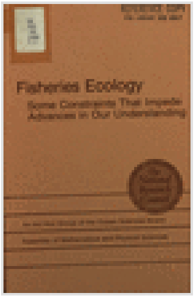

Fisheries Ecology: Some Constraints That Impede Advances in Our Understanding (1980)

Pages
24

Size
5 x 9

ISBN
0309331676

Ad Hoc Group of the Ocean Sciences Board; Ocean Sciences Board; Assembly of Mathematical and Physical Sciences; National Research Council

TI

[Fisheries Ecology:A

Some Constraints That Impede Advances in Our Understanding]

An Ad Hoc Group
of the Ocean Sciences Board
OR3 Ocean Sciences Board
OR1 Assembly of Mathematical and
Physical Sciences
National Research Council
OR1

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1980
D

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Available from

Ocean Sciences Board
2101 Constitution Avenue
Washington, D.C. 20418

OCEAN SCIENCES BOARD

WARREN S. WOOSTER, University of Washington, Seattle, Washington, *Chairman*
GUSTAF O.S. ARRHENIUS, Scripps Institution of Oceanography, University of California, La Jolla, California
JAMES D. BAKER, University of Washington, Seattle, Washington
WILLARD BASCOM, Southern California Coastal Water Research Project, Long Beach, California
RITA R. COLWELL, University of Maryland, College Park, Maryland
ROBERT M. GARRELS, Northwestern University, Evanston, Illinois
WILLIAM W. HAY, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida
DENNIS HAYES, Lamont-Doherty Geological Observatory, Palisades, New York
JOHN IMBRIE, Brown University, Providence, Rhode Island
MICHAEL M. MULLIN, Scripps Institution of Oceanography, University of California, La Jolla, California
WORTH D. NOWLIN, Texas A&M University, College Station, Texas
FRED N. SPIESS, Scripps Institution of Oceanography, University of California, San Diego, California
JOHN H. STEELE, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
KARL K. TUREKIAN, Yale University, New Haven, Connecticut
PETER R. VAIL, Exxon Production Research Company, Houston, Texas
RICHARD C. VETTER, National Research Council, Executive Secretary

AD HOC GROUP*

c1k ✓ JOHN STEELE, Woods Hole Oceanographic Institution, *Chairman*
COLIN CLARK, University of British Columbia
PETER LARKIN, University of British Columbia (by correspondence only)
REUBEN LASKER, National Marine Fisheries Service
ROBERT MAY, Princeton University
BRIAN ROTHSCHILD, National Oceanic and Atmospheric Administration
ERIK URSIN, Danish Institute for Fishery and Marine Research
JOHN WALSH, Brookhaven National Laboratory
WARREN WOOSTER, University of Washington

---

*Virgil R. Norton, Chairman of the Fisheries Task Group of the NRC Ocean Policy Committee, was invited to participate but was unable to take part. Lee Anderson of the University of Delaware attended part of the meeting. Dr. Norton did provide comments later on the draft of this report.

TERMS OF REFERENCE

Recent discussions within the Ocean Sciences Board (OSB) of the National Research Council have considered the needs for research on the ecological basis for fisheries management. These discussions revealed the diversity of questions that arise in this context. Some questions relate to external factors such as extension of national jurisdiction, others derive from studies of ecological structure. These, in turn, raise questions about the logistics of research operations ranging from long-term monitoring of fish stocks to short-term studies of small patches of plankton and fish larvae. Lastly, the management of the research itself needs to be considered in preparing coherent programs in this field.

The OSB proposed that a small group consider these questions, first by correspondence and then by a short meeting. The purpose of the group's activity was to prepare a position paper for the Board. The group met at Princeton University, May 14-15, 1979. (We are grateful to Dr. May for the local arrangements at Princeton.)

INTRODUCTION

The world fish catch had increased steadily for decades until, about 10 years ago, it leveled off between 60 million and 70 million tons per year. In many of the traditional fishing grounds of northern Europe and North America, the catch of important commercial species has decreased. The decrease is especially marked for pelagic fish such as herring, mackerel, and anchovy, and there are few of these pelagic stocks in the world's oceans whose current state does not give cause for alarm (Saville, in press). These stocks and some demersal species have collapsed because of a combination of inadequacies in the scientific advice available at the time and deficiencies in the management decisions. Resolution of these problems depends on improvement in both components. We are concerned, here, with the former and with the critical role of increased ecological understanding in increasing the scientific basis of advice to management.

The knowledge gained from recent changes in areas such as Georges Bank and the North Sea have underlined the importance of interactions between fish species. The desire that future management shall be on a multispecies basis will require detailed, quantitative information on these interactions. We wish to optimize the overall yield from an area, but the definition of the optimum fishing strategy is a complicated mixture of economic and social factors, as well as bionomic yields. General concepts such as "health of the ecosystem" or "maximum productivity" are insufficient definitions on which to take action. Thus we must prepare for management decisions based on close interrelations between ecological, economic, and social criteria.

We have been conscious of other factors--climatic change and pollution--that, potentially, can alter the marine ecosystem and so change the balance of fish stocks. We are entering a period in which climatic variability is likely to be accelerated and in which the large-scale effects of pollutants must be kept at low or negligible levels. Determination of the possible consequences for fish stocks is important, not only for the commercial fisheries but also as a critical index of the likely response of whole marine ecosystems.

These comments stress the essential connections between the problems of fisheries and of the rest of the marine ecosystem. The need for a unified approach arises both in the practical problems and in the underlying scientific questions. The large-scale perturbations in fish stocks create important social and economic problems, but also they can be considered as the consequences of critical ecological "experiments." To deal with these questions, we must bring together the interest and abilities of a wide range of disciplines from physical oceanography to theoretical ecology in the context of fisheries science. Such integration will require a long-term assurance of support if it is to provide the depth of knowledge to enhance our general management of the marine environment.

This report outlines some critical ecological problems centered on fisheries, suggests certain priorities for future research, and discusses some aspects of the organization necessary to fulfill these needs. It is intended as a basis for further and more detailed consideration of these questions.

ECOLOGICAL PROBLEMS IN FISHERIES MANAGEMENT

For any single fish stock, management is concerned with the balance between factors that increase the stock size

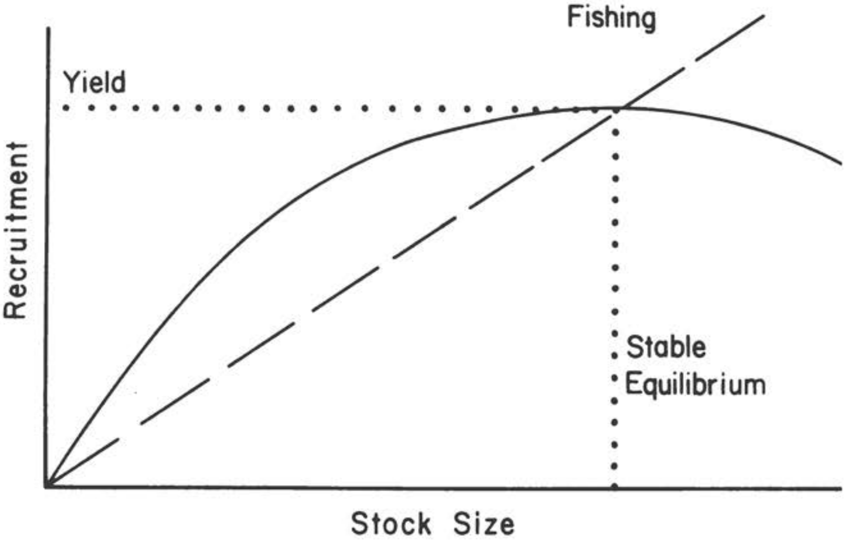

FIGURE 1 A dome-shaped stock-recruit relation combined with a fishing mortality proportional to stock size gives a stable equilibrium yield.

and those that decrease it. The former component is divisible into the yearly recruitment to the population fished and growth of fish thereafter that will tend to increase the biomass of the stock. The decrease in numbers may be divided into fishing and "natural" mortality. The natural mortality is really a catchall for a whole range of processes occurring at any time throughout the life of the fish, such as death from starvation in the early, larval phase, predation by other fish, and disease (Cushing, 1975).

The simplest representation of these processes concentrates on recruitment to the commercial phase of life and the depletion of the stock by fishing. It is assumed that, at very high levels of stock, competition for resources will lower recruitment (Figure 1). More significant, in the present context, at low levels of stocks there will also be a reduction in recruitment. This gives the essential shape of the response defining the rate of increase of the stock. For fishing, the simplest assumption is that rate of yield is proportional to stock size giving a linear relation for the rate of decrease in stock size (Figure 1). Where the two curves intersect, in this very simple representation, we have a stable equilibrium yield and stock size. By varying the rate of fishing, this intercept can be changed and, potentially, managed to give a maximum sustainable yield.

Actual fisheries methods are much more complex, but this illustration contains the essence of the reasoning. Why, then, have certain stocks been driven close to extinction? The major factors are related to aspects of the ecology of fish populations that alter the shape of these curves and produce major qualitative changes in the conclusions.

One factor is the relation of stock size to yield for a given fishing effort. The linear increase in Figure 1 depends on the assumption that the catch rate changes proportionately with stock size. We now know that this is not true for pelagic fish. As a consequence of the migration and behavior patterns of species such as herring, the size of shoals may remain approximately the same and the location of shoals by sonar is nearly as efficient for a few as for many shoals (Saville and Bailey, in press). The effort required to remove the last hundred shoals may be not much greater than that required for the first hundred (Paloheimo and Dickie, 1964). Thus the yield curve has a very nonlinear shape (Figure 2), and we have a second unstable intercept with

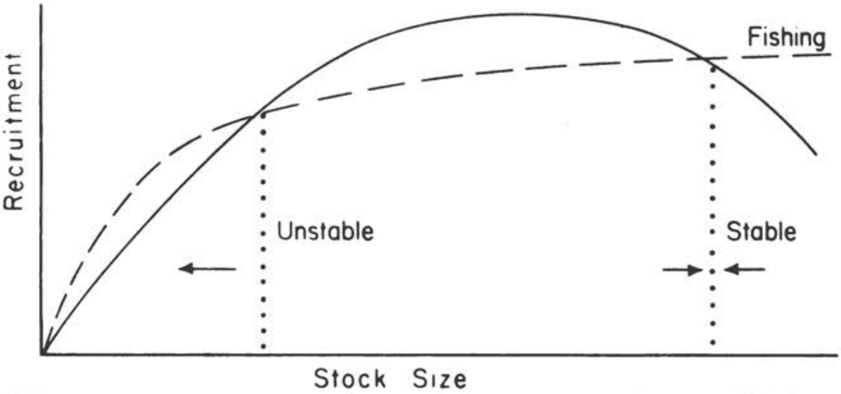

FIGURE 2 The recruitment curve combined with a fishing mortality relatively independent of stock size gives two possible yields. The smaller stock size yield is unstable and tends to drive the stock to zero.

the recruit curve. If the stock size decreases to this lower intercept, then it will continue to go toward zero unless there are drastic decreases in the level of fishing effort. Recovery of the stock may require cessation of fishing since only by this means can the process be reversed (Gulland, 1977).

The second factor concerns the shape of the recruitment curve. At lower stock sizes, this curve may also have a more complex shape, decreasing more rapidly than the simple illustration in Figure 1 and giving two intersections, the second of which is, again, unstable (Clark, 1976). This would produce the same trend for the population toward zero unless dramatic decrases or cessation in fishing are introduced. Such responses at very low stock levels have bbeen proposed for pelagic species when they get close to extension levels (Ulltang, in press).

These modifications of factors controlling stock size are believed to contain, singly or in combination, the essential elements of the way in which certain stocks have been driven near to extinction by excessive fishing that has resulted from new methods of location and capture. They provide an illustration of the way in which ecological factors affecting recruitment, migration, and aggregation can produce unexpected and dramatic changes in fish stocks. Evidence in support of these conclusions exists for certain pelagic stocks, but the cost of obtaining this evidence was the reduction of stock levels to near zero! If we are to benefit from these "experiments," we must recognize the critical role of these ecological components but produce alternative, and less dramatic, methods of study. It is necessary that we investigate each of the processes that define the separate elements making up the curves given in Figure 1.

RECRUITMENT

The factors controlling recruitment are obviously crucial, and we must clarify these elements if we are to determine the general nature of research needs. Unlike the simple representation of Figure 1, the great variability in recruitment normally gives graphs in which we have a cloud of scattered points (Figure 3, A). The experience with pelagic stocks indicates that, where we have data on recruitment from continued commercial fishing on very low stocks (B), we may have an almost

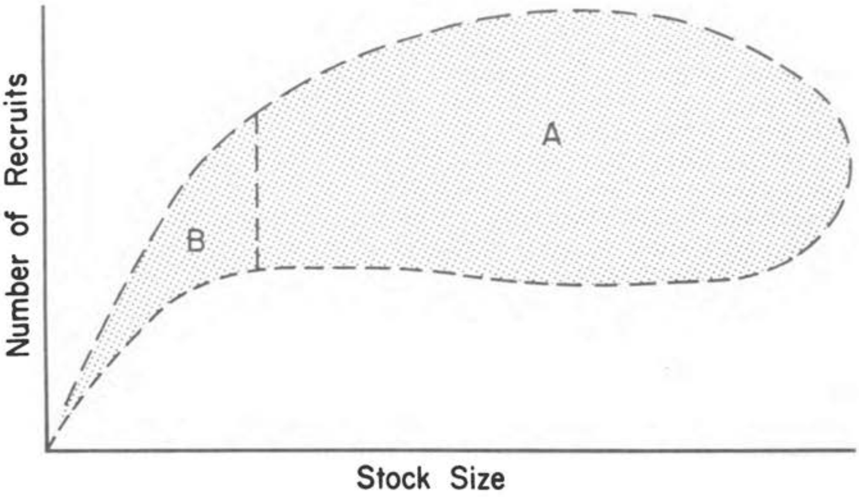

FIGURE 3 Very schematic representation to illustrate A, great variability normally found in yearly number of recruits for different stock sizes and B, decrease in numbers of recruits observed at low stock levels when populations may be in danger.

irreversible trend to very small populations. We might think of this cloud as a single curve with considerable variance about it or as a superposition of a set of curves, which is determined by a range of environmental parameters (Beddington and May, 1977). Ultimately, we would prefer the latter; for the near future, we may have to accept the large, unknown variance. Perhaps the major conclusion is that we should not use a single curve for recruitment, as this implies a regularity in nature that runs completely counter to the evidence.

Since only one or two of the 10^5-10^6 eggs released by a female actually recruit to the adult stock, factors affecting mortality must be critical to stock variations. We believe that much of the year-to-year variability in (A) arises ultimately from physical factors but depends more directly on the way in which these physical factors affect the planktonic food requirements of prerecruit larvae and juvenile stages. Detailed field studies have revealed the mechanisms in certain stocks such as the North Pacific anchovy (Lasker, 1975; 1978). Similar studies are needed in other areas. Such studies may help to give a longer lead time to the yearly forecasts of recruitment required for present management purposes. For a full understanding of processes controlling stock abundance, it will be necessary to separate trends due to alteration in climate from effects due to fishing and the possible consequences of pollution. General knowledge of the way physical factors, ultimately based on climate variations, affect food supply is likely to be of major importance in understanding the role of climatic change. The heavier the fishing, which decreases the average lifetime of the fish, the greater the significance of year-to-year variability.

The other main source of mortality in early life is predation. The larvae and young fish are exposed to a wide variety of predators ranging from small invertebrate carnivores to large fish, sometimes of the same species. Study of this predation requires a knowledge of the intricacies of the food web. Changes in recruitment to certain species in the North Sea suggest links with coincident changes in other fish stocks. Such links have important consequences for multispecies management (May et al., 1979; Steele, 1979). The acquisition of these data, however, is necessarily uncontrolled and cannot cover the extremes of stock size.

We must explore the possibility of using controlled ecosystem experiments to provide information on survival with a range of larval and juvenile fish densities in relation to variable food and predator concentrations. The techniques for operating controlled ecosystems have been developed in the Marine Ecosystem Research Laboratory (at the University of Rhode Island), in the Controlled Ecosystem Population Experiments (of the National Science Foundation's International Decade of Ocean Exploration program), and in various European countries. The ability to use these systems for larval and young fish studies has been demonstrated (Gamble, in press). They may provide a means of obtaining data at population concentrations that we cannot, or dare not, observe in nature. Such experimental systems not only provide some control over the ecosystem, they also compress the size of the ecosystems, which, in nature, can cover large areas of water and long periods of time. We must take account of these scales when we wish to consider theoretical or practical studies of fisheries ecosystems.

STRUCTURE OF ECOSYSTEMS IN SPACE AND TIME

The food chains in the sea exhibit great internal diversity through all the interactions between species at the same, or at different trophic levels. Also, the organisms are dependent on the physical structure of their environment, and this, in turn, has its own complexity occurring on different scales in space and time. One way to display both the biological and physical structure is to plot three main trophic levels --P (phytoplankton), Z (zooplankton), and F (pelagic fish)--in terms of their scales of patchiness, or of migration associated with their life spans (Figure 4). This picture is simplified and idealized for heuristic motives to display the great range of time and space scales that will be involved in any attempt to cover the complete food chain P-Z-F (Steele, 1978). Further, the earlier discussion has pointed out the importance of two other areas in Figure 4. Permanent or predictable frontal systems, where fish aggregate, making them easy to catch at low population levels, can be represented by (X). Short-term and unpredictable changes over relatively large areas due to weather-induced motions have major implications for recruitment and occur in the region (Y) of Figure 4 (Walsh et al., 1978).

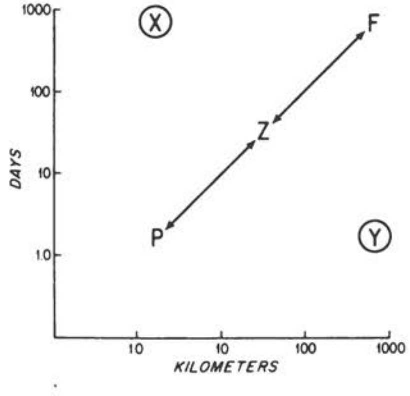

FIGURE 4 A heuristic presentation of scale relations for the food web: P (phytoplankton), Z (herbivorous zooplankton), and F (pelagic fish). Two physical processes are indicated by X, predictable fronts with small cross-front dimensions, and Y, unpredictable weather-induced effects occurring on relatively large scales.

This construction of scales and interactions is intended to display the inherent, and probably insurmountable, difficulties in producing a comprehensive representation of an ecosystem that contains all the significant biological and physical processes. The difficulties are comparable in principle with those in meteorological forecasting but significantly greater because of the biological factors. Thus any "model" must be a major simplification of the real world, omitting or parameterizing large areas of Figure 4 to produce a manageable system--conceptually as well as technically.

Similarly, any field program must select some region of Figure 4 and emphasize spatial or temporal sequences (horizontal or vertical lines on Figure 4). The fish surveys used for stock assessment are, naturally, centered on the scales at (F) in Figure 4, but these will be inappropriate for the study of recruitment processes or for observations of feeding concentrations at physical fronts.

Given these essential limitations, we can either (1) expand outward from our present techniques for fish population analyses or (2) select processes in Figure 4 that we consider critical for the fisheries aspects, and then define field programs based on these interactions. These programs can be linked with the construction of relatively simple theories, which can be regarded as metaphors that may give insight to our appreciation of the larger system. Of course, we should not ignore the potential use of other ecological concepts, niche theory, resource partitioning, bioenergetics, and optimum foraging.

THEORETICAL STUDIES

The recruitment processes demonstrate the need to study relations between fish species. Considering whole ecosystems, we believe that the basic productivity of any region sets limits on the total yield of commercial species that can be taken from that region (Steele, 1965). Thus the increase desired in size of each stock considered separately may not be achievable when the increases are added together (Andersen and Ursin, 1977). Further, certain species, such as cod, are predators on other species, such as herring or young haddock, and this imposes further limitations.

The problems of defining and quantifying the pathways of energy flow within a whole marine ecosystem form the basis for major ecological study that is an essential prelude for the longer-term management of multispecies fisheries. However, we must consider intermediate steps that utilize present knowledge for more immediate management purposes.

The basis for many present stock assessments is the theoretical model derived by Beverton and Holt (1957) for the growth and fishing mortality of single stocks. The calculations give a yield per recruit for a range of fishing effort assuming that, as in Figure 1, the catch is proportional to the effort. This theory is combined with yearly estimates of recruits about to enter the fishery. The aim is to estimate the effort, which, in the next year, will give the optimum yield--or at least tend in that direction. Thus the estimates combine year-to-year recruit data with a theoretical estimate of the long-term equilibrium yield.

We have already discussed the inadequacies of these formulations. (1) There is the need to introduce the overall energy limitations that arise when all the commercially harvested species are considered together. The sum of the equilibrium yields of each species taken separately is more than the equilibrium yield that can be sustained by the ecosystem.* (2) We must recognize that the very great temporal variability in recruitment nullifies the concept of equilibrium conditions and requires the use of "stochastic" models that take account of the risks associated with this variability. (3) The increasingly efficient technology of location and capture of fish means that catch per unit effort, for certain species with particular behavior patterns, diverges considerably from a linear relation with stock size.

All these factors, which are based on greater knowledge of the ecology of the system, require a change in the way we theorize not only for management purposes but also to increase our understanding of the ecological structure. The expansion in our recognition of these problems has coincided with the development in the techniques of computer simulation that can be applied to ecological questions. It is possible to produce very

---

*This factor has been recognized in the "two-tier" system operated for Georges Bank, where an overall quota is less than the sum of the individual species quotas.

large and complicated "models" which can include hundreds or thousands of interactions between fish species and their environment.

We have already stressed that even with very large models, we cannot hope to have a complete representation of the mixture of physics and biology. A judgment of appropriate or significant elements is required. We also need to decide on the uses of the model. Large simulations tend to be opaque, giving little, if any, insight into the processes that result in particular printed outputs.

On this basis, we foresee a progress toward larger and more complex models, but with the rate of evolution dependent on our knowledge of the underlying processes as well as on the quality and quantity of available field data. This progress can be made from several directions:

1. We have an existing need to elaborate on present single species models of fish stocks.
2. We should develop models of particular biological processes like predation which can be used as building blocks in future, larger systems.
3. We should use simple models as metaphors to explore general qualitative features of the larger systems.

Single-Species Problems

We are concerned here with the nature and the degree of interaction between one commercial fish species, its competitors, its food supply, and its physical environment. In certain cases, population fluctuations may be relatively independent of other commercial species. Examples would be the anchovy and menhaden. For such species, environmental variations may have a dominant role, and the appropriate model could be an extension of the single-species approach that takes account of highly variable recruitment and nonlinear fishing efforts in the calculation of a long-term optimum level of fishing.

Two-Species Problems

In other fisheries problems the dominant interactions may concern two species. Thus it has been proposed that cod and herring yields in the North Sea are related through the prey-predator interactions between these species (Andersen and Ursin, 1977). The potential for krill exploitation in the Antarctic (May et al., 1979) depends upon their role as food for whales (and other predators). The herring and mackerel stocks off New England appear to be interdependent and require joint management (Lett and Kohler, 1976).

These interrelations can be approached from two directions, as a combination of two single-stock models linked by specific interactions, or in terms of general theories about prey-predator or competitive relationships. A convergence between these two approaches may be a fruitful means of generalizing the former and testing the latter. Compared with "whole ecosystem" models, these proposed developments in theory are more gradual, but they may be appropriate to the present state of our knowledge and to our management capability (Larkin, 1978).

ORGANIZATION

We have noted the need for increased study of those environmental and ecological factors that relate directly to the present inadequacies in fish-stock evaluation. These studies require alternative or new approaches rather than an increase in present field work on "routine" surveys or an increase in size of computer models. Models will yield only marginal increases in information without additional, new kinds of observation. The most important observations, in terms of contemporaneous utility, are those related to ecological physiology and behavior of fish at different periods of their life cycle.

We have stressed the significance of the choice of appropriate space and time scales for these observations. We have emphasized the importance of the intermediate links in the food chain (the Z of Figure 4), which not only supply the energy to the higher trophic levels but through their variability in space and time (at X and Y of Figure 4) determine the corresponding variations in fish distributions.

Our research needs to accentuate the "diagonal" links between the intermediate levels of the food chain (Z) and certain scales of physical phenomena (X and Y). This will require a different organization of our research capabilities. At present, much of our work tends to be polarized around studies based on primary production (P) or on general fish-stock abundance (F). There are good historical reasons for this division arising from limitations in sampling methods. However, new techniques for physical and biological sampling are enabling us to overcome these limitations. But the polarity is also due to the way in which our research programs are structured and funded. The evolution of organizations that consider their roles to be centered on the lower and the higher trophic levels, respectively, has created a hiatus in the very area where most study appears to be required.

Further, there are similar problems in linking the ecological components with the corresponding social and political aspects of the management issues (Rothschild and Forney, 1979). Once we accept the concept of multispecies management, we are faced with the question, what (and how) do we optimize? We cannot answer this entirely in ecological terms but must introduce social and economic values such as return on investment. We must not let an emphasis on ecological aspects result in a failure to cope effectively with the conflict-of-interest questions that arise in many marine fisheries.

On this basis we need to develop ways of bridging the gap between the present institutions concerned with "marine ecology" and those concerned with "fishery management" as these are currently defined. A reallocation of funds is not the sole answer, since this could perpetuate the dichotomy, albeit with a different balance. But funds do need to be used to stimulate the required collaboration. Further, such funding must have a relatively long-term assurance so that appropriate programs and scientists will have time to grow and adapt to the joint endeavors.

The means for ensuring development of this middle ground may differ between institutes, regions, or seaboards. The scale of the problems, however, requires something more than an increase in individual contacts. The initiatives must begin at the agency or foundation level, but it would be simplistic to argue that we need only a reallocation of funds. A process that can develop ideas common to ecology and fisheries science will require the involvement of the scientific societies, the universities, the international commissions, and the fisheries laboratories. We hope this brief report of a short meeting may help stimulate this process.

SUMMARY

1. Fisheries ecology combines questions of great scientific interest with problems of significant social import.

2. Recent experience in stock assessment indicates the need to introduce new theoretical concepts and experimental techniques that will increase the ecological information relevant to management.

3. These components must be related to corresponding social and economic aspects, which become an integral part of assessment on a multispecies basis.

4. The factors controlling recruitment emerge as crucial elements dependent not only on physical conditions but also on interrelations within the food web.

5. In terms of theory, we need to emphasize the development and utility of models intermediate between single species theories and very large ecosystem simulations.

6. Correspondingly, for field and experimental work, we would emphasize the study of processes, particularly those at space and time scales intermediate between the study of fine structure of phytoplankton communties and the large-scale fish stock surveys.

7. The emphasis on research in these intermediate areas relates to the need to develop attitudes and long-term plans that can bring together the diverse interests and capabilities required for such studies, interests at present divided by organizational barriers and funding criteria.

REFERENCES

Andersen, K. P., and E. Ursin, 1977. A multispecies extension to the Beverton and Holt theory of fishing, with accounts of phosphorous circulation and primary production. Meddr Danm. Fisk-og Havunders, N.S. 7, 319-435.

Beddington, J. R., and R. M. May, 1977. Harvesting natural populations in a randomly fluctuating environment. Science 197, 463-465.

Beverton, R. J. H., and S. J. Holt, 1957. On the dynamics of exploited fish populations. Fish. Invest. Lond. Ser. 2, 19, 533 pp.

Clark, C. W., 1976. Mathematical Bioeconomics. Wiley, New York.

Cushing, D. H., 1975. Marine Ecology and Fisheries. Cambridge University Press, New York. 278 pp.

Gamble, J. C., P. M. MacLachlan, N. T. Nicoll, and I. G. Baxter, in press. Larval growth and feeding of herring (Clupea harengus L.). ICES Symposium on Early Life History of Fishes, April 1979, Woods Hole, Massachusetts.

Gulland, J. A., 1977. The stability of fish stocks. J. Cons. Int. Explor. Mer 37(3), 199-204.

Larkin, P. A., 1978. Fisheries management--an essay for ecologists. Ann. Rev. Ecol. Syst. 9, 57-73.

Lasker, R., 1975. Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. Fish. Bull., U.S. 73, 453-462.

Lasker, R., 1978. The relation between oceanographic conditions and larval anchovy food in the California Current: identification of factors contributing to recruitment failure. Rapp. P.-v. Reun. Cons. Int. Explor. Mer 173, 212-230.

Lett, P. F., and A. C. Kohler, 1976. Recruitment: a problem of multispecies interaction and environmental perturbation, with special reference to Gulf of St. Lawrence Atlantic herring (Clupea harengus harengus). J. Fish. Res. Bd. Can. 33, 1353-1371.

May, R. M., J. R. Beddington, C. W. Clark, S. J. Holt, and R. W. Laws, 1979. Management of multispecies fisheries. Science 205, 267-277.

Paloheimo, J. E., and L. M. Dickie, 1964. Abundance and fishing success. Rapp. P.-v. Reun. Cons. Int. Explor. Mer 155, 152-163.

Rothschild, B. J., and J. L. Forney, 1979. The symposium summarized. In *Predator-Prey Systems in Fisheries Management*, R. H. Stroud and H. Clepper, eds. Sport Fishing Institute, Washington, D.C., 504 pp.

Saville, A., and R. S. Bailey, in press. The assessment and management of the herring stocks in the North Sea and to the west of Scotland. *ICES Symposium on the Biological Basis of Pelagic Fish Stock Management (1978)*, A. Saville, ed., Document No. 5.

Steele, J. H., 1965. Some problems in the study of marine resources. *Spec. Publ. Int. Comm. Northwest Atlantic Fish. No.* 6, 463-476.

Steele, J. H., 1978. Some comments on plankton patches. In *Spatial Pattern in Plankton Communities*, J. H. Steele, ed., Plenum Press, New York, pp. 1-20.

Steele, J. H., 1979. Some problems in the management of marine resources. In *Applied Biology*, Vol. IV, T. H. Coaker, ed., Academic Press, London, pp. 103-140.

Ulltang, O., in press. Factors of pelagic fish stocks which affect their reaction to exploitation and require a new approach to their assessment and management. *ICES Symposium on the Biological Basis of Pelagic Fish Stock Management*, A. Saville, ed., Document No. 34.

Walsh, J. J., T. E. Whitledge, F. W. Barnevik, C. D. Wirick, S. O. Howe, W. E. Esaias, and J. T. Scott, 1978. Wind events and food chain dynamics within the New York Bight. *Limnol*. *Oceanog*. *23*, 659-683.