the third level of multispecies models, in which the changes in biomass of various species are investigated and related to the catches. The interspecific interactions might be revealed through the changes in the biomasses of interactive populations. Some properties in the ecosystem such as replacement and species succession can be studied, as shown by Smith (1968) and Daan (1978). Moreover, even the effects of environmental fluctuations in fish production can be examined (Doubleday, 1976; Lett and Kohler, 1976). It is rather unfortunate for the tropical fisheries that this magic door remains closed to them because of the lack of suitable aging techniques.

While practicing the applications of multispecies models at Level 2 or 3, another group of biologists may reach Level 4 by examining the interspecific relationships in the fish community. Analyses of plankton data and of early life histories are indispensable to the understanding of the role of interspecific interactions, which occur more strongly during the larval stages than at other periods of life. The classifications of major herbivorous and carnivorous plankton, fish larvae, and juveniles according to their feeding habits will certainly throw light on the study of energetics in this ecosystem in the long run. For the adult fish, food web analysis, as presented by Maurer (1975, 1976) and recently by Grosslein et al. (1978), served as examples for this approach. In the short run, these studies are also of value in identifying and classifying the interrelationships among the major economically important species groups in the fisheries. The economic consideration may also serve as one of the criteria in selecting groups for the study of interactions at this level.

Undoubtedly, it will take considerable time before one can gather enough information to investigate the dynamics of ecosystems. The details of Level 5 are beyond the scope of the present study. The only suggestion for the fishery biologists (not for management) is to keep a close watch on the advances in the field of ecosystem analysis so that relevant information can be collected at the proper time. Observations and experiments relevant to this aspect should also be encouraged for better understanding of the system under which the fisheries will be operated on a long-term basis in the future.

Application to Tropical Fishery Management

While the fisheries in temperate zones consist of a few exploited populations that have a long history of fisheries research which provide enough information to experiment with multispecies models, tropical fisheries suffer from lack of data and numerous populations. The task of fisheries management in the latter case becomes much more complex because of the varied social, economic, and political objectives that societies as a whole can pursue. Unfortunately, most of the developing coastal states that have new responsibility for the conservation and management of fishery resources lie in the tropical region. The need for practical management schemes for these multispecies fisheries is therefore greater than ever.

One must always bear in mind that management of tropical fisheries cannot wait for the better data and the research required by a refined model, since the fisheries are developing fast enough to overexploit the resources within a short period of time. Experiences from the trawl fishery in the Gulf of Thailand indicated that the MSY was attained within only five years after the beginning of the expansion of trawl fishing in the region. A similar phenomenon was observed in the scad (*Decapterus* spp.) fishery of Thailand. The fishery biologists are therefore assigned a difficult role in this dynamic situation; that is, to detect changes in the state of stocks and diagnose them, with an awareness of the time lags that are inevitable between the provision of advice based on scientific analysis and the enforcement of regulations as they are finally adopted by the fishery administration.

The difficulties of rational management of these fisheries have been recognized. The increased expectations of the coastal states to develop or expand the fisheries in their newly acquired exclusive economic zones and to invest more heavily in fishing effort will eventually lead to a mutually destructive race for both biological and economic resources. The sophisticated multispecies fisheries models will not serve the needs of fisheries authorities concerned. An alternative approach may be to develop a down-to-earth model for diagnoses of the state of the exploited stocks and advice on management measures such as effort control (direct or indirect) and control of the age or size at which fish are first exploited (e.g., mesh size regulation in trawl fisheries).

For the study of multispecies fisheries at the initial stage, the production model as shown by Pope (1975, 1976) and Brown et al. (1976) has the great advantage of simplicity. The experiments by Silliman (1968) and Lett and Kohler (1976) as well as that of Doubleday (1976) also confirm the applicability of this type of model to fisheries problems with multispecies interactions and environmental perturbations.

Pope (1975, 1976) has extended this model into the mixed-species fisheries problem as already mentioned. He shows that, if a multispecies fishery conformed to this model and if the development of fishing effort on the system occurred with a constant ratio between the efforts on different species, the form of the yield curve for total catch would be a parabolic function of total effort. Theoretical consideration of two interacting fisheries, however, indicates that the overall MSY would be associated with a particular species composition and its achievement would depend on the composition of the actual catches being matched to the "optimal" species composition. In other words, the general production model does not necessarily indicate the MSY of a complex. The true MSY is only likely to be achieved by a very mixed—i.e., indiscriminate—fishery and will result in a progressive change in species composition in the multispecies system.

While Pope's interactive production model deals directly with the multispecies fisheries problem and requires fewer parameters than would an analytical multispecies model (e.g., that of Andersen and Ursin), its use is limited in practice, since it still requires a considerable number of parameters. For the n-stock system, the parameters would be equal to $(n + 1)^2 - 1$, which makes it rather difficult to apply to tropical fish communities. Pope (1977), however, suggested an approximation for managing multispecies fisheries where the parameter values are unknown by trying to achieve maximum yield by maintaining each species at about half the level of its unexploited biomass. In practice, this is equivalent to the strategy derived at Level 1 of the multispecies models described earlier.

Pope (1977) also proposed an alternative method to deal with a complex fishery by employing principal component analysis. He showed that tropical multispecies fish stocks, at least in the Gulf of Thailand, tend to support a fishing effort which is not very species-selective. Therefore, there is a tendency for fishing mortality rates to increase in a fairly constant proportion for each species. The conditions for an overall yield curve to be applicable are therefore broadly satisfied and the MSY given by an overall Schaefer curve can be used. A principal component analysis of demersal catch rates along the Indian Ocean coast of Thailand indicated similar results.

It is important to note that, without reliable estimates of catchability coefficients for the various stocks under exploitation or the estimates of fishing mortality rates of each stock, the application of multispecies fisheries models for management purposes is likely to remain at Level 2 for the time being. In the meantime, however, biological investigations of feeding habits throughout the life history of major species, surveys on the abundance of plankton, eggs, and larvae, and so on should be encouraged so that a better understanding of the interrelationships among the exploited fish populations can be applied to higher-level models in the future

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A Tentative Structural Modeling Approach to Some Aspects of Small-Scale Fisheries Management

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Abstract

The concept of applying signed digraphs to the analysis of some types of fisheries problems is introduced. Two examples, based on the application of digraph methodology to fisheries problems associated with developing countries in tropical latitudes, are provided. The advantages and limitations of the method are demonstrated using these simple examples.

Introduction

The problems of managing tropical small-scale fisheries appear to be especially difficult, due in part to the high diversity of species and fishing methods, and the paucity and low quality of data (both catch statistics and the vital statistics of the important species). For example, Marr (1973) has pointed out that the past performance of fishery science in helping fisheries of Southeast Asia leaves something to be desired. Some of the data requirements for fisheries management and stock assessment for marine fisheries in developing areas have been summarized by Gulland (1976). Henderson (1976) has provided a review of approaches to the assessment of fish resources in inland waters of developing countries. From these reports it seems evident that there is still a need for exploring alternative management methodologies which are relatively simple to apply but which provide useful initial information on which administrators could take preliminary management decisions. One of these alternative approaches is briefly introduced in this report

A class of mathematical modeling techniques called structural modeling has been developed to provide analytical tools for addressing holistic, partially specified, complex systems. One of these structural modeling techniques is graph theory, which is now being applied in social science, psychology, engineering, and physics. Roberts (1976) has developed and described in detail the idea of studying various biological, social, and societal problems by means of a geometric methodology which has been termed "structural analysis." More specifically, Roberts used the signed or weighed digraph as a mathematical model to describe and analyze some of the above-mentioned classes of problems. Jeffries (1974) has used digraphs to model and test for ecosystem stability. Saila and Parrish (1972) have applied graph theory to food webs, and Levins (1975) and Lane and Levins (1977) have evaluated system stability by loop analysis, which is also a structural modeling technique.

The objective of this report is to provide elementary applications of digraph methodology, with emphasis on the construction of signed digraphs and on the analytical assumptions used in drawing conclusions from these digraph models. It is hoped that these applications will provide some indication of the contexts in which a digraph analysis might be usefully applied in developing fisheries and suggest further application of graph theory. Much of what follows has been freely adapted from the basic ideas and theorems put forth by Roberts (1976, 1978) and Jeffries (1974).

Digraph methodology is considered to be part of a geometric class of methodologies for analyzing complex systems, as contrasted to the more conventional arithmetic methodologies. The latter deal with specific numerical values, tend to make precise time-specific predictions, and often seek to maximize or optimize certain specific quantities. The analytic (Beverton-Holt or Ricker type) and stock production (Schaefer type) models of fishery science are examples. Geometric methodologies, on the other hand, deal with shape and structure. They require less detailed input, and they make general predictions about qualitative trends. The specific time attached to a prediction is not considered as significant as the general nature of the predicted behavior. Some examples of conclusions which are considered to be geometric in nature include: 1) a variable (the fishery) grows exponentially, 2) the level of the variable (the stock) shows damped oscillations; 3) the level of a variable (the stock) exhibits increasing oscillations; and 4) the system (fishery) is qualitatively stable; etc.

It is suggested that digraph methodology may be specifically useful in the early stages of a research or management project in developing fisheries, where for a relatively small investment of time and resources the methodology may help identify important variables and alternative management options, and qualitatively evaluate these options. Digraph methodology seems especially appropriate for decision-makers, because the method is graphic and easy to interpret with relatively little formal background.

In general, the method attempts to relate geometric conclusions about pattern or shape to structural properties of complex systems. Other applications and developments in structural modeling include Kane (1971) and Kane et al. (1973) for management decision-making in other disciplines. The properties and limitations of several structural modeling techniques have been reviewed by Cearlock (1977).

Fishing Industry Model Illustration

Some elements of the fishing industry of Penang and Kedah, Malaysia, based on information obtained from Munro and Loy (1979) as well as some observations made during a visit to Malaysia by the author are utilized in the examples that follow. First, an attempt is made to model some of the factors leading to a stagnation in the number of traditional inshore fishermen in these areas. It should be appreciated that the material which follows is presented as an extremely simplified example for illustrative purposes, but one which is based on some elements of reality.

In this example, only five variables considered relevant to the problem of stagnation in the inshore sector are utilized. These are the population of traditional inshore fishermen (P), the demand for fish (D), the traditional inshore sector manpower input to the trawler fishery (TMI), the inshore sector manpower input into the traditional mixed fishery (IMI), and the catch per unit effort of fishes affected by the trawler fishery (Y).

A diagram is drawn in which each of these variables is represented as a point or dot. An arrow is drawn from point x to point y if a change in x has a significant effect on y. The result of the connections of the dots by lines is a diagram such as the one illustrated in Figure 1 for the example mentioned previously. It should be noted that Figure 1 was constructed under several assumptions: The trawl fishery is considered to be in a condition of high exploitation with a negative effect on CPUE of increased effort. The population of traditional inshore fishermen is assumed to be uncontrolled by any outside measure. The effect of the demand on CPUE is ignored but the effect of CPUE on demand is included.

Figure 1 has a sign (+ or -) on each arrow. A plus sign (+) means that a change in x has a augmenting effect on y. The effect is augmenting if an increase in x leads to an increase in y and a decrease in x leads to a decrease in y. The effect is inhibiting if an increase in x leads to a decrease in y and a decrease in x leads to an increase in y. In Figure 1, for example, the arrow from P to D is +, because an increase (decrease) in population leads to an increase (decrease) in demand for fishing activity. A digraph consists of n points or dots together with from zero to n^2 connecting directed lines. The diagram in Figure 1 is termed a signed digraph for reasons indicated above. A signed digraph with n points may be associated with any n x n matrix, using the signs of the non-zero entries in the matrix.

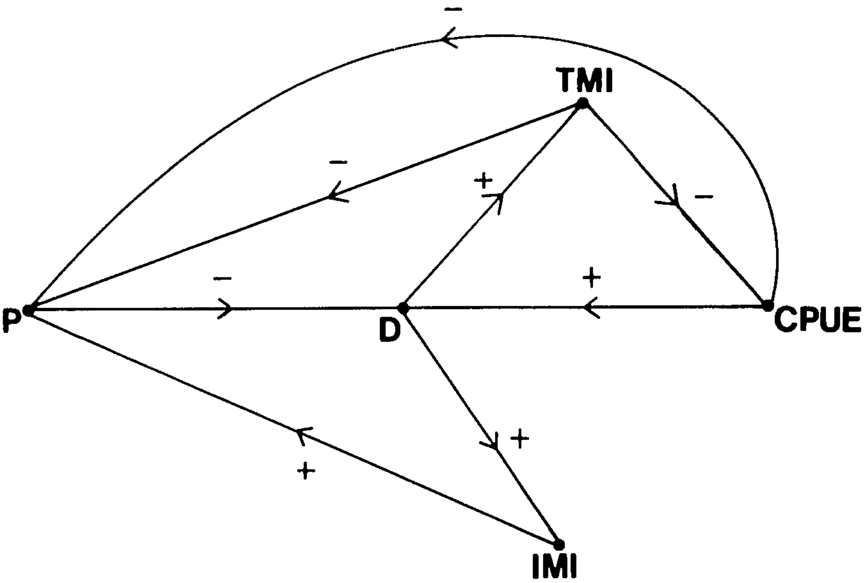

Figure 1. A simple signed digraph model of the effects of the trawl fishery on the population of traditional inshore fishermen based on some observations from a local Malaysian fishery.

It is useful to identify cycles in digraphs. Cycles are found by following arrows around until they return to the starting point. There are four simple cycles in this figure. They are: 1) P to D to TMI to CPUE to P; 2) P to D to TMI to P; 3) P to D to IMI to P; and 4) D to TMI to CPUE to D. A sign (+ or -) can be associated with each cycle. The sign is plus (+) if there are an even number of minus signs on it, and negative (-) otherwise. In Figure 1, (P, D, TMI, CPUE, F) and (P, D, IMI, P) are positive, and the simple cycles (P, D, TMI, P) and (D, TMI, CPUE, D) are negative. Jeffries (1974) has more formally defined a "p-cycle" in a digraph as a set of p distinct points through which a circuit may be traced by following p directed lines.

Cycles in digraphs correspond to feedback processes, and the sign of a cycle gives the sign of the feedback. For example, the sign of the longest cycle (P, D, TMI, CPUE, P) corresponds to positive feedback. An increase in the demand for fish leads, via this cycle, to increased manpower input for larger trawlers, to a decrease in the catch per unit effort in the demersal fishery, and to some decline in the population of traditional fishermen in the inshore sector. Further increases in the demand for fish lead to further pressures for change in the same direction, which is a loss of traditional fishermen in this case. The feedback loop (P, D, IMI, P) is also positive. However, in this case the demand for fish leads to increased manpower requirements in the traditional mixed inshore fishery, which promotes an increase in the population of traditional inshore fishermen. The other two cycles have negative signs. In a general way, too much positive feedback in a system can lead to rapid growth in a positive or negative direction, and it can cause instability in the system. Note that in this case the two positive cycles tend to offset each other somewhat, since one leads to continuous decline and the other to continuous growth. These two processes operating simultaneously may account to some extent for the stagnation condition of the traditional fishery in this example. The cycle (P, D, TMI, P) is negative, because the demands in manpower for the trawl fishery are generally not met by the traditional inshore fishermen. In this digraph, no effect of increased effort by the inshore sector on the catch per unit effort or demand for fish is postulated because of the more diverse nature of the inshore fishery. In a general way, negative feedback can be stabilizing.

The construction of a digraph, such as the one illustrated in Figure 1, and the identification of cycles and their signs, is a simple example of model construction and analysis of the geometric type. The conclusions from such a model are purely qualitative in nature. However, the understanding and identification of feedback loops in such a model can lead to better understanding of some of the processes inducing stability or instability. Furthermore, if a signed digraph is regarded as a reasonable model for a system, and if it is desirable to explore potential strategies for modifying the system, then modifications of the signed digraph may help in discovering strategies to change the system. Changes in the signed digraph may include the addition or deletion of points (variables), the addition or deletion of arrows, and/or changes of sign. Each of these changes (alone or in combination) corresponds to a potential strategy. For example, deleting the arrow from TMI to CPUE is a strategy for dealing with the reduction in traditional inshore fishermen. It breaks up a positive feedback loop which is leading to increased losses from the inshore sector. This strategy corresponds to putting some constraints on the trawler industry by limiting expansion in the industry only to the point where negative effects on the CPUE are not significant. Another strategy would be to change the sign of the arrow from TMI to P. This would indicate that the recruitment of fishermen to the trawl industry takes place only from the traditional inshore pool of fishermen instead of from outside sources.

Generally, a systematic analysis of various structural changes in a signed digraph leads to some nonsense strategies, or strategies which are impossible to implement, but it can also lead to potentially interesting strategies in some instances. For detailed analysis, the latter strategies should then be modeled using other, more rigorous techniques.

Structural Community Model

Jeffries (1974) has demonstrated that an ecosystem is qualitatively stable when it is possible to conclude that the system is stable on the basis of qualitative effects of member species on each other. He extended May's necessary but insufficient conditions for qualitative stability to sufficient conditions using signed digraphs.

In the same report, Jeffries also defined a predation community, a concept believed by this author to be useful in considering the effects of various exploitation strategies on localized multispecies fish populations, such as might be found in tropical latitudes. To effect some parsimony in the model, the term "species" is used very loosely in this report. It is applied both to individual species as well as to species groups (guilds), which are defined as groups which utilize similar environmental resources in a similar way. The guild concept has been defined and utilized by Sale (1975) in studying tropical reef fishes. In Jeffries' definition, if two species are involved in a 2-cycle, using the previously given definition of cycles, and if the 2-cycle involves a + line and a - line, then the species may be regarded as predator and prey. The species are then said to be related by a predation link. Associate with a fixed species all other species, if any, to which that species is related by predation links, and so on. The maximal set of all species so related to the first species and containing it is called the predation community. A single species not connected by a predation link to any other species is also called a predation community, albeit a trivial one. In this manner, any digraph may be partitioned into predation communities. Jeffries (1974) has also detailed certain qualitative stability conditions for signed digraphs, and these are considered further by Jeffries et al. (1977), as cited by Roberts (1978).

In community ecology, a predation community has usually been represented by a system of ordinary differential equations of the form

$$\frac{dx_i}{dt} = \sum_{j=1}^{n} a_{ij} x_j \qquad (1)$$

where a_{ij} is the community matrix, and where (0,0,...,0) represent the equilibrium state of the population levels (x_i). The variables (x_j) represent the difference between population levels and the given population levels at equilibrium. The matrix a_{ij} is called stable if the real part of every eigenvalue of a_{ij} is negative. Instead of performing this analysis, the results from Roberts (1978) are followed, and the stability of the community matrix described by Equation (1) is examined simply from a graphical analysis of the sign pattern of the matrix.

A simple predation community is illustrated in Figure 2. In this figure, the predation community is developed from some results of studies of demersal fish resources in the Gulf of Thailand (Ritragsa, 1976) and from the author's speculations concerning predator-prey relations in the fishery. The community utilized for this figure contains four species groups and man as a predator. The squid population is assumed to be very lightly exploited, with the result that it is not self-regulating. The other predator-prey relations are postulated and serve primarily for illustrative purposes.

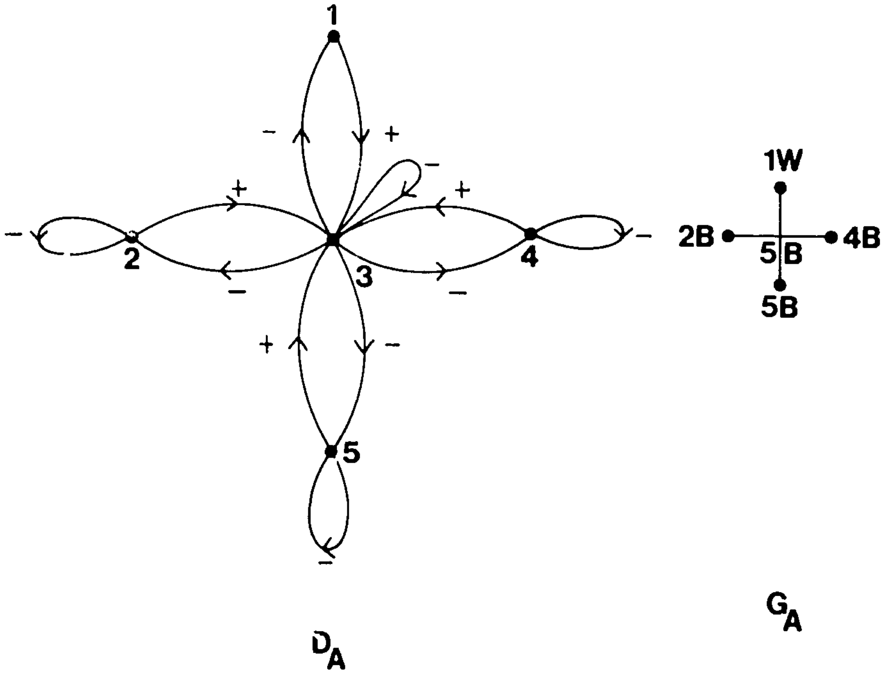

Figure 2. A signed digraph D_A and graph G_A of a system consisting of a predation community based on some segments of the trawl fishery in the Gulf of Thailand. The numbered vertices are assumed to correspond to the following: 1) squids, 2) Leognathidae, 3) man, 4) Mullidae, and 5) Sciaenidae.

A matrix a_{ij} associated with the signed digraph D_A of Figure 2 is shown below:

$$\begin{matrix} 0 & 0 & 1 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 \\ -1 & -1 & -1 & -1 & -1 \\ 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 1 & 0 & -1 \end{matrix}$$

Although it is possible to demonstrate directly whether the matrix is stable by determining if every eigenvalue of the matrix has a negative real part, this is computationally tedious, especially for the larger matrices. A graphic alternative prepared by Jeffries et al. (1977) is illustrated.

A graph G_A may be associated with the matrix a_{ij}. The vertices of G_A are the rows of a_{ij} and there is an edge between rows i and j, if and only if $i \neq j$ and both

$a_{ij} \neq 0$ and $a_0 \neq 0$. The graph G_A of the matrix illustrated above is shown on the right side of Figure 2.

Let

$$R_A = (i : a_{ij} \neq 0) .$$

In this example, the set R_A consists of the vertices 2, 3, 4, and 5. Now color the vertices of G_A using two colors, white and black, in such a way that the following conditions are satisfied: 1) every vertex of R_A is black; 2) no black vertex has precisely one white neighbor; and 3) every white vertex has at least one white neighbor. Such a coloring, if it exists, is called an R_A coloring of G_A.

A matching of a graph is a set of pairwise disjoint edges of the graph. If S is a set of vertices in a graph G, an S complete matching is a set, M, of pairwise disjoint edges of G, such that all vertices not covered by the edges in M are outside S. That is, $S = V - R_A$.

Jeffries' theorem quoted in Roberts (1978) is as follows. An n x n real matrix A is sign-stable if and only if the following conditions hold: 1) each loop in the signed digraph D_A is negative; 2) each cycle of length 2 (a 2-cycle) in D_A is negative; 3) D_A has no cycles of lengths larger than 2; 4) in every R_A-coloring of the graph G_A, all vertices are black; and 5) G_A has a $(V - R_A)$-complete matching.

In our example of Figure 2, an R_A coloring of G_A does not exist because criterion 2 of the black-white coloring is not met. Thus, condition 5 of Jeffries' theorem does not hold. The simplest way to satisfy these criteria is to introduce self-regulation into the matrix by changing the first diagonal element from 0 to -1. It is assumed that this self-regulation would be achieved by increased fishing pressure on the squid resource. Other alternatives for sign stability were not considered due to the restrictive nature of Jeffries' theorem.

Conclusion

Although these applications of signed digraphs are considered very simple, they may help to introduce the use of signed digraphs in fisheries management. They also suggest possibilities for more realistic future studies with structural models. Since this report, Flake (1980) has added considerably to these possibilities.

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Commentary

Saul B. Saila, *Co-Editor*

The following material represents an attempt to abstract and list some of the relevent comments and observations made by various workshop participants during all the discussion periods and sessions of working groups. It has been condensed and edited from tape recordings taken during the workshop and from the notes of various workshop rapporteurs. The editors acknowledge with gratitude the active verbal dialogue by the participants and their valuable suggestions and comments. The editors assume full responsibility for the errors or omissions, which we believe are inevitable in an undertaking of this nature. We also apologize for the cryptic nature of this section, which results from attempting to minimize redundancy. The authors of the various comments are identified to the extent possible, but the comments are not necessarily listed in the sequence in which they were made. Items listed without authorship were included if they were judged to have contributed to the session and to overall workshop objectives.

1. *Vincent Adebolu* (Nigeria)

   A major problem in fisheries management in Nigeria is government bureaucracy. Another is the lack of transport for fisheries products. Still another is the hostile attitude of the fishermen themselves.

   Nigeria is making use of fishery extension workers and of public media, including television and radio, to provide some level of public education.

2. *Ibrahim Mohammed* (Malaysia)

   In Malaysia there is a unique marketing system. A few hundred middlemen control the system, and all fishermen must work through them. There are two or three fishing ports with proper facilities; otherwise, fish are landed at the piers of the middlemen.

   There is considerable difficulty in obtaining accurate catch statistics. Boats are unloaded at the middlemen's facilities, on the beach, or at sea onto vessels from Singapore.

   Enforcement is generally poor. Many trawlers are unregistered. The government has attempted to centralize landings, but the fishermen ignore the government's landing facilities because of threats from the middlemen. This situation may be prevalent in other countries. How can it be handled?

   No taxes are levied on the fishermen. However, they are afraid to report their catches accurately because they might in time be taxed.

   A government survey is being conducted on a) resources and research abilities; b) legal aspects (including the crossing over of fishermen from one state into the waters of another); c) fishery technology infrastructure;

d) marketing and postharvest loss, and e) socioeconomic problems of the fishermen.

Question from Daniel Pauly. Malaysia is the only state with a program for shifting the artisanal fishermen out of fisheries to other forms of employment. This is believed to be a desirable practice. *Answer.* We are opening up new agricultural land in former jungle areas. The fishing villages tend to be closely knit communities, with the children of artisanal fishermen going into fishing themselves, and with the power of the middlemen continuing strong in the villages. One problem Malaysia has is that it cannot develop large trawlers because these would compete with the nearly 80,000 artisanal fishermen.

3. *G. Winston Miller* (Belize)

Belize has about 1,500 commercial fishermen, 1,400 of which are members of cooperatives. These cooperatives simplify the management problems.

The more one interacts with the fishermen, the better the data obtained from them.

A real problem in Belize is that of enforcement, particularly with respect to the independent fishermen. Much of the enforcement effort is directed toward the middlemen.

The cooperatives are allowed to export, but a small percentage of the lobster and conch are retained to be sold at low (subsidized) prices on the local market. The MSYs for lobster and conch are determined on a national basis, and then quotas are assigned to the various cooperatives.

Fishermen in Belize tend to concentrate on lobster and conch, and to ignore other species, such as finfish and mangrove oysters. Belize has no fishmeal plant.

North of the capital are full-time fishermen; to the south are part-time fishermen, many of whom do not belong to the cooperatives.

Question from David Stevenson. What criteria should you apply for improving small-scale fisheries management? What information do you as an administrator need from the biologists? *Answer.* We need information both on the biology of the fisheries and on cultural aspects of the fishermen.

4. *Soloncy Cordeiro de Moura* (Brazil)

Specific problems in Brazil related to the fisheries and to general ecosystem studies include:

a. There is much emphasis on large-scale fishery research, very little work on the small-scale fishery.

b. Small-scale fisheries are scattered all along the coast; the types of operations vary and data collection is difficult.

c. Data analysis requires the training of people.

d. There is a need to change the behavior of investigators so that they spend less time on issues of academic interest, more on applied aspects of the fishery.

e. There is competition for the same resource between large-scale fisheries and small-scale fisheries, especially with regard to shrimp and lobster.

f. There is application of experience gained in large-scale fisheries to the small-scale fishery. This type of application may not be valid, and more experience is needed in small-scale work.

5. *V. Hongskul* (Thailand)

There is a great need for information to guide management and investment decisions at the earliest stages of a fishery's development. Overexploitation can occur within a few years, and extensive data collection and analysis may take too long to provide timely answers. Developing countries need specific advice on objectives and data needs.

Available models include simple models depending on biomass estimates, but more sophisticated models addressing multispecies interrelationships need more data and are less well developed. Interactive models, dealing with predation and competition, are generally simulations with little or no biological explanatory value. Energy transfer (trophic level) models have received attention, but there has been little success in modeling the complex relationships in the tropics.

Caution should be exercised with methodologies which are too "quick and dirty" and lead to long-run policies which cause serious economic and social repercussions.

6. *Henry Regier* (Canada)

Empirical modeling should be considered an aid to advancing stock assessment. Specifically, it is possible to focus on relationships between a) stock yields, and b) abiotic and biotic environmental variables in homogeneous freshwater systems. One often-used independent variable is the MEI (morphoedaphic index), the total dissolved solids divided by mean depth. Other biotic variables which explain some variation include primary production and bottom standing crop. While this approach is a good first-order assessment, actual values fall as much as a factor of ± 2 from predictions.

Drainage basin size is a key variable in explaining river yields. Explanatory variables are chosen from those historically identified by biologists as important. Components of a community (e.g., predator-prey ratios) can be incorporated into this framework. Analogous work should be done in the environments of tropical small-scale fisheries.

7. *Lee Anderson* (U.S.A.)

A distinction between fish biology and fisheries management biology can be made, and the essence of the workshop and the nature of AID contributions to developing nations is broader than stock assessment and extends to formulation of management plans. Management is also concerned with the costs of harvesting fish, costs of management, sociocultural characteristics of resource users, etc.

Most important in addressing fisheries management is the formulation of objectives, which should be operationally stated so that a) research may be directed toward achieving the objectives, and b) measures of success can be evaluated.

Since objectives can conflict, it is important for managers to be willing to weigh criteria, or to choose to optimize one criterion given minimum acceptable constraints on the others.

The ranking of sources of information for achieving objectives of management depends on the objectives and the socioeconomic environment. For example, prices are clearly important pieces of data because they give relative species values, but sociological data are more important in cultures where fish are not exchanged in the market. Other data are important for regional development or balance of trade objectives.

8. *Bruce Rettig* (U.S.A.)

In choosing among alternative techniques for assessment, a diverse approach (best mix) is perhaps preferable. Also, benefit-cost analysis of different assessment techniques would be useful because of the high opportunity costs of resources (e.g., energy, human capital) used in stock assessment.

9. *Stephen Malvestuto* (U.S.A.)

In designing a sample survey, it is critical to integrate into the design the support capabilities of the developing country. Biological, hydrological, and cultural aspects must be considered in designing an effective and efficient sampling plan. All facets of assessment should be, as much as possible, done in cooperation with the local agency.

10. *Donald Bevan* (U.S.A.)

There is a general need for better fishery statistics; even in the U.S. Pacific fisheries, estimates of effort are universally bad.

11. *Brian Rothschild* (U.S.A.)

We need to understand the relationship between the information needed to manage small, medium, and large fisheries. Particularly, we are now concerned with a) variability in stock size (recruitment); b) multiple species; and c) how to link the biological stock considerations with economic and social considerations.

The research question is: Are we satisfied with the state-of-the-art? And, if not, what can we do about it? How can the developing countries participate?

Problem Areas and Discussions Related to Them

Problem

There is a notable lack of effective structure for information flow from fishery biologists to planners and policy makers.

Discussion

Sometimes administrators do not listen to the advice of scientists. In many instances, the administrators don't know what questions to ask of the scientist.

In many cases, the scientist must provide both question and answer, but he must be careful to define those questions which are likely to be fruitful.

Few of us like to disclose our ignorance by asking questions. An employer may even be loath to ask a question of his employee for fear of losing face. These problems of communication are deep, perhaps deeper than we realize.

Some improved mechanisms for a more effective information transfer ought to be considered

It is important that the fishery biologist be questioned (and listened to) by the policy maker early on in any decision-making process.

Effective communication between the fishery biologist and other professionals in a planning team before the inception of a program would be the ideal situation.

Problem

Economic and socio-cultural aspects of small-scale fisheries have been inadequately considered.

1. *Economic Aspects*
   a. The test of Title XII activities is the extent to which the well-being of small-scale fishermen and poor consumers is improved.
   b. Data is generated from biological and economic concepts made operational. Whether good or bad, it, in turn, feeds into a decision-making process (rational to cautiously suboptimal).
   c. Therefore, the process through which the data is transformed into information and information into decision-making, as well as the data itself (from the capture sector and resource assessment), must be examined critically.

Discussion

A model is an idealized expression of reality. Few are experts in more than one modeling approach. The right model will emerge in the market place of ideas over time.

Q. Do multispecies units like guilds present problems for the economists? A. Some. The value placed on the catch becomes clouded as the makeup of the catch changes with exploitation. These appear to be surmountable problems.

2. *Socio-Cultural Aspects*

a. There are socio-cultural preconditions to utilizing the information available on site; e.g., that held by fishermen.

b. Focusing on the act of data collection, we see the need to (1) engender trust; (2) show clear intent; (3) indicate utility to fishermen; (4) use proper code (language), setting, vehicle, opinion leader, etc. For example, research shows that the local taxonomies of species are complete, complex, and repeatable.

Discussion

Information from fishermen can be difficult to obtain and biased. However, there is a great amount of historical information held by fishermen; it is expedient to use it.

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