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Ocean Fishery Management: Discussions and Research

ADAM A. SOKOLOSKI (Editor)

SEATTLE, WA
April 1973

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Proceedings of a workshop sponsored by the Division of Economic Research, National Marine Fisheries Service, November 5-6, 1970

This report contains a group of independent research studies published on their own merits. They do not necessarily reflect the policies or intentions of the National Marine Fisheries Service.

SEATTLE, WA
April 1973

PARTICIPANTS

PAUL ADAM, Organization for Economic Cooperation and Development
HAROLD B. ALLEN, National Marine Fisheries Service
FRANK M. ANDERSON, Oregon State University
FREDERICK W. BELL, National Marine Fisheries Service
DANIEL W. BROMLEY, University of Wisconsin
ERNEST W. CARLSON, National Marine Fisheries Service
DONALD P. CLEARY, National Marine Fisheries Service
FRANCIS T. CHRISTY, JR., Resources for the Future
JAMES A. CRUTCHFIELD, University of Washington
JOHN P. DOLL, University of Missouri
RICHARD F. FULLENBAUM, National Marine Fisheries Service
JOHN M. GATES, University of Rhode Island
THOMAS GEER, International Bank for Reconstruction and Development
WILLIAM G. GORDON, National Marine Fisheries Service
LOREN GRANT, Canadian Department of Fisheries and Forestry
JOHN E. GREENFIELD, National Marine Fisheries Service
MURRAY L. HAYES, National Marine Fisheries Service
ANDREAS A. HOLMSEN, University of Rhode Island
PAUL HOOKER, University of Florida
A. M. HUQ, University of Maine
HARVEY M. HUTCHINGS, National Marine Fisheries Service
A. D. INSUL, British White Fish Authority
JOSHUA JOHN, Canadian Department of Fisheries and Forestry
MILTON G. JOHNSON, National Oceanic and Atmospheric Administration
EDWARD KANE, Boston College
E. A. KEEN, San Diego State College
RICHARD K. KINOSHITA, National Marine Fisheries Service
JUKKA A. KOLHONEN, National Marine Fisheries Service
RICHARD J. MARASCO, University of Maryland
BRUCE MATTOX, University of Rhode Island
MORTON M. MILLER, National Marine Fisheries Service
PAUL MLOTOK, University of Rhode Island
DARREL A. NASH, National Marine Fisheries Service
BRUNO G. NOETZEL, National Marine Fisheries Service
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FREDERICK L. OLSON, National Marine Fisheries Service
ERWIN PENN, National Marine Fisheries Service
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FREDERICK PROCHASKA, University of Florida
R. BRUCE RETTIG, Oregon State University
JACK RICH, Oregon State University
JACK A. RICHARDS, Kansas State University
JON C. RITTGERS, University of Rhode Island
RICHARD ROBERTS, Fisheries Service of Canada
MICHAEL A. ROBINSON, Food and Agriculture Organization of the United Nations
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DONALD R. WHITAKER, National Marine Fisheries Service
FREDERICK E. A. WOOD, Fisheries Service of Canada
ROBERT WILSON, Texas A & M University

PREFACE

Until recent years only biological or technical aspects of fisheries conservation have advanced beyond esoteric professional journals or smoke-filled back rooms to be given serious consideration when formulating working management programs. In recent years the social sciences, especially economics with its emphasis on rational management, have gained some respectability beyond mere conceptual discussion.

With the mounting urgency of fishery management problems serving as a catalyst, the National Marine Fisheries Service has multiplied its research in this area, aided in part by the rapidly growing Sea Grant program formerly within the National Science Foundation and now incorporated within the National Oceanic and Atmospheric Administration.

Within the past two years much progress has been made. To aid in assimilating these results and to provide some sense of a proper future direction for both research and the design of management programs, the National Marine Fisheries Service convened a Workshop on November 5 and 6, 1970. Invited were virtually all known researchers in Fishery Economics throughout the world, many administrators, and researchers in related disciplines.

What follows in this circular are the papers presented at this workshop, with an introduction which makes a first attempt at distilling the combined impact of these papers.

As editor I wish to thank all the authors for their diligent cooperation. The services of the secretarial staff of the Division of Economic Research, especially Miss Carol Reese, are gratefully acknowledged. The generous support of the many institutions that absorbed the financial burden of travel from distant geographic regions was necessary for the ultimate success of this workshop.

The National Marine Fisheries Service sponsors the publication of these papers, as it sponsored the workshop itself, to crystallize the issues relating to fishing management and to stimulate further debate. As such the papers present the views of the individual authors and none of the material contained herein should be construed as reflecting official policy statements of the National Marine Fisheries Service.

ADAM A. SOKOLOSKI

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(Continued)

INTRODUCTION

The Status of Fisheries Management Research: An Overview

Adam A. Sokoloski[1]

All disclaimers to the contrary, there is one research area near and dear to the hearts of virtually all economists conducting research on marine resources: measuring the gap between the "optimum" management solution for a given fishery and current management arrangements. This is not to say that this gap has ever been successfully measured for a fishery.

In recent years some first approximations have been made, however. These have been reasonably consistent with a body of economic theory which has existed in one form or another for several years. This theory is the original source of suggestions that the gap existed, as casual observation of practice revealed inconsistencies with "proper" theory. Initial empirical works unearthed several critical components which are currently complicating the issue. These are both empirical and conceptual in nature and multidisciplinary in scope. These may be listed as follows:

1. Existing yield functions need to be expanded and alternative functions need to be specified, both with respect to such factors as diminishing returns (success probabilities for effort on a fixed biomass) and multispecies interrelationships.
2. The appropriate emphasis for economics and biology in bioeconomic models.
3. The correct theoretical and empirical components of effort series are needed to construct indices of fishing power as utilized in management programs.
4. More effort is needed in the design of "correct" operational management plans: the choice between variations of licensing, quota, auction and/or leasing schemes.
5. A resolution of the choice between long run versus short run "optimal" solutions.
6. An evaluation of the appropriateness of directly applying theoretical models to fisheries for the purpose of deriving implied net gains from the practical application of identical working models.
7. The role of social transfer costs in the evaluation of benefits from new management programs.
8. The desirability of an incentive (pull) approach versus a limited entry (push) form of management program.
9. The place of jurisdictional consideration in program design and operation.
10. The desirability of a multidisciplinary objective simulation approach to the measurement of management ramifications as contrasted to simultaneous equations with maximization and other limiting assumptions.
11. The role of artificial propagation in the design of total management plans.
12. The role of competing uses for the resource base.

Virtually all of these items reflect the fact that as economists begin to penetrate the surface of the management issue they gain a greater appreciation of the vital role to be played by the physical scientist, usually a

[1] Formerly of Division of Economic Research, National Marine Fisheries Service; present address, Environmental Protection Agency, Division of Water Quality Standards, Arlington, VA 22202.

biologist who has become a population dynamics expert. This involves more than just using the output of the population dynamics expert; it entails understanding the intricacies of this work so that it won't be misused.

Here is where the first problems arise. Once familiar with population dynamics models the economist falls prey to the temptation to alter components which may not be ideally suited to his needs. What results is two versions of population dynamics with one being the result of both explicit and implicit imperfections in the other.

From this point several ramifications may develop, depending on how far each conceptual base may have been developed toward an actual working management program. If this has occurred original differences in population dynamics models will have been magnified. These resultant differences generate a debate, and a portion of this debate, as currently stated, is contained in the following papers. To amplify let me refer in greater detail to the twelve points mentioned above.

(1) *The Need for New Yield Functions:* The biologist's yield function is the analogue of the economist's production function. Production economics focuses upon the allocation of inputs to achieve production goals designated as optimum, this proper allocation being the most efficient (least cost) combination of these inputs. Partial derivatives, giving the incremental contribution of each unit of a particular input, may be used to construct efficiency indices roughly equivalent to the biologist's measures of the fishing power of a vessel.

These derivatives are obtained from general form equations of a linear, Cobb-Douglas (constant elasticity of substitution equal to one) or C.E.S. (any constant elasticity of substitution) type. Contained within these general types are certain assumptions concerning constant, increasing, or decreasing returns (output) from increasing increments of a particular input.

Critical here is an appreciation of the fact that these are fundamental calculations which would be carried out whether or not any related biological work existed. When this work does exist it serves as a reference point to the economist as he proceeds systematically through a series of steps dictated by the classical scientific method which has evolved for his profession.

When, therefore, an economist specifies a function implying diminishing returns to additional inputs, we have the potential for debate when the biologist has diminishing returns due to population dynamics but constant returns from a fixed biomass. These two differing approaches will lead to different evaluations of the historical effort being exerted on a fishery, to different estimations of the actual yield curve, to different calculations of MSY (maximum sustainable yield) and then to different management solutions.

The issue becomes further complicated when many species intermix and then must be considered simultaneously when designing and operating a management program. The economic portion of this analysis is actually more readily solved in this case via a standard analysis of the joint product case, whereas the biological literature still carries a debate concerning the proper use of Beverton-Holt dynamic pool models as opposed to the Schaefer logistic approach. This issue is becoming more critical as the trend in the technological capability of harvesting units is leading toward some point in the future where the flexibility and maneuverability of these units will make all management considerations multispecies to correctly reflect actual harvesting practices.

(2 & 3) *Economics and Biology in Measures of Fishing Power:* For management purposes what is the appropriate emphasis of economics and biology in bioeconomic models? One extreme suggests that it is necessary to understand the complete microdynamics of all stages of the food chain, an ecological approach, and all forces that act upon these stages, to properly specify the results of variation in fishing effort and, therefore, to suggest the optimum dimensions of that effort. This would confine economists to a role of evaluating the economic costs and benefits of the program suggested by this detailed formulation.

The opposite extreme finds the economist placing the fisherman in an active role, where he responds to various market incentives, these responses subsequently becoming an integral step in determining variations in fishing effort and resultant success. Some would suggest that prices, quantities landed, and a statistically acceptable production function are all that is needed to derive the functional relationship *necessary for management*, assuming that this production function can be used to determine the continuing relationship between effort and landings.

This last phrase is important, for it may well be that a final decision in the allocation of research and management resources will depend upon the spin-off, or secondary benefits from certain research endeavors above and beyond their direct contribution to management. This would, of course, be especially true with regard to the extreme of the broad-based ecological approach, with both long run and short run considerations, as suggested in some biological circles. The recent reorganization of certain agency functions within the National Oceanic and Atmospheric Administration may have some bearing here.

(4) *Using Research Results to Design Operational Schemes:* Existing schemes which may be actually classified as direct measures to limit entry have established certain precedents. Canadian programs in Atlantic lobsters and Pacific salmon have emphasized licenses for principal capital inputs, a limited entry program. The Inter-American Tropical Tuna Commission (IATTC) has utilized quotas and area restrictions while International Commission for the Northwest Atlantic Fisheries (ICNAF) has utilized mesh size and area restrictions and recently seasonal closures for overfished species. The Union of South Africa regulates via licenses issued through processing plants which allocate these among vessels.

The debate concerning these existing types and many other hypothesized forms may be divided into two subject areas, one concerning whether the plan will actually lead to an allocation of resources which approaches some predetermined optimum and the other whether the plan is operationally realistic, which may invoke social and political considerations as well as those of biology, technology, and economics. Mr. William Terry, in his opening statements to the participants of this workshop, emphasized the urgent need to begin evaluating the proper mix of all possible inputs into fisheries management. He asserted that we must begin now to define the components of the interface, looking beyond the immediate problems of each discipline. Consistent with this he suggested the possible need to develop new, broader objectives of fishing management.

Presently discussed mechanisms have two principal components, a way of limiting entry into fisheries and a means of allocating the quasi-property rights which result. Some mechanisms perform these functions simultaneously, such as an auction system, whereas others, such as a licensing system, require the administrator to make some judgement as to the number of licenses as well as how they shall be allocated. Relating to some historical experience in the oyster fishery, there are many unexplored questions regarding the applicability of leasing schemes for sessile resources.

The message here is clear. We have devoted considerable effort to developing sophisticated conceptual constructs for fisheries management. Regarding actual operational alternatives we have confined our efforts to informal and often exclusively internal debates. Responsible researchers must soon assume the task of a thorough evaluation of the many suggested working plans. This evaluation must be subsequently exposed to discussion via the professional journals so that all the preceding work can truly be productive.

(5) *Long Run Versus Short Run Solutions:* The fruits of economic modeling are proposals involving changes in the quantities of labor and/or capital in commercial fishing, often reductions of both in addition to increases in the capital/labor ratio. Capital inputs are usually quite fixed; indeed, this may be true of labor inputs also. What results is the quite obvious conclusion that achieving these optimum solutions will in all cases involve extended time periods. What then is the preference ranking for the many plans which may have to be initiated in the interim?

The truthful answer to these questions is that we really don't know. We have not fully designated the compromises which would be necessary, much less made a careful evaluation of which would be preferable. This suggests two immediate tasks to be undertaken by the economist.

The first of these relates to the fact that the responsible administrator will not wait for the perfect solution to be formulated for each time horizon. He must formulate plans and action programs on a continuing basis. In this instance the economist can indicate those steps which can be taken which will lead toward the optimum solution, or at least toward some "better" solution in the tradition of the theories of second best as discussed in the literature on welfare economics.

Simultaneously the economist can perform a second function, which would be to construct detailed interim plans and test and evaluate these. These could be constructed for alternative time periods and based upon restrictions suggested by the administrator or the other disciplines where additional intermediate term planning and research was also being conducted.

The result would be an array of economic research considering time horizons from the present to the long run optimum solution. With such an array it would be easier to incorporate the interdisciplinary (especially social) aspects of the overall problem as suggested in the other points I am presenting here. Most critical is the fact that immediate steps are necessary if there is to be a fishery to optimize in the long run.

(6) *Theoretical Versus Working Models:* This point relates to the previous issue and also to several of the following. Briefly the question here is whether theoretical models, confined solely to a select number of variables, and seldom involving more than two disciplines, can be utilized directly for generating a stream of benefits to be included in the calculation of a benefit/cost ratio for a particular management program. Some have argued that there is not sufficient realism in theoretical models for these to be applied directly. Conversely, it may also be argued that many of the imperfections of this approach are not so much inherent in the theoretical models themselves, but rather stem from the use of complementary information when performing B/C analysis. Such errors may be found principally on the cost side, where not all indirect program costs are included, especially when these costs may exceed the actual flow of benefits in the short run. What may be the most significant of these cost components is discussed next.

(7) *Social Transfer Costs:* Not long ago it was not possible to discuss limited entry except under the most constrained circumstances. Now, with the development of more forceful arguments and with a growing urgency in certain fisheries, limited entry plans are receiving wider consideration. As this occurs the operational elements of alternative plans are being formulated and new questions are resulting. The most prominent among these relates to the magnitude of the social transfer costs which may result from either the direct or indirect reduction of the fishing labor force in a fishery.

If displaced labor must be retrained and relocated, or absorbed on the welfare rolls, it may be wise to develop programs based exclusively on excluding excessive new entry, with input balances to be attained via attrition. This is tantamount to concluding that the short run solution must be contrary to the suggested long run optimum. Nevertheless, it is the desired means of achieving the long run optimum. Research is now beginning on this issue both within the National Marine Fisheries Service and the Office of Sea Grant Programs. The results will play a critical part in determining the character of future management plans.

(8) *Encouraging Exit Versus Limiting Entry:* Virtually all discussions of management plans emphasize licenses, or quotas, or some form of right which will accrue to a reduced number of harvesting units. The mechanics of reducing these units involve some form of exclusion. Seldom has a plan been suggested, however, which emphasizes a program whereby excess inputs would be attracted away from the fishery by a more rewarding alternative.

To my knowledge such a program has been attempted once, a recent attempt to divert excess capacity from the overfished haddock resource of the Northwest Atlantic to the underutilized pollock resource. As a limited short term program it met with only limited success. This is not inconsistent with other similar non-fishery programs, such as the more substantial effort designed for Appalachia. In all instances, unanticipated attractions, picturesquely described as "psychic income," resulted in a greater amount of labor immobility than original calculations suggested. Program costs had to be adjusted accordingly.

Nevertheless, if transfer costs, as discussed in the previous point, can be reduced by some increment by an incentive program costing less than this increment, then the overall costs of the total management program may be reduced sufficiently to result in a favorable B/C ratio. These calculations would be over and above the more favorable political response to a program which considered these transfer costs as opposed to one which did not.

The problem of response to incentives may be reduced in multiple species fisheries where we wish to reduce pressure on one of the species and this is technically possible. Hardships resulting from restrictions on the king crab resource were reduced by the ability of the harvesting units to adapt to alternative species. Indeed, New Bedford scallopers, 13 vessels in all, journeyed to Alaska when that resource appeared (somewhat falsely) more profitable than their traditional fishery. If they could have been induced to leave earlier then perhaps the degree of depletion in the Atlantic could have been reduced.

(9) *Jurisdictional Issues:* Fisheries researchers interested in formulating management plans usually focus on specific fisheries in their entirety. This is appropriate for every "discipline" except one, the area of legal-political considerations. Fish do not respect jurisdictional boundaries and this has long been a critical operational issue in fisheries management.

Resolution of these jurisdictional issues will involve more lead time than biological and economic questions. Developing interstate cooperative mechanisms *and* widely accepted international arrangements which will be politically acceptable while incorporating biological, economic, and social factors will be a herculean task, witness the slow progress of developing a national quota system in ICNAF and the 200-mile dispute with countries bounding the yellowfin tuna fishing areas.

The individual disciplines can contribute to solving this problem by orienting their work so that the trade-offs between alternative jurisdictional arrangements can be readily assessed in each disciplinary dimension. As the U.S. develops new coastal zone and contiguous zone legislation and as all nations prepare for another Law-of-the-Sea conference it becomes increasingly necessary that these trade-offs be specified in the near future.

(10) *The Potential of Simulation Models:* Much of the population dynamics research done to date has involved single or multiple equation regression techniques of constrained maximization. Within the capabilities of these techniques one (biology) or at most only two (biology-economics) disciplines would be considered, and even then only a limited number of variables in each. Many of the twelve points discussed here are not included within these analyses. At best they are appended on an ad hoc basis.

To formalize this ad hoc process one would set out specifically to systematize these multiple considerations via a simulation model, where each consideration would appear sequentially leading to outputs which would represent many combinations of these interactions. Within this framework each specialist would not be trying to extend his own area to include other disciplines in the process of specifying optimum solutions. Rather he would merely be characterizing his own special considerations, which might be one of several subroutines in the entire simulation program. The proper manner in which these inputs would be combined would be a joint responsibility of all researchers providing the principal inputs.

To be feasible, each separate input area must have reached a sufficient stage of sophistication and accuracy to be of use in a simulation model. I believe this judgment can now be made. This suggests that the work that has been initiated at the University of Washington and Massachusetts Institute of Technology should be expanded to encompass all major fisheries. Work on other water resource, game resource management problems provide an additional base of expertise to facilitate development of these models.

Initially these models would include: (1) an assessment of the resource base, (2) a population dynamics model, (3) cost and earning functions, (4) demand functions, including provision for foreign trade flows, (5) exit-entry functions based on profitability, (6) characterization of existing and alternative regulatory constraints, and (7) a depiction of the social response function, with some reference to transfer costs. These models would originally be constructed for each of the principal fisheries of Alaska, the Pacific Northwest, the tuna fisheries, the shellfish and menhaden fisheries of the Gulf and the Middle Atlantic and lobster and groundfish in the North Atlantic. Ultimately multispecies regional models would be developed, leading to a national model which would characterize the entire U.S. fishing industry.

Initial failures in the construction of these models will suggest immediate research needs. The output of each model will indicate the sensitivity of each component of the model for each fishery.

(11) *Artificial Propagation and Fishery Management:* With few exceptions, when we identify a fishery which has excess capital and/or labor in relation to the sustainable resource base we recommend reduction in these inputs. A Canadian fishermen's group has eloquently phrased another course, that is, expand the resource base. This would especially be recommended if the incremental returns from dollar expenditures on expansion exceeded the incremental benefits from dollars spent withdrawing inputs.

At this time such a possibility could only be anticipated for Pacific salmon. Several factors could enhance these trade-offs, among these being the possibility that demand rising faster than costs would bring the cost of hatchery production into a more favorable light and a full realization of the political resistance to withdrawing excess inputs. With the further development of hatchery technology other fisheries, perhaps shellfish, may be supplemented by artificial propagation and rearing. As this occurs it will be necessary to include the dimensions of this alternative as an new subroutine in the simulation models discussed in point 10 above.

(12) *Competing Uses:* A new dimension, an additional complication, has entered upon the scene of fishery management, suggesting new priorities here as it has elsewhere. It comes under the banner of ecology, an old word with new urgency. With the scarcity of natural resources increasing relative to multiple demands, and with the new insistence upon quality in addition to (or rather than) merely quantity, the management of coastal resources has suddenly taken on a new dimension. Management of commercial fisheries will be obliged to reflect this trend.

Coastal fisheries must now be managed as part of the total coastal resource. No suggestion has yet been made as to how this will be done. Suffice to say that such critical issues as fishery tolerances to certain water quality levels and the interrelationship between sports and commercial fisheries will be critical issues. I will forego an attempt to treat this issue in a few brief paragraphs here, acknowledging the likelihood that the next fisheries workshop will certainly treat this area as one of its principal topics.

With this general background on the principal issues in fisheries management we can now look briefly at the workshop contributions to summarize their contents. With these papers serving as the stimulus the discussions at the workshop inevitably revolved around two related issues: (1) the necessity for developing short term models due to the extreme urgency of resource management problems in many fisheries and (2) the need to assume the full responsibility for measuring all social costs associated with alternative resource use plans and to suggest ways by which these social costs can be minimized.

At the conclusion of this workshop one was definitely left with the impression that if significant steps cannot be made in both of these areas in the near future (2-4 years) then serious questions will have to be raised about the utility of the bioeconomic, socio-political research and planning which we are conducting. In this light much of the work reported at the workshop provides some encouragement that progress will be made on these issues.

ISSUES IN FISHERY MANAGEMENT

The opening paper by Van Meir appropriately cites the Burkenroad observation that fisheries should be managed for people not fish, a trite, but occasionally overlooked admonition. He emphasizes that the critical element now is that time is running out in many fisheries. The solution is to replace common rights with private rights, these rights to be consistent and in balance with allowable yield. The program should not only permit, but also promote economic efficiency both in the short run and in the long run.

To begin limited entry programs we must emphasize three areas: (1) a resolution of jurisdictional conflict, (2) an educational program which will communicate the potential benefits and dispel the idea that the scheme is to be a government monopoly and, (3) trial programs which will demonstrate how limited entry operates in practice.

Van Meir suggests that in practice we must be willing to accept a second-best solution, i.e., agree with biologists on harvesting maximum sustainable yield (MSY) and proceed to specifying the most efficient way of doing this. We must develop a system which will insure that fishing rights will be allocated to the most efficient producer at any point in time.

Van Meir concludes by suggesting a system for doing this. It is here that he introduces the first real element of controversy. He suggests a licensing mechanism. Licenses would be allotted so as to include all grandfather rights. They would be reduced by attrition with the total number changing as technology changes. Monopoly powers would be restricted and rents would be redistributed via license fees or taxes.

Undoubtedly this is a reasonable step toward a politically palatable solution. Others would argue that there are other schemes that would be more appropriate for certain fisheries. They would argue that this proposal contains the same faults as U.S. agricultural programs of the past decade, where a central authority is granted the right to determine the number of licenses. To do so it must use existing measures of technological capacity and technological change, when both of these may change substantially under the exogenous influence of a newly introduced licensing scheme. Some alternative suggestions would allow both the rate of technological change and the size and number of property rights to be determined within the market mechanism. The paper presented by Holmsen refers briefly to one alternative. Also the paper by Carlson could serve as a basis for preliminary calculations of the appropriate number of licenses in the tuna and groundfish fisheries.

Pontecorvo introduces several broad conceptual issues, among these being the need for short run models which can be utilized directly in resource management. If the short run is critical we should examine those models which appear to be more satisfactory for the short run.

Pontecorvo focuses upon the difficulties of choosing biological models and combining these with economic models for both short run and long run analysis — to determine optimum solutions. He cites violent fluctuations in the Pacific red salmon resource as a characteristic which militates against the use of even short run models, and also where the costs of improving the information flow may exceed the benefits. Further complications arise due to instability on the economic side (demand and the general state of the economy) and changing political and social considerations. One suggestion here is that a program geared to catch some average level, less than the allowable yield during the highest year, may be the desirable economic solution — one case where we would suggest taking less than MSY.

Pontecorvo's position on social and political issues is that these are fully accounted for (albeit incorrectly) in the economists' assumptions of full employment and factor mobility.

The economists' assumption of human rationality forces the social-political ordering into the same ordering as economics. The more reality deviates from this ordering the more the economic conclusions must be altered by subsequent ad hoc social and political considerations.

This can be extended to multiple use issues as well. Often we treat the fishery as if it were the only user of the resource. Future regulatory organizations will have to incorporate such considerations directly and this will affect the design of these organizations.

Rettig adds to the mounting chorus warning of the social implications of certain fisheries management plans. He suggests that these may lead us to actually restructure the objectives of these plans. Absence of these considerations may be one reason for our failure to initiate revised management programs. Other reasons for failure may be the present existence of a severe divergence between the objectives of administrators and researchers, incompletely specified models, or the mere absence of sufficient educational programs.

Regarding the incorrectly specified models Rettig makes the intriguing observation that market imperfections on the buyers' side could alter the optimum solution. Ignoring this fact would actually result in a further misallocation of resources. He suggests a further evaluation of inter-market linkages before making irreversible management steps.

Additional issues which must be faced are the multispecies management problems and the absence of a reasonable discount rate in the sustainable yield curve. This relates to some degree to his final conclusion that we must include so many diverse factors that in the end our "theory" may be useless. Nevertheless, like many others as well as participants at this workshop, he can see no other alternative but to follow this course unless we intend to ignore realism and the needs of fishery administrators.

In the last of four general papers on the issues in fishery management, Crutchfield reviews the inputs to fishery modeling work now developing for four Pacific Northwest fisheries: anchovy, salmon, king crab, and halibut.

These models have three basic components: economics, biology, and law. In the economics portion the cost and earnings and profit and loss statements for representative vessels are developed, related to certain catch rates, technological factors and market conditions (product price, interest rate, alternative employment). By this manner the complete operation of vessels in the selected fisheries can be specified and from this it is possible to construct an exit-entry function which would relate to changes in these economic variables, independently, or as affected by biological and/or legal variables.

The biological elements of this model include gross stock parameters and a yield-effort function which generates catch rates, these serving as direct input into both the economic model and into population dynamics components of the biological model. In the case of the salmon fishery separate, though similar models, are developed for five different stocks at ten locations, a 50-cell matrix. Any pertinent species interactions are also included.

The legal portion of this model specifies the existing regulatory structure which may determine the components of both the biological and economic models, determining what is fished for, when, how, and to what extent. As in other portions of the model, alternative legal structures will be posited to allow for alternative patterns of resource utilization.

The ultimate purpose of this model is to take a complete interdisciplinary approach to fisheries management. Alternative management programs will be specified. Among these an optimum plan will be identified, with the sequence of steps which would most effectively lead toward this plan. In its most extensive form this model will consider multiple species management cases such as anchovy-mackerel-tuna in California and salmon-tuna-crab-halibut of the Pacific northwest. As emphasized by Crutchfield, in its present form the model emphasizes the multidisciplinary nature of the management problem and will readily incorporate many of the suggestions made at this workshop.

A. A. S.

Problems in Implementing New Fishery Management Programs

LAWRENCE W. VAN MEIR[1]

ABSTRACT

Even though an "optimum" management program, in an economic sense, may never be achievable in the management of commercial fisheries, changes can be initiated which will allow individual governments to realize economic gains over the status quo in harvesting common property fishery resources. These changes primarily involve jurisdictional issues; country quotas for international fisheries; accord between the Federal government and the states; and a within-industry system for allocating fishing rights. A system of vessel licensing is described with reference to the ultimate use of licenses on units of fishing effort.

The management of fisheries is intended for the benefit of man, not fish, therefore, effect of management upon fish stocks cannot be regarded as beneficial per se.

Martin D. Burkenroad

These words by Burkenroad were published almost 20 years ago. This statement is a particularly cogent phrasing of the crux of the question of fishery management for it raises both the question of what benefits will be sought in managing fisheries and the question of to which men will these benefits accrue. These are the two 64 dollar questions in the area of fishery management policy.

In spite of Burkenroad's admonition that the conservation of fish stocks per se cannot be regarded as beneficial, and articles and studies on the economic aspects of fishery management that have appeared in the last decade, most fishery management programs remain oriented to the conservation of fish stocks with no consideration of the economic results that may be obtained. We still resort to practices that either encourage the inefficient use of vessels, gear, and labor, or that limit and impede the efficient use of these economic inputs as a means of conserving fish stocks. This does not mean that we do not advocate conservation, but rather that we state more completely our objectives for the conservation program.

Time is running out on us. With technological development yielding a 3.5 to 4.0% annual increase in the productivity of labor in the economy, the fishing industry will find itself in an ever increasing economic squeeze if positive steps cannot be taken to include economic objectives in fishery management. We may continue to conserve fish stocks but it will not be for the benefit of U.S fishermen or fishing communities.

The entire problem of fishery management of course stems from the common property status of fishery resources. In the past, when scientific evidence indicated that a particular fish stock was being overfished, or in danger of being overfished, the solution was to place a quota on the fishery and/or add regulations that either impaired the efficiency of fishing gear, or in some cases required the use of inefficient gear and fishing methods. The consequences of such programs have been completely discussed in other articles and are not the purview of this paper. Instead I want to concentrate on the question of what must be accomplished to change the situation, and how it is to be done.

Obviously, common property status must be replaced by explicit fishing rights. Moreover, in the process of conserving fish stocks we must do so by bringing these specific fishing rights in balance with the allowable yield of the resource in a manner that not only permits efficiency but also actually promotes economic

[1] Staff Economist, National Canners Association.

efficiency and technological development in both the short and the long run. In short, some system must be developed to limit the amount of labor and capital employed in harvesting the allowable catch and at the same time assure that the labor and capital is used in an economically efficient manner.

Various economic advantages can result from limited entry. Catch per vessel and fisherman employed will increase, thus increasing wages and return on investment. The overall value of fish landed may be increased in some cases if the fishery management program results in a better marketing pattern. Labor and capital employed in processing and distribution can be brought into better balance with the volume of fish processed, thus realizing economic gains in these sectors.

A number of complex problems must be overcome in order to realize the fruits of limited entry. In the first place, the question of fishery jurisdiction must be solved. In the case of international fisheries, the solution to jurisdiction will necessitate some system of national quotas. Once national quotas have been agreed to and established, then each individual nation can institute its own program for harvesting its quota. Jurisdictional problems also exist between States and between the Federal government and the States. Many fish stocks are fished by fishermen from more than one State. In the case of pelagic fish, the fish may migrate through the waters of several States or between international waters and waters under the jurisdiction of several States. Moreover, a specific fishery may involve waters under the jurisdiction of several States and the Federal government. Consequently, no one jurisdiction or authority by itself can come to grip with the problem. Certain enabling legislation will be needed at both the Federal and State levels of government.

An important prerequisite to solving the jurisdictional and legal questions will be a thorough understanding of the concept of limited entry, and the need for limited entry, on the part of the fishermen, government officials, and congressional representatives. Many individuals in commercial fishing today are convinced of the necessity for a limitation on the entry of labor and/or capital in those fisheries that are fully exploited. However, these individuals are still in a minority. Somehow, the problems we are facing in many of our fisheries, and the effectiveness of limited entry in dealing with these problems, must be brought to the attention of the rest of the commercial fishing industry in a meaningful way.

One reason why many commercial fishermen are wary of limited entry proposals may be because they have not been presented a specific proposal to study and, hence, are understandably cautious about embracing a new concept without having some idea of how they might fare under the new regime. Thus, specific proposals likely will have to be worked out and presented to industry as a step in overcoming their resistance to the idea.

A second reason why some people are suspicious of the concept of limited entry is because they have formed the opinion that limited entry is a scheme to put the government in monopolistic control of fisheries to enable them to extract either the monopoly profit or economic rent from the fishery. Economists may have contributed to this image in their writings on objectives of fishery management.

From the viewpoint of the economist, progress toward a more rational fishery management program will be a process of accepting second best solutions. One of the first instances in which we need to be willing to accept a second best solution, at least initially, is on the objective of a fishery management program. If we accept the historical precedence of "maximum sustainable yield" (MSY) and seek agreement with the biologist on the importance of harvesting the MSY as efficiently as possible, it should be possible for the economist and the biologist to approach industry with a common argument. The improvement in returns to capital and labor in moving from present management methods to a method which achieves a reasonable degree of efficiency in harvesting the MSY, will represent the major share of total improvement in returns that might result from any other management objective. As a starting point I would suggest that the emphasis be placed on improving the returns to labor and capital in the fishery management program while deleting the argument for either seeking to maximize net economic return or economic rent.

If we are going to accept MSY as the basis for managing a fishery, what economic objectives should we try to build into a new fishery management program? As I mentioned earlier, the first objective would be to seek the optimum amount of effort to harvest the MSY, or at least a reduction in effort, as a means of improving the catch and return per unit of effort in the fishery. In addition to this, we should also seek to build into the management program some means of insuring continued efficiency through time. This means that over time the management program must allocate the fishing right to those economic resources that are most efficient in fishing. Thirdly, the program must stimulate the development and adoption of technological advancements in fishing. How can these objectives be attained in fishery management?

The system I foresee consists of a commercial fishing license issued either by the Federal government or by joint agreement of the Federal government and the individual States concerned. Each license issued would represent a specific amount of fishing effort. Initially, the number of licenses and fishing effort would have to accommodate all vessels and crews that have historically been employed in the fishery. However, as vessels were retired from use, licenses would be cancelled until normal attrition reduced the amount of effort to the desired level. When the number of licenses have been reduced to the optimum number, a market for the licenses would be allowed to develop. Licenses could be sold or leased. Thus, the more efficient manager of a fishing enterprise would be given the opportunity to lease or buy fishing rights from the less efficient operator. The total number of licenses could be adjusted over time as productivity of fish stocks and technology merited. In this manner, the management program would work toward allocating the limited fishing rights to those fishing firms that were most efficient. Moreover, it would now be advantageous to the fishing firm to seek means of improving its efficiency and to adopt new technology that improved efficiency. Limitations could be placed on the number of licenses that any one company could own or control as a means of preventing someone from developing a monopoly over the fishery.

A licensing scheme of this nature would generate a certain amount of economic rent in the fishery. This economic rent could either be taxed away in the form of the license fee or could be allowed to accrue to the resources employed in the fishery. If the rent is taxed away, it should be used for administration of the management program and for research on and development of the resource itself. If the rent is allowed, either in total or in part, to accrue to the resources employed in the fishery, it would in turn be redistributed in the economy through taxes, and would ultimately be built into the cost of production through the cost of fishing licenses. In either case, this should not be a serious deterrent to initiating a licensing system.

One of the most difficult problems to cope with in the licensing system will be the adoption of the effort base for the licenses. Licenses could be based on vessels, tonnage of fish, or an index of fishing effort. Vessels would be the least adequate base for issuing fishing licenses because of the variation in fishing ability from vessel to vessel. It would certainly seem technically possible to develop an index of fishing effort and to define licenses in units of fishing effort. Ideally the units of fishing effort would be the link between the economic aspects of harvesting and the biological model used in assessing stock and yield characteristics.

The steps toward a more rational system of managing fisheries will no doubt be a system of compromises. Perhaps the way to facilitate these compromises with the least loss of time and effort will be to include the commercial fishing industry in the actual development of the specifics of new management programs. The situation is sufficiently urgent that this should be given the highest priority in our "new look" toward the oceans.

On the Utility of Bioeconomic Models for Fisheries Management[1]

Giulio Pontecorvo[2]

ABSTRACT

Short run and long run biological and economic models are inevitably bound together in any comprehensive plan to manage commercial fisheries. While these disciplines can be treated rigorously, political and social considerations can be considered only generally and therefore on an ad hoc basis. Within this framework long run models are useful primarily for goal setting. More work must be done in developing short run models which will measure the immediate biological and economic impacts of alternative management steps in addition to immediate political and social ramifications. Emphasis would then be placed upon the economic sources of short run instability, with an initial economic rationalization of the fishery providing the funds for subsequent management and biological forecasting which will concentrate on extending management from a rationalized fishery at a given harvesting level to rationalized fishing at some optimum level.

BIOLOGICAL MODELS

The Yield from Ocean Resources

A 19th century view was that the high seas fisheries were inexhaustible. We who are preoccupied by our failure to control our own numbers and the possibility of worldwide ecological disaster can at best regard such notions as quaint. Nevertheless, certain implications of the 19th century view of the oceans, with its infinitely elastic aggregate supply curve for fish, are worth considering here in our attempt to understand the biologists' concept of the maximum sustainable physical yield.[3]

The need for biological regulation of fisheries arose because the economic interests involved in exploiting these resources became aware, through rapidly declining yield-effort relationships, that the supply of any particular species was limited.[4] Recognition of the existence of these limits led the biologist to investigation of the characteristics of particular populations in order to find, if possible, a level of exploitation that would be safe. A safe level is defined as that maximum rate of exploitation that would preserve the stock, and yet allow the catch to continue at the maximum rate through time.[5] The imposition on the stock of the appropriate (to achieve the maximum sustainable yield) level of fishing mortality involves the movement from one long run equilibrium condition of the fish population to another, with both equilibriums considered stable.[6]

The development of the argument thus far

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[1] I wish to express my thanks for helpful suggestions to Dr. Brian Rothschild and Dr. Edilberto Segura.

[2] Professor of Economics, Graduate School of Business, Columbia University.

[3] The elasticity of the supply function may be with respect to the inexhaustibility of one stock of fish or as indicated below it may arise from a process of substitution of one stock for another.

[4] The concept of limit is highly ambiguous. It may be thought of as the maximum sustainable yield; the level of scarcity of fish beyond which it would not pay to fish, i.e., an economic limit, the level that maximizes the net economic yield from the resource, or in complete destruction of the stock.

[5] For the development of an alternative view of the relationship between the maximum sustainable yield and the net economic yield, see (Schaefer, 1970a). Schaefer also develops the necessary conditions for adequate biological management (p. 9ff.)

[6] The first equilibrium is the natural or unexploited state of the stock. The second is the condition of the stock being exploited at the maximum sustainable yield. There is a question about the relative stability of the two equilibriums both per se and also because of the effect of fishing effort on ecological conditions. More simply, populations that are heavily exploited by fishermen may show greater fluctuations in stock size.

has already led to a conceptual difficulty.[7] There is some evidence that in certain of the populations which historically were overfished the costs to society of rehabilitation of the populations exceeded the benefits from the subsequent higher yields which resulted from the imposition of the biological control program required to obtain the maximum sustainable yield.

The debate between economists and biologists over the "success" or "failure" of the International North Pacific Halibut Commission as an instrument in fisheries management is an illustration of this type of difficulty.[8]

Aggregate Yield and Biological Models of Particular Species

A more subtle set of difficulties is involved in the interrelationships between an aggregate yield function and the partial yield functions derived by the biologists for particular populations. In the recent development of the economic literature on fisheries the economists have looked to the biologists' yield function for a particular species as the source of the production function upon which subsequent economic analysis of the fishery can rest. This development is logical in that the most money for biological research has been spent (for the most part) on those populations that are economically interesting. More directly put, the market demand for fish has been an important determinant of the direction of application of biological work.

In the historical development of ocean fisheries the interaction between market forces and biological limits on the supply represented by specific fish populations has been a typical case of exploitation at an extensive margin. In the long run, for certain fisheries (given a positive income elasticity of demand) operating on a particular stock of fish, there has been a tendency for the fishery to extend itself both geographically and temporally. If, after this extension has taken place, we assume that through the imposition of biological regulation the supply function for the stock in question becomes infinitely inelastic, economic adjustments will take place and the fleet will tend to move on to another similar stock or perhaps to a completely differentiated stock.

Thus we have the development of fisheries management essentially on an ad hoc basis as a response, often belated, to the expansion of fishing effort against a finite supply of fish. The continuous expansion of fisheries at the margin (taken collectively) has resulted in an aggregate supply curve which has been elastic. World production of protein from the oceans has risen and is expected to continue to rise. The ultimate limit will be determined by a trade off between the capacity of the basic chemical biological processes of the oceans to produce protein and the cost of collecting it.[9] At the same time the expansion in world fisheries has tended to conceal the condition of the specific stocks already exploited and

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[7] More precisely, if biological overfishing has occurred, and if a population is pushed well beyond the second equilibrium point, does it enhance the material well-being of the society to spend time and money (labor and capital) to restore it to the second equilibrium?

[8] It is also appropriate to point out that the Halibut Commission has been an important training ground for biologists interested in population dynamics and fisheries management problems, a benefit not included in the economic calculus. And also it is important to note that there should be a clear distinction between population dynamics as part of an academic discipline and the administrative process of a social institution such as a commission. The two activities have different goals, but in the field the practitioners interact so closely it is difficult for outsiders to observe the distinction. For a biologist's view of the Halibut Commission's work, see Schaefer (1970a, p. 14). Another illustration may be in the sea lamprey control program.

Since the economist, like St. George, traditionally defends the general welfare — the maximization of Gross National Product — of the society against the onslaught of particular interests it seems appropriate to me to make this argument an economic one. What is omitted, however, from the economic analysis is adequate consideration of the place (role) of any particular species in the ecological structure. This omission, together with the usual inadequacy of the definition of the appropriate rate of social discount, is probably sufficiently important to make one want to proceed with care with a decision to fish out a resource. It does not follow, however, that such a resource should be "saved" by a costly biological rehabilitation program.

[9] The inputs, the labor and capital utilized to bring about the increase in aggregate output of fish are not on the average highly specialized. Both are able to shift from one fishery to another. Vessel construction and reconditioning is a relatively easy process. Labor immobility is a larger problem but it is less acute in high seas than in inshore fisheries.

complicate the problem of management (Stewart and Pontecorvo, 1970).

For a first approximation we may visualize the fisheries management apparatus as requiring several aggregate yield functions as operational concepts. The plurality is necessary because our concepts of aggregate yield are ambiguous: it may be a regional concept, a concept associated with a particular level of the food chain, a concept that involves a set of stocks that are either economically or ecologically consistent in some way, etc. The ambiguities involved derive from the inadequacy of biological knowledge of aggregate yield, what the economists might call macro biological ocean processes, and also from the open access common property status of the stocks. This latter situation permits each nation state to define its output goals in terms of its own tastes (exploitation of alternative species) and then to proceed to bargain for its share in purely nationalistic terms.

In the absence of adequate goals at the level of aggregate yield, fishery administrators are left dealing with partial equilibrium systems, i.e., yield functions for particular species, a circumstance which makes them particularly vulnerable to pressure from economic interests, fluctuations in the stocks and the interaction between the two.

Population Dynamics

The population models developed by the biologists are basically consistent with economic models. Difficulties in the process of data collection, statistical problems in fitting functions, and the development of accurate forecasts are all familiar ground. The question of the adequacy and the cost of basic data does require further comment. The observation of wild populations is a time-consuming and costly process. The fishermen are close observers of the behavior of these populations and the commercial catch is therefore an important data source. Several types of bias may be involved in using catch data, the most obvious being that the data are restricted largely to what the fishermen want to catch when they want to catch it.

Perhaps more important, however, are certain problems inherent in the structure of the biological models. Biologists distinguish a number of types of biological models, among which are the logistic and the dynamic pool-type.

The logistic model results in a parabolic yield curve with a well-defined maximum, and this has been utilized by many economists. The maximum point on the yield curve represents the maximum sustainable yield.[10] At this point the stock is roughly half as abundant as in its initial state or maximum size. Two assumptions of interest to economists lie behind this model, the first "that the rate of increase in the stock responds immediately to changes in population density; second, that the rate of natural increase at a given weight of stock is independent of its age (or size) composition."

Naturally the adequacy of the assumptions and the intrusion of exogenous forces affect the adequacy of the model. But the matter of greatest concern to the economist lies in the first assumption. If there is not, as the biological evaluation of this type of model suggests there is not, an instantaneous adjustment between changes in population density and population rate of growth the economist for one becomes immediately interested in the time dimension of the adjustment mechanism and the lag function that may be utilized to describe it.[11] Unless we limit ourselves to consideration of long run equilibrium solutions the integration of the biological yield function into an economic system will require the specification of the lag function. For many purposes, particularly exposition, it may be adequate to define the biological system in terms of equilibrium points. However, if, as appears to be the case, the time lags are significant, i.e., if they are of such duration as to influence economic variables (price, fishing effort, entry and exit), then

[10] Holt, (1962 p. 141-142), has suggested that this particular function may be flat topped which "simply means that the biological facts are not very relevant to determining where fishing becomes stabilized over quite a range of variations in the situation." See also Gulland (1968).

[11] Prof. G. Paulik has pointed out to me that the time lags involved are a function of the species to which the model is applied. In general tropical species fit the first assumption fairly well but those in temperate zones show much slower time rates of adjustment.

equilibrium models of this type lose a great deal of their utility as a basis for regulation. The short run characteristics of the economic adjustment process will be discussed later in this paper but at this point it should be clear that the short run economic and biological adjustment processes are inexorably bound up with each other.

A second type of model, distinguished within the biological literature, the dynamic pool, presents an even thornier set of difficulties for fisheries management.[12] There are two problems inherent in dynamic pool models. The first is that the maximum sustainable physical yield is defined as a limit that can be reached only by the expenditure of infinite fishing effort (infinite cost). The second difficulty is more analogous to those found in trying to maximize the net economic yield from the resource. Various degrees of overfishing and underfishing are quantities of output which are deviations from the eumetric yield curve or curve of best yield, i.e., catching the appropriate size of fish for that level of fishing effort. Deviations from the eumetric curve are controlled by making changes in the selectivity of the gear utilized. The necessary conditions for making these gear adjustments is a knowledge of the condition of the stock and a reasonable degree of flexibility in the regulatory process. The absence of an operationally definable maximum sustainable yield plus the necessity of adjusting regulatory technique is a requirement on management that is similar to the adjustments in output level and inputs that would be required by changes in price and cost under economic regulations.

Forecasting with Biological Models

In the commercial fisheries the forecasting problem is a mix of the complexity of the life cycle of the individual species and the availability of resources to carry on the necessary biological research programs. For the bulk of the populations fished the effort devoted to biological research is simply insufficient to provide sophisticated forecasts. And while at first glance the cure for this particular inadequacy would appear to be simple it is not. In general it seems unlikely that sufficient funds for meaningful broad-based biological programs can be obtained except from the income generated by the fisheries themselves.[13] If this hypothesis is approximately valid then it suggests that economic rationalization (realization of the potential net yield) is a necessary condition for achieving the level of funding of biological research sufficient to allow the development of dependable forecasts.

The type of forecast made depends upon the behavior characteristics of the species. The Bristol Bay red salmon fishery has been studied intensively by three agencies; the National Marine Fisheries Service, the Alaskan Department of Fish and Game, and the Fisheries Research Institute of the University of Washington.

Table 1 presents a summary of salmon runs and a rough measure of the accuracy of the forecasts for the recent decade. Despite the investment in research and the heavy payoff for accurate forecasts in the Bristol Bay fishery it is clear that the existing forecasts are not completely satisfactory.[14] Furthermore, even if forecasting in this fishery was 100% accurate the instability on the supply side would (does) cause severe economic problems.

Few other species present the forecasting problems of the red salmon.[15] In the simpler cases it is possible to estimate the stocks, and then assign under biological regulations catch limits in some form. In subsequent time periods the limits may be adjusted to allow for errors in estimation of stock size.

[12] From the viewpoint of the analysis of the biological condition of the stock it appears to have certain advantages over the logistic model.

[13] This follows from the common property status of the resource which means that the rate of return to the firm or the nation on investment in research is zero in long run equilibrium.

[14] Crutchfield and Pontecorvo, (1969), especially Chapter 7, develop the rationale for the high payoff for accurate forecasts in Bristol Bay.

[15] Schaefer (1970a), discusses the approach to the maximum sustainable yield that may be utilized with species such as the Peruvian anchoveta, halibut, etc. Even within these more stable populations there is room for substantial disagreement about the appropriate level of yield. For further examples see (Schaefer, 1967; 1970b and Segura, 1972).

Certain deductions can be made about the biological and economic implications of this lagged response approach to maximum sustainable yield. *A priori*, it appears that its economic viability is a function of the stability of the population. And since we have already suggested that those populations which are fished heavily, i.e., those exploited close to or even beyond the maximum sustainable yield, tend to show greater fluctuations, it follows that accurate forecasts of short run supply changes will require a continuous extensive biological research program.[16]

Political Science and Sociology

The discussion thus far has been aimed at understanding the nature and limitations of the maximum physical yield as a biological construct and as a tool in fisheries management. The technical side of the problem is however just one part of it. As one distinguished fisheries administrator put it:

> I wish to inquire whether social and political problems are included within the scope of fisheries economics. If so, we may be able to arrive at a fairly broad and comprehensive view on matters of fishery regulation. If not, then I think they must be treated as separate aspects (McHugh, 1962).

Neither the economist nor the biologist will, based on what can be learned from the individual disciplines, accept responsibility for the social and political problems associated with the fisheries. They have both been guilty of implying that social and political objectives will best be met by choosing the alternative they espouse. However, since social and political objectives themselves are apt to be as disparate as are the biological and economic, the debaters have grasped at only those aspects of social and political policy that have best fit their needs at the moment.

[16] One alternative would be to limit fishing effort to that sufficient to harvest only the lower portion of the range of variation in the stock. This would give a small output at low cost with little or no requirement for investment in biology. Since, however, this would be a disequilibrium situation with long run excess profits in all probability it could not be sustained in the face of the economic pressures to expand.

Table 1. — Run of sockeye salmon to Bristol Bay, 1960-1970.*

	Millions of fish		
1960	36.3		
1961	18.0	Range	7.7-53.1
1962	10.4	Median	17.5
1963	6.8	Mean	20.8
1964	10.7	Coefficient of variation	74%
1965	53.1		
1966	17.5	Approximate forecasting errors:	
1967	10.3	1960-1970 ± 40%	
1968	7.7		
1969	18.5	Anticipated accuracy of forecasts in near future:	
1970	39.6	± 20% in 4 years out of 5	
		± 50% in 5th year	

* I am deeply indebted to Dr. Donald E. Rogers of the Fisheries Research Institute of the University of Washington for assembling the complex data on the runs and forecasts of Bristol Bay and Western Alaska Sockeye (from which Table I is excerpted). As noted in the text, the purpose in presenting these figures is to emphasize the year-to-year variations in supply.

They have not dealt in a rigorous analytical way with these problems.

In this it seems fair to say that the biologists have been the political realists while the economists, to the extent that they have dealt with the question of labor mobility, income distribution, and the impact of barriers to entry on the scale of enterprise, have been closer to social realities.

Economists have insisted correctly, in my judgment, in their discussion of the problems of fisheries, that the general economic welfare of the state and the individuals in it are best served by maximizing the net economic yield from the resource. Their occasional willingness to temporize their position arises for the following reason. For species of fish with a high unit value such as lobster, red salmon, etc., the discrepancy between the maximum sustainable physical yield and the net economic yield is not apt to be very large, the former being a second best solution that does not deviate significantly from the economic optimum.[17]

Of greater significance is the political appeal of the idea of achieving the maximum sustainable physical yield. The economist categorically rejects the idea that it is "good" to maximize the output of any commodity just because it is physically possible. To the politician negotiating fisheries agreements both nationally and internationally it is important to be able to state that the agreement makes possible the utilization of all the fish available for all time, none will be "wasted." The simplistic political argument runs as follows: the production of food, particularly protein food, is good. The maximum sustainable physical yield is the most food that can be obtained. Any other definition of optimum output such as the net economic yield would either represent less food (a waste) or if it was greater than the maximum physical yield it would be a threat to the stock.

The danger in this political exposition of the problem is, of course, that it conceals the underlying complexities of the biological process as well as the interaction between those processes and economic variables.[18]

THE NET ECONOMIC YIELD AND LONG RUN PARTIAL EQUILIBRIUM MODELS

Economic and Biological Models

As a first approximation we may assert that the utility of economic models in fisheries management is symmetrical with the biological counterparts upon which they rest.[19] The argument developed about the inadequacy of partial models and the difficulty of utilizing long run equilibrium systems for management decisions are applicable to both biology and economics.

By ignoring underlying definitional problems as well as those which result in short run fluctuations in output, the biological concept of the maximum physical yield can present a facade of stability. No such facade exists with the net economic yield. The appropriate level of output is defined by the interrelationship between market price and costs. Since the price of most fish products is determined in markets that are describable as workably competitive, it is clear that when the physical yield function is transformed into a revenue function the appropriate level of output will shift in response to price changes.[20]

The voluminous literature on the economics of uncertainty is suggestive of the magnitude of the administrative and political problems it creates for the regulatory mechanism, and also the lengths administrators will go to minimize it. But how much uncertainty actually would be created by the imposition of regulatory practices aimed at maximizing the net economic yield? The major sources of disequilibrium in most fisheries appear to be attributable to two forces, short run variations in the supply of fish and shifts in the demand function. In this context it is important to distinguish between stability in the demand function and stability of price. Within the economic models price changes are caused by short run variations in supply which cause

[17] There is for the noneconomist a possible confusion here. Both the output that will maximize the net economic yield from the resource and the output that will maximize the physical yield in the long run are points derived from the same biological yield function. However, the maximization of the net economic yield requires, given the common property status of fish stocks, an economic control mechanism as well.

[18] We have ignored any discussion of what has been referred to as social problems. A good illustration of the interaction of all the forces can be found in the Norwegian coastal fisheries. For reasons that are political, social, and national, the Norwegian government has seen fit to subsidize coastal fisheries. These subsidies have been indirect: education for dependents, health care, transportation, etc., and direct: price supports for raw fish, vessel construction subsidies, etc. A key objective of this policy is to maintain the population living along the coast of western Norway, the traditional farmer fisherman. Other considerations are military, economic (balance of payment), and political in that it is important to participate in the exploitation of stocks as a claim against any future regulation that might involve national quotas, etc.

[19] There are of course important differences. For an exposition of certain properties of variable proportions diminishing returns unique to the fisheries, see F. W. Bell, and E. W. Carlson (1970).

[20] See Crutchfield and Pontecorvo, (1969, pp. 28-88). The usual assumption is that cost functions are linear and stable. This follows from the size of labor markets, the general availability of the type of capital instruments required in most fisheries, and especially from the small scale of most fisheries encompassed by the partial equilibrium systems analyzed.

a change in price and are therefore the primary source of uncertainty. This effect will be dampened if the demand function is highly elastic, a condition that seems applicable to many fisheries.

In the long run, however, the situation is different. The dynamics of short run supply changes continue through time but in the long run the demand function tends to be responsive to income changes and therefore shifts to the right, adding to the degree of uncertainty.

Given the high level of uncertainty inherent in fisheries, the workability of fisheries as industries is highly dependent on their economic efficiency, i.e., their ability to operate profitably and not dissipate the rent from the resource among redundant inputs.

Sources of Short Run Economic Instability

If, for the moment, however, we limit our argument to the short run and we hypothesize that the source of instability is on the supply side then it is correct to say that regulations aimed at either maximizing physical yield or net revenue are not significantly different from each other in terms of the level of uncertainty involved. An analogy may be useful in putting this problem in better perspective.

Academic economists are virtually unanimous in the opinion that some degree of flexibility in exchange rates is desirable. Central bankers and to a lesser extent businessmen are generally opposed to the creation of the uncertainty that flexible rates would bring. At the heart of this debate are two different views of the stability of the underlying system. If equilibrium not disequilibrium is the norm then problems involving the short run adjustment process are minimal. But if short run variations are inherent and important in the system then the regulatory process must be flexible to be consistent with the dynamics of the short run.

The short run economic adjustment process in fisheries, unlike certain industries, is particularly responsive to changes in market conditions. Common property and easy entry, a relatively low level of specialization of inputs, and the possibility of shifts of economic units between fisheries, have combined to create this condition.

Let us define the short run to be a period sufficiently brief to exclude new entry. By new entry we mean that fishing effort would be carried on by units of capital and labor with no previous experience in the fishery in question. Fisheries (except in initial growth stages or periods of significant technological change) tend to be characterized by excess capacity. In these circumstances short run shifts in the price/cost ratio brought about by changes in either supply or demand can generate wide swings in fishing effort. This effort may come from greater productivity (longer hours, better organization, harder work), by the activation of units previously participating in this fishery but currently "on the beach," or by the response of economic units that work in several fisheries on a part-time basis to the enhanced profit position in this one.[21] If the excess profits continue in the face of the increase in fishing effort, new entry will take place fairly rapidly.

The labor and capital utilized in many fisheries may be characterized as having three elements, one is a core of labor and capital that is primarily identified with the particular fishery in question and this core may expand and contract its efforts in response to market conditions but it lacks the mobility required to shift rapidly to alternative fisheries.

The second element is a stock of standby capacity, either currently employed elsewhere or unemployed, that can and does respond to changes in profit prospects. These two components, possibly each individually if restrictions on productivity are considered, represent more capacity than is needed to harvest any average level of catch and perhaps even more capacity than is required to land the upper limits of the frequency distribution of the abundance of the stock.

[21] These responses are not symmetrical, i.e., fishing effort increases more rapidly in response to profit opportunities than does exit to a reduction in earnings. Inertia, the possibilities of windfall gains and the inadequacy of the forecasts of short run supply all contribute to the asymmetry. It is particularly important to note that we have not mentioned changes in technology. In many fisheries the relationship between technological change and fishing effort is circumscribed by the regulatory process.

The third element is the continuous threat of entry. If the excess profits observed in one time period continue, or if they are expected to continue, entry will take place. Expectations and the competitive illusion play a role in all industries but the great flexibility in the capital instruments employed in fisheries tend to make the interaction between market conditions, expectations, and capacity particularly close (Pontecorvo and Vartdal, 1967).

Supply fluctuations, excess capacity, the rapidity of responsiveness to changes in the market, and the influence of expectations all contribute to short run instability in fisheries. Control of capacity, improvements in forecasting supply in order to reduce uncertainty, plus recognition that capacity sufficient to capture some average level of catch less than the maximum sustainable yield may be appropriate, are all elements in a management program geared to meeting the conditions imposed by the short run dynamics of fisheries.

Long Run Equilibrium

If short run economic objectives are definable in the terms indicated above it is appropriate to inquire next about the long run equilibrium conditions. Economic analysis of fisheries has accepted as given the biological yield function for the species in question, as well as the usual assumptions of static equilibrium analysis of full employment and factor mobility. In these circumstances the condition of Pareto optimality is roughly fulfilled if the policy recommendations (essentially creation of a set of regulations aimed at maximizing the rent of the resource and in all probability requiring barriers to entry) required to rationalize the fishery are met. Within the framework of economic analysis (maximization of Gross National Product) this is a necessary and sufficient condition for making the maximization of the net economic yield the appropriate goal of fisheries management. Any alternative is less satisfactory in that it will result in a lower level of material well-being (GNP).[22]

Attacks on this goal have come from two sources, biologists and fisheries administrators, and also from within the economics profession. The position of the former group rests in large part, in my opinion, on a fundamental misconception concerning the meaning of economic optimization. Economics is not sufficient to explain (or optimize), particularly in the short run, the entire set of variables involved in a fishery. The economist accounts for the social problems by his assumption of full employment and factor mobility. He does not normally account for political factors except indirectly in his underlying assumption of human rationality which tends to force the political preferences into the same ordering as the economic.

A bioeconomic position dominates thinking about fisheries management simply because there is no body of social or political theory sufficiently powerful (relative to welfare maximization in economics or population dynamics in biology) to force a modification of either the biological or economic position. In these circumstances, which appear unlikely to change in the foreseeable future, political and social considerations can only be considered on an ad hoc basis. More specifically, it is normally true that the biological optimum and economic optimum are consistent with each other in that both will protect the stock. The economic goal is more general and therefore preferable in that in addition to protecting the stock it also provides the maximum economic benefits to society. Any deviation from the economic maximum involves therefore a cost, a cost measurable in terms of output foregone. Nothing in this argument suggests that ad hoc reasons are not sufficient grounds (given the weakness in the two underlying assumptions in certain circumstances) to make an alternative objective (political, military, social, etc.) either the primary or a subsidiary goal of fishery management.

In this circumstance the economist's primary concern would be to calculate the cost of the alternative. The latter calculation presupposes that the alternative can be specified, a condition that is seldom met. What tends to emerge as the management goals in fisheries under the long run equilibrium condition that dominates today's thinking is an unspecified

[22] A crucial assumption is that the opportunity cost for labor is positive. Most of the attacks on the concept of economic regulation of fisheries assert the contrary. Perhaps the needed empirical investigation of this point could start with a classification such as suggested in Approaches to Fisheries Management.

mix of all factors including purely administrative considerations.

The attack within the profession has raised an appropriate question about the implications of limits on entry for Pareto optimization. Another position also has been advanced based on an assumption questioned throughout this paper that the maximum physical yield is so fundamentally sound in the operational sense that its utility as a tool outweighs its defects.[23]

In the competitive model there is no limit on entry beyond that provided by what Knight has called the "social function of ownership." In the fishery with the resource being common property the objective of the economist in calling for a limit on entry is to provide the ownership function while retaining the Pareto optimum conditions inherent in the competitive model.

Two questions may be raised about this goal and the procedures necessary to achieve it. Will the barriers to entry result in a situation that goes beyond competition, i.e., does the creation of property rights just restore the conditions that would be found with private property operating under competition or does it also imply the creation of monopoly power so that buying and selling is no longer on a competitive basis? The second question is an integral part of the first. Does the establishment of barriers to entry and the subsequent economic regulation of the fishery in the public interest require the creation of a regulatory mechanism so costly and complex as to be self defeating?[24]

Economic theory does not provide an answer to these questions. It is possible, however, based on experience with the social control of industry, to advance certain tentative hypotheses. No control mechanism based solely on biological considerations is workable in the long run in the face of economic and other pressures. Therefore, the cost of the control mechanism is ultimately a joint bioeconomic cost. Even in these circumstances it may be that the costs of control are disproportionately large relative to the value of the resource left unprotected.[25]

A second hypothesis is that if the cost of bioeconomic control is not excessive then the capacity to regulate the fishery in the public interest, i.e., to preserve the stock and prevent the emergence of significant monopoly power, is well within the power of regulatory processes and tax arrangements that have proved themselves workable in other circumstances.

APPROACHES TO FISHERIES MANAGEMENT

A major constraint in the development of a consistent monetary policy is that the monetary system itself is continuously evolving. The analogy seems applicable to regulatory problems involving ocean resources. The pattern of resource exploitation in the oceans and the law of the sea are changing rapidly. In addition, military uses of the oceans, while not a new phenomenon, are being transformed and at the same time the very existence of the ocean in the way we have known it is threatened by the effects of the population explosion and the rising level of real income. Furthermore, our capacity to deal effectively with ocean living resource problems is limited by the inadequacy of our scientific knowledge of life processes in the ocean, the generally weak economic condition of fisheries, and the nationalistic interests involved.

It is beyond the scope of this paper to go into these structural questions. It is clear, however, that in the future the organizations by which fisheries are to be regulated must be prepared to negotiate the basic issues of control of the environment and the priorities

[23] See Wantrup (1970, p. 18): "While maximum sustainable yield constitutes a relevant, operational, and noncontroversial objective of conservation policy, this is quite different for the objective of 'maximum net economic yield' — even if its realization through limitation of entry could be agreed upon by the fishing industry." Also (Wantrup, 1962, p. 292): "My approach, therefore, would be set more modest regulation goals which would concern themselves more with the resource base than with rent. We are dealing then with matters we can measure. If we try to maximize rent as a policy goal, then we get into an area where I for one would put out a 'caveat' sign."

[24] Virtually the entire literature on the economics of fisheries has commented on these two questions albeit in a not very satisfactory manner. For the details on control plans to limit entry see Sinclair (1962) and Royce et al. (1963).

[25] It might be desirable to protect the resource for other reasons, i.e., because it was unique, etc.

appropriate to multiple use situations in the oceans with external forces. In these activities the strength of their bargaining position will depend heavily on their having rationalized both the economic and biological sides of the fisheries. Regardless of what potential economic yields may be or what social pressure for employment is present, a realized net economic yield of zero from fishing does not provide an adequate base for defending ocean space for commerical fisheries in competition with the oil industry, recreational use, power generation, etc.

In recent years progress has been made by governments, fisheries commissions, and academic researchers in the analysis of fisheries problems. What are the elements of this analysis that may be utilized to help reorient our approach to fisheries management?

The long run partial equilibrium systems constructed thus far make a major contribution by an exposition of the problems in static terms. It is clear, however, that they are inadequate for resource management. In most circumstances they do provide limits within which the regulatory process may operate. In the analysis of particular species the distinction between the net economic yield and the maximum sustainable physical yield is subject to empirical verification depending on the unit value of the species, but in any case it is a second order question. In any set of priorities established for fisheries management the first is to move toward meeting the criteria of economic efficiency, probably by establishing limits on entry. Once the fishery is rationalized then the solution to the problem of the appropriate level of output should be greatly simplified. This follows from the nature of the adjustments that must be made in the process of economic rationalization. The administrators will be forced to consider simultaneously the appropriate amount of fishing effort (amount of inputs) relative to the forecast of the frequency distribution of supply and the impact of productivity changes on fishing effort. Once the fishery is defined in this way, the economic implications and advantages of various levels of output will be more apparent to all and self interest, which today drives producers toward overfishing the resource, will move them toward limiting the catch to maximize the net yield from the resource.[26]

Given recognition of the long run bioeconomic limits, the adequacy of the regulatory mechanism may be evaluated in terms of how well it handles the short run maximization problem and its success in restructuring the fishery from a disequilibrium position (excess capacity) to one of equilibrium. This latter will require evaluation of the possibilities inherent in aggregative yield functions and clarification of the goal of a workably competitive structure for the fisheries. The rents captured in the rationalization process are available to finance this transition. In these utopian circumstances the essence of the internal regulatory mechanism will be found in the interaction between changes in biological supply, prices, and technology.

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[26] This statement is more than a pious hope but less than a certainty. Its validity depends in part on the nature of the frequency distribution of catch among the participants in the fishery, i.e., if the fishery were the property of a monopolist he would operate at the level of the net economic yield. Only under certain assumptions will this be true of the behavior of a set of competitors. Their recognition of the desirability of maximizing aggregate net revenue will come as a process of education as studies of the characteristics of the fishery reveal the advantages inherent in various alternatives.

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Multiple Objectives for Marine Resource Management[1]

R. Bruce Rettig[2]

ABSTRACT

Management decisions suggested by recent bioeconomic models have been largely disregarded by fishery managers. This negligible impact may be due to error on the part of management, an incomplete grasp of the role of noneconomic objectives, and/or the possibility that more sophisticated economic models might yield markedly different results. More sophisticated models are suggested which consider the problem of second best, risk and uncertainty, transaction and adjustment costs, and income redistribution. Creation of analytical systems amenable to treatment of noneconomic variables along with economic variables is suggested.

During the past two decades, a growing body of economists has been articulating a rationale for management of ocean fisheries which is based upon the principle of maximum sustainable net economic yield. The usual paradigm emphasizes the lack of clearly defined property rights and arrives at a conclusion of a need for limited entry, most commonly suggested through a system of licensing and/or taxes. While the better analyses have often hedged their conclusions with a set of qualifications, even these balanced policy programs are rejected by authorities actually responsible for fishery management.

That articulate arguments from a respected cross-section of the economics profession continue to carry only minor weight with their intended audience is quite disconcerting. This paper consists of an examination of two possible reasons for the treatment of the bioeconomic models to date. The first possibility is a divergence between what public authorities consider appropriate objectives to pursue and the assumptions of goals implicit or explicit in the bioeconomic models. The second possibility is that bioeconomic models are incompletely specified and that more complete models would be better received. A third possibility that will not be handled in this paper is that existing analysis is correct and that all that remains is to educate the resource managers on the merits of implementing the correct suggestions already available.

THE ELUCIDATION AND LEGITIMIZATION OF SOCIAL GOALS

The characteristic of the fishery which lies at the root of the problem is the lack of clearly defined property rights over the fishing ground. The severe depletion of such fisheries as the Pacific halibut fishery and the sardine fishery off the California coast stand as stark testimony to the value of property rights. That the problems associated with fisheries can be easily related to the absence of property rights is seen by considering the central economic functions of property as set forth recently by Bjork (1969, p. 65):

> First, it provides incentives for the creation and improvement of assets. Second, it provides incentives for efficient control of existing assets. Third, it rations the use of scarce assets to ensure that they will be used for those purposes which society values most highly.

Bjork argues that property rights exist largely because stable market-oriented societies value the performance of these functions so highly.

Investment incentives, efficient allocation of fishing effort and living fish, and distribution to him who values the resource most highly are indeed the central objectives behind the bioeconomic models of current interest. These are not apparently the sole objectives of the societies

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[2] Department of Agricultural Economics, Oregon State University.

whose mandates the resource managers must have in order to perform their duties viably. It is useful to lump these other objectives into two categories — equity in the distribution of income, and noneconomic objectives. Equity of income distribution is relevant both in constraining changes from the status quo and in defining acceptable distributions of income. This latter can be illustrated by the popularity among some authors of giving some supranational agency control over all marine resources and by current claims of U.S. nationals to the natural right of the citizens of a country over fish which swim over "their" continental shelf. Noneconomic objectives are important in the arguments of some concerning the inherent evil of blocking entry to a fishing ground. Of course, several objectives can be classified more than one way. The repercussions of sudden, unexpected unemployment of fishermen can be called adjustment costs or could be appropriately titled sociological phenomena.

In any case, it is not appropriate for economists to identify conclusions of their positive models with normative policy proposals. Society is not composed of economic men (Boulding, 1969). Rather the economist must first try to maximize economic gain subject to noneconomic constraints. However, when noneconomic objectives are not postulated at unique target levels, the tradeoffs between economic and noneconomic objectives must be considered. I will return to this practical problem after considering some problems of analyzing economic objectives.

SECOND-BEST FISHERIES, OR WHEN IS AN OPTIMUM NOT OPTIMAL?

The application of the theory of common property resources to ocean fisheries leads inexorably to two conclusions. First, it is possible to observe an allocation of human and capital resources in fishing with social marginal products which are negative. Second, the optimal allocation of resources is one in which social marginal revenue product equals social opportunity cost of factors used to catch fish. This is to say that less fishing effort should be employed than would be required to harvest the maximum sustainable yield unless the alternative use of the marginal resources is valueless.

Crutchfield and Pontecorvo (1969, p. 35) have pointed out that the need for intervention in fishery management hinges upon the assumption of competitive behavior by the downstream purchasers of the resource.

> A monopsonist would impose a rational solution on the fishery, i.e., he would capture the rent by offering sellers a price that would permit only the most efficient exploitation of the resource to take place, and the malallocation of resources, which results from the combination of free entry and common property, would be avoided. If, in turn, the product market in which he sells is highly competitive, monopsony could provide a near-optimal level of output and real costs.

While Crutchfield and Pontecorvo go on to point out that the industry which purchases fish from fishermen is a competitive oligopsony and does *not* lead to a socially optimal solution, their argument still holds qualitatively. When an oligopsonistic industry faces a group of competitive sellers the price paid for the output of the competitive sellers is less than the social valuation for an incremental unit, i.e., the social marginal revenue product exceeds the market price. This divergence alters the optimal intervention in the market structure of fish buyers and alters the optimal fishery management scheme, assuming control over the two cannot be coordinated.

If the market between fishermen and fish processors is not perfectly competitive, the correction of fisheries resource allocation ignoring this fact could actually misallocate resources. Equating the social marginal product of fishing effort multiplied by observed market price to social opportunity cost of factors used to catch fish would secure a level of fishing effort less than the one where the true value of social marginal product equals social opportunity cost of factors. If the demand for fish is elastic throughout the relevant range, the correct solution would still occur prior to attainment of maximum sustainable physical yield. The simple maximum sustainable physical yield criterion is still in error and the error is still in the same direction, but the error is smaller than the simpler analysis. Thus the efficiency loss from using the physical rule is smaller than previous analysis has suggested.

On the other hand, if a social suboptimum does not exist in an ocean fishery, the dissolution of oligopsonistic structure in the fish processing industry would further misallocate resources. Assume that effort had entered until the effort level which would secure maximum physical sustainable yield had been exceeded. Breaking up the monopsony and allowing the higher social marginal valuation to be revealed would further overcapitalize the fishery and lead to a lower physical sustainable yield.

While the argument has not proven that suboptimization in either fisheries or fish processing industries will lead to a misallocation of resources, the possibility of such an event may lead to a desire to gather more information about upstream-downstream linkages in these industries before taking large irreversible policy actions. It also may comfort those who wish for maximum physical sustainable yield in the fisheries and those who are hesitant about breaking up what appears to be an oligopsonistic fish distribution chain in the near future.

An extension of the preceding analysis may lead one to observe that imperfectly competitive factor markets from one side allows the theoretical possibility that the unorganized fishermen may be able to organize and bargain collectively for higher prices without third-party effects. Nevertheless, the tenor of this piece has suggested that third-party effects may possibly be involved and that the public interest may imply that this bargaining should be observed by representatives of the third parties, such as the Government.

Directly parallel to the problem of second best in the economy is an ecological second best. If two species are competitors in the ocean, an increase in the sustainable yield of one may reduce the sustainable yield of the other. Likewise, increasing the sustainable yield of a species may increase the sustainable yield of its predators and/or decrease the sustainable yield of its prey.

RISK, UNCERTAINTY, AND INTERTEMPORAL CHOICE

Anthony Scott (1962) has pointed out and Plourde (1970) has recently given a concise proof that looking for solution values on steady-state curves (which these sustainable yield curves are) is akin to ignoring the existence of a positive rate of time discount. This becomes obvious when one assumes an infinite rate of time discount and immediately finds the instantaneous yield curve to be the only relevant one for consideration.

When one backs away from steady state solutions, tries to pose the relevant horizon curve, and tries to determine the role of time discount, one realizes that he is postulating expected values of a probability distribution of possible yield curves with only a vague awareness of the yields in short and long run which will occur. It may be useful to separate problems of uncertainty into two categories. On the one hand, demand for particular fish species is uncertain. It is one thing to extrapolate desires for particular fish species into the near future. It is quite something else to fail to realize that current demand is dependent upon current techniques of processing and marketing fish. The rapid rise of consumption of frozen fish steaks and fillets in recent years is only suggestive of changes which we can expect in the future.

Major research programs, such as those supported by the Sea Grant college system, are currently attempting to reduce uncertainty about fish supply. A number of important areas need to be resolved. To manage the supply of anchovy, one needs to know the biological production function of anchovy. As already suggested, ecological parameters are needed to manage both independent fisheries and biologically interdependent species. Thus we need to understand the nature of supply of all possible species which might occupy an ecological niche. It is interesting to examine the controversy over total yield of food from the sea. As Chapman has pointed out frequently in recent years, the wide divergence in estimates really depends upon the trophic level assumed. Consequently, not only is there uncertainty about the supply of any particular species of fish, but there is uncertainty about the relevant definition of supply of fish.

THE COST OF MOVING TO A PARTIAL EQUILIBRIUM POINT

Equilibrium points in static analysis are illuminating for recommendations concerning direction of change. There are several reasons for realizing, however, that one may not choose to move to the point of maximum rent. This reservation is strongest in short-run analysis, but several parameters in a bioeconomic model can be expected to shift in the long run.

Before proposing that a fishery should be managed at the point of maximum net economic yield, one must first show that the present value of the fishery at maximum sustainable net economic yield is greater than the value of the status quo by more than the transactions costs of moving to the new point. This was brought out dramatically by Wantrup (FAO 1962) and also in a comment by Crutchfield to the effect that not reducing the existing level of fishing effort could conceivably be a country's cheapest unemployment or welfare policy in cases where the excess number of fishermen truly had no viable alternative to fishing.[3]

However, even if the maximum sustainable net economic yield point is greater in value than status quo by all relevant costs of change, this does not preclude the possibility that some other point, intermediate to those two, might be more desirable. In summary, the proof of superiority of a theoretical optimum over a status quo position leads to an argument for direction of change in effort, but does not show the magnitude of change until the costs of such a change are themselves considered.

PROBLEMS POSED BY REDISTRIBUTION OF INCOME

Such a recommendation as moving to the point of maximum net economic yield is roughly akin to the statement that a readjustment is recommended whenever the dollar value to potential gainers is greater than the dollar value to potential losers. This is the famous Kaldor-Hicks criterion for an improvement in social welfare. The criticisms of this criterion are now well-known (Rothenberg, 1961) but of them all, the most commonly cited is the inability to judge among different income distributions. To say that one state is better than another state, when even one individual is worse off in the former state, is to make those interpersonal utility comparisons which the economics profession has largely disavowed.

To confess that economists have no straightforward technique for judging among alternative income distributions does not alter the fact that judgments can and will be made. It does mean that economists should try to describe the effects of alternative management decisions upon the distribution of income. In addition to this, economists can realize that the general interpretation of equity seems to frequently preclude drastic changes in the distribution of income. Management schemes in bioeconomic models should include systems which compensate losers whenever possible. It may be wise to attach grandfather clauses, unemployment relief funds, and the like to licensing or other limited entry proposals. The costs of preserving stability and the existing distribution of income should not be overlooked, creating a parallel to the awesome headaches of our contemporary farm program.

AN OPERATIONAL PROPOSAL — THE USE OF TARGET VARIABLES

Academics who would wish to have a voice in public policy cannot devote themselves to being solely naysayers. Decisions must and will be made. While there are many reservations which must be made about bioeconomic models, there is also something intrinsically appealing about them. How can one use the information concerning net economic yield and still consider other objectives?

One possible technique is to simply array a group of options for the authority who has received society's mandate. However, it is likely that the fishery management body itself will be somewhat removed from direct interaction with the society. Hence, they will probably need to infer relative values from another source. Our experience with many operating agencies has tended to show that "the wheel that squeaks gets the grease." Thus, the use of operating agency discretion may not reflect the values of the underlying society.

A second technique is that proposed in most bioeconomic models. Namely, net economic

[3] The comment was made in August 1969, during discussions after a panel presentation given at Oregon State University.

yield would be maximized subject to certain constraints on acceptable rules for redistributing income and constraints with respect to minimum levels of the assorted noneconomic objectives. There is no denying that this system solves the problem of weighting the various objectives by simply avoiding the problem. While weights are not explicitly chosen, they are implicit in the levels of the noneconomic variables selected. Consequently, some technique will have to be devised for continuous reconsideration of non-economic objectives with periodic adjustments in the level of the constraints being made by an authority responsible to society.

The technique of constrained maximization will operate best where clear threshold levels of other variables can be designated. In cases of international fisheries management, it will operate best when the parties to the international agreement can agree on the objectives other than net economic yield and when relative weights of more than one species can be specified where more than one commercially important species is affected by the management decision. When this is not true, a third technique of explicitly agreeing on relative weights of several objectives and maximizing the weighted function may be superior.

It may well be that developing a general theory of fishery management is to develop an empty theory. Special consideration will be needed for different species of fish and different groups of nations. Nonetheless, it is apparent that management of ocean fisheries is desired. It is also apparent that biological criteria are not sufficient to manage a resource in a world in which there are more goals than merely consuming one particular species of fish. It is thus incumbent upon us to try to specify public policy actions which public authorities can undertake to achieve the best possible mix of a large assortment of goals.

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Economic, Political, and Social Barriers to Efficiency in Selected Pacific Coast Fisheries

James A. Crutchfield[1]

ABSTRACT

Multidisciplinary models are being developed for the salmon, halibut, king crab and anchovy fisheries as an aid in fisheries management. These models will provide estimates of economic rent in these fisheries, with an evaluation of alternative management structures available to capture these net benefits. The character of the models for each of these differing fisheries is described, including reference to the nature of the products, markets, processors, harvesters, regulators, stocks, and locations sectors of these fisheries. Introductory observations are made on the future role of multifishery modeling studies.

INTRODUCTION

In June 1970 the University of Washington and the University of Rhode Island were funded by the National Marine Fisheries Service to take a first step in identification and quantification of the economic costs of institutional barriers to the efficient use of commercially fished marine stocks. Anyone familiar with the American flag fisheries will recognize that the time and financial limitations of these one or two year studies preclude any definitive findings applicable on a broad scale. Nevertheless, first steps must somehow be taken, and the two university teams, together with their NMFS counterparts, share the view that a convincing demonstration of substantial economic gains from the elimination of obvious sources of inefficiency is one of the most important of these steps. Hopefully, it will represent one phase of a broad-based attack on the problems of modernizing the American fisheries and rationalizing the objectives and techniques of management.

This paper presents a summary progress report of the Pacific Coast studies. The project has two objectives. In the short run it is intended to provide reasonable estimates of potential net economic rent in representative Pacific Coast fisheries, and to explore the feasibility of alternative management regimes to realize at least a portion of these net benefits. The importance of this objective is underscored by increasing pressure for tangible evidence that the overall activities of the National Marine Fisheries Service can be translated into economic benefits: an outcome that is anything but likely under present institutional arrangements in the fisheries. In the face of increasingly insistent demands on the inshore waters of the United States, and the likelihood of severe budget stringency for an indefinite period, a convincing demonstration of the net benefits that can be generated by the elimination of unnecessary barriers to efficient harvesting of marine stocks may well determine the future existence of a strong federal fisheries function.

The longer term objective of the study is to develop primary data and modeling capacity to test fully alternative management and development regimes. Previous studies of individual segments of the American fisheries (Crutchfield and Zellner, 1962; Crutchfield and Pontecorvo, 1969; and Bell and Carlson, 1970) have been concerned primarily with maximum potential net economic rent in long run terms, with varying assumptions as to acceptance or modification of existing legal and other constraints. It is clear, however, that a full reevaluation of fishery management objectives requires a much broader frame of reference and a larger kit of tools. Since it is politically unlikely that all barriers to efficiency will be removed simultaneously, it would be most useful to develop a modeling technique that would permit us to look at a wide variety of measures or combinations of measures, at relatively low cost but with

[1] University of Washington.

real numbers to provide real estimates of economic and biological effects.

There is equally urgent need for a quantified model that can be manipulated in terms of multiple objectives: economic efficiency, income distribution, structural unemployment, and perhaps others. The modeling technique lends itself well to assessment of a range of management measures that might be undertaken to achieve multiple objectives, or to maximize certain elements subject to constrained values for others.

There are both biological and economic reasons for development of a more sophisticated model than the long term equilibrium constructs used in earlier work. Short term adjustments of both fish stocks and fishermen to altered parameters must be scrutinized much more carefully. Similarly, the usual analysis of yield functions, and of bioeconomic models based on them, is cast in terms of a single fishery, while most American fishing gear either exploits more than one species or is capable of doing so. Even before the economic numbers to be used in a more complex process model of this sort can be developed, it is possible to derive a great deal of knowledge of immediate benefit in assessing alternative management regimes by framing appropriate functional relations in model form and testing their sensitivity to various assumptions as to quantitative values.

In short, it would be highly desirable to develop a set of models specific to individual fisheries but geared to a central common framework that would permit comparison among fisheries. Obviously, this will not be done in a day or a year; but if a good start can be made in isolating the functions that must be quantified and delineating data requirements, the ultimate payoff in terms of flexibility and low operating cost will make possible a dynamic concept of fisheries management that can really utilize increases in scientific knowledge, improved technology, and more flexible administrative arrangements.

THE FISHERIES

The four fisheries chosen for analysis were selected for characteristics which make them broadly representative of the kinds of problems to be faced in future fishery management programs geared more closely to economic objectives. The Pacific halibut operation is a mature fishery, relatively simple in economic structure, and employing only a single type of gear. It has been under a carefully conceived regulatory program for a sufficiently long period to generate excellent data on both biological and economic variables.

The Pacific salmon fishery stands at almost the opposite extreme. It is complex in every sense — biological and economic — that can be imagined. It is subject to inherent data limitations since it is based on populations that are in constant short run disequilibrium, and it is now regulated on such an irrational basis that great improvement is possible with relatively simple alterations in management techniques.

The California anchovy fishery, barely exploited at the present time, represents one of the largest single latent resources available to American flag fishermen. On the assumption that present legal limitations on commercial exploitation are removed, the potential physical yield from the fishery is almost as great as the total United States landed catch. The possibility of creating a new and highly attractive industry under controlled entry conditions is intriguing, to say the least. Data on the California anchovy are still rather limited, but the basic stock information is being developed rapidly, and both the biological and economic analysis can borrow extensively from the broad experience of the Peruvian anchoveta fishery.

The king crab fishery of the North Pacific presents a classic example of the speed with which modern technology, under conditions of open entry, can lead to overinvestment, overfishing, and potential economic disaster. In addition, the hastily conceived regulations now in effect present some of the worst examples of efficiency-reducing techniques, coupled with obvious efforts to redistribute income from one set of fishermen to another. Data are woefully inadequate in this fishery, but its economic value and potential make it an excellent case study.

THE MODELING FRAMEWORK

The simulation approach which serves as the basis for the longer run aspects of this project is hinged on a general model which is adaptable to each of the specific fisheries to be studied. It involves a large computer program which provides a framework for studying short term and long term effects of alternative regulatory policies on economic and biological performance of various sectors of a fishery. The basic program is written in a version of FORTRAN IV. A schematic of the basic model is shown in Figure 1. The sectors simulated by the program are: products, markets, processors, harvesters, regulators, stocks, and locations. General operation of the model is as follows. The stock sector "grows" the resources and determines the amount of each stock which is available for harvest in each location. Harvesters operate in locations of their choosing, catch a portion of the available stock, and sell it to processors. Processors convert their purchases into finished goods and offer them for sale in the markets which are available. Demand (and the marketing activity of the processors) determine sales by each processor of each product in each market. The regulators are free to impose restrictions of various types on the activities of both processors and harvesters. In operation the program compiles statistics on the operation of the system and prints out monthly and annual summaries of these statistics. The detail of the printout is optional.

Each harvesting group operates as a semi-independent unit, constrained only by links to a location and one set of processors. At the start

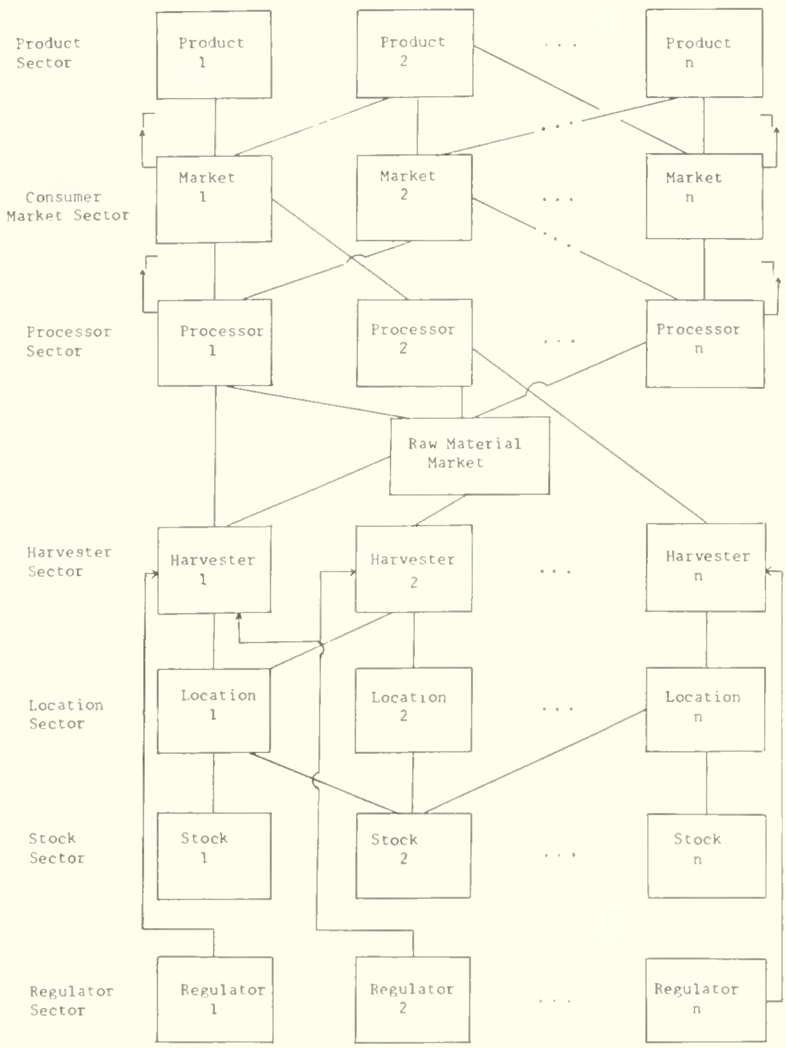

Figure 1. — Structure of fishery simulator.

of each month a group of fishing units moves from its initial location to the harvesting location, operates there for a specified number of days, and sells its catch to the processor which will produce the maximum profit to the group. If the processor cannot absorb the group's total supply, the group sells what it can and moves to the next most profitable processor and so on. A group may only sell to the set of processors linked to the harvester that owns the group.

Any catch unsold at the end of the month is recorded and discarded since it has no economic value. The harvesting time for each group is limited not only by harvester and regulator decisions, but by the group's harvesting capacity. Primary operating costs for the harvester built into the model are distance costs, time costs, harvest-proportional costs, and license fees.

A processor is a managerial entity that operates in one physical location, buying stocks from harvesters, transforming them into finished products, and selling them in markets. As the program is now set up, each processor's share of the market can be made to depend on his previous market share and on marketing expenditures and product price relative to those of other processors linked to the same market. The cost structure of the processors is in standard accounting terms.

A regulator is an agency that imposes restrictions on the activities of harvesters or processors in any of the variety of ways now employed or discussed in the literature. These include: (1) license fees; (2) size limits; (3) gear efficiency limits; (4) effort limits; (5) operating limits for processors; (6) seasonal closures; (7) monthly quotas; (8) annual quotas.

The model can be run in either of two basic operational modes: as a conventional computer simulation model, with built-in decision-making algorithms specifying the behavior of processors, harvesters, and regulators; or with human intervention at intervals to allow for intuitive and heuristic decisionmaking.

A stock is any type of renewable marine resource. It is treated in the model as linked to a given location, and the quantities available to harvesters at any given time are computed continuously.

It should be stressed that each entity is a subroutine, and can be designed to any degree of complexity warranted by the purpose of the routine and the adequacy of the data base. Similarly, the degree of detail for a readout on monthly or annual bases can be predetermined.

The model can be programmed not only to maximize specific objective functions, but can accommodate dynamic feedback factors in assessing different kinds of management alternatives. It can also handle a wide range of spatial distributions of stocks and harvesters without difficulty.

THE ANCHOVY FISHERY

Figure 2 shows, in schematic form, a preliminary version of the model of the California anchovy fishery. This model reflects the activities of the types of vessels presently exploiting the fishery, and therefore attempts to deal with the complications imposed by their harvesting of bluefin tuna and mackerel as well as anchovy. It is also complicated by the interaction between the markets for sport fishing bait and for meal and oil, both of which now absorb considerable quantities of anchovy. Sufficient data are available to permit some preliminary conclusions as to the economic return from this limited fishery, which is now prosecuted at a level so low that the more fundamental problems in the stock sector are not really involved. These preliminary findings suggest, as one might suspect, that the return to vessels fishing for anchovy on a full-time basis during a nine months open season would be substantially more attractive than the returns from mixed operations.

Accordingly, the model which will be used to test regulatory alternatives will probably be based on the assumption that a specialized fleet of vessels optimized for the anchovy fishery will develop once catch quotas are established at levels sufficiently high to induce long term investment in fishing and processing equipment by major firms in the meal industry. Preliminary work in a dissertation by Dr. Dennis Paulaha (1970) provides excellent data on the type of vessel and gear best adapted to the fishery. Work on the complex stock model is reasonably well advanced, and it is expected that a fairly sophisticated and realistic approximation to the behavior of the anchovy stocks under various rates of exploitation can be developed.

The economics of the anchovy operation are relatively simple to simulate, since total produc-

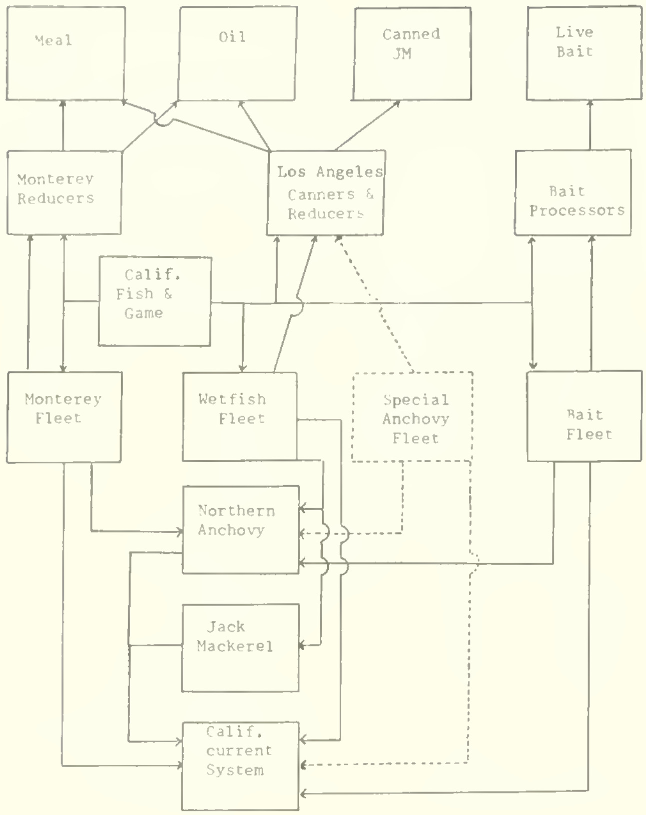

Figure 2. — Graphic representation of the logical relationships between sectors of the *Simplified* Northern Anchovy Fishery System. (Area quotas of total system are considered to be levied as production quotas in the simplified system.)

tion from the fishery, even at a catch level of one million tons, would still produce only a small fraction of total American fish meal consumption. Market price can thus be taken as given to the California meal producer, and the estimated net economic rent available under various assumptions as to management regime can then be calculated on the basis of alternative forecasts of the time-path of fish meal prices.

THE PACIFIC SALMON FISHERY

In Appendix 1 the general format of a preliminary program for modeling the Pacific salmon fishery is presented. The objectives in modeling this extraordinarily complex operation are partly methodological and partly aimed at answering specific management problems of real significance. The complications are apparent. Five separate species of salmon are involved, and since each river usually contains more than one species (and separate races of the same species), the number of "management units" which should, in theory, receive separate treatment in modeling the stock sector is probably from *eight to ten thousand*!

"The salmon fishery" is actually a large number of geographically separate operations, linked in varying degrees by the mobility of the gear involved. Several types of gear are used, and the relative importance of each type varies from area to area. Finally, salmon deteriorate very rapidly unless processed soon after being captured, which creates a large number of primary markets in which processors generate several different end products from each of the types of salmon purchased.

Even with the prodigious capacity of the modern computer, overall modeling of a fishery this complex is obviously severely limited by available data, and the marginal cost of generating the necessary data is very high. In one sense, then, the broader modeling exercise is intended to provide some guidelines to the limitations on the technique in dealing with highly complex fisheries.

On the other hand, the program is flexible enough to permit specific consideration of important policy questions in separable segments of the salmon fishery. For example, the Columbia River, Puget Sound, and British Columbia fisheries are plagued by serious problems arising from the spectacular growth of the ocean troll fishery. Since the trollers take large numbers of immature fish, they do a considerable, though unknown, amount of damage in returning undersized fish to the water. The troll fishery is inherently highly inefficient from both biological and economic points of view. A substantial part of its catch is made up of two and three year old chinooks and two year old cohoes which would almost certainly gain substantially more in body weight than would be lost to natural mortality if allowed to mature another year. It is possible, with a restricted model, to test the biological and economic impact of the elimination or limitation of the troll fishery in specified areas under varying assumptions as to the resulting net increment in weight and the distribution of the troll catch among other types of gear. This analysis is, incidentally, crucial to another public policy issue of major proportions — the allocation of chinook and coho salmon among commercial and recreational users.

Earlier work by a University of Washington team on the Puget Sound salmon fishery (Royce, et al., 1963) indicates that modeling permits surprisingly accurate prediction of the net economic benefits and catch distribution effects by area of different techniques for reduction of gear and expansion of intraseasonal fishing time. The earlier study was, for strategic reasons, constrained by the assumption that any reduction of gear must be proportional for each type of gear. It is obviously desirable to develop the capability to test quickly and inexpensively the effects of altering gear mix by area and by time period. Since any gear reduction program in the salmon fishery will inevitably involve intensely partisan political negotiations, a display of the impact of a wide range of alternatives is essential if any progress is to be made.

Finally, the model can be used to predict the impact of recent court decisions requiring that Indian fishermen must be granted a "prior claim" on any total catch permitted under regulation.

THE PACIFIC HALIBUT FISHERY

This fishery presents a far simpler set of modeling problems. The stocks have been under intensive study for more than 40 years, and a wealth of reliable statistical information is available on both the stock and harvesting sectors. In addition, the use of standard gear (whatever its economic validity) makes analysis much simpler, as does the widespread use of a standard accounting system for halibut vessels devised by the Fishing Vessel Owners Association. The fact that halibut is marketed almost entirely in fresh and frozen form further simplifies the analysis. The principal gain in the modeling exercise for this fishery will be the ability to incorporate badly needed studies of the effects of introducing different types of gear, potentially much more efficient, if and when limitation of the number of operating units becomes possible. It will also be possible to introduce into the analysis the effect of shifting many of the halibut vessels from their present multipurpose form into larger, specialized units — a process which would almost certainly follow any effective gear limitation program.

THE KING CRAB FISHERY

It is doubtful that the king crab fishery will be amenable to very effective empirical work in the near future. Not only are data extremely limited, but the fishery is based on a relatively long-lived, slow-growing animal, and it is currently in a state of disequilibrium. Consequently, the fragmentary statistical information on catch, effort, and economic returns from the fishery cannot be considered representative of long term equilibrium values. Nevertheless, the situation in the king crab fishery with respect to stock depletion is so serious, and the regulatory methods already adopted so questionable, that some analysis of this fishery, even with very limited data, is clearly necessary if we are to avoid serious and perhaps irreparable mistakes.

CONCLUSIONS

If the approach embodied in this study proves to be as useful as expected, it is considered possible that the techniques could be extended to provide a broader approach to multifishery cases. The seasonal nature of the availability of fish and of weather conditions on the Pacific Coast suggests that an optimal harvesting technique for virtually all species (with the possible exception of halibut and some other bottomfish) will involve multipurpose gear exploiting multiple species in different geographic locations. For example, salmon, crab, and albacore fishing by combination units may be significantly more attractive economically (always assuming some control over entry) than the present hodgepodge of vessels involved in each. We do have combination vessels at present, of course, but they are not designed to any set of specifications that present data would make available if an integrated view of the fisheries available to each type of gear were taken as the frame of reference.

The discussion above suggests the nature of the outputs to be expected from these models in the short run. We are still limited to synthetic numbers in many of the sectors at present, but these are being systematically whittled down. It cannot be stressed too strongly that the whittling down process can be done far more economically and effectively once the sensitivity of the desired outputs to the various parameters involved has been established by the model. Moreover, some of the fisheries and some elements of the model have now reached a point where reasonably hard data are available which can be manipulated to provide at least rank-ordering of a number of management options. While the overall program is clearly geared to longer range objectives, short run outputs of real usefulness in management planning can be expected, and will increase in number and predictive value as the work progresses.

Members of this workshop and other interested scientists and economists are urged to communicate to us the nature of their interest in the problems addressed by the University of Washington team. In addition, it might be mutually advantageous if visits to the University of Washington could be arranged to permit actual operating experience with these models.

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APPENDIX I: PACIFIC SALMON SIMULATION MODEL COMPONENT

The proposed simulation model will treat the five species of Pacific salmon in the North American fisheries as five separate stocks:

S_1	Chinook
S_2	Chum
S_3	Pink
S_4	Sockeye
S_5	Coho

The location sector in the model will be based on the areas for which statistical information is available in published data sources:

L_1	Western Alaska
L_2	Central Alaska
L_3	Southeastern Alaska
L_4	Northern B.C.
L_5	Southern B.C./Fraser River
L_6	Puget Sound
L_7	Washington Coast
L_8	Columbia River
L_9	Oregon Coast
L_{10}	California

Stock/location interaction will be as follows:

		Chinook S_1	*Chum* S_2	*Pink* S_3	*Sockeye* S_4	*Coho* S_5
L_1	Western Alaska	X	X	X	X	X
L_2	Central Alaska	X	X	X	X	X
L_3	Southeastern Alaska	X	X	X	X	X
L_4	Northern B.C.	X	X	X	X	X
L_5	Southern B.C./Fraser River	X	X	X	X	X
L_6	Puget Sound	X	X	X	X	X
L_7	Washington Coast	X	X	X	X	X
L_8	Columbia River	X	X	X	X	X
L_9	Oregon Coast	X	—	X	—	X
L_{10}	California	X	—	—	—	X

and these interactions reflect the distribution of species in the actual fishery. Data will be collected to permit segregation of stocks into age groups, with age specific weights and spawner-return curves (Ricker, 1958) developed for each stock/location. In effect, this scheme results in a total of 45 separate stocks, since each species in each location will be treated separately with respect to spawner-return characteristics.

Regulators will be based on locations, with one regulator in each location.

The principal types of fishing gear in the Pacific salmon fisheries are as follows:

Gill nets, drift
Gill nets, anchor
Seines

Troll lines
Reef and Pound nets

In order that each harvester be able to fish for each species with each type of gear, it is necessary that the harvesters be defined as follows:

		Chinook S_1	*Chum* S_2	*Pink* S_3	*Sockeye* S_4	*Coho* S_5
H_1	Seine, Western Alaska (L_1)	X	X	X	—	X
H_2	Seine, Central Alaska (L_2)	X	X	X	X	X
H_3	Seine, Southeastern Alaska (L_3)	X	X	X	X	X
H_4	Seine, Northern B.C. (L_4)	X	X	X	X	X
H_5	Seine, Southern B.C./Fraser (L_5)	X	X	X	X	X
H_6	Seine, Puget Sound (L_6)	X	X	X	X	X
H_7	Anchor Gill Net, Western Alaska (L_1)	X	X	X	X	X
H_8	Anchor Gill Net, Central Alaska (L_2)	X	X	X	X	X
H_9	Anchor Gill Net, Southeastern Alaska (L_3)	—	—	—	X	X
H_{10}	Anchor Gill Net, Puget Sound (L_6)	X	X	X	—	X
H_{11}	Anchor Gill Net, Wash. Coast (L_7)	X	X	—	X	X
H_{12}	Anchor Gill Net, Columbia River (L_8)	X	—	—	X	X
H_{13}	Drift Gill Net, Western Alaska (L_1)	X	X	X	X	X
H_{14}	Drift Gill Net, Central Alaska (L_2)	X	X	X	X	X
H_{15}	Drift Gill Net, Southeastern Alaska (L_3)	X	X	X	X	X
H_{16}	Drift Gill Net, Puget Sound (L_6)	X	X	X	X	X
H_{17}	Drift Gill Net, Wash. Coast (L_7)	X	X	—	—	X
H_{18}	Drift Gill Net, Columbia River (L_8)	X	X	—	X	X
H_{19}	Gill Net, Northern B.C. (L_4)	X	X	X	X	X
H_{20}	Gill Net, Southern B.C./Fraser River (L_5)	X	X	X	X	X
H_{21}	Troll, Central Alaska (L_2)	X	—	—	—	X
H_{22}	Troll, Southeastern Alaska (L_3)	X	—	—	—	X
H_{23}	Troll, Northern B.C. (L_4)	X	—	X	X	X
H_{24}	Troll, Southern B.C./Fraser (L_5)	X	—	X	X	X
H_{25}	Troll, Puget Sound (L_6)	X	—	X	—	X
H_{26}	Troll, Wash. Coast (L_7)	X	—	X	—	X
H_{27}	Troll, Columbia River (L_8)	X	—	X	—	X
H_{28}	Troll, Oregon Coast (L_9)	X	—	X	—	X
H_{29}	Troll, California (L_{10})	X	—	—	—	X
H_{30}	Reef & Pound Nets, Puget Sound (L_6)	X	—	X	X	X

The above table indicates that there is no fleet for a particular species in those cases where the annual catch for that species in that location by that gear type is less than one percent (1%) of the total annual catch of that species in that location by all gear types.

There will be one processer in each location, with processer locations defined for distance computation purposes as follows:

P_1 Bristol Bay (Western Alaska)
P_2 Cook Inlet (Central Alaska)
P_3 Yakutat (Southeastern Alaska)
P_4 Prince Rupert (Northern B.C.)

P_5	Vancouver (Southern B.C./Fraser River)
P_6	Seattle (Puget Sound)
P_7	Westport (Washington Coast)
P_8	Astoria (Columbia River)
P_9	Newport (Oregon Coast)
P_{10}	San Francisco (California)

Markets will be synonymous with products, with demand relationships developed for each product as follows:

D_1	Fresh/frozen
D_2	Salted or pickled
D_3	Mild cured
D_4	Smoked or kippered
D_5	Canned
D_6	Roe (cured)

Products will be produced by processers as follows:

		Chinook S_1	*Chum* S_2	*Pink* S_3	*Sockeye* S_4	*Coho* S_5
P_1	Bristol Bay					
	D_1 Fresh/frozen	X	X	X	—	X
	D_2 Salted or pickled	X	X	X	X	X
	D_3 Mild cured	X	—	—	—	—
	D_5 Canned	X	X	X	X	X
	D_6 Roe (cured)	X	X	X	X	X
P_2	Cook Inlet					
	D_1	X	X	X	X	X
	D_2	X	—	—	—	X
	D_5	X	X	X	X	X
	D_6	X	X	X	X	X
P_3	Yakutat					
	D_1	X	X	X	X	X
	D_3	X	—	—	—	X
	D_5	X	X	X	X	X
	D_6	X	X	X	X	X
P_4	Prince Rupert					
P_5	Vancouver					
P_6	Seattle (data available for Washington as a whole)					
P_7	Westport					
	D_1	X	X	X	X	X
	D_3	X	—	—	—	X
	D_4	X	—	—	—	—
	D_5	X	X	X	X	X
	D_6	X	X	X	X	X
P_8	Astoria (data available for Oregon as a whole)					

		Chinook S_1	*Chum* S_2	*Pink* S_3	*Sockeye* S_4	*Coho* S_5
P_9	Newport					
	D_4	X	—	—	—	—
	D_5	X	X	X	X	X
P_{10}	San Francisco					
	D_1	X	—	—	—	X
	D_3	X	—	—	—	X
	D_4	X	—	—	—	X

PRODUCTION FUNCTIONS AND BIOECONOMIC MODELS: RESEARCH IMPLICATIONS

Against the broad background of these four introductory papers we can proceed to some of the more specific research which will constitute the principal inputs into the broader management process. The first of these papers relates the results of an extensive effort by Carlson to specify production functions for the North Atlantic groundfish and tropical tuna fisheries. In each case the research is designed to identify the most significant determinants of vessel productivity, with some of the investigation devoted to the question of a proper measure of productivity.

Using existing data series on the area and time patterns of fishing activity, landings statistics on species, quantity and value, and other sources of data on vessel characteristics, specific effort combinations are related to productivity. The "best" measure of productivity was found to be value in groundfish and a weighted combination of species landed in tuna.

This research output has many possible uses, among these being the suggestion of the optimum input package to maximize output and the development of a fishing power index which could be used to measure effort, a critical input into those types of management plans that require the administrator to develop seasonal or sharing arrangements based on the fishing capabilities of the fleet. This is the case for the Inter-American Tropical Tuna Commission. Here a technique of measuring fishing power has evolved which is somewhat different from the Carlson approach. Future investigations will determine the advisability of each approach. Indeed, if differences and difficulties cannot be resolved, this may have some effect on the choice between management plans which require this type of calculation and types which do not.

The paper by Segura relates part of his broad investigation into the world supply and demand for fish meal. His efforts for this paper have concentrated on a measure of fishing power in the Peruvian anchoveta fleet for the purpose of determining the optimum harvest level. His focus is upon the role of technological change as this relates to time series calculations of effort indices.

In his paper, Segura points out the differing results which will be forthcoming if you use the most recent years' measure of yield-effort, the index of vessel productivity, to calculate changing pressures on the resource, the response of the resource to that pressure, and use these relationships to determine an optimum catch quota for the coming year. He compares these results to calculations now used where these interrelationships are all derived based upon some earlier base year. The results are substantially different, resulting in a suggested catch of 16.2 million ton trips derived via the existing method.

The work done by Segura relates closely to that of Carlson in that a method of cross-sectional analysis of recent years' data is being developed which obviates the need to use standard vessels from some base period, supplemented by ad hoc measures of technological change. These considerations are in addition to the question of diminishing returns as introduced by the Carlson-Waugh-Bell function.

The research reported by Rich is an extension of a generalized model to be applied to the Pacific halibut fishery. The purpose is to evaluate possible losses which may have resulted in the fishery from the use of MSY as a regulation goal.

Consistent with the Carlson-Waugh-Bell exposition, the function developed incorporates short run diminishing returns. When combined with a fish growth function it is possible to measure the long run externalities associated with this alternative specification of the yield-effort function.

This approach is the antithesis of that suggested by Pontecorvo in that it is explicitly structured upon the classic assumptions of full employment and complete labor mobility, both in the short run and the long run. Political and social questions are definitely excluded and would have to be appended on an ad hoc basis to determine if there was any cause for modifying the constrained results. The work done by Rich would serve as but one component in the simulator described by Crutchfield, albeit possibly the dominant component.

Bell, Carlson, and Waugh focus on the issue of diminishing returns in fisheries, relaxing a strong assumption of fixed proportionality utilized by most writers in the existing literature.

The motivation for this exercise is the appreciation that we are rapidly approaching total utilization of the world's fish resources. As this point is approached, demand pressures and considerations of maximum efficiency dictate the need to make maximum use of these resources consistent with any overriding conservation objectives. The work done by these authors, though preliminary, suggests that some degree of diminishing returns can be identified for the fisheries studied: Chesapeake Bay menhaden, Atlantic and Gulf blue crab, Atlantic longline tuna, Bering Sea king crab, and Cape Flattery sablefish.

As with the other five papers in this section, this paper modifies existing biological functions. The modified logistic introduced here is the author's candidate for a "better" function, based primarily on the inclusion of diminishing returns in the logistic specifications. As with the other contributions this paper suggests an area meriting further discussion in the near future, with our best use of marine food resources being the stake.

Thompson continues the parade of alternative functions with his concern being the absence of a proper dynamic component within the prevalent fisheries models. To correct this error he proposes the marriage of the Schaefer model and the Thompson-George (TG) production-investment model. He also suggests some alterations in the Schaefer model.

The TG model replicates the sequence of investment-production decisions which are involved in the operation of the individual fishing firm (vessel). Pertinent stocks and flows are specified with elaborate preconditions for entry, though there are no provisions for entry within the decision period, an interesting trait in light of the Johnson fixed asset theory as referred to by Stevens and Mattox subsequently. By adjoining this model to the Schaefer biological fluctuation we have a bioeconomic model which is uniquely micro in character; the dynamics of change in the fishery stock (and hence fishing success) will be reflected in the investment decision of the sole owner as the limiting case, and vice versa.

This method avoids the critical use of static methods prevalent in economic literature. Inherently, the adjustment mechanism in the individual owner also facilitates the modification of the Schaefer function to incorporate decreasing returns to effort, as discussed by Bell, Carlson, and Waugh and by Rich and increasing returns to scale. Relaxation of the sole owner condition further amplifies the critical nature of these alterations and within the confines of standard economic assumptions reaffirms the desirability of limiting entry and suggests an additional method of measuring the critical management variables.

The final author in this section addresses the problem of multiple species fisheries — or combination vessels. In this regard three issues are of prime importance to Adam. The first of these relates to the existence of yield curves for fisheries. Adam views most of these curves as average curves, pointing out that for many fisheries this average curve will be bounded by upper and lower curves which are usually the result of substantial fluctuations in either effort and/or recruitment. The average curve is essentially a product of a stable fishery whereas the boundary curves are the result of a rapidly growing fishery. In his opinion we do not move along the average curve as a fishery rapidly develops. We move from one curve to another, somewhat erratically as the fishery develops. He looks to the economist, via a function akin to Carlson, where effort is value-dependent, to indicate what effort will be in subsequent years, as the fisherman's response to his monetary success is one of the few reliable variables which can be presented to a biologist in such a dynamic situation.

His second point extends this argument to multiple species. If a vessel has the capability to adjust his harvesting pattern based upon conditions in the fishery or the market, this would preclude estimation based solely on biological factors. It suggests that many of these calculations must be made instantaneously, at that time each year when a fishery is being initiated. It suggests also that this must be done for several fisheries simultaneously if those fisheries are interrelated. For the North-east Atlantic this is increasingly the case.

Adams's final related point concerns the measurement of fishing effort. Simply stated, he concludes that there is no single measure which can unequivocably serve the needs of all the disciplines. These different measures should be closely examined, however, so that we may maximize their comparability and/or ascertain which measure would be most appropriate for each circumstance.

A. A. S.

Cross Section Production Functions for North Atlantic Groundfish and Tropical Tuna Seine Fisheries

ERNEST W. CARLSON[1]

ABSTRACT

This paper explores the use of cross section production functions to estimate the fishing power of individual vessels. The problems addressed are: The proper measurement of output; the measurement of technological change, and the effect of location, crew size and important vessel characteristics.

Regression analysis upon data from the North Atlantic groundfish fishery and the tropical tuna seine fishery yielded highly significant results. Many of the hypothesized relationships are measurable and stable with relatively small errors. The tests indicate that: there are better measures of output then total pounds; fishing time is measured better using days absent rather than days fishing; the use of more vessel characteristics improves explanatory power; crew size can be an important variable; the effects of location can be measured; and technological change can be measured.

The production functions measured can then be used as inputs in devising management schemes.

INTRODUCTION

One of the more difficult problems in the management of fisheries has been the measurement of vessel productivity. If the vessels in a fleet were physically homogeneous and utilized for the same amount of time and if no learning took place, the problem of measuring productivity indices would be less difficult. The problem does exist, though, because vessels are far from homogeneous. For example, a typical fleet may have vessels that are 10 or more times larger than the smallest vessels in a fleet. Obviously, under such conditions there will be serious errors introduced if attempts are not made to measure the productivity of different vessels.

To handle this and related problems, economists have developed techniques of measurement that fall into a general category called production functions. One of the important attributes of using a production function is that it allows the simultaneous measurement of as many parameters of fishing power as may be thought to be important in its determination. Accordingly, production functions were estimated using data from the New England trawl fleet and the tropical tuna seine fleet. Many problems were considered in arriving at a "best" production function for these fisheries.

THE PRODUCTION FUNCTION FOR A FISHERY

The basic assumption of this paper is that a production function can adequately describe the relationship between inputs and outputs in a fishery. The production function is a technical or engineering relation between inputs and outputs and is the base upon which the economic theory of supply is built. Since it is an engineering relationship, considerations such as prices and costs are not relevant to the production function itself. The schedule of maximum output for given inputs is the production function we are trying to measure.

The classical production function for the individual firm is usually presented as follows:

[1] Economist, Economic Research Laboratory, National Marine Fisheries Service.

$$x = f(l,k,t),$$

where x = output,
l = labor,
k = capital,
t = natural resources.

Output (x) is measured as the flow of goods and services during an accounting period. The input variables (l, k, t) are the various kinds and qualities of labor, capital, and natural resources that go into producing the output. It is assumed that a given set of inputs produces as much as possible.

The estimation of the parameters of the production function is accomplished by running a regression upon a cross section of fishing vessels. A cross section is a sample of the vessels in a fishery for a fixed time period. The parameters estimated from the cross section will give the marginal contribution to output of each variable being used to explain output.

We will discuss the variables that will be used in the production function in the following section.

Output in a Fishery

Most systems for measuring relative vessel productivity have, ultimately, related output to some fishing vessel characteristic. The basic problem with this is that output, when using commercial landings statistics, is a very complex concept. Except in extremely simple fisheries, fishermen do not ordinarily attempt to maximize pounds of fish landed. One working hypothesis is that in all fisheries, the fishermen attempt to maximize their profits. This is not necessarily the same as maximizing total pounds of fish landed. Using total pounds as a measure of output would be an acceptable measure of output (1) where there is a single species fishery or (2) if, in a multispecies fishery, the prices of the target species are approximately the same and the species are equally catchable. In the general case, these conditions are not met.

How do the fishermen decide where to go and what to catch when there are multiple species in a fishery? Again, the answer to this question is difficult. Let us consider two models of behavior that might help answer this question. In the first type of fishery, the vessel captains take into account the species that are available, the grounds where they are available, the prices for which they can be sold, and the expected catch rates for their vessels on the grounds. Integrating all this information, the captain, if he is a profit maximizer, will decide to go to the grounds and fish for the species which provide the highest net profit. His decision may or may not be to fish where the catch rates are highest or for those species that bring the highest prices.

We have been discussing this as if the choice were always between species. The choice can also be made within a species, such as a decision to fish on local grounds rather than on distant grounds where the catch rates are higher. In this case, the higher catch rates may not offset the extra running time necessary.

If this abbreviated discussion is an adequate description of how fishermen behave in one type of fishery, then it follows that we may not be able to estimate relative vessel productivity with total pounds, but must rely on some higher order measure such as the value of catch.

Value was considered by Gulland (1956) as a measure of output and rejected because of the variability of prices. A large part of the variability of fish prices is due to the seasonal availability of the fish themselves with prices moving inversely to availability. We can lessen the objections to value at least partially by using annual data so that the interseasonal effects of availability average out. Another alternative would be the estimation of relative efficiency on a quarterly basis.

The second type of fishery is one where the location of the fish by species is generally known, but where there is considerable mixing of single species schools in the same area. If locating any school has a low probability per unit time, the fishermen will attempt to catch all that they can of those they do locate. In this case, the fish will be joint products of the fishery. If the fish are equally catchable and their prices are not too different, then total pounds could be the measure of output. If they are not equally catchable, it would take more fishing power to catch one than the other. In such a case, we might have to utilize a modified estimation scheme to arrive at a proper weighting for output. One such scheme will be discussed under the statistical section on tuna.

Inputs in a Fishery — Fishing Time

The abstract production function refers to outputs and inputs per unit of time. The unit of time is undefined. When using annual vessel data, we have to note the fact that the vessels are not utilized for the same amount of time and standardize for this.

In the simple case, an economist would prefer to use days absent from port as a measure of fishing time rather than days fishing. If a fisherman is an economic maximizer, he will attempt, *ceteris paribus*, to maximize his gross revenue per day at sea and will plan his fishing strategies accordingly. Under this assumption, the fisherman may or may not fish when or where his expected catch is higher.

The theory is not clear as to how time should enter the production function. Two basic specifications are possible:

(1) $x = D^{\alpha} f(l,k,t)$, or
(2) $x = D^{1} f(l,k,t)$

There are theoretical reasons that could justify the use of either. Equation (1), with D^{α}, can be justified if we hypothesize that the fishermen makes *trips* of varying length. Therefore, we would want to find the marginal contribution of an extra day at sea. Equation (2), with D^{1}, can be justified if we hypothesize that *all* inputs are being used to produce output all the time, so that the relationship is strictly linear. Experiments were run initially in both forms, but the second form was abandoned for what may have been specious reasons. If further work is done the alternative specification will be tested more fully.

Capital — The Vessel Characteristic Variables

The abstract production function has a variable called capital. This represents the dimensions of the equipment being utilized. In fishing, the individual firms and many of the characteristics of their capital are identifiable and measurable.

Vessel size has been recognized as a determinant of catch and is explicitly recognized in most of the productivity measures in use. Beverton and Holt (1957) related gross tonnage to fishing power, and the Inter-American Tropical Tuna Commission (IATTC) focuses on the capacity of a vessel's freezers (Shimada and Schaefer 1956).

Other researchers have noted that there are other measures of vessel size that are correlated with output, among them horsepower and length. Gulland (1956) and Noetzel and Norton (1969) experimented with production functions that included both tonnage and horsepower. Their results showed that these variables may make an independent contribution to output. In fisheries, the possibility of independent contributions should not be overlooked because there may be a tendency for vessel configurations to be changed in such a way that fishing power is increased. This happens especially with horsepower relative to gross tonnage as old engines are replaced and also as new vessels are built.

The role of horsepower in the trawl fleet appears to be that the larger the engine, the larger the net that can be dragged, the faster the net can be dragged, or the deeper the water that can be fished. In this type of fishery, the profit-maximizing skipper will adjust his net to obtain the "best" results. Although it has been noted that trawlers do not often use the full power of their engines, a larger engine increases the number of possibilities a skipper can consider when deciding where to fish and what to fish for.

In a seine fishery, the role of horsepower is less clear, except that, *ceteris paribus*, higher horsepower increases the "search power" of the vessel. A better measure of this search power than horsepower would appear to be running speed. The only way to obtain this information is by interview or sea trials.

Hull construction is an identifiable parameter of a vessel. Throughout the U. S. fisheries, there has been an increasing tendency to build new vessels of steel rather than wood, in spite of the extra initial cost. One would presume, then, that there are lower operating costs for steel, or that it is more "productive." It is possible to test for the effect on productivity of a wood hull by creating a dummy variable that takes on the value "one" if the hull is wood and "zero" otherwise.

The last capital input variable that was considered was age of the vessel. Most people would consider older vessels less productive, *ceteris* *paribus*, than newer vessels. It is rather simple to test this hypothesis by including in the tests the age of the vessels.

Hence, the dimensions of the capital input will be measured by (1) gross tonnage, (2) horsepower, (3) construction materials, and (4) age of the vessel.

Labor — The Crew

Crew size could also be tested as an input variable in the production function. It seems reasonable that a larger crew would produce a higher output, and this should be tested.

One need not work in fisheries very long before he is made cognizant of the "good captain hypothesis." That is, the catch of a vessel depends as much upon the managerial skill of the captain and crew as it does upon the characteristics of the vessel. As such, there is no way to test this hypothesis.

One might attempt to test the good captain hypothesis by using the years of schooling or the years of experience of the captain to arrive at a proxy for his skill. One may suspect on economic grounds that the best captains would gravitate to the best vessels because they would be able to buy the more productive vessels or be hired away from the poorer vessels. In other words, part of the higher output of a larger vessel may not be due to its hardware but to the superior men running it. In this analysis we are restricted to crew size as one measurable variable.

Location

The production function provides for the differential productivity that could be due to location with respect to the fishing grounds through the variable called *land*. Vessels from some ports could have higher productivity than vessels from other ports by being located closer to the better grounds. Since these locations cannot be appropriated, the vessels will allocate themselves between ports so that effects on net profits will be dissipated. It is possible to test whether certain locations are more productive by creating dummy variables that correspond to home ports. If their coefficients are statistically significant, then a location may be either more or less productive than the average location.

Technological Change

One of the major problems encountered in the management of fishing power has been the difficulty in adjusting for technological change. Attempts have been made to adjust for technological change, but on the whole they have been less than satisfactory.

The test for the added productivity of an innovation should be done when the fleet is in a period of transition from the use of the old to the new technique. This method will hold abundance and availability constant and therefore, all vessels will have the same opportunities. Bell (1966) used a dummy variable to measure the increased productivity due to stern trawling. He created a variable that was 1 if a vessel was a stern trawler and 0 if it was a side trawler. The coefficient of the dummy variable was the added productivity due to stern trawling.

This technique can be used to test the added productivity of any innovation, for example, a new electronic instrument or the use of spotter planes or maybe even the use of a radically new technique such as switching from bait boats to purse seining. The added productivity of a new technique would thus become a permanent attribute of the vessels even after it was no longer possible to measure the contribution of the technique, i.e., even after it was universally adopted.

THE DATA

The New England Trawl Fishery

The National Marine Fisheries Service (NMFS) has collected comprehensive data on the landings of the New England trawl fleet for many years. The data consist of landings information by trip. The following information is noted for each trip:

1. Official number
2. Departure date
3. Arrival date
4. Number of days fishing
5. Grounds fished
6. Pounds landed, by species
7. Price/pound by species

The data are stored on magnetic tapes and can be manipulated with a digital computer.

The data used were for the years 1964, 1965, and 1967. The data were aggregated by vessel for the whole year. For each vessel, the following information was produced:

1. Days at sea
2. Days fishing
3. Total trips
4. Days at sea by calendar quarter
5. Days fishing by calendar quarter
6. Trips to major areas: offshore, inshore, off Canada
7. Pounds caught, by major species
8. Value, by major species
9. Total pounds caught
10. Total value

This information was augmented by the addition of information from the *Merchant Vessels of the United States* (1965), including:

11. Gross tons
12. Horsepower
13. Hull construction
14. Year built

Information from National Marine Fisheries Service files was added on:

15. Crew size
16. Home port

Vessels with total landings valued at less than $10,000 were excluded from the sample; we made the assumption that these were casual fishermen. There were about 120 vessels excluded per year, accounting for 3% of New England landings. Otherwise, no editing was done; therefore, the sample contains all trips, including brokers. Thus, the estimates have built into them all conditions that vessels from this fleet experience on the North Atlantic. The total sample consisted of about 383 vessels per year or 1,149 vessel years.

The Tropical Tuna Purse Seine Fleet

The Inter-American Tropical Tuna Commission (IATTC) kindly let us transcribe landings data from their files for the years 1966,1967, and 1968. The data were for the whole year for the full-time purse seiners. The data transcribed were as follows:

1. Official number
2. Days at sea
3. Landings by species
4. Major area fished: Atlantic or Pacific

This information was supplemented by the addition of information from the *Merchant Vessels of the United States* (1965) including:

5. Gross tons
6. Horsepower
7. Length
8. Year built

Finally, the following information was added:

9. Capacity (American Tunaboat Association)
10. Crew size (NMFS files)

The total sample consisted of 89 vessels per year or 267 vessel years. The data were divided into two periods: (1) when there was unrestricted fishing for yellowfin and (2) when yellowfin was restricted to 15% of the total catch. The data from the restricted season were not used in the analysis because of the different conditions following the season closure.

THE STATISTICAL RESULTS

Overall Results

The statistical results of these experiments are quite encouraging. It is possible to explain very high variations in catch with a minimum of information. In the tropical tuna fishery we can explain approximately 70% of the variation in the dependent variable, and in the New England trawl fishery, approximately 84%.

Tests for heteroscaedasticity showed that it existed in the linear equations. When it is present, we have inefficient estimators. Logarithmic transformation of the variables in both fisheries removed this problem. Results in both forms are reported, but only the logarithmic results are suitable for analytical work.

Several regression experiments were run

using a single year's observations in both fisheries on the same variables. The results were very encouraging in that there was a high degree of stability in the coefficients and their t ratios. These stable results were obtained in fisheries which, if anything, are notorious for their variability in almost all aspects: biological, economic, atmospheric, and oceanographic. Some results illustrating this stability for the trawl fishery are shown in Appendix 1.

The New England Trawl Fleet

The statistical results for the New England trawl fishery were very good. The overall "fit" of the data in the equations was very high, especially when one considers the heterogeneity of this fleet. The equations are rich in information in that many of the variables about which hypotheses were made were statistically significant with the right signs.

Because of the unclear nature of variables discussed, the equations were run using the alternatives for the same variables where possible. This will allow direct comparison of the results. In a sense, we shall permit the data to decide which are better variables. We will briefly run through the results according to the topics covered in the theoretical section.

The following general production function was established for the New England trawl fleet:

(3) 0 = f(FT, GRT, HP, CR, AGE, C, PT)

where
- O = output, either total pounds or total value,
- FT = fishing time, either days fished or days absent,
- GRT = gross registered tonnage,
- HP = horsepower,
- CR = crew size,
- AGE = age of the vessel,
- C = construction, 1 if wood, 0 otherwise,
- PT = homeport dummy variables.

The equations providing the best results are shown in Table 1. These equations will be discussed below. A more complete set of regressions is shown in Appendix Table 1.

The tests of whether total value or total pounds was the better measure of output in this fishery are shown in Problems 1 through 4. The measures of overall fit (R^2) are lower in Problems 1 and 2, which use total pounds as the dependent variable (0.40 and 0.54), than in Problems 3 and 4, which use total value as the dependent variable (0.83 and 0.83). Thus, the fishermen appear to have implicitly taken into account expected prices, expected catch rates, and steaming time to the grounds and made decisions as to where to go and what to fish. Hence, relative total revenue appears to reflect the fishing power of New England vessels. The more fishing power, the higher revenues are expected to be.

The most powerful explanatory variables for either total pounds or total value were the fishing time variables. That is, the more days fished or days absent, the higher the total value and total pounds. On the basis of contributions to the overall goodness of fit, there is no way to choose between these two variables. Our choice, therefore, will have to rest upon their effects on other variables and on the cost of gathering the information.

In Problem 3, using total value as the dependent variable and days fishing as the measure of fishing time, crew size becomes statistically nonsignificant and negative. In Problem 4, when days absent is used, crew size becomes statistically significant and a very powerful explanatory variable. Days fishing appears to be a less desirable measure of fishing time in that: (1) It is theoretically inferior on economic grounds as discussed previously; (2) it causes other important variables to have the wrong sign; (3) it costs more money to collect this information; and (4) it is probably more subject to error.

The vessel size variables used were gross registered tonnage (GRT) and horsepower (HP). GRT was the more powerful of these variables as it was statistically significant in all equations and explained a large part of output. HP was not as powerful a variable in terms of its partial correlation coefficient. However, it was statistically significant when total value was the dependent variable, indicating that it made an independent contribution to fishing power.

The variable that indicated the age of a vessel had a negative coefficient and was statistically significant in most cases. There are at least three hypotheses why older vessels

Table 1 — New England trawler production functions, alternate specifications.

Dependent variable	INDEPENDENT VARIABLE											
	LOG DAYS ABSENT	LOG DAYS FISHED	LOG GRT[1]	LOG HP[2]	LOG CREW	LOG AGE	CONSTRUCTION[3]	DUM 65[4]	DUM 67[4]	Y INT	$\bar{R}^2$	F
Problem 1												
Log total pounds (All years)												
Reg. Coef.		.649	.409	.038	-.410	-.240	-.138	-.018	-.084	4.69	.405	98.70
t ratio		18.300	6.340	.525	5.160	4.540	3.780	.776	3.420			
Part. Cor. Coef. [5]		.477	.184	.016	-.151	-.133	-.111	-.022	-.100			
Problem 2												
Log total pounds (All years)												
Reg. Coef.	1.060		.429	.002	-2.66	-.207	-.024	.011	-.059	3.39	.542	170.28
t ratio	27.800		7.580	.037	4.040	4.470	.752	.533	2.750			
Part. Cor. Coef. [5]	.636		.219	.001	-.119	-.131	-.022	.015	-.081			
Problem 3												
Log total value (All years)												
Reg. Coef.		.886	.365	113	-.002	-.107	-.043	-.024	.0006	2.43	834	724.34
t ratio		47.900	10.800	2.980	.062	3.860	2.280	1.920	.0500			
Part. Cor. Coef. [5]		.817	.305	.088	-.001	-.113	-.067	-.057	.0010			
Problem 4												
Log total value (All years)												
Reg. Coef.	1.080		.373	.074	.347	-.129	.095	.023	.010	1.44	.833	718.97
t ratio	47.600		11.000	1.940	8.830	4.660	5.000	1.790	.855			
Part. Cor. Coef. [5]	.815		.309	.058	.253	-.136	.146	.053	.025			

[1] Gross registered tonnage.
[2] Horsepower.
[3] Construction; equals one if wood, zero otherwise.
[4] Dummy variables for year of observation.
[5] Partial correlation coefficient.

may be less productive: (1) Older vessels might tend to have more breakdowns and equipment that was not in the best working order; (2) older vessels might have poorer working conditions and accommodations and, therefore, attract less able crews; (3) older vessels may embody older technologies. If the last hypothesis is dominant, vessels do not become less productive as they get older, rather old vessels are less productive. This would have different implications than the first hypothesis when fishing power factors are computed.

The dummy variable created for hull construction took on the value 1 if the hull was wood and 0 if steel. The results using this variable were mixed. In Problem 4, using total value and days absent, it was positive and significant. This may mean that *ceteris paribus* wooden hulls are 25% more productive.[2] There is no theoretical reason why these results should be obtained. The data in Appendix Table 3 show that the large vessels in the fleet are steel and the small ones wood, with a very small overlap. We may be observing an upward adjustment for the wood vessels because they fish many fewer days during the most productive portion of the year.

The tests for locational differences in productivity were made by creating an array of six dummy variables, one for each of the major ports in New England. A "one" was placed in proper location in the array corresponding to a vessel's home port and a "zero" in all the others. Equations showing the results of these tests are given in Appendix Table 1. In the logarithmic forms of the equations, there are no consistent differences between ports when total value is the dependent variable, the ports designated "Maine" appear to catch significantly more and "Boston" significantly less (Problem 10). These differences appear because Maine specializes in low value species and Boston in

[2] The antilog of 1 is 10. We have $10^{.095}$ which equals 1.25. Therefore, a wooden hull is 25% more productive.

high. When weighted by value, these differences disappear.

On the basis of these statistical tests, we conclude that the best specification of the production function for the New England groundfish fleet is shown in Problem 4, where total value is the measure of output and days absent is the measure of fishing time. Good descriptions of the capital variable are given by gross registered tonnage, horsepower, vessel age, and construction materials. The contribution of labor is measurable and important.

The Tuna Seine Fleet

In fisheries such as the tropical tuna fishery, the species are, in the jargon of the economist, "joint products." That is, the fishermen take as much of both species (yellowfin and skipjack) as they can in an effort to fill their holds as quickly as possible. They are essentially indiscriminate between tunas in that they do not appear to pass up any that they sight solely because it is the less desirable species, although such behavior was noted up to about 1950 (Shimada and Schaefer, 1956).

According to IATTC records, the probability of a successful set on yellowfin is higher than on skipjack. This leads one to hypothesize that a ton of skipjack represents in some way more input than a ton of yellowfin because it takes more work to catch skipjack. There are at least two techniques that might be used in this fishery to determine a weighting system for output. One technique (which is not used here) is canonical regression which was developed by Hotelling and described by Tintner (1952). In a sense, it is a search technique that "weights" the dependent and independent variables in such a way that the sum of the squares of the unexplained variance of all the variables is minimized. The second technique[3] is to systematically try different weights (whose sum is one) for the dependent variable and run a series of regressions using a common set of independent variables. The regression that maximizes the coefficient of determination would have the weights, which are, in a sense, best.

[3] Suggested by Henri Theil during a discussion of this problem with the author.

The following regression was run in an attempt to arrive at the best weighting system for output:

(4) $Q = f(D, T, CAPAC, GRT, ND, PR, CR, AGE, HP)$

where $Q = (\alpha Y + \beta S + \delta B)$ and $(\alpha + \beta + \delta) = 1$

and
Y is tons of yellowfin landed,
S is tons of skipjack landed,
B is tons of bluefin landed,
D is days at sea of each vessel,
T is the number of trips of each vessel,
CAPAC is the capacity of each vessel,
GRT is the gross registered tonnage,
ND is a dummy for new design,
PR is 1 for Puerto Rico home port, zero otherwise,
CR is the crew size,
AGE is the age of the vessel,
HP is the horsepower of each vessel.

The results of this experiment are shown in Table 2, where the left hand column shows the different weights applied to each species. The column headings are for each year's observations and for pooled observations. Tests using the *H* statistic show that the observations are not random. Weights of .3 for yellowfin, .4 for skipjack, and .3 for bluefin are best. This fits our *a priori* expectation that a vessel exhibited more productivity when it caught a ton of skipjack than a ton of yellowfin. The statistical results indicate that a vessel does one-third more work to catch a ton of skipjack than a ton of yellowfin.

The above experiment presents one approach to the determination of output in a fishery. Three alternative specifications of output in the tuna fishery were used in estimating the production function. These specifications were as follows: total value, total pounds, and weighted total pounds using the weights determined above.

Selected results of the regression experiments run are shown in Table 3 and in Appendix Table 2. The various specifications of the dependent variable could be explained with varying degrees of precision. As expected, weighted total pounds had the highest coefficient of determination, followed by total pounds, total value, skipjack and yellowfin, in that order. The actual difference between co-

Table 2. — Regression results using various weights for tuna species holding independent variables constant.

Weights of yellowfin, skipjack, and bluefin	1966 $\bar{R}^2$	1967 $\bar{R}^2$	1968 $\bar{R}^2$	All years $\bar{R}^2$
.7, .1, .2	.559	.332	.697	.486
.6, .1, .3	.573	.351	.701	.505
.6, .2, .2	.650	.542	.731	.612
.5, .1, .4	.588	.380	.705	.531
.5, .3, .2	.730	.785	.758	.757
.5, .2, .3	.677	.622	.739	.652
.4, .1, .5	.598	.426	.711	.565
.4, .4, .2	.772	.873	.775	.779
.376, .286, .344	.756	.837	.767	.763
.4, .2, .4	.703	.711	.748	.698
.4, .4, .3	.756	.837	.767	.760
.3, .5, .2	.770	.884	.778	.776
.3, .2, .5	.707	.790	.757	.740
.3, .4, .3[1]	.775	.883	.778	.785
.3, .3, .4	.764	.868	.774	.783
.2, .3, .5	.723	.875	.774	.775
.2, .5, .3	.744	.877	.769	.757
.2, .4, .4	.745	.879	.774	.769
.2, .2, .6	.646	.833	.762	.748
.3, .1, .6	.584	.494	.715	.603
.2, .1, .7	.523	.572	.713	.619

[1] The "Best" solution.

Source: Economic Research Laboratory, National Marine Fisheries Service, 1970.

efficients of determination in the weighted total pounds equation and the total pounds equation is not statistically significant (0.70 vs. 0.68).

The total pounds variable has, of course, almost the same weights (⅓, ⅓, ⅓) as the weighted output variable so that, ultimately, it may be of marginal significance to distinguish between them in this fishery. Nevertheless, we cannot know this before further experiments are conducted.

Total value as a dependent variable is inferior to total pounds. This tends to confirm our hypothesis that yellowfin and skipjack are joint products in this fishery. The weight of skipjack in total value is less than the weight for yellowfin and bluefin.[4] Therefore, it appears that the amount for which skipjack can be sold is not reflected in the extra work done in catching it, at least relative to yellowfin and bluefin.

The best production functions for the tuna fishery are shown in Table 3. The only fishing time variable available for this fishery was

[4] The relative price weights are .286 for skipjack, .376 for yellowfin, and .344 for bluefin.

Table 3. — Tuna purse seine production function: alternate specifications.

	INDEPENDENT VARIABLE							
Dependent variable	LOG CAPACITY	LOG DAYS	LOG H.P.[1]	66 DUM	67 DUM	Y INT.	$\bar{R}^2$	F
Problem 1								
Log total value								
Reg. coef.	.365	.310	.368	.067	.044	-.196	.587	76.17
t ratio	5.14	3.32	4.66	2.08	2.21			
Part. Cor. Coef.	.303	.201	.277	.128	.136			
Problem 2								
Log total pounds								
Reg. Coef.	.438	.373	.339	-.024	.049	.453	.680	113.84
t ratio	7.39	4.79	5.15	.914	2.94			
Part Cor. Coef.	.416	.284	.304	-.056	.179			
Problem 3								
Weighted total pounds								
Reg. Coef	.520	.416	.328	-.026	.065	.168	.704	127.07
t ratio	8.41	5.12	4.77	.946	3.71			
Part Cor. Coef.	.462	.302	.283	-.058	.224			

[1] Horsepower

Source: Economic Research Laboratory, National Marine Fisheries Service, 1970.

days absent so that alternative specifications of the equations could not be run. Days absent, however, was not as important a variable in this fishery as in the trawl fishery. The reason for this may be that there is a basic difference in the way the vessels in these fisheries operate. The trawl fishery is a wetfish fishery so that the vessels are constrained by time when they go to sea, whereas the tuna boats are freezers, and they stay at sea until their holds are filled; hence, there is a different connotation to the fishing time variable.

The vessel size variables used in the final equation were capacity and horsepower. Capacity was the more important of these variables. This indicates that the industry is justified in using capacity as an index of a vessel's fishing power. Several tests were run with gross tonnage in place of capacity, but the results were not as good, although they were still meaningful.

Horsepower makes an important independent contribution to explanation of output. The contribution of horsepower to the increase in the coefficient of determination, though small at any point in time, may be important in the maintenance of an effort series as the composition of a fleet changes.

Tests were run using crew size but results were poor, presumably because there is such small variation of crew in this fleet (12-14 men). In addition, crew size is defined by custom and union contract according to the capacity of a vessel, hence crew size does not give additional information.

The tuna fleet has two main bases: Puerto Rico and southern California. To test whether vessels located in Puerto Rico were more productive, a dummy variable was created that took the value one if a vessel's home port was Puerto Rico and was zero otherwise. The results were generally positive but not statistically significant. This indicates that the fleet's shift toward Puerto Rico is because of reasons other than catching more fish (see Appendix Table 2).

Tests to see if the age of the vessels could explain some of the variation in output generally showed that older vessels were less productive in the linear forms of the equations. When the logarithmic transformations were made, the age variable became nonsignificant; hence, it is not included in the final equations.

The original purse seine fleet consisted of vessels converted from either military craft or bait boats. There has been a major expansion of this fleet since 1963 with vessels designed specifically for purse seining. To see if these vessels were superior in a way that could not be accounted for by either horsepower or capacity, a dummy variable was created that took the value one if a vessel were built after 1962 and zero if built before 1963. It was hoped that this would pick up technological change. The results using this were generally positive and sometimes statistically significant, but the dummy variable is not included in the final equations because it was not statistically significant in them.

We conclude that for the tuna fishery the best production function is given by Table 3, Problem 3, where weighted total pounds is the dependent variable, days absent is the measure of fishing time, and capacity and horsepower are measures of the capital used.

CONCLUSION

The basic assumption underlying this work is that a production function can adequately describe the productivity of vessels. The stability of the estimates arrived at using this technique rely most upon the constant patterns of economic behavior. The coefficients would have to be re-estimated if the ratio of days absent to days fishing changed significantly in a fleet, or if the form of regulation changed the pattern of fishing. Pattern changes are undoubtedly taking place in the tuna fishery where the quota system of regulation makes it imperative for vessels to leave the home port the day the season opens and to fish as intensively as possible. This makes vessel utilization in the first part of the year much higher than it has been historically or would be without the quota regulation system. It has probably had the effect of changing the effective productivity markedly by putting a premium upon running speed.

Once an estimating equation has been determined suitable, it should be used as long as possible, say up to 10 years to provide continuity. Checks should be made periodically to see if the equation being used is still appropriate.

The technique of using dummy variables to measure technological change can be a very powerful means of keeping productivity indices up to date. Any new device, strategy, or vessel design can be tested for its ability to increase productivity as it is being introduced and therefore, can be permanently built into the vessel productivity indices.

One of the more important attributes of these production functions is that they provide a simple way to test whether information being gathered is relevant to the task at hand. For example, fishing days are collected in New England. Upon further testing it may be decided that this information is not worth its cost.

The technique can also provide a way to handle some of the causes of secular changes in the productivity of a fleet. For example, in both of the fleets considered, both vessel size (GRT and capacity) and horsepower made significant contributions to the determination of productivity. Thus, as new vessels are added to a fleet, their productivity can be estimated even though they have larger engines relative to vessel size than other vessels in their size class. It is also possible to keep estimates of productivity current as the engines of old vessels are replaced or upgraded and changes in crew size are made.

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Appendix Table 1 New England production function

Dependent variable	DAYS ABSENT Reg Coef	DAYS ABSENT t val	DAYS FISHING Reg Coef	DAYS FISHING t val	G R T[1] Reg Coef	G R T[1] t val	CREW Reg Coef	CREW t val	YEAR BUILT Reg Coef	YEAR BUILT t val	H P[2] Reg Coef	H P[2] t val
Problem 1												
Total pounds 64			2677	2 47	6334	6 19	33074	1 42	10899	2 64	1140	2 58
Total pounds 65			2215	2 02	6282	6 13	30615	1 31	7291	1 75	1256	2 79
Total pounds 67			1506	13	6198	6 87	33566	2 70	11076	2 95	607 6	1 59
Pooled total pounds			2498	4 15	6395	11 41	38441	3 83	8561	3 73	596 8	3 67
Log total pounds 64			4914	8 87	9850	11 59	1912	1 62	2665	2 18	7188	12 76
Log total pounds 65			2530	4 48	9640	12 56	0500	47	2510	2 30	6430	12 38
Log total pounds 67			1032	1 85	9800	11 84	0206	18	5560	4 67	9110	[illegible]
Problem 2												
Total pounds 64	5687	8 01			5415	5 74	-42049	2 26	6252	1 62	951 6	2 31
Total pounds 65	5455	7 28			5375	5 62	-41627	2 22	3234	83	1081	2 54
Total pounds 67	5037	6 40			5153	5 94	-45400	4 07	5828	1 63	372 8	1 02
Pooled total pounds	5796	13 87			5365	10 18	-44789	5 24	4395	2 05	718 9	3 15
Log total pounds 64	8527	11 08			7662	8 95	-1051	98	2256	1 93	4669	7 18
Log total pounds 65	5070	6 00			8320	10 45	0200	20	2170	2 02	5050	8 39
Log total pounds 67	3263	4 07			8940	10 55	-0330	32	5140	4 41	7750	11 43
Problem 3												
Total value 64			889 2	24 77	214 2	6 32	1939	2 51	128 4	94	103 7	7 08
Total value 65			884 3	22 61	200 5	5 47	2082	2 50	41 75	28	117 7	7 31
Total value 67			728 2	21 30	204 4	7 43	-380 6	1 00	82 99	73	72 24	6 20
Pooled total value			889 1	42 58	223 2	11 47	416 2	1 19	26 93	34	94 88	11 19
Log total value 64			9603	25 20	5459	9 34	0497	61	1779	2 12	0927	2 39
Log total value 65			7880	23 95	4990	11 18	1714	2 75	2060	3 23	0830	2 75
Log total value 67			6848	22 52	5530	12 22	045	73	2620	4 03	2730	8 66
Problem 4												
Total value 64	566 1	19 78			30 36	80	8706	11 61	148 3	95	89 94	5 40
Total value 65	582 1	18 24			11 16	27	8778	11 00	119 1	71	103 6	5 73
Total value 67	538 5	21 31			154 0	5 52	1324	3 69	90 76	79	77 16	6 62
Pooled total value	607 8	34 90			100 4	4 57	4476	12 58	69 60	78	96 03	10 03
Log total value 64	1 349	23 08			2402	3 69	3465	4 26	1633	1 84	-2122	4 29
Log total value 65	1 140	21 38			2290	4 53	4190	6 69	2017	2 95	-1560	4 08
Log total value 67	9900	21 81			3930	8 19	2200	3 65	2860	4 34	0360	94
Problem 5												
Total value 64			896 5	24 45	206 7	5 95	1759	2 21	133 1	97	101 7	6 88
Total value 65			894 0	22 44	190 9	5 10	1854	2 17	48 61	33	114 3	7 01
Total value 67			730 7	21 13	201 1	7 04	-426 9	1 08	80 81	71	71 4	6 06
Pooled total value			896 1	42 24	214 3	10 69	262 3	73	28 70	36	92 45	10 78
Log total value 64			9690	25 22	5154	8 38	0369	45	1855	2 21	082	2 09
Log total value 65			7960	23 92	4750	10 09	1600	2 57	2090	3 29	0740	2 40
Log total value 67			6877	22 36	5430	11 58	0390	63	2600	4 00	2710	8 54
Problem 6												
Total value 64	563 6	19 92			61 4	1 58	9046	12 06	114 0	74	96 96	5 84
Total value 65	581 0	18 35			36 43	88	9040	11 33	87 10	52	111 2	6 12
Total value 67	535 6	21 18			165 5	5 74	1460	3 96	94 66	83	79 59	6 78
Pooled total value	605 1	34 94			122 5	5 44	4729	13 16	55 37	62	101 4	10 64
Log total value 64	1 352	23 26			2846	4 24	3536	4 37	1469	1 66	-2040	4 15
Log total value 65	1 140	21 61			2700	5 17	4240	6 83	1890	2 79	1460	3 83
Log total value 67	9890	21 91			4200	8 56	2330	3 87	2880	4 39	0390	1 04
Problem 7												
Total value 64			921 1	24 25	198 5	5 49	2203	2 47	63 16	45	102 1	6 86
Total value 65			927 3	22 57	187 0	4 84	2102	2 20	21 7	14	116 0	7 10
Total value 67			865 3	22 92	168 0	6 05	-279 3	72	4334	003	68 96	6 15
Pooled total value			951 57	43 00	200 8	9 92	502 3	1 33	-25 40	32	92 60	10 92
Log total value 64			9626	23 87	4611	6 80	2064	2 24	1467	1 73	100	2 29
Log total value 65			8039	22 93	4610	8 90	2760	3 91	1610	2 53	09526	2 79
Log total value 67			7550	21 93	4660	9 35	1969	2 95	1749	2 73	2 557	7 24
Problem 8												
Total value 64	561 1	19 55			63 58	1 56	5686 7	9 68	132 7	85	100 4	5 98
Total value 65	578 9	17 91			40 95	93	8806 1	9 12	7642	45	115 3	6 24
Total value 67	554 6	21 05			162 5	5 55	1308	3 33	143 3	1 23	79 43	6 78
Pooled total value	606 3	34 49			130 1	5 61	4157	10 30	96 70	1 07	103 4	10 79
Log total value 64	1 344	21 93			2518	3 39	3413	3 59	1953	2 20	-1900	3 43
Log total value 65	1 130	19 79			2830	4 78	4050	5 40	2000	2 90	-1240	2 80
Log total value 67	1 006	19 51			3920	7 14	2880	4 12	2780	4 12	0340	75
Problem 9												
Total pounds 64			3982	3 53	6973	4 44	10062	38	10111	2 45	754 2	1 71
Total pounds 65			3546	3 09	4981	4 62	-17193	65	7576	1 80	867 6	1 90
Total pounds 67			2983	2 32	5251	5 56	26509	2 02	8165	2 14	512 3	1 34
Pooled total pounds			4386	6 90	5180 6	8 92	-27597	2 55	7471	3 26	639 2	2 63
Log total pounds 64			5389	9 57	6974	7 37	2183	1 70	2400	2 03	66009	10 85
Log total pounds 65			2827	4 82	7771	8 96	3120	2 64	2310	2 17	6550	11 47
Log total pounds 67			1420	2 21	8430	9 06	2820	2 27	4879	4 08	9330	14 17
Problem 10												
Total pounds 64	5955	8 47			3774	3 78	10501	48	6796	1 77	613 4	1 49
Total pounds 65	5828	7 80			3893	3 84	5528	71	4626	1 18	731 9	1 71
Total pounds 67	6698	8 50			3959	4 52	-26853	2 28	3868	1 11	371 3	1 06
Pooled total pounds	6402	15 50			4062	7 45	-23614	2 49	4556	2 16	528 1	2 34
Log total pounds 64	8643	10 94			5303	5 53	24291	1 98	25445	2 22	4233	5 93
Log total pounds 65	4814	5 52			6810	7 52	3260	2 84	2320	2 21	5340	7 90
Log total pounds 67	3600	4 04			7540	7 95	2320	1 96	4810	4 13	7800	9 86

[1] Gross registered tonnage
[2] Horsepower

Dependent variable	CONSTRUCT[3] Reg Coef	CONSTRUCT[3] t val	MAINE[4] Reg Coef	MAINE[4] t val	GLOUCESTER[4] Reg Coef	GLOUCESTER[4] t val	BOSTON[4] Reg Coef	BOSTON[4] t val	NEW BEDFORD[4] Reg Coef	NEW BEDFORD[4] t val	RHODE ISLAND[4] Reg Coef	RHODE ISLAND[4] t val	Y INT	R^2	$\bar{R}^2$	F
Problem 1																
Total pounds 64													-90900	368	362	44 37
Total pounds 65													74900	387	381	46 096
Total pounds 67													11300	285	277	29 541
Pooled total pounds													38300	339	337	117 5
Log total pounds 64													1 83	650	646	141 2
Log total pounds 65													2 35	592	588	105 85
Log total pounds 67													1 52	568	563	101 06
Problem 2																
Total pounds 64													355000	451	445	62 48
Total pounds 65													222000	460	453	61 915
Total pounds 67													209000	354	347	42 122
Pooled total pounds													-261000	426	424	169 7
Log total pounds 64													1 70	681	677	162 0
Log total pounds 65													2 22	608	604	113 29
Log total pounds 67													1 49	578	528	107 10
Problem 3																
Total value 64													-48000	877	876	543 1
Total value 65													-46200	871	870	494 17
Total value 67													-18600	814	813	338 33
Pooled total value													-35000	.846	845	1260
Log total value 64													1 56	845	843	415 0
Log total value 65													1 86	876	878	516 19
Log total value 67													1 63	845	843	419 96
Problem 4																
Total value 64													-82900	842	840	404 6
Total value 65													85500	838	846	378 53
Total value 67													-48100	814	812	336 77
Pooled total value													-70700	808	807	960 3
Log total value 64													1 28	828	826	365 3
Log total value 65													1 54	858	857	442 78
Log total value 67													1 26	839	838	402 3
Problem 5																
Total value 64	-5419	.96											-41800	878	876	452 6
Total value 65	-7455	1.24											-37700	872	870	412 89
Total value 67	2020	44											-16200	815	812	281 3
Pooled total value	-5982	1 81											-28000	847	846	1053
Log total value 64	- 0581	1 58											1 67	846	844	347 6
Log total value 65	- 0420	1 56											1.94	877	875	432 17
Log total value 67	- 0180	66											1 67	845	843	349 59
Problem 6																
Total value 64	19489	3 16											105000	846	844	346 8
Total value 65	17085	2 61											104000	841	839	321 68
Total value 67	7184	1 56											-56600	815	813	282 14
Pooled total value	14256	3 95											-87100	810	809	813 1
Log total value 64	.0923	2 40											1 12	830	828	309 3
Log total value 65	0780	2 74											1 40	861	859	376 95
Log total value 67	0670	2 35											1 14	842	840	340 43
Problem 7																
Total value 64	-690 9	12	11319	1 55	-808 7	12	4635	62	1174	17	11044	1 52	51000	881	878	251 3
Total value 65	-1323	21	12207	1 55	-853 1	11	8115	1 00	1470	20	14986	1 91	-49700	876	873	232 05
Total value 67	-382 1	09	3708	61	-5542	94	-7683	1 23	-19939	3 42	7313 1	1 19	-13300	839	835	178 81
Pooled total value	-1253	45	8604	1 99	-2798	67	2738	62	-7520	1 86	11149	2 57	34700	854	852	605 9
Log total value 64	- 0529	1 36	1055	1 95	0044	02	-.0535	97	0251	50	0363	67	1 67	853	849	197 7
Log total value 65	- 0310	1 09	0790	1 96	- 0007	002	-.0280	68	0320	87	0820	2 02	1 88	884	881	248 8
Log total value 67	- 0164	57	0110	25	- 0960	67	- 1620	3 54	- 1060	2 54	0320	74	1 827	862	858	214 64
Problem 8																
Total value 64	18171	2 79	7228	88	-7694	98	-6246	75	-2402	32	14404	1 77	-96600	848	844	190 2
Total value 65	18068	2 59	-5969	68	-8943	1 04	-4459	47	- 3492	42	-9282	1 05	-99100	842	838	174 48
Total value 67	7666	1 64	14675	2.31	8656	1 39	-7234	1 10	-16873	2 77	-9428	1 45	-48900	822	818	159 45
Pooled total value	14241	3 78	12459	2 56	8300	1 75	-2039	41	-8035	1 75	12687	2 59	-78900	812	811	449 3
Log total value 64	0581	1 43	0034	06	0268	49	- 0283	49	0046	09	1293	2 30	1 15	838	834	175 9
Log total value 65	0600	1 93	- 0160	39	0037	09	- 0200	45	0120	30	0510	1 17	1 40	863	859	206 2
Log total value 67	0634	2 08	- 0260	57	- 0370	81	- 0740	1 53	- 0560	1 28	- 0220	49	1 19	843	839	185 77
Problem 9																
Total pounds 64	339024	1 96	562668	2 60	351898	1 69	59089	27	29683	15	358050	1 66	51500	408	392	23 4
Total pounds 65	380585	2 19	479210	2 18	332023	1 59	103437	45	61156	30	355627	1 62	189000	418	401	23 393
Total pounds 67	-102455	67	85775	42	124072	62	-354221	1 67	-409081	2 06	215326	1 03	257000	330	313	16 979
Pooled total pounds	-272358	2 83	386757	3 12	181225	1 51	-52889	42	135014	1 16	321650	2 58	196000	378	372	62 83
Log total pounds 64	0678	1 25	2383	3 16	0319	44	- 1261	1 63	0587	84	0658	87	2 15	694	686	77 14
Log total pounds 65	0280	60	1960	2 91	0079	12	1300	1 86	0190	31	0190	28	2 41	638	628	57 558
Log total pounds 67	0560	1 06	0330	42	- 1400	1 75	- 3240	3 80	1670	2 13	- 1470	1 81	1 80	598	587	51 203
Problem 10																
Total pounds 64	-265530	1 66	475561	2 37	319786	1 65	47985	23	-45782	25	205331	1 03	-312000	487	473	32 25
Total pounds 65	298694	1 85	429528	2 10	302920	1 53	82596	39	20693	11	230513	1 13	187000	489	475	31 19
Total pounds 67	106493	76	52962	28	-314526	1 69	532042	2 71	-655419	3 60	50766	26	105000	430	415	25 934
Pooled total pounds	-209963	2 37	278594	2 43	103667	93	-118571	1 01	250792	2 33	159885	1 38	130000	965	460	89 87
Log total pounds 64	0017	03	1834	2 53	0584	82	0926	1 23	0722	1 07	01951	27	1 88	711	704	83 81
Log total pounds 65	0050	12	1670	2 52	0170	27	1160	1 66	0290	47	0240	37	2 22	645	635	59 29
Log total pounds 67	0330	64	- 0390	50	1300	1 65	3040	3 62	1910	2 50	- 1570	1 96	1 72	610	599	53 770

[3] Equals 1 if wooden vessel 0 otherwise

[4] Equals 1 if vessel's homeport Puerto Rico, 0 otherwise

Appendix Table 2. — Alternative specifications of production functions for vessels in the eastern tropical Pacific tuna fishery, 1966, 1967, 1968

Dependent variable		INDEPENDENT VARIABLE												
		CAPACITY	DAYS ABSENT	HORSEPOWER	GRT[1]	CREW	PUERTO RICO[2]	YEAR BUILT	PURSE SEINE[3]	DUM 66[4]	DUM 67[4]	Y INT	F	$\overline{R}^2$
Problem 1														
Total value														
Linear –	Reg Coef[5]	.407	594	124						- 37 300	- 6 920	36.890	96.28	.643
	t ratio	7.590	.285	4 820						1 350	2 440			
Log -	Reg Coef[5]	.365	.310	.368						067	044	- .196	76.17	.587
	t ratio	5.140	3.320	4.660						2.080	2 210			
Problem 2														
Total pounds														
Linear	Reg. Coef.[5]	3.840	5.620	.751						582.000	202.000	- 660.400	121.20	694
	t ratio	1.030	3.890	4 180						2 750	1 030			
Log -	Reg. Coef.[5]	.438	.373	.339						- 024	.049	453	113.80	680
	t ratio	7.390	4 790	5.150						914	2.940			
Problem 3														
Weighted total pounds														
Linear -	Reg Coef.[5]	4.810	6.740	605						255.000	732.000	- 116 300	132.00	.712
	t ratio	11.800	4 270	3 080						1 180	3.500			
Log –	Reg. Coef.[5]	520	416	328						- .026	.065	168	127 00	704
	t ratio	8.410	5.120	4 770						946	3 710			
Problem 4														
Total pounds														
Linear	Reg Coef[5]	3.930	5.780	179 000					414 000	209 000	540 000	-1735 000	102.00	697
	t ratio	10.700	3.960	2 880					1.980	1.060	2.810			
Log	Reg. Coef.[5]		410	.061	242	1 67			010	- 037	051	- 559	70.74	649
	t ratio		4 870	5.860	3.330	2 87			304	1 290	2.870			
Problem 5														
Weighted total pounds														
Linear	Reg. Coef.[5]	4 440	6.300	217	1 230	-283 00	370 00	13 30	-143.000	-668 000	-479.000	1856 000	69 68	.648
	t ratio	8.030	3 940	829	1.750	1.54	1 97	1 22	458	3 290	3.890			
Log –	Reg. Coef.[5]		448	.065	.317	1.56			- 010	- .039	6.580	- 762	75 87	653
	t ratio		5 030	586	4 111	2 53			287	1 300	3.530			

[1] Gross registered tonnage.
[2] Equals one if vessel's home port is Puerto Rico, zero otherwise
[3] Equals one if vessel was built after 1962, zero otherwise
[4] Dummy variables for year of observation.
[5] Regression coefficient.

Appendix Table 3. - New England trawl fleet: average vessel data by tonnage class, 1964, 1965, 1967.

Tonnage class	Number of observations	GRT	Days absent	Days fishing	Trips	Horsepower	Year built	Crew	Construction (percent wood)	Measures of output	
										Thousands of pounds	Total value ($1000)
0-50	492	30	118	48	87	163	42	3.6	98	808	37
51-100	354	70	149	89	36	253	43	5.9	93	1086	83
101-150	147	120	162	104	24	349	44	7.9	88	1225	118
151-200	57	170	168	96	20	479	44	8.6	24	1142	114
201-250	33	229	235	155	24	604	45	14.4	0	2672	242
251-300	15	271	224	152	23	630	38	13.7	0	2591	253
301-400	15	313	235	141	17	623	36	9.0	0	4942	191
400	6	495	221	126	24	503	44	12.7	0	3439	260

Appendix Table 4. - Tropical tuna seine fleet: average vessel data by tonnage class, 1966, 1967, 1968.

Capacity class	Number of observations	Capacity	Days at sea	GRT	Horsepower	Year built	Measures of output		
							Total value ($1000)	Total in thousands of pounds	Weighted total in thousands of pounds
100-199	47	173	152	210	508	46	236	1504	1388
200-299	83	251	168	370	731	48	292	2542	2401
300-399	62	346	172	421	908	51	360	2550	2461
400-499	24	453	182	482	1100	50	389	2765	2766
500-599	19	537	162	619	1281	56	523	3749	3719
600-699	5	650	133	673	1649	59	448	3166	3319
700-799	4	793	180	856	1589	63	817	6447	6946
800-899	6	811	191	804	1600	64	781	6016	6479
900-999	12	924	161	793	1850	53	637	5092	5492
1000	5	1067	171	855	1600	43	687	5751	6454

Optimal Fishing Effort in the Peruvian Anchoveta Fishery

EDILBERTO L. SEGURA[1]

ABSTRACT

This paper introduces a new approach to measuring technical change, increased skills of the skipper and the fishermen, water temperature, etc., to obtain a better measure of fishing effort and therefore a revised estimate of the optimum quantity to be landed. The revised technique used adjusts the level of landings to an index rather than the level of fishing effort, indicating the level of landings that would have resulted in previous periods if the current landings/effort relationship is used.

The revised yield/effort relationship which results yields 16.2 million ton-trips as the optimal fishing effort, as opposed to the 23 million ton-trips which were obtained without this measure of technical change.

INTRODUCTION

During the last decade the Peruvian fishing industry has become one of the most important elements of the Peruvian economy. In 1969 Peruvian exports of fish meal and fish oil reached U. S. $195 million, or 30% of total Peruvian foreign exchange earnings during that year. Almost all fish meal and fish oil production has utilized "anchoveta" (*Engraulis ringens*) as raw material. Total landings of anchoveta have increased from 1.9 million metric tons in 1959 to 8.9 million metric tons in 1969. This increase in landings represents an average annual rate of growth of 18%.

In recent years, due to the rapid expansion of the industry, its importance to the Peruvian economy, and the size of the landings, several studies have been made to determine the maximum sustainable yield of the Peruvian fish stock and the optimal level of fishing effort (Boerema et al., 1965; Schaefer, 1967, 1970; Gulland, 1968). Although these studies contain extensive discussions of fishing effort, there remain some doubts about the adequacy of the measures used to evaluate fishing effort. As a result, the estimation of the optimal level of fishing effort has been biased. In this paper I attempt to estimate the optimal level of fishing effort taking into consideration the effect of input variables not previously included, such as technological change, increased skills of skippers and fishermen, water temperature, etc.

CONCEPTUAL ISSUES

In a bioeconomic model, fishing effort is an index or proxy for several inputs that participate in the fishery, including capital, labor, management, technological change, and other variables. Although the fishing effort index might vary for different fisheries, it can be generalized as being the product of fishing time (number of days in grounds, number of trips made, number of hours fished, etc.) multiplied by some measure of fishing power (gross tonnage, length, engine horsepower, etc.). This measure should be a proxy for capital and labor. The resulting measure of fishing effort should be corrected by such factors as technological change (introduction of power block, echo sounder, steel vessels, etc.), changes in managerial and fisherman skill, and other variables that represent changes in fishing power. To determine the optimal fishing effort in the fishery and the maximum sustainable yield, most of the studies of the Peruvian stock have utilized the following Schaefer production function:

(1) $C/E = a - bE$ or, $C = aE - bE^2$

Where:

C = Total landings of anchoveta
E = Fishing effort
a,b = Parameters

[1] Ph.D. Candidate, Columbia University and Economist of Bailey, Tondu, Warwick and Company, Ltd., New York.

Schaefer (1967) used as a measure of fishing effort the average number of boats during the period, adjusted for changes in the size composition of the fleet. In 1970, Schaefer, recognizing that this measure could generate some bias, utilized as a measure of fishing effort the number of trips made by the fleet, times the average vessel capacity (ton-trips). This unit was also utilized by Boerema et al. (1965). However, all these studies ignored the effect of technological change and increased fisherman skills on the level of landings. This neglect arose from the difficulty in quantifying these variables. Although for several advanced fisheries these two variables can indeed be ignored, such neglect is questionable in the Peruvian anchoveta fishery. The importance of such variables was recognized by Gulland (1968).

The size of the Peruvian fleet has increased from 462 units in 1959 to 1,064 in 1962 and to 1,836 in 1964. After 1964, fleet size began to decline, reaching 1,308 units in 1969. From these figures it is clear that up to 1964 a large percentage of the skippers and fishermen were fishing for the first time. However, after 1964, with the reduction of the fleet size, only the most efficient skippers remained in the fishery. This situation and the experience gained by the fishermen after several years of operations, have served to increase the average skill of the fisherman.

In addition to increased labor skills, during the last decade several technological innovations, such as power block, echo sounder, steel vessels, and pumps for transferring the fish from the net to the hold, have been gradually introduced into the fleet. In 1969, 92% of the fleet had at least three of these items of gear, as opposed to 79% two years before. If a measure of fishing effort omits the effect of increased labor efficiency and technological innovations, then the most recent estimates of fishing effort will be biased. The estimation of the optimal fishing effort will also be biased.

The type of bias that will be introduced by omitting the increased efficiency of the fleet can be deduced from Figure 1.

In Figure 1, if the efficiency of the fleet increased during periods 1 to 3, the observed data for catch and effort will produce curve A. However, the relationship of catch to effort in terms of efficiency in year base "0" is given by curve B. The effect of ignoring increased efficiency would be to underestimate the most recent measures of fishing effort. If the observations of fishing effort, unadjusted by efficiency, are consistent from year to year, they still will give a correct measure of the maximum sustainable yield, as it is shown in Figure 1. However, the determination of the optimal level of fishing effort, in terms of some constant level of efficiency, will be biased. Usually, one is interested in obtaining the optimal level of fishing effort in terms of efficiency during the current period. This relationship is given in Figure 2, where "period 3" is the current period.

Since vessels are more efficient during period 3, to obtain the maximum sustainable yield C_2, the industry will require a smaller effort in terms of number of ton-trips than the effort used in period 2. In fact, instead of requiring an effort E_2, the industry will require only an effort E'_2, considering the higher efficiency of vessels in period 3. It is obvious that to obtain an unbiased optimal level of fishing effort at current efficiency, it will be necessary to adjust the index for fishing effort to reflect technological change, changes in fishermen skills, and other variables.

Although the construction of an index for fishing effort that includes technological change and other such variables is the ideal method to determine an unbiased level of optimal fishing effort, usually it is not easy to construct such an index. This is because several of the above-mentioned variables are difficult to quantify. When this is the case, an alternative approach has to be devised.

The alternative approach that is used in this paper is to adjust the level of landings obtained, rather than the level of fishing effort, for changes in efficiency. That is, given the observed unadjusted fishing efforts and the landings in several periods, the problem is to obtain a catch-to-effort relationship that will show that level of landings that would have been obtained in the several periods if vessels of efficiency of the current period would have been used. This adjusted curve and the actual observed curve are shown in Figure 3. The optimal level of fishing effort in terms of vessels of current efficiency (E^*_2 in the figure) will be obtained by maximizing catch in curve A.

The difference between this approach and the

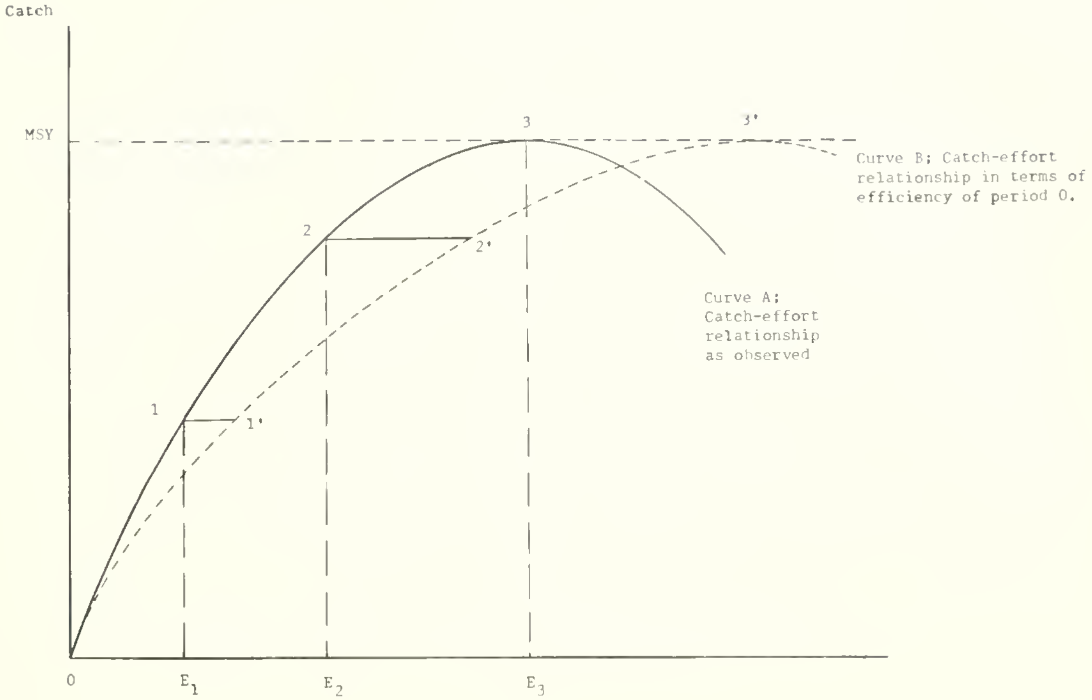

Figure 1. — Biased estimate of fishing effort due to an underestimate of increased efficiency.

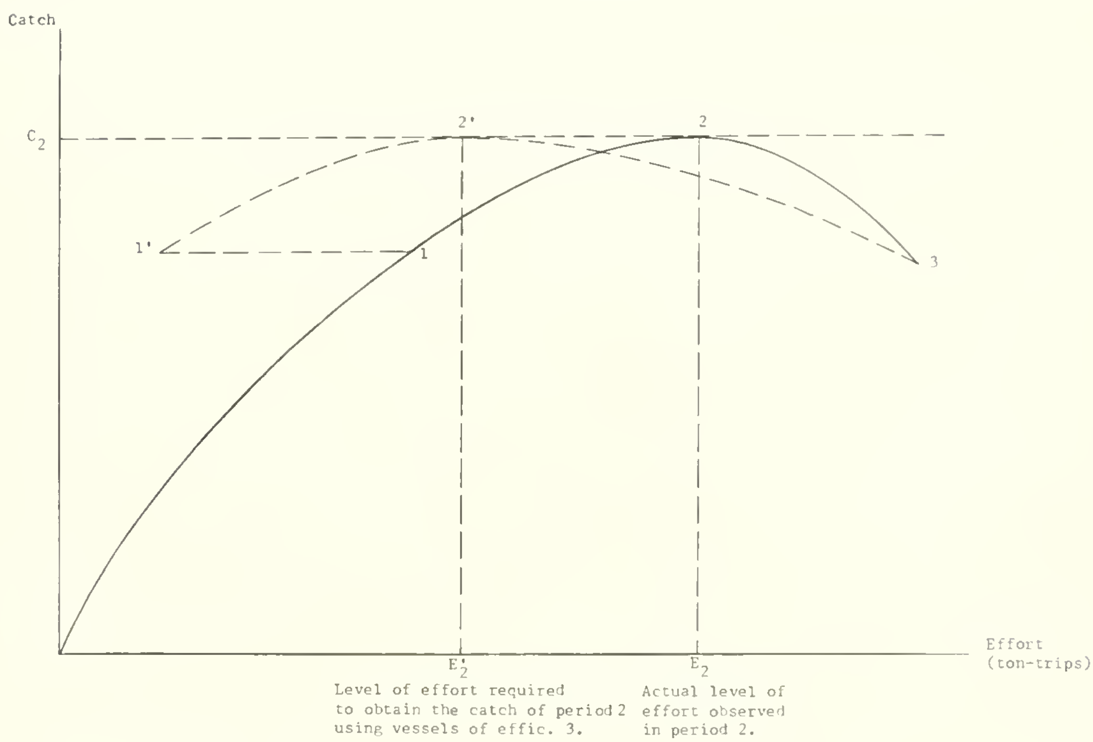

Figure 2. — Optimal fishing effort based on current efficiency levels.

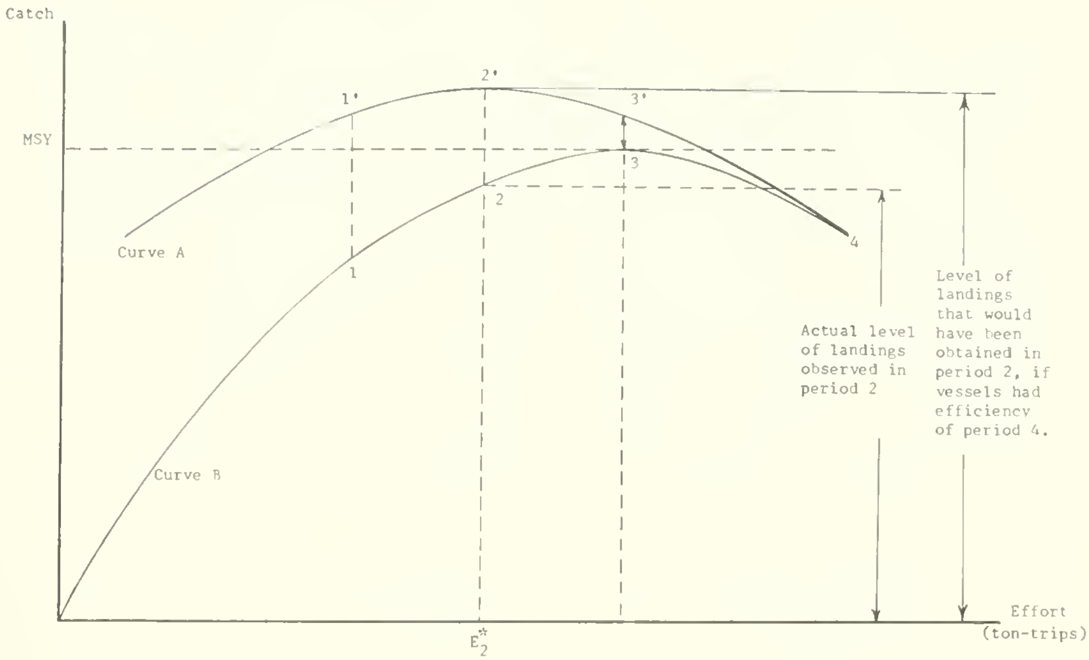

Figure 3. — Actual and adjusted catch effort curves.

first one is that in the first approach the *fishing effort* is adjusted for efficiency changes and catch remained at the observed levels; in the second approach *the catch* is adjusted for efficiency changes and the fishing effort remains at the level observed. The second approach has the advantage that it can be more easily handled with statistical techniques. It should be noted that curve A in Figure 3 gives the level of landings that would have been obtained in past periods if vessels at that time had the efficiency of the current period. Actually, this curve has not been observed; and the maximum of the curve, although it indicates the optimal level of fishing effort in terms of current efficiency, will not give the maximum sustainable yield of the stock. The maximum sustainable yield will in fact be given by curve B, as it was shown in Figure 1.

Since curve A in Figure 3 is actually the relationship of effort to catch keeping all other variables (including efficiency) constant, the multiple regression technique can be applied. In fact, the statistical meaning of a partial regression coefficient is that it measures the effect of the independent variable on the dependent one, keeping all other variables constant. The use of the regression analysis to obtain the optimal fishing effort is presented below.

The logistic model as presented by Schaefer (1957) and reproduced in equation (1) is a stochastic rather than an exact relationship:

(2) $C = aE - bE^2 + e$

Where "e" is an error term.

In this model, if the measure of effort used were a proxy for all the several inputs utilized when fishing and affecting catch, then the error term "e" should be randomly distributed. That is, no other input variable, when added to equation (2), should be statistically significant in explaining changes in the level of catch. In fact, if no variables have been omitted in equation (2) (all of these are represented in the proxy fishing effort), then no sign of autocorrelation of the error term should exist. If this is the case, one could conclude that the measure of fishing effort used is adequate and that it can be reliably used to estimate both the maximum sustainable yield and the optimum level of effort.

We can further test if the measure of fishing effort is adequate by introducing into equation (2) input variables such as technological change and crew size. If we did this the following equation would result:

(3) $C = a_1E - b_1E^2 + cL + dT + e$

Where:

C = Total landings
E = Fishing effort
L = Labor employed or crew size
T = Technological change expressed as T = 1 in period 1, T = 2 in period 2, T = 3 in period 3, etc.

If the coefficients of "L" and "T" are statistically significant (as given by their t-values), it means that the measure of fishing effort used, "E," did not adequately include the effect of these variables on catch. Consequently, the use of equation (2) alone would produce biased estimators of the coefficients "a" and "b" of "E" and "E^2," respectively. In this case we can either correct the measure of fishing effort used (which is the first procedure indicated in Figure 1) or we can isolate the effect of other variables on catch using a multiple regression equation that would include these variables (which is equivalent to the second approach indicated in Figure 3).

If the second approach is used, technological innovation and crew size must be kept at a fixed level in equation (3). Usually this would be at the current levels. After this is done we can obtain the true value of fishing effort by maximizing catch in equation (3). Keeping the effect of "T" and "L" on catch at some constant level K, equation (3) would become

$$C = a_1E - b_1E^2 + K$$

or

(4) $(C - K) = a_1E - b_1E^2$

Which is the model as developed by Schaefer (1957) after the effect of technological change and crew size is removed. The optimal level of fishing effort, at constant vessel capacity and crew size, that will maximize catch is given by equating zero to the first derivative of equation (4) as follows:

$$\frac{d(C - K)}{de} = a_1 - 2\,b_1\,E = 0$$

or

(5) Optimal fishing effort = $E^* = \dfrac{a_1}{2\,b_1}$

STATISTICAL RESULTS

Using the data presented in Table 1, several regressions were made to test for the adequacy of the measures of fishing effort available to us. In Table 1, total landings is defined as the catch by the fishermen in thousands of pounds. The unit used for fishing effort is the number of trips made times the average vessel capacity. Data on fishing effort was compiled by the Instituto del Mar del Peru, and it is supposed to be adjusted for the effect of closed seasons, strikes, and for some changes in gear efficiency. Other variables included in the analysis are the number of fishermen employed in the industry, the size of the bird population (which is supposed to be an important element in fishing mortality), and veda (closed) seasons.

As has been recognized by Gulland (1968) and by Schaefer (1967), because of the rapid growth of the Peruvian fishery, it has not remained in steady state equilibrium in every year. Under these circumstances, the use of a relationship of catch to effort will produce too high an estimate of steady state abundance and catch for a given fishing effort. One way to correct this situation is to use the "Gulland Method" (Gulland, 1961) in which the total landings are related to the average effort existing during the life span of a fish in the fishery, which is approximately two years. This method has been used in this paper.

Schaefer (1970) used the same data presented in Table 1 to estimate the maximum sustainable yield of the stock and the optimum level of fishing effort. I have added observations for the year 1968-1969. The regression equivalent to the one used by Schaefer in 1970 is as follows:

(6) $C = 0.7769\,E - 0.1706\,E^2$
$\qquad\quad (8.6) \qquad\quad (-3.8)$

Coefficient of Determination (R^2) = 0.84
Durbin-Watson Statistic (D − W) = 0.7
Standard Error of Estimate (SEE) = 813
Figures in parentheses are t-values.

Equation (6) is useful for finding the maximum sustainable yield of the fishery. The estimated MSY is given at 8.8 million metric tons. This value is very close to the value of 8.5 million metric tons obtained by Schaefer (1970). By observing the data of total landings in Table 1 we cannot appreciate the danger of overfishing

Table 1 — Catch and Effort Data for the Peruvian Anchoveta Fishery, 1960-1969.

Fishing year	Catch by fishermen 10^3 metric-tons	Fishing effort 10^3 ton-trips	Number of fishermen employed	Adult bird population 10^3	Catch per unit of effort
	(1)	(2)	(3)	(4)	(5)
1960-61	3,934	6,367	8,800	12,000	0.551
1961-62	5,502	8,131	11,750	17,000	.603
1962-63	6,907	11,788	19,100	18,000	.478
1963-64	8,006	17,866	20,100	15,000	.376
1964-65	8,037	21,329	18,900	17,300	.376
1965-66	8,096	22,058	19,000	4,300	.356
1966-67	8,242	20,845	17,800	4,800	.435
1967-68	9,818	19,874	17,500	4,500	.472
1968-69	10,088	22,350	19,600	5,000	.421

Source: (1), (2), (4) Years 1960-1968, from Schaefer (1970)
Year 1968-1969, from Instituto del Mar del Peru, Resumen General dela Pesqueria, Lima, 1970.
(3): From Sociedad Nacional de Pesqueria, unpublished materials.

in the Peruvian stock, since landings have increased throughout the period. However, by analyzing data for calendar years up to 1969 a different picture of the situation is observed. During recent years annual landings have been as follows:

Year	*Million Metric Tons*
1961	4.58
1962	6.28
1963	6.42
1964	8.80
1965	7.23
1966	8.53
1967	9.82
1968	10.44
1969	8.95

It is clear from these data that landings will not continue to increase at the rates experienced in the past, and that we can only expect to see fluctuations in landings around the MSY, if fishing effort is kept under control.

The result given by equation (6) as to the optimal level of fishing effort is less than satisfactory. The value given by this equation, and which is close to that obtained by Schaefer (1970), is 23 million ton-trips. Observing the data in Table 1 we can see that this value of fishing effort has not been obtained up to now. This result is very unrealistic since it says that the Peruvian fishery has actually surpassed the MSY but has not yet reached the optimum level of fishing effort. However, from the discussion in the first part of this paper, it seems that the measure of fishing effort used is inadequate.

In equation (6) we can see that the value of 0.7 for the Durbin-Watson statistics indicated that there is a strong autocorrelation of the error term. This level of autocorrelation is an indication that important variables have been omitted from the equation. Using the procedure indicated above, several input variables will be introduced in equation (6), in order to determine their significance and the bias of the estimation of fishing effort. Some of the regressions that were run are the following:

(7) $C = \underset{(15.7)}{0.7022\,E} - \underset{(-9.5)}{0.2167\,E^2} + \underset{(5.2)}{541.0\,T}$ $\quad R^2 = 0.97$, D−W = 1.8, SEE = 382

(8) $C = \underset{(2.7)}{0.5225\,E} - \underset{(-3.4)}{0.1722\,E^2} + \underset{(5.1)}{561.1T} + \underset{(1.0)}{0.0884\,L}$ $\quad R^2 = 0.98$, D−W = 2.2, SEE = 384

(9) $C = \underset{(4.2)}{0.499\,E} - \underset{(-4.0)}{0.1556\,E^2} + \underset{(5.2)}{733.7\,T} + \underset{(1.8)}{903.0\,V}$ $\quad R^2 = 0.98$, D−W = 2.8, SEE = 325

$$(10)\ C = \underset{(4.3)}{0.4977\,E} - \underset{(-4.0)}{0.1539\,E^2} + \underset{(5.7)}{690.9\,T} + \underset{(1.8)}{6.43\,B} \qquad R^2 = 0.98,\ D-W = 3.0,\ SEE = 322$$

$$(11)\ C = \underset{(13.5)}{0.6584\,E} - \underset{(-10.3)}{0.2129\,E^2} + \underset{(5.9)}{582.2\,T} + \underset{(1.6)}{0.215\,^{\circ}C} \qquad R^2 = 0.98,\ D-W = 2.5,\ SEE = 360$$

Where:

- C = Total landings
- E = Fishing effort
- T = Technological change, labor skills (1961, T = 1; 1962, T = 2; 1963, T = 3; etc.)
- L = Labor employed in the fishery
- B = Adult bird population
- V = Dummy variable: closed season $V = 0$; open season $V = 1$
- °C = Temperature of water in Trujillo, Peru

Due to the fact that the theoretical Schaefer model does not include a constant term, the estimations of the *t*-values of the coefficients presented above are biased upwards. However, in regressions having the constant term in it, it happens that this constant term is not significant in any regression (*t*-value around 0.2). The difference between coefficients of regressions with and without the constant term is not significant, since in all cases this difference is less than 0.4 standard deviations of the coefficients.

In all regressions having the constant term, the variable technological change (T) is statistically significant at the 1% level of significance. In the equations presented above, even though the *t*-values are biased upwards, the variables labor size (L), veda seasons (V), bird population (B), and temperature (°C) are not statistically significant. However, the importance of technological change (T) alone is such that its introduction into equation (7) is sufficient to improve substantially the coefficient of determination of the equation from 0.84 in equation (6) to 0.97 in equation (7). Also the Durbin-Watson statistics (1.8) are now in the acceptable range (1.6-2.4).

Using expression (5) on page 61 we can obtain the optimal level of fishing effort in terms of the efficiency of 1969 vessels. Equation (7) gives 16.2 million ton-trips as the optimal level of fishing effort. Equations (8) to (11) give the following values for optimal effort in terms of million ton-trips: 15.2, 16.0, 16.0, and 15.0, respectively. All these estimates are in close agreement, but differ markedly from the value of 23 million ton-trips obtained by Schaefer (1970), and from equation (6). However, because of the statistical significance of the variable "T" in equation (7), the high autocorrelation in equation (6), and the theoretical appeal of the procedure, it seems that the value of 16.2 million ton-trips is closest to the true optimal level of fishing effort. Also, this value makes more sense in terms of the data presented in Table 1. In this table we can see that in 1962-1963, with vessels of less efficiency than those existing today, 11.8 million ton-trips produced 6.9 million metric tons of landings. A simple extrapolation would indicate that 8.8 million tons of fish could be landed by 18.3 million ton-trips of vessels with 1963 efficiency levels.

CONCLUSIONS

The method presented here appears useful in obtaining an unbiased estimation of the optimal level of fishing effort in a fishery. It adequately considers the effect of several significant inputs that cannot be directly introduced into the traditional measure of fishing effort. Using this procedure, the optimal level of fishing effort in the Peruvian fishery is 16.2 million ton-trips, or only 68% of the level of effort used in Peru in 1968-1969. This result has clear implications for the management of the Peruvian fishing industry.

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Natural Resources and External Economics: Regulation of the Pacific Halibut Fishery

JACK RICH[1]

ABSTRACT

In a static, long run competitive equilibrium framework, a catch function allowing for short run diminishing returns is combined with a fish growth function developed by Pella and Tomlinson which facilitates the derivation of an expression for the long run marginal cost of "effort" in a common property resource such as a fishery. This expression takes into account both "congestion" and "growth" costs. The diagramatic technique of Crutchfield and Zellner is modified to take account of these externalities. The modified Crutchfield-Zellner diagrams are used to illustrate the potential economic losses from maximum sustainable yield regulation or other nonoptimal output.

INTRODUCTION

The task of the International Pacific Halibut Commission, as established by treaty between the United States and Canada, is to regulate the Pacific Halibut Fishery at maximum sustainable yield (MSY). The purpose of this paper is to develop a model which will permit the estimation of the economic losses which may be associated with MSY regulation or other nonoptimal output levels. The model has certain inherent limitations. It is static, deterministic, partial equilibrium, and ignores income distribution and second-best effects. Still, it may be useful in analyzing a fishery not much affected by others, such as the Pacific halibut fishery, and in focusing attention on the potential magnitude of economic losses resulting from the present type of regulation and from a decentralized, unregulated fishery, although, at least at present, it does not provide an answer to the problem of how long run equilibrium is to be attained.

THEORETICAL FOUNDATION

The starting point for the current model is the Crutchfield-Zellner model (1962). Modifications to this model are made which are designed explicitly to account for technological externalities resulting from the common property nature of the fishery, several of the modifications having been developed by Smith (1969), Carlson (1969), Bell (1969), and Worcester (1969), among others. The present paper develops a framework for the estimation of the rent and consumer surplus losses (conventionally defined) resulting from MSY regulation or other nonoptimal output in the static framework outlined above.

Figure 1 depicts the Crutchfield-Zellner model. Growth of the fish stock biomass as a function of stock size is illustrated in Part A, and has the typical characteristics. The decentralized, competitive supply and demand for fish are illustrated in Part B, where the individual "S" curves are "short run" supply curves for fish and show how the amount supplied varies with prices, increases in quantity resulting from additional units of "effort" entering the fishery at higher prices. Decreases in fish stock, such as from OC to OB, result in an upward shift of the S curves, from S-OC to S-OB; hence, with fewer fish exposed to the gear, the costs of catching any given quantity of fish are increased. The curve XX "traces out the locus of points on each of these supply curves which are sustainable; that is, where the catch at the corresponding population will

[1] Department of Economics, Oregon State University, Corvallis, Oregon.

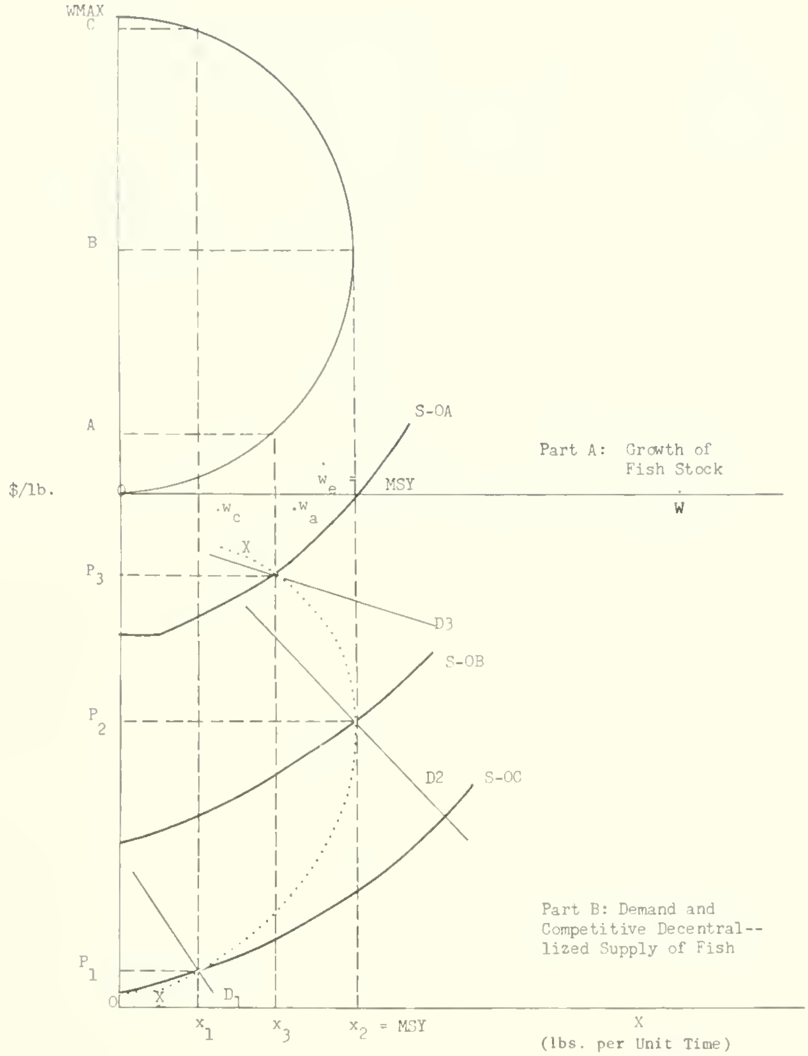

Figure 1. — Industry demand together with competitive supply of fish.

leave population (biomass) constant over time" (Crutchfield and Zellner, 1962).

Since the individual competitive fisherman has no control over the size of the fleet or the stock of fish, these factors do not enter the decision making process of the individual fisherman, although they do enter the cost function. Thus there are technological externalities associated with a fishery — a "congestion" cost, reflecting the decreasing catch per unit effort from a given stock of fish as more vessels enter the fishery, and a "growth" cost, reflecting the decreased catch per unit effort by a given number of units of effort from a reduced biomass of fish, and represented by the upward shifting of the S curves as the stock of fish is reduced.

The curve XX is thus a long run *average* cost curve. A regulatory agency which has as its purpose the maximization of the net economic benefits of a fishery will have to take account of the technological externalities inherent in a common property resource, such as a fishery.

Figure 2 adds Long Run Marginal Cost (including congestion and growth costs) to the Crutchfield-Zellner model. The LRMC curve is the sum of the marginal congestion and marginal growth cost curves, and is asymptotic to MSY since, as sustainable yield harvest increases, equilibrium fish biomass decreases (from its maximum level W_{max}) until eventually a further increase in effort results in a

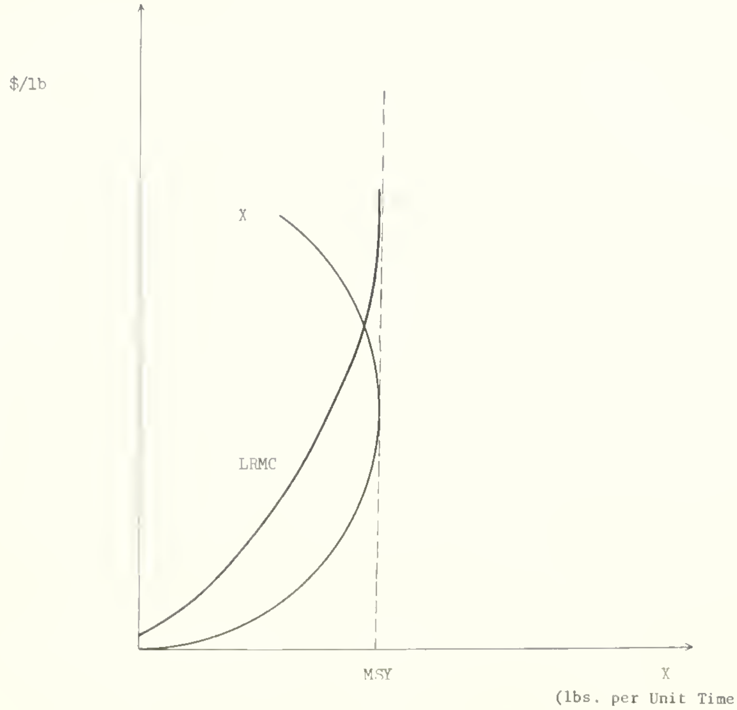

Figure 2. — Longrun marginal cost added to Crutchfield-Zellner model.

zero increase in sustainable yield. That is, the marginal physical product of another unit of effort (in terms of sustainable yield) is zero. This occurs when sustainable yield is maximum, and at this point the cost of an additional pound of fish (in terms of sustainable yield) is infinity (Carlson, 1969). In the static framework of this model, the economic benefits from the fishery are maximized when price is set equal to long-run marginal cost, including congestion and growth costs — that is, where the extra costs of an additional pound of fish are just equal to what consumers are willing to pay for that additional pound.

Assuming a normal downward sloping demand for fish, long run equilibrium under a regulatory agency which sets price equal to marginal cost can be determined, and this equilibrium can be compared with that for an unregulated, competitive regime, and with MSY regulation.

Under a decentralized, competitive regime, the fishery will be in long run equilibrium where the long run average cost curve (including normal returns) is equal to price — point A in Figure 3 — with catch X_0 and price P_0. But, as noted by Carlson (1969, p. 20), "the cost . . . of (harvesting) an additional unit of fish [X_0B] at this level is in excess of what consumers are willing to pay for it" [X_0A]. Since LRMC is always above XX, a competitive fishery always operates in long run equilibrium at a non-optimal output, with too small a stock of fish, although the harvest may be larger than (Figure 3), equal to (Figure 4), or smaller than (Figure 5) the optimum level.

Under the present assumptions (including instantaneous transfer of resources to their next best alternative use, and that demand accurately reflects consumer preferences), the "social" or "welfare" loss of a decentralized as compared to an optimally regulated fishery is the area ABE of Figure 3 — the excess of the extra cost above what consumers are willing to pay for the extra production of fish $X_0 - Y_1$, beyond the level X_1. ABE is also the *extra* value, above the gain in consumer surplus P_1EAP_0 the resources used to produce the extra fish $X_0 - X_1$ could have produced had they been used in their next best alternative

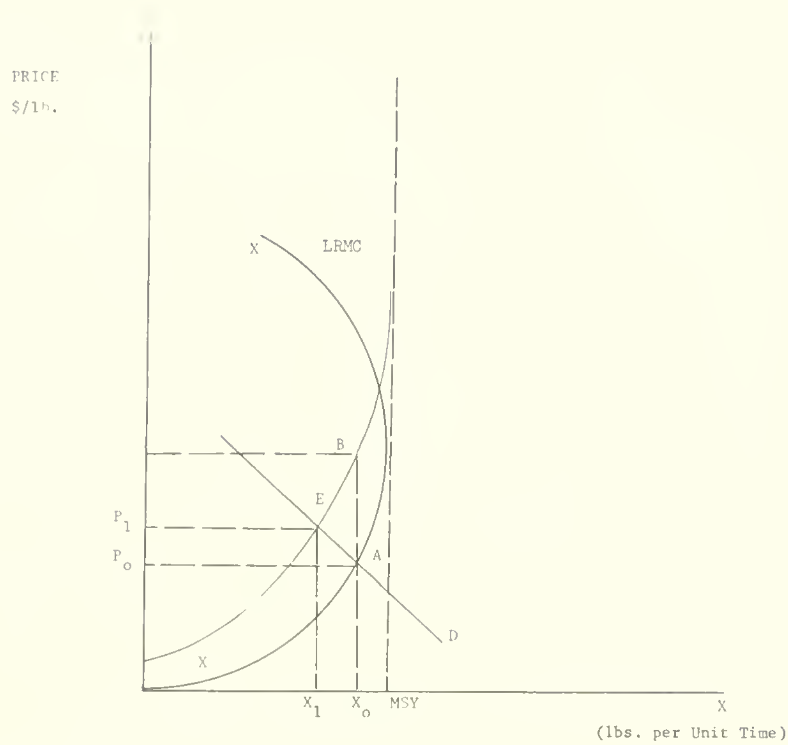

Figure 3. — "Deadweight" loss (Area ABE).

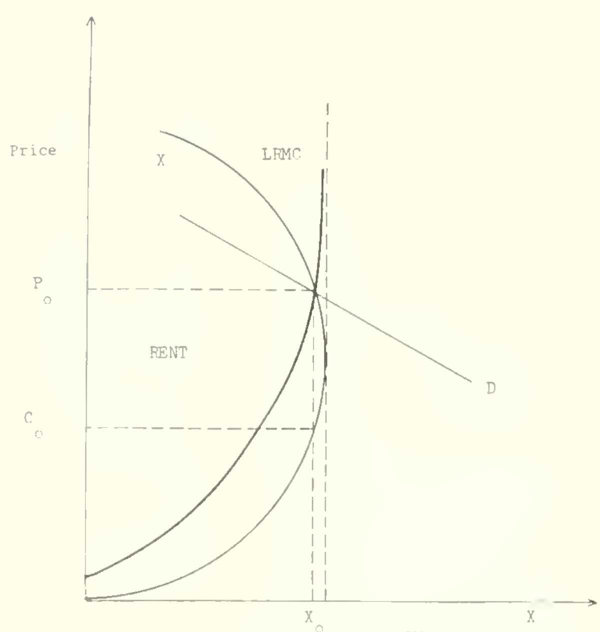

Figure 4. — Identical competitive and regulated output rent loss only (Area $(P_0 - C_0) X_0$).

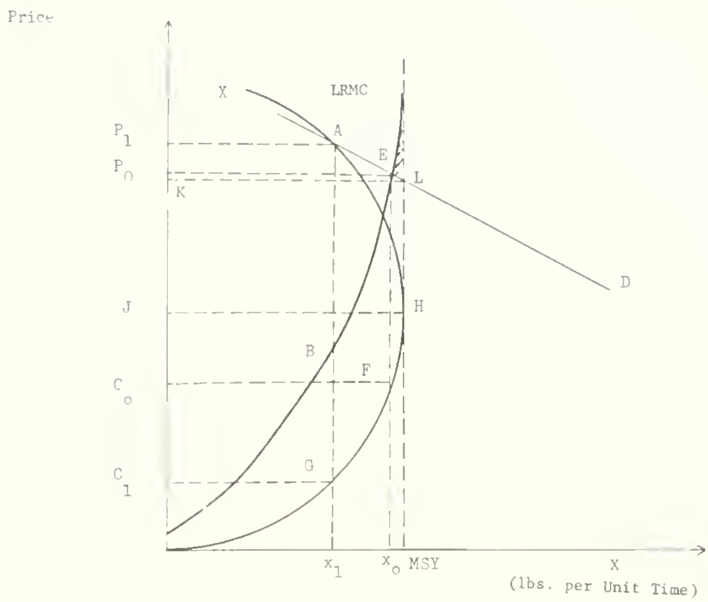

Figure 5. — Comparison of equilibria: competitive output lower than regulated output. (If, with demand as given, output is restricted to MSY, the welfare loss is area HJKL plus the shaded area above the demand curve and to the right of LRMS curve.)

use. In Figures 4 and 5, a rent loss (P_1AGC_1) is also included. In Figure 4, the entire loss consists of rent. That is, output under decentralization and optimal regulation are identical. However, that output would be produced with a much larger stock of fish, and hence lower costs, under optimal regulation than under a regime of decentralization. Thus, all the extra units of effort used to produce output X_0 are "wasted," and could better have been used in other industires.

A MEASUREMENT MODEL

The derivation of marginal congestion and growth costs can be expressed mathematically. This will permit estimation of the production function, once specific growth and catch functions are determined. With the addition of costs and demand, estimation of the welfare losses discussed above may be achieved.

Summarizing all inputs under the umbrella term "effort" (E), catch (X) is a function of effort and the stock of fish (W):

(1) $X = f(E, W)$.

Effort, catch, and stock can all be expressed in terms of the long run equilibrium catch, $\hat{X}$, which will give us an expression in terms of long run equilibrium catch alone:

(2) $E(\hat{X}) = g(\hat{X}, W(\hat{X}))$,

where $E(\hat{X})$ is the effort associated with a long run equilibrium catch of $\hat{X}$, and $W(\hat{X})$ is the stock of fish consistent with a sustainable catch of $\hat{X}$ — i.e., one such that $dW/dt = \hat{X}$. Since cost is a function of effort, we have, for long run equilibrium,

(3) $C = C(\hat{X}, W(\hat{X}))$.

From (3), we can obtain marginal congestion cost, marginal growth cost, and long run marginal cost:

(4) $\text{MCC} = \partial c/\partial \dot{x} = C\dot{x}$

(5) $\text{MGC} = \partial c/\partial \dot{w} \cdot \dfrac{d\dot{w}}{d\dot{x}} = C\dot{w} \cdot \dfrac{dw}{d\dot{x}}$

(6) $\text{LRMC} = \text{MCC} + \text{MGC} = C\dot{x} + Cw \cdot \dfrac{dw}{d\dot{x}}$

Equations (7) — (16) summarize the model developed by J. J. Pella and P. K. Tomlinson for the Inter-American Tropical Tuna Commission (1969) (hereafter called the TC model). The TC biological model results in a curve relating growth of population to population size. It resembles models previously used by the International Pacific Halibut Commission (Southward, 1968) although it is in terms better suited for economic analysis. The biological portion of the TC model will be used in what follows for an unexploited fishery. In the discussion of an exploited fishery modifications will have to be made to take account of the congestion phenomenon, and this will be achieved by use of the Carlson "engineering" function for a fishery (1969).

In the TC model the growth of the fish stock is

$$(7)\quad dW_t/dt = HW_t^{m} - KW_t$$

where H, K, and m are constants. Limiting population to some absolute maximum W_{max}, and integrating (7) yields the population at any time t:

$$(8)\quad W_t = [W_{max}^{1-m} - (W_{max}^{1-m} - W_0^{1-m}) \times e^{-K(1-m)t}]^{1/1-m}$$

where W_0 is the population at time zero, and

$$(9)\quad W_{max} = (K/H)^{1/(m-1)}$$

Further, W_{msy}, the stock which yields the maximum sustainable yield, can be expressed as

$$(10)\quad W_{msy} = (K/mH)^{1/(m-1)}$$

The TC model for an exploited fishery hypothesizes a constant "catchability coefficient," q, which is the fraction of the population caught by a standard unit of fishing effort per unit of time. The model assumes that the instantaneous catch rate, dX_t/dt, can be expressed as:

$$(11)\quad dX_t/dt = qf_tW_t,$$

where f_t is the number of units of effort applied to the fishery at time t. It is the assumption that qf varies in the same proportion as q or f that must be modified to take account of the congestion externality. The TC model implies a constant short run marginal physical product of effort, and hence a constant short run marginal cost of fish, at least until the stock of fish is exhausted. This assumption does not hold for the Pacific halibut fishery, and may not hold for any fishery. However, maintaining the TC assumptions for the moment, (7) for an unexploited fishery becomes

$$(12)\quad dW_t/dt = HW_t^{m} - KW_t - qf_tW_t$$

for an exploited fishery.

With effort constant in the time interval $(0, t)$, and excluding those cases in which the stock of fish is fished to extinction, integration of (12) yields

$$(13)\quad W_t = \left[\frac{H}{k+qf} - \left(\frac{H}{k+qf} - W_0^{(1-m)}\right) e^{-(k+qf)(1-m)t}\right]^{1/1-m}.$$

Eliminating the time variable, and considering only those populations that have adjusted to the given constant level of effort (i.e., as t approaches infinity), we have

$$(14)\quad W = \left(\frac{qf+k}{H}\right)^{1/m-1}$$

Biological equilibrium when catch (X) is equal to growth of the fish stock is

$$(15)\quad X = HW^{m} - KW = qfW.$$

From (15) we can now express biological equilibrium catch as a function of effort:

$$(16)\quad X = qf\left(\frac{qf+k}{H}\right)^{1/m-1}$$

To take account of congestion externalities the Carlson "engineering" function will be used. Let k be the fraction of a stock of fish caught by the first unit of effort applied to the fishery; assume that two units of effort catch not $2k$ of the original stock, but only $k + k(1-k)$ of the initial stock. That is, each unit of effort catches a fraction k of the stock remaining after all previous units of effort have been applied to the fishery. For N units of effort the fraction, F, of a fish stock caught is

$$(17)\quad F = 1 - (1-k)^{N}$$

where total catch is

$$(18)\quad X = (1 - (1-k)^{N})W$$

or, writing W in terms of N

$$(19)\quad X = [1 - (1-k)^{N}]\left[\frac{1-(1-k)^{N} + k}{H}\right]^{1/m-1}.$$

That is, whenever we find qf in equation (16) we replace it with equation (17).

Restricting ourselves to equilibrium values (that is, where catch is equal to growth), differentiation of (18) with respect to N yields the marginal physical product of effort in long run equilibrium:

$$(20)\quad d\hat{X}/d\hat{N} = -(1-k)^{\hat{N}}\ln(1-k)\hat{W} + [1 - (1-k)^{\hat{N}}]d\hat{W}/d\hat{N}$$

The first expression on the right of (20) is the short run marginal physical product of another unit of effort, and is always positive for any positive W, and declines as N increases, thus illustrating short run diminishing returns. The second expression on the right of (20) shows the effect on long run equilibrium catch of another pound of fish stock, and is equal to the percentage of the stock caught by N units of effort multiplied by the change in equilibrium stock resulting from a marginal change in equilibrium effort. Thus, (20) includes both congestion and growth externalities.

Solving explicitly for $d\hat{W} / D\hat{N}$ and rearranging terms can also yield the expression for $d\hat{X} / d\hat{N}$ in terms of W, N, and the parameters k, m, and H:

$$(21)\quad d\hat{X}/d\hat{N} = -[(1-k)^{N}\ln(1-k)]\left[\frac{1-(1-k)^{N}}{(m-1)H}\cdot W^{2-m} + W\right].$$

If we assume that the cost per unit of effort is some constant A, then the marginal cost per pound of fish under biological equilibrium conditions, and including both congestion and growth externalities (the long run marginal cost, LRMC) is

$$(22)\quad \text{LRMC} = A/(d\hat{X}/d\hat{N}).$$

Estimation of the parameters H, K, m, and k, together with data on demand and the cost of effort can be used to estimate long run equilibrium catch and the welfare losses in any year associated with MSY regulation or other nonoptimal output.

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Production from the Sea

Frederick W. Bell, Ernest W. Carlson, and Frederick V. Waugh[1]

ABSTRACT

The sea constitutes a common property resource which causes factor productivity to be heavily influenced by technological externalities. The sea is also subject to the spectre of Malthusian scarcity since man cannot manipulate the ocean environment (Barnett and Morse, 1963). We estimated the parameters using ordinary least squares of the dynamic Schaefer production model of the intervention of man into the oceanic ecosystem. A second production model for the sea to specify diminishing returns to capital and labor for any fixed biomass was developed. The parameters of the latter model were estimated by a computer search technique. The results indicate that the industry production function for marine life is subject to diminishing physical returns to capital and labor. For the cases considered in this study it also appears that the parabolic yield function developed by Schaefer, assuming constant returns to factors inputs, is not as realistic as a production function with diminishing returns to inputs with a given biomass.

INTRODUCTION

After explaining the principle of diminishing returns in agriculture, that great economist, Alfred Marshall (1920, p. 166) wrote:

> As to the sea, opinions differ. Its volume is vast, and fish are very prolific; and some think that a practically unlimited supply can be drawn from the sea by man without appreciably affecting the numbers that remain there; or in other words, that the law of diminishing returns scarcely applies at all to sea-fisheries; while others think that experience shows a falling-off in the productiveness of those fisheries that have been vigorously worked, especially by steam trawlers. The question is important, for the future population of the world will be appreciably affected as regards both quantity and quality, by the available supply of fish.

We have waited 50 years to answer Marshall's question. We must not wait much longer. The world's population will double by the year 2000. What will happen to the production, prices, and consumption of fish (Bell et al., manuscript)?

As in Marshall's day, some doubtless still think that the future supply of fish is practically unlimited. But those biologists and economists who are studying fisheries doubt this. They know that some species of fish have already been "overfished"; that is, increased inputs of capital and labor have actually *reduced* yields. Examples are menhaden and haddock in the Atlantic fisheries. Biologists have found that the catches of eastern tropical Pacific yellowfin tuna and of northeastern Pacific halibut have reached their "maximum sustainable yields." International controls have been found necessary to prevent depletion of the aforementioned species.

Of course, these are only a few of the many species of commercial fish. But we doubt if any fishery biologist today would be among those who Marshall said, " . . . think that a practically unlimited supply can be drawn from the sea." To be sure, the sea is vast, but Ryther (1969), a prominent biologist, says:

> The open sea — 90% of the ocean and nearly three-fourths of the earth's surface — is esentially a biological desert. It produces a negligible fraction of the world's fish catch at present and has little or no potential for yielding more in the future.
>
> Upwelling regions, totaling no more than about one-tenth of 1% of the ocean surface (an area roughly the size of California) produce about half the world's fish supply. The other half is produced in coastal waters and the few offshore regions of comparably high fertility.

We could cite many other fishery biologists

[1] The authors are respectively Chief and Economist, Economic Research Laboratory, National Marine Fisheries Service, and Professor, Department of Agricultural Economics, University of Maryland. The ideas expressed in this article do not necessarily reflect the official position of the National Oceanic and Atmospheric Administration (NOAA).

to indicate that the potential supply of fish from the sea is limited. But, even if there were no fixed limit to fish production, we believe that diminishing returns would apply to fisheries at least as much as to agriculture; perhaps more. This has important implications to public policies, as Marshall noted. Hence, the purpose of this article is to explore the production function for the sea.

DIMINISHING RETURNS OF FISHERIES

Marshall's (1920, p. 150) first statement of the law of diminishing returns in agriculture was:

> An increase in capital and labour applied in the cultivation of land causes *in general* a less than proportionate increase in the amount of produce raised, unless it happens to coincide with an improvement in the arts of agriculture.

In the case of fisheries, indices of capital and labor inputs are known as "effort." Diminishing returns from fishing means (paraphrasing Marshall) that an increase in effort results in less than a proportionate increase in the yield of fish, assuming no change in technology. Thus, if effort were doubled, the yield would be less than doubled.

But if we are to manage the world's fisheries well, we need more than general comments about diminishing returns — we need usable estimates of the effort-yield functions for the major species of fish. Schaefer (1954) wrote a pioneering paper on the theory and measurement of such functions. In recent years, many biologists have added to the theory in this area, and have presented important statistical verifications and measurements (Pella and Tomlinson, 1969; Fox, 1970).

The necessary theory is in two parts: (1) the theory of biological growth, and (2) the theory of yield from a given biomass.

Theory of Biological Growth

First, consider biological growth — for example, the growth of "biomass" or the total weight of marketable fish. Schaefer (1954), hypothesized that if there were no fishing, the growth curve of the biomass would look something like that shown in Figure 1. The species, in each region, would tend to approach some maximum biomass, M. Here natural mortality would just offset recruitment (from young stock) and growth in body size.

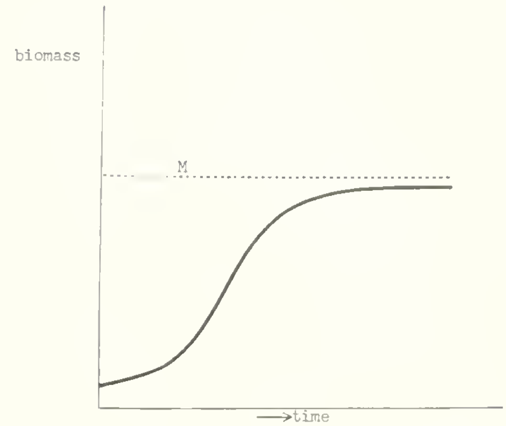

Figure 1. — Growth with no fishing.

A curve commonly used to represent such growth is the logistic,[2]

$$(1) \quad m_t = \frac{M}{1 + be^{-at}}$$

where m_t is the biomass at time t, M is the potential maximum biomass, e is the base of natural logarithms, t is time, and a and b are parameters. (We shall generally measure time in years.) Davis (1941) discussed the properties of this curve in detail, and gave many references to its uses in biology and in the study of growth of human populations. Its derivative is:

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[2] Most work using the logistic has been done with numbers in populations, here we are applying it to the total weight of the population. Tomlinson and Pella (1969) have suggested that the following function be used to approximate biological growth:

$$\frac{dP(t)}{dt} = HP^{m}(t) \quad KP(t)$$

When $m = 2$, the growth function becomes the well-known logistic or as used by Gulland, an autocatalytic equation. Fox (1970) has suggested a Gompertz function to approximate biological growth.

(2) $dm_t/dt = am_t\left(1-\frac{m_t}{M}\right)$.

So the proportional rate growth (with no fishing) is:

(3) $\frac{dm_t}{m_t dt} = a\left(1-\frac{m_t}{M}\right)$.

The second derivative of (1) is:

(4) $\frac{d^2 m_t}{dt^2} = a^2 m_t\left(1-\frac{m_t}{M}\right)\left(1-\frac{2m_t}{M}\right)$.

Maximum absolute growth occurs when (4) equals zero; that is, when $m_t = \frac{1}{2}M$ (when current biomass is one-half the potential maximum). At that point, equation (2) shows that the maximum growth, $dm_t/dt = aM/4$.

Suppose $aM/4$ were taken from the biomass each year by fishermen: each year, the biomass would grow by $aM/4$; biological growth would just offset the amount taken by fishermen; and there would be a steady-state equilibrium.

The Theory of Yield from a Given Biomass

We now consider how yield responds to effort when we abstract from changes in biomass. Schaefer (1954) made the simple assumption that the catch m_t would be proportional to effort, k is the constant of proportionality, and x_t is effort:

(5) $y_t/m_t = kx_t$.

Schaefer assumed that, with a given biomass, there would be constant returns to effort; doubling the effort would double the yield, tripling the effort would triple the yield — and so on. As a first approximation, this may be adequate in many cases within the observed range of the data. Schaefer and others have used it to make many important estimates of maximum sustainable yield; and as a basis for economic controls.

But we think that a more realistic catch function is:

(6) $y_t/m_t = (1-z^{x_t})$,

with $0 < z < 1$, and with m_t fixed.

The rationale of (6) was explained by Carlson (1969). Briefly, assume that the original biomass is m_t and that one unit of effort will catch pm_t, leaving $(1-p)m_t$: assume that the next unit of effort will catch the same proportion of the remaining biomass — that is, it will catch $p(1-p)m_t$, leaving $(1-p)^2 m_t$. The same reasoning shows that n units of effort will catch ([illegible]). In equation (6), we simply let $z = 1-p$. We believe that on an *a priori basis* (6) is more realistic than is (5). But probably there is no magic mathematical formula that is exactly right for all species and for all amounts of effort.

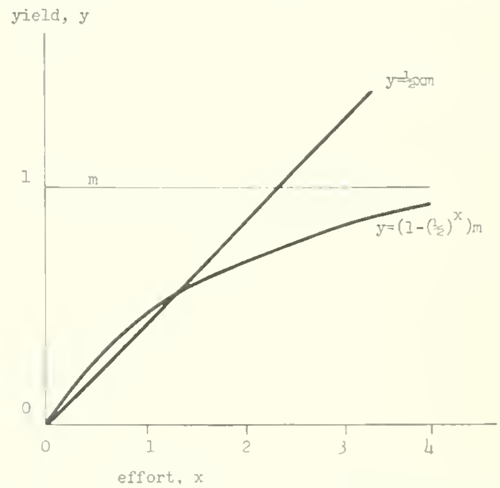

Figure 2. — Two yield functions. (Based upon equations 5 and 6, assuming that one unit of effort yields one-half of the existing biomass.)

Figure 2 compares the growth functions represented by equations (5) and (6). Each assumes that one-half the existing biomass was caught with one unit of effort in some base period. (The units are arbitrary. We find it desirable to "normalize" both yield and effort by dividing by the base-period data.) Note that equation (5) would indicate that the entire biomass would be caught with two units of effort. But equation (6) would indicate that if effort were increased indefinitely, the existing biomass would be approached as a limit, but never quite reached. Within the observed range of historical data, it may not be easy to choose between the two curves in Figure 2. But they give far different results when they are extrapolated to estimate the effects of large increases in effort. This is especially critical where one must make forecasts of the likely effect of the expansion in fishing effort.

STATIONARY STATE EQUILIBRIUM

The stationary state equilibrium is found by letting annual yield equal annual growth:

(7) $\hat{y}_t/\hat{m}_t = \frac{1}{m_t}\left(\frac{dm_t}{dt}\right)$

where y is the equilibrium yield and m_t is the corresponding biomass. Thus, Schaefer let:

(8) $kx_t = a\left(1 - \frac{\hat{m}_t}{M}\right)$

Solved for m_t

(9) $m_t = M\left(1 - \frac{kx_t}{a}\right)$

and got the equilibrium yield as a function of effort:

(10) $\hat{y}_t = \hat{m}_t k\hat{x}_t = Mk\hat{x}_t\left(1 - \frac{k\hat{x}_t}{a}\right)$.

This is a simple quadratic. To estimate it from statistical data using ordinary least-squares, we write:

(11) $\hat{y}_t = Ax_t - Bx_t^2$

where $A = Mk$ and $B = \frac{Mk^2}{a}$.

The graph of (11) is shown in Figure 3. Note that while Schaefer assumed constant returns from a fixed biomass, his curve of equilibrium yield indicates decreasing returns. In fact, average yield per unit of effort is easily seen to be (by dividing (9) by x),

(12) $y_t/x_t = A - Bx_t$.

If we use (6), instead of (5) as an estimate the response of yield to effort with a fixed biomass, we have:

(13) $1 - z^{x_t} = a\left(1 - \frac{\hat{m}_t}{M}\right)$.

Solving for m, we find:

(14) $\hat{m}_t = M\left[1 - \left(1 - \frac{z^{x_t}}{a}\right)\right]$.

So the steady-state equilibrium yield is:

(15) $\hat{y}_t = \hat{m}_t(1 - z^{\hat{x}_t}) =$

$$M\left[\left(1 - z^{\hat{x}_t}\right) - \frac{1}{a}\left(1 - z^{\hat{x}_t}\right)^2\right];$$

that is,

(16) $\hat{y}_t = C(1 - z^{\hat{x}_t}) - D(1 - z^{\hat{x}_t})^2$

where $C = M$ and $D = M/a$.

This is not as easy to fit statistically as is the Schaefer function (11). It can be handled without undue difficulty on a computer by a "search method," trying a series of values for z; in each case computing R^2, the Durbin-Watson statistic (D-W), and the t values of the two regression coefficients; then by interpolation we find the "best" fit.

Equations (15) and (16) indicate decreasing returns to effort. Their graph is like that in Figure 4. In this case — which we think is more realistic — we get diminishing returns for two reasons:

1. Because annual growth declines as the fish population increases, and

2. Because the yield-per-unit-of-effort declines with effort; that is, doubling the effort will result in less than doubling the yield, even with a fixed biomass. The net result is a much flatter curve after MSY is reached.

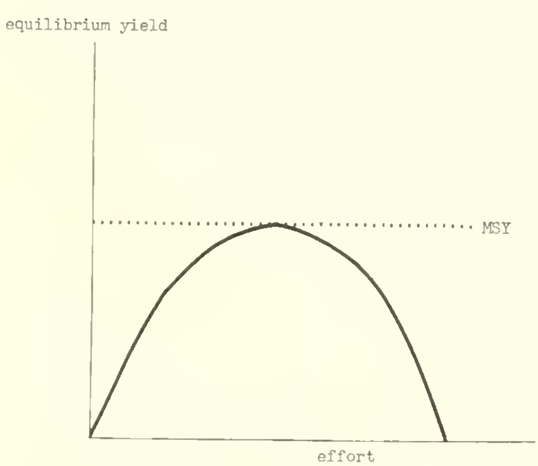

Figure 3. — Equilibrium yield-effort with constant returns.

STOCK ADJUSTMENT MODEL

So far, we have considered only the steady-state equilibrium. This assumes that full adjust-

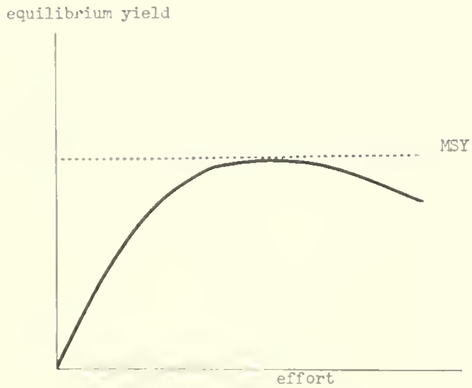

Figure 4. — Equilibrium yield-effort with diminishing returns.

ment is made instantaneously, thus the present catch is a function of the present effort only. This may give a satisfactory approximation for some species. But in other species, several time periods may be required to establish a new equilibrium. In such cases, current yields are affected not only by current effort, but also by the efforts of several past periods.

That is, annual observations on catch and effort do not represent equilibrium observations. To remedy this situation, biologists have suggested various adjustments to the data (Appendix I).

In reality, the observed catch in any given year may be the result of effort expended in previous periods; i.e., the observed catch is some kind of weighted average of catch produced by fishing effort in previous periods. The Gulland procedure employs a similar assumption in that it assumes that this year's observed catch is parabolically related to a simple average of previous effort. An alternative specification of the yield effort-relation for many stocks of fish may take the following form (assuming for example a logistic and constant returns equilibrium relation):

$$(17)\quad y_t = ax_t - bx_t^2 + a_1 x_{t-1} - b_1 x_{t-1}^2 + \dots \epsilon_t .$$

Let us now make the classic assumptions about the disturbances, ϵ_t, of constant variance and zero covariance.

Although (17) is a general specification of the yield-effort relationship, its estimation presents obvious difficulties. Since our sample will be finite in size, the infinite set of lagged regressors must be terminated at some point. Also, there is likely to be colinearity among the successive regressors.

One way of solving the problem is to hypothesize that the coefficients on the lagged variables diminish in size as the time period is more distant from the present observation on catch. Put differently, let us hypothesize that the coefficients on successive x's decline systematically as we go further back in time. This was suggested by Fisher (1925); more recently it has been revived and extended by Koyck (1954) and by Nerlove (1958). We shall call this a Koyck specification. Koyck hypothesized that a useful approximation would be that the coefficients of (17) decline geometrically:

$$(18)\quad a_k = a\lambda^k \quad (k = 0, 1, \dots) \text{ and}$$

$$(19)\quad b_k = b\lambda^k \quad (k = 0, 1, \dots).$$

(17) may be rewritten as the following:[3]

$$(20)\quad y_t = ax_t - bx_t^2 + \lambda a x_{t-1} - \lambda b x_{t-1}^2 + \dots \epsilon_t .$$

If we lag (20) by one period and multiply by λ, we obtain

$$(21)\quad \lambda y_{t-1} = \lambda a x_{t-1} - \lambda b x_{t-1}^2 + \lambda^2 a x_{t-2} - \lambda^2 b x_{t-2}^2 + \dots \lambda\epsilon_{t-1}$$

Now, subtract (21) from (20) and rewrite:

$$(22)\quad y_t = ax_t - bx_t^2 + \lambda y_{t-1} + \varepsilon_t$$

where

$$(23)\quad \varepsilon_t = \epsilon_t - \lambda\epsilon_{t-1} .$$

[3] Equation (20) may be interpreted to mean that observed catch depends on this year's effort (a common assumption used by many population dynamicists) plus effort expended in previous periods. This is merely a hypothesis that can be tested empirically.

Equation (22) may be estimated using ordinary least-squares.[4]

Nerlove provides an alternative theory to justify (22). Suppose that x_t determines y_t^*, the "equilibrium value" of catch,

$$(24)\quad y_t^* = ax_t - bx_t^2,$$

but that the adjustment to the equilibrium value in one period is only gradual (i.e., not complete):

$$(25)\quad y_t - y_{t-1} = \delta(y_t^* - y_{t-1})$$

where $0 < \delta < 1$ is the coefficient of adjustment. Inserting (24) into (25) and rewriting gives the same form as (22):

$$(26)\quad y_t = a\delta x_t - b\delta x_t^2 + (1-\delta)\, y_{t-1}$$

where $(1-\delta) = \lambda$.

Using (26) or (22), we may also compute how many periods it takes one-half the gap to be filled. If y_{t-1} is in equilibrium, then the gap at period $t(G_t)$ is equal to the following:

$$(27)\quad (y_t^* - y_{t-1}) = G_t.$$

Each period a constant percentage of the remaining gap is filled; so that at time $t + k$ the remaining gap is

$$(28)\quad G_{t+k} = G_t\,(1-\delta)^K.$$

If $K = 0$, (29) indicates that *all* the gap remains to be filled. When will one-half of the initial gap be filled? This may be found by substituting $\frac{1}{2}G_t$ for G_{t+K}, or

$$(29)\quad G_t\,(1-\delta)^K = \tfrac{1}{2}.$$

Hence,

$$(30)\quad (1-\delta)^K = \tfrac{1}{2},$$

or

$$(31)\quad K = \log 1/2 \div \log(1-\delta) = \frac{\log 2}{\log\left(\frac{1}{1-\delta}\right)}.$$

K is the "half-life"; that is, the number of periods required to cut the gap in half. In $2K$ years, the gap will be reduced to ¼; in $3K$ years to ⅛ . . . and so on. It would never completely disappear. In theory, K should be related to the following biological factors:

(1) Fertility of the species (i.e., number of eggs laid and reaching full term);

(2) Rate of growth of the species (i.e., how many periods it takes to reach maturity). K should be large for relatively unfertile and slowly growing species and small for very fertile and rapidly growing species.

In sum, we are interested in eight estimating equations. First, a group of four equations based upon the assumption of constant returns from a fixed biomass; these are all designated LCR (logistic constant returns). LCRa is the static function with total yield, y_t, dependent. LCRb is the same with average yield per unit of effort, y_t/x_t, dependent. Then LCRaS and LCRbS are lagged or stock adjustment models. This gives us four functions. There are four more (designated LDRa, LDRb, LDRaS, and LDRbS) based upon the assumption of decreasing returns from a fixed biomass. Finally, we have included an estimate of the parameters of LCRa using the Gulland technique for adjusting the effort series.[5]

RESULTS OF THE ANALYSES

In order to illustrate the applicability of our theoretical yield functions, we selected five species for consideration: (1) Chesapeake Bay menhaden; (2) Atlantic and Gulf blue crab; (3) Atlantic longline tuna; (4) Soviet and Japanese king crab fishery in the eastern Bering Sea; and (5) Cape Flattery sablefish.

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[4] In essence, a researcher attempting to estimate the parameters of the yield function can run the following regressions: $y_t = ax_t - bx_t^2$,

$$y_t = ax_t - bx_t^2 + \lambda y_{t-1} \text{ or } y_t = a\left[\frac{x_t + x_{t-1} + \ldots + x_{t-n}}{n+1}\right] - b\left[\frac{x_t + x_{t-1} + \ldots + x_{t-n}}{n+1}\right];$$

where $(n + 1)$ is the number of years the fish are in the fishery. The latter is the Gulland technique where the first two specifications are with and without the Koyck formulation respectively. Equation (20) may be specified as the following:

$$(y/x)_t = a - bxt - \lambda bx_{t-1} - \ldots - \lambda^k bx_{t-k}.$$

With this form, the final estimating equation will have (y/x) as a lagged independent variable.

[5] For the five fisheries studied (below) the fish are in the fishery about two years. Therefore, a two-year moving average of effort was computed.

Chesapeake Bay Menhaden

Table 1 shows the empirical results for this fishery. Based upon the R^2 criterion, LDRa represented the "best" function where total catch was used as an independent variable. There is no doubt from the statistical analysis that the Schaefer function (LCRa) is definitely inferior when compared to the LDRa model in its ability to describe the catch-effort relation in the menhaden fishery. No evidence of autocorrelation was detected in the LDRa function. As shown by LDRaS, there seems to be no stock adjustment effect as the coefficient on the lag variable is not statistically significant. Among all the functions, LDRb shows the best fit when catch per unit of effort is used as the dependent variable. From a theoretical point of view, there should be no difference between the "a" and "b" functions. However, the statistical estimation procedure does yield two estimators for each parameter. LDRa and LDRb do yield similar estimates of y^* and x^*. Also, the Gulland -LCRb equation yielded very similar estimates of y^* and x^* as the LCRb (unadjusted data). Further the choice between the "a" and "b" functions should be made on the basis of just what one wants to predict — catch or catch per unit of effort. The LCR and LDRa functions are shown in Figure 5. It should be noted that in equation (16) $M = A$. Thus, the LDRa equation estimated by least-squares will also yield the maximum biomass *without fishing*. That is, MSY = $M/4$ = 158.7 thousand tons. M is therefore equal to 634.8 thousand tons. The logistic function can be directly computed since $a = A/B$ and $a = 1.1512$, and if $t = 0$ at the point of maximum growth, then

$$m_t = \frac{M}{2} = \frac{634.8}{1 + be^0}\text{ , so } b = 1\text{, or}$$

$$m_t = \frac{634.8 \text{ thousand tons}}{1 + e^{\;1.1512t}}$$

This is one additional advantage of the LDRa over the LCRa function.

Atlantic and Gulf Blue Crab

Table 2 shows the empirical results for this fishery. Based upon the R^2 criterion, it would seem that we have little basis on which to choose between the LCRaS and the LDRaS models, each having an R^2 of 0.94. Both show a strong stock adjustment effect. The half-life for the adjustment process was 0.57 years. In this case, the data cannot adequately distinguish between the two functions. The MSY ranges from 129.6 million pounds in the LCRaS model to 189.0 million pounds in the LDRaS model. The autocorrelation test for the two functions is inconclusive. Hence, the choice between the functions must be made on *a priori* grounds. Since the LDRaS model seems more plausible on *a priori* grounds, it would seem that this function should be selected for fishery management purposes. As the fishery expands, additional data will be generated to verify the existence of one or the other function. This general prescription will probably apply to many fisheries where data are only available in the upward expansion phase (i.e., catch is below MSY). Finally, as with Chesapeake Bay menhaden, there seems to be little difference between Gulland LCRb and LCRb unadjusted. Figure 6 shows the two functions discussed above.

Atlantic Longline Tuna

Table 3 shows the results for the Atlantic longline tuna fishery. On the basis of R^2, the LDRa model is superior in predicting changes in catch in response to effort. The stock adjustment coefficient was not statistically significant. The autocorrelation test is inconclusive for LDRa. The MSY for the LDRa function is 106.7 thousand metric tons with 140.1 million hooks of effort. Notice that the MSY's associated with the LCRa and LDRa functions are not appreciably different; however, the number of hooks necessary to harvest MSY is vastly different. This is due to the flatness of the function generated by the LDRa model. The Gulland-LCRb gives a much higher estimate of y^* and a lower estimate of x^* than the unadjusted LCRb. Figure 7 shows the LCRa and LDRa functions.

Bering Sea King Crab

Table 4 shows the results for the Bering Sea king crab fishery. On the basis of R^2, the LDRa model is the best in "explaining" the catch-effort

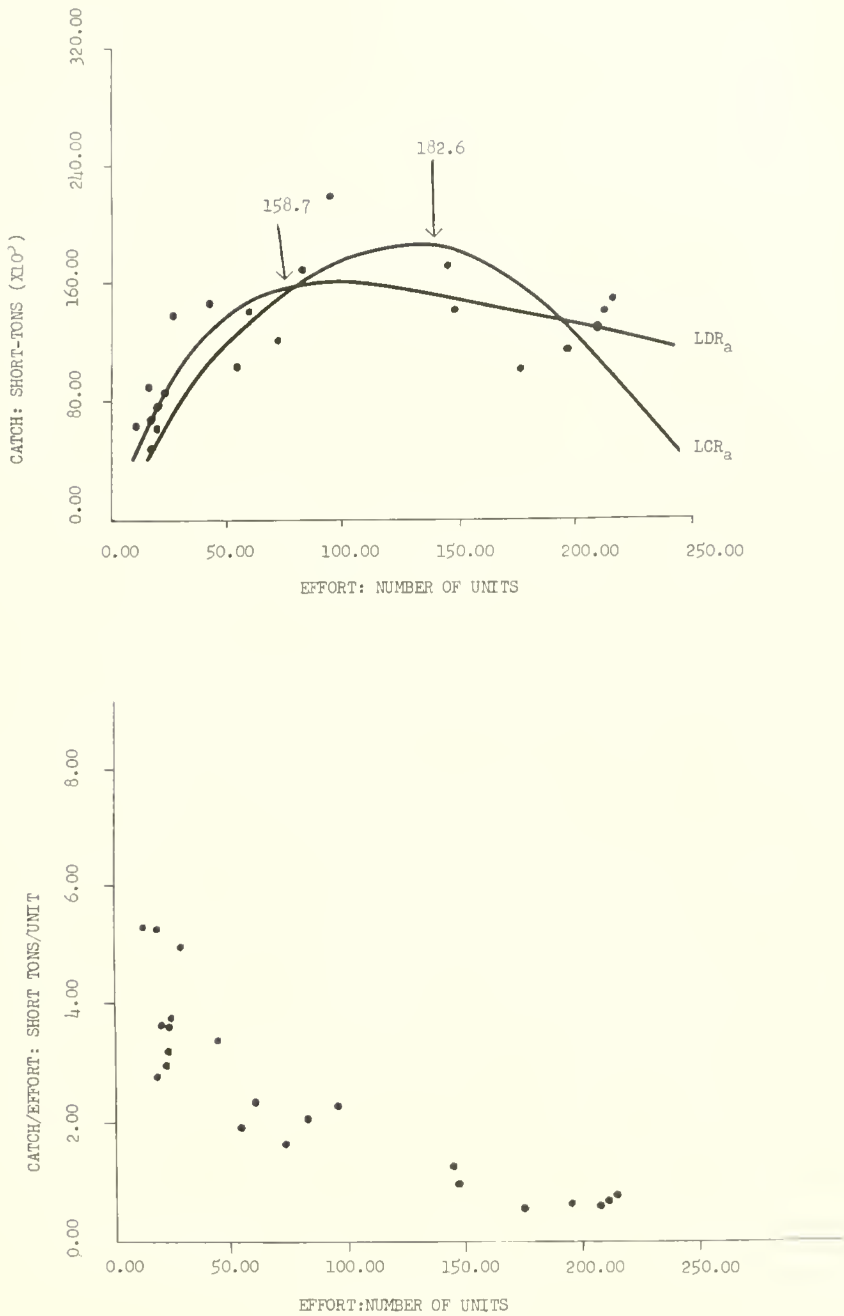

Figure 5. — Chesapeake Bay menhaden fishery, 1946-68: Catch, effort, and catch per unit of effort.

Table 1 — Chesapeake Bay menhaden: yield-effort functions.†

Function	Empirical estimates	R^2	D-W	Note	K (half-life)	MSY short tons	Max. effort No. of Units
Gulland (LCRb)	$y_t \; (x_t + x_{t-1})/2 = 4.70629 - 3.4578\,(x_t + x_{t-1})/2$	.71	3.28 △			222,000	108.0
LCRa	$y_t = 3.25287\,x_t - 2.01105\,x_t^2$	.29	1.03 ▽			182,581	128.6
LCRb	$(\frac{y}{x})_t = 4.39781 - 3.13725x_t$	.77	1.16 ▽			213,928	111.4
LCRaS	$y_t = 1.88162x_t - 1.8915x_t^2 + .44965y_{t-1}$	.44	1.87		.86	187,732	125.8
LCRbS	$(\frac{y}{x})_t = 3.13581 - 2.25857x_t + .307982\# \frac{y_{t-1}}{x_t}$	.78	1.42		.59	151,081	110.4
LDRa	$y_t = 3.9692\,(1-.25^{x_t}) - 3.44565\,(1-.25^{x_t})^2$	.63	1.91			158,665	98.4
LDRb	$(\frac{y}{x})_t = 4.45944\,\frac{(1-.30^{x_t})}{x_t} - 4.25226\frac{(1-.30^{x_t})^2}{x_t}$	.82	1.37 ▽			162,288	98.1
LDRaS	$y_t = 4.12472(1-.25^{x_t}) - 3.57599(1-.25^{x_t})^2 - .04\# y_{t-1}$	.63	1.84		NA	158,485	98.6
LDRbS	$(\frac{y}{x})_t = 4.61018\frac{(1-.30^{x_t})}{x_t} - 4.38835\frac{(1-.30^{x_t})^2}{x_t} - .037\# y_{t-1}$	.82	1.34 ▽		NA	162,115	98.4

L = Logistic growth
CR = Constant returns to fixed biomass
DR = Decreasing returns to fixed biomass
a = total function
b = average function

† = All variables expressed as absolute value divided by 1960-64 average for standardization purposes.

S = Stock adjustment model (Koyck function)
# = not statistically significant at 5 percent level
1 = R^2 selected by search procedure was not highest, but did yield maximum for function. Highest R^2 yielded no maximum for function or data insufficient at maximum R^2 to estimate MSY.
Sample size = 23 (1946-68)

△ Durbin-Watson Statistic (D-W) indicates autocorrelation is present at the 5% level. Estimates of the parameters are unbiased but their variances are unduly large

▽ D-W is inconclusive.

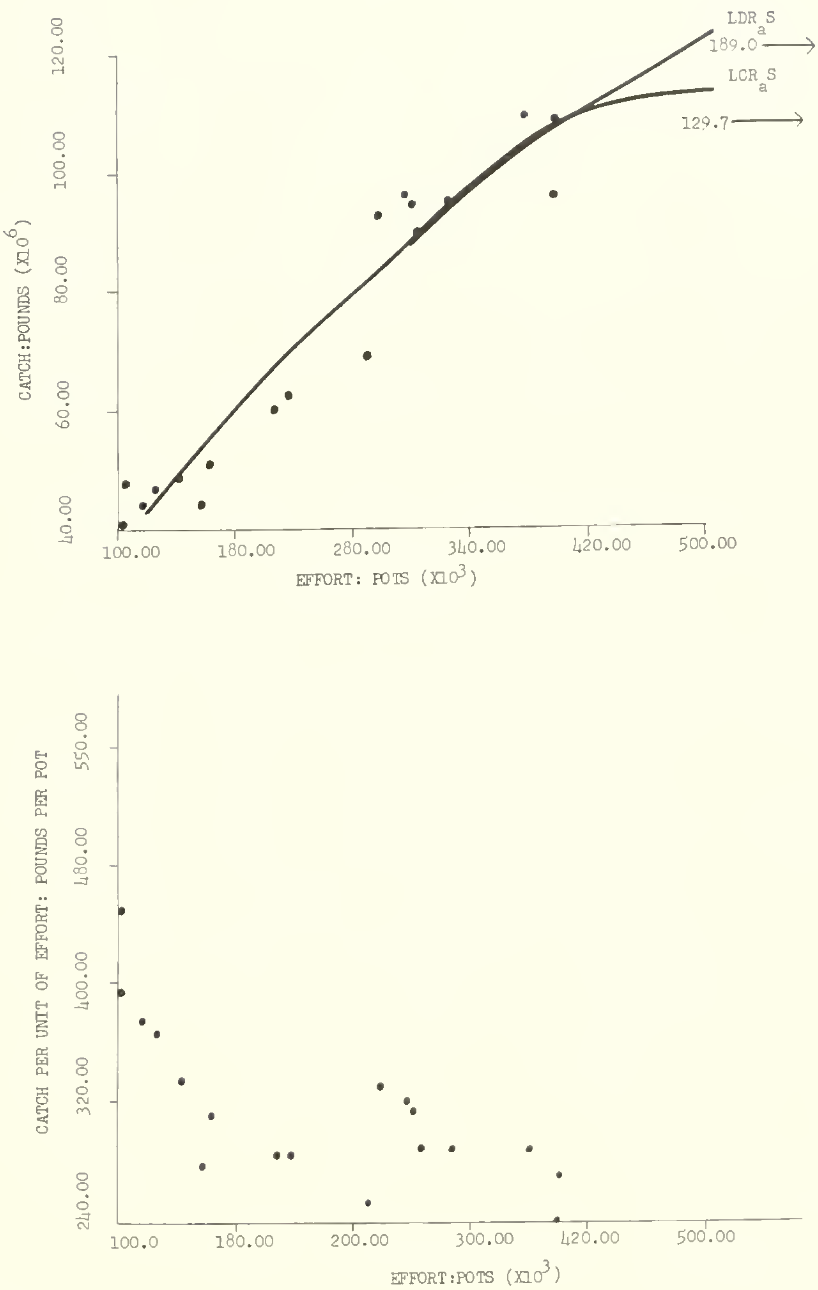

Figure 6. — Atlantic and Gulf blue crab pot fishery, 1950-67: Catch, effort and catch per unit of effort.

Table 2 — Atlantic and Gulf blue crabs: yield-effort functions.†

Function	Empirical estimates	R^2	D-W	Notes	K Half-life	MSY Thou. lbs.	Max. efforts No. of pots
Gulland (LCRb)	$y_t/(x_t + x_{t-1})/2 = 1.3165 - .2507\,(x_t + x_{t-1})/2$	.51	1.03 ▽			122,710	622,000
LCRa	$y_t = 1.22444x_t - .19914x^2_t$	.93	1.18 ▽			135,170	731,430
LCRb	$(y/x)_t = 1.27126 - .23732x_t$	.49	.91 △			122,266	637,239
LCRaS	$y_t = .89723x_t - .15821\,x^2_t + .29526y^{\#}_{t-1}$	.94	1.57		.57	129,632	674,635
LCRbS	$(y/x)_t = .74090 - .12752x_t + .42052\,\frac{y_{t-1}}{x_t}$	.70	1.80		.80	77,288	691,165
LDRa	$y_t = 24.0972\,(1.95^{x_t}) - 72.2439(1-.95^{x_t})^2$	.93	1.17 ▽			144,310	846,288
LDRb	$(\frac{y}{x})_t = 5.89231\,\frac{(1-.8^{x_t})}{x_t} - 3.76506\,\frac{(1-.8^{x_t})^2}{x_t}$	.51	.92 △	1		165,564	1,626,560
LDRaS	$y_t = 4.15894(1-.8^{x_t}) - 2.31852\#\,(1-.8^{x_t})^2 + .29143\#y_{t-1}$	.94	1.53 ▽	1	.56	189,033	2,422,440
LDRbS	$(\frac{y}{x})_t = 3.45591\,\frac{(1-.8^{x_t})}{x_t} - 1.80317\#\,\frac{(1-.8^{x_t})^2}{x_t} + .411723\,\frac{y_{t-1}}{x_t}$	.70	1.78	1	.78	202,150	3,387,260

L = Logistic growth
CR = Constrant returns to fixed biomass
DR = Decreasing returns to fixed biomass
a = total function
b = average function
Sample size = 18 (1950-67)

† = All variables expressed as absolute value divided by series mean for standardization purposes.

S = Stock adjustment model (Koyck function)
\# = not statistically significant at 5 percent level
1 = R^2 selected by search procedure was not highest but did yield maximum for function. Highest R^2 yielded no maximum for function or data insufficient at maximum R^2 to establish MSY.

△ Durbin-Watson Statistic (D-W) indicates autocorrelation is present at the 5% level. Estimates of the parameters are unbiased but their variances are unduly large.
▽ D-W is inconclusive.

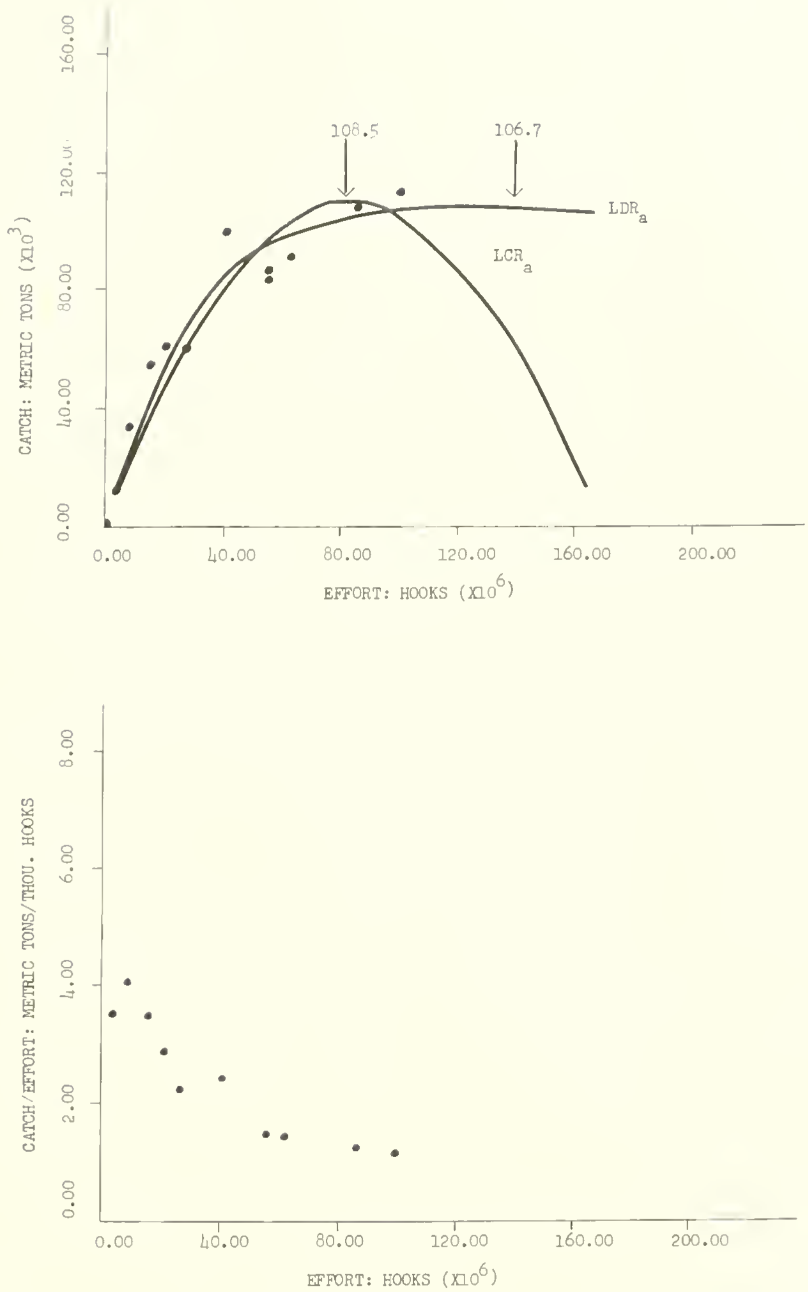

Figure 7. — Atlantic tuna longline fishery, 1956-67: Catch, effort, and catch per unit of effort.

Table 3: — Atlantic Longline tuna: yield-effort function.†

Function	Empirical estimates	R^2	D-W[2]	Note	K (half-life)	MSY Thou. metric	Max. effort Thou. hooks
Gulland (LCRb)	$y_t/(x_t + x_{t-1})/2 = 3.0590 - 1.3740\,(x_t + x_{t-1})/2$	.76	.65			123.8	48,517
LCRa	$y_t = 1.58261\,x_t - .41791\,x^2$	.75	1.29			108.6	82,534
LCRb	$(\frac{y}{x_t}) = 2.1476 - .76904\,x_t$	.82	1.08			108.7	60,861
LCRaS	$y_t = 1.11912\,x_t - .295898\#x^2_t + .31955\#y_{t-1}$	.79	1.57		.61	112.7	82,427
LCRbs	$(\frac{y}{x_t}) = 2.64085 - .88922\,x_t - .35455\#\frac{y_{t-1}}{x_t}$	.84	1.07		NA	142.2	64,725
LDRa	$y_t = 3.29706\,(1 - .50^{x_t}) - 1.84745\,(1 - .50^{x_t})^2$	.88	1.44	1		106.7	140,148
LCRbS	$(\frac{y}{x_t}) = 2.71251\,\frac{(1 - .35^{x_t})}{x_t} - 1.37048\,\frac{(1 - .35^{x_t})^2}{x_t}$	.95	1.22			97.3	189,650
LDRaS	$y_t = 2.65136\,(1 - .45^{x_t}) - 1.33876\,(1 - .45^{x_t})^2 + .124763y_{t-1}$	.89	1.77	1	.33	108.7	252,680
LDRbS	$\frac{y_t}{x_t} = 3.62193\,\frac{(1 - .45^{x_t})}{x_t} - 2.21896\,\frac{(1 - .45^{x_t})^2}{x_t}$ $112\,(\frac{y_{t-1}}{x_t})$	.95	1.07	1	NA	96.4	92,444

L = Logistic growth
CR = Constant returns to fixed biomass
DR = Decreasing returns to fixed biomass
a = total function
b = average function
Sample size = 11 (1956-67)

S = stock adjustment model (Koyck function)
# = not statistically significant at 5 percent level
1 = R^2 selected by search procedure was not highest, but did yield maximum for function Highest R^2 yield no maximum or data insufficient at maximum R^2 to estimate MSY
2 = Durbin-Watson tables not available for 11 observations.

† = All variables expressed as absolute value divided by series mean for standardization purposes.

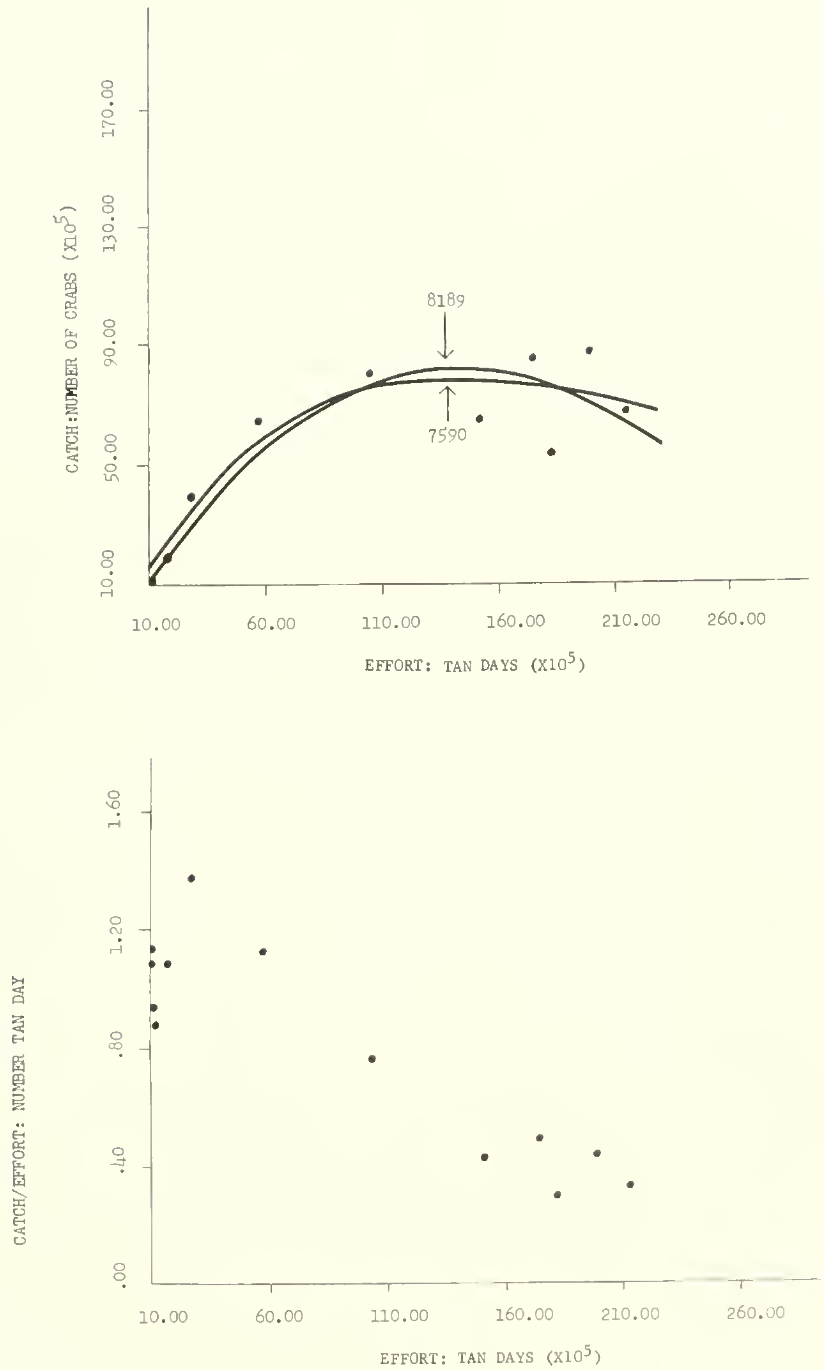

Figure 8. — Soviet and Japanese king crab fishery in the Eastern Bering Sea, 1955-67: Catch, effort, and catch per unit of effort.

Table 4 — Soviet and Japanese king crab in the Eastern Bering Sea: yield-effort functions.†

Function	Empirical estimates	R^2	D-W[2]	Notes	K (half-life)	MSY No. of crabs in thousands	Max. effort Ten days in thousands
Gulland (LCRb)	$y_t / (x_t + x_{t-1})/2 = 2.5902 - .8862 (x_t + x_{t-1})/2$	.74	1.80			6, 910	10,404
LCRa	$y_t = 2.21066x_t - .69361x^2_t$	.85	1.82			8,188.96	14,445.9
LCRb	$(\frac{y}{x})_t = 2.25544 - .70933x_t$	.82	1.29			8,335.19	14,411.9
LCRaS	$y_t = 1.84883\#x_t - .59717\#x_t^2 + .20382\#y_{t-1}$	.85	1.94		.43	8,355.78	14,032.63
LCRbS	$(\frac{y}{x})_t = 3.71464 - 1.08931x_t - .84831 \frac{(y_{t-1})}{x_t}$	.87	1.68		NA	14,722.4	15,456.2
LDRa	$y_t = 6.02438 (1-.6^{x_t}) - 5.5576 (1-.6^{x_t})^2$	.88	1.14	1		7,589.92	13,857.2
LDRb	$(\frac{y}{x})_t = 44.3224 (\frac{1-.95^{x_t}}{x_t}) - 278.495 (\frac{1-.95^{x_t}}{x_t})^2$	.81	1.20	1		8,198.42	14,654.3
LDRaS	$y_t = 3.6086 (1-.5^{x_t}) - 3.13573 (1-.5^{x_t})^2 + .38632\#y_{t-1}$	.89	1.49		.72	7,864.94	11,202.8
LDRbS	$(\frac{y}{x})_t = 72.9199 \frac{(1-.95^{x_t})}{x_t} - 425.32 \frac{(1-.95^{x_t})^2}{x_t} - .84628\#\frac{(y_{t-1})}{x_t}$	.87	1.53		NA	7,870.06	15,838.8

L = Logistic growth
CR = Constant returns to fixed biomass
DR = Decreasing returns to fixed biomass
a = total function
b = average function
Sample size = 13 (1955-67)

† = All variables expressed in absolute value divided by series mean for standardization purposes.

S = Stock adjustment model (Koyck function)
\# = not statistically significant at 5 percent level
1 = R^2 selected by search procedure was not highest but did yield maximum for function. Highest R^2 yielded no maximum for function or data insufficient at maximum R^2 to establish MSY

2 = Durbin-Watson tables not available for 13 observations.

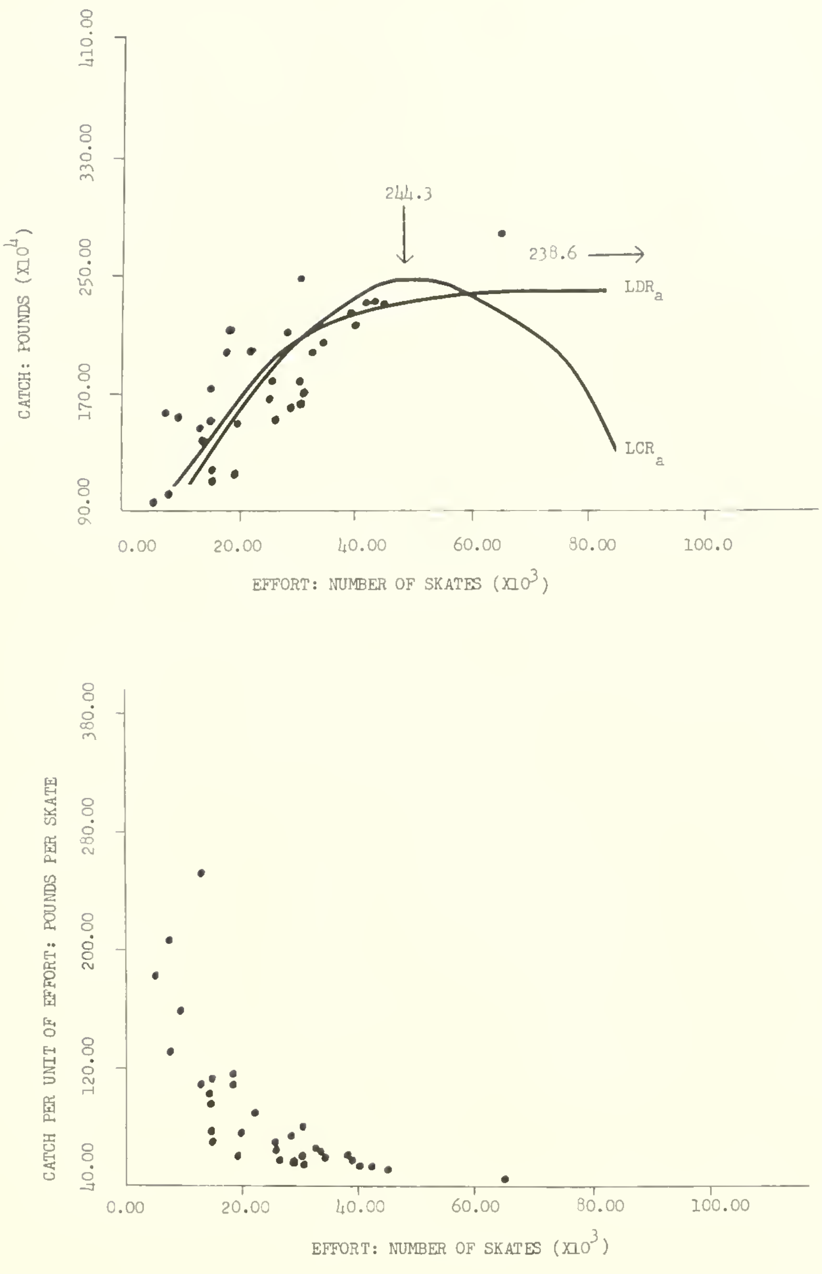

Figure 9. —Cape Flattery sablefish fishery, 1917-52: Catch, effort, and catch per unit of effort.

Table 5 — Cape Flattery sablefish: yield-effort functions.†

Function	Empirical Estimates	R^2	D-W	Note	K (half-life)	MSY Thou. Pounds	Max. effort Thou. Hooks
Gulland (LCRb)	$y_t/(x_t + x_{t-1})/2 = 2.0792 - .90252\,(x_t + x_{t-1})/2$	.61	2.6			2124	29140
LCRa	$y_t = 1.35838\,x_t - .34366\,x^2_t$	.35	.63 △			2444.37	50905
LCRb	$(\frac{y}{x})_t = 1.98981 - .81680\,x_t$	.57	.89△			2206.76	31373.3
LCRaS	$y_t = .95968x_t - .20679x_t^2 + .24298y_{t-1}$	.49	1.27▽		.49	2678.3	59766.5
LCRbS	$(\frac{y}{x})_t = 1.18752 - .40464x_t + .28622\,(\frac{y_{t-1}}{x_t})$	.79	1.80		.55	1586.59	37795.6
LDRa	$y_t = 2.84035\,(1 - .50^{x_t}) - 1.53945\,(1 - .50^{x_t})^2$	.54	1.07△			2385.77	95045.3
LDRb	$(\frac{y}{x})_t = 2.13803\,\frac{(1-.20^{x_t})}{x_t} - 1.11853\,\frac{(1-.20^{x_t})^2}{x_t}$	.80	1.63	1		1860.5	49892.6
LDRaS	$y_t = 2.55607\,(1-.55^{x_t}) - 1.32721\,(1-.55^{x_t})^2 + .13993\#y_{t-1}$	.57	1.41▽	1	.35	2605.69	141983
LDRbS	$(\frac{y}{x})_t = 1.99541\,(1-.35^{x_t}) - 1.10871\,(1-.35^{x_t})^2 + .1861\,\frac{(y_{t-1})}{x_t}$	.84	2.07	1	.40	2008.74	56463

L = logistic growth
CR = constant returns to fixed biomass
DR = decreasing returns to fixed biomass
a = total function
b = average function
Sample size = 35 (1917-52)

† = All variables expressed in absolute value divided by series mean for standardization purposes.

S = stock adjustment model (Koyck function)
\# = not statistically significant at 5 percent level
1 = R^2 selected by search procedure – was not highest but did yield maximum for function. Highest R^2 yielded no maximum for function or insufficient at maximum R^2 to establish MSY

△ Durbin-Watson Statistic (D-W) indicates autocorrelation is present at the 5 percent level. Estimates of the parameters are unbiased but their variances are unduly large.

▽ D-W is inconclusive.

relationship (the LDRaS model gave a larger R^2, but y_{t-1} was not statistically significant). However, the LDRa model was marginally significant over the LCRa model (R^2 of 0.88 versus 0.85). There is evidence of positive autocorrelation for the LDRa function. The Gulland-LCRb does give somewhat different estimates of y^* and x^* than unadjusted LCRb. Figure 8 shows the LCRa and LDRa functions.

Cape Flattery Sablefish

Table 5 shows the results for the Cape Flattery sablefish fishery. Again, the LDRa model is superior in explaining the catch-effort relation with an R^2 of 0.54. The stock adjustment coefficient was not statistically significant at the 5% level. Positive autocorrelation was found for the LDRa function. There does not seem to be an appreciable difference between the Gulland-LCRb and the unadjusted LCRb.

On the basis of the sample fisheries it would seem that the LDRa function is a more realistic description of the catch-effort relation than the LCRa model employed by Schaefer. In addition, it is apparent that for the above species the Gulland method of adjusting this data yields very similar results to the unadjusted. Catch-effort data have been gathered on 49 stocks of fish by the Economic Research Laboratory. We plan to carry out similar investigations for the other stocks since the basic computer programs have been written. Figure 9 shows the LCRa and LDRa functions.

CONCLUSIONS

We do not claim to have discovered the "true" relation between effort and yield for the stocks of fish discussed in this paper. We have no guarantee either that biological growth is exactly a logistic function, or that $y_t = m_t(1 - z_t^x)$ is exactly the relation of effort to yield from a fixed biomass. But we believe that (1) the decreasing-returns functions $y_t = m_t\,(1 - z_t^x t)$ is theoretically better than the constant-returns function $y_t = km_t$ employed by Schaefer; and (2) the decreasing returns function also gives better statistical results as shown graphically in Figures 6 to 9 and is confirmed by the correlation coefficients.

So far, we think that the logistic-decreasing-returns function has considerable merit. It should, of course, be tested further. Other functions should also be tried, including those assuming a Gompertz growth function and the more generalized function used by Tomlinson and Pella. It is also hoped that this effort by economists will be reviewed by people in the field of biology.

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APPENDIX I. METHODS OF ADJUSTING CATCH AND EFFORT DATA TO REPRESENT EQUILIBRIUM OBSERVATIONS

The Schaefer (1957) Method

The Schaefer analysis (using his notation) is based on the assumption that the rate of population change can be represented by the equation

$$(1)\quad \frac{dP}{dt} = k_1 P(L-P) - k_2 FP$$

where k_1 is the rate of population increase, k_2 is the catchability coefficient, L the maximum population size, F is fishing effort, and P is the current population size. Further, it is assumed that at level P_i in year i, equilibrium yield, Y_e is estimated by P + Catch, and that

$$(2)\quad AP = \frac{\bar{P}_t + 1 - \bar{P}_{t-1}}{2} = \frac{C_{t+1}/F_{t+1} - C_{t-1}/F_{t-1}}{2}$$

where C is catch. To use these equations it is necessary to relate P and u, catch per unit effort, that is

$$(3)\quad \bar{P} = k_2 u.$$

If P in equation (1) is replaced by $\bar{P}$, then all three parameters k, k_2, and L can be estimated from a series of data on catch and catch per unit of effort. This 1957 procedure of Schaefer's was first tried as a basis for a decision rule.

Initially a 15-year series of data was divided into three equal parts, that is, 1 to 5, 6 to 10, and 11 to 15 years. The three parameters were estimated from the three sets of data by solving the simultaneous equations of the form

$$\frac{1}{n_i}\sum_{j=1}^{n_i} \Delta u_i = k_1 \sum_{j=1}^{n_i} \frac{L \bar{u}_j}{n_i} - \frac{k_1}{k_2} \sum_{j=1}^{n_i} \frac{\bar{u}_i^{2}}{n_i} - k_2 \sum_{j=1}^{n_i} \frac{f_{ji}}{n_i}$$

where k_1, and k_2, and L are parameters, Δu_i is the change in catch per unit effort, $\bar{u}_i$ is the average catch per unit effort $\bar{u}_i^2$ is the average catch per unit effort squared, f_i the number of units of effort and n_i the length of the period in years.

Pella and Tomlinson suggested that the series of data be divided into periods with the greatest differences in stock levels to avoid absurd results. They also pointed out the lack of a unique solution, since different partitioning of the data may give different results. There is also no statistical basis on which to infer properties of the parameters such as bias, consistency, or efficiency, etc.

Gulland (1961, 1968b) Method

This method involves relating the mean annual catch per unit of effort in a given year to the fishing effort, averaged over that year and a certain number of previous years corresponding to the mean number of years that a year-class contributes to the fishery.

For example, the catch in period t would be related to the average effort over the last 3 years for the yellowfin tuna since a year-class contributes to the fishery for about 3 years. We are doubtful of the validity of this since it gives equal weight to each year of effort in computing the average effort. We feel the hypothesis expressed in this paper is more realistic. In addition, the statistical properties of a moving average of effort as used in regression are not well known. Finally, the technique is not as direct a test for adjustment of the population to effort as the one used in this paper (see below). See Schaefer, M. B. "A Study of the Dynamics of the Fishery for Yellowfin Tuna in the Eastern Tropical Pacific Ocean," *Inter-Amer. Trop. Tuna Commission. Bull.* 2(6) 1957, pp. 245-285 and Gulland, M. *Manual of Methods for Fish Stock Assessments.* Part 1. Fish Population Analysis. FAO Fish Technical Paper, 1968, FRs/T40 (Rev. 2), 97 pp.

Some Suggestions for the Development of a Bioeconomic Theory of the Fishery[1]

Russell G. Thompson[2]

ABSTRACT

In this study, the fundamental characteristics of the Schaefer model and the Thompson-George (TG) production-investment model are reviewed, and extensions of the TG model are discussed. It is then indicated how a bioeconomic model for the sole ownership fishery may be obtained by adjoining the Schaefer model to the TG model (or any of the extensions). This leads into a discussion of the fundamental variables in a dynamic analysis of the fishery problem and the limitations of published bioeconomic analyses. It is further pointed out that further work needs to be directed to the formulation of catch functions allowing for varying marginal returns with respect to fishing effort, in particular.

INTRODUCTION

In 1954 Schaefer used the first-order terms of the sigmoid growth law to describe the dynamics of an unexploited fish population and assumed the catch to be proportional to effort[3] to describe the exploitation by man. The catch function was subtracted from the natural growth law to obtain the following model (which is commonly referred to as Schaefer's model):

$$\dot{x}(t) = \tau x(t)\,(\upsilon - x(t)) - \sigma y(t) x(t) \quad (1)$$

where x is the fish biomass, y is fishing effort, t is time, $\dot{x}(t) = dx(t)/dt$, and the remaining symbols are parameters.

In 1968 Thompson and George formulated a production-investment model for the firm involving stocks and flows. Less than full use of the capacity was allowed for by introduction of a production scale variable. Short- and long-run distinctions in economics were thus possible. The firm could increase the capital stock by the purchase of capacity in excess of attrition. None of the capital stock could be sold within the decision interval of finite length; it could only be sold at the end of the interval. Therefore, the problem was irreversible during the finite period. Extensions to allow for increasing marginal costs are straightforward and were left to the reader. The decision rules for the optimal production and investment controls were derived by use of control theory methods. An algorithm was developed by which to compute solutions to the controls so that the model had practical as well as theoretical value.

In 1970 George showed that solutions to the optimal controls for a cash flow form of analysis (as used by Thompson and George) were identical to those for a discounted form of analysis. That is, in reference to the TG model, the optimal controls are the same for the case where $\delta(t) > o$ and $D(t) \equiv o$ as for the case $\delta(t) = o$ and $D(t)$ is evaluated at the market rate of interest $i(t)$. George further showed that one model or the other must be used (in an exclusive sense).

In 1971 Thompson, Hocking, and George showed how the initial values for the physical and money capital accounts can be derived optimally as a part of the solution to the investment-production problem (as well as the values for the controls during the decision-making period). In 1970 Proctor studied the investment problem for the firm in a reversible and also in an irreversible setting (where the

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[1] Partially supported by the National Science Foundation as a part of the Sea Grant Program for 1970.

[2] Russell G. Thompson is Professior of Quantitative Management Science, University of Houston.

[3] As indicated by Schaefer and Beverton (1963), this assumption is common to the Beverton-Holt approach as well.

firm may buy and sell its capital stock during the period as well as at the end). He further derived the demand functions for capital in each case and deduced their economic characteristics.

CONCEPTUAL MODIFICATIONS

By adjoining the Schaefer model to any one of these formulations, a production-investment model for the sole ownership fishery is obtained.[4] Such a formulation has a number of distinct advantages: First, the inherently dynamic problem of the fishery is formulated accordingly in a mathematical sense, second, the model (since it encompasses the economic and biological relations) is bioeconomic in form; third, given meaningful expressions for the functions involved, decision rules for the production and investment controls (and hence the basis for a bioeconomic theory) may be derived by the straightforward use of published mathematical methods.

Lack of such a methodology may be the reason for the historical development of the bioeconomic theory for the fishery. For example, virtually all economists who have published in the professional journals (or by the way of Resources for the Future) have commonly assumed the inherently dynamic problem of the fishery to be static at the outset of their analyses (cf. Smith 1969), Christy and Scott (1965), Gordon (1954), and Crutchfield and Pontecorvo (1968).

Another example is provided by the form of the catch function used. Until recently, economists have not seriously questioned the form of the catch function introduced by Schaefer, σyx. This formulation implies constant marginal returns with respect (w.r.) to effort and increasing returns to scale.

Crutchfield and Zellner (1962) made static and dynamic analyses of the fishery problem (with this catch function) and found different constant solutions! They failed to note that a capacity limitation must be imposed on fishing effort. The problem is similar to maximizing the function $y = x$ in which the domain must be bounded from above for the problem to have finite solution.

Following this analysis, Crutchfield and Zellner introduced a Cobb-Douglas form for the catch function and made a partial analysis of this case. This problem also requires a capacity limitation on effort to be well posed. In addition, increasing returns to scale in capacity for sufficiently small expenditures may be necessary as well as decreasing returns beyond some point. This is particularly relevant when the competitive model is desired for a reference framework. Decreasing returns everywhere are inconsistent with the market requirements for a competitive structure (Proctor, 1970).

Still another example of the unusual approach used to date is the specification of an infinite horizon for the completely irreversible investment problem. The optimal length of the horizon in a common property resource problem might well be one of the fundamental results being sought in the analysis, and not an input to the analysis, as specified by Crutchfield and Zellner. There are no transferable rights to the fishery resource; and hence, the entrepreneur might desire to take all of the resource within a finite period of time. Thus, the optimal solutions to the investment and production controls and the length of the decision horizon would be expected to be the fundamental variables for a bioeconomic theory of the fishery.

For the case of the Schaefer model, the decision rules for the production-investment controls follow immediately from the TG model. The necessary condition for the optimal length of the decision interval, if one exists, follows as an immediate extension of their results. In fact, the decision rules for investment and production are particularly straightforward and easy to state. Let v = investment, m = the investment upper-bound, γ = the fish price, θ = production cost per unit of effort, ζ = investment cost per unit of capacity, ϕ = the discount function, z = fishing capacity, p_1 = the marginal value of the fish per unit weight, and p_2 = the marginal value of capacity. Then the decision rules are:

$$(2)\quad v_o = \begin{matrix} 0 \text{ if } p_2 - \phi\zeta < 0, \\ m \text{ if } p_2 - \phi\zeta > 0, \end{matrix}$$

[4] Any of these forms of the problem are consistent with Turvey's formulation (1964). Variations in mesh size would be associated with different capital characteristics, and require the introduction of more than one capacity variable and possibly functions relating vessel types and mesh size.

$$(3)\quad y_o = \begin{cases} 0 \text{ if } \phi\gamma\sigma x_o - p_I \sigma x_o - \phi\theta < 0, \\ z_o \text{ if } \phi\gamma\sigma x_o - p_I \sigma x_o - \phi\theta > 0. \end{cases}$$

with the subscript on v, y, x and z denoting optimum values.

The sole owner firm invests the maximum possible amount if the marginal value of capacity is greater than the discounted marginal cost of capacity and does not invest at all if the opposite is the case. The firm uses all of its capacity if the discounted net marginal revenues from fishing effort, $\phi(\gamma\sigma x_o - \theta)$, are greater than the marginal value of the fish resource, $p_I \sigma x_o$, and the firm does not fish at all if the marginal value of the fish resource is greater than the net marginal revenue from fishing.

The difference between a sole owner firm and a competitive firm is immediate. In the latter case, the effects of fishing on the resource are ignored; and hence, the marginal value of the fish resource is always zero (since $p_1(t) \equiv o$). It can further be shown that $p_I \gtrless (t)$ for all t. Thus, the marginal value of the fish resource reduces the value of the decision rule for fishing effort.

If the Schaefer model is augmented to allow for a Cobb-Douglas type of catch function, for example, then an interior solution (in the interval $[o, z_0]$) for fishing effort is possible. Similarly, an interior solution (in the interval $[o, m]$) for investment costs is possible if increasing marginal costs of capacity are specified.

The main difficulty in applying the TG model (as first developed) is specification of the investment upper-bound. It is clearly a proxy for various limitations on investment. For instance, there might be borrowing limitations imposed by the financial community. If so, Rahman's extension (1970) of the TG model may be appropriate. On the other hand, the investment upper-bound may be superfluous if the catch function is of a traditional production function form. Few serious efforts have been directed to investigations of alternative forms for the catch function. Further efforts of the type being pursued by Carlson (1969) surely need to be given top priority in fishery research.

In summary, an operational methodology for the management of a fishery is available by adjoining the Schaefer model to the TG model, or one of its extensions. The potential for this method may be further enhanced considerably by the development and estimation of more robust forms of the catch function.

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Practical Problems of Constructing Bioeconomic Models for Fishery Management

PAUL ADAM[1]

ABSTRACT

In many practical cases it is impossible to construct a complete bioeconomic model of a given fish stock, such as when one or several fleets move irregularly from one stock to another, or when fishing effort increases so rapidly that it is not possible to accurately specify a reliable yield/effort relationship. A continuing bioeconomic model is proposed here which will allow inclusion of these dimensions while allowing both for year-to-year fluctuations in managed effort and also for gradual adjustment of labor and capital to those levels designated as optimal within the broad ranges of this continuing model. Year-to-year re-evaluation of fish stocks and capital-labor requirements is stressed.

INTRODUCTION

This paper is devoted to the problem of mixed fisheries. Few fish stocks are exploited by one fishing fleet only and few fishing fleets are dependent upon only one fish stock. In the rare cases of isolated fisheries (one main species, one fleet, one market) there are often incidental catches which, although they may be relatively small, are important for the overall profitability of the fleet. It can be said that in most fisheries the rule is to switch from one type of fishing to another or from one stock to another, according to the seasons or to the variable fish abundance in the different stocks. These continuous adjustments, occurring irregularly, make the problem of fishery management a most complex one.

Furthermore, it must be added that in the last 10-15 years the techniques used in some of the most important world fisheries have been considerably improved. These developments include: long distance stern trawling associated with freezing at sea, purse seining for pelagic species in the North Atlantic, purse seining for tuna species in the Central Pacific and Atlantic, double beam trawling in the North Sea, etc. As a consequence of these recent developments, it is more difficult to study those fisheries which are the most advanced and consequently the most interesting.

The study made in this paper will obviously be economic, but no serious or complete economic study of any fishery can be undertaken without consideration of the available resources. In other words, the work of the economist in this context cannot begin or would have no solid basis without starting with the findings of marine biologists. It is therefore indispensable to examine the nature, the scope and especially the shortcomings of the biological findings inasmuch as they have to be used by the fishery economists.

SHORTCOMINGS OF THE BIOLOGICAL MODELS

The whole process of the fishing operations is expressed in Figure 1. The arrows indicate the basic components of an operating fishery. It makes it apparent that any research which would isolate either biology or economics would be cut off from the feedback occurring in reality. Any model used to describe reality will be false if it is divided into two isolated parts.

The traditional catch curve derived from the biological findings on one fish stock cannot be directly used by the economists. In fact, this curve, which is an average catch curve, should be supplemented with two curves indicating the maximum and minimum yields according to the

[1] Head of the Fisheries Division, Organization for Economic Cooperation and Development. The author is solely responsible for the ideas and information presented in this paper.

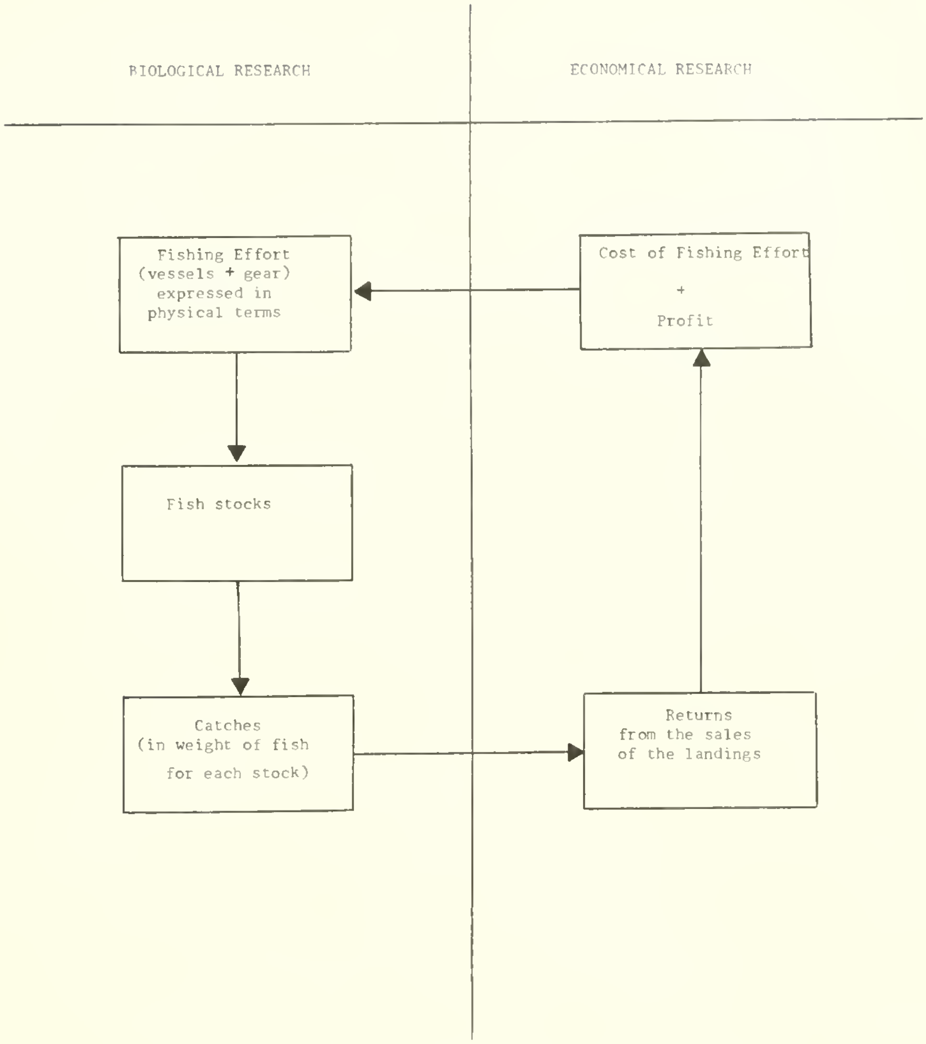

Figure 1. — The basic components of the fishing process.

fluctuations of abundance. As shown by Figure 2, these curves of maximum and minimum yields accentuate departure from MSY as compared to the average curve with increasing fishing effort (and, after the point of MSY, increasing overfishing). The reason is that the more intensive is the fishing effort, the faster the year classes are exhausted, as there are often rather wide fluctuations in the strength of the successive year classes. The fluctuations of the catches can only be increased with a faster exhaustion of the best year classes.

As shown by Figure 2, it is difficult to evaluate the social cost of fishing effort unless we have the simple case of a given fleet exploiting a given fish stock. In such a case, the losses of years of bad catches are compensated by the profits made in better years. Or, if the market for the landings is also isolated, it might be that the returns are more or less equalized by higher prices when there is a scarcity in landings and lower prices when the landings are more abundant.

For mixed fisheries, Figure 2 should be transformed into Figure 3, thereby taking into account the fact that the fishing fleet exploiting a given stock at a given average level is maximum when the abundance in the given stock is maximum and when the abundance in the other stocks that can be fished by the same fleet is minimum, and vice versa. No stock can be subject to a stable fishing effort. It will vary

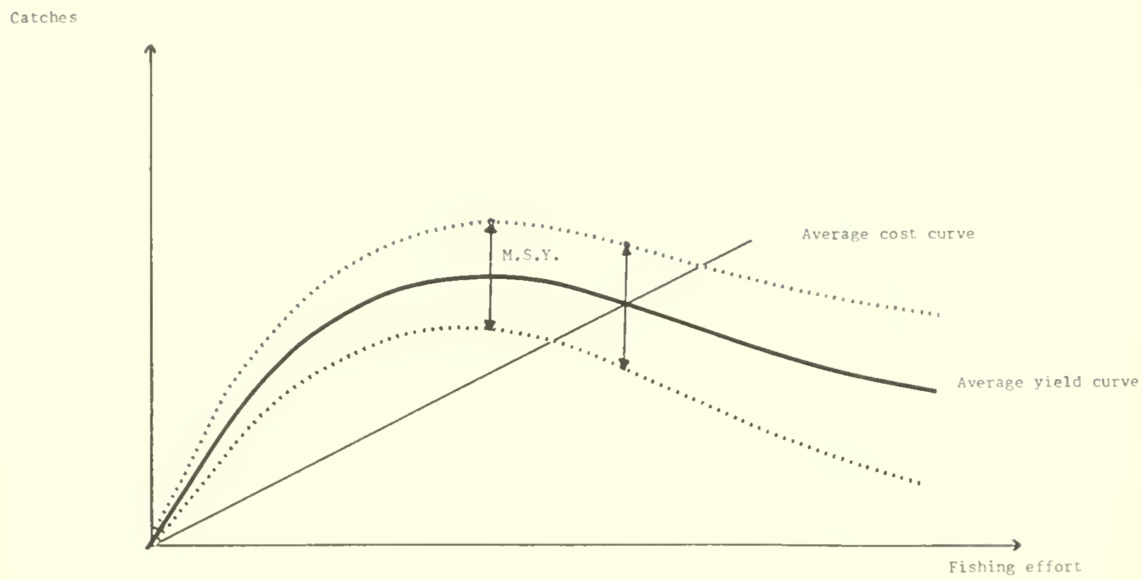

Figure 2. — Maximum, average, and minimum catch curves for a single fish stock.

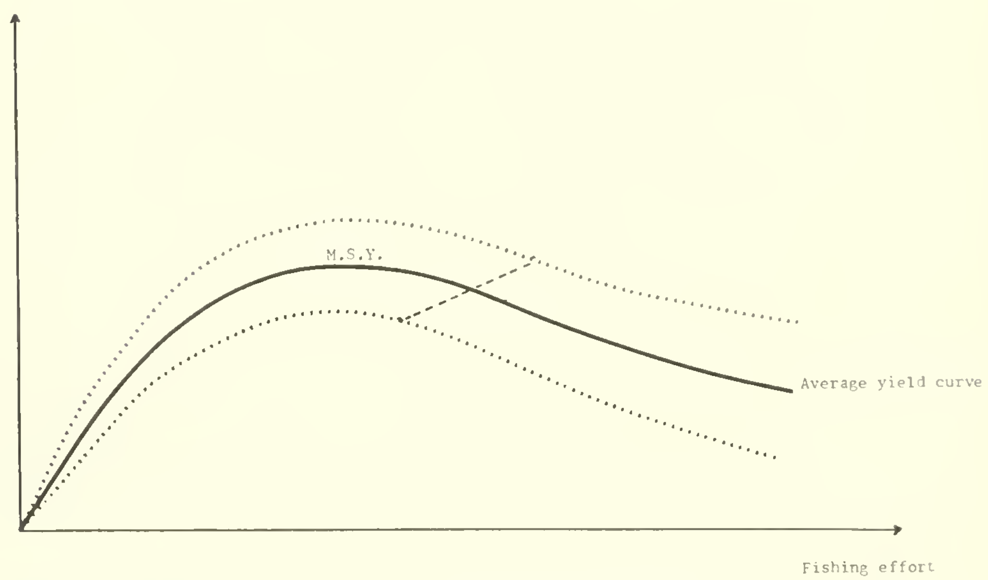

Figure 3. — Maximum, average, and minimum catch curves for a multiple stock fishery.

between two extremes determined by the abundance in the stock considered but which also depend upon the abundance in the neighboring stocks. It should be noted that the shape of the resulting curve and the location of the point of equilibrium would have to be determined for each particular case. Each case would not only be the result of the structure of the given fish stock and of the exploitation borne by this stock, it would also be the result of the structure of the other stocks which would be more or less attractive, i.e., profitable. The findings of the biologists should therefore cover all the stocks which are exploited by the fleets considered by the economist, otherwise there would be a substantial gap in an essential part of the needed information.

The previous paragraphs were based on the assumption that the pattern of the recruitment to the fish stocks remains unchanged whatever the size of the stock and the level of the fishing effort. In practice, this assumption is certainly not realistic. But the opposite assumption that the level of recruitment is linked solely to the size of the stock is certainly equally erroneous.

These two remarks oblige us to enter somewhat into the intricacies of the computations made by the marine biologists. When these scientists are examining the past catches they proceed along analytical lines which are corrected every year according to what has happened. Their analyses are summarized and systematized with the help of mathematical functions. These functions can serve the additional purpose of making forecasts about the effect of a diminishing, sustained, or increased fishing effort in the years to come, *ceteris paribus*.

Among these other factors the main one is the pattern of recruitment. When a constant rate of recruitment is assumed, the mathematics lead to a curve tending asymptotically to a minimum yield equal to an exploitation level associated with average yearly recruitment. When recruitment is assumed to be aligned with the size of the stock, mathematics lead to a curve asymptotic to the *X* axis or to a parabola. In fact, both assumptions are false and known to be false; the real curve for each stock is in between these two different mathematical formulations, but present scientific knowledge in marine biology does not allow us to know when the pattern of recruitment becomes different.

The resulting margin of error is of course without practical importance when there is a stable fishing effort. When the increase of fishing effort is slow, the impact can be surveyed step by step and the margin of error remains small. But when the increase of fishing effort is fast and furthermore when fishing effort is, as is true in complex fisheries, significantly varying from one year to the other, the margin of error is bound to be as large as the distance between the two curves. This precludes an accurate forecast. In any case, it seems that most often the yield curve is relatively flat around the maximum. The Schaefer model tends to exaggerate the sharpness of the turning point at MSY, whereas the Beverton and Holt model may tend to exaggerate the flatness after MSY.

Let us imagine a fish stock exploited as in Figure 4 at a variable level of fishing effort, with fluctuations stabilized at maximum and minimum levels unchanged for a number of years. The calculations of the biologists lead to a derivation of a yield curve as drawn in Figure 4. The margins of error in the calculations are such that, if there were a change in recruitment function around the point of average yield, it could not be easily seen; the actual average yield curve could well be drawn by the dotted lines and no one could prove which is the real one. This is not critical if the fishing effort is not increased, but assuming, as it is often the case at present, an increasing demand for protein and improved productivity due to technological change, the only practical problem would be the problem of an increased fishing effort . . . for which, with such data, no forecast at all could be made before a new stabilization of fishing effort for a subsequent number of years. Before such a stabilization, the most detrimental consequences could have materialized (cf. the California sardines). The faster the increase in fishing effort, the more difficult are the assessments.

PARTIAL BIOECONOMIC MODELS

While initially I attempted to prove that biological models cannot be complete, at least in the most important cases of increasing fishing effort, it is not necessary to stress that complete bioeconomic models cannot exist. It is an obvious fact that in bioeconomic models biology comes first; they are fully dependent on the reliability of the basic biological data. This is a very big drawback which would well render the whole exercise of very little practical help in managing fish resources. But it should not be forgotten that, in most cases, the biologists can, with reasonable accuracy, indicate the level of maximum sustainable yields. This limit gives a very important and solid basis for assessment

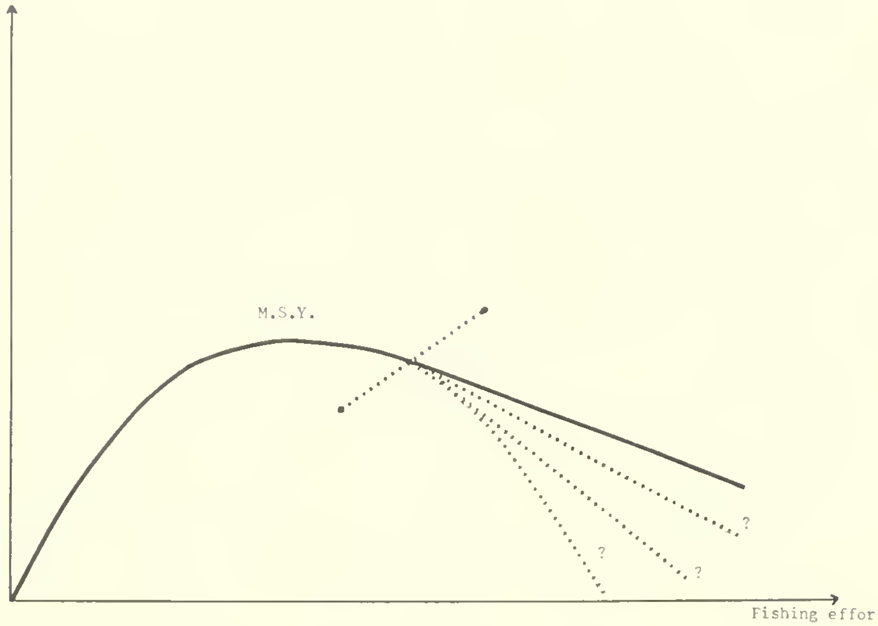

Figure 4. — Alternative yield curves for a fish stock exploited at variable levels of fishing effort.

as such a limit cannot be overstepped without economic losses.

It could also be added that the impossibility of constructing complete bioeconomic models is not as harmful as might be thought. In many cases of advanced overfishing, complete bioeconomic models would not necessarily supply practical management policies. In a situation of advanced fishing effort, the benefits to be expected from fishery management are benefits which could not be reaped before the stock is rebuilt to its MSY level. In the meantime the reductions likely to be made in fishing effort would cause problems of de-investments (e.g., scrapping premiums . . .) and of employment (re-employment of the fishermen concerned). Furthermore, a reduced and less costly fishing effort exploiting a rebuilt stock would give rents; it is possible to imagine regulatory means by which such rents would be at least partly taken from the remaining fishermen, but this could only be made on the basis of the fishing techniques prevalent at the time of making the regulation. It would often be difficult to find the regulations which would result in the desirable aggregate effort while permitting new technological developments at the same time. Some success has been achieved in the Canadian salmon program toward attaining both of these ends. In other words, even if complete bioeconomic models would exist they would not as such provide complete solutions to the problems of re-establishing overfished stocks to the ideal situation of MSY.

Before going further it is necessary to say a few words about the techniques of communication between biologists and economists. In fact, there is not much difficulty with the basic Schaefer model which is widely used in the United States. Its mathematical expression is as follows:

(1) $Y = aE + bE^2$

where

Y = yields, expressed in weight of catches

E = fishing effort, expressed in number of given vessels during given times

a,b = parameters characterizing each particular stock.

The economist has little difficulty in following and utilizing biological results from this model.

Unfortunately the Beverton and Holt model is not so easy to handle. In its simplest expression, it reads:

$$(2)\ Z = M + F = \log_e \frac{\text{number of fish at beginning of year}}{\text{number of fish at end of year}}$$

where

Z = total mortality
M = natural mortality
F = fishing mortality.

If calculated on a weight basis instead of a number basis, account should also be taken of the rate of growth of live fish.

With such a model converting the figures of the biologists into units which can be utilized by the economists is most often impossible. No mathematical barrier exists as long as it is understood that the natural logarithm of a ratio between the catches or the stocks of two years is, in fact, a percentage. However, an important part of the data utilized by the biologists, when it is all published, is scattered in many different publications. It is not sufficient to know the ratio of abundance derived from fishing effort (F) and the ratio of natural mortality (M); the ratio of the growth of the fish and the assumed recruitments are also indispensable but not easily available. Furthermore, the relationship between ratios and actual figures are too often summarized to an extent which forbids reconstruction of the details of the computations and of the results.

While the present paper is mainly directed toward an improvement of the cooperation between biologists and economists, it should be stressed that a prerequisite is to have access to the results of the computations of the other discipline. Cooperation does not require working at the same desk, but it would ask for this minimum of understanding.

Unfortunately, the facility with which the Schaefer model can be used by the economists does not always mean that there is a perfect and total understanding between fishery biologists and economists. More important perhaps than the unit of measurement are a few basic concepts which are commonly used with different meanings. The fishing effort concept is by far the most important one.

Fishing effort is in fact usually expressed in many different ways: either by its physical characteristics or by its returns in weights of different fish species or in money values (either returns or costs, or profits). The usage of these different units should be systematized, otherwise the concept of fishing effort would be misleading as is too often the case when so many researchers use it with different and implied assumptions on the way it should be expressed. In fact, there could not be one single way of expressing fishing effort; fishing effort considered in its full and general meaning is a combination of the different units by which it could be expressed.

Physical Characteristics of Vessel and Gear

This could include any kind of measure describing the characteristics of the vessel: GRT, power, length . . . also taking into account items like the number of berths (which might be significant for pole-and-line techniques), or the sonar (for purse seining), or the number of pots (for crab or lobster, etc.). Obviously, for each specific case the most important characteristic(s) to be used as a measure of the impact of the fishing on the stock or as a measure of the fishing power in relation to a given fish stock will vary. Therefore, a multipurpose vessel has a different fishing power according to the gear it is utilizing; it might even be that the fishing power has to be different when the same vessel with the same gear is exploiting different stocks. As a result the fishing effort of the same boat would have to be expressed differently for each type of exploitation, each season, each year, each stock, etc.

Cost of Fishing Effort

Building costs and operating costs which could be combined by using operating costs including depreciation plus overhead are a more permanent type of unit. First, the costs of a given boat are not so much changed when it changes gear. Secondly, many boats have been built for a definite type of usage. The costs of a boat will be easily defined by so much per day at sea.

Unit of Time

The biologist and the economist will be naturally inclined to use different units of time (time at sea for the second and time fishing for the first). Anyway, the distance to the grounds will have an opposite effect for both researchers, the longer the distance, the higher the costs or the fishing effort for the economist; the shorter the distance the higher the impact on the fish stocks, or the fishing effort for the biologist.

The conclusion is obvious. There cannot be such a unit as a *unit* of fishing effort. Fishing effort is a complex concept; it is a ratio or a relationship between different units. To assume that it can be defined once and for all and be used indifferently by researchers of both disciplines, economics and biology, is a complete mistake. Each time that the concept of fishing effort is utilized it should be made clear what it really means. Attached to a stock or fishing technique, its value is limited to this stock or technique. Given in money terms its comparability is attached to the economic systems of which it forms part.

CONCLUDING REMARKS

A substantial complexity is the consequence of the impossibility of building up a complete bioeconomic model, of the difficulty of converting to economic measurement the ratios used by a number of biologists, of the lack of a clear understanding of what fishing effort is, of the impossibility of forecasting the pattern of recruitment of the fish stocks. To overcome this complexity it does not seem that one can indefinitely rely upon equations which, whether they are Schaefer's or Beverton and Holt's, are mostly used analytically to give account of past developments but cannot make apparent the mechanisms through which future developments are taking place. Figure 5 shows that these biological equations only concern the squares 1, 2, and 3 when a complete simulation

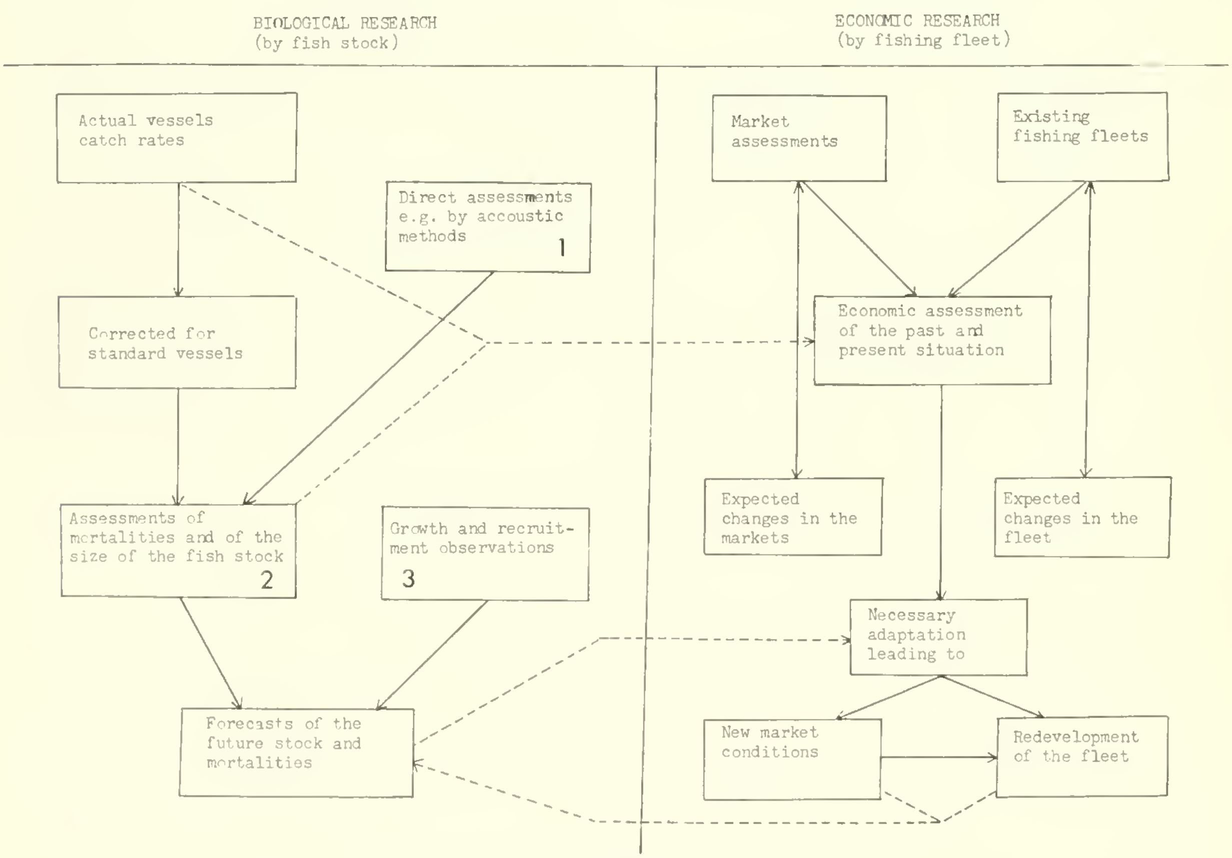

Figure 5. — A simulated flow chart of a fishery.

model should incorporate the 14 squares including independent measures of the size of the stocks and of recruitment and the feedback from the economic side.

It is often said in international fishery discussions that no regulation should be adopted or even proposed before it can be justified by sufficient "scientific evidence." Nobody is fooled any more by this sophisticated expression which means that national economic short term interests should prevail as long as there is no definite proof that such national interests are leading to detrimental international economic consequences. It is obvious that such scientific evidence has often been supplied by the biologists, if only when they stated that numerous stocks are exploited beyond the point of MSY. But the precise economic consequences of these statements are very rarely available; and there is practically no case where the economic consequences of the cuts to be made in the fishing effort have been evaluated (short term costs or losses and long term benefits according to the possible regulations to be adopted). It is obvious that such "practical" evidence will never be supplied without a close cooperation between biologists and economists. The possibility of successful fishery management is entirely dependent on such bioeconomic research work.

ISSUES RELATED TO FISHERY MANAGEMENT: RESEARCH RESULTS

In the final section concerning other issues related to fishery management, the first paper by Holmsen summarizes the results of his study of the Peruvian anchoveta fishery. His is very much an applied study, for he is interested in indicating the critical components of what they have done in the past, the faults that may exist, and an evaluation of alternative management programs.

By his measure the current excess capacity in the fleet should be reduced by 14-38% depending upon the biological or social constraints imposed (length of closed season). Alternative plans which might correct this situation are reviewed, including:

(1) restrictions on fleet size.

(2) government purchase of scrap fleet, the cost to be covered by an assessment on the remainder of the fleet; new entry would be restricted simultaneously.

(3) require private scrapping to permit new private construction — a scrapping ratio.

(4) tie fleet size to licensed capacity of factories.

(5) a quota system with variable, long-lived shares allocated via an auction system.

As there is excess capacity at the processing level also this becomes part of the consideration. Possible controls here would be (1) reducing licensing capacity leading to forced insolvency, (2) government purchase of plants, or (3) transferable factory quotas.

Holmsen recommends a combination program including both levels. Emphasized would be a high scrap/rebuild ratio and lifting the debt moratorium on plants.

In the paper by Thompson, Callen, and Wolken the Thompson and George model, as previously referred to, is expanded to account for income taxes and depreciation. Emphasizing the desire for survival as a key decision element the authors apply this model to sample firms in the Gulf shrimp fishery, using alternative sets of price and landings data. The critical nature of each decision variable is noted for each set of inputs.

Anderson, Connolly, Halter, and Longhurst present another version of a simulation approach to evaluation of management alternatives, relating experience in the management of deer population subject to different hunting strategies defined by alternative sets of regulations.

Some interesting general methodological points are made in this paper. Among these is the stress on the iterative-feedback elements of the simulator. By stressing this mechanism in fisheries we could obtain a continuing evaluation of the quality of the input in addition to the quantitative dimensions of alternative programs. Thus, a type of continuing sensitivity analysis can be performed on such items as estimates of MSY, alternative measures of fishing power, the existence of diminishing returns, social transfer costs. and alternative discount rates.

As does Adam, the authors consider biological issues to be the essence of first generation models. Second generation models would include economics and other considerations. This differs somewhat from Pontecorvo, who would have biology and economics as first and second generation models, respectively, and other considerations as part of third generation models.

A final element of general interest is the use of a random number generator to create an array of "forage factors." This would be a method of considering the many combinations of environmental factors that affect recruitment in fish stocks. In particular, as Pontecorvo suggests, there may be tradeoffs between levels of accuracy and the costs of these levels. This analysis could be performed within a complete simulated fishery system with the aid of this generator.

The paper by Stevens and Mattox is actually a report on two separate, but related studies, one on the economics of salmon hatchery operations and the other on the supply response of fishing vessels (boats) to changes in catch/effort ratios and market conditions. The hatcheries issue is one which has achieved little attention in the economics literature and is timely considering the growth in salmon hatcheries and the increasing research and development work being conducted for other species.

That these hatcheries programs are critical to the overall management plans is a patently obvious, but seldom mentioned, fact. As pointed out by the authors, with hatchery fish ranging from 30-80% of all fish caught from hatchery streams and 20% of all Pacific salmon, no management program could be successful without explicit consideration of the hatcheries. In this examination of 15 Oregon hatcheries production functions were estimated which indicated fixed input proportionality, constant returns to size and substitution between the fixed proportional input and water temperature.

In the study of entry and exit an irreversible function was found to exist. Entry followed good years, but exit did not follow bad years to the same degree. Thus, successful "hatchery years" would lead to entry and expanded fleet size which could not be justified by lesser, even average years. This is a further enforcement of the argument for limited entry as the effectiveness of hatcheries programs in raising fishermen's incomes will be mitigated unless the countervailing tendency to overcapitalize is restricted. Part of this restrictive element may include a deliberate effort to increase opportunity costs, as discussed previously.

Keen is the only author here reflecting on a historical system used to limit entry, the Japanese experience. When reviewing this work it is necessary to recall that the principal objective of the Japanese program has always been "to maintain the viability of the individual enterprise." As this objective is somewhat akin to "maintaining the family farm" it differs from the objective held by most economists to be desirable. If the Japanese program can be judged successful in meeting its own objective, it may still not be suitable to our purposes. Nevertheless, we can proceed to evaluate the components of the program to determine its failure and successes and to gain an appreciation of the critical decisions which need to be made in a management program as it evolves over time.

The Japanese system began in 1946 when all craft greater than 10 tons had to be licensed. It evolved to include area restrictions and to be divided into tonnage groupings, with different restrictions for distant-water fisheries as these developed. Its principal overall characteristic was its pliability. When pressures for additional development of certain fisheries mounted, adjustments were made to allow for some of this investment. In some instances, when certain fishing operations were no longer viable, attractions to divert excess effort to other fisheries were established. The principal thrust of these regulations was to modify the tendency to overinvest and dilute capital values. In some instances, the growing value of fishing licenses attest to the success of this program.

Critical is the effect of these programs on the development of technology. It can be shown that in some cases technology took some strange courses because of the regulations, somewhat akin to our own Alaskan limit seiners. This and other elements of an existing scheme could prove a fruitful area of examination in the future, now that substantial progress has been made in theoretical studies.

The final paper by Huq is so timely as to appear to be at the unanimous request of the other authors and participants in the workshop. This is because the subject is labor mobility and social transfer costs, with the study reported on being confined to three representative communities in the Maine pot-lobster fishery.

In this study the goal is to evaluate such measures of labor mobility as age, level of education, income levels, technical skills, other employment, time in present occupation, investments in the fishery, attitudes toward fishing as an occupation, and attitudes toward certain elements of the harvesting process so that alternative forms of limited entry would be evaluated. Results indicate that immobility is substantial, but that this may not be a problem as the limitation may successfully be applied to capital inputs with little reduction in the labor input for much of the sample examined in the three communities. For the remainder, some form of an adjustment assistance program may be necessary, particularly since a portion of the labor force in the fishery is currently supplementing public assistance or social security incomes with its lobstering activity. These members of the labor force truly have limited opportunities. Restricting their participation would place a greater burden on other family members, who may also be in the lobster fishery.

A.A.S.

Management of the Peruvian Anchoveta Resource

ANDREAS A. HOLMSEN[1]

ABSTRACT

The best available estimate of the maximum sustainable yield of the Peruvian anchoveta resource is 9.5 million metric tons (+ 1 million). The productive capacity of the purse-seine fleet and the fishmeal factories far exceed this tonnage with the result that the open season is becoming shorter year by year. This paper describes the current fishery management program in Peru and the degree of overinvestment in the industry. It further outlines the alternative methods which can be used to reduce excess capacity in the catching and processing phase and the advantages and disadvantages of the various alternatives.

INTRODUCTION

It is well known among fisheries people that Peru is the leading fishing country of the world in terms of tonnage landed. About 97% of the catch is anchoveta, which is used strictly for production of fishmeal and oil. Besides the employment and earnings derived from the harvesting and processing of this resource, fishmeal makes another valuable contribution to the economy of Peru. Like many other less developed countries, Peru has balance of payments problems and exports of fishmeal and oil account for approximately one-third of foreign earnings. With the exception of Iceland, I doubt that any other country is as dependent on its fishery resource as Peru, and few are so concerned about it.

To protect the resource Peru claims a 200-mile fisheries limit which may be twice as much as is necessary. Seventy miles is the maximum distance from shore that anchoveta fishing takes place. The stock is concentrated in the waters off the southern two-thirds of the country, so except for some mixing on the Chilean border it is entirely a national resource.

Peru's emergence as a fishing nation began in the 1950's, but most of the growth of the industry has taken place during the last decade. During the 1960-61 fishing season (September-August) Peru's landings of anchoveta were about 4 million metric tons. During the 1969-70 season, landings reached about 11 million metric tons, and every season during the decade landings were higher than the previous year.

During the early years of the decade, the rapid development of the industry took place with little planning, basic knowledge, and experience. As a result, overexpansion, particularly in processing capacity, has plagued the industry ever since.

The number of vessels in the fleet reached a high of 1,778 vessels during the 1963-64 season, but later gradually declined to the current size of about 1,400. The vessels have become bigger every year, however. While 5-6 years ago, a vessel with 180-ton hold capacity was a large vessel, the smallest built today has a capacity of 275 tons and most vessels built during the last 2 years have a 350-ton capacity. Thus, the fleet capacity has increased from about 180,000 tons capacity in the mid-60's to somewhat above 200,000 tons during the 1969-70 season.

A large part of the fleet is considered obsolete, consisting of wooden vessels built from 1962 to 1964 (in Peru, 7 years are considered the economic life of such vessels). In recent years, most vessels have been built of steel and construction of fiberglass vessels has started. Echo sounder, powerblock, and fish pump are standard equipment in the fleet, and the most modern vessels also have sonar. A fishing trip normally is a day trip, the vessel leaving early in the morning and returning with or without catch in the afternoon.

[1] Department of Resource Economics, University of Rhode Island.

Most of the Peruvian fishing fleet is owned by firms who also own factories and only about 20% of the fleet is owned by independent vessel owners. A fair number of these are tied to a particular factory, however, and have to deliver their catch there, owing to financial help rendered when buying the vessel or for similar reasons.

As the number of vessels has declined so has the number of processing plants. A consolidation has taken place into fewer and larger units. Currently, Peru has 127 fishmeal factories with a total capacity of close to 8,000 tons of fish per hour. About 10 of these plants did not operate last season. While most firms own only one factory, a number of larger firms own several each. These are generally located in different ports or geographic regions as a hedge against poor fishing in one particular area.

CURRENT MANAGEMENT PROGRAMS

Both the Peruvian authorities and the Peruvian fishing industry have for several years been aware of the danger of overexploiting the anchoveta stock, and have taken steps to reduce the pressure on the resource. Fishing effort expanded quickly until the 1963-64 season when the total catch reached a level of 8 million tons. Thereafter, first closed seasons and then overall catch quotas were established. At the present time, the following programs or restrictions are in force:

1. The fishery is closed on Saturdays and Sundays.
2. The fishery is closed about 1 month in summertime during the "peladilla"-season. That closure ("veda") takes place when there are large amounts of small fish (peladilla) in the catch. The time of the veda varies from year to year. In 1970 the closure was from mid-February to mid-March, which was too late.
3. During the fishing season, after the peladilla have entered the fishery and exploratory cruises to assess the recruitment have taken place, an overall quota is established for the season. When this quota is reached, the fishery is closed.[2]
4. Each factory has been given a license for a certain daily input of raw material. The license capacity is stated in terms of tons per hour. This quantity multiplied by 24 is the maximum quantity a factory is permitted to accept in one day. Due to the fact that both the licensed and the technical capacities of the fishmeal factories have far exceeded landings, factory licenses have not been effective in reducing fishing pressure.

[2] Except from the port of Ilo close to the Chilean border.

THE CURRENT SITUATION

The Anchoveta Resource

Anchoveta generally spawns in late winter (August) and reaches a harvestable stage in midsummer (December-February). It has a life span of 2 to 3 years. In the early and middle 60's, fish 1-year old or more contributed to most of the catch, while later the zero year class has become dominant in the annual catch and its percentage of the total catch is increasing. This is considered a warning signal. Actually at the beginning of last season, September-November 1970, the catch was lower per month than in any month in 1965, five years ago. The rich 1969-70 fishery did not perform well before the zero year class came of size. An FAO panel on stock assessment which met in Peru in January 1970 came to the conclusion that the maximum sustainable yield of the Peruvian anchoveta resource most probably was 9.5 million tons ($\pm$ 1 million tons). The experts recommend that the authorities permit a 10-million ton catch coupled with close observation of the fishery to see what effect this fishing pressure would have. The authorities, however, permitted 11 million tons to be caught, which biologists think will significantly hurt the fishery in 1970-71, both because too much of the 1-year class already might have been harvested and possibly also due to reduced reproductive stock.

Fishing Pressure

While the summer veda is of biological significance since it prevents the catching of large quantities of very small fish, and while the prohibition of weekend fishing might have some social advantage, the long winter veda, which has been increasing over time to reach 3½ months in 1970, is only due to an excessive catch capacity of the fleet relative to the resource available. Given a maximum sustainable yield of 9½ million tons, increases in capacity or technological improvements of the fleet will mean a longer winter veda.

During the two years from 1966-67 to 1968-69, hold capacity increased by 16,000 tons per year, or about equal to old tonnage leaving the fleet. During 1969-70, however, about 32,000 tons of new construction entered the fleet and according to interviews with the various shipyards that rate of construction has continued for the remainder of 1970 (Holmsen, 1970b). Thus, the fishing season (the number of fishing days permitted) has gradually declined from 289 in 1963-64 to 166 days in 1966-67 and 155 days in 1969-70. To catch a quota of 9½ million tons, a 145-day fishing season would have been sufficient in 1969-70. Due to the amount of new construction, with the same abundance and availability of fish as last season, the fleet would be able to catch 9½ million tons in less than 140 days in 1970-71. As long as fishmeal prices are high and factories have to pay considerably more to independent owners per ton of fish than the cost per ton for operating their own vessels, construction will continue, resulting in a shorter and shorter season, to the detriment of the industry as a whole. There are similar examples from other fisheries where overall catch quotas have been established with no limit to entry, such as Pacific halibut and yellowfin tuna.

Peru is short of investment capital and particularly short of foreign exchange. In addition to being a misallocation of capital, however, the pressure of an excessive fleet poses the danger of pressure on government to keep the season open longer than the period recommended by stock assessment experts.

Processing Capacity

The same problem of overcapacity is found in the processing phase. Some years ago, the government prohibited the building of more factories and issued licenses restricting the input to a specific tonnage per hour for the existing fishmeal plants. The technical capacities of various plants were increased, however, without regard to the license. Last year, the government started to enforce the law and several firms had to buy plants to bring their own licensed capacity up to their technical capacity, even when they had no use for the purchased plant's buildings or equipment. Thus, some consolidation took place and the total licensed capacity now reasonably reflects the total technical capacity. The licensed capacity is about 50% more than is needed, however, even with the short season now in effect, and the excess capacity would of course be even greater if the fleet size were reduced so the season became longer.

The fishmeal industry as a whole is deep in debt, liabilities about equal to assets. Since some firms are in a good financial position, this means that many firms are thoroughly insolvent, and would have been bankrupt but for a moratorium on debt collection.

DESIRABLE OBJECTIVES

The problem facing the Peruvian anchoveta industry is how to reduce the excess capacity both in the catching and the processing phase, so that excessive closed seasons can be prevented and the productivity of the remaining production units improved.

A reduction in capacity and lengthening of the fishing season has a fourfold advantage:

1. Less pressure will be placed on the government to exceed recommended levels of catch.
2. Fewer investment funds will be needed for the industry.
3. The remaining units will be more productive and thereby, the economic situation for the industry will improve.
4. The sustainable yield in the fishery will increase, as more fish will be caught at a higher age or larger sizes.

The cost savings which will accrue depend on the percentage of fixed and variable costs in the catching and processing phase. For the catching phase, it will also depend on what percentage of the variable costs are associated with volume and what percent with time.

Based upon budgetary data for 1970-71 from a handful of companies, the following break-down might be a reasonable approximation.[3] Forty-seven percent of the cost of harvesting was found to be fixed and not related to the number of fishing days, nor the size of catch. Thirty-five percent of the cost was apportioned to the size of the catch, of which 34% was the crew share and social benefits. The remaining 18% was related to the number of days the vessels were out fishing, catch or no catch.

For a fishmeal factory the cost of fish is a variable expense and this item alone amounted to 59% of total cost. The variable cost of producing meal and oil amounted to 75% of total costs and the fixed cost 25%. Excluding the cost of the fish, the variable costs were 39% and the fixed costs 61% (Holmsen, 1970a).

What the current overcapacity in industry is depends on what kind of management program one has in mind — whether one recommends a 1- or 2-month peladilla veda, whether one sticks to the 5-day week rather than a 7-day week, etc. Based on various alternatives from a 7-day week and no veda to a 5-day week and a 2-month peladilla veda, the fleet reduction necessary was found to range from 38% to 14% (Boerema and Holmsen, 1970). By using the coefficients above, this would lead to savings ranging from about $20 million annually in the first case to about $6 million in the latter case. The savings in the processing phase would also be significant. An FAO management panel, which met in Peru in June 1970, concluded that the technical capacity of the factories could be reduced nearly 50% under year-round fishing, and that total savings to industry from reduction of fleet size and number of plants could perhaps run as high as $50 million. No value can presently be put on the lessened risk of overfishing and depletion of the stock.

ALTERNATIVE CONTROLS

A fisheries management program should have a double goal: 1) to protect the resource from overexploitation, and 2) to prevent overinvestment and economic wastes in harvesting and processing. To achieve these goals in the anchoveta fishery, restrictions can be put on the fleet or on the factories or on both. Some programs might achieve the desired result rather fast, while others might take more time. Alternative programs related to the catching phase will first be discussed.

[3] The percentages are median observations based upon representative vessel size (140- to 220-ton capacity) and plants with technical capacity of 60-90 tons per hour.

Restrictions on Fleet Size

(1) A reduction in the size of the fleet to the desired level can be achieved by an embargo on new construction. Despite the fact that a number of vessels, which otherwise would have been scrapped, would be repaired and remain in the fishery, a fair number of vessels would disappear from the fishery each year and the season for those remaining would become longer. Arguments against such a proposal would be that older, smaller vessels in the fishery, which are the highest cost producing units, would get an additional "lease on life" and the fleet would stagnate technically.

(2) Another possibility with immediate effect would be for the government to buy up the scrap part of the fleet (the high cost producer), and assess the cost on the remainder of the industry, preferably through a fee per ton of meal produced. A large number of such vessels would have to be bought since each contributes very little to the total catch. The industry would be better off, however, since the marginal cost of the remaining vessels would be far below the average cost of the vessels removed from the fishery. Such a program would have no long run effect, however, if restrictions on new construction were not implemented at the same time.

A scrapping ratio would have to be introduced limiting the annual output of productive capacity to the amount of productive capacity leaving the fleet during the year. Such a program, which has some support in Peru, still leaves a difficult question unanswered. Which vessels should the government buy and scrap and what would the prices be? Two 6-year old 150-ton vessels are not necessarily worth the same price. Appraisal and judgment are called for, which could easily result in kickbacks in a country where civil service salaries are low and where bribery has not been unfamiliar in doing business.

(3) A third alternative would be to rely entirely on a scrapping ratio. If a firm or individual wants to build a new vessel, he would have to scrap a larger tonnage of old vessels. If a firm has no vessels to scrap, it will have to buy tonnage for scrapping. The time necessary for an adjustment of the fleet size to the desired level will be longer than under the previous alternative. A scrapping ratio (based either on gross tonnage or tonnage capacity) has to be relatively high in the beginning, possibly three to one, but will, over time, come close to one to one, just sufficiently high to offset the effect of technological improvements in vessels and gear. If nobody is willing to scrap vessels at the initial ratio (except for credits obtained when vessels sink or burn) the effect will be the same as an embargo on vessel construction. The price of obsolete vessels will then be close to zero, however, so some new construction will surely take place. Some vessels, which ordinarily would not have been removed from the fishery, might be removed if the owner can sell them to someone needing tonnage to scrap.

This program falls somewhere between the two previously mentioned, but neither does it involve government outlays nor does it prevent technological improvements in the fleet during the transition period. All these three programs would necessitate a scrapping ratio when the fleet is reduced to the desired level.

(4) Recommendations have been made to the government of Peru to reduce fishing effort by tying the size of the fleet to the licensed capacity of the factories. The recommendations called for a maximum of 1.4 tons of hold capacity per ton of daily processing capacity.[4] Even if a ratio were imposed on a firm (some firms have several factories) rather than on a factory so that vessels can be used where fish are abundant, there seems to be certain disadvantages with such a program. While previous programs mentioned have not differentiated between factory owned and independently owned vessels, the question now arises as to how to deal with the 20% of the fleet which is independently owned. Secondly, such a program would lessen competition and freeze the industry in a given pattern.

[4] This ratio is too high, as few firms currently have a higher ratio.

(5) To reduce the size of the fleet and expand the fishing season, a quota system can also be implemented. Catch quotas can be established for individual vessels, factories, or firms. To reduce uncertainties about investment, quotas should be given for a number of years and not for one season at a time. Further, due to changes in recruitment and the amount of effort the resource can bear, quotas should be allotted as a percentage of the overall annual quota.

A quota system for the purpose of reducing the number of producing units would most likely have to be based on an auction system. Such a system, whether introduced on the vessel, factory, or company level, would tend to eliminate not only the less efficient producers but also those which are financially weak. Such a program would transfer significant funds from the fishing industry to the public treasury. Due to the structure of the Peruvian anchoveta industry, a company quota would seem preferable as this would reduce the size of the fleet (overhead costs) more than a quota on factories or vessels. Under the two latter arrangements, many vessels may be tied up because they have reached this quota, while others still are fishing because a factory may be located in an area where availability of fish is low in a particular season resulting in excessive steaming time by the factory fleet. Even company quotas would result in an excessive fleet, however, as each company would keep a fleet big enough to be sure it will catch its quota.

The various management alternatives so far mentioned have been directed towards reducing the capacity of the fleet and extension of the fishing season and thus, reducing the size of investment in the catching phase. Some of the alternatives will have little or no impact on the excess investment and low capacity utilization of the fishmeal factories, while others will have a significant impact.

Reduction in Processing Capacity

(1) Reduction of the total licensed capacity of fishmeal plants will indirectly affect the fleet. As indicated earlier, the industry as a whole is in a poor financial position. By lifting the moratorium on debt collection, many firms

would go bankrupt and this would improve the situation for those remaining. Since most of the debt is to the public sector, it would mean the government would have to write off some bad or uncollectible claims.

(2) Spokesmen for Sociedad National de Pesqueria (a trade organization for the fishmeal producers) are extremely concerned about excess capacity and have indicated a willingness to bail out the government through a program where the government buys up the high-cost plants and assesses the cost on the remainder of the firms over 2-3 years by a fee per ton of meal produced. Whatever methods are used for eliminating the excess capacity, they will be beneficial for the industry as a whole and reduce the pressure on the government to increase the overall catch quota.

(3) In addition to eliminating the insolvent, high cost, or marginal producers, a further reduction in the licensed processing capacity will be needed. Capacity should be reduced to a level just sufficient to process the catch over an extended fishing season. Currently the licensed capacity of a plant is for tons of fish per hour, and only rarely does a factory produce at full capacity. To encourage fleet reduction, the license should be issued to companies rather than on a factory basis and as previously mentioned, should be a percentage of the overall catch quota. A quota might be either on input of fish or output of meal. The latter is easier to control since the meal is exported through a government monopoly. A quota on input, however, would give a strong incentive to increase the yield (output per ton of fish) and improvement in this respect is badly needed. Quotas could be based on the company's current share of the market, or be put up for auction.

Quotas or licenses to operate might be transferable or nontransferable. A transferable quota could put large and small companies (one-plant operators and multiplant operators) on a more equal competitive basis. The author can see little advantage in a nontransferable quota except for the fact that it might prevent consolidation of the industry into too few hands.

CONCLUSIONS

To manage the anchoveta industry solely through regulation of the processing phase would very likely put the independent vessel owners at a serious disadvantage. To prevent this, a management program for the Peruvian anchoveta industry should include both regulations at the catching and the processing level. Of the various alternatives available for management of the Peruvian anchoveta industry, the author would be in favor of relying on a fairly high scrap and rebuild ratio to reduce the fleet. Lifting of the moratorium on debt collection, combined with transferable licenses for factories, so market forces could be effective, might be sufficient to reduce processing capacity to the desired level.

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A Stochastic Investment Model for a Survival Conscious Fishing Firm

Russell G. Thompson, Richard W. Callen,

and Lawrence C. Wolken[1]

ABSTRACT

In this study, the stochastic investment model for a survival conscious firm developed by Thompson and George (1970) is extended to take into account income taxes and depreciation of the capacity. This model is applied to shrimp fishing on the Texas Gulf coast. Values of the parameters, as in the deterministic application by Thompson et al. (1970), were based on proprietory information, current market conditions, and present institutional restrictions. The effect of growth in real per capita income on shrimp prices is estimated, and two different rates of income growth are analyzed. Solutions to six problems based on two different sets of random sequences are computed and discussed. The results indicate the effect of the survival constraint on investment decisions, and the importance of revealed information in decisionmaking.

INTRODUCTION

In 1970, Thompson and George formulated a stochastic dynamic investment model for the survival conscious firm, derived the optimal decision rules for investment, and computed solutions to several problems. This model takes into account the probability distribution of the yield (output per unit of capacity) and output price, as well as all of the information known to the decisionmaker at the time of each investment decision. The entrepreneur is initially assumed to be in a financial position where a feasible investment solution always exists if the lowest output price and yield occur in every period of the planning horizon. In the model, the objective of the firm is to maximize expected net worth at the end of the planning horizon. All production expenses, investment outlays, interest costs, and planned cash withdrawals must be paid for as incurred (or scheduled).

In this study, the Thompson-George model is extended to take into account income taxes and depreciation. This requires the introduction of another state variable to account for the value of the firm's capital — the investment in capacity. Straightforward extensions of the fundamental constructs (developed by Thompson and George) were required, and are available from the authors upon request.

Because of the vagaries in fish prices and catches, this model would be expected to be a particularly appropriate decision aid for investments in fishing capacity. There are generally few, if any, alternative uses for specialized fishing equipment. Also, fishermen typically have poor alternative opportunities by which to earn a living. Low prices and small catches would be expected, as a result, to be dreaded much more than high prices and large catches are desired. A sequence of worse than expected net revenues (even in the case of a very favorable expectation) could terminate the existence of the fishing firm. This could well be an unacceptable risk of failure. Hence, survival of the fishing firm would be expected to be a fundamental factor influencing the firm's investment decisions.

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[1] Russell G. Thompson is Professor of Quantitative Management Science, University of Houston; Richard W. Callen and Lawrence C. Wolken are Lecturers in Quantitative Management Science, University of Houston. This work was partially supported by the National Science Foundation GH 59 as a part of the Sea Grant Program for 1970.

DEVELOPMENT OF THE SURVIVAL MODEL

In the survival model, the decisionmaker evaluates the worst sequence of net revenues that could occur in every year of the decisionmaking period. This sequence, in conjunction with the value of the initial investment in capacity and the value of the money account, determine the survivable set of fishing capacity purchases at the beginning of the first year. The decisionmaker selects from this set the investment that contributes the most to his terminal net worth. After the first year and before the second operating year begins, the output price received and the yield obtained in the first year have been observed. This is now a part of the information known to the decisionmaker for planning in the second year. The decisionmaker again evaluates the worst sequence of yields and prices that could occur in every remaining year of the decisionmaking period. This abbreviated sequence is now evaluated in conjunction with the capacity and money position at the end of the first year. It determines the survivable set of capacity purchases for the second year. Again, as in the first year, the decisionmaker selects from this second set the investment that contributes the most to his terminal net worth. This procedure is repeated in every year throughout the decisionmaking period. Investment decisions are conditioned by experience, and are not based solely on expected values.

By definition, the firm survives in a given year if the value of the capacity exceeds the value of the indebtedness. A survivable investment is defined in the following way: the decisionmaker has completed operations in year k-1 and is now planning for year k. He wants to survive above all else during the remaining $N - (k\text{-}1)$ years of the decision period, even if all future yields and prices are the lowest possible. An investment decision in the k^{th} year, s_k, is said to be survivable if the value of the capacity in every remaining year is never less than the indebtedness owed (with capacity not being purchased in any of the years after the k^{th} one and the lowest net revenues being visualized in every year of the yet undisclosed future).

Under these conditions, a survivable capacity purchase in year k is found to be equivalent to the following one: the product of the capacity units purchased in year k and the marginal value of capacity calculated under the assumption of the lowest net revenue occurring in every forthcoming year — the marginal cost of capacity visualizing the worst — is never greater than the value of the money account in year $k-1$ plus the terminal value of the capacity in all of the remaining years (with the lowest prices and smallest catches occurring) minus any fixed cash withdrawals in the rest of the planning period. (All money flows are adjusted for the values of alternative opportunities, income taxes, and depreciation.) This upperbound would be the value of the firm's assets if the worst possible sequence of net revenues occurred — the decisionmaker's final asset position visualizing the worst.

To reflect the fear of low net revenues, revenue per unit of capacity when the lowest price and yield occurs is assumed to be less than the operating cost per unit of capacity. It is also assumed that per unit prices of capacity are not increasing so rapidly that operating losses per unit may be covered by value appreciation in capacity. (Speculation is never a sure bet.) This implies that the marginal cost of capacity visualizing the worst is positive. Hence, dividing the lower bound for the firm's final asset position by this positive marginal cost, the upper bound for a survivable purchase of capacity in a given year is obtained. This represents the maximum amount of capacity that the decisionmaker can purchase and still insure survival of the firm throughout the rest of the decision period. It depends upon the value of the firm's money account, the amount of capacity owned, and the value of that capacity in the previous year. This upper bound function in year k is denoted by $Hk(z_{k-1}, y_{k-1}, x_{k-1})$, where at the end of the $k-1^{\text{st}}$ year z_{k-1} is the cash balance, y_{k-1} is the units of capacity owned, and x_{k-1} is the purchase value of the firm's capacity. The firm is in debt if z_{k-1} is negative and has savings if z_{k-1} is positive.

We will also introduce the following notation now; s_i is the units of capacity purchased at the beginning of the i^{th} year (and used for the first time in year i); τ_i is the operating costs per unit of capacity in year i: σ_i is the per unit purchase price of capacity before the beginning of the operating season in year i; [illegible] is the cash withdrawal in year i for sundry expenses; γ is the interest rate paid (or received) on the cash account z; ω_i is the unknown revenue per unit of capacity in the i^{th} year; N is the number of years in the planning period; β is the fraction of the value of the capacity recoverable at the end of the planning period; δ is the income tax rate; and ϵ is the straightline depreciation fraction. Also E will be used to denote the mean of the random variable ω_i; and L will be used to denote the smallest possible annual net revenue having a positive probability of occuring. The symbol a_i is used to denote the output price where only the yield is a random variable in the application below.

Using the above development, the survival model may be stated as follows:

Maximize $E(z_N + \beta\sigma_{N+1}y_N)$ over all n-tuples of functions $s_i(\omega_1, \omega_2, \ldots, \omega_{i-1})$, $i = 1, 2, \ldots, N$, satisfying the difference equations

(1) $x_i - x_{i-1} = \sigma_i s_i, x_0 = \sigma_0 y_0,$

where

$$y_i - y_{i-1} = s_i, \; y_0 \text{ given and non-negative,}$$

(2) $z_i - z_{i-1} = \gamma z_{i-1} + y_i(\omega_i - \tau_i) - \sigma_i s_i$
$- \triangle_i - \delta\,[y_i(\omega_i - \tau_i) + \gamma z_{i-1} - \triangle_i$
$- \epsilon x_i], \epsilon = 0.091,$

where z_0 given, and $i = 1, 2, \ldots, N$, and satisfying the inequalities

$$0 \leqslant s_i \leqslant H_i(z_{i-1}, y_{i-1}, x_{i-1}), i = 1, 2, \ldots, N.$$

In words, the decisionmaker desires to maximize expected net worth at the end of the decision period where the purchases of capacity are selected from the survivable set in each year (delineated by the inequality restrictions). Thus, in the maximization process, the decisionmaker, who takes into account all of the information known at the time of the decision, selects the investment from the survivable set of capacity purchases that maximizes expected net worth at the end of the planning horizon.

THE DECISION RULE FOR INVESTMENT

By the use of dynamic programming methods, the method developed by Thompson and George was extended, as mentioned above, to allow for depreciation and income taxes. The extended rule for optimal investments is summarized in the following theorem.

Theorem: Suppose $H_1(z_0, y_0, x_0) \geq 0$, i.e. the upper bound for investments in the first year is non-negative. Let R_k be the expected marginal value of capacity for survival investment decisions—the marginal value of capacity visualizing the worst. Then the decision rule for optimal survivable investment is as follows:

(3) $s_k^o = H_k(z_{k-1}^o, y_{k-1}^o, x_{k-1}^o)$ if $R_k > 0$,
and $s_k^o = o$ if $R_k < 0$

with the feasible value of s_k being immaterial if $R_k = 0$.

In other words, the decisionmaker buys the survivable limit of capacity in year k if the marginal value of capacity visualizing the worst is positive in that year, and he makes no capacity purchases if this marginal value is negative. It also follows that the optimal purchase is immaterial in any year (because of the linearity of the problem) whenever the decision rule is zero. The upper bound for investments in the first year insures the existence of a feasible investment solution in each year of the planning horizon.

An Application to Shrimp Fishing

To indicate how the model may be applied to a shrimp fishing firm, parameters were specified for a relatively small fishing firm operating 73-foot steel hull trawlers (see Table 1). In the specifications, the values of the parameters were specified to reflect prices, costs, and landings per vessel as reported by the firms cooperating in the study. There is an exception with regard to Problem 3. Average landings per vessel which were found to be 57,560 pounds of heads-off shrimp per year in the years 1958 through 1969 were specified to be one standard deviation above the mean to evaluate the effect of better than average management. That is, in Problem

Table 1. — Values of the parameters for four survival problems: the Gulf shrimp fishery.

Parameters		Problems 1	2	3	4
N	number of years in planning period	5	5	5	5
Z_o	initial cash balance in dollars	0	96,145	0	0
y_o	initial number of boats in fleet	1	0	1	1
x_o	initial investment in dollars	100,000	0	100,000	100,000
γ	annual interest rate per dollar	0.085	0.085	0.085	0.085
τ_t	annual production cost per vessel in dollars	$30{,}000 \times (1.03)^t$	$30{,}000 \times (1.03)^t$	$30{,}000 \times (1.03)^t$	$30{,}000 \times (1.03)^t$
σ_t	per vessel purchase price in dollars	$100{,}000 \times (1.03)^t$	$100{,}000 \times (1.03)^t$	$100{,}000 \times (1.03)^t$	$100{,}000 \times (1.03)^t$
ϵ	annual depreciation fraction per dollar invested	.091	.091	.091	.091
ζ	annual income tax rate per dollar of taxable income	.25	.25	.25	.25
β	recoverable fraction of investment in fishing capacity	.65	.65	.65	.65
Δ	annual cash withdrawal for sundry expenses in dollars	$3{,}600 \times (1.03)^t$	$3{,}600 \times (1.03)^t$	$3{,}600 \times (1.03)^t$	$3{,}600 \times (1.03)^t$
E_t	owner's expected annual revenue per vessel in dollars	$49{,}790 \times \hat{p}_t(1.03)^t$	$49{,}790 \times \hat{p}_t(1.03)^t$	$54{,}400 \times \hat{p}_t(1.03)^t$	$49{,}790 \times \hat{p}_t(1.03)^t$
L_t	owner's lowest annual revenue per vessel in dollars	$22{,}500 \times (1.03)^t$	$22{,}500 \times (1.03)^t$	$22{,}500 \times (1.03)^t$	$22{,}500 \times (1.03)^t$

3 landings per vessel were 63,291 pounds of heads-off shrimp per year.

Since the real price of shrimp — the price adjusted for the purchasing power of money — is highly influenced by growth in real per capita income, and since it appears that the economy may be entering a period of modest growth (possibly much like the late 1950's), the real price of shrimp was specified to reflect a 1.5% rate of growth in real per capita income in Problems 1, 2, and 3, and to reflect a 3.3% rate of growth (as observed in the mid 1960's) in Problem 4.

To evaluate the economic attractiveness of shrimp fishing versus the best alternative to fishing (as reflected by the interest rate on money), the decisionmaker in Problem 2 initially has the approximate money equivalent of an investment in one vessel. Recall that the entrepreneur is a profit maximizer, given that he can survive. Thus, the decisionmaker would opt for the savings alternative whenever the net rate of return from a dollar invested in fishing capacity is less than the interest rate on money. That is, the second problem indicates the economic advantage (or disadvantage) of investing in fishing relative to loaning the money to someone else.

Since the model takes into account the information obtained through time as the values of

Table 2. — Solutions to four survival problems in table 1; landings per vessel are random.

Problem	Year	Marginal value of another vessel (dollars)	Investment in boats (number)	Boats owned (number)	Cash balance (dollars)	Debt to gross asset ratio
	0	–	–	1.00	0	–
	1	5,843	1.44	2.44	-146,356	.57
	2	- 784	0	2.44	-127,678	.48
1	3	- 7,896	0	2.44	-116,862	.43
	4	-15,474	0	2.44	-108,022	.38
	5	-23,490	0	2.44	- 74,436	.26
	0	–	–	2.44	96,145	–
	1	5,843	2.44	2.44	-145,083	.57
	2	- 784	0	2.44	-126,507	.48
2	3	- 7,896	0	2.44	-115,728	.43
	4	-15,474	0	2.44	-106,908	.38
	5	-23,490	0	2.44	- 73,534	.26
	0	–		1.00	0	–
	1	21,419	1.44	2.44	-136,487	.53
	2	16,198	1.13	3.57	-216,534	.56
3	3	7,080	4.03	7.59	-581,958	.68
	4	- 5,562	0	7.59	-511,662	.58
	5	-18,570	0	7.59	-358,977	.40
	0	–	–	1.00	0	–
	1	10,655	1.44	2.44	-145,128	.56
	2	9,943	.80	3.23	-240,502	.58
4	3	2,624	3.15	6.38	-503,596	.70
	4	- 7,595	0	6.38	-462,898	.63
	5	-19,119	0	6.38	-341,999	.45

the random variables are revealed, solutions to two sets of problems were computed. In the first set, the landing per vessel is random; whereas in the second set, the price received is random as well. The first set of results is presented in Table 2, and the second set in Table 3.

It is important to note that this application of the survival model is not exhaustive of the many that could be made, or to imply that the normative results presented are likely to occur. This work is only meant to indicate how an investor interested in shrimp fishing, who has a limited amount of money capital, might obtain bench marks (from the model) for investment planning.

Values of the Parameters

In this application, the firm's initial fishing capacity was specified to be one vessel in Problems 1, 3, and 4. The values of the data (excluding the basis for the expected shrimp price in the first set of problems) are given in Table 1. The initial purchase price of one vessel was taken to be $100,000. In Problems 1, 3, and 4, the firm is visualized as having an initial debt-free investment of $100,000 with no savings. This relatively large amount of initial equity was necessary for the survival problem to have a feasible solution. The minimum value for the firm's initial equity in Problem 1 was found to be $97,000.

In Problem 2, where the entrepreneur has his equity in savings rather than invested in fishing capacity, the initial value for savings is $96,145. This is approximately equivalent to owning one vessel initially because of the procedure used to calculate interest earnings and tax allowances in the model.

There is only one money account in the model, and accordingly one interest rate. This rate was specified to be 8½% per year.

Table 3. — Solutions to two survival problems in table 1; shrimp prices and landings per vessel are random.

Problem	Year	Marginal value of another vessel (dollars)	Investment in boats (number)	Boats owned (number)	Cash balance (dollars)	Debt to gross asset ratio
	0	–	–	1.00	0	0
	1	5,843	1.44	2.44	-156,026	.60
	2	- 784	0	2.44	-126,538	.48
1	3	- 7,896	0	2.44	-118,206	.43
	4	-15,474	0	2.44	-118,517	.42
	5	-23,490	0	2.44	-100,311	.34
	0	–	–	1.00	0	–
	1	21,419	1.44	2.44	-147,856	.57
	2	16,198	.69	3.13	-176,191	.52
3	3	7,080	4.22	7.34	-569,170	.69
	4	- 5,562	0	7.34	-533,307	.63
	5	-18,570	0	7.34	-438,263	.50

To reflect inflation, the purchase price of new vessels was specified to increase at 3% per year. This rate is 2% below reported price trends, which include costs of technological improvements. Newer vessels have been powered by larger engines. This has allowed for larger trawls to be towed at faster rates. This rate of improvement in technology is believed to have increased investment costs by 2% per year.

From the cost records of the cooperating firms, the annual cost of operating a 73-foot trawler was found to be $30,000 in 1969. This cost figure includes an allowance for overhead and insurance. Representatives of the firms interviewed indicated these costs have increased 3% per year in recent years. Thus, the annual production cost per vessel, τ_t, was specified to be 30,000 $(1.03)^t$.

Straight line depreciation methods were used for tax purposes with an 11-year depreciation period being used for a fully outfitted vessel. This average was estimated on a value weighted basis from the records of a number of firms. The reciprocal of this figure, 0.091, was the value used in the depreciation function.

Income is the sum of the revenues received (by the owner after the "lay") less operating costs, interest costs (or plus interest earnings), and taxes. The income tax rate, which is denoted by ζ, was taken to be 25% of the taxable income. This rate was paid in the late 60's by a number of the firms studied.

In shrimp fishing, the captain and first mate on a vessel are commonly paid on a "lay" basis wherein they receive for services rendered a percentage of the revenue earned by the vessel. The header, who is the third crew member, is typically paid on a per box basis; his wages are included in the production cost per vessel. For 73-foot vessels, the "lay" for the captain and first mate is commonly 35% (with the owner getting in effect 65% of the ex-vessel price); they typically pay for all of the groceries.

In interviewing the cooperating firms, the relative resale value of the vessels sold was found to be fairly well approximated (for vessels 5 to 6 years old) by summing the accumulated depreciation fractions with an appropriate adjustment for technological improvement. This procedure, which implies that the resale value of a vessel 5 years old would be 65% of the purchase price, was used as the basis for specifying β to be equal to 0.65[2].

To project per vessel expected revenue received by the owner, the log of the real shrimp price received by the cooperating firms, P_t, was regressed on the log of the index of real per capita income (in the United States after taxes), y_t, and the log of per unit effort landings, l_t, caught in depths beyond 10 fathoms off the Texas coast. (See the earlier study by Thompson et al. (1970, p. 12) for data.) The estimated regression equation was as follows:

$$(4)\quad \ln p_t = -4.571 + \underset{(t = 3.6)}{1.175 \ln y_t} - \underset{(t = 3.5)}{.379 \ln l_t},$$

$$R^2 = .748, \sigma_e = .0888.$$

[2] This approximating procedure was necessary, since the vintage was not accounted for in the model.

Variations in landings per unit effort, which were found to be highly correlated for the Texas and Gulf-South Atlantic fisheries, are still regarded by biologists as being largely random. Thus, to remove the effect of landings on price, landings were specified to be equal to the mean value observed for the Texas fishery in the period 1958 through 1967. Hence, the price estimating equation with an adjustment to a 1969 base year was as shown below.

(5) $\ln p_t = -1.332 + 1.175 \ln y_t$

To use this equation, the index of real per capita income had to be projected for the years 1970 through 1974. This was done by regressing $\ln yt$ on time, t, for the years 1953 through 1960, and also for the years 1961 through 1968. The following two income projection equations were developed for the period t = 1970, 1971, . . ., 1974.

Specification I: 1.5% rate of income growth

(6) $\ln y_t = 4.94 + .015t$

Specification II: 3.3% rate of income growth

(7) $\ln y_t = 4.94 + .033t$

By substituting the desired specification from (6) into (5), the price projection equation was obtained. The effective expected real shrimp price, a_t, was 0.65 of the antilog of p_t. To convert to money terms, the projected prices were multiplied by the consumer price index value for 1969, 1.277, and by a price inflating factor of 3% per year thereafter. In Table 1, $\tilde{p}_t$ denotes the price reflecting the high rate of income growth and $\hat{p}_t$ the low rate.

For the first set of four problems, the estimate of the owner's lowest annual revenue per vessel, L_t, was found by taking the lay residual of the product of the 1969 shrimp price, a_{69}, and the projected lower bound for landings per vessel. This lower bound was taken to be 3.4 standard deviations (in t units for 11 degrees of freedom) below the mean landing per vessel of 57,560 pounds with the sample standard deviation being 5,731 pounds. Thus, the probability of the landings per vessel being greater than this lower bound (assuming this to be a valid probability basis) is greater than 0.99. Moreover, since the growth rate in real per capita income is not taken into account in L_t, the probability of revenue per vessel falling below the implied estimate of the owner's lowest annual revenue per vessel (where the price is projected under either specification) decreases steadily as the planning period unfolds. In other words, the estimate of L_t is very conservative for the year 1970 and becomes increasingly conservative thereafter in the planning period.[3]

For the second set of two problems in which the shrimp price is random as well as the landing per vessel, the same value was used for the owner's lowest annual revenue per vessel. This resulted in a slightly smaller probability of survival than in the first four problems (because of the additional randomness in the price), but one still greater than 0.99. Thus, in the interest of simplicity, the same value of L_t was used in both sets of problems.

Knowledgeable industry representatives (who were consulted with regard to the above specifications) indicated a 5-year survival period would be especially meaningful for firms operating the 73-foot trawlers. Accordingly, two 5-year sequences of random revenues per vessel were developed with only the landing per vessel being random in the first sequence. Landings per vessel were regarded as independent of price, since the fishery is relatively competitive; moreover, for the period studied, per vessel landings for the cooperating firms were not highly correlated with landings per unit of effort in the Texas fishery[4] (r^2 = 0.16). Using the regression estimate for price in each year 1970 through 1974 and the estimated standard error of the regression, and also using the sample mean and standard deviation for landings per vessel of the cooperating firms, the random prices and landings per vessels were calculated as follows: (1) By use of the Box-Muller (1958) method, normal random deviates for prices and landings per vessel were independently generated; and (2) the products of these two random variables were adjusted for the lay and expected changes in the purchasing power of money. The following random sequences were accordingly obtained and used in the analysis.

[3] To have a probability support at L_t, this small probability of non-survival is implicitly assumed to be insurable.

[4] Landings per unit effort in the Texas Fishery are highly correlated with those for the Gulf and South Atlantic.

Random Sequences of Revenues per Vessel

Sequence No. 1

Problems 1 & 2	*Problem 3*	*Problem 4*
$30,741	$36,141	$31,413
42,572	48,233	44,457
39,859	45,795	42,531
39,797	46,020	43,393
50,784	57,308	56,583

Sequence No. 2

Problem 1	*Problem 3*
$25,450	$29,920
47,261	53,546
38,810	44,589
36,077	41,719
44,747	50,495

It may be helpful to recall that the decision-maker is regarded as being a better than average manager in Problem 3. The 1.5% rate of real economic growth per capita is used in Problems 1, 2, and 3; and the 3.3% rate of economic growth is used in Problem 4.

In evaluating the solutions to the first set of four problems in Table 2, the results indicate the profitability of investing in shrimp fishing capacity during the 5-year planning period. The model fisherman opted for investing in fishing capacity in Problem 2, even though he could have left his money in savings at 8.5% interest. Thus, the rate of return over cost from shrimp fishing was greater than 8.5%. In further analysis, it was found to continue to be so until the rate of interest reached 9.5%; then the rate of return over cost switched in favor of savings.

The value of better than average management is indicated by the results in Problem 3. There, the average landing per vessel was taken to be one standard deviation (5,731 pounds) greater than in Problem 1. The same amount was invested in the first year; but in the second and third years there were striking differences. The model fisherman bought 5.2 vessels in Problem 3, while he did not buy any in Problem 1. He chose to pay off debt in the first problem after the initial investment, since that represented a more profitable use of the money. It may be noticed that the investment upper bound limited the size of the purchases in the first 3 years of Problem 3 (and the first year of Problem 1). The marginal value of another vessel was positive; however, the money was not available for investment given the desire to survive.

Success in shrimp fishing is clearly influenced by the rate of income growth in the economy — compare Problems 1 and 4. In Problem 4, the marginal value of another vessel is almost twice as large in the first year as in Problem 1, and remains large in the second year when the value in the first problem goes negative. This increased growth in per capita income results in an increased ability to invest in the second year in Problem 4 and still further increased ability, at a lower marginal incentive, in the third year. The model fisherman carries a considerably larger debt load, as a result of the increased profitability, in Problem 4 than in Problem 1.

In evaluating the second set of results given in Table 3 and comparing these solutions to the ones in Table 2, only slight differences between the results may be noticed. Somewhat less is invested over the planning period in Problem 3 in the second case than in the first. Also, a slightly larger debt load was generally carried in most of the planning period. Of course, the marginal investment incentives were the same in both sets of problems; they are based on expected values. Vagaries in landings seem to be much more important than unexpected variations in price.

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APPENDIX

Appendix Table 1. — Values of projected index of real per capita income.

Year	Specification I	Specification II
1	136.98	139.52
2	139.06	144.27
3	141.17	149.19
4	143.32	154.27
5	145.50	159.53

Appendix Table 2. — Values of projected real shrimp prices.

Year	Specification I, $\hat{p}_t$ (cents per pound)	Specification II, $\hat{p}_t$ (cents per pound)
1	85.68	87.56
2	87.22	91.07
3	88.78	94.73
4	90.37	98.53
5	91.99	102.49

Appendix Table 3. — Values of landings per vessel for random sequences 1 and 2.

Year	Problems 1, 2 & 4 (pounds)	Problem 3 (pounds)
1	41,965	49,336
2	55,435	62,806
3	49,501	56,872
4	47,140	54,511
5	57,375	64,746

Simulation Experiments to Evaluate Alternative Hunting Strategies for a Deer Population[1]

F. M. ANDERSON,[2] G. E. CONNOLLY[3]

A. N. HALTER,[2] and W. M. LONGHURST[3]

ABSTRACT

A population dynamics model of the deer herd in Mendocino County, California, is presented. Environmental influences are modeled as density dependent birth and death rate functions. The computer program for this biomanagement model is outlined and validity checks devised to improve the model are discussed. The output shows the impact of selected hunting strategies on productivity, natural mortality, and other population characteristics. Tests of hunting strategies related to alternative management goals are summarized. Implications of computer simulation methodology for the management of wildlife and fish populations are discussed.

INTRODUCTION

Management of a natural resource, such as a deer herd or fishery, is the manipulation of that resource and/or its environment in an attempt to satisfy a set of objectives. The objectives can be economic or noneconomic. They may or may not be quantifiable, and hence, the management problem may or may not be solvable in the framework of "extremum" problems.

The management of a deer herd, like that of a fishery, can be directed toward multiple objectives. The deer herd may be maintained at a particular level and age composition to achieve a hunting kill having the greatest value; alternatively, the herd may be maintained for purely aesthetic reasons. A multiple objective of management may be to sustain a certain deer density (deer per square mile) at one time of the year to provide hunting, or at another time of the year to provide scenery for sightseers.

Under certain environmental conditions, managers may be prevented from knowing whether or not the objective(s) has (have) been attained. In areas of dense ground cover, managers must often resort to crude sampling techniques to derive population estimates. Other parameters can be readily measured. For example, in a deer herd where hunting is done only by license, the kill figures are available soon after the hunting season, and can be used in the formulation of subsequent management strategies. It may be that certain objectives will be satisfied if crucial parameter values are between certain upper and lower bounds. Alternatively, the objective of management may be to maximize the value of a parameter. Examples of these two cases are (1) to keep the average size of the herd between two values, and (2) to maximize the annual hunter kill, respectively. Other parallels to the objectives of management for a deer herd can be found in the management of a fishery resource.

Both deer and fish populations are members of complex, dynamic ecosystems. For each, the age composition changes over time due to the changes of such parameters as birth rates and death rates. In addition to relatively simple variability about these parameters, changes in the population are compounded by environmental changes.

To illustrate, assume there is a functional relationship between deer density and the mortality rate of each age category. Furthermore, assume a fixed habitat structure and that variability in the biosystem is introduced only by changes in the weather. The effect of these changes will usually be lagged. Other

[1] Technical Paper Number 2998, Oregon Agricultural Experiment Station, Corvallis, Oregon.

[2] Department of Agricultural Economics, Oregon State University, Corvallis, Oregon.

[3] Department of Agricultural Zoology, University of California, Davis, California.

relationships can be hypothesized to complete the abstract model. For each time period, the mortality rate in each age category depends upon the density. Over time this density will change, as will the inventory of deer in each category. Hence, mortality rates will differ over time, even if, the same functional relationships are hypothesized.

Now, add in the complicating factor of changes in some or all of these mortality functions consistent with an improved habitat and a higher plane of nutrition. In the real world, changes in the deer habitat — and its counterparts in other fish and wildlife species — are occurring continuously.

In making management decisions, some knowledge is assumed of the structure of the relevant biosystem. However, knowledge is, at best, uncertain, and heroic assumptions are aften made about the effect of a structural change. Thus, decisions may be made which move the biosystem toward the objectives desired in an unpredictable manner. Management is usually carried out within the boundaries described by legally authorized regulations, which are, hopefully, both consistent with a set of objectives and flexible enough to afford the on-the-spot manager some discretionary action. When regulations are for more than one distinct resource unit this flexibility is desirable because each unit is unique.

For example, regulations for deer hunting in a particular state usually embrace more than one herd. No two herds will be identical at any point in time, and the regulations must be sufficiently flexible to allow for these differences. Regulations are ideally formulated with regard to the structure of the relevant biosystems, but knowledge of these biosystems is not complete. The response of the biosystems to particular management actions cannot be predicted with certainty. Therefore, there is a limit to the rigidity of the regulations. Beyond this limit, management will be ineffective in attempts to satisfy the set of objectives.

Thus far, we have briefly described three components of the management system of a public resource. These are the complex biosystem, the set of objectives, and the set of regulations relating to the particular resource. One more component is necessary to complete a workable management system; that is, a means of monitoring the system is required. For any biosystem, the selection of the parameters to be monitored is the result of experience and expertise. However, to be useful to management, the selected parameters must be indicative of the performance of the biosystem so that it can be determined whether, or to what extent, objectives are being accomplished.

Typically, only relatively few parameters can be monitored accurately and rapidly enough to be useful. Information on the state of the system is of most value when it is current. The role of time in monitoring systems cannot be overemphasized. Information on the state of a biosystem at any time is usually incomplete. For example, the total number of deer in a herd is a useful parameter in developing management strategies. In most herds it is impossible to take an accurate annual census, and estimates of the total population must be based on samples, which often may be collected only at certain times of the year.

Historically, researchers and managers have been restricted to experimentation on the real biosystem. However, with the advent of computers and programming languages, it is now feasible to perform simulated experiments on biosystems that can be described by mathematical equations. This paper is concerned with the computer simulation of the deer population in Mendocino County, California. The model shows the population dynamics and some of the economic and recreational consequences associated with various hunting strategies.

COMPUTER SIMULATION METHODOLOGY

Simulation involves building and operating a model designed to represent those features of the real system under study and to provide information about the performance of the system under assumed controlled conditions.

Three classes of simulation models can be distinguished: (1) physical models, such as scale models of river systems and planetariums, (2) mathematical models where a set of equations describing the system under study is written and these equations are solved, perhaps analytically, and (3) computer simulation where the system is described and the logic is programmed for computer calculation. In the latter case, the intent is to simulate complex systems which usually involve nonlinear relationships, random components, and time varying events.

Computer simulations are applicable to problems of the type where management can influence the system's behavior. The purpose of simulating a management system is to test the impact on variables of interest within particular management policies, before such policies are implemented, and influence the real system. Here, the simulation performs the important function of providing information about the possible consequences over time of various alternative management policies. Thus, it provides answers to the managers' questions which are of an if-then type. The computer program is an if-then calculator. Systems could be simulated using paper and pencil, but computers can carry out these calculations more efficiently.

Simulation should be viewed as an iterative problem-solving technique which involves four stages: (1) problem definition, (2) mathematical modeling, (3) refinement and testing of the resulting model, and (4) creative design and execution of simulation experiments to provide information relevant to the management problem. In Figure 1, arrows indicate that the general sequence is from problem definition to application, but the reverse arrows indicate that the process is iterative, or learning in nature. A prior stage might have to be repeated on the basis of information acquired during a subsequent stage of the modeling process.

Problem definition is fundamental to building a simulation model. This study's interdisciplinary team, composed of biologists and agricultural systems analysts, initially met to determine the types of questions the model was to answer. The questions fell into three categories:

1. Biological questions involving the dynamics of the deer population.
2. Economic questions involving the value or worth of certain events and occurrences within the system.
3. Management questions which affect the biological system and have economic and social consequences.

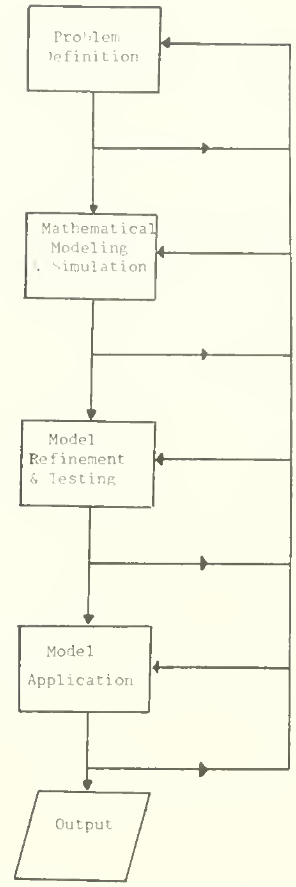

Figure 1. — Computer simulation as an iterative problem-solving process.

In its present form, the model construction cuts across all three types of questions, and should be viewed as the first generation model of a sequence of models which, hopefully, will be able to answer these questions at more sophisticated levels. This first generation model is essentially a population simulator capable of answering questions mainly of a biological nature, but provides output for management questions — in particular, hunting strategies. Other sections of the output could easily be given economic interpretation. The second generation model will include economic variables such as losses due to deer damage to agricultural and forest lands, and gains, such as hunter expenditure and the value of venison. The proposed third generation model will include a management component which would be capable of evaluating management strategies in the broader context of their biological, economic, and social consequences.

DEER HERD SIMULATION MODEL

A comprehensive flow chart of the components and interrelationships of a deer herd was developed. The available data did not permit all relationships to be quantified and proxy variables were devised to overcome this difficulty. For other relationships a complete specification of the biological interactions would have been possible, but this would have resulted in a model of substantial complexity. Model building is a continual compromise between abstraction and complexity. Models which are too abstract are devoid of interest, and the results will not be easily related to the operations of the real system. When the models are large, and incorporate complex mathematical formulations, it can be difficult to extract meaningful guidelines for management. Such models may be expensive to run, and thereby not achieve one objective of the modeling process, namely, to simulate the systems and generate information and knowledge about the systems at a cost less than alternative analytical techniques.

The flows and relationships identified for the Mendocino County deer herd are summarized in Figure 2. In this figure the time series of events is not obvious. These are discussed in more detail later in the paper. The model as depicted in Figure 2 is best viewed as a summary of the most pertinent interactions which occur each year in the deer biomanagement system. The basic components of the system are the birth and death process. Each year fawns are born into the herd, and the number of fawns born is a function of the exponential average of the density in particular

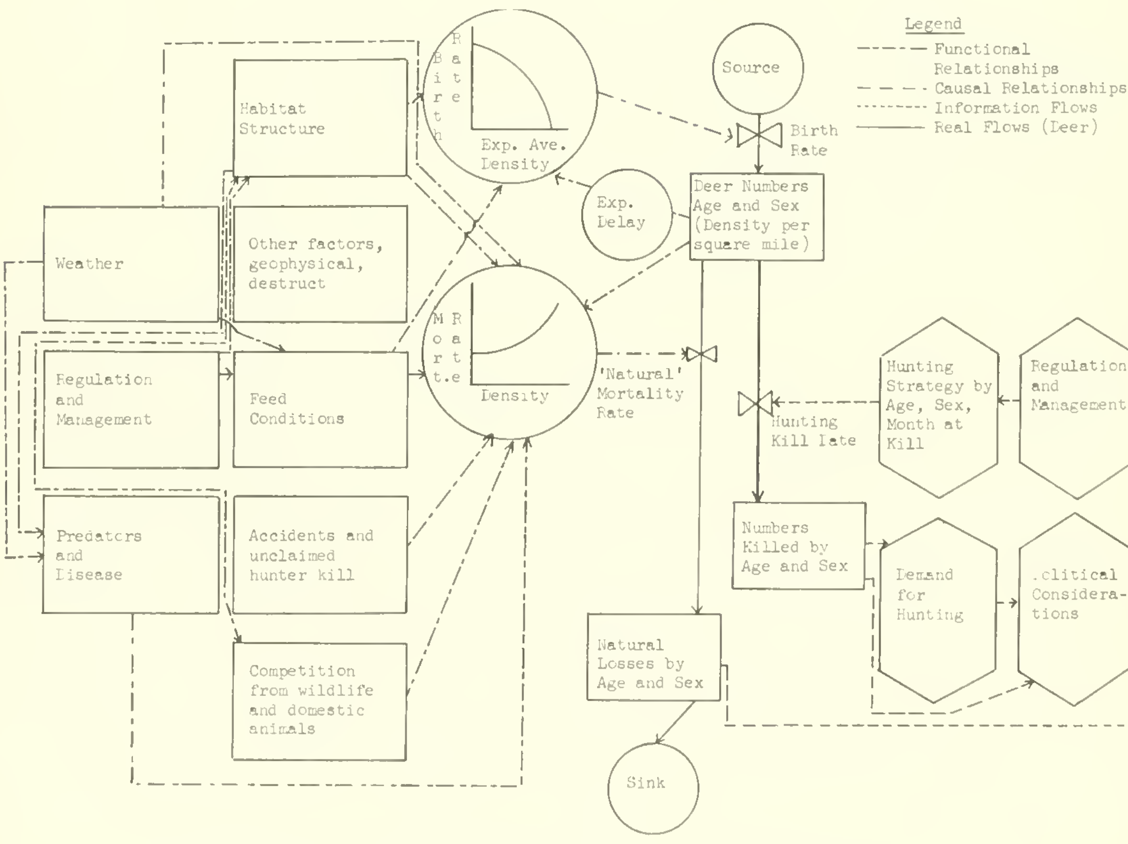

Figure 2. — Biomanagement system of a deer population.

months prior to the time of birth.[4] Thus, the exponential average density is a proxy variable which summarizes all relevant causal influences of the real system. The casual influences are indicated in Figure 2, but are not explicitly programmed into the computer.

In the model, losses are defined as either natural or due to hunting. Natural losses are the residual of losses after accounting for the recorded hunter kill. The natural losses will include those due to age, the plane of nutrition, the action of predators, disease, and accidents on the highways. Both natural and hunting losses are computed each time period. Natural losses are computed for each category of deer by reference to functions relating the density of deer at the beginning of the period to the rate of mortality. Here, density is the proxy variable for an array of causal relationships, as indicated by Figure 2. These natural mortality functions were based upon biological theory and the available empirical evidence. The paucity of data, however, precluded statistical estimation; hence, use was made of interpolation techniques between data points to derive the mortality rates for particular densities. Natural losses are therefore endogenous to the model.

Hunting losses are treated differently. The hunting loss rates are defined by age category and the time period in which hunting is allowed, as specified prior to the execution of a computer run. The hunting losses could be made endogenous, but in the first generation model, where accent is on formulating a reasonable biological model, it is advantageous to manipulate these losses to test the model. In the real world, hunting strategies are fomulated cognizant of political considerations, regulations, management capability, and the demand for hunting. They are the consequences of interactions which are not fully indicated by Figure 2.

Thus far, the model has been presented as deterministic. The real world is characterized by random variability. The response of the deer biosystem to a particular set of conditions is variable, due to random, uncontrollable elements such as the weather conditions. Randomness must be accounted for in any simulation which purports to model reality.

In the deer model, a random number generator is used to generate variability.[5] Variability is due to weather conditions which are assumed to result in particular forage quality-quantity relationships or forage conditions. The notion of a forage factor is used as an index of forage conditions. Each year, a random number is computed which, in turn, implies a particular forage factor. Only five forage conditions are identified. A forage factor of five corresponds to average conditions; and a forage factor of one corresponds to poor conditions. Forage factors of two and four correspond to below and average conditions, respectively.

The probability distribution of forage factors can be easily modified, consistent with the investigation of the impact of changes in the pattern of forage conditions over time. Once the forage factor is selected for the year, it is used to modify the components of the system which are considered to be subject to variability due to changes in the forage conditions — namely, natural mortality rates and birth rates. The notion of the forage factor has proved most useful in the development of the computer model, in addition to its primary role in carrying out experiments with the model after development.

Thus, the biomanagement system is presented as a network of flows, rates, and levels. The system being modeled is complex, but by suitable abstraction, a workable dynamic model which permits examination of the system in a manner not permitted by the usual comparative statics formulation, can be developed.

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[4] The exponential average density each month is computed as follows:

$$EAD_t = EAD_{t-1} + 1/\mathrm{T}\,(D_t - EAD_{t-1})$$

where: t = Time period (month)
EAD = Exponential average density (deer/square mile)
D = Density (deer/square mile)
T = Exponential smoothing time constant (number of months)

[5] The computer program generates a sequence of pseudo-random numbers which provides the facilities for comparing results of different runs under identical simulated conditions.

Time Sequence of Events

A flow chart of the computer program of the deer herd is shown in Figure 3. For any simulation model concerned with the flow of variables over time, a unit of time must be defined for purposes of calculation. The computer moves in discrete steps through time, and calculates the variables at each step. In the deer herd model, the unit of time is one month. For each month of a computer run, the relevant calculations are made, and the status of the system at the end of that month is generated. The status of the system is an array of rates and levels for all variables in the system. The time counter is advanced one unit (one month) and the appropriate calculations for that month are made. Calculations can be made conditional upon any event or series of events in the past, but not upon future events, because they have not occurred.

Starting with the opening inventory shown at the top of Figure 3, the computer program selects a forage factor for the year as of November 1, and computes natural losses as a consequence of the forage factor and deer density. Figure 2 shows the array of interactions which are summarized in the mortality rate-density functions. The mortality rate in each age and sex class is described as an exponentially increasing function of density. Hunting losses are then computed in accordance with the hunting strategy specified for the simulation run, and the closing inventory by age and sex is calculated. Loss totals are then accumulated, and can be included in the output as desired by the analyst. Each month, the above sequence of events is carried out.

After accumulating losses in May, the number of new fawns to be introduced into the herd is computed. The birth rate in each age class of does is described as a decreasing function of the exponential average density. The age categories are then advanced one year. Bucks and does in their sixteenth year are removed from the system — represented in Figure 2 by the sink. Fawns born 12 months previously are separated into bucks and does, and redefined as deer in their second year.

Two accounting years are defined in the computer program. The first is from November 1 to October 31. November 1 is the time when managers are best able to make population counts indicative of the age and sex composition of the herd. The second accounting year used in the model, July 1 to June 30, facilitates the summarization of the hunting results for each year. Selected parameters are printed at the end of each accounting year. After all the October operations are performed, the year counter is advanced and the simulation proceeds until the specified number of years has been executed. At the end of each run, summary statistics are printed.

Input Data

The model is intended to simulate the Mendocino County deer herd, but the primary data source was the University of California Field Station at Hopland, where the deer population has been under continuous and intensive study since 1951. The investigators at Hopland compiled these data and integrated them with the California Fish and Game Department data for the remainder of the county.

Data input for each run is separate from the computer program. This permits changes in the data assumptions to be made without altering the computer program. The program is designed to be applicable, with minor modification, to other big game populations.

The data block for each run includes constants to initialize the run, such as the opening inventory, the area of land available to the herd, and the length of the run. Other data used in each year include birth rate and natural mortality functions, hunting loss percentages, and the distribution of forage factors.

HUNTING STRATEGY RESULTS

While an infinite variety of hunting strategies can be tested in this model, the options of the wildlife manager are limited because certain hunting strategies that are biologically feasible may be socially or politically unacceptable. In addition, hunters can usually distinguish only a few age and sex classes in the field. Limited hunter access to extensive areas of private forest and range lands precludes the achievement of uniform hunting pressure over the entire county.

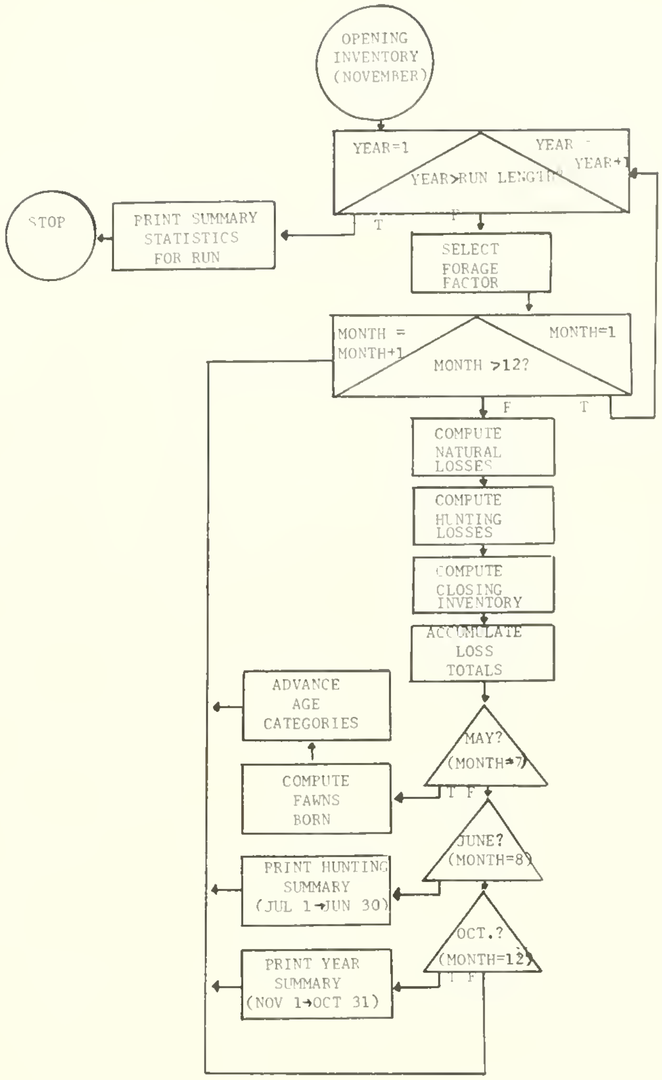

Figure 3. — Flow chart of the computer program of the deer herd.

The hunting strategies summarized in Table 1 include the range of options which could be practically implemented in Mendocino County. Two kinds of population parameters are shown: those which can be maximized or minimized as management goals, and those comparable with field data to determine whether management goals are being achieved. Some parameters, such as the hunting kill, serve both purposes. The current program prints out many other parameters in addition to those presented in Table 1.

Although it is physically possible to hunt deer at any time of the year, in California it is customary to set the deer seasons in late summer and fall, for numerous biological and sociological reasons. In the simulation runs presented in Table 1, all buck hunting was conducted during August and September, in accordance with existing custom, and potential doe and fawn hunts were set for November and December, the months when antlerless deer are in the best condition. All parameters other than hunting specifications were held constant throughout these runs, and the values shown were selected from the output after

Table 1. — Selected parameters of the Mendocino County deer population as affected by alternative hunting strategies.

	Strategy			
	No hunting	25% adult bucks	45% bucks 30% does 15% fawns	50% bucks 15% does 60% fawns
	(1)	(2)	(3)	(4)
Total deer				
June 1	236,000	251,000	141,000	168,000
November 1	191,000	191,000	117,000	141,000
May 30	150,000	148,000	90,000	93,000
Annual Losses				
Natural	85,000	95,000	15,000	22,000
Hunting		7,900	36,000	53,000
Natural hunt-loss ratio	—	12:1	0.4:1	0.4:1
Kill as percent of June 1 population		3	26	32
Percent composition of kill				
Bucks	—	100	42	22
Does		0	41	18
Fawns	—	0	17	60
Herd composition data				
Fawns/100 does				
Spring	41	41	90	50
Fall	64	64	83	96
Bucks/100 does				
Fall	86	43	41	22

stability had been attained. Year-to-year variability was suppressed to highlight the differences among the hunting strategies. The principal features of each strategy are summarized below:

1. *No Hunting:* This strategy is presented mainly for comparison with the other runs. It is characterized by a high buck:doe ratio, low productivity, and high natural mortality.
2. *Twenty-Five Percent Adult Bucks:* This is an estimate of the hunting effected in Mendocino County during the past 10 + years. Hunting is limited to males with two or more points per antler. Natural mortality is higher than in Strategy 1 because the population includes relatively more does, as indicated by the buck:doe ratio, and the number of fawns born is, therefore, higher. Fawns are most susceptible of all age classes to natural mortality. Overall deer numbers do not differ markedly between Strategies 1 and 2. For every deer taken by hunters, about 12 die of starvation and other natural causes. Although the management goals are not explicitly defined, current regulations result in the maintenance of maximum deer numbers and maximum natural losses. This strategy provides no constraint upon overall deer numbers.
3. *Forty-Five Percent Bucks, Thirty Percent Does, and Fifteen Percent Fawns:* Where the hunter is allowed to select either bucks or does, this strategy represents the results of the heaviest hunting

pressure likely of achievement. Although hunters generally avoid killing fawns if possible, data from other areas indicate that fawns comprise 15% to 20% of the kill in antlerless hunts. The annual kill of 36,000 would probably require private lands to be hunted as heavily as public lands. Comparison with Strategy 2 indicates that the hunting kill would increase about 45%, even though the overall population decreases about 40%. Natural losses are also much reduced.

4. *Fifty Percent Bucks, Fifteen Percent Does, and Sixty Percent Fawns:* While the previous strategy would tend to maximize the hunting kill if hunters were allowed their free choice of animals, the kill could be further increased by selectively hunting fawns. This strategy is comparable with the usual sheep management regime in Mendocino County, where a high proportion of lambs is marketed annually. Although the kill would be considerably higher than in the previous strategy, the total biomass yield would be slightly lower because of the relatively small size of fawns. It may be unrealistic to propose that 50% of the bucks can be killed annually. However, if the goal of management is to maximize the number of animals taken by hunting, it is necessary to maintain the highest possible proportion of breeding does in the herd, and this can be achieved only by heavy hunting of adult males.

A convenient way of showing hunting yield and population numbers at equilibrium for different strategies is by plotting the results from many computer runs on graphs like these shown in Figures 4 through 6. These graphs permit a comparison of the relative effects of selective hunting pressure directed against does, fawns, and buck, respectively.

Figure 4: This graph depicts population trends and yields of deer when various percentages of does are taken by hunting when (A) no bucks or fawns are taken, and (B) 50% of all bucks and 15% of the fawns are taken annually. Several pertinent aspects of population performance are apparent from this graph:

(1) With no hunting of bucks and fawns, a slightly higher total population of deer tends to be maintained when any given removal of does is carried out.

(2) Maximum productivity or yield of the population is achieved when approximately 25% of the does are removed annually. However, the total yield is approximately five times higher if bucks and fawns are taken as specified in Strategy (B).

(3) As hunting pressure on does increases, overall deer numbers decrease at an increasing rate.

Figure 5: Figure 5 indicates the effect of increasing fawn removals accompanied by (C) no buck or doe hunting, or (D) annual hunting removals of 50% of the bucks and 30% of the does. It shows that:

(1) The total population will decline only slightly with the increasing removal of fawns only, as depicted by (C).

(2) Under the buck-doe strategy in (D), maximum yield and population size will diminish rapidly if annual fawn removal exceeds approximately 30%.

Figure 6: The hunting conditions set forth on this graph are, (E) no does or fawns are taken as related to the increasing take of bucks, and (F) a removal of 30% of the does and 15% of the fawns in relation to an increasing take of bucks. The graphs show that:

(1) Buck removal alone has only a slight effect on yield, and even less effect on total population.

(2) When does and fawns are taken as specified in Strategy (F), the total yield of the population is roughly doubled, as compared to taking bucks only.

GENERAL RELATIONSHIPS

Consideration of the three graphs shows that:

(1) Maximum yield of the Mendocino County deer population is only achieved through exploitation.

(2) Reduction of the large, unexploited population through hunting produces a more dynamic population, with greater turnover. The basic relationship is to lower stocking rate on the range, which reduces competition for available feed, and thereby raises the plane of nutrition. This, in turn, improves fecundity and survival.

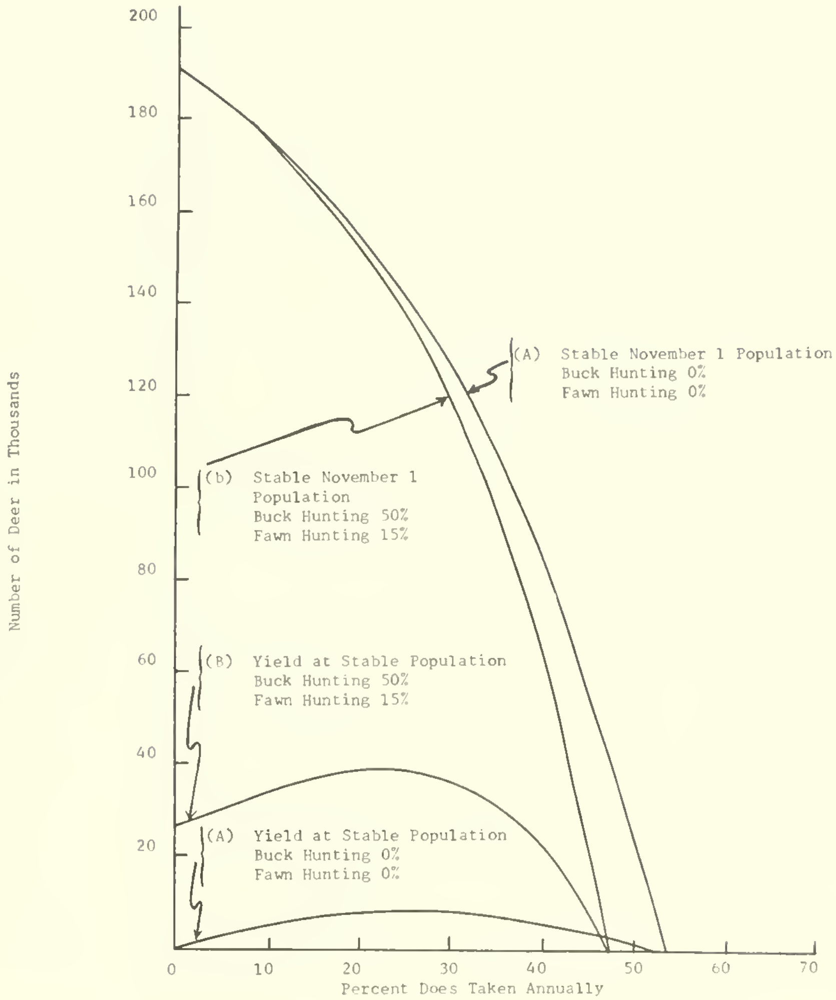

Figure 4. — Yield and population numbers at equilibrium for two buck-fawn hunting strategies and variable doe hunting percentages.

(3) It appears that maximum population and yields will probably be achieved with a hunting removal of about 20-25% of the does, 15-30% of the fawns, and over 50% of the bucks annually. At this rate of buck removal, there is no possibility of reducing the breeding success of the population, but it is highly unlikely that such a high rate of buck take can ever be achieved over the county as a whole. The density of cover on much of the deer range precludes it. Under present hunting practices, a buck removal of possibly 20-25% is being achieved. At best, this might possibly be doubled.

Likewise, it is highly unlikely that hunters can be forced to take large numbers of fawns selectively. Most either-sex hunting efforts can be expected to produce a take of fawns of about 10-20%, and it is difficult to increase this, as hunters try to avoid taking fawns because of their small size.

(4) Removal of does above the 25% level is the most powerful means available for total population control, since it reduces total reproductive potential. This finding is readily applicable to the special management problems in National Parks, where big game numbers

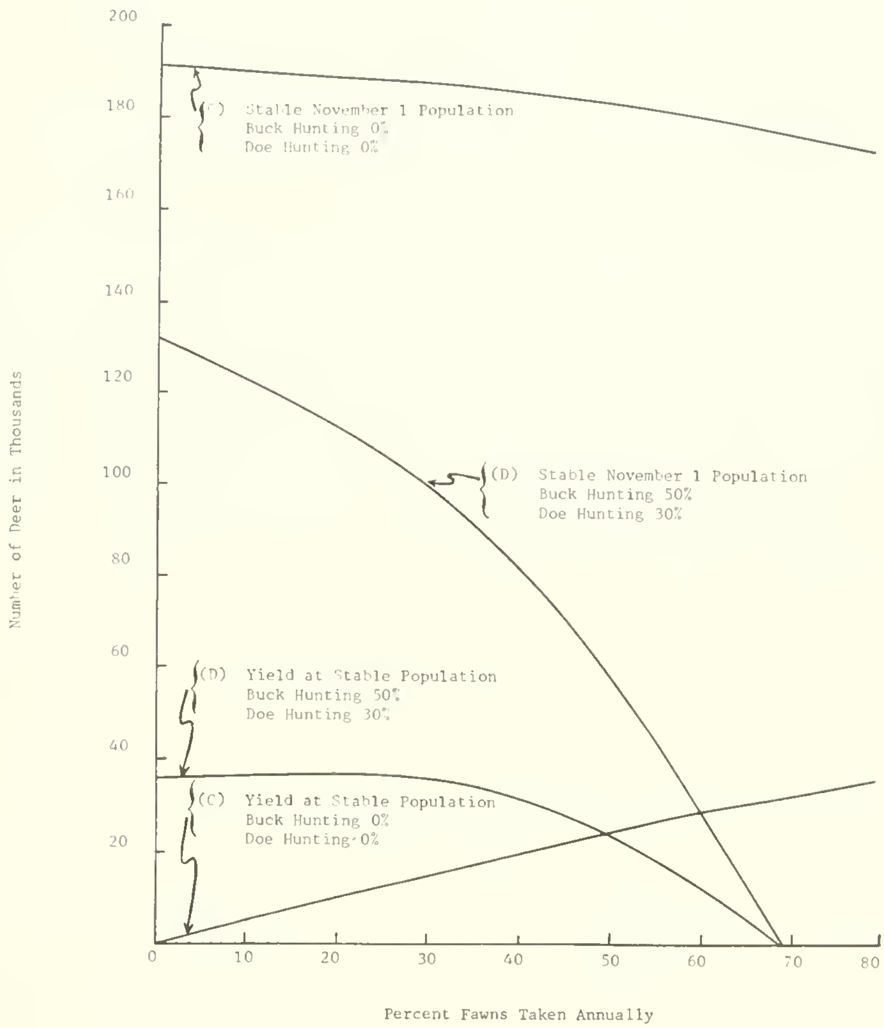

Figure 5. — Yield and population numbers at equilibrium for two buck-doe hunting strategies and variable fawn hunting percentages.

must be controlled, but public hunting is considered incompatible with other management goals. In such situations, it is customary for surplus animals to be shot by park officials. Our calculations indicate that these removal programs should be directed solely against adult females to provide the most effective population control. This would minimize the number of animals to be killed, as well as the manpower requirements, and would additionally maintain a high proportion of the aesthetically desirable adult males in the population.

CONCLUSIONS

Computer simulation of dynamic biomanagement systems appears to provide a means of generating information useful to resource managers and to research administrators. In building computer simulation models, researchers and managers put together their theoretical and practical knowledge of a system. This process frequently results in finding existing gaps in empirical data, and helps to revise

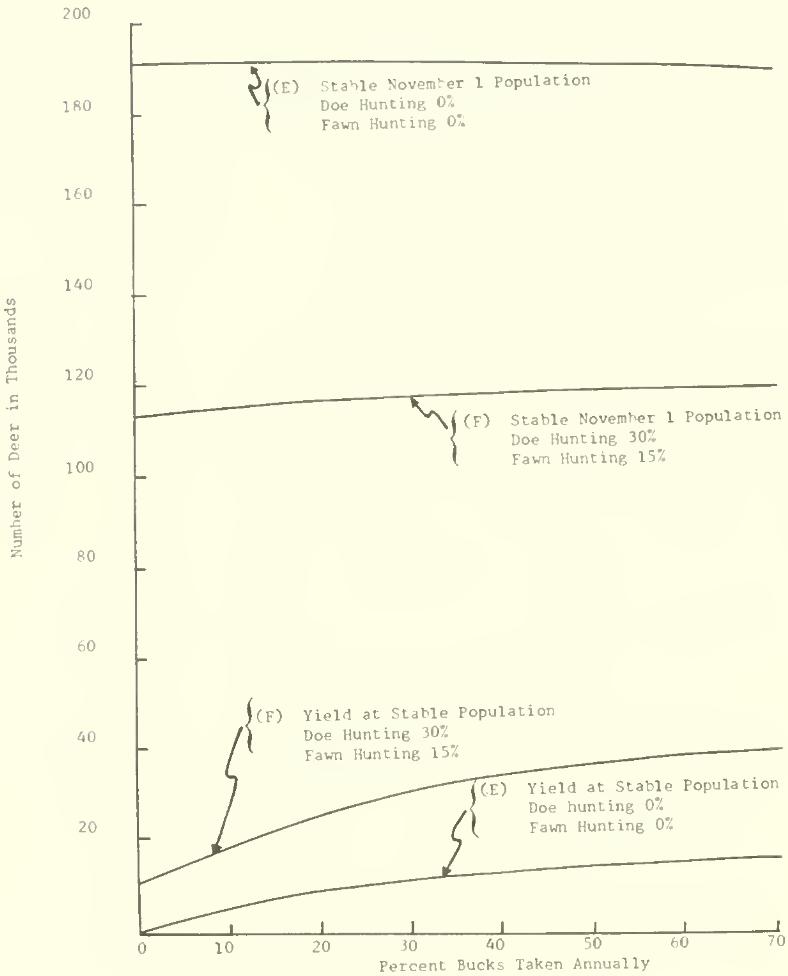

Figure 6. — Yield and population numbers at equilibrium for two doe-fawn hunting strategies and variable buck hunting percentages.

research plans and data collection procedures for monitoring the real system. Outside of this important research administration outcome, information about consequences of management policies which might otherwise not be obvious can be provided. For example, our results to date indicate that annual revisions of the hunting regulations will not, in general, cause management objectives to be attained more rapidly than following a fixed hunting strategy. This is due to the compounding effects of random variability and the difficulties in monitoring the system.

The systems analysis approach, and its concomitant technique of computer simulation, can and has been used to study other wildlife resources such as fish populations. Models developed for fish populations would necessarily incorporate the unique features of each system, and the output would be designed according to the special needs of the resource manager. However, further exploration of the usefulness of computer simulation in studying fish populations is needed before the optimism shown for big game management can be expressed for management of fisheries.

Augmentation of Salmon Stocks through Artificial Propagation: Methods and Implications[1]

JOE B. STEVENS AND BRUCE W. MATTOX[2]

ABSTRACT

Eighty-one hatcheries on the Pacific Coast now rear significant numbers of salmon and steelhead for sport and commercial fisheries. Annual operation and maintenance costs amount to $6.6 million. A production function analysis of 15 Oregon Fish Commission hatcheries produced tentative conclusions that (a) controlled inputs were combined in fixed proportions, (b) constant returns to size were realized, and (c) some degree of factor substitution existed between the controlled "fixed proportion input" and water temperature. The latter relationship may allow hatchery managers to improve efficiency at the hatchery level. Uncertainty with respect to downstream environmental conditions, however, must be considered along with returns to size for the hatchery production function when new investments are undertaken.

Fixed asset theory was used to conceptualize exit and entry of salmon harvesting resources between 1947 and 1966. Net entry followed years of good catches, but net exit did not occur following the bad years. If a major objective of hatchery programs is to augment fishermen's incomes, consideration must be given to increasing the opportunity costs of extant resources as well as to limiting entry of new resources.

INTRODUCTION

It is a moot question to ask whether or not the public sector should involve itself extensively in hatchery rearing of salmon and steelhead on the Pacific Coast. Eighty-one hatcheries, valued at over $56 million with annual operation and maintenance costs of $6.6 million, now rear significant numbers of chinook and coho salmon and steelhead trout for sport and commercial fisheries. It is a relevant question, however, to ask under what conditions continuing investment of this type should be undertaken. Although this is a question which can and should be posed, it is not easily answered; thus we do not attempt to do so, aside from exploring some obvious and not-so-obvious implications. Our major attention herein is devoted to asking and partially answering the question: "Given the decision to augment resource flows by artificial propagation, what can be gleaned from existing data which will allow the public sector to increase efficiency at the hatchery level?" In exploring this question, we recognize the dangers of a partial analysis, i.e., divorcing hatchery objectives from higher order objectives. Our defense is pragmatic, i.e., that it is better to start fitting the pieces of the puzzle together, one by one, than to not start at all or to theorize how they might all be fitted simultaneously.

THE CURRENT SIGNIFICANCE OF SALMON AND STEELHEAD HATCHERIES[3]

The first Pacific Coast salmon hatchery was constructed in Northern California by the U.S. Fish Commission almost a century ago. Since that time, artificial propagation of salmon has alternately been viewed as a panacea and as no solution at all. Improvements in propagation methods have allowed,

[1] Technical Paper No. 3010, Oregon Agricultural Experiment Station.

[2] Associate Professor of Agricultural Economics, Oregon State University, and Assistant Professor of Resource Economics, University of Rhode Island, respectively. This publication is supported in part by the National Oceanic and Atmospheric Administration (maintained by the U.S. Department of Commerce) Institutional Sea Grant 2-35187. Nothing stated herein is to be taken as representing the views or policies of the Oregon Fish Commission.

[3] Data on the nature and contributions of hatchery programs were taken freely and gratefully from Wahle, (1970).

and environmental deterioration has forced, increased reliance on hatchery operations, especially in the past decade. Eighty-one hatcheries are now operated by fishery agencies of Alaska, Canada, California, Oregon, and Washington, and by the Bureau of Sport Fisheries and Wildlife. Extensive evaluation programs are carried on by the Columbia Fisheries Program Office of the National Marine Fisheries Service and by some of the other agencies. The evaluative work of the NMFS program has included extensive fin-clipping, sampling for marked salmon, and benefit-cost analyses for brood years by species.

The current status of these resource augmentation programs has recently been summarized by Wahle (1970) of the NMFS, and is portrayed in Table 1. Survival rates of 4 to 5% indicate that a multitude of fingerlings must be released in order to affect resource stocks. The cost of production for one fingerling, on the other hand, is relatively low. Our study revealed that the 15 hatcheries of the Oregon Fish Commission produced the equivalent of about 70 million salmon and steelhead fingerlings between October 1, 1968 and April 30, 1970, at a cost of slightly over two cents per fingerling.[4] Assuming that the survival rates in Table 1 are appropriate, the cost per fish caught at some time in the future rises to about $1.35, disregarding any discounting for time.

The contributions of hatchery-reared fish to the ocean troll fishery is impressive, ranging from 30 to 80% of total catch in 1968. Wahle points out, however, that the proportion of hatchery fish to wild fish was higher than usual in that year. The true contribution to the sport catch of coho, for example, may be closer to 50%.

It may be useful to this group to have the hatchery programs put into perspective with the total salmon catch for the West Coast States of Washington, Oregon, and California.

Table 1 — Survival rates and contributions to ocean troll fisheries of hatchery-reared salmon and steelhead in 1968.

Species	Survival rate[1]	Hatchery-reared fish as a percentage of total ocean troll catch (1968)[2]
Coho	0.04 (.037)	Commercial: 30%
		Sport: 80%
Fall Chinook	.004 (.003)	Commercial: 70%
Spring Chinook	.05	Sport: 65%
Steelhead	.04	--

[1] Survival rates for coastal streams are shown in parentheses.
[2] The commercial fishery data for chinook salmon include landings from the west coast of Vancouver Island, in addition to landings in Oregon, Washington, and California. The sport landings include only the latter three States.
SOURCE: Wahle, 1970.

To do so, we have done some quick (and dirty) calculations for which we assume sole responsibility. The total yearly landings of all salmon in this region flucuate widely because of the odd-year cyclical nature of pink salmon, an important species for which hatchery propagation work is now in advanced experimental stages (McNeil, 1969). Averaging one recent cycle year for pink salmon (1967) with one non-cycle year (1964), about two-thirds of the total salmon catch is comprised of coho and chinook (U.S. Department of the Interior, 1947-1967). Assuming that Wahle's data from Table 1 are appropriate for coho and chinook, regardless of method of capture[5] (troll, gill net, purse seine), and using a conservative hatchery-contribution share of 30%, it would appear that perhaps 20% of the total West Coast (U.S.) salmon fishery is supported by hatchery programs. This share is increasing over time, and success in rearing pink salmon will provide further augmentation.

[4] This assumes that coho and spring chinook were released at 15 fingerlings per pound of fish, fall chinook at 100 per pound, and steelhead at 10 per pound. Costs include variable operating expenditures plus and imputed 5% charge on the $7.5 million replacement value of fixed facilities (Mattox, 1970 and Wahle, 1970). The latter sum is no doubt an overestimate of real capital values.

[5] The troll fishery accounted for about 63% of total coho and chinook capture, averaging 1964 and 1967 data. Ocean troll alone would constitute at least 50% of total catch.

PRODUCTION FUNCTION ANALYSIS OF HATCHERY PROPAGATION OF SALMON AND STEELHEAD

The Incentive Framework of Hatchery "Firms"

As is usually the case, our initial research objectives were more elegant than could be accomplished with existing time and data. Initial plans were to estimate marginal productivities for each of several factors of production relevant to the 15 major hatcheries of the Oregon Fish Commission, and to estimate the total elasticity of production or returns to size for these hatcheries. If possible, we wanted to incorporate into the function post-hatchery phenomena, especially the physical returns to the fishery of hatchery-reared fish. In that the NMFS data on the latter were not yet precise enough to identify differential returns by hatchery, it was necessary to restrict the analysis to the hatchery production function.

One of the most interesting aspects of the analysis was the influence on model specification of the incentive framework of the hatcheries. Federal and State hatcheries receive no price for their product, have no responsibility for realizing profit, and are managed by professionals trained primarily in terms of biological relationships. Budget constraints are imposed by the political rationing process. Furthermore, the nature of the incentive framework is such that it is only partially conducive to providing data in a form which is useful for economic analysis.

On the other hand, hatchery managers are not unaffected by economic forces, since they face constraints on operating capital and technology as well as constraints with respect to factor prices, fixed facilities, and natural phenomena. Among the latter are yearly and seasonal variations in water quantity, which often result in the non-use of rearing ponds, and seasonal variations in water temperatures which affect metabolic processes of fry and fingerlings.

The absence of a product price, of course, does not mean that the conventional economizing model is not relevant. The influence of technological, budgetary, and factor price constraints seemed sufficiently strong to postulate that hatcheries attempt to maximize output subject to these constraints. In one major respect, however, it was anticipated that the decision framework of the hatchery managers would give rise to a type of empirical result not usually obtained in analyses of private firms. That is, it was hypothesized that the particular set of hatcheries we observed were (a) combining controlled inputs in fixed proportions, and (b) realizing constant returns to size.

The reasoning behind this hypothesis largely reflects the institutional nature of the hatcheries, although physical attributes of the productive factors serve as necessary conditions. The primary institutional factor is the influence of centralized supervision on the Fish Commission hatcheries. Resident managers appear to operate within guidelines set by the central office with respect to input combinations, a system which is reinforced by disciplinary training of both groups. The physical attributes of factors which would allow them to be combined in fixed proportion is a relatively high degree of divisibility. The latter is elaborated below.

The Biological Production Function

The underlying production function for fingerlings can be viewed as consisting of three controlled factors — food, labor, and rearing space — and one non-controlled factor — water temperature. The food variable is nutritionally complex, but a convenient one for analytical purposes since the Oregon Moist Pellet is a "complete" ration. This food, fed in a variety of pelletized and mash forms, was specially formulated to satisfy the nutritional demands of fingerlings at different ages as well as for prevention and treatment of disease. Further, the food is centrally purchased, thus eliminating any price differentials between hatcheries.

Although mechanical feeders have been tried in some areas, the Fish Commission feeds entirely by hand application of the pellets. In that a pool of temporary labor is usually available to resident managers, both labor and food variables are quite divisible.

The third major controlled variable, rearing space, might be described, tongue in cheek, as water surrounded by concrete. Water flows, as noted earlier, vary in quantity and temperature. Both of these physical dimensions are largely outside the control of management. Although some low flow augmentation is accomplished, the usual result of low flows during summer months has been an inability to fully utilize rearing space. Since the rearing ponds are fairly small and numerous, low flows are adjusted for by maintaining water volume in some ponds and temporarily retiring others. Thus, the rearing space actually used is also fairly divisible, although some seasonal excess capacity may exist.

Although our initial inclination was that separate marginal factor productivities might be estimated, discussions with hatchery managers soon revealed the similarity of practices in combining controlled inputs. Levels of inputs and outputs at larger hatcheries seemed to be constant multiples of those found at smaller hatcheries, although opportunities for variable input proportions seemed to be present in a physical sense. One could, for example, stock rearing ponds with fingerlings at different rates, or spread existing water flows over all rearing ponds. Centralized management, of course, may not be conducive to such experiments. On the other hand, it may well be that past "experiments", intended or otherwise, have revealed that other factor combinations involve a greater degree of risk. For example, disease spreads rapidly in rearing ponds; overcrowding of fingerlings might be disastrous. Similarly, lower water levels in all ponds would increase water temperature and accelerate the spread of disease.

Our hypotheses of fixed factor proportions and constant returns to size were equivalent to expecting that the Fish Commission *acts as if* the isoquants for hatchery production of fingerlings are right-angled, whether they actually are or not. The hypothesis was strongly dependent, of course, on our prior decision to analyze Fish Commission hatcheries. A cross-section analysis over various agencies, in retrospect, would possibly have yielded more empirical information.

The non-controlled variable, water temperature, can be quite important during periods of either cold or warm weather. Extremes of either type seem to effect primarily the voluntary rate of metabolic activity, rather than the efficiency of food conversion (Paloheimo and Dickie, 1966). It was expected, then, that growth would be retarded in the upper and lower limits of observed water temperature. This noncontrolled variable, then, was viewed as the principal shifter of a constant returns production function.

Exploratory Estimation

The time period selected for analysis was October 1, 1968 through April 30, 1970. This 19-month period allowed the propagation process to be observed for at least one brood year for each species of interest (Figure 1). These included coho, spring chinook, fall chinook, chum, and steelhead. In the absence of cost data which were separable by species, it was necessary to estimate an aggregate function over all species.[6]

In view of the fixed proportions hypothesis, the initial attempt at estimation involved several of the factors which were thought to be jointly combined. We were limited in this analysis by the absence of data on either actual water flows or rearing space used. As a fairly unsatisfactory proxy, these variables were replaced by a measure of the replacement value of all fixed facilities. This variable, along with food, operating expenses (largely labor), and cumulative water temperature units[7] for the warm weather period and the cold weather period, constituted the five independent variables in the initial run.

As anticipated, a high degree of intercorrelation resulted between food, operating expenses, and the value of fixed facilities in both Cobb-Douglas and linear estimations. Correlation coefficients between these three variables approached or exceeded 0.80, and resulted in a considerable inflation of standard errors. Since it appeared that some degree of factor substitution could be estimated between any

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[6] An interagency effort is now underway to explore cost accounting systems by species.

[7] A cumulative temperature unit (CTU) is defined for each day in which the average water temperature exceeds 32°F by one degree. One month of 40° water temperature, for example, would constitute 240 CTU's.

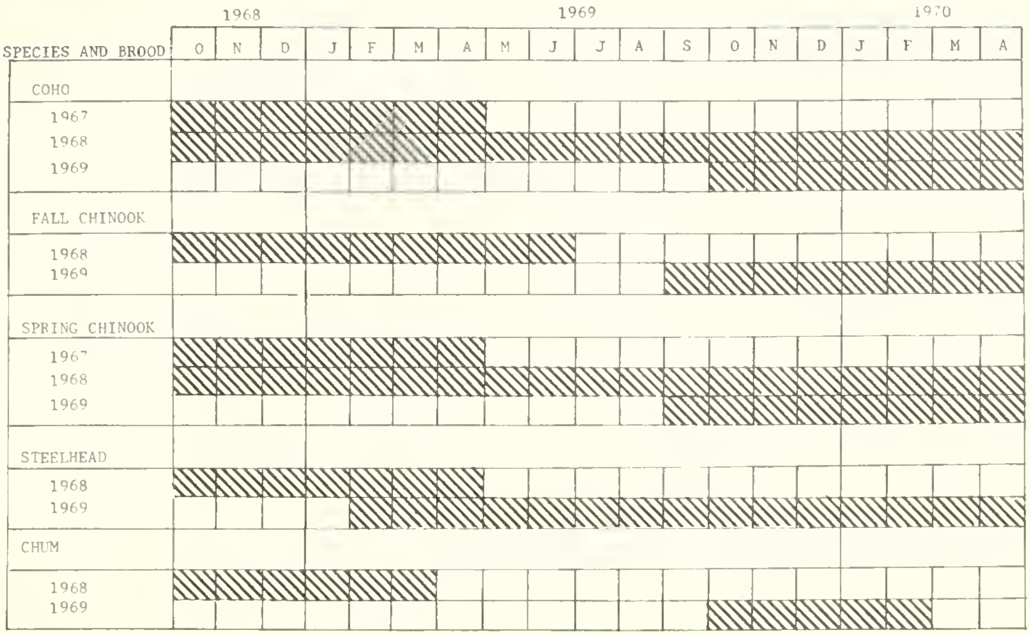


Figure 1. - Brood year classification of species propagated from the beginning of October 1968 through April 1970.

one of these variables and water temperature, the food variable was retained in further analyses.

Marginal Factor Productivities and Returns to Size

Since the underlying functional relationships were unknown, output response functions were estimated in both linear and log-linear (Cobb-Douglas) forms. Within each functional form, estimates were obtained relating to two different assumptions about the intercept term.[8] The output response functions and marginal physical productivities are shown in Table 2.

Several items are worthy of note. First, the R^2 values were uniformly high, regardless of functional form. Second, the marginal productivity estimates appeared reasonable and were fairly constant over the various functional forms. The marginal productivity of one pound of food was about 0.58 pounds of salmon, a

[8] While output would logically be zero if all input levels were zero, an estimate of the intercept may be helpful in assessing the "constant returns" argument for the linear function.

Table 2. — Output response functions and marginal physical productivities for the 15 Oregon Fish Commission salmon hatcheries.

Functional form	Intercept b_c	Variables[1] b_1	b_2	b_3	R^2
I. (a) Linear	[2] -13,998	.572	-15.694	33.324	0.959
	[3] (.10)	(.01)	(.10)	(.05)	
		[4] .572	-15.694	33.324	
I. (b) Linear	0	.563	-16.735	29.715	.991
		(.01)	(.05)	(.05)	
		.563	-16.735	29.715	
II. (a) Log-Linear	- 23.74	1.106	- .334	.526	.960
	(.01)	(.01)	(.20)	(.05)	
		.620	-11.281	31.618	
II. (b) Log-linear	0	1.047	- .450	.332	.999
		(.01)	(.10)	(.20)	
		.588	-15.217	19.958	

[1] Variables:
- Y = pounds of output of salmon (released either as fingerlings or swim-up fry)
- X_1 = pounds of food fed (Oregon Moist Pellet).
- X_2 = average cumulative temperature units (CTU's) of water from May through October (warm season).
- X_3 = average CTU's of water from November through April (cold season).

[2] Regression coefficients.
[3] Significance level.
[4] Marginal physical productivities.

figure that seems consistent with the literature in fisheries biology (Paloheimo and Dickie, 1966). Adding one day with water temperature one degree in excess of 32°F (i.e., one CTU) during the cold season would add about 30 pounds to total output; one additional CTU during the warm season would reduce output by about 15 pounds. Third, the high R^2 values support the hypothesis of fixed factor proportions, although we recognize that another analysis, covering several agencies and systems of management, might well yield different results. Fourth, the evidence appears to support the "constant returns" hypothesis, although this is somewhat conjectural. Summing the coefficients for Cobb-Douglas forms is hindered by the negative coefficient on warm season water temperatures. One might, as we did, view the water temperature variables as "shifters" of food-input relationship. If so, the coefficients on the food variable do not differ significantly from unity.[9]

Our estimates of marginal productivities thus enabled us to ask, "What would be the change in hatchery output if one were to increase (or decrease) water temperatures by a given amount?" A 10% reduction in CTU's during the warm season would reduce average water temperature from 52.97°F to 50.87°F and cause output to increase by 5,684 pounds, or about 4.36% of the mean hatchery output. Raising cold season water temperatures from 43.99°F to 45.19°F would add 6,218 pounds of output, or about 4.77% of mean hatchery output.

Factor Substitution

If controlled inputs are combined in fixed proportions, as evidenced above, the data obviously do not allow estimation of substitution possibilities. On the other hand, our analysis does permit us to identify degrees of substitution between the fixed proportion input, using food as a proxy variable, and changes in the noncontrolled water temperature variables. The marginal rates of factor substitution, as estimated from both linear and log-linear functions, are shown in Table 3. Although log-linear models no doubt conform more closely to biological reality, linear rates of substitution may be appropriate for some decisions. The degree of isoquant curvature is largely a matter for the judgment of fisheries biologists; experimental work in this area should be useful in checking and refining our estimates. Our confidence in the linear rates would be greatest in the neighborhood of mean CTU values (e.g., Figure 2).

Table 3. — Linear rates of factor substitution between inputs.[1]

Functional form	∂ [Food (X_1)] / ∂ [Summer CTU's ($-X_2$)]	∂ [Food (X_1)] / ∂ [Winter CTU's (X_3)]
I (a) Linear	-27.462	-58.309
I. (b) Linear	-29.714	-52.762
II. (a) Log-linear	-18.186	-50.972
II. (b) Log-linear	-25.867	-33.935

[1] Estimates are based on mean values. The sign on the X_2 variable (warm season water temperatures) is reversed here for convenience since decision makers would attempt to *reduce* summer temperatures and *increase* winter temperatures.

Increased environmental control, as through controlling water temperature, is in fact one means that Pacific Coast fishery agencies are now considering for output augmentation. Thus far, the agencies have primarily adapted to, rather than controlled, this aspect of the environment. The hatching of fry is concentrated to some degree in those hatcheries which have water temperatures most conducive to this operation; other hatcheries tend to specialize in the rearing of fingerlings. Control of temperatures would allow both food and transport costs to be lowered, although empirical data on factor price ratios were not available. It was our thinking that the estimates of factor substitution in Table 3, together with a step-by-step presentation of "output maximization, given budget constraints" would aid agencies in increasing efficiency at the hatchery level.[10]

[9] The negative intercept on the linear model was significantly different from zero at the 0.10 level. This gives some evidence of increasing returns, and is consistent with the b_1 estimates of 1.106 and 1.047 for the log-linear models. Acceptance or rejection of "constant returns" thus, depends partly on one's preference for significance levels.

[10] Specific attention was directed to the problem of determining factor prices when there is significant unused capacity at existing hatcheries. As mentioned earlier, seasonal low water flows often force non-use of some rearing ponds.

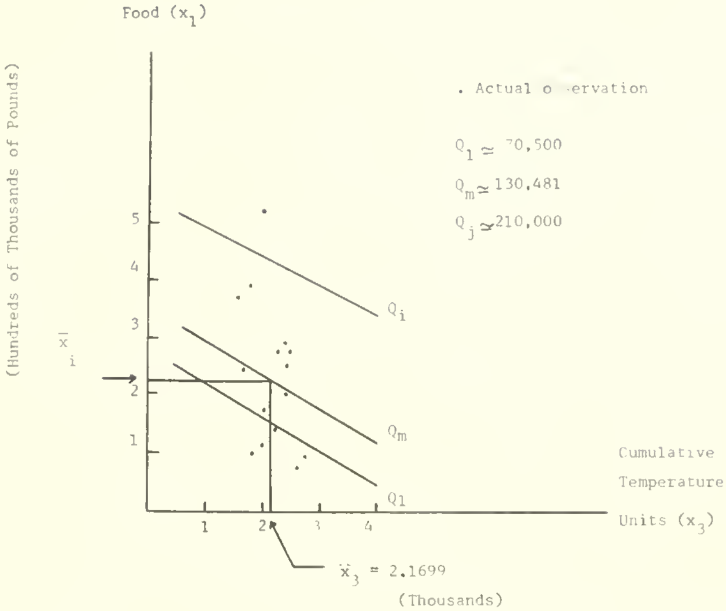


Figure 2. — Observed relationships between food and cumulative temperature units (November through April).

This information will be made available to hatchery management through an Oregon State University Marine Economics publication.

Concluding Comments on the Hatchery Production Function

Several strengths and qualifications of our research became clearer as the work progressed. The principal strength is that our conventional cross-sectional analysis of "firms" can be useful to public decisionmakers in spite of their "unconventional" incentive frameworks. Our principal lesson in methodology has been that differences within frameworks of the various agencies may be more crucial than differences between those of private and public firms if the researcher's objective is to provide a substantial empirical input. In retrospect, had we included a number of agencies in our study, it may have been possible to estimate additional substitution relationships. If our limited empirical results are useful to management agencies, however, we may have opened the door for a data system reorganization which will both allow for improved economic analysis and facilitate consideration of a broader range of production alternatives.

Our policy advice is accordingly limited by the methodological constraints of this study. Constant returns from hatchery operations may exist, *ceteris paribus*, but the latter may not be a very legitimate assumption when uncertainty exists as to downstream environmental conditions. Agencies could, for example, spread production over many small hatcheries located on different streams, but it may be more desirable to construct fewer and larger hatcheries if environmental protection can be assured on specific streams.

SOME IMPLICATIONS OF INCREASED HATCHERY PROPAGATION FOR COMMERCIAL FISHERIES MANAGEMENT

Associated Harvesting Costs

The principal limitation on policy advice stemming from our research is, of course, whether or not increased efficiency at the hatchery level necessarily leads to increased efficiency at the fishery level. The problems of open-access in U.S. commercial fisheries are well known to this group and will not be repeated here (Christy and Scott, 1966 and

Crutchfield and Pontecorvo, 1969). Let it be sufficient to say that there is both theoretical ambiguity and a lack of empirical information on the private and public costs associated with harvesting open-access resources (Bromley, 1969).

Two lines of thought, however, would probably receive acceptance by this group. The first is that in the *short run*, hatchery production could increase output in most salmon fisheries with only minor increases in associated harvesting costs, since excess capacity does exist. The Crutchfield-Pontecorvo research supports this for the Pacific salmon fisheries. The second argument is that the open-access tradition insures that resource augmentation through publicly operated hatcheries will induce additional effort into the fishery, especially when the additional inputs are provided without cost to the fishermen. The resultant equilibrium levels of factor returns, output prices, and excess capacity may differ from initial equilibrium levels, but *a priori* speculation about empirical magnitudes is just that. Furthermore, the time pattern of adjustment and the distribution of benefits and costs, over both time and space, can be discerned only vaguely.

We would maintain, however, that resource augmentation efforts should be placed in perspective with the total institutional setting.[11] Hatchery contributions to fish stocks may perpetuate the tendency toward excess harvesting capacity, but it should not have to bear the entire burden of responsibility for economic and social ills of the fishery. The tendency toward excess capacity pervades open-access fisheries, most of which do not rely on hatchery propagation. It would be our guess that the magnitude of inefficiency associated with the larger issue probably overshadows any undesirable effects of hatchery production, if the latter in fact exist.

Having confessed that we do not have all the answers, we hasten to add that we do have some empirical observations on entry and exit, over time, of salmon harvesting resources. We view these not as definitive proof of anything, but as a piece of the empirical jigsaw puzzle which must eventually be put together if economists are to be looked to for policy advice.

Entry and Exit of Resources in the Commercial Salmon Harvest: Fixed Asset Theory

The rise and fall of the Pacific Coast salmon harvest has been well documented elsewhere (Cooley, 1963 and Crutchfield and Pontecorvo, 1969). Peak harvest years were reached in the 1930's, and catch has trended downward since that time. The quantity of resources committed to the fishery, however, has increased over time. The number of fishermen and the net tonnage of vessels increased by about 30% between 1947-1949 and 1964-1966 periods, total landings declined by about 25%, and the deflated value of landings per fisherman decreased by about 15% (Table 4). It appears, however, that the deflated average value of landings per fisherman has remained about constant since 1950, with year-to-year fluctuations. This can be taken, recognizing the limitations on accuracy of the data, as very superficial evidence of the open-access phenomenon, i.e., the dissipation of rents through entry of additional resources.

Even though there has been *net* entry into the fishery since 1947, the time path of entry and exit of harvesting resources has not been fully explored. In particular, is there a degree of symmetry between the relationships which explain entry, on one hand, and exit, on the other? Miss Peerarat Aungurarat attempted to answer this question in another portion of our Sea Grant research at Oregon State University (1970). Her results are especially interesting in light of the increased reliance on hatchery programs.

Conventional firm theory suggests that a high degree of symmetry would exist in explaining entry and exit of resources. Given a constant factor price, leftward (rightward) shifts in the marginal value product function would imply a reduction (increase) in the utilization of a factor of production. Dissatisfaction with the state of the arts in explaining the inelastic supply of agricultural products led Glenn L. Johnson to formulate a "fixed asset" theory (1958). Johnson's contribution

[11] We are indebted to Emery Castle for this perspective.

Table 4. — Salmon fishing effort, quantity of landings (pounds and values) and average values per fishermen in Alaska, Washington, and Oregon, 1947-1966.

Year	Labor (number of fishermen)	Vessels (net tonnage)	Landings (thousands of pounds)	Value of landings[1] (thousands of dollars)	Average landings per fisherman (thousands of pounds)	Average value per fisherman[1] (thousands of dollars)
1947	16,249	44,003	486,560	47,541	29.94	2.92
1948	19,334	59,443	395,981	43,222	20.48	2.24
1949	18,451	59,510	477,074	54,441	25.86	2.95
1950	19,241	63,156	321,575	42,464	16.71	2.21
1951	23,589	70,799	367,030	55,840	15.56	2.37
1952	22,318	71,842	344,999	46,960	15.46	2.10
1953	21,889	69,231	304,945	38,500	13.93	1.76
1954	20,321	66,742	315,217	43,925	15.51	2.16
1955	24,608	69,268	277,900	39,389	11.29	1.60
1956	19,522	63,869	312,837	44,651	16.02	2.29
1957	[2]	[2]	260,125	38,580	[2]	[2]
1958	[2]	[2]	303,797	43,976	[2]	[2]
1959	19,990	58,099	194,915	32,221	9.75	1.61
1960	21,546	53,285	229,227	40,146	10.64	1.86
1961	23,206	63,060	301,760	45,421	13.00	1.96
1962	21,921	62,767	307,892	49,649	14.04	2.26
1963	23,689	66,553	286,316	42,222	12.09	1.78
1964	22,384	66,057	342,765	47,128	15.31	2.11
1965	23,486	65,691	317,068	54,717	13.50	2.33
1966	24,987	67,314	378,066	60,671	15.13	2.43

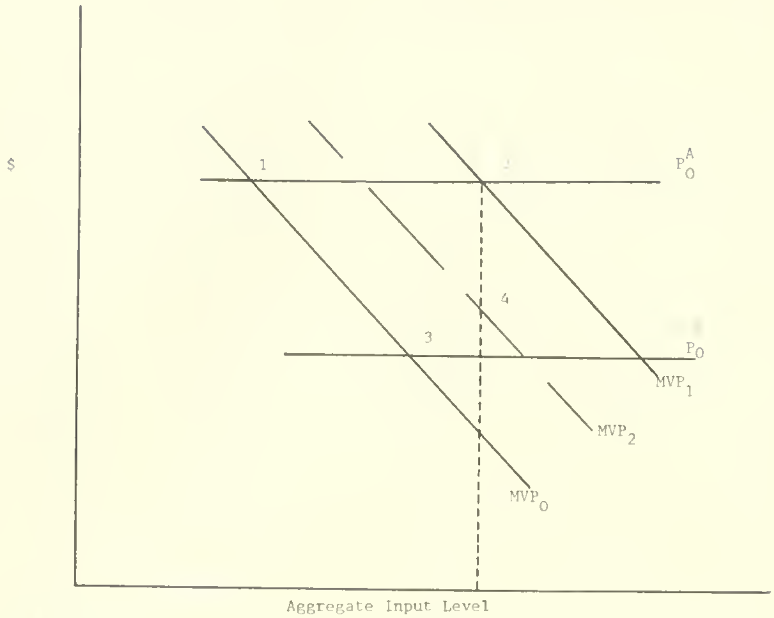
[1] Deflated by Consumer Price Index (1957-59 = 100).
[2] Data not available.
SOURCE: Derived from *Fishery Statistics of the United States*, U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries.

was his recognition of a particular form of imperfect factor markets, and involved relaxing the assumption that firms or industries can *at the same price*, both buy and sell inputs. A "fixed asset", by Johnson's definition, is not fixed because it has a certain physical life expectancy, but because it is more economical to keep it in production than to sell it. Two factor prices are involved, i.e., an acquisition price and a salvage value. Applied to the fishing industry, the acquisition price is what a fisherman (or the industry) has paid or must pay for an additional productive asset, e.g., a vessel; the salvage value is what the fisherman (or industry) could derive from the asset if it were sold rather than used. For individual fishermen, the difference between the two prices might be small if the quality of assets is assumed constant. For the salmon industry or even a particular segment of the industry, the margin might be substantial. The more specialized the gear or vessel, the less one might expect to derive from selling it to another segment of the industry.

If there is a large difference between acquisition price and salvage value, then, it would be possible for no change to occur in the aggregate level of a resource even if there were significant changes in factor productivity or product price. Figure 3 illustrates the variety of adjustments that could conceivably take place, depending upon (a) the starting point, (b) the magnitude of the shift in the MVP function, and (c) the divergence between acquisition price and salvage value. In the absence of specific knowledge about these factors, the notion of symmetry between exit and entry in the salmon fishery becomes an empirical question. Fixed asset theory, however, does provide a conceptual framework for specifying a statistical model and interpreting the results.

Empirical Analysis

In that we had access only to secondary data (U.S. Department of the Interior, 1947-67), most of the variables in the analysis were



Starting Point	Parameter Change	Given	implies:	Entry	Exit
1	$MVP_0 \rightarrow MVP_1$	P_0^A, P_0^S		$1 \rightarrow 2$	
	$MVP_1 \rightarrow MVP_0$	P_0^A, P_0^S			$2 \rightarrow 3$
2	$MVP_1 \rightarrow MVP_0$	P_0^A, P_0^S			$2 \rightarrow 3$
	$MVP_0 \rightarrow MVP_1$	P_0^A, P_0^S		$3 \rightarrow 2$	
3	$MVP_0 \rightarrow MVP_1$	P_0^A, P_0^S		$3 \rightarrow 2$	
	$MVP_1 \rightarrow MVP_2$	P_0^A, P_0^S		(no change)	

Figure 3. — Expected factor adjustments, given alternative assumptions on key parameters.

proxy variables. Additionally, the quality of Bureau of Commerical Fisheries historical data on resource levels in specific fisheries is far from perfect. A major data limitation of this study was that it was not possible to separate full-time from part-time commercial fishermen.

The secondary data precluded any meaningful estimation of marginal factor productivities. Also, reliable data on factor acquisition prices or salvage were not available. The first problem was bypassed by means of three assumptions; the second was resolved by the choice of units of observations. Both require some explanation.

First, it was assumed that the demand for salmon is price-elastic at the ex-vessel level. Some support for this assumption comes from two studies conducted at Oregon State University under the supervision of Dr. R. S. Johnston (Charoenkul, 1970 and Wood, 1970). Second, it was assumed that for the salmon fishery as a whole, the supply of factors is essentially fixed prior to the fishing season. The direct implication of these two assumptions is that increases (decreases) in landings bring about increases (decreases) in average short-run rents and/or profits over the industry. The third assumption was that actual rents in the year t equal expected rents in the year $t+1$, *ceteris paribus*. The expectation of cyclical fish runs should be accounted for empirically, since *ceteris paribus* is not a realistic assumption in areas with pink and sockeye salmon.

These assumptions, in context with the earlier discussion of fixed asset theory, imply a statistical model wherein changes in resource quantity (labor or vessels) are regressed on changes in salmon landings, lagged by one year. Ideally, the influence on resource use levels of acquisition prices and salvage values of the productive factors should also be taken into account. In that these data were not available, the units of observation were defined both cross-sectionally and over time. Specifically, yearly data between 1957 and 1966 for each of ten NMFS statistical regions on the Pacific Coast were used.[12] This yielded a total of 80 observations and allowed us to take into account, in a rough, implicit fashion, cross-sectional differences which might give rise to a variety of deviations between acquisition prices and salvage values. The statistical model is as follows:

$$(1)\ X'_{(t+1)} = f\ [L_{(t)}, C_{(t+1)}, U_{(t+1)}, D]$$

where

X' = index of fishing effort (number of fishermen and net tonnage of fishing vessels),

L = index of salmon landings (pounds),

C = cyclical nature of the fishery (dummy variable: 1 for all expected good runs, whether or not they actually materialized, and 0 for all expected poor runs),

U = unemployment rate of the civilian labor force in the major labor market,

D = distance from the center of salmon fishing activity in the region to the nearest major labor market.

In order to test for symmetry between exit and entry relationships with this model, the 80 observations were divided into two subsets. One subset, with 42 observations, consisted of those years in which landings had *increased* over the preceding year. Given our assumptions of an elastic product demand, fixed factor supply (in the short run), and rent expectations, it follows that these observations represent years in which the MVP schedule of factors had shifted to the right and was expected to remain there, *ceteris paribus*. Similarly, the 35 observations[13] in the second subset represented years in which MVP had shifted leftward.

Fixed asset theory would suggest that aggregate factor levels in an industry would either increase or remain constant following years of increased landings, and would either decrease or remain constant following years of reduced landings. Table 5 indicates a definite asymmetry between entry and exit relationships. For example, in years of increased landings, the index of vessel inputs in year $t+1$ increased 0.32 per unit increase in the landings index for year t. The coefficient for years of decreased landings was very slightly negative, but not significantly different from zero. Asymmetry is strongly suggested by the fact that the $\hat{B}_1$ coefficients for the two subsets are significantly different from each other in both the labor and vessel equations.

This ratchet mechanism is illustrated in Figure 4. Net entry follows years of "good catches," but net exit does not occur following the "bad years". This is not hard to imagine for specialized trolling vessels which may have low salvage values outside of fishing or even in other segments of the salmon fishery. It is somewhat more difficult to rationalize, on the other hand, for the labor resource, although the human resource would no doubt be affected by lack of mobility of the capital resource.

The relationships of resource use levels to the other variables in the analysis are also of interest, and are summarized here:

(1) Expectations of cyclical runs in encouraging entry were more important following years of declining landings than following years of increased landings. This

[12] The regions were Southeastern, Central, and Western Alaska; Puget Sound and Coastal in Washington; Columbia River in Washington and Oregon; Coastal Oregon; and Northern, San Francisco and Monterey in California (U.S. Department of the Interior, 1947-1967).

[13] Three observations were not usable due to lack of a "bench mark" year.

Table 5. — Regression analysis of factors affecting resource use.[1]

Dependent variable (X_{t+1})	B_0	B_1 (L_t)	B_2 (C_{t+1})	B_3 (U_{t+1})	B_4 (D)	R^2	n
All years:							
Labor	85.88	+0.19 (3.40)	+ 6.48 (1.15)	-1.00 (-0.68)	+0.009 (0.51)	0.14	80
Vessels	89.95	+0.19 (3.25)	+ 6.25 (1.06)	-1.89 (-1.22)	+0.02 (0.93)	0.13	80
Years of Increased Landings:							
Labor	77.33	+0.31 (3.26)	-2.41 (-0.26)	-2.51 (-1.17)	+0.04 (1.24)	0.24	42
Vessels	84.43	+0.32 (3.26)	-6.41 (-0.68)	-4.46 (-1.99)	+0.05 (1.95)	0.28	42
Years of Decreased Landings:							
Labor	102.90	+0.03 (0.43)	+10.77 (1.62)	-1.37 (-0.64)	+0.005 (0.25)	0.08	35
Vessels	99.39	-0.002 (-0.003)	+1.15 (1.89)	-0.19 (-0.09)	-0.005 (-0.25)	0.13	35

[1]Variables are as defined in text. Parentheses contain "t-values" of the regression coefficients.

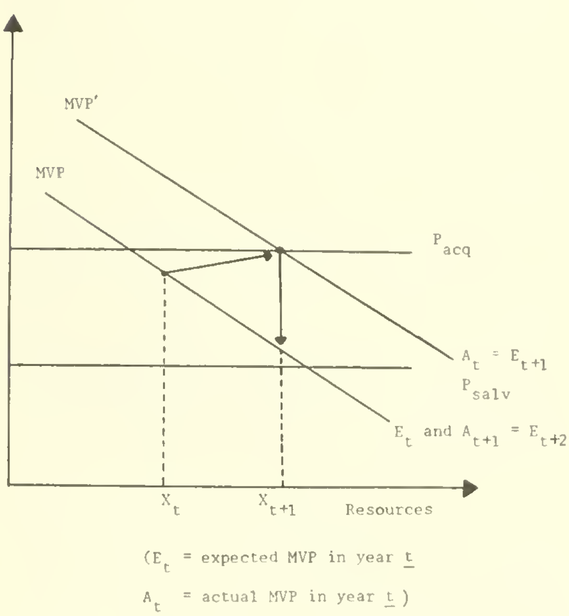


Figure 4. — Asymmetry between entry and exit of resources.

may be somewhat spurious due to the 2-year cycle of pink salmon.

(2) Increased unemployment rates in major labor markets reduced entry into the fishery, especially in years of increased landings when the incentive to enter would have been highest.

(3) Increased distance from major labor markets had a positive relationship to the index of resource use, and was relatively more significant in years of increased landings. In retrospect, both distance and unemployment rates might contribute more to an explanation of the $\hat{B}_1$ coefficient which related resource levels to landings $[\hat{B}_1 = \frac{\partial X^i_{t+1}}{\partial L_t}]$ if these coefficients could be estimated for each district, rather than the overall fishery. Our data did not permit this to be done.

Policy Implications

Although this analysis was fairly superficial because of the reliance on secondary data, it did indicate that entry of resources is systematically related to profit expectations based on an increasing level of aggregate landings. The same may be said for exit from the fishery if "systematic" is interpreted in terms of consistency with fixed asset theory. The *empirical* *values* by which entry and exit are systematically related to profit expectations, however, differ markedly.

This policy implication for augmenting salmon stocks through hatchery programs is apparent; it is evidently easier to induce resources into the fishery than to induce them to leave. If the real social objective of hatchery programs relates to improving incomes in the fishery, rather than producing and catching fish, research and action programs designed to increase salvage values of labor and capital resources would seem to be of a high priority.

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Limited Entry: The Case of the Japanese Tuna Fishery

E. A. Keen[1]

ABSTRACT

Limited entry has been advocated strongly as an important but as yet usused management tool for U.S. fisheries. Japan has maintained a policy of limiting entry into its high seas fisheries since 1949 and thus has considerable experience of potential value to the use of this tool in U.S. fisheries. This paper presents an assessment of the limited entry system as it has been developed for the Japanese tuna fisheries. Attention is given to effects on the acquistion of capital and overall allocation of national resources, specific effects on the size and nature of the fleet, pressures to permit additional entry, and effects on the location of shore-based activities. Special attention is given to problems that were unforeseen at the time of the initiation of limited entry that, with experience, could have been avoided. The paper is based largely on field research conducted in 1963 and 1964.

INTRODUCTION

Limitation of the number of craft in a fishery has been advocated strongly as a management tool for American fisheries. The volume of literature in which its usefulness is analyzed, primarily by economists, has become substantial and continues to grow. A brief survey of work by Crutchfield, Scott, Christy and others readily convinces the reader that economic benefits to be gained through its use more than justify its advocates. In the case of the extremely crowded northeastern Pacific salmon fishery, limitation of entry appears to be almost mandatory if rational management only for maximum sustained yield from the physical stocks is to be attained. Whether one is concerned with maximum sustained yield or with maximum economic return, limitation of entry obviously is a powerful tool and one that deserves greater use.

As with all powerful tools, implementation and operation of a limited entry system just as obviously is not an easy matter. Fisheries cannot be considered apart from the highly complex human and physical systems with which they are intertwined. Foreseeing all effects of a major change in regulatory inputs is extremely difficult. Decisions once made and institutionalized are equally difficult to change. In light of the complexity of fisheries and of the difficulty with which mistakes can be corrected, it behooves those who would design and implement a system of limited entry to take advantage of actual experience in other fisheries to the extent possible.

The purpose of this paper is to explore the experience of the Japanese with limitation of entry into one of their major fisheries, the skipjack-tuna fishery.[2] Much of this experience is, of course, specific to this fishery and is therefore, only indirectly relevant to other fisheries in Japan or elsewhere. Many of the problems grew out of the needs of a rapidly expanding fishery, a condition that is not likely to occur too frequently in the future. However, some generalizations can be drawn from it that can be of use in management of a number of fisheries. A brief summary of the initiation and development of the regulatory system is presented first to show the complexity of its development. This provides background for a discussion of the major effects, favorable and unfavorable, that concludes the paper.

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[1] Associate Professor of Geography, California State University, San Diego.

[2] The term "skipjack-tuna fishery" is a direct translation of the Japanese term "Katsuo-maguro gyogyo." All species of tuna are sought by those in the fishery, not the skipjack alone as the translation might apply.

INITIATION OF THE REGULATORY SYSTEM

Basic aspects of the system of limited entry were set by a series of administrative ordinances and laws passed during the Allied Occupation of Japan. An administrative order issued in July 1946 required registration of all skipjack-tuna craft over 20 gross tons in size as an aid to limit the operation of these craft to areas designated by the Occupation Government.[3] An ordinance issued by the Fisheries Agency in July 1947 brought these craft under a formal licensing system and forbade the construction of additional craft. Licenses were issued to all owners of craft over 20 tons for the gross tonnage of their existing craft. An ordinance, issued in May 1949, regularized the licensing system, made provision for building larger craft by combination of the licensed tonnage of two or more craft, and limited the activities of craft engaged in the skipjack-tuna fishery on a seasonal basis. The essence of these ordinances were all codified into a new basic fisheries law passed by the National Diet in November 1949. An important additional measure included in the new law was that licenses, while issued for periods of 5 years, had to be reissued to the original holder or his heirs except in cases of serious infraction of laws on the part of the holder. It also created a new category of fisheries, called Designated Distant Sea Fisheries, into which all skipjack-tuna craft of over 100 tons in size were placed. A separate fisheries protection law passed by the Diet in 1950 set a limit of 300 skipjack-tuna vessels in the Designated Deep Sea category.

Conditions were favorable to establishment of the system during the few years over which it evolved. The administrative order and the basic regulatory law were established at a time when profits from the fishery were low or nonexistent. In the first years of the Occupation, the Japanese were anything but prone to resist rules issued in the name of the conquering powers. The fleet had been heavily decimated during the war but recovery, with encouragement of the Occupation Government, was rapid afterward. By the end of 1947, the fleet had recovered to its approximate prewar size and was more than adequate to harvest resources within the area enclosed by the so-called MacArthur Line.[4] Catch per unit of effort had fallen off rapidly with the increase in numbers of craft and little opposition was expressed to institution of the regulatory system. Those who already owned craft in the fishery, of course, stood to profit by limitation of entry and supported it. The low rates of return of the fishery discouraged outsiders from protesting because entry was forbidden to them. The system imposed no onerous restrictions on fishing effort, such as closed seasons or closed areas within the fishing grounds available to the fleet. It appears to have been accepted fairly readily by the fishing community and functioned without change until near the end of the Occupation in April 1952.

Several factors were put forth to support imposition of the system during its development. However, the main motivations for establishment of the limited entry system centered on conditions in the fishery at the time, not on the condition of the resource. That is to say, conservation or management of the resource was not a real issue. It was an issue and an important one in controlling entry into the East China Sea trawl fishery which was placed under a limited entry system at the same time as the skipjack-tuna fishery. Concern growing out of the serious overfishing by the East China Sea fleet undoubtedly influenced the lawmakers in their decision to bring the skipjack-tuna fleet under control and to limit the number of vessels over 100 tons to 300. However, the skipjack-tuna fleet exploited species that migrated over great distances and showed no signs of depletion from year to year because of overfishing in waters off Japan used by the fleet. Sufficient fish might not be available to support the fleet during that part of their migration that made them available to the Japanese fleet,

[3] An excellent treatment of the regulatory system as it developed up to 1962 appears in Masuda (1963). All tonnage figures used herein refer to metric tons.

[4] The MacArthur Line, as the line bounding the area open to Japanese fisheries that was established by the Occupation Government came to be known, originally included only the waters within 12 miles of Japan. However, it was gradually expanded eastward and southward and by 1950, included most of the traditional Japanese skipjack and tuna ground in the northwest quadrant of the Pacific.

but little evidence existed to suggest that reduction of the stocks in any one year seriously reduced the runs the following year. Thus, the main reasons were to prevent overcrowding and conflict on the fishing grounds and to maintain economic viability of the individual fishing enterprise. This latter reason was to become clearly the overwhelming one in subsequent years.

DEVELOPMENT AFTER THE OCCUPATION PERIOD

If the system was accepted and proved adequate as it stood during the first years of its effect, it patently was going to require modification after Japan regained full sovereignty. As stated above, the fleet, both in reference to numbers and size of craft, was more than adequate to harvest resources in the area to which it had been restricted by the Occupation Government. However, Japanese tuna fishermen had begun to open up tuna grounds in the west central Pacific and East Indies waters prior to World War II. Catch rates had been high, the resource was known to be large and many were anxious to return to these grounds denied them during the Occupation. To do so, larger vessels were desirable; the resource could support a larger fleet than existed in 1952. Pressures developed to permit expansion of the fleet — internal pressure from existing license holders to build larger vessels, external pressure from nonlicense holders for permission to enter the fishery.

The following decade was marked by continual modification of the regulatory system as the fishery expanded beyond the most sanguine anticipations of anyone connected with it in the early 1900's (see Figure 1). The 1949 fishery law was explicit as to the number of craft that could be licensed, the 1950 law as to the number that could be larger than 100 tons. The upper limit of 300 craft over 100 tons in size had already been approached. The only expansion possible without a new law from the National Diet was of tonnage within the framework of the existing law. Subsequent laws and administrative orders based on them were numerous and increasingly complex. No attempt will be made to treat all of these in detail; to do so would become extremely tedious. However, the first two are covered in some detail to show the pattern set for expansion of the fleet.

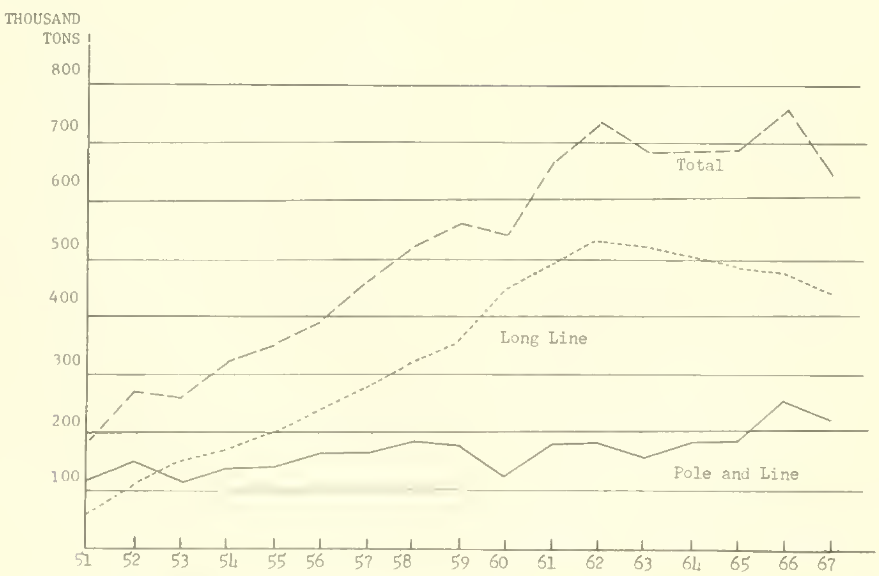

Figure 1. — Landings of tuna and other species by skipjack pole-and line craft and by tuna longliners, 1951-67. Data for 1951-1961 from Masuda (1962, p. 361), and for 1962-1967 from Japanese Tuna Fisheries Federation (1968 and 1969).

The first measure for expansion was contained in an administrative order from the Fisheries Agency issued in March 1952. This order permitted enlargement of vessels by a combination of free, additional, licensed tonnage and licensed tonnage from decommissioned existing craft. The owner of a Designated Distant Seas craft, i.e., one over 100 tons in size, could build a vessel 40 tons larger than the existing one without withdrawing additional tonnage from another license. If the new vessel were between 40 and 100 tons larger than the original, a 50-ton vessel had to be withdrawn from the fleet; if a new vessel 100-200 tons larger than the original were desired, two 50-ton or one 50- to 100-ton vessel had to be withdrawn. A similar system was set up for the "medium-sized" vessels as vessels in the 20- to 100-ton category had come to be called. The legal requirement that these craft be less than 100 tons cramped measures to enlarge them but a graduated system of free and decommissioned tonnage was instituted. Any vessel could be enlarged up to 10 tons with no restriction but half of any enlargement over this had to come from vessels withdrawn from the fleet. Any permitted enlargement assumed, of course, that the new vessel was to be less than 100 tons in size. This technique of granting limited free tonnage, to be combined with tonnage withdrawn from other vessels, became integral to the regulatory system during the ensuing decade.

The March 1952 measure was inadequate to meet pressures for enlargment of vessels in the existing fleet and did nothing to meet pressure to permit additional entry. This latter pressure was especially strong from fishermen in the offshore trawl fisheries, the resources for which were judged to be exploited excessively. The expanding tuna fishery appeared to offer an opportunity for relief for these fisheries. The apparent need for additional tuna vessels could be met by permitting transfer to the tuna fishery.

These conditions led rather rapidly to modification of aspects of the 1949 fisheries law that related to the fishing power of the tuna fleet. The National Diet passed a law that became effective in July 1953 and that, for two years, set aside aspects of the 1949 laws that limited the size and number of vessels in the fleet. Under the new law, known as the Exceptional Measures Law, craft already in the fleet were divided into four size categories based on their size as of December 1952. Licensed craft between 20 to 70 tons were permitted to go to 100 tons, those between 70 and 95 tons to 135 tons, those between 95 and 100 tons to 150 tons, and those over 100 tons to enlarge with no limitations. Owners of licenses for the medium-sized craft complained strongly that the permitted increases were not adequate. In April 1954, the upper limits for 70- to 90-ton craft and for 90- to 100-ton craft were rasied to 160 and 180 tons respectively. The 2-year moratorium, however, was not extended beyond its original July 1955 termination date.

Pressure for additional entry was also vented somewhat by the 2-year law. Originally, it permitted issuance of 100 full-time and 240 part-time skipjack tuna licenses. This aspect, too, was revised further in April 1954. New licenses were granted for 120 skipjack-tuna craft up to 85 tons in size, for 10 craft between 85 and 100 tons in size, and for 150 part-time licenses of less than 85 tons. These licenses were granted to craft owners in certain fisheries deemed to be overcrowded, primarily the offshore trawl and purse-seine fisheries. Recipients in all cases had to agree to give up their right to fish in their original fishery and to withdraw their craft from it.

The Exceptional Measures Law resulted in a much larger and greatly changed fleet. Between December 1953 and December 1955, the number of licensed craft increased from 1,154 to 1,372 or 19%; gross tonnage increased from 112,945 tons to 176,026 tons or 57%; and craft over 100 tons in size increased from 290 to 621 (Masuda, 1963, p. 354). The 1950 limitation to 300 craft of over 100 tons had obviously been abandoned.

Fundamental changes had also taken place in the nature of many of the craft. If defined by fishing method, the skipjack-tuna fishery is actually two fisheries, the skipjack live bait pole-and-line fishery and the tuna longline fishery. Historically, the pole-and-line fishery is the older of the two. It developed to exploit the large runs of skipjack and to a lesser extent, albacore, that appear off Japan during the spring and summer months. The longline fishery developed as on offseason activity for craft in the former and remained subordinate to it until the end of the Allied Occupation. Equipment and crew requirements for the two bear little similarity. The maximum sized craft that could be used efficiently in the pole-and-line fishery was about 150 tons at the time.[5] Live bait wells are an absolute essential for the pole-and-line fishery but are unnecessary for the longline fishery. Crew size for the former is usually a little more than double that needed for the longline fishery with consequent additional space required for quarters. The world market for tuna grew rapidly after World War II and tuna soon provided a higher return than did skipjack. Larger craft could operate year round on the new longline grounds being opened up in the southern Pacific and Indian Oceans. As a consequence, most of the craft built when the Exceptional Measures Law was in effect and afterward were specialized vessels for the longline fishery only. Lack of a live bait well alone effectively denied their use in the pole-and-line fishery.

Landings of the fishery increased proportionately along with the tonnage of the fleet. Tuna longliners landed 117,000 tons in 1952; in 1955 this had increased to 197,000 tons (Japanese Tuna Fisheries Federation, 1961, p. 16). The value of the landings fell rapidly; the average price of yellowfin tuna at Yaezu, Japan's most important tuna port, dropped from $289 per ton in 1953 to $192 in 1955 (Yaezu Fishery Cooperative, 1963, p. 25).[6] Lingering effects of the Bikini nuclear weapon incident of 1954 that had greatly reduced demand for fresh tuna in Japan accounts in part for the lower price. However, the main reason was excessive supply. The world market for tuna, limited at the time largely to Japan and the United States, was not able to absorb the added catch at the 1953 price levels.

The Fisheries Agency policy with the end of the Exceptional Measures Law called for absolute restrictions on new entry. However, it did continue the policy of permitting and encouraging enlargement of craft. In a few cases, slight enlargements were permitted without abolishment of licensed craft. The heart of the policy, however, was to permit use of licensed tonnage for medium-sized vessels for combination with other licenses to build larger craft. The net effect of this was to reduce the total number of craft but to increase the number of larger craft for operation on distant grounds. The rapid increase in vessels over 200 tons at the expense of those under that size is shown graphically in Figure 2. The total number of licensed craft decreased from 1,380 in 1956 to 1,243 in 1957.

Landings continued to grow at about 50,000 tons annually into the early 1960's. The market also began to recover after the lows of 1955 and prices began a steady upward trend. By 1962, the average price of yellowfin at Yaezu had risen to $328. Small fortunes were being made by the end of the decade. It became apparent that craft of at least 250 tons in size were needed to operate efficiently from Japan on the south Pacific and Indian Ocean grounds as well as from bases on the newly opened Atlantic grounds. The value of licenses for supplementary tonnage increased rapidly. Supplementary tonnage could be purchased for about $100 per ton in 1955, rose to about $500 in 1959, and in 1960 approached $1,000 per ton (Masuda, 1963, p. 556).[7] In 1960, additional free tonnage was permitted for craft of less than 240 tons in size if they were wooden craft over 6 years old or steel craft over 12 years. Also, restrictions on the use of the licenses for the less than 100-ton vessels issued after 1953 as supplementary tonnage, licenses that previously could not be used for this purpose, were relaxed. Another building boom was underway and the average size of the vessels in the fleet grew with it (see Figure 3).

Pressure for additional entry into the tuna fishery, never quiescent, began to rise markedly with the rise in profits from the fishery. Pressure was especially strong after 1956 from

[5] A vessel of about 150 tons is the minimum sized vessel needed to operate from Japan on the west-central Pacific grounds to which the pole-and-line fishery expanded in the mid-1960's. In 1967, forty-one vessels in the 200-500 ton category were used in the newly developed distant seas pole-and-line fishery (Japanese Tuna Fisheries Federation, 1969, p. 13).

[6] Conversions from yen to dollars was made at the rate of 360 to 1.

[7] Precise figures on sale value of licenses are difficult to obtain since profits from their sale is subject to capital gains tax. Underreporting to avoid taxes appears to have been the rule.

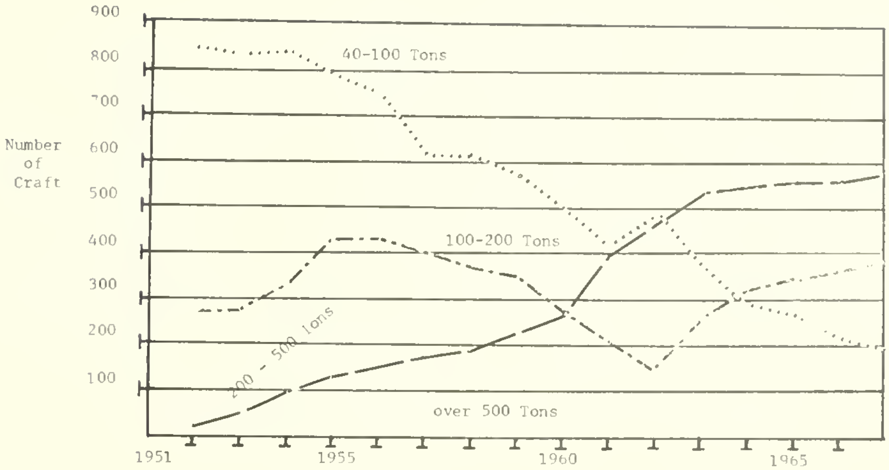

Figure 2. — Trends in numbers of licensed distant sea skipjack-tuna craft by size category. Data: (Japanese Tuna Fisheries Federation, 1969, p. 6).

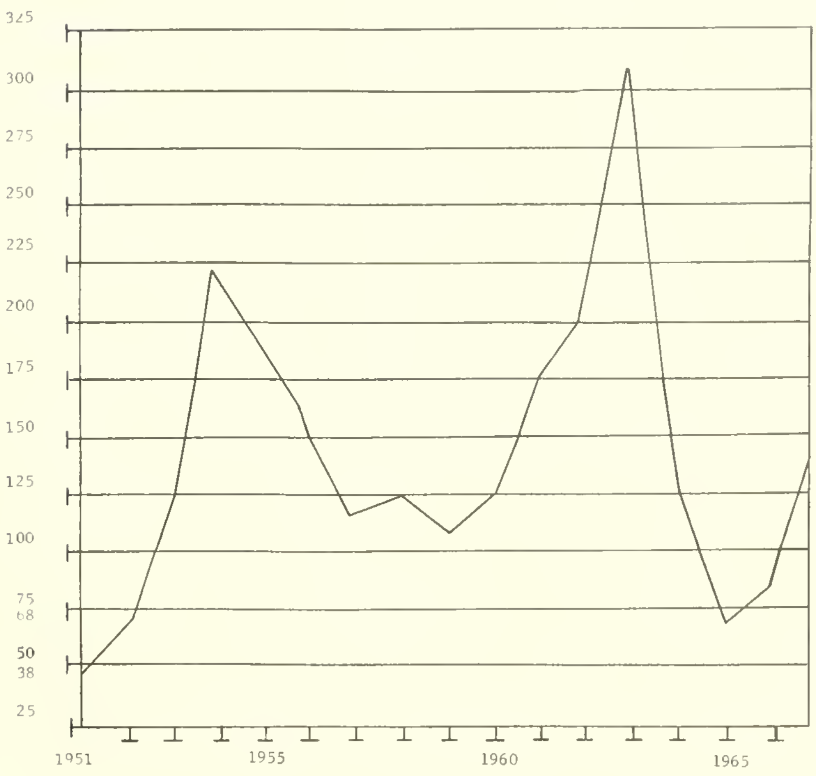

Figure 3. — Annual construction of skipjack-tuna craft over fifty gross tons in size. Data for 1951-52 from (Masuda, 1963, p. 542), for 1963-67 from (Japanese Tuna Fisheries Federation, 1969, p. 9).

the salmon fishery as a result of restrictions on that fishery growing out of the USSR-Japan agreement concerning it. An attempt to relieve this pressure was made in June 1957 by raising the lower limit for licensed skipjack-tuna vessels from 20 to 40 tons. The result was the almost instantaneous creation of a 39.9-ton tuna vessel fleet.[8] A fairly large number of "39-tonners" were built by owners in the traditional salmon ports of northern Japan but a majority of these new "free entry" vessels appeared in the traditional skipjack-tuna ports. The measure thus did provide some relief for the depressed salmon and other fisheries but the main effect appeared to be increased investment by those already in the skipjack-tuna fishery. Pressure from the salmon fishermen continued and some fifty new "medium-sized" tuna licenses were given craft owners in this fishery between 1960 and 1962 in exchange for their abandonment of the salmon fishery.

A demand to permit increased use of motherships also began to develop in the late 1950's. Large motherships operating with independent licensed tuna vessels had been authorized since 1948. Fairly stringent restrictions had been placed on the annual catch and on place of fishing of those "independent vessel motherships" as they came to be called.[9] However, in the late 1950's, the larger tuna longline vessels began to carry "portable catcher boats" on board. Once on the fishing ground, these catcher boats proved almost as efficient in terms of catch rates per day as the independent vessels. A new category of licensing was established for these craft in April 1961 and revised in September 1962. Two classes of these "catcher boat carrying motherships," as they came to be called, were created — less than 2,000 ton craft where the mothership was permitted to fish, and over 2,000 ton craft where the mothership was not permitted to fish. A complex system of computing licensed tonnage was established for the catcher boats. In general, it required that regular licensed craft be decommissioned in considerable larger tonnage for the catcher boat than the maximum size of 20 tons established for each skiff. Restrictions were also placed on area of operation of these two new classes of motherships. Regulations as to place of operation were designed generally to limit them to the southwestern Pacific, Indian, and Atlantic Oceans.

The regulatory system had become somewhat outmoded and unwieldy by the early 1960's. The basic fisheries law was inadequate for proper regulation of the new motherships and the need for regulation of the new "39-ton" fleet was becoming apparent. The former medium-sized vessels that had been allowed to expand to over 100 tons but held below 200 tons in size, about 150 in number, were proving to be uneconomical. Not large enough to operate effectively on grounds south of the equator, they were too large to compete effectively with the large number of "39-ton" "free-entry" craft and less than 100-ton licensed craft on grounds adjacent to Japan. The price of licenses continued to rise to a peak of about $1,200 per vessel ton in 1962. Few owners of these "in between" craft could afford to purchase supplementary tonnage for craft enlargement at these prices. For these and other reasons, the realization became general that a new legal framework for administration of the fishery was needed, a condition that was true of other fisheries as well.

A revision of the basic fisheries law by the National Diet in August 1962 provided a new framework. In reference to the tuna fleet, the new law codified the system for motherships described above, rationalized a number of complexities that had developed in the licensing system, and lowered the age at which a vessel could be replaced to 4 for wooden vessels and 8 for steel vessels. The only aspect of the new

[8] Accurate records were not kept on the number of such craft until a centralized licensing system was established in 1964. However, one study by Fisheries Agency personnel in which an attempt was made to trace the growth of this fleet showed only three such craft were launched in 1957, 23 in 1958, 117 in 1959, and 194 in 1960 (Japanese Fisheries Agency, May 8, 1963, p. 6). No data are available on the number of salmon longline craft under 40 tons that switched to tuna longlining but the number probably was substantial.

[9] Motherships were limited in place of operation to designated areas in the central and southern parts of the Pacific and always under a catch quota system. The maximum number of motherships used in any one year was six, each with up to 50 independently licensed tuna longliners. In the early 1950's, Antarctic whaling motherships were used as tuna longline motherships in the offseason. However, salmon motherships came to be used with restrictions on that fishery imposed by the Japanese-Soviet agreement in 1956. Each mothership fleet was granted a maximum catch quota before leaving port. The total quota for all mothership fleets reached a high of 28,000 tons in 1958.

law that specifically permitted additional tonnage to the fleet concerned the "in between" craft between 100 and 180 tons. These were granted permission to enlarge to 240 tons, about the smallest sized vessel that could operate effectively south of the equator from Japanese ports.

Landings from the longline fishery peaked in 1962. Declines in catches from that year, increased competition in international markets from the Taiwanese and Korean fisheries, and sudden rises in labor costs greatly reduced pressure for further expansion of the fleet. The "39-ton" fleet was brought back into the limited entry system in 1964 with a passage of a law that established a "near seas" skipjack-tuna industry. The law limited the number of licenses for 20- to 50-ton craft engaged in the skipjack-tuna fishery to 1,850 vessels, a number selected primarily because it was sufficiently large to cover all craft of this size range already in the fishery. In 1964, 1,708 craft were licensed and registered under this law but the number has declined slightly since.

Changes in the regulatory system since the near seas fleet was established have been relatively few in number compared to earlier years. As longline catches declined, the pole-and-line live bait fishery received increased attention. The more substantial changes in regulations have been designed to permit or encourage decommissioning of large vessels to build smaller vessels for this fishery. Strong pressure has developed since the mid-1960's for reduction in the size of the fleet. Agreement appears to be general that this should be done but as yet an acceptable method to do so has not been devised.

EFFECTS ON DIFFERENT ASPECTS OF THE FISHERY

As can been seen from the above overly simplified description, measures for regulation of the Japanese skipjack-tuna fishery center strongly on limitation of the size and number of craft. Only minor use has been made of catch quotas and restrictions on place of fishing, measures that tend to reduce the efficiency of use of vessels and equipment. The fleet as it developed is very much a result of regulation through use of limited entry and controls on size of vessels. Discussion will now turn to the major effects, some obvious and foreseen, some less obvious and forseen dimly if at all, that the regulatory system had on the fishery.

Capital Acquisition and Resource Allocation

One of the more striking aspects of the fishery was the rapidity with which the fleet was expanded after the Allied Occupation ended. Vessels used in the fishery are not extraordinarily large as fishing vessels go nor were construction costs in Japan high by any standard. However, they do represent a sizeable capital investment and requirements for operating capital are substantial. Owner-operator enterprises dominated the fishery in the early days. This meant that most were small enterprises headed by individuals with poorly established lines to sources of capital. Two- and three-boat enterprises became common by the early 1960's but the fishery continues to be made up largely of small enterprises. The large fishing corporations of Japan have played and continue to play a relatively minor role in the fishery.

The effect the system as applied had on acquistion of capital is, of course, obvious. Licenses from the beginning became, for all practical purposes, the personal property of the recipient. As such they were sold, traded, or used as security for loans. Even at the depressed tuna prices of the mid-1950's, license values ranged from 10% to 20% of construction costs for a vessel. At 1962 earning levels, the value of the license almost equaled that of the vessel. With security of this nature to offer, no license holder had any difficulty in gaining loans for either fixed or operating capital. Without the limited entry system and property characteristics of the licenses, the fishery possibly would have expanded more slowly, paradoxical though this may sound. Enlargement of craft also would have been more dificult had these valuable licenses not been available to use as security for loans. One could postulate that the fleet would have come to consist of a much larger number of smaller craft without it, although larger craft constructed and owned by large corporations may have come to dominate the fishery.

Licenses decreased in value rather precipitously after 1962 to a low of about $330 in

1965 (Commercial Fisheries Review, 1966, p. 73). Rates of indebtedness at the peak of license values in 1962 had been much higher than in other Japanese fisheries. Debts on the fixed capital alone of craft over 200 tons in 1962 averaged 72%, almost an inverse ratio to the 30% rate in the East China Sea trawl fishery (Masuda, 1963, p. 539). Debts on smaller licensed vessels averaged over 50%. Improvement in the earning position of tuna vessels in the late 1960's with the rapid increase in price of tuna in Japan stabilized the economic picture for most owners after 1965. However, many marginal enterprises were forced out of the fishery during the mid-1960's.

It can also be argued that the licensing system as it evolved also led to a misallocation of resources within the national economy as a whole. From the standpoint of the national economy, investment in the tuna fishery obsiously was profitable at least through 1962. However, the high, and at times unrealistic, value of the licenses in the tuna fishery gave this fishery an extremely favorable competitive position within financial institutions specializing in fisheries, and, indeed, in the national capital market as a whole. The total investment was substantial and, as proved later, was larger than needed to harvest the resource. Where the investment level would have proved most advantageous is difficult to determine and no effort to do so is known by the author. Few would argue, however, that a better allocation of national resources would not have been obtained had part of the investment in the tuna fleet been directed to other channels.

Size and Nature of the Fleet

That the size and characteristics of craft in the fleet was shaped strongly by the regulatory system is apparent from the earlier discussion of the development of the system. Enlargement of craft was a basic and continuing policy throughout the period of expansion. The most effective measure used to fulfill this policy was the frequent granting of additional free licensed tonnage that could only be used with the licensed tonnage of the old vessel which was in turn decommissioned. This, and the practice of allowing only licensed tonnage from decommissioned "medium-sized" craft to be used for enlargement under any circumstances, hurried the disappearance of these smaller licensed craft as well as the construction of larger ones.

The measures used were highly effective as is shown by the increase in average vessel size from 91 to 230 gross tons between 1952 and 1962. It also meant that many vessels were retired well before their useful life was ended. This wasteful aspect was recognized and an attempt made to minimize it by placing minimum ages on craft that could be decommissioned. That this time was shortened from 6 to 4 years for wooden vessels and from 12 to 8 years for steel vessels illustrates the pressures applied to take advantage of grants of tonnage, grants which usually carried a 2-year maximum for use from the date they were granted. A recognized shortcoming of the system, it was nevertheless one that was never solved satisfactorily during the period of expansion.

An unforeseen result, or certainly one that was predicted poorly, concerned adverse effects on the structure of individual vessels. As the fishing grounds became more distant, a premium was placed on hold capacity for fuel and fish. Given the absolute limit on gross tonnage permitted for an individual vessel, the owners designed around this limit with emphasis on increased carrying capacity. First started in the late 1950's, craft with 20% to 30% greater carrying capacity were soon being built with no increase in computed tonnage (Masuda, 1963, p. 546). Crew quarters and below-deck working space became more cramped in the process and safety equipment was reduced to the minimum permissible standards and often stowed in inaccessible places. Seaworthiness also often suffered because of rearrangement of storage space that decreased stability, a factor that undoubtedly contributed to the loss at sea of a number of smaller craft. Many of these adverse aspects have been corrected subsequently but only through greater expenditure of administrative time for inspection, additional tonnage concessions that could not be used for hold space, and a weakening of the competitive position of the fishery for labor because of poor working and living conditions while at sea.

Effect on Other Fisheries

One could argue, as was pointed out earlier, that the superior competitive position of the tuna fishery possibly had some adverse effects on other fisheries, primarily in reference to competition for capital. Comparatively high returns to labor in the tuna fishery also gave it a competitive position in this respect. However, labor was not a major problem for any fishery prior to the early 1960's and since labor was generally drawn from families and acquaintances of vessel owners, the tuna fishery appears to have had little effect even on the quality of labor available to other fisheries.

The overall effect on other fisheries, or at least the administration of them, probably was positive. Since entry was controlled, relief could selectively be provided fisheries creating the greatest administrative problems. Certainly the Minister of Foreign Affairs must have been happy to see pressure relieved on the East China Sea and North Pacific Salmon fisheries in light of the adverse reaction of mainland China and the Soviet Union to these fisheries. Had these new licenses for the tuna fishery been placed on open bid, one could hardly have expected fishermen from depressed fisheries to compete for them with any degree of success.

Effects on other fisheries may be somewhat nebulous and difficult to define with precision, but the effect on the live bait pole-and-line fishery is much clearer. That the two methods, or fisheries if one wishes, were administered as a single fishery meant that expansion of the live bait fishery was neglected for over a decade. Catches by the live bait method did not decline during expansion of the longline fishery, in fact the secular trend was up slightly (see Figure 1). However, resources for this fishery were underutilized, a fact known at the time and borne out by the increase in landings since the mid-1960's. Craft of sufficient size to properly exploit this resource and permitted to do so were also the only ones permitted to fish with longlines for tuna. Given the higher rate of return on tuna, the choice of a vessel owner is not difficult to see. That most did specialize in longlining is shown by the fact that the number of licensed craft using the live bait method declined from 737 in 1953 to 231 in 1961; total tonnage of vessels so used declined from 80,000 tons at the peak to 33,000 tons in 1961 (Masuda, 1963, p. 358 and 546).

That the total catch by the live bait method continued to be stable throughout expansion of the tuna longlining can be attributed primarily to unlicensed craft, including the "39-tonners" after 1957. These craft were sufficiently large to exploit the traditional grounds adjacent to Japan. However, craft of over 100 tons in size are needed to exploit the large skipjack resources in more distant southern waters. By 1960, nearly all craft of this size had been rebuilt without live bait wells. With the decline in longline catches, a distant seas live bait fishery developed fairly rapidly. In 1964, only 138 craft over 100 tons in size used the live bait method; by 1967, the number had increased to 224 (Japanese Tuna Fisheries Federation, 1969, p. 13). Had craft using the live bait method been administered separately, it can be assumed that craft would have been available to develop these distant grounds during the 1950's. That this was not done can be regarded as a loss to the national economy during the period.

Effects on Location of Shore-Based Activities in Japan

The regional pattern of economic activities connected with the fishery changed considerably during the period of rapid expansion. Fishing ports and the fleet were distributed fairly evenly between the southern tip of the island of Kyushu and the northeastern port of Honshu when the live bait method dominated the fleet's activities. Most of the fleet would gather in the south in early spring to pick up the annual runs of skipjack and to a lesser extent, albacore, and follow them northward along the Pacific Coast until they disappeared in late summer off northeastern Honshu. Landings were made at the nearest port, nearly all of which had a dried skipjack stick processing industry, the main use for most of the catch. Craft would then be converted for tuna longlining on winter tuna grounds adjacent to Japan. The main market for tuna was in the Tokyo region and catches from the winter fishery were landed at ports in that area.

As tuna longlining increased in importance and became a year round activity, one could easily have predicted that activities would concentrate in a smaller number of ports. Grounds for the year round tuna fishery were so distant from Japan that no port had a locational advantage of any significance in reference to the grounds as was the case with the live bait fishery. The main markets for tuna were the canneries, export companies, and the large urban population in the Tokyo area. As craft became larger, smaller markets were unable to handle the full load of most vessels expeditiously, a factor that further favored concentration. Concentration of economic activities of the longliners in a few ports thus would have been expected quite apart from the regulatory system.

The regulatory system as applied did, however, influence the regional pattern significantly. Among the more readily apparent influences perhaps was that it hastened enlargement of craft and thus increased tendencies toward concentration in the central ports. Conversely, in another aspect, it tended to favor continued dispersion of economic activities other than landing of the fish. This derived from the fact that ownership of the fleet was dispersed at the time licenses were issued. Ties of Japanese fishermen, both economic and social, to their home port are strong. A man's boat is his livelihood and sale of the right to use it is restricted by strong pressures of tradition. That the value of the license increased steadily during most of the period of expansion meant that most holders, even in more remote areas, were able to fund new craft and expand along with the fishery. Without this source of funding, the longliners would almost certainly have been concentrated in all respects in the centrally located ports where capital was more readily available and where attention to the fishery would have been much stronger. However, having been given the licenses, owners in outlying ports generally kept pace with the switch to longlining; without the license as security, lack of capital alone probably would have been a major deterrent to so doing. Landing and most resupplying of vessels might be carried out in centrally located ports such as Yaezu, Misaki, or Tokyo but the economic stimulation from other activities such as management, labor recruitment, and expenditures by management and labor largely accrued to the ports where the owner of the license resided. As such, the fishery continued to contribute to regional economies to a larger extent than if the regulatory system had not existed. Thus, the net effect of the regulatory system appears to have been a conservative one working against an expected tendency toward concentration in the major market ports.

Flow of Capital to Other Countries

A predictable effect of a limited entry system in a profitable fishery such as the tuna fishery in which overall control of entry to the fishing grounds is impossible would be a flow of capital to other countries. This was recognized early in the period of expansion and fairly effective controls were developed to control it, at least through 1963. The method used was to restrict export of tuna longliners. The craft themselves are not particularly complex nor is the equipment used on them. However, countries that had the industrial establishment to build them, by and large were not able to compete with the Japanese in the fishery because of labor costs. Countries that desired to enter the fishery and were in a favorable competitive position in reference to labor costs were not able to build the vessels. Given these conditions, strict controls on export of longliners were used to prevent Japanese entrepreneurs from transferring registration to other countries and using Japanese or foreign crews and, at the same time, retard the development of the fishery by other countries. Some transfer of registration was permitted for operation by joint Japanese and foreign companies from ports in the country of the latter. However, conditions under which this could be done were restricted severely; in a 1965 survey by the Fisheries Agency, only 17 vessels were found to be so operated (Commercial Fisheries Review, 1966, p. 85). Pressures to permit export, especially by shipyard owners in Japan, were great, but were contained until 1964. By this time, other nations, especially Korea, were developing a capacity to build longliners and the restrictions were relaxed.

Japanese capital has played an important role in the development of foreign fleets since the early 1960's. Large Japanese trading companies handle most of the tuna exported from overseas bases, bases originally established to serve Japanese vessels. As other countries, namely Taiwan and Korea, began to develop fleets, they also used these bases and sold their catches to the Japanese companies. In return, vessels from these countries have received financial assistance, largely operating capital, from these large companies. A new base opened recently by a large Japanese company in Mombasa, Kenya reportedly is to be used almost entirely by Taiwanese vessels (U.S. Bureau of Commercial Fisheries, February 24, 1969). However, this Japanese investment must be attributed primarily to the higher labor costs of Japanese vessels not to restrictions on their number. Under conditions in the Japanese fishery since the mid-1960's, it is doubtful that any significant increase of Japanese vessels operating from these bases could be expected even if the fishery were opened to unlimited entry.

CONCLUSION

In retrospect, no one in Japan or elsewhere would consider the regulatory system developed for the Japanese skipjack-tuna fishery to be a complete success. However, few would argue that the fishery and the country were not served better by limitation of entry than they would have been had no controls been imposed on the number of craft. The system did have a goodly measure of success in reference to its main goal, that is, to maintain a high level of economic viability of enterprises in the fishery. Without it, a gross over-investment in small vessels is almost certain to have taken place in the early 1950's. Depression of the market, strained financial condition of enterprises, and a loss of all economic rent from the fishery likely would have occurred long before the resource approached full exploitation. Conflicts on the fishing grounds, international incidents, and disasters at sea also would have been more numerous. Thus, a second major goal, harmony within the fleet and on the fishing grounds, was at least partially achieved. If the system has been less successful since the early 1960's, the fault can hardly be laid at the feet of the fishery policy makers and administrators. Their control over entry of fishermen of other countries ended with Japanese ability to control the technology of the fishery. Had fishermen from other nations had the wherewithal to enter the fishery from 1950, acceptance of the system by the Japanese fishermen would have been far more difficult to attain.

Mistakes were made, many of them avoidable. Perhaps the largest was to raise the minimum size of licensed vessels to 40 tons. That it was done appears to have resulted from an inadequate assessment of technological developments. Less than 40-ton craft in existence at the time were patently too small to operate on distant grounds but could relieve the need for more vessels to exploit the annual runs of skipjack and albacore on near seas grounds. Vessels of 19.99 tons could never be designed for effective operation on distant grounds. However, redesign of vessels of 39.99 tons led to craft with the fishing power of a 70-ton vessel designed by standards used in the mid-1950's. At the catch rates and prices of tuna in the late 1950's, these vessels could operate profitably on distant grounds although the large number of disasters suggest they should not have attempted to do so. The problem of safety was corrected only by granting permission to increase size of these vessels to 50 tons with the provision that the additional tonnage would be used only to increase crew comfort and safety and limiting their use to waters adjacent to Japan. However, the number of such vessels far exceeds needs and the problem of overcapitalization has been far more intractable.

Some lawmakers and administrators were troubled also by the tremendous value that the licenses came to have at no cost to the holders of the licenses. Had the tremendous expansion of the fishery and its profitableness been foreseen at the time the fishery was brought under regulation, some means possibly could have been devised to siphon off at least part of the economic rent represented by the licenses into the public coffers. However, to have worked out an acceptable scheme for the fishery after the basic system was already operating would have been extremely difficult. Certainly it would have added complexities to an already overly complex structure that possibly would have caused the entire system to break down. Also, a national law that singled out one fishery for such treatment probably would not be acceptable to the lawmaking body. Values of licenses in more stable Japanese fisheries have never reached levels considered to be a problem; to impose controls on these fisheries would create more administrative problems than could possibly be justified by gains resulting from the controls. In short, to have solved this problem, if it was one, in the political arena of Japan or any other country with representative government would have been extremely difficult. Possibly ignoring it was the wiser route to follow.

The problem of overcapitalization of the world tuna fleets appears to be approaching rapidly if it has not already been reached. The Japanese were able to limit entry to the fishery and maintain economic viability of enterprises in it during the period that they controlled longline technology. Beyond question, limited entry could also be used to control excessive fishing power and the excessive pressure on world tuna stocks that it is certain to bring. The Japanese experience illustrates many of the problems that would attend the far more complicated problems foreseeable in establishment of an international system. It also suggests the benefits, in reference to stock management as well as economic viability of the fishing enterprise, could be well worth the effort required to establish the system.

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A Study of the Socioeconomic Impact of Changes in the Harvesting Labor Force in the Maine Lobster Industry[1]

A. M. Huq[2]

ABSTRACT

The basic question of the mobility of the labor force in the Maine lobster fishery is investigated with particular emphasis on the productivity of control groups within a sample and their social, educational, economic, and demographic characteristics. Under various assumptions which would lead to exit from the fishery of these groups certain consequences are enumerated, both with regard to those leaving and those remaining as well as the impact on and role of the local communities involved. A preliminary assessment of the impact of certain types of management programs upon the labor component of the harvesting sector is presented.

INTRODUCTION

In any discussion of alternative management strategies (e.g., limited entry) that might affect the labor force in the lobster fishery in Maine, it is important to examine the socioeconomic repercussions of the contemplated change. In some circumstances this may involve the dislocation of labor. In this case one must, for example, investigate whether alternative employment would be available to those fishermen who will be excluded because of limited entry; their employability (and trainability) relative to the local labor market, their geographical and occupational mobility patterns, the adaptability of their skills, alternative income earning possibilities ("salvage value" of displaced labor), the potential for upgrading their existing skills and for the acquisition of new skills, the barriers to their mobility including sociological, psychological, and economic variables are some of the crucial elements to be carefully considered.

Furthermore, the policy maker has to evaluate the potential impact on the local and regional economy in terms of shifts in income and employment and associated fiscal consequences including welfare expenditures and changes in tax revenue. Finally, it would be important to examine how limited entry in a given fishery such as the lobster fishery might affect other fisheries such as shrimp and scallop fisheries. In a comprehensive study, all these questions need to be investigated before any definitive conclusions can be reached. However, the present study is of much more limited scope and pertains to only some of these questions bearing on limited entry.

This study focuses on the possible socioeconomic impact of hypothetical reduction in the harvesting labor force in the Maine lobster fishery. As to how this reduction is or can be brought about is outside the scope of the study. The study utilizes the data obtained from a sample survey of 131 fishermen from three selected communities. The problem posed for investigation was simply this: if a group of fishermen from this sample is excluded from lobster fishing based on some specified criterion, what sort of socioeconomic impact can be expected: Can certain indicators be developed to measure such impact in order to consider alternative management strategies? For this purpose, it was considered desirable to (a) introduce the notion of a target group composed of fishermen regarded as candidates for limited entry and (b) to develop alternative

[1] This paper is based upon a study sponsored by the National Marine Fisheries Service. In addition to the author, the research team consisted of Harland I. Hasey and Anita Wihry, Research Associates.

[2] Director, Manpower Research Project, University of Maine, Orono, Maine.

criteria for the construction of a set of target groups rather than singling out one specific target group.

Constrained by time and resources available for this project, the study addressed itself only to selected dimensions of socioeconomic impacts of limited entry into the Maine lobster fishery. It is to be clearly understood that some of the findings of this study, because of its very limited scope, are essentially for illustrative purposes rather than for use as supportive materials for or against any implicit management strategy that may be suggested by the format of the target groups.

OBJECTIVES

The major objective of the study is to present an evaluation of the socioeconomic impacts of limited entry into the Maine lobster fishery. A complete evaluation may include but not be limited to the income and employment effect on the displaced fishermen, income effect on the surviving fishermen, income and fiscal effect on the local and regional economy, effect on other fisheries and so on. However, for reasons stated above, the limited objectives of this study are:

1. To make an appraisal of the employability and alternative income earning possibilities of displaced labor.
2. To derive some measures of social impact in terms of (a) income effects and (b) income maintenance burden associated with displacement because of limited entry.

RESEARCH DESIGN

The study was designed as a small-scale pilot effort, concentrating on three typical communities rather than encompassing the entire Maine lobster fishery. These communities are Phippsburg, Beals, and Corea. The selection was made in consultation with the Maine Department of Sea and Shore Fisheries and the National Marine Fisheries Service. The existence of some contrasts in the structure of the local economy and the relative importance of the lobster fishery in their economy weighed heavily in the selection process. Corea represents a highly specialized, isolated economy where lobstering is the predominant economic activity. Beals is also highly specialized but less isolated than Corea. Phippsburg's economy is more diversified and in close proximity to sources of alternative job opportunities. Each of the areas has one feature in common: the lobster fishery is a major economic activity.

It is difficult to say how representative these three communities are of the entire lobster fishery. Sufficient information is not readily available to identify the economic characteristics of the population of lobster fishermen in Maine and relate them to those of the sample fishermen in these communities.

For the purpose of the study the following hypotheses were formulated for investigation:

1. Limited entry could eventually exclude a certain fraction of the lobster harvesting labor force that will be otherwise unemployable. (Alternative hypothesis: a significant fraction of labor displaced because of limited entry will be employable, given the conditions in the local labor market, the type of skill possessed, the potential for adapting skills to job market requirements, the availability of retraining opportunities, motivation for training, and mobility and so on).

2. Displacement of labor because of limited entry may adversely affect the local economy because of loss of income from lobstering not being compensated for by income from alternative jobs and from additional lobstering by surviving fishermen, and because of loss of income from lobstering on the part of those who are not in the labor force.

To generate the information needed for this investigation, a stratified random sample of 131 fishermen was selected. The size of the sample depended essentially on the estimated cost per interview and the budgetary constraint. The allocation to each stratum was strictly according to proportion of fishermen in each community to the total number of fishermen of all three communities. The survey data were supplemented by information on the local labor market obtained through the cooperation of the regional offices of the Maine Employment Security Commission.

For the survey, a structured questionnaire was developed and pretested. Using the modified questionnaire and personal interviews, the survey was completed in 6 weeks. The response rate was better than 90%.

The survey resulted in a large volume of information on the sampled fishermen. The following broad categories of information may be identified:

Categories	*Types of Information*
Demographic	Age Family Size and Composition Mobility Marital status
Socioeconomic	Income Employment history Education and training Monetary return Parental occupation Housing
Operational	Gear types Investment in boat and gear Operating expenses Maintenance and repair expenditures Size of operations Seasonal patterns Rate of capacity utilization
Behavioral-Attitudinal	Reasons for lobstering Job interests Attitudes towards leaving the lobster industry Job-seeking Attitudes toward training, views on excess capacity

ANALYSIS

The Maine Lobster Fishery: Some Basic Facts

The lobster industry in the State of Maine landed 19.8 million pounds of lobsters worth $16.1 million in 1969. This accounted for 10.4% of the quantity and 58.3% of the value of the total fish and shellfish landings for that year (Maine Landings, 1968-70, p. 3).

There were 5,750 lobster licenses issued in the State in 1969. These 5,750 lobstermen fished a total of 805,375 traps or approximately 105.7 million trap-days during the year 1969. The gross earnings per unit of effort was $0.18 per trap-day. This value is arrived at by adjusting Maine landings up by 16% to include landings not reported. This produced total landings of 18.7 million which were divided by total trap-days yielding the return of $0.18 per trap-day. The average gross income was approximately $3,000. The total investment in gear (i.e., boats, traps, buoys, etc.) is about $10 million.[3]

There have been fluctuations in the number of licenses issued over the past 10 years. Table 1 illustrates a seemingly cyclical pattern of lobster licenses, showing a high of 6,472 in 1961, a low of 5,425 in 1962, and another high of 6,316 in 1970.

The communities chosen for study — Phippsburg, Corea, and Beals — represent 277 fishermen or 4.4% of the 6,316 fishermen licensed in 1970. A sample of 131 of the fishermen was randomly selected by community as shown in Table 2. The geographical locations of these three communities are shown in Figure 1.

Economic Profile of the Sample Communities

Beals is an island community of 658 persons located across Mossabec Reach from Jonesport, Maine, population 1,337 (1970 Census — Preliminary Report, Population Counts for States). The two communities — Beals and Jonesport — are integrated as a labor market but have separate political identities. The only administrative connection between the towns is a shared high school.

Employment opportunities are limited to the fishing industry and service industry occupations. The Department of Sea and Shore Fisheries issued 142 lobster licenses to the residents of Beals in 1969. Other licenses include worms — 52, and clams — 89. Many of the fishermen hold more than one license. No license is needed for shrimping.

Businesses on Beals include seven lobster pounds, most of which are family owned and operated. The pounds are used to store lobsters until market prices increase and the

[3] Information supplied by Robert Dow, Research Division, Maine Department of Sea and Shore Fisheries.

Figure 1. — Maine — selected geographic locations.

Table 1. — Number of lobster licenses issued in Maine 1961-1970.

Year	Number of licenses	Year	Number of licenses
1961	6,472	1966	5,613
1962	5,658	1967	5,425
1963	5,695	1968	5,489
1964	5,803	1969	5,750
1965	5,802	1970	6,316

Source: Maine Department of Sea and Shore Fisheries.

Table 2. — Distribution of the sample fishermen by Communities.

Communities	Total fishermen	Sample
Beals	137	61
Corea	73	27
Phippsburg	67	44
TOTAL	277	131

pound may be filled by the family owning it or the pound operator may become a dealer for part of the year, buying from fishermen until he has the pound stocked. A third use of the pound is leasing to a full-time dealer for his own stocking activities. If the family does not operate the pound on a part-time basis, the employment provided rarely exceeds one job. The two full-time lobster dealers on Beals employ between two and four laborers each. The 12 boatyards are father and son operations although occasionally one non-family employee may be hired. The two clam shops on the island employ a total of between 25 and 30 persons together — mainly women who shuck clams for shipment outside the area. The service industry employment available on Beals consists of jobs in three general stores, one garage, one oil company, one television and radio sales, the local elementary school, and various part-time jobs available in the town government (mostly elective positions) (Table 3).

Table 3. — Occupational distribution of the work force in Beals, 1960.

	Male	Female	Total
Professional	8	8	16
Clerical	15	4	19
Craftsmen	28		28
Operatives	17		17
Service		4	4
Laborers (farm)	11		11
Laborers	77		77
Total	156	16	172

Source: 1960 Census Special Report for Maine Employment Security Commission. Approximately 90% of the "laborers" may be classified as lobster fishermen.

In Jonesport employment opportunities are in much the same industries as they are in Beals. Ninety-nine lobster licenses, 60 worm licenses, and 81 clam licenses were issued by the Department of Sea and Shore Fisheries. Employment opportunities available in Jonesport include jobs in one restaurant, one bank, one sardine factory, two grocery stores, one clothing store, one drug store, four gas stations, three gas or oil companies (total employment each is no more than three), one dentist's office, one doctor's office, two lobster dealers and a lobster cooperative which has four employees. Other firms in the area providing substantial employment are two sardine factories — one in Milbridge and one in Machiasport. This employment is part-time and seasonal.

The 1969 value of product given by the Census of Maine Manufacturers for Beals is $283,258, the total gross wages are $70,856, and average gross $2,443. These figures are for manufactured products only and do not include income from lobstering, shrimping, or other fishing unless the catch has been processed in some manner. Total employment in these industries is given as 29. For Jonesport the corresponding figures are value of product — $681,509, gross wages — $192,495, and average gross wage — $2,406. Total employment was 80.

Total assessed value of property on Beals in 1969 was $237,560. The town budget shows total receipts of $99,376, and total expenditures of $73,910, of which about $55,000 was for wages distributed to inhabitants of the town.

Table 4. — Occupational distribution of the work force in Gouldsboro, 1960.

	Male	Female	Total
Professional		4	4
Managers	21	14	35
Clerical	4		4
Sales	8	9	17
Craftsmen	50		50
Operatives	9	17	26
Private household	8	8	16
Service	5		5
Laborers	137		137
No information	33	9	42
Total	275	61	336

Source: 1960 Census Special Report for Maine Employment Security Commission. Approximately 90% of the "laborers" may be classified as lobster fishermen.

Corea (Gouldsboro): The community in Corea is part of the township of Gouldsboro. The 1970 population of Gouldsboro is 1,270, an increase of 170 people over the 1960 figure of 1,100. In 1960 there were 363 households. There were 420 males over 14 years of age and 406 females.

Corea's major industry is lobster fishing, providing some 70-80 jobs. Other types of fishing, which are part-time or supplemental, include seining, clamming, and worming. There are some nine stores, a boatyard which employs six-seven people year around, fish cannery, a naval tracking base, and eight teachers employed by the town's elementary school. These activities employ 109 full-time and part-time workers.

Table 5. — Occupational distribution of the work force in Phippsburg, 1960.

	Male	Female	Total
Professional	8	4	12
Farmers and farm managers	4		4
Managers	16	11	27
Clerical	4	20	24
Crafts	68		68
Operatives	60		73
Private household			20
Services	12		12
Farm labor	12		12
Laborers	71		71
Others	27	8	35
Total	282	70	358

Source: 1960 Census Special Report for Maine Employment Security Commission. Approximately 80% of the "laborers" may be classified as lobster fishermen.

Phippsburg: In 1970 the population of Phippsburg was 1,180, an increase of 59 people. Of the 1,121 people listed in April of 1960, 397 were in the labor force; 358 were employed, and 39 were unemployed. Of those over 14 years of age, 394 were men and 403 were women. There were 335 households.

Phippsburg's major industry is the summer tourist and summer resident trade. At Phippsburg there are several large tenting grounds, a state park, and many summer residences located on its several miles of ocean frontage. Other local industries include fishing, which consists of a fish factory, several large offshore fishing boats, and a fleet of lobster boats. There are also two small construction companies that build and repair summer homes. The bulk of Phippsburg's employed population, however, commute to other towns and cities for employment. Probably the largest employer of Phippsburg people is Bath Industries located in the adjacent city of Bath.

Selected Socioeconomic Characteristics of the Sample Lobstermen

Average age of the lobstermen in the sample is 42.6 years. There are 15 below the age of 19 and 18 in the age bracket of 65 and over. The median income for the group is $5,280 and average income in $6,213. There are 13 fishermen with income less than $1,000 and 15 with income over $14,000. Of the 118 fishermen who gave reasons for lobstering, 33 (which includes 3 students) responses may be categorized as "economic" and the rest "non-economic" including home consumption, preference for the particular way of life, influence of family, and so on.

Of the 109 fishermen who supplied information on number of traps, slightly over 50% owned less than 300 traps; 23 fishermen owned more than 500 traps. Of the 93 fishermen who gave information on investment in trap gear, approximately 50% had investment of less than $2,000; only 3 had investment of $8,000 and over. The average years of education was 9.8. Approximately 40% had less than 9 years of education. Of 131 fishermen, 41 indicated that they received some type of formal vocational training in areas including carpentry, metal working, mechanic, professional and clerical work. Of 81 fishermen asked about preference for receiving vocational training, 63 indicated no preference. Only a small fraction expressed preference for training in electrical, professional, and carpentry work.

Among the 109 fishermen who supplied information on income from part-time jobs, 77 indicated that they had little or no income from this source. Only 7 indicated that they received more than 50% of their income from alternative jobs.[4]

Analysis of Target Groups

In order to analyze the *potential* socioeconomic impact of limited entry, it is necessary to identify the possible candidates who might be considered targets for limited entry or any

[4] More detailed information on these and other aspects of the study may be found in the complete final project report, available from the Economic Research Laboratory, National Marine Fisheries Service.

other management strategy that might affect the harvesting labor force.

For the purpose of this study, four groups have been constructed, using alternative criteria. It is not intended that the groups be mutually exclusive.

The variables chosen for this analysis include the following: income, investment, effort, and earnings/effort ratio.[5] It should be noted that with the exception of one target group, combinations of variables were used to define the target groups. Admittedly, similar groups could be constructed using different criteria. Groups selected appeared to be quite meaningful for the purpose of this study.

Target Group I was chosen on the basis of a combination of two criteria: (a) low earnings/effort ratio, and (b) low number of trap-days serving as a proxy for low income. It was arbitrarily decided that to be eligible for this group a fisherman had to have an income/effort ratio of less than 0.3 and had to fish less than 30,000 trap-days per year. Those fishing over 30,000 traps were not included because they earned sufficient income for subsistence. Table 6 was especially constructed for this purpose.

Forty fishermen met the conditions set for this group. As it turned out, this group had an average earnings/effort ratio of 0.182 compared to 0.230 for the entire sample and they fished an average number of 12,570 trap-days compared to 30,707 trap-days for the sample as a whole. Their average income was only $2,061 compared to an average income of $6,213 for the sample as a whole. The fishermen in this group fish fewer number of days and have invested small amounts of capital in gear and boat.

In any discussion of deliberate or planned changes in the harvesting labor force in the lobster fishery, this group with a low earnings/effort relationship and low absolute level of income would warrant consideration. Presumably, the economic status of the remaining fishermen would improve the terms of a higher ratio of income to effort and higher absolute level of income, if this group is eliminated. Of course, one has to look at the social cost of such a change and the political feasibility of such a change. Some measures of social cost are developed later in this paper.

An alternative approach to the problem would be to consider only low levels of productivity as measured by the low income/effort ratio, regardless of the absolute size of income. Here one could argue that shifting away from lobstering in this case may be socially gainful, given possibilities for improving the income/effort ratio in alternative employments. From such a reallocation of effort as an economic resource, both the displaced fishermen as well as the surviving fishermen might benefit, as the marginal productivity of both groups is likely to increase.

On this premise, Target Group II has been constructed. Those fishermen who recorded an income/effort ratio of less than 0.2 were

[5] The earning/effort ratio was calculated by dividing the number of trap-days into gross income reported by the sample fishermen.

Table 6. — Distribution of sample lobstermen according to income/effort ratio and trap-days.

Earning effort ratio	Trap-days fished per year									
	5,000	5,001-10,000	10,001-20,000	20,001-30,000	30,001-40,000	40,001-50,000	50,001-60,000	60,000+	N/I	TOTAL
0.100	1	2	1	–		1	2			7
.100-.199	2	3	7	8	5	4	4	8		41
.200-.299	5	1	8	2	4	-	6	1		27
.300-.399	–	2	2	2	2	1	1			10
.400-.499	–	2	1	–	–		1			4
.500 +	2	–	–	–	2		1			5
N/I	6	1	1	2	1		1	5	19	37
TOTAL	18	10	20	14	14	7	15	14	19	131

Source: University of Maine Survey Data, 1970.

considered eligible for this group (See Table 6). There will be some overlap between this group and Target Group I.

Different combinations of investment and effort suggest other possible approaches to management alternatives. For instance, one could identify a group that represents relatively high effort and low investment input combination; another group may represent relatively higher investment and lower effort input combination.[6] The reasoning for at least considering these groups as possible target groups may be explained as follows: in the absence of any precise knowledge about the optimum combination of effort and investment, two contrasting groups — high-effort low-investment versus low-effort high-investment — might suggest alternative goals for management strategies. For instance, one might consider eliminating excessive capital versus eliminating excessive effort as possible goals. As a minimum, the differences in socio-economic impact of such changes should be examined.

It is reasonable to assume that excess capacity exists in the lobster fishery, although it is difficult to establish whether such excess capacity is due to excessive effort or excessive investment or both. Under these conditions, it seems meaningful to isolate for analytical purposes, two cases, one showing evidence of excessive effort and the other of excessive investment. Admittedly, the state of the art does not provide absolute measurement of excess capacity either in terms of effort or in terms of investment.

Target Group III has been constructed to reflect excessive effort in the sense that these fishermen supply a large amount of labor to their operation relative to their investment. They fish, on an average, 150 days per year compared to 109 days for the entire sample; their average investment amounted to $4,410 compared to $7,575 for the entire sample. As a practical device, the criteria of those fishing over 100 days per year with investment of less than $8,000 in gear were used to select the candidates for this group of 28 fishermen.

Target Group IV represents excessive capital in the sense that the fishermen in this group have substantial investments in gear relative to the number of days per year fished. On the average they have invested $12,410 compared to $7,575 for the entire sample and they fish an average of 78 days per year compared to 109 days per year for the sample. This group of six fishermen included those who have invested more than $8,000 and who fish less than 100 days per year.

Table 7 provides the basic information from which Target Groups III and IV have been derived.

[6] This approach was suggested by Dr. Adam A. Sokoloski, National Marine Fisheries Service in personal correspondence dated December 16, 1970.

Table 7. — Distribution of sample lobstermen by investment and number of days fished.

Days fished per year	Investment in gear: 2,000	2,001-4,000	4,001-8,000	8,001-12,000	12,001-16,000	16,001-20,000	20,001-24,000	24,000+	N/I	Total
	dollars									
50	10	3		1	—	—			3	17
51-100	16	7	8	2	2	1			2	38
101-150	3	7	8	1	4	3	2	4		32
151-200	—	2	5	6	2	2	1		—	18
201-250		1	2	—	1		1	1		6
N/I	—	—	—		1		1		18	20
TOTAL	29	20	23	10	10	6	5	5	23	131

Source: University of Maine Survey Data, 1970.

Table 8. — Distribution of lobstermen in target groups by trap-days, gross income, and capital invested

	Target groups				Total Sample
	I	II	III	IV	
Trap-days	502,799	1,753,287	973,198	185,560	3,470,000
%	14.5	50.5	28.0	5.3	
*(No.), %	(40) 32.0	(48) 38.4	(28) 22.4	(6) 4.8	(113)
Income	$82,450	$250,233	$161,583	$61,000	$596,500
%	13.8	41.8	27.0	10.2	
*(No.), %	(40) 41.7	(48) 50.0	(26) 27.1	(5) 5.2	(96)
Capital	$97,043	$332,566	$123,485	$74,465	$833,209
%	11.6	39.9	14.8	8.9	
*(No.), %	(40) 36.4	(48) 43.6	(23) 25.5	(6) 5.5	(110)

*The number in parentheses refers to the total number of fishermen relevant to a particular category; the other number is the relevant number of fishermen expressed as a percentage of the sample.
Source: University of Maine Survey Data, 1970.

Distribution by Trap-days, Income, and Capital Invested

Table 8 presents a distribution of the lobstermen in each of the target groups by trap-days, gross income and capital invested in boat and gear. Target Group I emerges as a critical group in that its share in trap-days, income and capital investment is the lowest relative to its size in the total sample. Target Group II contributes more trap-days, more capital, and more income compared to Group I. However, relative to its size, its share in income and capital investment is less than in proportion. Target Group III contributes relatively more in trap-days and relatively less in capital and its income share corresponds closely to its size. Target Group IV accounts for more capital relative to size and to number of trap-days and substantially more income relative to size. For this reason, this group can hardly be considered as a target group for limited entry on the basis of income-effort relationship. However, if the income-capital ratio is considered, this group does not appear to be equally efficient.

Socioeconomic Characteristics of the Fishermen in Each of the Four Target Groups

Beals will be most affected if Target Group II is eliminated, and Corea the least. If Target Group I is considered, the impact on the three communities is comparable. Corea will be affected in the least if one focuses on Target Group III. The effect on the other two communities is about the same. Target Group IV does not affect Phippsburg but will affect the other two communities equally (Table 9).

Table 10 provides average values for certain socioeconomic characteristics of the lobstermen in each of the Target Groups.

Table 9. — Geographic distribution

	Target groups							
	I		II		III		IV	
Community	No.	%	No.	%	No.	%	No.	%
Beals[1]	18	29.5	31	50.8	16	26.2	4	6.5
Corea[2]	7	26.9	3	11.5	3	11.5	2	7.7
Phippsburg[3]	15	34.1	14	31.8	9	26.5		–
Total	40		48		28		6	

[1]Beals 61.
[2]Corea 26.
[3]Phippsburg 44, includes 10 from Bath.
Source: University of Maine Survey Data, 1970.

The average income of Group I is the lowest attributable both to low labor and low capital intensity in its operation. In constrast, Group IV has the highest average income primarily due to high capital intensity in its operation in spite of low labor intensity. Group II ranks second in average income which can be explained in terms of relatively more effort and

Table 10. — Comparative average value for selected socioeconomic variables in the sample of lobstermen and the four target groups.

Socioeconomic variable	Sample	Target groups I	II	III	IV
Family size	3.2 (122)	2.9 (38)	3.6 (46)	2.9 (28)	3.6 (5)
Age	42.4 (131)	42.5 (40)	44.0 (48)	49.4 (28)	31.7 (6)
Education: years	9.8 (126)	9.7 (40)	9.7 (48)	10.0 (28)	11.0 (6)
Investment (gear & boat)	$7,575 (110)	$2,426 (40)	$6,949 (48)	$4,410 (28)	$12,410 (6)
Gross income	$6,213 (96)	$2,061 (40)	$5,213 (48)	$6,214 (26)	$12,200 (5)
Months per year fished	7.2 (113)	5.7 (40)	8.0 (48)	8.5 (28)	6.6 (5)
Trap-days per year	30,707 (113)	12,570 (40)	36,526 (48)	34,757 (28)	30,927 (6)
Days per year lobstered	109.2 (113)	87.0 (40)	132.2 (47)	147.9 (28)	78.0 (6)
Earning-effort ratio	.230 (96)	.182 (40)	.140 (48)	.183 (26)	.355 (5)

*The number in parentheses refers to the total number of fishermen relevant to a particular category.
Source: University of Maine Survey Data, 1970.

capital used compared to Groups I and III. Group III ranks third in average income. Here the high level of labor intensity offset the effect of low capital intensity. Its income/effort ratio is almost the same as that of Group I.

Socioeconomic Impact of Changes in Harvesting Labor Force

As pointed out earlier, the different target groups were constructed on the basis of different criteria such as low earnings/effort ratio, low level of both effort and investment, high labor and capital input combination. The rationale for this procedure is simply to facilitate comparative analysis of alternative management strategies. For instance, one might consider limiting entry on the basis of low earnings/effort ratio combined with low level of income (Group I); one might also focus on low earnings/effort ratio regardless of the level of income (Group II); alternatively, one might emphasize high labor-low capital input combination associated with low income as an indicator of inefficiency (Group III); finally, high capital-low labor input combination regardless of a relatively higher level of income may be construed as an indicator of excess capacity (Group IV).

It should be noted that it was not the purpose of this study either to advocate or repudiate any particular management strategy and its implicit goal. The intent here is simply to analyze the potential socioeconomic impact of a change in the harvesting labor force in the Maine lobster fishery if such a change amounts to reducing inefficient inputs from given target groups.

For the purpose of this study such impact is analyzed primarily in terms of employment effects and income effects relative to the target group populations and the local economy.

Employment Effects

Taking into consideration the employment-related variable such as skills either from currently held part-time jobs or alternative jobs held in the past, level of education, and age, a simplified profile of labor market participation potential of the target groups is shown in Table 11.

The category "potentially employable" includes those individuals who have marketable skills acquired from formal vocational training and/or alternative job experience. This survey information was supplemented by information on the local labor market through the cooperation of the regional offices of the Maine Employment Security Commission. If there was a match between the kinds of skills in demand in the local labor market and the skills possessed, an individual was considered eligible for the category "potentially employable."

The category "possibly trainable" includes those who on the basis of age and level of education would be likely to benefit from and

Table 11. — Labor market participation potential of target groups I-IV.

Target group	Total number	Potentially employable[1]	Possibly trainable[2]	Potential hard-core unemployed[3]	Not in the labor force[4]
I	40 100.0%	14 35.0%	4 10.0%	8 20.0%	14 35.0%
II	48 100.0%	18 37.5%	4 8.3%	17 35.4%	9 18.7%
III	28 100.0%	11 39.3%	2 7.1%	10 35.7%	5 17.9%
IV	6 100.0%	4 66.7%	1 16.7%	1 16.7%	–

[1]Those having marketable skills.
[2]Those having no skill but less than 35 years of age.
[3]Those having no skill and in the age bracket 35-65 years.
[4]Students and those over 65 years.
Source: University of Maine Survey Data, 1970.

be capable of participating in a training program. Admittedly, this is only a first approximation.

The category "potential hard-core unemployed" includes those fishermen who have no marketable skills other than lobstering and who fall into the critical age bracket by labor market criteria, 35-65. In all likelihood, these individuals, if excluded from lobstering, will find it extremely hard to make any vocational readjustment.

The last category, "not in the labor force" is self-explanatory. This includes those fishermen who are either students or over 65 years of age and are not likely to participate in the labor market as active job seekers, barring purely part-time or seasonal jobs.

It should be emphasized that the above classification is only a preliminary step in identifying the differences in labor market participation potential of various subgroups within each of the target groups. To be sure, potential employability, trainability, and hard-core unemployability require considerably more in depth analysis than was possible in the present study.

It is apparent from Table 11 that a substantial proportion of the fishermen in each of the target groups is potentially employable (ranging from 35% to 67%). Of those who are classified under "potentially employable," some already have full-time jobs and others have marketable skills. However, Target Groups II and III are likely to result in more hard-core unemployment. Paradoxically, the group that has a high earnings/effort ratio (Target Group IV) also happens to be the one with a relatively larger proportion of potential employability. With the exception of this group, other groups include several fishermen not in the labor force, students, and those 65 years and over. The question of their employability is, therefore, irrelevant in the present context.

In analyzing the expected socioeconomic impact of limited entry, the survey data on each of the fishermen in each of the target groups were examined in depth by communities. In this investigation, attention was focused on such socioeconomic variables as age, family size, level of education, types of skill, alternative job experience, alternative source of income, and so on. On the basis of information from survey data combined with information on local labor market, Table 12 is reconstructed to reflect the differences in labor market participation potential by communities.

Income Effect and Expected Socioeconomic Impact

To perform the necessary analysis, the following procedures were adopted:

1. Assume each target group to be a candidate for exclusion from lobstering.
2. Estimate private loss of gross income due to non-participation in lobster fishery.
3. Assume that 50% of the lost gross income would be subsequently earned by the remaining fishermen. The survey date did

Table 12. – Labor market participation potential of target groups I-IV by geographic location.

Target group by communities		Total number	Potentially employable[1]	Possibly trainable[2]	Potential hard-core unemployed[3]	Not in the labor force[4]
	Phippsburg	15	7	2	3	3
I	Corea	7	3	1	–	3
	Beals	18	4	1	5	8
		40	14	4	8	14
	Phippsburg	14	8	–	4	2
II	Corea	3	1	1	–	1
	Beals	31	9	3	13	6
		48	18	4	17	9
	Phippsburg	9	5	–	3	1
III	Corea	3	2	1	–	–
	Beals	16	4	1	7	4
		28	11	2	10	5
	Phippsburg	–	–		–	–
IV	Corea	2	1	1	–	–
	Beals	4	3	–	1	–
		6	4	1	1	

[1] Those having marketable skills.
[2] Those having no skill but less than 35 years of age.
[3] Those having no skill and in the age bracket 35-65 years.
[4] Students and those over 65 years.
Source – University of Maine Survey Data, 1970.

indicate some evidence of excess capacity in terms of number of traps owned and number of traps fished and days fished. It was recognized that the remaining fishermen may not be willing or able to capture the entire amount of output attributable to the excluded fishermen, at least in the short run. Furthermore, the purpose here is to *illustrate* what might happen if this assumption holds. If a different figure proves to be more realistic, the results will change.

4. Estimate the savings in effort measured in trap-days on the basis of (3) and convert this into monetary values. For this purpose, we first calculated how many trap-days would be needed by the excluded fishermen in a given target group to produce the gross income attributed to this group. An average earnings/effort ratio for this group was used to calculate the number of trap-days required. Next, an average earnings/effort ratio was computed in the given target group. This average ratio was applied to 50% of the total gross income of the group to come up with the number of trap-days that would be required to produce this income by the remaining fishermen. The difference between the two values for trap-days is stated as saving in effort. This quantity multiplied by the average earnings/effort ratio of the remaining fishermen produced a monetary measure of saving that can be expected under the stipulated conditions.
5. Estimate the sum of expected new incomes generated by those who are considered "potentially employable" based on information of types of jobs available and skills needed in the local market. The number of fishermen in each target group that fits this category was identified and typical wages for indicated jobs were applied to the number of employable fishermen to produce a sum of expected income.
6. Estimate the expected annual income of

those that are classified as "possibly trainable." Assume that training facilities and programs are made available and that individuals are willing to paticipate. Communication from people involved with Manpower Development and Training Act (MDTA) programs provided some information as to typical wages MDTA trainees can expect post-training. These figures were used to derive expected incomes that the "possibly trainable" fishermen in each target group can expect if they receive training comparable to those under MDTA programs.

7. Estimate the training cost of those classified under "possibly trainable."
8. Estimate the potential income-maintenance burden on society imposed by the loss of lobstering income of those who are classified under "potentially hard-core unemployed" and under "not in the labor force." Fifty percent of current gross income from lobstering was used for estimation purposes. The rationale for using this percentage is based on the consideration that the net income from lobstering is substantially lower than reported gross income, although exact figures for net income were not readily obtainable. During the course of the interviews, several fishermen indicated that although they could not provide information on net income, roughly 50% of their gross income could be considered net, after allowing for business expenses. The assumed percentage is considered reasonable for illustrative purposes.

The reason why the individuals in these categories — "potential hard-core unemployed" and "not in the labor force" — and their loss of income from lobstering are used as the basis for measuring the income maintenance burden on society is to indicate the upper limit of the social burden. This yields a relative measure of income loss and corresponding welfare loss for a group of people who are technically outside the labor force. At least in the short run, the process of adjustment will be quite severe for a bulk of this group. Conceivably, some low level, unskilled jobs would be available which would moderate the impact. However, considering the high level of current unemployment and the generally depressed conditions of the local economies under consideration, it appeared reasonable to assume that alternative sources of income would be unavailable in the short run, thereby imposing a burden on society.

9. The estimated value of investment in boat and gear by the fishermen in each of the target groups is included in the profile of socioeconomic impact of limited entry because these values have definite implications for compensation.

Assuming zero salvage value of such capital equipment, the stated figures provide the upper limit of the compensation burden imposed on society. It is reasonable to think actual compensation will differ from the stated figures because of some positive salvage value. For illustrative purposes, without making such allowance, the quoted figures do serve as indicators of upper limits of the cost of compensation that may be entailed.

Using the above procedure, the following tabulations were made to present a comparative picture of the socioeconomic implications of limiting entry of different groups by using alternative criteria (Table 13).

Group II is likely to cause the largest decline in income from lobstering. It will be partially offset by additional income from lobstering by the remaining fishermen, income from alternative jobs for the displaced fishermen, and the savings in effort measured by the fewer number of trap-days required to capture at least 50% of the gross income lost. In absolute terms, this group may present the severest income maintenance burden on society. By comparison, Group I is likely to impose a relatively smaller burden on society. On a per capita basis, Group III will impose the severest burden on society.

The proportion of the "potentially employable" and "possibly trainable" among Groups I-III are quite comparable. The proportion of the same categories for Group IV is considerably higher. This accounts for the relatively small social burden indicated for this group. However, it should be noted that this underestimates the total real burden on society in that there will be a dissaving in effort and potential negative difference between their current income from lobstering and their ex-

Table 13. — Profile of socioeconomic impact by target groups.

Impact variables	Target groups I	II	III	IV
1. Loss of income from lobstering ($)	-82,450	-250,223	-161,583	-61,000
2. Gain of income from lobstering ($)	+41,225	+125,116	+ 80,791	+30,500
3. Monetary value of saving in effort ($)	+18,574	+168,670	+ 31,346	-11,083
4. Gain of income from alternative jobs (marketable skills) ($)	+19,000	+ 41,500	+ 38,000	+21,000
5. Gain of income from alternative jobs (post-training) ($)	+24,000	+ 24,000	+ 12,000	+12,000
6. Training costs ($)	-13,800	- 13,800	- 6,400	- 6,400
7. Income maintenance burden on society ($)	-26,775	- 64,225	- 54,200	- 3,500
8. Estimated value of investment in boat and gear ($)	-97,043	-332,566	-123,485	-74,465
9. Number of fishermen	40	48	28	6

Source: University of Maine Survey Data, 1970; local Manpower Development Training Act program officials.

pected income from alternative jobs.

It would have been desirable to compute a ratio of total gains and losses. However, with the data in hand, it does not appear to be feasible and meaningful. First, the quantities calculated are not additive. Second, costs and benefits have different time dimensions. For instance, training costs are once-over cost items whereas the expected income is a flow over time. Finally, the figures for income maintenance burden on society do not take into consideration the loss of income from lobstering of those who are classified as "potentially employable" but are already employed. Furthermore, the discrepancy between current income from lobstering and expected income from alternative jobs for those employable but currently full-time fishermen is also disregarded.

Despite these limitations, the results do give certain indicator values that should be considered and comparatively analyzed relative to alternative management strategies and implicit goals. Admittedly, these values involve many simplifying and rather arbitrary assumptions, although hard data were utilized when available. The value of this type of approach is primarily methodological, which is to be expected in a pilot study.

CONCLUSIONS

Several qualifications need to be attached to the foregoing analysis before any generalization is made. *First*, some fishermen who are considered as candidates for a given target group may continue to lobster because of noneconomic reasons. *Second*, expected new incomes from alternative jobs for the displaced fishermen may not materialize because of lack of motivation and reluctance to move geographically and/or occupationally. *Third*, there is no assurance that the additional new income earned by the remaining lobstermen will exactly equal the lost income due to limited entry. There is, however, a strong probability that if they were to capture the same number of lobsters as attributable to the displaced fishermen, they could do so more efficiently because of excess capacity and potential economies of scale. *Fourth*, there may be a significant gap between the number of those considered trainable and those who will take advantage of training if made available. *Fifth*, a fraction of those trained may still remain unemployed due to labor market conditions. *Sixth*, the income maintenance burden may not be as severe as indicated because some of the potentially hard-core unemployed may be absorbed in unskilled jobs or in the lobster industry as "helpers." Conceivably, jobs may be redesigned to facilitate the entry of these men into the labor market. *Finally*, some of those who are not in the labor force, e.g., students, will, in course of time, participate in the labor market and reduce the stated social burden.

It is important that in this kind of analysis one takes cognizance of the time element relative to the process of adjustment. The short run impact may appear to be quite severe because of the imperfections in the labor market. For instance, men who are unemployed now may not have marketable skills; men who have marketable skills may not have information about available jobs or may have very restricted mobility; job structure may be such that it precludes entry of unskilled workers; those who are trainable may not have access to adequate training facilities or programs. Given time, however, some of these market imperfections may be reduced, partially through deliberate planning and partially through autonomous changes in the labor market itself. For instance, the quality of job information and job counselling can be improved; training programs may be initiated; jobs may be restructured; local economic development may generate new demands for labor; the lobster fishery itself, if efficiently managed by fewer fishermen, may need additional helpers.

It is a reasonable expectation that if a management strategy results in an improved return to both labor and capital and if deliberate efforts are made to aid the process of adjustment, net social gains are likely to materialize in the long run. Although the present study did not consider, nor was intended to consider, any specific management scheme with respect to its socioeconomic impact, it did generate data pertinent to such an evaluation.

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