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REPORT OF THE FISHERIES ECOLOGY MEETING
JUNE 8-11, 1981

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TECHNICAL REPORT

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FISHERIES ECOLOGY MEETING

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

June 8-11, 1981

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Woods Hole, Massachusetts

ABSTRACT

An Ad Hoc Group of the Ocean Sciences Board of the Assembly of Mathematical and Physical Sciences, National Research Council, was formed in 1980 to study the constraints that impede advances in the understanding of fisheries ecology. In order to continue the discussions of the Ad Hoc Group and plan strategies or actions that might be taken to resolve the critical questions of fisheries ecology, the Woods Hole Oceanographic Institution and the National Oceanic and Atmospheric Administration sponsored a Fisheries Ecology Meeting at Woods Hole, June 8-11, 1981. The Woods Hole meeting addressed various topics related to a) fisheries ecology: the point of view of management, b) regional experience, c) fish and their environment, d) population dynamics, e) socioeconomics, f) the national environment for conducting fisheries ecology research, and g) actions that need to be undertaken.

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STEERING GROUP

Fisheries Ecology Meeting
June 8-11, 1981

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SUMMARY AND ACTIONS

The meeting reached a consensus on the following points:

1. Large and often unexpected fluctuations in fish population abundance are commonplace.
2. Understanding, predicting, and perhaps, to some extent, controlling these fluctuations is one of the most important problems facing fishery managers.
3. While important scientific advances have been made in understanding the relative roles of "on the average" behavior of fishing mortality, stock, size and recruitment, there remain substantial critical problems in forecasting year-to-year changes in stock size and, in particular, the dynamic interactions among species.
4. Information on recruitment and the dynamic interactions among species will contribute a basis for managing multiple-species fisheries, particularly in those circumstances where it might be desirable, as a management technique, to modify the species composition of the catch.

5. Advances will require the development of new paradigms and concepts which take into account, in a holistic fashion, the critical elements of fish stock variability.
6. The development of new paradigms and concepts will require an increase in the store of observations on variations in fish production as they relate to interactions among stocks, larval and juvenile food and predation on these stages, and micro- and fine-scale variations in the physics and chemistry of the oceans.
7. A review and assessment of this material would lead to the specification and design of large experiments (e.g. east and Gulf coast, west coast) to gather the appropriate data. The experiments would coordinate field studies involving both university and government scientists and might be funded by a consortium of agencies.
8. These experiments should be closely coupled in one conceptual package to consider hypotheses relative to causal mechanisms associated with stock fluctuations.

9. The participants in the meeting believed that the planning and conduct of such experiments would focus the interest of managers, fisheries scientists, and academia on real-world problems and so provide the best context to further our knowledge regarding the ecological aspects of fishery management.
10. Further discussions to implement these plans are in progress.

FISHERIES ECOLOGY AND FISHERIES MANAGEMENT

By the late 1970s most coastal states extended their fishery jurisdiction to 200 miles from their coastline. The extensions of jurisdiction enabled the coastal states to exert fishery management authority where they previously had none. With management authority, the coastal states could make fishery management decisions to "optimize" economic and social benefits from the catch, increasing the importance and value of fishery management.

The quality of fishery management decisions, however, depends upon a number of factors. One of the more important factors is the amount of information available to the decision maker. It is obvious that decisions made in a scarce information setting are less likely to approach optimality than when information is abundant. The quantity and quality of information utilized in the management or decision making process is critical. The dynamics of the fishery stocks is an important component of management information. Many fishery management decisions require information on the population dynamics of fish. Critical questions arise, such as, why do stocks fluctuate in abundance and can these fluctuations be forecast? How do the various stocks interact with one another and to what extent is the interaction affected by fishing? How much fishing effort will be required to optimize the catch? Is it possible to rehabilitate depleted stocks? What is the effect of pollution on stocks? Can environmental variables be used to forecast changes in abundance and distribution of fish stocks?

These questions are difficult to answer. The difficulty does not arise from the quality of population dynamics research conducted during the past several decades, but rather from the profound complexity of the problems that have been studied. Fortunately, in recent years, a number of important studies have lent new insights into these problems.

Examples of syntheses may be found in the study of fine- and micro-scale water motion and particles (e.g. Steele, 1978); fish larvae (e.g. Lasker and Sherman, in press); prey-predator interactions (e.g. Stroud and Clepper, 1979), and detailed studies of particular important fishery areas such as the North Sea (e.g. Hempel, 1978).

While these syntheses represent significant advances, it is generally recognized that accelerating the acquisition of new knowledge will require collection of new kinds of information and the development of new concepts and paradigms that are specifically oriented toward drawing together the information requirements of management and fisheries ecology research. Fortunately, it is now possible, given broad advances in the field of oceanography and an enhanced appreciation of the requirements of fishery management, to enhance the utility of fisheries ecology to management through the development of large scale experiments specifically designed to provide information on the ecological effects of fishing, pollution, and natural phenomena on fish populations abundance.

Taking these factors into consideration and recognizing the scientific and practical importance of fisheries ecology, the Ocean Sciences Board of the Assembly of Mathematical and Physical Sciences,

National Research Council formed an Ad Hoc Group to study the constraints that impede advances in the understanding of fisheries ecology.* In addition to discussing questions of technical importance and stressing the joint fundamental and practical importance of fisheries ecology, the Ad Hoc Group, which met in Princeton, suggested that the development of a common research strategy (that is, an agreement on critical problems and methods for their solution) among the academic and government research community could do much to accelerate progress in this important area.

In order to continue the discussions of the Ad Hoc Group and plan strategies or actions that might be taken to resolve the critical questions of fisheries ecology, the Woods Hole Oceanographic Institution and NOAA sponsored a Fisheries Ecology Meeting at Woods Hole, June 8-11, 1981. The Woods Hole meeting addressed various topics related to a) fisheries ecology: the point of view of management, b) regional experience, c) fish and their environment, d) population dynamics, e) socioeconomics, f) the national environment for conducting fisheries ecology research, and g) actions that need to be undertaken. This report summarizes the discussion of each of these topics.

*Fisheries Ecology. Some Constraints That Impede Advances in Our Understanding. An Ad Hoc Group of the Ocean Sciences Board. Assembly of Mathematical and Physical Sciences. National Research Council. National Academy of Sciences, Washington, D.C. 1980. 16 p.

FISHERIES ECOLOGY: THE POINT OF VIEW OF MANAGEMENT

The basic function of fisheries management is to allocate fishery resources among various competing users and over specific time intervals. The manager is thus faced with a variety of decisions regarding, for example, the optimal amount of fishing effort, the proportion of fishing effort that might be distributed between large boats or small boats, whether there should be a moratorium on fishing a depleted stock to allow the stock to rebuild itself to former levels of abundance, or the length of a fishing season. The quality of these fishery management allocational decisions can be measured in terms of net benefits that result from the decisions. These net benefits may be related to economic benefits derived from the fishery, to conservation, to fishing community welfare, and to benefits to the fishing industry.

In order to maximize benefits, it is critical that fishery managers are able to understand and forecast the variability of fishery stocks. A number of examples of variability were cited, e.g., the dramatic collapse of the Peruvian anchoveta, the explosion of the Japanese sardine, the increase in cod-like fish and the decrease in herring in the North Sea, and the considerable fluctuations in abundance of various Georges Bank stocks. The variability is attributable to either natural causes, fishing, or pollution. There is, however, a growing awareness that attributing economically important fish stock fluctuations to natural causes, overfishing, or pollution is probably too simplistic, particularly when these fluctuations are considered in the context of a more realistic multiple species setting.

One manager* viewed the problem as follows:

...In recent years, the degree or significance of natural variations in abundance has largely been overlooked. And yet even though these variations have not entered seriously into fish managers thinking about the status of the stocks, I suspect that fish managers have the feeling the natural variations may be the explanation of at least some of the changes in abundance they see, independent of fluctuations resulting from fishing activity. Even so, our knowledge of the nature, degree, or causes of natural variability is generally anecdotal and hardly to be considered as a basis of management action when compared with the quantitative information routinely offered on the level of fishing mortality and its impact. Given this situation, the manager may restrict fishing effort needlessly - with all the consequences of economic impact, unnecessary interference into fishing patterns, and further erosion of the credibility of management.

An understanding of fishery ecology - or how the system works - would provide the manager with a most powerful asset; a substantial basis for forecasting of fish abundance or at least understanding the probability and nature of natural stock fluctuations.

A better understanding of the way the system works is clearly needed. The recent emphasis on quantitative assessments as the basic management tool has not been very helpful to managers because assessments contain little predictive content... Perhaps a more qualitative understanding - which I believe is possible - of the characteristic functions of the system would be more useful for managers and less expensive. A manager frequently is not primarily concerned with an accurate estimate of the abundance of a stock. He is more likely concerned with a probable trend of relative abundance.

The recent experience in New England with quota management for yellowtail flounder, herring, cod, and haddock - all based on conventional, single-species assessments [see page 15 of this report] - undoubtedly has resulted in a great loss of confidence by the industry in this approach to fish conservation. In the near future we can only expect very substantial industry skepticism about further management efforts of this kind - skepticism which probably will make similar management efforts very difficult at best, and without the essential widespread industry support. In this sense, fishery management has suffered

*Spencer Apollonio, Commissioner, Department of Marine Resources, State House, Augusta, Maine 04333.

substantially even though the need for effective management grows. The greatest need for management now, at least in New England, is to reestablish its credibility with the industry. Fishery ecology can contribute to that process. It holds the potential of analyzing the consequences of multi-species interactions that result from mixed trawl fisheries and from disproportional mortality among species of varying commercial value. It has the potential for understanding the inherent variability of various kinds of species, and the influence of environmental factors on those variations, and it has the potential of providing a predictive capability - at least in a qualitative but very useful sense - for the probable trends of relative abundance of fish species - or whether such predictions are possible for certain species. It is just as important for the industry - and conceivable as a management option - to know which species are not amenable to forecasts of trends in relative abundance.

Even grossly qualitative forecasts may be most useful management tools and serve to reestablish belief in the management process. For example, the probably valid prediction that increased fishing effort will lead to increasingly variable stock abundance can be tested by the industry itself and thus enhance the credibility and thus the usefulness of management. Similarly, by taking full cognizance of the biological characteristics of the species, it should be possible to state which species are legitimate candidates for efforts at stock stabilization, and which are inherently highly variable. The industry believes that the latter is true of many species and it is probably right on at least some of them. Current management practice does not seem to acknowledge the probability - but instead seems to promise sustained yield for all species, regardless of their biological peculiarities, if only the proper regulations are promulgated. It is almost as though managers consider all species biologically equivalent and that the species characteristics are without management significance...

...If a manager, concerned with stocks, people, economics, and regulation, is to meet his responsibilities, he must have advice on how the system works. Species cannot be managed in isolation, just as many of them are not caught in isolation. The manager must understand interspecific relations if he is to manage interrelated fisheries. He must understand the nature of normal variations in abundance if he is to judge which species can be managed and at what cost. He must understand how the system operates if there is to be any hope of forecasting stock abundance. These are the capabilities we hope to attain through fisheries ecology.

Thus, the perception of fisheries management requirements for ecological research has changed since the late 1960s and early 1970s. In the late 1960s and early 1970s, fisheries managers were primarily concerned with specific questions concerning the relation between catch and fishing effort, the relation between stock and recruitment, and the relation between yield-per-recruit and age-specific fishing mortality. While contemporary managers continue to be concerned with these concepts, they have broadened their concerns toward a need to understand and, therefore, identify and predict the mechanisms that cause departures from these more or less standard approaches.

REGIONAL EXPERIENCE PAPERS

As a survey of fishery ecology work being conducted at various federal laboratories, reports were presented by representatives of the National Marine Fisheries Service (NMFS): the Northwest and Alaska Fisheries Center, the Southwest Fisheries Center, the Southeast Fisheries Center, and the Northeast Fisheries Center.

Work at the Northwest and Alaska Fisheries Center involved major domestic fisheries for salmon, king crab, halibut, tanner crab, herring, and shrimp, and minor fisheries for sablefish, groundfish, and scallops. Two major cooperative programs were described. The first was the BLM-NOAA/OCSEAP*. This program is an environmental assessment which

*Bureau of Land Management-National Oceanic and Atmospheric Administration/Outer Continental Shelf Environmental Assessment Program

been conducted since 1975 and represents an investment of more than \$150 million. The NMFS contribution is mostly oriented toward developing an Alaska waters bibliography for the program. A second major interdisciplinary program conducted in association with the Northwest and Alaska Fisheries Center is the National Science Foundation-supported Processes and Resources of the Bering Sea (PROBES). PROBES has focused on studying energetic relationships of Alaska pollock. Work on "big systems models" such as the Dynamic Numerical Ecosystem model (DYNUMES) was described, and some emphasis was placed on models that were oriented toward working backward from higher levels in the food chain rather than working forward from primary production.

The Southwest Fisheries Center reported on their work on the pelagic fisheries of eastern boundary currents. The extreme variability of these stocks and changes in species composition were stressed. Examples were given of the replacement of the California sardine stock by a larger northern anchovy stock along with an increased Pacific mackerel stock. Work at the Southwest Center is oriented toward studying the requirements of larval fishes both in the laboratory and in the field and relating these to various oceanographic indices.

Discussions by the Southeast Fisheries Center concentrated on the interrelationships between shrimp and groundfish. In very round numbers, the catch of groundfish is about .7 million tons, but the catch of shrimp is about .1 million tons. Most of the groundfish are discarded. If the groundfish could be utilized then they would be a valuable addition to the fisheries of the region. It is not known,

however, whether the utilization of groundfish would negatively affect the valuable shrimp stocks. This is a critical ecological question. Detailed models were presented which described the interrelationship between groundfish and shrimp.

The Northeast Center reported on their Fisheries Ecosystem Study. The study covers a large part of the continental shelf from the Gulf of Maine to Cape Hatteras. The fish biomass in this region declined by 50 percent from 1968 to 1975. Most of this decline probably resulted from fishing. Various critical questions are being addressed (e.g., Does the reduction in stocks of important predator species, herring, mackerel, cod, haddock, hake, and others release secondary production to be consumed by short-lived, fast-growing, smaller, less desirable species? What is the probability that over-exploited species can be returned to their former levels of abundance?).

The collection and analysis of Northeast fisheries data has been done primarily by NMFS, in contrast to the Northwest, where states had the primary role for domestic fisheries. The pervasive effect of foreign fisheries, beginning in 1960, rapidly affected the whole of the fish stocks and led to studies of the total fisheries biomass. The International Council of North Atlantic Fisheries (ICNAF), in 1973, adopted a total biomass quota regulation. Determination of the total potential fisheries production led to studies of interspecific relations, and to studies of the production process in the entire ecosystem.

The extensive fishery and routine surveys have provided observations on the high degree of variability in resource abundance, reflecting a high degree of variability in recruitment. The causes of this variability are a prime focus of Northeast Center studies. Studies of the effects of warm core rings and other "frontal" phenomena are now being pursued. Satellite images are critically important for these studies.

FISH AND THEIR ENVIRONMENT

A central problem in the study of fish and their environment is the identification and measurement of the complex of mechanisms that cause fish population abundance to fluctuate. Critical in the identification of causal variables is the separation of phenomena that actually drive fish stock fluctuations from those that are merely correlated with fish stock abundance. Specific methodology for such a separation is not yet obvious; however, it is becoming more and more evident that the identification of actual causal mechanisms will require fundamental studies oriented toward studying specific mechanisms rather than correlative empirical studies.

Various related topics were discussed. For example, it was pointed out that correlative studies are particularly difficult because they are generally based on a single data point per year. Thus, it is necessary to observe the relationship between fish stock abundance and the environmental variable for a number of years. In addition, an assumption implicit in this methodology is that the environment remains essentially the same over the time period of the study.

Comparative studies also require relatively strong assumptions. This is because, while it is easy to compare fluctuations in stock abundance in two locations, it is much more difficult to compare the mechanisms that produce changes in abundance, particularly if the mechanisms are complex and not well-identified.

More fruitful approaches appeared to involve relating biological variables to physical oceanographic features. Various examples were discussed, such as the interrelationship between qualitative and quantitative aspects of the injection of nutrients into the photic zone and the temporal-spatial distribution of mid-ocean eddies and upwelling. Another example given was the study of the relation between production, critical depth, and North Sea plaice recruitment. The study of the coherence of patches of fish eggs, larvae, predators on larvae, and larval food relative to various scales of turbulence seemed to be particularly rewarding.

The need for systematic examination of recruitment mechanisms was stressed. One such examination could begin by considering the twelve cardinal questions of fisheries ecology, namely the interactions between heat, light, and motion as physical variables, and egg production, larval food, predation on larvae, and the genetic constituency of the stock as biological variables (Rothschild, 1981). Such a systematic examination could obviate the concern that studies of the physical processes and of the biological processes were tending to proceed more or less separately and that there were few cross-disciplinary interactions. A consensus of the meeting felt that it was important to

identify and extend knowledge on the physical and biological interactions. Such holistic studies would then lead the way to more efficient specification of data requirements such as, perhaps, distributions of particles of certain size in the surface layer and synoptic measurements of surface currents and wind stress.

In summary, the discussion of fish and their environment was dominated by a recognition of the often extreme variability in fish stocks, that understanding of the causal mechanisms associated with these variabilities was primitive at best, and that there was a reasonable likelihood that new insights could be developed through an interdisciplinary fertilization between biological and physical oceanography. Constraints in obtaining new knowledge could be greatly reduced by joint efforts among physical and biological oceanographers as well as fishery biologists.

POPULATION DYNAMICS

The population dynamics discussion focused on the nature of population dynamics questions that are frequently posed by fishery managers. The response to these questions depends upon whether they are in a context of a single- or multiple-species setting, and whether they relate to long or short time horizons.

For management questions that relate to events that might occur over a short time horizon of two or three years, there are a number of models and methods which can be applied. For example, the cohort

analysis techniques can be used to estimate past population size and fishing mortality rate. When cohort analysis is combined with information on stock abundance which may be gleaned from either survey data or catch-per-unit of effort data, estimates of contemporary population size and fishing mortality can be made. The estimation of fishing and natural mortality rates and growth then enables computations of the yield-per-recruit, a technique which indicates the optimal value of size-specific fishing mortality.

When fishery management questions extend to time intervals of greater than several years, the question of recruitment becomes particularly important. Traditionally, most recruitment studies examine the relationship between recruitment and stock size. However, the relationship is usually quite variable. The sources of this variability are not generally known. Some of the variability may owe to measurement error, while other components may owe to environmental variables operating as density independent factors. While there have been numerous attempts to correlate environmental variables with recruitment, most of these have not been useful for forecasting.

Biomass production is a major concern in fishery population dynamics. The magnitude of recruitment is critical to understanding the productivity of a stock. Recruitment is therefore an important, although sometimes implicit, component of production models. Production models are based on the relationship between the change in stock size and stock size. Setting the change in stock size to zero gives the equilibrium yield for any particular stock size. The maximum

equilibrium yield is, of course, the maximum sustained yield used in many fisheries management settings. The maximum sustained yield concept has been criticized for a number of reasons but most of these have either been indicated by the developers of the maximum sustained yield models or occur when there is an attempt to utilize the models in a more general way than that which was originally contemplated.

One of the fascinating components of the discussion of population dynamics involves the possible genetic effects of exploitation. There is a reasonable chance for exploitation to affect the genetic constituency of the stock in circumstances where fishing removes some component of the population in a non-random manner. For example, skipjack tuna that are taken in the eastern tropical Pacific are spawned in the central Pacific. They then migrate to the eastern Pacific, spend a short time there, and finally emigrate from the eastern tropical Pacific to spawn in the central Pacific. Not all skipjack, however, migrate to the eastern Pacific. There is likely to be genetic selection against those fish which migrate to the eastern Pacific.

There was considerable discussion of multiple-species problems. The basic conclusion, however, was that there was little empirical knowledge on how stocks interact with one another and therefore the effect of fishing one stock, say, on another stock was difficult to predict. It became obvious that trophic relationships among stocks would need a much clearer formulation before much work could advance in the important multiple-stock population dynamics. Put another way, it is relatively simple to generalize mathematically single-species models

to the multiple-species case. However, it is difficult to obtain the observations to estimate the parameters in the multiple-species setting.

An important distinction was made contrasting (in a multiple-species setting) single-species stock assessments with single-species management. Single-species stock assessments in the multiple-species setting can often be useful, particularly in the short range, for determining the effects of fishing on the stocks. Single-species management in a multiple-species setting which, however, attempts to manage each species as if it were independent of other species, can cause considerable difficulty because, in the real-world fisheries, management decisions affecting one species often have a critical impact on management decisions directed toward an associated species.

The discussion concluded with the observation that the problem of stock fluctuation, particularly as it is affected by survival and mortality of early life history stages, remains a critical issue in fisheries science and indeed this problem seriously affects the quality of management advice. Traditional population dynamics models have been extended as far as possible. New advances will require an improved understanding of fisheries ecology, particularly in the areas of recruitment and multiple-species interactions.

SOCIOECONOMICS

The discussion of socioeconomics developed the contextual basis for fisheries ecology. Several areas of concern were highlighted. The general subject of fisheries ecology and economics was discussed initially. The goal of economic efficiency in fishery management was stressed. While economic efficiency tends to be elusive in practice, there appear to be several approaches that might facilitate its attainment. These include orienting management to be more responsive to market mechanisms, the presentation of management options rather than single alternatives to managers, and recognizing the importance of using, in addition to "experts", the public forum to gain insights to optimal socioeconomic objectives. With respect to research in fisheries ecology and economics, it was observed that funding for bioeconomic research was limited. Particular research needs involved the empirical study of fishermen's behavior and the cost effectiveness and economic efficiency implications of alternative management strategies.

The definition and attainment of optimum yield are important socioeconomic issues. Optimum yield, while often difficult to define operationally in a single-species setting, is even more difficult to define in a more realistic multiple-species setting. This situation motivates particular research requirements in terms of multiple-species production models, the trophodynamics of fish populations, and a more realistic depiction and theoretical analysis of both fisheries and markets in a multiple-species setting.

The increased importance of fishery management suggests more critical study of the most cost effective ways of developing scientific and management information. Critical among these are the analysis and development of the most cost effective methods of monitoring (e.g., acoustics versus egg and larval surveys), the best mix of monitoring and fundamental studies, and assessing the production of information by fisheries ecologists.

Finally, the highly stochastic nature of fish populations and associated economic variables suggest an orientation of future research toward explicit investigations of fish stock and economic variability. This means that investigations will need to consider not only average values, but variances and distributions as well. In addition, the effect of management per se on uncertainty needs to be considered along with fishermen's response to uncertainty. In particular, distinction needs to be made among management approaches which ignore uncertainty, which simply recognize its existence, and those which both recognize the existence of uncertainty and develop adaptive strategies to either minimize or take advantage of its effects.

NATIONAL ENVIRONMENT FOR CONDUCTING FISHERIES ECOLOGY RESEARCH

Most of the discussions highlighted the complexity and magnitude of fisheries ecology problems. The complexity of fisheries oceanography underlined the possibility that one-investigator approaches may be

infeasible, stressing the need for coordinated efforts to focus upon the critical problems of variability in recruitment and fish stock productivity. The requirement for at least some large scale activities suggested an examination of the national environment for conducting fisheries ecology research to determine whether it was conducive to the kinds of efforts that would be necessary to advance fisheries ecology research or, on the other hand, whether the environment tended to constrain research to studies which may not have adequate support or which would not be focused on important questions in fisheries ecology.

The environment for fisheries ecology research seems to be less than optimal in that conceptual development and predictive ability appear to be developing less rapidly than would be the case if there was more focused support for fisheries ecology and/or if there was greater collaboration among those engaged in the research.

Possible explanations for the current situation include the priority assigned by NMFS relative to the priority for fundamental fisheries ecology research, the divergence between oceanographers and fishery scientists, and funding practices of NMFS, NSF and other relevant agencies.

Of the several hundred million dollars spent annually on fishery and oceanographic research, less than ten percent appears to be spent on research directly related to fishery ecology, that is, to research oriented toward understanding causal mechanisms of fish stock fluctuation. That proportion of the ten percent devoted to ecology of the early life history of fish appears to be much less. There is no

national strategy whereby this allocation of effort is determined. It is not clear why NMFS allocates less support to such research than might appear desirable. Furthermore, NSF finds it difficult to support research involving species of commercial interest without respect to whether or not the research is fundamental or basic in nature. Other ocean-related agencies support research only within the constraints of their generally narrow missions, making it difficult to support the study of fish-ocean interactions as a holistic problem.

Fundamental studies of fish production and variability in fish stocks should be of interest to both academic and federal scientists who should be encouraged to develop new approaches and paradigms. There are a number of instances where academic fisheries research has avoided the critical issues of biological oceanography, focusing on freshwater problems and aquaculture. In some instances, academic projects were small, involving a faculty member and a few graduate students, and the selection of problems was influenced by sponsoring bodies. The university system, at least in fisheries, was not conducive to development of large, interdisciplinary cooperative teams, an approach that requires much additional effort.

More generally, biological oceanographers have not engaged in large "experiments" in the way that physical oceanographers have. During the International Decade of Ocean Exploration (IDOE), there were only two such projects, the Controlled Ecosystem Population Experiment (CEPEX) and the Coastal Upwelling Ecosystem Analysis (CUEA), but several are now under development. In fishery ecology, it is possible that such

large scale approaches may be needed to achieve the desired "quantum jump" in understanding. These will require long term commitments in funds to be successfully implemented.

In order to obtain insights into the environment for fisheries ecology research in other countries, such as Canada and Europe, experiences in these countries were discussed. The Marine Ecology Laboratory (MEL) in Canada is devoted to "targeted basic research" in fishery ecology. This function is organizationally separated from those of stock assessment, resource survey, and quota recommendations, and the MEL staff is free to concentrate on the development of new approaches. Such a "think tank" is vulnerable to funding pressures when more directly applied work is seen as meriting higher priority, but it is defended as an essential counterpart to the management body, a unit that can focus on the longer term scientific problems of management. In Canada, the agency that supports academic research, the National Scientific and Engineering Research Council, will fund projects of hypothesis testing that involve species of commercial interest. In Europe, oceanography grew out of fishery research, and biological oceanography has tended to drive much of physical oceanography. Interaction and communication among physicists, biological oceanographers, and fishery scientists is much closer, although it does not appear that fishery management has been any more successful because of this. At Lowestoft and Aberdeen, government fishery laboratories in England and Scotland, there is a broad spectrum of research including that in fishery ecology, but that which is long term in perspective is always vulnerable to more urgent demands.

Possible ways to improve the U.S. national environment for research in fishery ecology include reexamining the priority assigned to supporting such research, promoting the convergence of oceanography and fishery science, promoting communication among interested scientists and coordination of activities, and stimulating the production of scientists educated in these problems. Indeed, the problems of fishery ecology for targeted basic research and the best method for promoting and protecting such research must be given careful thought.

ACTIONS

The meeting concluded that the most critical problem facing fisheries management and fisheries ecology is the need to develop an understanding of the mechanisms that cause fish populations to fluctuate in abundance. The meeting observed that, while important advances have been made in this area in the past decade, the level of understanding had not in general reached the stage where fish stock fluctuations could actually be forecast. The meeting recognized that the current state of knowledge is limited by existing concepts and that a rapid acceleration of knowledge in the area of fish stock variability would require the development of new paradigms and concepts which would take into account in a holistic fashion all of the critical elements of fish stock variability.

The meeting felt that it was essential to develop new concepts. In this regard, there was a feeling that existing modeling efforts have

reached a point of declining marginal productivity and that this condition could be reversed by increasing the store of observational material on variations in fish production, particularly as they relate to the interactions among stock size, larval food, larval predation, and the physics and chemistry of the ocean, particularly at the micro- and fine-scales that seem so important to the success and failure of larval survival, and hence the success and failure of year classes. A carefully designed observational program would thus lend new data and observations of new interrelationships to the development of new models which would in fact be the embodiment of a new conceptual framework for the understanding of fish stock variability.

The meeting suggested a process for increasing the information base on fish stock variability, hence stimulating conceptual development. To begin, it is necessary to review and assess the state of knowledge regarding fish stock variability. While there are a number of reviews of fish stock variability, there are no assessments that critically examine the problem lending insights, not only to present lacunae in knowledge, but which identify as well the critical directions that need to be taken in the next decade to materially advance ability to predict stock fluctuations and rigorously sort out natural, fishing, and pollutional causes for variability.

Such a review and assessment would lead to the specification and design of large experiments, e.g., located on the east and Gulf coasts and west coast, which would actually gather the appropriate data. The experiments would be characterized by coordinated field studies which

might be funded by a consortium of agencies and involve both university and government scientists.

It was stressed that the east and west coast experiments should be very closely coupled to the review and a critical assessment. Thus, each experiment, or the two experiments in concert, should be based upon an "intellectual package" which is rich in its consideration of hypotheses regarding causal mechanisms for stock fluctuations and an experimental design that has an excellent probability for resolving the issues raised by the hypotheses.

The meeting felt that, rather than consider the problem of "the national environment" in the abstract, the conduct of the above experiments would pinpoint the constraints in the national environment to a real world setting where they could be dealt with in the context of the mutual goodwill and desire to further our knowledge regarding the ecological aspects of fishery management.

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