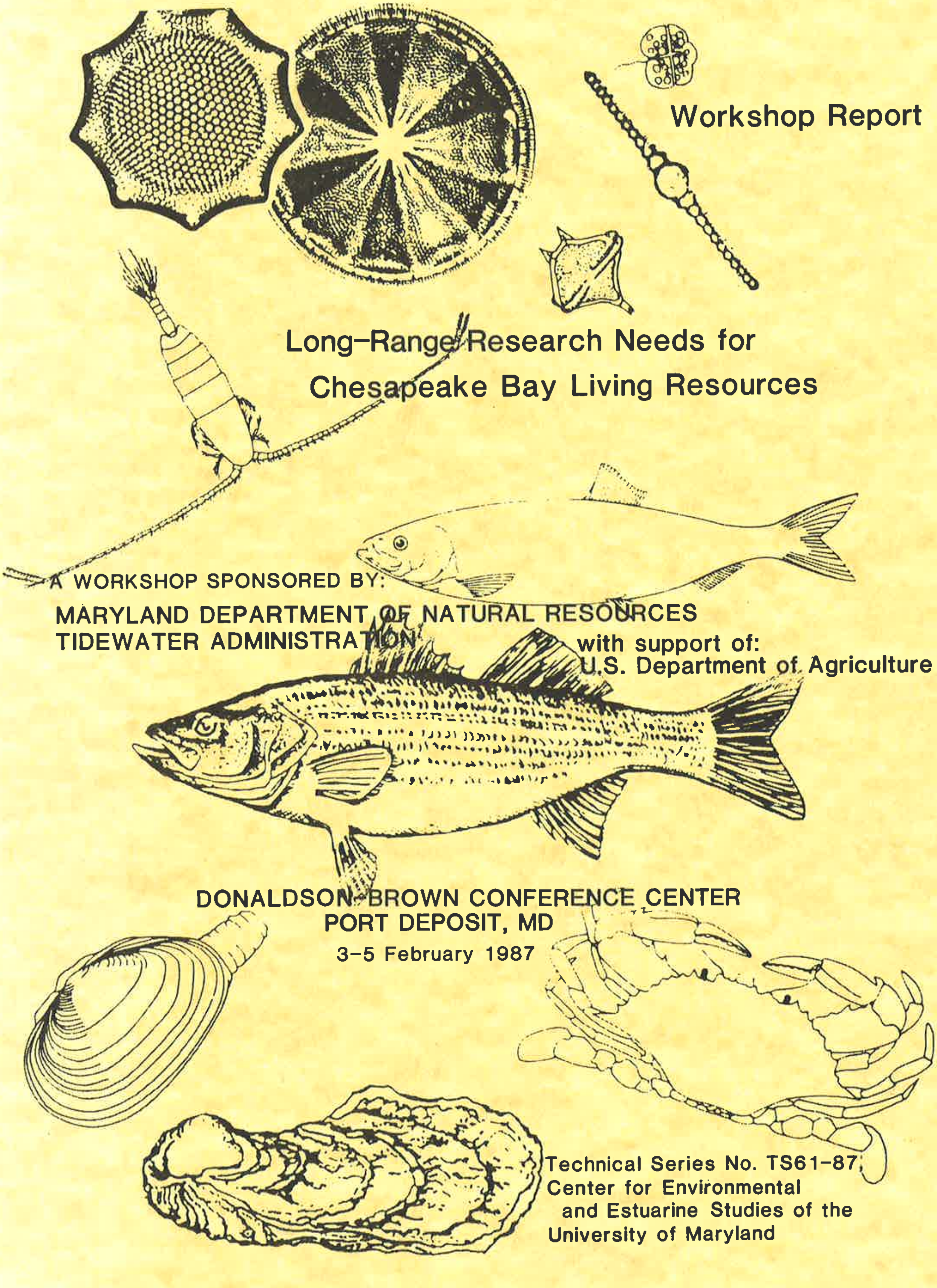

Workshop Report

Long-Range Research Needs for Chesapeake Bay Living Resources

A WORKSHOP SPONSORED BY:

MARYLAND DEPARTMENT OF NATURAL RESOURCES
TIDEWATER ADMINISTRATION

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3-5 February 1987

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Center for Environmental and Estuarine Studies of the University of Maryland

LONG-RANGE RESEARCH NEEDS FOR CHESAPEAKE BAY LIVING RESOURCES

Workshop Report

June, 1987

Sponsored by: Maryland Department of Natural Resources
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With support of: U.S. Department of Agriculture

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PREFACE

The wellbeing of living resources in Chesapeake Bay is dependent on the complex interactions among habitat quality, effects of fishing, species interactions and bioeconomic influences. The Bay can be viewed as a life support system. Understanding it is a formidable challenge to scientists and managers. Gaining the understanding that is necessary for effective management requires long-range research on the harvestable resources and other components of the Bay ecosystem.

The workshop was convened to address the needs and the potential for long-term research on the Chesapeake Bay in support of living resources management. Scientists from several disciplines participated, coming from all regions of the United States and from Europe to meet for three days at the Donaldson-Brown Conference Center. Results of their discussions and recommendations are included in this report. The report is intended as a planning guide for long-range research, from which specific research programs can be developed. Further effort by small working groups of scientists and managers will be required to develop the general recommendations made here into specific research or monitoring programs.

Nineteen background papers, which dealt broadly with living resources science and management, were presented on the first day of the workshop. Some presentations were specific to the Chesapeake Bay while others focused on issues, processes or concerns of general relevance to research or management needs in the Chesapeake region. After considering the background papers participants were assigned into six working groups. The groups deliberated during the second day and produced draft reports and recommendations, which were presented and discussed in plenary on the third day of the workshop.

In addition to the 48 scientists, many agency and academic representatives participated in the general sessions on the first and third days of the workshop. The report primarily provides recommendations on long-range needs by the scientists to agency managers, but its content has been influenced substantially by input of all participants in the general sessions.

It was my pleasure to interact with the scientists and agency representatives who contributed to the workshop. The excellent interaction among individuals and the interdisciplinary discussions were highpoints of the workshop that hopefully can be sustained as cooperative Bay-wide research programs are developed. The task of editing the report and writing the Overview, Summary and Recommendations was my responsibility. I hope that I have accurately synthesized and communicated the recommendations of the working groups and that their advice will be used to plan the specific research needed to better understand and manage Chesapeake Bay living resources.

Edward D. Houde
12 June 1987

ACKNOWLEDGMENTS

Primary support for the workshop was provided by the Maryland Department of Natural Resources, Tidewater Administration. Additional financial support came from the United States Department of Agriculture.

Staff and graduate students of the Chesapeake Biological Laboratory provided logistical help which greatly facilitated the preparation for and implementation of the workshop. Secretaries, Ms. Gail Canaday and Ms. Toni Heimer, were especially helpful in organizing the program, typing the numerous draft reports and insuring that documents were available to workshop participants. Others who assisted with logistics to insure the success of the workshop are Gerard Dinardo, Sarah Houde, Helen Large, Timothy Mulligan, Timothy Newberger, Cluney Stagg, and Colleen Zastrow.

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INTRODUCTION

The objective of the workshop was to define long-term research needs for living resources in the Chesapeake Bay. Of necessity, much fishery management in the Bay and elsewhere involves crisis-oriented response to resource problems that demand immediate attention. However, a significant part of a fisheries management program should include long-term strategic research directed at understanding how a complex system such as Chesapeake Bay produces living resources and what factors limit and cause variability in potential for production. Accordingly, the emphasis of the workshop was on the ecosystem and the need to understand it in a fundamental way as a step toward better management and utilization of its living resources.

It is noteworthy that the past EPA Chesapeake Bay Program and its subsequent recommendations indicated that the wellbeing of living resources should be an important criterion for judging effectiveness of water quality improvement and cleanup efforts in the Bay. Since then, extensive Bay-wide programs have been instituted by the States of Maryland and Virginia to monitor water quality, plankton productivity and benthic processes. Both State and Federal agencies support considerable research on fisheries in the Bay but the effort is not well-integrated into the new monitoring programs, although there is a need to relate the water quality work to potential production, harvest and management of living resources.

Advice by L. Eugene Cronin (Appendix B, p. B-5), who looked back at past research and management on the Bay, encouraged workshop participants to cooperate and interact in a meaningful way. His five points are listed here:

1. As fully as possible, consider the living resource to include all economically useful species, ecologically important organisms, aesthetically or intellectually significant flora and fauna and all of those which are abundant.

2. Avoid trivial questions and interests. Think no small or self-serving thoughts. Identify the truly important questions and design adequate research. The cost is worth it.

3. Avoid the false premise and the cheap alternative. The first destroys faith and the second is never cheap in research.

4. Design the necessary research and sequence it from fundamental to technical, involving as many disciplines as are necessary. Review progress and improve the design.

5. As scientists and managers, approach management-related research cooperatively and cordially, each with 60:60 tolerance for the other.

The sound advice in these recommendations hopefully will be remembered long after the workshop has been concluded and considered again in the next stage of the process, the actual planning of specific research programs.

Workshop participants adopted the premise that the Chesapeake Bay can be viewed as a life-support system for harvestable, living resources. A schematic diagram (Figure 1) illustrates the factors that affect living resource populations in the Bay and indicates the processes and areas of concern addressed by each of the six working groups. The conceptualization in Figure 1 suggests the complexity of the Bay system and indicates that an interdisciplinary effort will be necessary to carry out strategic, long-term research on its living resources.

The workshop recognized that both monitoring and research will be required in any long-term effort to understand the productive potential of the Bay. There was a consensus that long-time-series measurements, whether made in a monitoring or research context, were extremely valuable when made on appropriate temporal and spatial scales. They can provide the means to develop data bases on variability and levels of productivity, from which realistic expectations of living resources harvests can be derived. The importance of the present Bay-wide monitoring program was recognized and the need to supplement it with more fisheries-specific components than now included was recommended.

Some participants were concerned that the link between long-range research and subsequent management action may not have been expressed clearly enough or had not been considered sufficiently in the workshop. However, most participants believed that a solid understanding of the Bay system and its harvestable resources will provide managers with the fundamental knowledge necessary for informed action to sustain or restore living resources. The knowledge gained through long-range research will not provide quick answers to solve the crises that occur all too frequently, but it will lead to better management of living resources and increased benefits in the long-term. Moreover, such informed management will be carried out with realistic expectations of the Bay's capacity to produce harvestable resources. This result is particularly important in systems such as the Chesapeake Bay which have experienced major changes in recent decades caused by habitat destruction/alteration, pollution, overfishing, and excessive nutrient loading.

Can the Bay sustain harvests or produce living resources at levels that prevailed in the past? We cannot answer that question today. A strategic research program on the Bay system and its resources could provide the answer in the future.

WORKSHOP STRUCTURE AND PARTICIPATION

The workshop was held 3-5 February 1987, at the University of Maryland's Donaldson-Brown Center, Port Deposit, Maryland. The agenda is

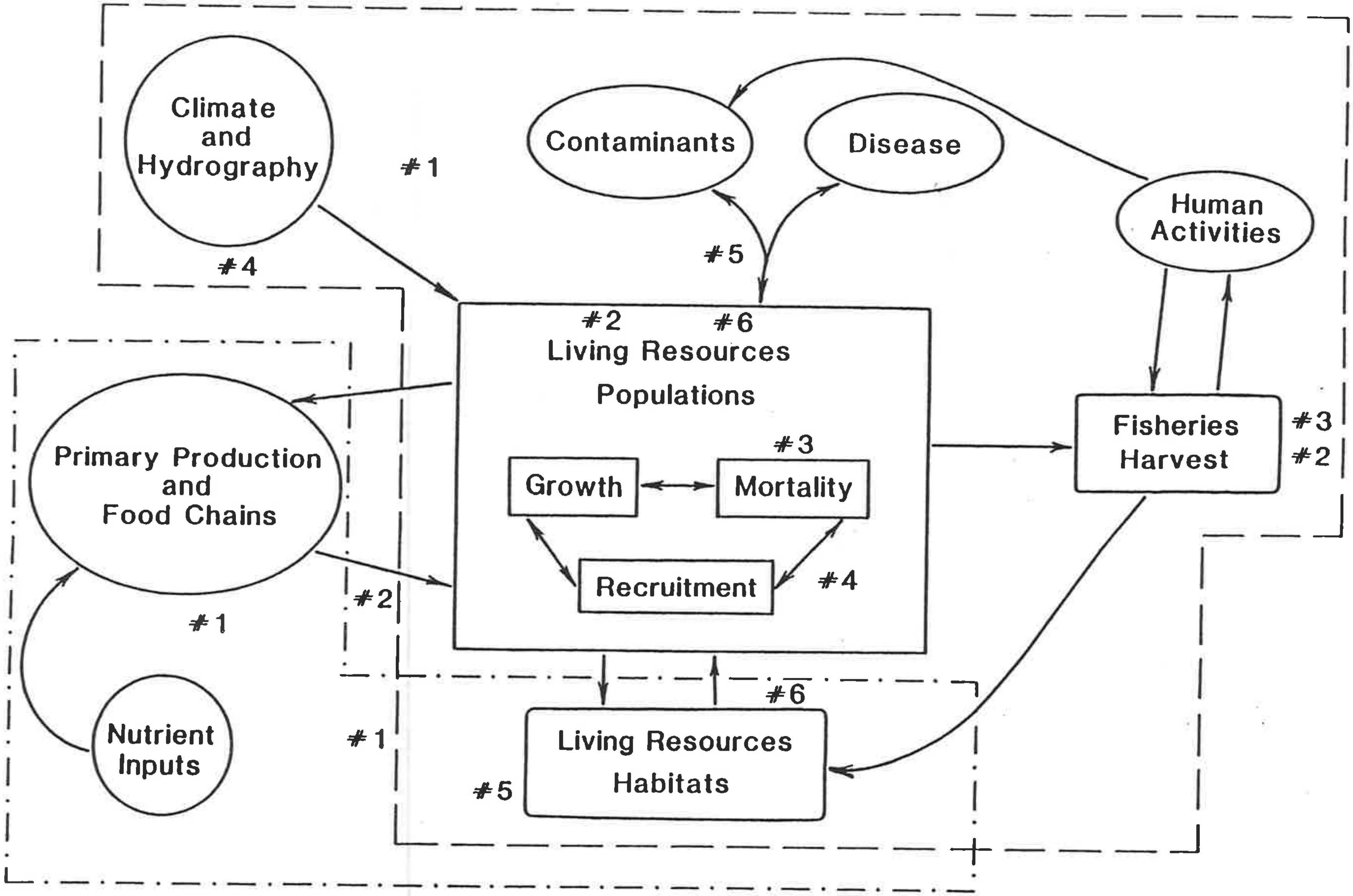


Figure 1. Schematic of the Chesapeake Bay "life support system," indicating components that must be studied in a long-range, strategic research program. Numbers indicate working groups and elements of the program with which they were concerned. The dashed line encompasses the traditional realm of interest to fisheries science. The dash-dotted line encompasses the realm of interest to biological oceanography and aquatic ecology. #1: Nutrients, Anoxia and Fish Production, #2: Predator-Prey Relationships and System Energetics, #3: Effects of Fishing, #4: Recruitment Variability, #5: Pollutants, Toxicants and Disease, #6: Restoration Strategies.

included here as Appendix A. The first day's general session was attended by the workshop participants and invited guests from agencies and academia. Speakers presented background and experience papers (Appendix B) which set the tone for the following day's working group deliberations (Appendix C). In addition, a document "Strawman II -- Living Resources Habitat Requirements for Chesapeake Bay" was reviewed. Recommendations on its structure and content were made to the Chesapeake Bay Living Resources Task Force. The third day of the workshop was a plenary session in which reports of the working groups were presented for discussion by participants and invited agency/academic representatives.

There were 48 workshop participants (Appendix E), representing a broad range of scientific disciplines. Scientists who have studied the Chesapeake Bay predominated, but participants with experience on the Pacific Coast, San Francisco Bay, the Great Lakes, Baltic Sea, North Sea, Gulf of Mexico, and Northwest Atlantic provided valuable perspectives from other ecosystems with problems similar to those in the Chesapeake.

The reports of each of the six working groups are included in the report. The working groups are:

1. Nutrients, Anoxia, and Fish Production.
2. Predator-Prey Relationships and System Energetics
3. Effects of Fishing
4. Recruitment Variability
5. Pollutants, Toxicants, and Disease
6. Restoration Strategies

In addition, the participants met briefly in subgroups to make recommendations on species-specific research needs (Appendix D).

MAJOR RECOMMENDATIONS

The major recommendations represent a synthesis and summarization of recommendations by the individual working groups. Here, we list those which most participants thought essential in a strategic research plan. Details of the recommendations are included in the individual working group reports. Additional recommendations, specific to the disciplinary areas of the individual working groups, also are discussed in each of the group reports.

1. **Conceptual Model of the Bay**: As a guide to research and a tool for understanding, a detailed conceptual model of the Bay system should be developed and updated continuously. To be effective, the model should evolve as research defines the limits of variability in living resources production. A conceptual model of the major elements of the Bay system, which includes the living resources and which recognizes the influences of human activities, will serve as a blueprint to direct research on key components and relationships among variables. The model should be evaluated annually by an interdisciplinary team of scientists and managers whose task would be both to update the model and to identify the elements or linkages

where additional research is required or management action should be taken. Modeling, even at this conceptual level, will foster continuity and cooperation in research programs on Chesapeake Bay living resources. Care should be taken so that such models are not adopted as decision making surrogates for management action.

A conceptual model of the Bay ecosystem could be developed immediately by an interdisciplinary team of experts, who also could specify research priorities identified by the model. Ideally, as the model evolves and its elements and linkages are quantified, then numerical models of the Bay system and subsystems can be developed to predict limits and variability of living resources production.

2. **Strategic Long-Term Research on Food Chain Relationships**: A carefully planned, long range research program that focuses on predator-prey relationships is recommended. The trophic relationships among key species or guilds of species at major trophic levels can be determined from fishery-independent abundance surveys, stomach analyses and energetics modeling. The program should have both "bottom-up" and "top-down" elements. In the bottom-up approach, the influence of nutrients on food chain dynamics and productivity at higher trophic levels is emphasized. In the top-down approach, effects of predators (or organisms at relatively higher trophic level) on lower trophic levels -- both production and biomass -- and, ultimately, on water quality itself are investigated. A growing body of evidence suggests that predators in aquatic ecosystems play an important regulatory role on system productivity. Increased nutrient loading in the Bay indicates that bottom-up principles may be important in determining whether metazoan (typical primary producer, zooplankton, fish) or microbial (production centered on microorganisms) food webs predominate. The trend toward increasing hypoxic conditions and the high bacterial biomasses in the Bay suggest that biogeochemical processes controlling biological production may have changed over the years which, in turn, indicates that microbial food webs may have increased in importance, with attendant negative effects on both fisheries productivity and water quality.

Little is known about top-down control in the Bay but important questions related to effects of specific predator abundances and biomasses (e.g. bluefish or striped bass) on planktivore abundances, or oyster abundance on primary production and water quality, need to be addressed. The possibility that water quality can be managed to some extent through control of abundance of organisms at higher trophic levels is an important area for future research in the Bay.

3. **Correlative and Process-Oriented Recruitment Research**: Studies to identify the environmental factors correlated with recruitment variability, followed by process-oriented research to identify the causes and mechanisms, are advocated. Results can be used to quantify density-independent, environmental effects in stock-recruitment models, which will lead to better understanding of the density-dependent relationships between parent and progeny that often are obscured because of the large component of recruitment variability attributed to environmental factors.

There is a critical need for fishery-independent data on abundance, and estimates of variability in abundance of young stages of fish and invertebrates. Environmental data, including biological data on effects of predators and competitors, the abundance of potential food and the role of transport and other physical processes are essential in recruitment research. Much of the environmental data needed for the statistical (i.e. correlative) part of the program can be derived from monitoring on appropriate temporal/spatial scales. This last point is emphasized. Monitoring, to be useful in recruitment studies, must be done frequently and in the areas where pre-recruits are found if relationships between recruitment, hydrographic variables, and associated organisms (e.g. prey and predators) are to be established. Monitoring on infrequent time scales or over broad geographic areas may demonstrate long-term trends in environmental variables that can be related to trends in recruitment, but it is unlikely to provide much insight into understanding effects on recruitment in a given year. The process-oriented components of recruitment research will require carefully-designed research to estimate life stage abundances, mortality and growth rates as well as experimental research to directly estimate the effects of biological and physical factors on survival and potential for recruitment success.

4. **Fishery-Based Population and Yield Models**: Fishery-based models, specific to the Chesapeake Bay and which take into account system variability, must be developed. In the short-term, single species models can serve, but, in the long-term, multispecies models are needed. Good models depend upon high quality data, particularly Bay-wide information on the age-specific/sex-specific catch and on fishing effort for key species. The recently-instituted Chesapeake Bay Stock Assessment Committee is beginning to develop single species assessment models. A Bay-wide multispecies monitoring survey is recommended which will provide fishery-independent abundance data that can be used in population models, but which also will provide immediate information on abundance that can be used in management decisions.

In the case of harvested living resources, life stage-specific abundance estimates may be important input variables for the model. Trawling surveys, acoustic assessments and other coordinated surveys can be employed to provide both indices of abundance or, where feasible, absolute abundance estimates (with confidence limits) on a annual basis. Information on abundance and biomass from fishery independent surveys can provide immediate information for management (e.g., juvenile indices for striped bass). Such estimates often are the only reasonably reliable way to estimate abundance of prerecruit fish or shellfish and are the only way to estimate abundances of non-harvested resources that are foods of harvested species.

5. **Development of Assessment Technology to Evaluate Contaminant and Disease Effects**: The problems of evaluating effects of contaminants and disease on living resource abundance and productivity have many similar-

ities. Except in small parts of the Bay that are grossly impacted, it cannot be stated unequivocally that contaminants or disease regulate abundance or recruitment of living resources. The development of new assessment technologies to demonstrate how population/community dynamics and structure are affected by contaminants or disease will require an interdisciplinary effort. Approaches that incorporate effects of contaminants and disease into fishery models and express those effects as "fishing mortality equivalents" hold promise and should be pursued. Development of quantitative structure-activity relationships (QSAR), in which contaminants of similar chemical structure are ranked and categorized with regard to their potential to impact organisms, may allow hazard assessment of multiple contaminants without the need to assess effects of each individual contaminant.

Bioeconomic research, particularly development of methods to estimate the impact of disease and contaminants on utilization and values of living resources, has an important role. Assessment technology is needed in which the quality (or its perception by the public) of harvested resources in relation to contaminants or disease is determined. Improved quality may lead to increased utilization and values which, in the case of resources that can sustain increased harvest, may have a significant effect on resource abundance and on the ecology of the Bay.

6. **Evaluation of Stock Restoration and Enhancement Efforts**: There is opportunity to restore, rebuild and enhance stocks of resources now in decline in the Chesapeake Bay. Long-range research that considers three options -- stock restoration, stock enhancement and habitat restoration is required. Both restoration and enhancement possibilities depend on life stage-specific habitat suitability. Because Chesapeake Bay habitats have changed significantly they must be evaluated to determine their carrying capacity for living resources that are candidates for restoration. We cannot be certain how many striped bass or oysters can be restored to the Bay. Before restoration through hatchery production is initiated, many biological and economical problems must be solved. Research on the potential of hatchery progeny to restore or enhance populations is needed. The numbers of hatchery progeny required, the interaction of hatchery stock with wild stock, the impact of stocked progeny on gene pool diversity, and the economics of restoration/enhancement efforts all are appropriate areas for long-range research. There also is a significant need for research and development of policy to evaluate the long-term expectations of restoration programs, including the attendant risks and benefits.

7. **Infrastructure, Cooperation, Support and Information Dissemination**: Because the Chesapeake Bay is a large and complex system that spans jurisdictional boundaries, successful research and the management of living resources must be coordinated and carried out cooperatively. Some life stages of many of the Bay's animal resources migrate, or are capable of migration, making it essential that research programs on these species be carried out over the range occupied by the organisms. For some species this means throughout the Bay. For others, such as striped bass or shad, the

coast-wide range must be included. Cooperation in research is particularly necessary between research agencies in Virginia and Maryland but other States, as well as local and Federal agencies, also must be involved.

A. Institutions

An infrastructure or institution to plan, guide and report research results on Chesapeake living resources is needed. A successful model of such an institutional structure is the California Cooperative Oceanic Fisheries Investigations in which State, Federal and academic institutions have collaborated to study the resources of the California Current system. A similar institution could serve an important role in the Chesapeake region. Steps in the right direction have been taken recently in forming the Chesapeake Bay Stock Assessment Committee (CBSAC) and in the initiation of monitoring programs by the States of Maryland and Virginia. The role of CBSAC is specific to assessment and statistical evaluations of harvestable resources. While some of the monitoring programs are concerned with fisheries resources, most focus on water quality issues. Coordination and direction are needed to link the stock assessment efforts and the broader environmental assessments in a strategic research program. A research/-management institution with broader interest and responsibilities could serve a useful purpose to coordinate systems-level research that has fisheries management as an ultimate goal.

B. Funding

Long-range strategic research requires stable and dependable funding. Several years of interdisciplinary research will be needed to understand the Bay as a system, its potential for productivity and the variability in living resources production. Both State and Federal agencies should legitimately share the cost of research that will benefit both the region and the nation.

C. Information Dissemination

Workshop participants recognized the need for a mechanism to report scientific research on the Bay and its living resources. A peer-reviewed, annual publication on research and management of Chesapeake Bay resources, with general distribution, would serve the purpose of reporting results and would help to minimize duplicative research efforts. A significant problem today is the common use of "gray literature" to report many major findings on the Bay. A credible, peer-reviewed publication would improve scientific reporting and information dissemination. In addition, scientists should be encouraged to submit data to a general repository such as that maintained by the Chesapeake Bay Program in Annapolis to increase the availability of information to scientists and managers alike.

SPECIES-SPECIFIC NEEDS

A. Species-Specific Subgroup Reports

Participants met in subgroups to discuss species-specific research needs. Summarized results are briefly reported in Appendix D. Not surprisingly, many of the concerns and recommendations reflect the lack of knowledge about the Bay system and its potential to sustain the resources. The interactions among species, recruitment variability, the need for fishery-independent stock assessments, early life stage ecology, and effects of contaminants were topics that concerned most of the subgroups.

B. Review of Habitat Criteria Document

An additional task of the Workshop was to review and provide comments on a draft of the document, "Living Resources Habitat Requirements for Chesapeake Bay," prepared by the Chesapeake Bay Program's Living Resources Task Force. The completed version of this report will be an important reference that documents habitat requirements for key species in the Bay region. Its synthesized information, presented in a matrix format, can serve to identify both research needs and gaps in knowledge required for management initiatives. Workshop participants provided comments and suggestions directly to the Living Resources Task Force.

RESEARCH AND MANAGEMENT

Research programs should produce knowledge that managers can use to insure larger or more stable harvests of living resources from the Chesapeake Bay. It was beyond the scope of the workshop to specifically consider the link between research that is needed and subsequent management action. But, there is no doubt that results of strategic research will have important use in future management decisions. Lacking such research it is unlikely that we will be able to answer questions such as, "How many striped bass can the Bay sustain?" or "How many oysters could be produced and harvested annually in the Bay today?" The Bay system has changed over the years. We cannot state with certainty how much primary production occurs and how much, or what quality, is needed to produce an oyster harvest equivalent to that several decades past. We do not know the level of forage fish abundance necessary to sustain a striped bass population or potential competitors such as bluefish or weakfish. And, we are unable to evaluate the probable impacts of diseases, contaminants, and declining habitat quality on the Bay's ability to produce and sustain living resources. These kinds of questions and problems dominate the long-range management picture. The complexities of water quality management and the possible application of restoration strategies add to the need for better understanding of the Bay life support system. Only interdisciplinary, long-range research programs are likely to provide answers that will lead to successful management.

Having completed the initial task of identifying research needs, a strategic planning group of scientists and living-resource managers is recommended to formulate long-range research plans. Such a group, composed of State, Federal, and academic representatives, should meet at least annually to recommend and evaluate research needs. Meeting together, managers and scientists can formulate reasonable plans for strategic research to be used ultimately for Bay-wide management of living resources. One way to foster this interaction immediately is to designate a group to develop the proposed conceptual model of the Bay and its resources. With the model in hand and a commitment to use it to guide the direction of research and to regularly update it, a meaningful research program can be planned that will benefit management of the Chesapeake Bay and its living resources.

II. Working Group 1 Report

NUTRIENTS, ANOXIA AND FISH PRODUCTION

Thomas C. Malone (Chairman), Donald F. Boesch, Walter R. Boynton, James E. Cloern, Christopher F. D'Elia, W. Michael Kemp, Scott W. Nixon, and Mary G. Tyler

INTRODUCTION

The working group was concerned with developing a quantitative understanding of how nutrient inputs from the watershed of Chesapeake Bay influence water quality and fish production (total annual production of all fin and shellfish) within the Bay. The supply of these new (as opposed to recycled) nutrients sets an upper limit on fish production that can leave or be harvested from the Bay. The extent to which this upper limit is approached depends on the rates and pathways by which phytoplankton production is transferred through the food web connecting phytoplankton and fish. There are indications that changes in the trophic dynamics of this food web have occurred as a consequence of nutrient enrichment and fishing effort in the Bay. These changes are likely to be intimately related to both the degradation of water quality and reduced fish yields. Indications that such changes have taken place include the following:

(1) Nutrient inputs to the Bay have increased and the production of organic matter has probably increased as a consequence.

(2) The production of heterotrophic bacterioplankton appears to be exceptionally high relative to other estuarine and coastal systems as well as to phytoplankton production within the Bay.

(3) The amount and quality of habitat for the growth and reproduction of living resources has declined due to the loss of historical spawning areas, loss of submerged aquatic vegetation (SAV), and oxygen depletion on diel to seasonal time scales.

(4) The stocks of many important living resources have declined, and their relative abundances appear to be changing in many regions of the Bay.

Given these changes and the potential effects of changes in fish stocks on production at lower trophic levels (e.g., a shift in energy flow from metazoan food chains which support fish to microbial food chains and reduced water quality; or, increased phytoplankton production with the decline in oyster stocks), we have defined a set of key issues that should be addressed in the context of ongoing monitoring and stock assessment programs. These issues can be divided conceptually into two categories:

(1) changes in trophic dynamics that relate nutrient supply and phytoplankton production to fish production; and

(2) changes in habitat availability that influence the survival of important fish stocks not only by directly limiting usable habitat space but also through effects on trophic interactions involving fisheries resources.

<u>TROPHIC DYNAMICS</u>

The issues which should be addressed are:

(1) How are variations in nutrient input from the watershed related to variations in phytoplankton production and nutrient cycling? What is the relationship between variations in phytoplankton production and the fate of this production in terms of consumption, production and nutrient recycling by pelagic and benthic communities? What fraction of the annual supply of new nutrients to the Bay is ultimately incorporated into fish and shellfish populations at different stages of their development? How does this fraction vary in relation to the balance between nutrient input and nutrient recycling?

(2) How do short-term variations (days to months) in the production of intermediate trophic levels relate to variations in fisheries production on the longer time and space scales which characterize their reproductive cycles and distribution? How is production by small organisms (e.g., phytoplankton and zooplankton) with high turnover rates integrated over longer periods to produce fish biomass?

(3) How is production at key points in the trophic structure (e.g., phytoplankton size classes, bacteria, copepods, and sea nettles) regulated, and how do physical processes influence interactions among trophic levels?

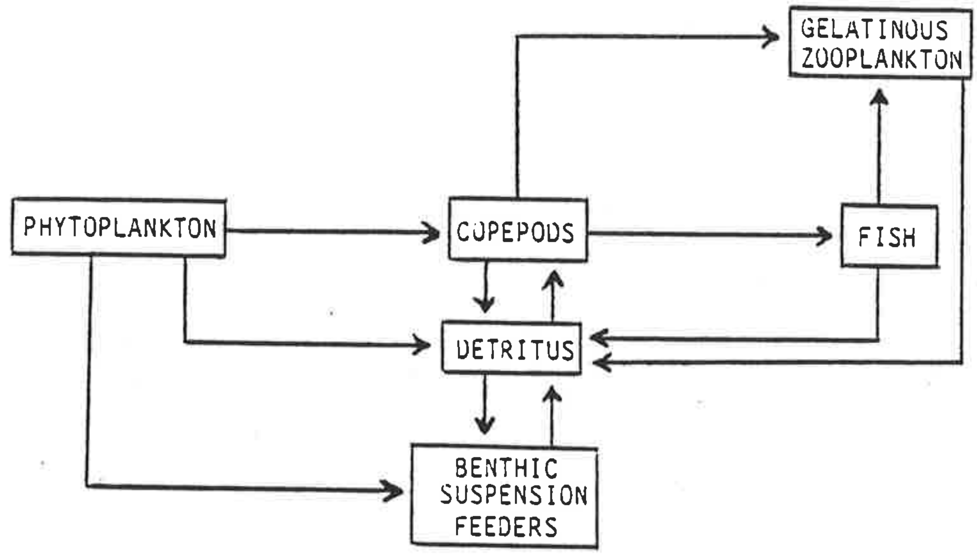
Specific objectives for research relating to these issues are:

(1) to quantify the effects of variations in nutrient supply (new and recycled) and grazing (by both pelagic zooplankton and benthic suspension feeders) on phytoplankton production on weekly, seasonal and interannual time scales;

(2) to determine how variations in nutrient supply affect the relative importance of microbial and metazoan food webs (Fig. 2) in terms of energy flow and nutrient cycling on weekly, seasonal and interannual time scales;

(3) to determine how variations in nutrient supply and phytoplankton production are related to the partitioning of organic nutrients among planktonic and benthic communities in terms of oxygen demand and nutrient cycling on weekly, seasonal and interannual time scales; and

SIMPLIFIED METAZOAN FOOD WEB



SIMPLIFIED MICROBIAL FOOD WEB

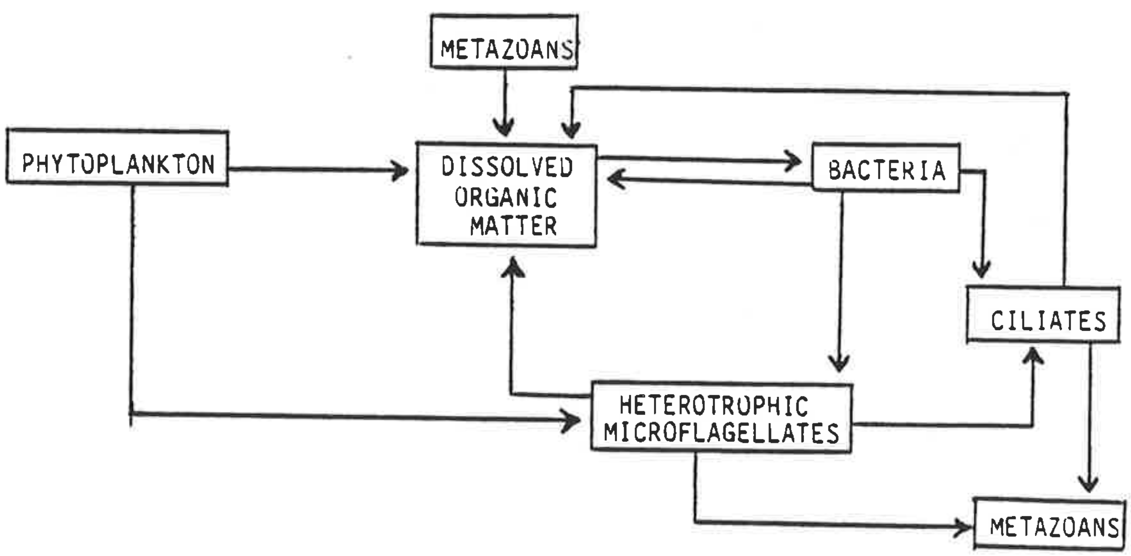


Figure 2. Generalized examples of metazoan and microbial food webs. The main flows in the traditional metazoan food web are from phytoplankton to copepods and fish and to suspension feeders such as clams and oysters. Only particulate organic matter is transferred and recycling occurs via the detrital pool. The pool of dissolved organic matter is of central importance in the microbial food web. Bacterial utilization of dissolved organic compounds results in the production of particulate organic matter, a process which may ultimately enhance metazoan production or may be more or less independent of the metazoan food web. To the extent that the latter occurs, increases in bacterial production may be indicative of a trend toward lower water quality and a shift from a metazoan to a microbial dominated food web.

(4) to evaluate the extent to which the production and biomass of important consumers (food items for fish and gelatinous zooplankton) are related to interactions between microbial and metazoan food webs in the water column and between pelagic and benthic communities.

The magnitude and variability of production in an ecosystem such as Chesapeake Bay are generally greater at the phytoplankton level than at the fish level. Thus, an underlying theme of our recommendations is the need to determine how phytoplankton production is partitioned among alternative planktonic food chains and between benthic and pelagic communities. We have emphasized trophic levels leading to and including major prey of fish populations rather than fish populations *per se*. Thus, implementation of the research efforts described above must be coordinated with stock assessment programs.

HABITAT

The working group also considered long-term research needs to determine the effects of hypoxic and anoxic waters on fisheries production. The central issues are the causes of time- and space-dependent oxygen depletion as well as the mechanisms by which oxygen depletion affects the survival and production of fisheries resources and their prey.

Specific objectives relating to oxygen depletion and habitat are:

(1) to describe variations in the distribution of hypoxic-anoxic water and elucidate the underlying mechanisms on tidal to interannual time scales;

(2) to determine the relative importance of aerobic and anaerobic metabolism by planktonic and benthic populations in oxygen depletion and nutrient regeneration on tidal to seasonal time scales (for example, to determine the effects of anoxia on the coupling between nitrification and denitrification).

(3) to determine the effects of variations in hypoxia-anoxia on the survival and production of shellfish and finfish populations (e.g. oysters and anchovies) and their prey on tidal to interannual time scales (including the effects of variations in the volume and distribution of hypoxic water on the distribution, growth and mortality of fishes and their prey).

The subject of oxygen depletion and its effect on habitat raises the question of the importance of habitat in general. We feel that the influences of habitat space and quality on fisheries production is of greater importance than our treatment implies. This is particularly true of the role of SAV as a habitat and refuge during various stages in the reproduction and development of fish populations. In short, the problem of habitat remains to be addressed as a major issue in itself (see Working Group 6 report).

APPROACHES

Few serious attempts have ever been made to relate nutrient supplies to fisheries production with the goal of determining the functional relationships involved. We believe that this approach should be pursued to understand how nutrient enrichment influences the relationship between water quality and fish production in estuarine and marine systems. The achievement of this goal will require coordination among research, monitoring and stock assessment programs. Research will be required to develop a theoretical basis for relating the results of monitoring and stock assessment programs to nutrient enrichment and fishing effort. Results of these programs should, in turn, be used to help guide the development of research projects. Certain aspects of the research effort outlined above are better addressed by monitoring. These include seasonal and interannual variations in phytoplankton production and the spatial and temporal extent of oxygen depletion. The problem of determining underlying mechanisms and effects of variability will continue to be the main focus of research. Because of the complexity of the problems and because many of the important forces which impinge on the Bay vary on yearly or longer time scales (e.g., the magnitude of the spring freshets, storm frequency, the occurrence of catastrophic events such as hurricanes), multi-year research efforts will be needed.

Research efforts should continue to develop with a variety of coordinated approaches involving both physical and biological programs.

(1) A modelling effort will be needed to provide a framework for hypothesis testing and a theoretical basis for defining limits and predicting effects. A first step is to develop a conceptual model of the Chesapeake Bay ecosystem (see Working Group 2 Report) that is continuously updated and from which analytical models can be derived.

(2) Coordinated physical and biological field programs will be required to address problems such as the degree of coupling in time and space among trophic levels linking phytoplankton production, water quality, and fisheries production (see Working Group 2 Report). This will involve ship-board experimental research to determine rates of production and establish cause-effect interactions, moorings to develop high resolution time-series, and remote sensing to achieve synoptic descriptions of changes in such properties as temperature and chlorophyll. These observations and experiments must be made over seasonal and interannual time scales to evaluate trophic dynamics over a wide range of nutrient inputs, particularly under spring and summer conditions.

(3) Because the issues identified here are complex and difficult to resolve, questions posed will not be answered by field observations alone. Rather, a coordinated strategy coupling appropriate field research with controlled experimental studies should be pursued. For example, experimental manipulations of mesocosm enclosures could be used to address such questions as nutrient-induced shifts between metazoan and microbial food webs and the effects of suspension feeders on plankton trophodynamics.

III. Working Group 2 Report

PREDATOR-PREY RELATIONSHIPS AND SYSTEM ENERGETICS

Robert E. Ulanowicz (Chairman), Stephen B. Brandt,
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INTRODUCTION

Long Term Goal: To assess the limits of production of living resources within the Chesapeake Bay system and to evaluate factors controlling that production. (This goal provided the framework for discussions by the working group.)

The limits of biological production within the Chesapeake Bay system set the bounds for fishery yield and restoration expectations, but these limits remain unknown. The Bay can be viewed as a *life support system* whose range of production is determined by trophic relationships of components within the system. Availability of biological and chemical resources and pressures exerted by predators are the major biological arbiters determining how much a given species can produce above any limits imposed by abiotic factors. Because these biological mediators are subject to limits of their own, it is necessary to acquire knowledge of the structure of the food web as a whole before one can understand potential production at the level of harvestable fisheries products. Additionally, predator-prey dynamics may subtly affect key issues of interest in Chesapeake Bay, such as the relationship between water quality improvement and fishery yield, the upper limit of striped bass production via restoration efforts, and the sequestering of contaminants through biological production.

To achieve the cited goal requires an integrated program of conceptual modeling, system quantification, monitoring and long-term strategic research. To assess the production limits of the Chesapeake Bay system, quantitative knowledge of trophic relationships within the ecosystem must be acquired. Four closely linked tasks are proposed.

TASKS

1. The creation of a conceptual model of biological production within the Chesapeake ecosystem based on available data and expert opinion.

2. System quantification to evaluate production limits.

3. Additional monitoring of key species and processes.

4. Long-term strategic research to evaluate mechanisms and processes affecting and limiting production.

These tasks are envisioned as components of a long-term, multidisciplinary and cooperative research effort on Chesapeake Bay. The first and most crucial task, that of building a conceptual model, can be initiated now with modest resources and immediately would point out critical research directions. Tasks 2, 3 and 4 will require more intensive efforts at the integration of modeling, monitoring and research.

Task 1. Conceptual model of Chesapeake Bay Biological Production.

As a first step in developing long-term research on the Chesapeake Bay system and its living resources an updated conceptual model should be built based on existing data and ideas. An interdisciplinary working group of experts could accomplish this initial task in a few days. The exercise, in addition to framing the model, would identify critical information and data gaps. It is possible that more than one conceptual model might emerge. Conceptual models, as opposed to predictive models, act as bookkeeping devices that define the system boundaries and integrate the major driving forces and state variables via biological/geochemical pathways into a total system. One of the conceptual models should be designated a "master model," i.e., a total model that integrates major physical, chemical, geological and biological variables and processes. If the effort is to remain feasible, some biological variables may have to be pooled into guilds or functional groups of organisms of similar trophic status. It is important that linkages between biotic and abiotic components and among trophic levels be clearly articulated.

The requirement for aggregation of biological variables can be compensated to some extent by a series of submodels in which major species are highlighted. It is important that the total life support system of a species be made clear. Because the "maintenance" requirements of a species (food, spawning areas, foraging areas) are often dispersed throughout space and time (e.g., spawning in the upper estuary, young in the middle estuary, adults in the coastal regions or off-shore), the full requirements of a species for energy and habitat may remain unspecified unless careful analyses are done.

Conceptual models will force scientists to define relationships between variables, point out deficiencies in knowledge and, most importantly, act as a blueprint for research. The system model will clearly indicate the research roles of various scientific disciplines as well as the need for interdisciplinary investigations. As such, it can be the framework for long-term research that ultimately will benefit fisheries management and harvest.

Annual working conferences would allow the conceptual model to be updated, results reported, objectives revolted, efforts refined, and new problems identified. Modeling efforts and regular evaluation of progress will bring continuity, cooperation and stability into Chesapeake Bay research programs on living resources.

Task 2. System Quantification to Evaluate Production

The results of the initial conceptual model analysis should be used to design a Bay-wide field program to quantify temporally and spatially the species biomasses (energies) and fluxes among major trophic levels and across the mouth of the Bay. The three-year (or longer) program would include both research and monitoring elements. A major part of the effort should be fishery-independent surveys to obtain biomass estimates of living resources which would yield immediate information for fisheries management decisions. Other trophic levels must be included to quantify the system. Studies should extend into tributaries to the upper limits of distribution for anadromous fishes. Temporal and spatial scales for sampling would be determined from the modeling task, but obviously must cover all seasons and major habitats within the Bay system. Sampling techniques would include acoustics and diverse conventional equipment for gathering benthos, plankton and fishes. The biological samples must be accompanied by measurements of critical environmental parameters. Fluxes through the Bay mouth would be inferred from seasonal changes in organism densities in the Bay, consideration of migratory behavior and transport dynamics across the Bay mouth.

The temporal and spatial dynamics of fluxes among species and areas would be obtained from research on food habits, metabolism, movements, reproductive effort, growth and mortality. In some cases these studies would focus on key species but in many cases could be adequately carried out at the guild or species group level. The research will require field, mesocosm, and laboratory components. Data would be gathered to evaluate rates of consumption by predators, losses to predation by prey, respiration, and production.

Historical conditions on the Bay should be evaluated to estimate production limits and realistic possibilities for rehabilitation. Sediment cores can provide historical time series of phytoplankton, zooplankton, and microfossils. Possibly they would also yield clues to past grazing and oxygen levels, to determine structure of undisturbed plankton communities and the timing and extents of change in those communities. Future shifts back towards an earlier community structure might be an indication of success for rehabilitation programs.

Task 3. Additional Monitoring Needs

Once preliminary estimations of trophic interrelationships and dynamics have been accomplished, we recommend targeting key species for further monitoring. To understand the dynamics of the Chesapeake System, it is imperative that major components of the energy flow throughout the system be followed by long-term monitoring. The Chesapeake Bay monitoring program began sampling in 1983 and will continue through 1993. It will provide a critical base of information on hydrography, sedimentation, nutrients, primary production, chlorophyll and zooplankton.

Other organisms should be included in the monitoring program to insure adequate system quantification. Recent data have shown bacterial production to be equal to or greater than that due to phytoplankton (Working Group 1 Report). Numbers of fish eggs and larvae can yield fishery-independent indices of spawning stock size of finfishes, particularly for those unexploited but abundant species that are both forage for predators and important consumers of plankton (e.g., anchovies and menhaden). Gelatinous zooplankton are extremely abundant in the Chesapeake Bay and presumably are major consumers of zooplankton and larval fishes. The existing monitoring effort should be augmented by concurrent sampling of bacteria, ichthyoplankton, and gelatinous zooplankton. This could be achieved with only small changes in sampling gear and incremental effort.

Additionally, fishery-independent trawling surveys or other assessment technologies (e.g., acoustics) should regularly be used to evaluate finfish and shellfish stocks. Juvenile fish and forage species are often ignored or poorly sampled. However, their probable importance as consumers and as forage stocks calls for the routine assessment of their numbers and the evaluation of their year-class strengths -- much as is done for striped bass in the juvenile index surveys.

Task 4. Long-Term Strategic Research:

Predator-prey relationships, including man's predation by fishing, and system energetics strongly influence production dynamics, limits of system productivity, and the way in which biological production is packaged. Enhanced productivity from anthropogenic eutrophication possibly is being shunted into bacterial or gelatinous zooplankton production, rather than contributing directly to fishery yield. To have realistic expectations and goals for the Chesapeake Bay system in general, and fishery production in particular, we need to understand the production dynamics, trophic relationships and factors that affect the subsequent compartmentalization of production. Predator-prey relationships can be studied by a combination of field, mesocosm, and laboratory research projects. We believe that there are three primary areas of interrelated long-term research that are needed to achieve our stated goal.

A) Trophic Relationships within the Bay

Although information is available on the diet of many species, there are few quantitative data on overall pathways that lead to the production of any major harvestable species. Specific studies are needed on diet, ration, feeding behavior, prey selectivity and the impact of environmental factors on feeding strategies. Specifically:

1) What is the current biological production of harvestable resources in the Chesapeake Bay system and what are the spatial and temporal scales of its variability?

2) What are the major pathways of energy flow to or away from fisheries production?

3) How does climate and habitat affect trophic relationships? For example, we need to consider how some of the following factors affect predator-prey dynamics and production;

a) Chronic effects[a]
   (1) anoxia
   (2) pollution
   (3) nutrient input
   (4) sedimentation
   (5) altered habitats
   (6) artificial restoration

b) Long term climatic factors

c) The influence of abundant but little-studied groups (e.g., forage fish and gelatinous zooplankton) on system productivity and fishery yield.

d) the relevance of short-term episodic events

B) Bay System Energetics

Logic suggests that the Chesapeake Bay must be considered on a system-wide basis. Presently we know little about the way that predator-prey interactions in one part of the Bay affect production in other parts of the Bay. The same could be said of fisheries harvest -- a complex predator-prey interaction in which man is the predator. To answer system-level questions we must understand the relationships between Bay subsystems and components:

1. What effects do trophic interactions and production in one part of the Bay or on one component of the system have on those in other parts of the Bay or on other components?

2. What are the transport mechanisms?

3. Can the Bay be considered to have the following subsystems and, if so, how are they linked?

a) benthic-pelagic
b) Bay-coastal
c) subestuary-estuary
d) watershed-Bay

C) Fish Production and Water Quality

Evidence from the Great Lakes and elsewhere suggests that water quality and phytoplankton abundance can be directly affected by fish predation. This effect sometimes is referred to as top-down control and produces cascading trophic interactions (Fig. 3). Piscivory affects zooplanktivore

[a]These specific factors are discussed in other Working Group reports.

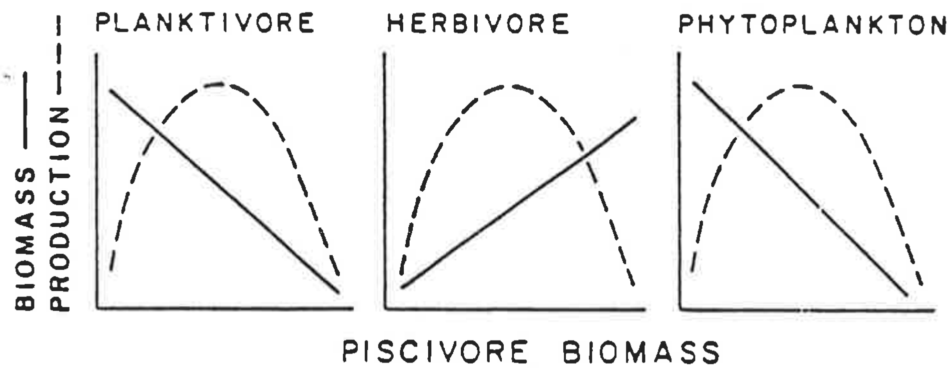

Figure 3. Illustration of the "top-down" concept of community regulation in which piscivore biomass is a major factor controlling biomass and production of planktivores, herbivores and phytoplankton. (Illustration taken from Carpenter, S.R., J.F. Kitchell and J.R. Hodgson. 1985. Cascading trophic interactions and lake productivity. Bioscience 35:634-639.)

abundance, which can affect zooplankton species and size structure, which in turn influences grazing rates on phytoplankton. One hypothesis pertaining to the Chesapeake Bay is that lowered oyster abundance may have reduced the level of grazing on primary producers, thereby leading to increases in phytoplankton biomass. Specific questions are:

1. Do predator abundances in Chesapeake Bay significantly alter prey community composition and size structure, and ultimately water quality and clarity (i.e., do top-down principles apply)?

2. How has the Chesapeake Bay already been altered, and are the changes reversible?

3. Does the relationship between control by predators (top-down) and control by nutrients (bottom-up) vary seasonally or with production levels?

4. Are there enhancement strategies (e.g., oyster aquaculture or striped bass restoration) that will help to manage Chesapeake Bay water quality?

5. What effects do water quality, nutrient loading, and oxygen levels have on fish production?

Some Data Needs

Studies on trophic relationships need to address short-term (diel, episodic) and long-term (seasonal, interannual) intervals and need to consider ontogenetic changes in diet, behavior, distribution and feeding efficiency within a species. A fishery-independent stock assessment program is deemed essential to any Bay-wide production estimates of fishery resources. Species-specific bioenergetic models will be needed to estimate the production potentials for key species.

Other questions that require data include:

1. What roles do the abundant gelatinous zooplankton and juvenile fishes play in system energetics?

2. Have the size compositions of zooplankton and phytoplankton populations been shifted downwards in recent years? If so, how does this affect biological production in the Bay?

3. Are there easily-obtained indicators of system state or stress (e.g., changes in zooplankton size structure, cycling rates, fish growth) that can be incorporated into a monitoring program?

IV. Working Group 3 Report

EFFECTS OF FISHING

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INTRODUCTION

Our objective was to identify research needs to establish rational recommendations for research necessary to manage Chesapeake Bay fisheries. While the focus was on effects of fishing, it was clear that data and information to assess fishing effects are in many cases identical to those required to document effects of other factors on stock status. The specific types of data, information and methods to be applied to those data, as well as perspectives on implementation and organizational strategies, are presented below:

A. Assessing Effects of Fishing.

1. Develop fishery-based models specific for Chesapeake Bay to simulate consequences of various management measures. These models should incorporate and reflect system variability, to the extent possible.

Rationale

In discussing research needs for model development to assess fishing effects, it is notable that traditional fisheries models are applicable to single species; however, most traditional finfisheries in Chesapeake Bay are multispecies in nature. These include the gill net, pound net, and fyke net fisheries. Furthermore, socio-economic factors, which strongly influence the catch and distribution of effort in Bay fisheries, are intrinsically multispecies. Research on model development will be valuable to manage such fisheries. This research may require use of multispecies virtual population analysis (VPA), multispecies yield per recruit models, and network analysis. The modeling approaches will depend on both fishery-dependent and fishery-independent data, and must recognize the basic dependencies among species, within the Chesapeake Bay system. Fishery managers must be included in the research development process to insure that the modeling addresses realistic harvest strategies, and defines in an understandable manner the consequences of different harvest options on long-term yields of the multispecies complex.

2. In the interim, apply existing single-species models to obtain first approximations of the potential consequences of harvest strategies, and to identify research hypotheses and data needs.

Rationale

While developing new modeling approaches, application of existing yield-per-recruit, production, and single-species VPA models using the limited fisheries data that are available will contribute to establishing priorities for research and associated data needs. In addition, some limited modeling results will contribute to rational decision making. For example, versions of yield-per-recruit models that reflect potential egg production per recruit are now being used to determine the impacts of harvest strategies on the coastal migratory stock of striped bass.

Fishery models, unlike ecosystem models which generally serve as blueprints or guides to understanding, often are used by managers in the decision-making process to regulate the fisheries. Because they are used in this mode, it is critically important that the models be evaluated and updated continuously. Models, whether they be single- or multispecies, are derived from less-than-perfect knowledge of biology of species and behavior of fishermen. One of the values of fishing effects models is that they can be applied carefully as decision-making surrogates, but the responsibilities of scientists and managers take on increased importance under conditions where the models are more than research guides or tools for understanding.

B. Data and Information Needs.

1. Implement fisheries-independent monitoring and associated short-term research programs to collect basic population information and to track the status of stocks on a regular and long-term basis. For migratory species, this may require a coast-wide rather than solely a Bay-wide effort to be most effective.

Rationale

Data currently available on nearly all fisheries in the Bay are insufficient to support high quality modeling. Fishery-dependent data are weak and often unreliable (especially fishing effort statistics) and they are often unrepresentative. For example, much of the finfish harvest is taken by non-directed effort. Fishery-independent information collected to satisfy modeling needs also can satisfy other research needs, for example to determine levels of recruitment, effects of contaminants, and evaluation of restoration by stocking. Important types of fishery-independent data include estimates of abundance by life stage, growth rates, mortality rates, fecundity, sex ratios, age at maturity, spatial and temporal patterns of movements/migrations, stock identification, the extent of stock mixing, and use of various habitat types for spawning, as a nursery, for overwintering, etc.

We recommend a well-designed, multispecies monitoring study (perhaps stratified by time and habitat type category) that is Bay-wide and which would continue long-term. It must be supplemented by short-term, hypothesis-based research to address specific scientific issues. The short-term studies would be ideal as dissertation and thesis topics for students in Bay-area colleges and universities.

2. Develop a program for collection of recreational and commercial fisheries statistics on a Bay-wide basis. At a minimum, the collected information should include total catch and fishing effort, and species-specific age, sex, and size composition of the catch. Other recommended information includes gear type, time and location of the fishing effort, and non-harvest (i.e., discard) fishing mortality.

Rationale

Although requested many times, such a program has not been established. For example, Maryland and Virginia continue to base catch statistics on information collected from different sectors of the fishery. The statistics that are required not only are immediately useful for management but are essential for most modeling that examines and predicts the effects of fishing. The recently established, Chesapeake Bay Stock Assessment Committee (CBSAC) is concerned with these issues and is moving toward the establishment of such a program. The work of CBSAC and its recommendations are critically dependent on high quality fishery statistics.

3. Convince fishery managers of the importance of accurate and complete catch and effort data, and make them more aware of the ability of fishery stocks to respond to changes in fishing regulations.

Rationale:

Collection of fishery statistics is hampered both by inaccurate reporting of data and by incomplete data. To improve this situation scientists must gain the trust of the harvesters. Managers need to have reasonable expectations of what can be learned about the effects of fishing, the time it will take to assemble such knowledge, and the time required for stocks to go through enough reproductive cycles to demonstrate benefits of changes in harvest strategies.

4. Develop publications specific to Chesapeake Bay which will present, in a timely manner, results of living resources investigations.

Rationale

Documentation of results of fisheries and related investigations in the Bay need to be published in a way to insure that activities are not repeated, especially the ones that have not succeeded. Condensing information in the "gray literature," which is often voluminous and inaccessible, into an available publication will greatly enhance evaluation of scientific progress in the Bay. An example of such a publication exists in the California Cooperative Oceanic Fisheries Investigation Reports. This annual report is very effective in presenting research and monitoring results on living resources and the environment of the California Current region.

C. <u>Data/Specimen/Information Storage and Retrieval</u>.

1. Develop a system for entry of acquired data and storage of specimens, for use in subsequent studies of life history and population dynamics.

<u>Rationale</u>

The value of time series data in fisheries work cannot be overemphasized. Specimen collections can be an alternative method to track change in the physiological state and morphological characteristics of populations -- e.g., changes in contaminant concentrations, growth rates, and other physiological and morphological features. These collections, combined with long-term key species monitoring (see Working Group 2 Report), can provide an important data base that can be analyzed using present and future technologies.

D. <u>Strategies and Plans</u>

1. Develop stable and dependable funding sources for collection of long-term time series data to understand the effects of fishing and other factors on living resources populations.

<u>Rationale</u>

It is impossible to plan and execute long-term monitoring programs without the assurance that funding for those programs will remain stable and dependable. Because estimates of many fishery-related parameters are available only on annual cycles (recruitment, spawning, fishing, etc.), most studies of fisheries stocks and the factors controlling their abundance need many years of sampling to record the scales of variability and trends in population parameter values. Long-term programs will allow stock variability to be related to year-to-year environmental changes or long-term trends in the environment induced by anthropogenic causes. Effects of occasional catastrophic events (e.g., tropical storm Agnes) or effects of environmental and stock conditions exceptionally favorable for production may only be fully understood when they are included in long time series that span the range of environmental variability and associated stock responses.

V. WORKING GROUP 4 REPORT

RECRUITMENT VARIABILITY

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INTRODUCTION

The working group was concerned with the highly variable and generally declining recruitments of exploited resources in the Chesapeake Bay. The problem is particularly acute for anadromous finfishes and for oysters. Because the Bay environment, climate, effects of fishing, toxicants, and abundances of interacting species all may play a role in regulating recruitment and affecting stock-recruitment relationships, a broad-based research program is necessary to understand the causes of variability and decline. When the problem is understood, it may be possible to develop management strategies to improve or stabilize recruitment levels.

Two categories of monitoring and research were identified as necessary to make progress on the recruitment problem. These can be termed statistical (i.e. correlative) and process-oriented studies. The statistical studies should be designed to detect significant relationships between key hydrographic or other environmental variables and recruitment to the spawning stocks. The emphasis of statistical studies frequently is on interannual variability in recruitments. Process-oriented studies should be designed to determine the mechanisms by which environmental variables influence recruitment and should specifically provide information on the temporal and spatial scales of environmental events that affect recruitment. These studies often require intensive intra-annual efforts to detect and quantify the biotic and abiotic mechanisms affecting recruitment. Results from the statistical and process-oriented studies can be used to construct environment-dependent stock-recruitment models to predict future recruitments and surplus products to the fisheries, as well as stock biomass at maximum surplus production. This is one example of an approach that can provide the linkage between biotic and abiotic mechanisms that impact recruitment and affect stock stability.

The working group recognized that little is known about causes of recruitment variability for most Chesapeake Bay living resources. Nevertheless, it focused its attention on four species because they are Bay-dependent during a part of their early life history, they are important in the fisheries, or because they have experienced precipitous declines in abundance. They are oysters, blue crabs, American shad, and striped bass. The working group recognized that anthropogenic inputs, e.g., contaminants, as well as natural environmental influences, can affect recruitment and considered some approaches to evaluate their effects (see also Working Group 5 report).

Data Needs

Before statistical analysis can begin, a relatively long (perhaps 12+ years) time series of fishery-independent stock and age composition data is desirable for key species to index or estimate stock biomass and recruitments. In addition, a long time series of juvenile abundance indices is needed for each key species to determine if year-class strength is established at the juvenile stage or earlier. Significant, positive correlations between juvenile indices and recruitment to the exploited stock would indicate that "critical periods" occur mainly in the egg and larval stage. Determining the life stage at which recruitment is fixed would in effect define "recruitment" as the relative or absolute abundance at that life stage and at successive life stages.

Indices of recruitment and of exploitable biomass are most useful when calibrated to allow estimation of absolute abundances or biomass. For the exploitable stage, when catch is recorded, and if fishing mortality rates are known, absolute abundance can be determined. This is very desirable in quota-based management, in which number of recruits or exploitable population size often is required. Furthermore, many ecological or multi-species models require estimates of absolute recruitment or population size, not just indices of abundance (see Working Group 3 report).

Statistical (i.e. Correlative) Analysis Stage

A general approach, considered by the working group, is outlined below:

Data Needed	Statistical Properties and Tests	Potential Importance of Results
1) Long time series of recruitment and parent stock estimates.	1) Identification and correction of biases in abundance estimates.	1) Suggestions of possible causal relationships between hydrographic events and early life stage mortality.
2) Hydrographic and meteorological data (e.g., wind stress, Ekman transport, river flow, etc.) on a spatial and temporal scale compatible with early life stage development.	2) Estimates of variances associated with population abundances indices.	2) Use in sampling design for process-oriented studies.
	3) Linear and non-linear regression analyses to relate recruitment to several environmental factors.	

Relationships that are suggested by the statistical studies need to be validated by process-oriented research that estimates the effects of environmental and biological factors on short-term changes in growth and mortality of larval cohorts. Biases in abundance estimates must be corrected and variances must be estimated. Otherwise it will not be possible to use the abundance data to test hypotheses or to obtain unbiased parameter estimates in recruitment-based modeling.

Process-Oriented Stage

If statistically significant correlations between environmental factors and recruitment are found, the next stage is to examine the relationships and their link to growth or mortality of early life stages. The proposed, process-oriented research on finfish and shellfish recruitments is similar in many respects but differs enough to warrant the separate outlines provided below.

A. Finfish

Data Needed*	Methods and Experimental Design	Potential Importance of Results
1) Growth and mortality rates of early life stages.	1) Identification of cohorts and age structure by otolith daily ring analysis.	1) Rigorous examination and test of whether key environmental factors affect the stock-recruitment relationship.
2) Information on abundances of predator and prey of early life stages.	2) Estimation of birth dates and their relationship to environmental factors.	2) Establishment of causal links between environmental variables and recruitment level.
3) Environmental, climatic, hydrographic data.	3) Cohort-specific mortality and growth rates in relation to environmental variables.	

*All to be measured on relevant spatial and temporal scales.

B. Shellfish

Data Needed*	Methods and Experimental Design	Potential Importance of Results
1) Spatially extensive and temporally resolved abundance information on the larval and juvenile stages.	1) Time series measurement of larval production, spat settlement (oysters); determination of juvenile	1) Rigorous examination and test of whether key environmental factors affect the stock-recruitment relationship.

2) Related environmental and transport data.

3) Growth and mortality rates of early life stages.

abundance and identification of causes of mortality.

2) Intensive studies at selected, spatially confined sites keyed to larval transport studies.

3) Spatially extensive studies to expand the knowledge from intensive studies at selected sites to the ecosystem level.

2) Establishment of causal links between environmental variables and recruitment level.

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*All to be measured on relevant spatial and temporal scales.

The Need for Models

The complexity of the recruitment process and its dependency on a variable environment will require models to help understand the causes of recruitment variability. Both conceptual models (see Working Group 2 report) and numerical models that explicitly relate environmental factors to recruitment and adult stock sizes are needed. No single, environmentally-influenced model will suffice for all key species and it seems unlikely that any single modeling approach will be fully successful. The working group advocated a broad-based approach, recognizing that modeling would play a crucial role in recruitment research.

An example of a mechanistic, environmental-dependent, stock-recruitment model that has promise if environmental forcing variable(s) have been identified by statistical analysis and validated in process-oriented research is:

$$R = a * P * \exp(b * P) * \exp(c_1 * E_1) \ldots * \exp(c_k * E_k)$$

where R = predicted recruitment

P = spawning stock size

$E_1,\ldots,E_k$ = key environmental forcing variables

$a,b,c_1,\ldots,c_k$ = coefficients and exponents, to be estimated with their standard errors.

This model belongs to the Ricker family of domed stock-recruitment curves. The parameter b is the coefficient of density-dependent mortality and may be useful to determine the stock's resiliency to fishing and other anthropogenic factors that influence stock density and its compensatory reserve. Any of the E_k validated, environmental variables and corresponding coefficients, c_k, may be added, including toxicants or key climate variables. To the extent that these environmental variables can be successfully added, the model will be improved and the density-dependent component will be more accurately assessed. This example illustrates how a modeling approach can separate stock-dependent from environmentally-mediated influences on recruitment. Other, more comprehensive models may be equally good, or even preferred, once an adequate data base is available.

Key Species

1) Blue Crab: commercially important, bay-dependent for reproduction and nursery areas.

Data Available	Data Needed
30-year time series of recruitment and relative stock size, length frequency and landings by Virginia Institute of Marine Science.	Age-frequencies; determine stage(s) at which year-class strength is established.

2) Oysters: commercially important, bay-dependent for reproduction; probably a good indicator species of environmental change or degradation.

Data Available	Data Needed
46-year time series of oyster abundance and reproduction by Maryland DNR.	Size-frequencies and age-frequencies; determine stage(s) at which year-class strength is established.

3) Striped Bass: anadromous species, commercially and recreationally important; uses Bay and tributaries for reproduction and as a nursery.

Data Available	Data Needed
Juvenile indices from 1954-1986; relative abundances of spawning stock size, recruitment and age composition from 1981-1986 by Maryland DNR.	Longer time series on spawning stock size; stock biomass and recruitment to adult stock.

4) American shad: anadromous species, commercially important; uses Bay and its tributaries for reproduction and as a nursery.

Data Available	Data Needed
Population estimates, age composition and landings from 1980-1986 by Maryland DNR.	Longer time series on population size; juvenile indices.

Contaminants and Recruitment

The working group believed that effects of contaminants and their effects on recruitment must be studied. Some potentially fruitful approaches are:

1) determine Bay-wide egg/larval mortality and growth and then compare these to regional estimates, where regions are known to have different contaminant loads.

2) alternatively, estimate egg/larval mortality and growth for selected regions and compare these estimates between heavily contaminated and uncontaminated regions.

3) mesocosm experiments using larval survival and growth as criteria and local water quality as the treatment.

4) pathology of reproductive adults (especially for striped bass and American shad) and its effects on fecundity and egg quality.

Note: The Working Group 5 report treats the contaminant issue in detail.

Some Specific Recommendations and Needs

1) life-stage specific, fishery-independent surveys of abundances of key fisheries resources.

2) long time series of recruitments and adult spawning stock.

3) long time series of climatic, environmental and hydrographic data on appropriate time/space scales.

4) statistical and process-oriented research to identify and quantify recruitment-related phenomena.

5) modeling approaches for conceptualization, quantification and prediction of recruitment variability.

VI. Working Group 5 Report

POLLUTANTS AND DISEASES

James G. Sanders (Chairman), L. Eugene Cronin, Michael J. Fogarty, Michael Haire, Lenwood W. Hall, Jr., Stephen J. Jordan, George E. Krantz, Paul M. Mehrle, Ivar E. Strand, Jr., Chu-Fa Tsai

I. POLLUTANT IMPACTS

INTRODUCTION

An unanswered but basic question is, "Are the pollutants entering and contained within the Chesapeake Bay significantly altering biological processes or affecting stocks of living resources?" Except in small, isolated areas of the Bay that are grossly polluted, this straight-forward question cannot be answered with present-day technology. We are unable to define critical contaminant concentrations and document biological changes in natural ecosystems. Also, we cannot realistically predict from laboratory experiments the concentrations of toxic substances that will cause significant change in the Bay because experimental methodologies are not adequate to assess effects at the population or community level.

GOAL

To answer the basic question, the working group identified the following goal for long-term research:

"Develop assessment technology to determine the influence of contaminants on populations and community structure and their dynamics."

Achieving the goal will require long-term studies with sufficient data gathering efforts in both time and space to separate natural variability from change caused by anthropogenic inputs. It also will require an integrated team of scientists with expertise in aquatic toxicology, analytical chemistry, geochemistry, and ecology. Bioeconomic research also has a significant role because of the need to determine values and costs associated with different contaminant abatement strategies.

AREAS OF CONCERN

Concerns about contaminant impact fall into three general areas which must be successfully integrated to achieve overall success:

1. Contaminant loading. Contaminant levels within the Chesapeake Bay and sources of contaminants to the system need to be determined. A particular concern is the need to improve knowledge of inputs from effluents, especially from participants in voluntary compliance monitoring. In addition, strict attention to Quality Assurance/Quality Control

procedures in contaminant studies is essential to ensure that accurate and repeatable determinations are made.

2. Mechanisms of contaminant transport and transformation. "Bioactive" compounds undergo physical, chemical, and biological alterations in chemical form and partitioning. These changes drastically affect the transport of the compound, its ultimate deposition, and its toxicity in the system.

3. Ecological effects. "State-of-the-art" toxicology procedures cannot adequately assess impact of current, chronic loadings of low concentrations of contaminants on populations, much less on the community or the ecosystem. Current techniques, although greatly improved recently, must continue to evolve. And, the overwhelming number of potential toxic substances requires that assessment efforts be focused on some smaller, manageable subset. The assessment of ecological effects will require continued development of new experimental approaches and models to help predict and manage living resources.

To achieve the goal and successfully integrate the above three areas, three primary research needs were identified.

RESEARCH NEEDS

A. Develop experimental techniques to determine contaminant effects at the population and community level in specific Chesapeake Bay habitats.

Organisms in their native habitats are challenged by a complex mixture of contaminants. Even if it were feasible to measure all of them on time scales relevant to the organisms and communities, the measurements would not be sufficient to assess population or community impacts. Techniques are needed to estimate population declines, impacts on recruitment or year-class strength (see Working Group 4 Report) and changes in biological communities caused by both background and elevated contaminant concentrations and mixtures (Figure 4). These techniques must be specific to Chesapeake Bay resources, communities and habitats.

Specific research goals

1. Develop efficient assessment and monitoring tools:

   a. rapid inexpensive methods for contaminant analysis

   b. new, sensitive laboratory techniques for toxicological studies

   c. mesocosms

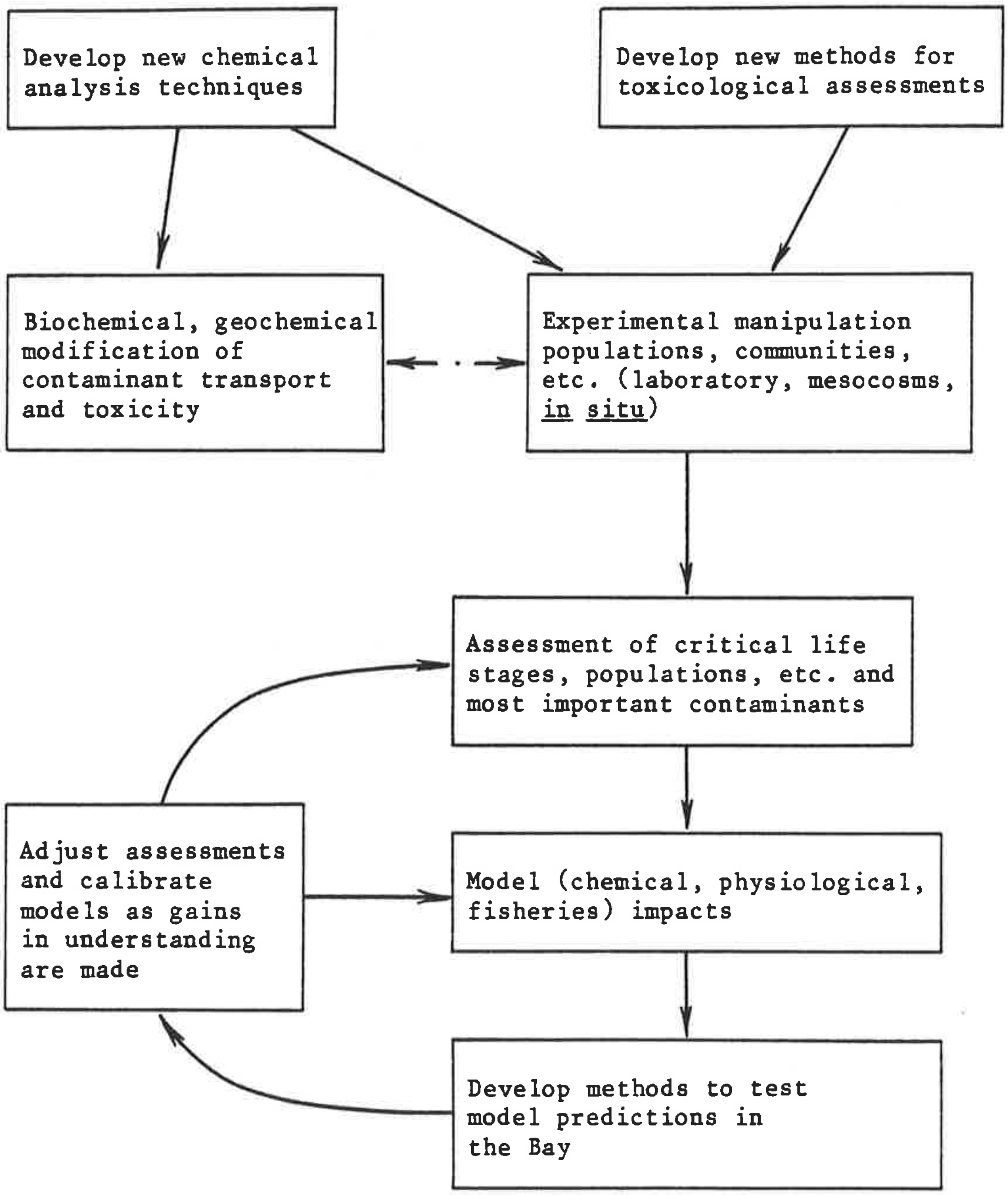


Figure 4. Conceptualization of the methods development required to understand impact of contaminants on populations and communities.

d. *in situ* techniques

e. portable/mobile laboratory techniques

2. Determine biochemical and geochemical mediation of contaminant transport, transformation, and toxicity:

   a. partitioning between solid and dissolved phases

   b. biological uptake and transformation

   c. effects of chemical form on contaminant toxicity

3. Identify species, life stages, populations, and communities that are:

   a. sensitive to contaminants

   b. representative of a variety of Bay habitats (salinity zones, sediments, water column)

   c. amenable to population modeling

   d. amenable to controlled, reproducible experiments

4. Identify cumulative and synergistic effects of contaminants via:

   a. chemical models

   b. physiological models

   c. ambient and experimental biological testing

5. Develop efficient toxicity screening methods for Chesapeake Bay habitats:

   a. bacterial/plankton/biochemical assays

   b. calibrate to experimental and modeling results for populations and communities

B. Develop modeling and analytical techniques that will relate toxic effects and ultimate fisheries yield.

A general analytical framework is required to evaluate potential effects of anthropogenic factors, including fishing mortality, contaminant stress and habitat degradation, on the stability and resilience of natural populations. One approach is to modify traditional fishery models to consider explicitly effects of contaminant/habitat degradation and fishing mortality. Many results of the research recommended in Section A could be directly used to estimate parameters of new fishery/contaminant models.

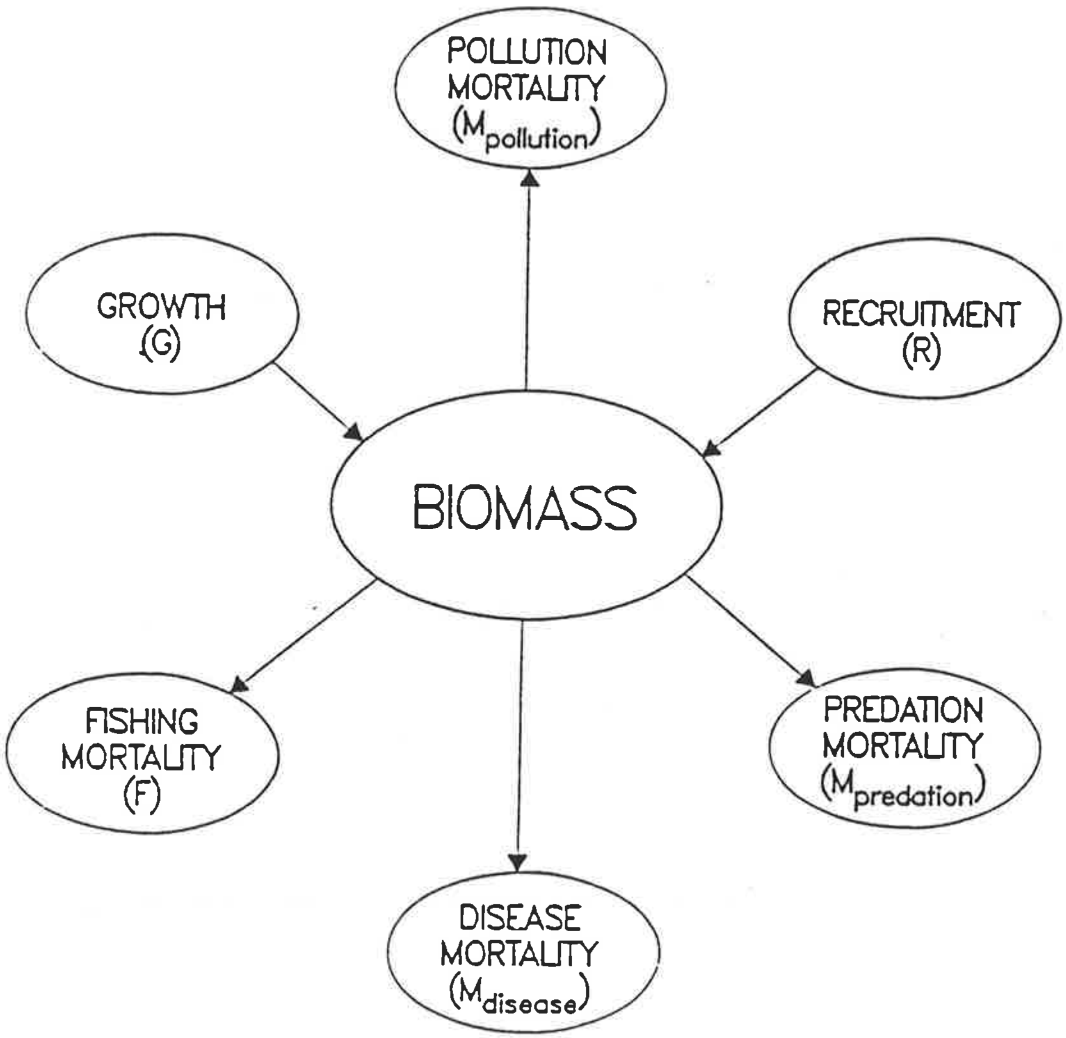
Fishery models are based on elementary demographic principles, specifically birth and death rates (and to a lesser extent, individual growth rates). A principal goal of fishery research is to determine the effect of fishing mortality on long-term potential yield, recruitment, and other population parameters. For populations subjected to additional stresses, such as pollution, it is necessary to consider the cumulative and/or synergistic effects of all man-induced stress.

Traditional fishery models can be easily modified to incorporate additional terms for pollution-related mortality or effects on growth. Different life history stages may be sensitive to pollutant stress to varying degrees (also see Working Group 4 Report). There also may be subtle, non-lethal effects of contaminant stress (e.g. reduced reproductive success, increased susceptibility to disease and predation). The modified fishery models must be able to accommodate these factors.

It is possible to describe pollution effects in terms of fishing mortality equivalents and to specify losses in potential yield due to pollution-related mortality (Figure 5). Critical inputs to such models are estimates of mortality rates under varying levels of contaminant stress at different life stages. In principle, it is possible to estimate these mortality rates using a combination of laboratory and field studies. Mesocosms and large, in-situ enclosures appear to be particularly promising research methods.

C. Extend our understanding of contaminant effects into the Chesapeake Bay, determine the components of the ecosystem which are most sensitive to the toxicants, and develop a predictive capability for new compounds.

When techniques have been developed, they must be used in the Bay. Emphasis should be on predicting long-term chemical effects of contaminants on biological properties such as growth, reproduction, and behavior (i.e. prey-predator relationships). For both efficiency and effectiveness in minimizing damage to Chesapeake Bay living resources, it is essential that we improve our ability to identify the most serious toxicants, those of less but serious potential, and those which are relatively unimportant. Different contaminants affect organisms in drastically different ways, because there are many modes of uptake and biological impact. Techniques must be developed to allow classification of toxic substances into groups with similar effects. Especially needed are predictive techniques using "quantitative structure-activity relationships (QSAR)" that will allow hazard assessment of multiple contaminants with minimal data generation requirements. Assuming that chemicals with similar chemical structure will produce



$$B_{t+1} = B_t + G + R - F - M_{predation} - M_{disease} - M_{pollution}$$

Figure 5. Generalized relationships between forces affecting the biomass of an exploited population. Components of mortality other than those due to fishing can be expressed as fishing mortality equivalents. B=Biomass, G=Growth, F=Fishing Mortality, M="natural" mortality. (Illustration courtesy of M.J. Fogarty, National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, MA.)

a similar impact upon organisms, contaminants can be ranked and priorities set based upon their similarity to chemicals of known toxicity. Thus, the use of QSAR will allow rapid prediction of toxicity and bioconcentration of contaminants and their mixtures.

Hazard assessment of chemicals and mixtures requires identification of the most important living organisms of the Bay -- including appropriate representatives of major species at each trophic level and the most sensitive life stages of important species. Because it is unlikely that effective hazard assessment of all living organisms can be carried out, subsets of key organisms must be identified.

We must initiate (expand) long-term contaminant monitoring programs in key Chesapeake Bay habitats. Biomonitoring on appropriate time scales should assess significant inorganic and organic contaminants and include important Chesapeake biota from all major trophic groups. Important Chesapeake Bay habitats, such as spawning grounds for anadromous fish, should be the primary areas evaluated, including, where feasible, stations already included in ongoing and previous monitoring efforts. This information is needed to develop time-series data to evaluate adverse changes in water quality, contaminant conditions and effects on important Chesapeake Bay biota.

D. Resource Economics: Role of contamination and disease in consumer perception of resource quality.

Quality can dramatically influence the economic importance of living resources and seafood products. An understanding of contaminant (and disease) effects on consumer perception of quality and demand for Chesapeake Bay resources is an important element in determining "acceptable" pollution loading. If consumers perceive resources as "unhealthy" because of poor Chesapeake Bay water quality, this lowers utilization and economic values generated by the resources. A failure by management agencies to recognize or understand this relationship can lead to acceptance of excessive levels of pollution.

One testable hypothesis is that disease and contamination lower consumer perception of quality, driving down seafood consumption. For example, time series data on several important species (e.g. oysters) should be analyzed to determine effects of specific contaminants (e.g. kepone) or disease organisms (e.g. *Vibrio*) on consumer demand for Chesapeake Bay seafood. Such information could be used to justify pollution controls because benefits of improved water quality could be demonstrated by the increase in value and utilization of living resources. A caveat is required here because increased utilization could lead to further declines in abundance of resources already depleted by overfishing.

A survey of the Chesapeake Bay human population could determine how environmental parameters such as pollution or degraded habitat influence uses of the Chesapeake Bay. Preliminary analyses have suggested substantial variation in use based on environmental quality but documentation will require in-depth research. While we await accurate and precise information about contaminant effects on abundance of living resources, human perceptions of water quality and its effect on utilization of living resources can promote effective management of both the Bay habitat and its fisheries products.

II. DISEASES

INTRODUCTION

Many of the issues, concerns, research goals, and research needs identified for toxic contaminants and hazardous substances are generic and applicable as well to diseases. For example, the basic, as yet unanswered question is similar: "Is there a disease problem in the Chesapeake Bay?" An acceptable response must be well-documented for specific populations of living resources. Scientists must clearly demonstrate how diseases and parasites harm living resources and influence both population and community dynamics. A change in thrust from descriptive laboratory research towards quantitative field and laboratory research is needed.

The proposed strategy for research could parallel the sequence proposed for research on contaminants. Thus, we need to focus first on sources and levels of disease and parasites in the Chesapeake Bay. To accomplish this, monitoring of resources is required and there is need to develop new methods to rapidly detect changes in host response to disease and flux of disease within host populations.

Procedures to assess the dynamics and impacts of disease must adhere to the same Quality Assurance/Quality Control scrutiny used in contaminant research. This will improve the reliability of long-term trend analysis and is essential if disease information is to be used effectively in modeling impacts on population abundances and ecosystem dynamics.

RESEARCH NEEDS

Several areas of concern require research.

1) There is evidence that many diseases are intensified because they interact with environmental stress. Disease may express itself in host populations as a consequence of synergistic interactions with stressors such as sublethal toxicants, hypoxia or pH changes.

2) There is a need to include histopathology in research and resource monitoring to enhance understanding of disease mechanisms.

3) Technical procedures and institutional policies must be developed to prevent introduction of exotic diseases and parasites, and to limit the spread and intensity of endemic pathogens. These procedures and policies must be prominent in management strategies, especially in restoration

programs using hatchery-reared or genetically-engineered organisms, and in geographical translocation of stocks (see Working Group 6 report).

4) Once disease mechanisms have been described and are understood, there is a need to provide functional and cost-effective mechanisms to control the diseases and to enhance management of the resources. Also, both research and monitoring programs must be prepared to anticipate the problems created by new parasite and disease phenomena.

III. INFRASTRUCTURE AND LONG-TERM GOALS

For research initiatives on contaminants and disease to result in meaningful end products -- protection, maintenance and enhancement of living resources -- they must evolve from a conceptual to an implemented stage. To achieve implementation, several suggestions are offered:

1. Clearly define research programs to focus on research needs of specific users (resource managers, regulating agencies).

2. Establish an integrated, multi-disciplinary approach at both scientific and management levels. Bi-state and District of Columbia cooperation are essential.

3. Develop a long-term commitment to the program -- answers will not come quickly or easily.

4. Develop a multi-source funding base that should include both research and regulatory agencies at the State and Federal levels.

5. Ensure that data are readily available to other researchers, and to resource and regulatory agencies. A centralized, well documented data base (e.g., within the Chesapeake Bay Program data base) should be established.

6. Develop (where necessary) and implement standard laboratory and field methodologies. Formalize stringent quality assurance/quality control protocols for research.

7. Produce, in a timely manner, peer-reviewed documents which report findings of both individual and integrated research. A report series, specific to Chesapeake Bay living resources and environmental problems, is suggested (see Working Group 3 Report). Summaries of research results, addressed to managers, regulators, and citizens should be issued periodically.

VII. Working Group 6 Report

RESTORATION STRATEGIES

Reginal M. Harrell (Chairman), Edward J. Chesney, Jr., Dennis A. Powers, Victor S. Kennedy, Robert J. Orth, William G. Pearcy, Louis J. Rugolo, Charles M. Wooley

INTRODUCTION

Declines in abundance of economically important living resources within Chesapeake Bay and its tributaries have created a need for evaluating and, where feasible, implementing restoration programs. Organisms that may be candidates for extensive restoration efforts include striped bass, American shad, oyster and seagrasses. In these cases, restoration programs already are being planned and implemented to some extent. There is a pressing need to evaluate such programs, which will require research on the biology of species, the ecology of the Bay ecosystem, and the economics of restoration.

Restoration programs offer opportunities to restore degraded habitat as well as to increase the abundances of species which have declined. Certain responsibilities accompany the opportunities. The Bay ecosystem must not be threatened by the restoration programs themselves; the genetics of stocks and gene pool diversities must be maintained; and diseases should neither be introduced nor spread via hatchery release programs. With those caveats, restoration strategies can be developed. Evaluation of the strategies is necessary at each stage, from planning through implementation. Long-term research programs and monitoring are essential to develop the strategies and to understand the impacts that will result from habitat modifications or hatchery releases of shellfish and finfish.

Both Stock restoration and Stock enhancement strategies can be developed. These strategies differ in degree and philosophy. Stock restoration is undertaken to restore a living resource to an acceptable level of abundance to allow the restored population to maintain yields via reproductive self-sufficiency. Alternatively, stock enhancement programs increase stock levels by hatchery releases (put and take) but without expectations of longterm stability or self-sufficiency of the stocked population. Although management procedures may be similar in stock restoration and stock enhancement programs, requirements for research and knowledge of the ecosystem may be very different. A third concept is that of habitat restoration. Degraded habitats can be restored to increase carrying capacity of living resources. The implications of habitat restoration can be systemwide and require monitoring as well as research to evaluate effects. The costs and benefits of stock restoration, stock enhancement, or habitat restoration in the Chesapeake Bay are generally unknown and are proper topics for bioeconomic research.

APPROACHES, PROTOCOLS AND QUESTIONS

Before fully implementing a restoration program it may be necessary to restore the habitat to some minimal acceptable level. And, it may be necessary to augment natural production of native stocks with hatchery-produced organisms. A carefully designed restoration strategy, with clear objectives, well developed protocols, a good plan for evaluation of results, and a well defined end point can be used as an effective management tool.

The following questions should precede restocking a living resource:

1. Has a social or economic need for restoration been demonstrated?

2. Has the feasibility (i.e. technical and practical probability) of stock restoration from a biological economic, social and political viewpoint been determined?

3. Can a scientifically and technically sound plan be developed to address reestablishment or protection of habitat and stocks?

Once a need is demonstrated and the feasibility of restoration established, questions to be addressed by research or monitoring must be considered.

1. Is the problem of depressed populations caused by habitat degradation, or is the decline in spawning stock precipitated by excessive fishing, disease or recruitment failure from undetermined causes? Without fundamental understanding of the cause of stock decline, restoration programs will be unsuccessful and enhancement programs may be costly.

2. If habitat degradation is responsible, can habitat quality be returned to an acceptable level?

3. If the problem has resulted from causes other than habitat degradation, can the stocks be managed to increase abundance and, if not, is stock enhancement a viable alternative to stock restoration?

4. Where habitats have been altered and cannot support self-sufficient stocks, are there alternative restoration or enhancement strategies for living resources that could be evaluated and which would be economically, politically and socially acceptable?

5. When restoration programs are in place, how will they be evaluated to determine long-term probability of success?

HABITAT AND RESTORATION GOALS

Minimum habitat quality must be known before effective stock restoration programs can be instituted. Research is needed in four areas related to habitat quality.

1. Identification of key habitat requirements for each life stage of living resources that are candidates for restoration.

Retrospective analyses of historical data on habitat, combined with development of Habitat Stability Indices (HSI) for target species, will provide a baseline of knowledge. These steps may be essential before undertaking restoration of self-sustaining, living resources populations.

2. Restoration of habitats to previous acceptable levels to promote reestablishment of self-sustaining populations and communities.

Once identified, the habitat quality required to reestablish species must be provided. Research must focus on determining the feasibility of recreating or restoring Chesapeake Bay habitat and, ultimately, on testing the quality of habitat through release of hatchery-produced progeny, which must be monitored at each life stage.

3. Determination of the carrying capacity of habitats in the Chesapeake system for target species and desirable biological communities.

Carrying capacity and productivity of habitats must be defined to avoid unrealistic expectations in restoration programs. If habitat cannot be fully restored, or if the present-day Chesapeake system is unable to sustain historical abundances of living resources, hatchery-release programs or other measures to restore populations may be fruitless. Estimates of carrying capacity also are necessary to assess potential effects of stock enhancement on associated species. For example, what effects will hatchery release of striped bass have on competing species or on forage species in the Bay? (See Working Groups 1 and 2 reports for related discussion.)

4. Evaluation of stock enhancement as an alternative to stock restoration when habitats cannot be fully restored.

When full restoration of habitat is not feasible, it may be difficult or impossible to restore living resources to historical, self-sustaining levels. In these cases, the alternative strategy of stock enhancement may be justified. Biological research to determine the probability of increased yield and bioeconomic research to determine societal costs and benefits from enhancement programs will be necessary.

STOCK CONDITION AND QUALITY

Ideally, population biology of native stocks should be fully understood before restoration activities begin. Historical estimates of trends in stock size and age composition data of a stock are needed. Factors that limit recruitment should be identified and the life stages that are most vulnerable to adverse environmental impacts should be known.

An acceptable practice of fisheries management includes utilization of hatchery stocks to enhance or restore native populations. Hatchery-produced stocks may differ genetically from wild stocks because current hatchery practices do not employ gene pool conservation methodology. When minimal numbers of brood stock are used to produce gametes, gene pool variability can be reduced. Because artificial selection may replace natural selection after several generations of hatchery dependency, the overall fitness of wild stocks may be affected.

It is possible that degraded habitat in the Chesapeake Bay already has acted in a selective way on the gene pool of living resources. For example, present-day stocks of oysters, striped bass and shad may have faced selective pressures that have significantly altered allele frequencies relative to those that prevailed decades ago. Research on stock structure and genetic diversity of living resources in Chesapeake subestuaries that have suffered varying degrees of alteration will allow inferences about changes in gene pool diversity that may have occurred.

If potential genetic problems are not minimized, stock traits such as migrational tendencies, age at maturity, time of spawning, availability to local fisheries and reproductive potential could be affected. In addition, hatchery selection may produce progeny that are susceptible (or resistant) to disease, more (or less) vulnerable to predation after release, or more (or less) highly aggregated than wild fish. Interbreeding between hatchery and wild fish potentially may be detrimental to fitness of wild stocks. The introduction of new species or hybrids of existing species also may pose threats to existing gene pools if interbreeding occurs. Selection and evaluation of local brood stocks for hatchery production are required. Determination of the fitness of hatchery progeny, and their relative contribution to restored populations and to the spawning stock are critical in evaluating a restoration program.

HATCHERY PRODUCTION

Evaluation of benefits from hatchery releases requires identification of hatchery and wild individuals. This can be achieved, at least in finfishes, by tags, marks, or scale/otolith characteristics. Recaptures of marked fish will permit estimates of migrations, growth rates, size-selective mortality (by means of scale/otolith analyses) and their relative contribution to the fishery.

Before restoration is considered via hatchery production, some questions should be answered.

1. What is the size of the stock and how has it varied historically?

2. What is the age composition, sex ratio, and age at maturity?

3. What is the quality of reproductive products (eggs, sperm) and how does it vary with age or size, and among different areas of the Bay?

4. What factors limit recruitment? Are they man-induced or natural and at what life stage do they operate?

HYPOTHESES AND TESTS

Many of the questions on potential for successful restoration, fitness and genetic integrity of hatchery-produced stocks could be addressed by testing hypotheses in Table 1.

OPPORTUNITY

Release of significant numbers of marked hatchery fish provides a unique opportunity to evaluate the status of pre-recruits in stressed wild stocks. Based on the proportion of marked fish in surveys, population estimates of pre-recruits in the wild stock as well as in the hatchery component can be obtained. Relative survival rates of pre-recruit wild and hatchery fish also can be determined from change-in-ratio estimators based on surveys of hatchery and wild fish. If absolute mortality rate of the marked, hatchery component can be determined, then a mortality rate estimate of wild stock also is possible.

BIOECONOMICS

There is an important need for bioeconomic research to evaluate restoration programs. Because costs of restoration can be high, the real and perceived benefits must be considered. Research on utilization by commercial and recreational fisheries is critical to determine how hatchery production should be allocated. The impact of potentially large increases in amounts of striped bass or oysters on markets and on participation in the recreational fishery must be investigated. Questions related to costs of restoring ecosystems, when benefits to fisheries are largely unknown (e.g. restoration of seagrass communities), but which still may be highly desirable from a societal point of view, need to be addressed.

POLICY

Research on and implementation of restoration measures must go on simultaneously. Thus, an overall restoration policy should be developed within an institutional framework that can guide the restoration effort but which is responsive to legitimate concerns about such efforts. A policy group is needed to identify research needs, recommend implementation of restoration measures, and evaluate the benefits and costs that are incurred.

Table 1. Hypotheses and tests to evaluate hatchery-released progeny and their contribution to restoration enhancement efforts.

Hypothesis	Test
1) Hatcheries can produce sufficient progeny to enhance native populations and make a significant contribution to the total stock and population recruitment.	1) Mark-recapture studies to determine proportion of hatchery-produced individuals in the population and on the spawning grounds. Alternatively, use genetic markers to identify hatchery-produced progeny.
2) Mortality rates (natural, predation and fishing) of hatchery-produced stocks are similar to those of wild stocks.	2) Analyze predator stomachs to determine the proportion of marked, hatchery-produced progeny. Determine relative exploitation rates of marked hatchery stock relative to wild stock.
3) Maximum contributions to restored or enhanced populations result from releases of optimal-sized individuals.	3) Make simultaneous releases of individuals of different sizes/ages from the same brood stock into the same habitat. Recovery of marked individuals will assess relative survival rates.
4) Optimal time of release of hatchery fish is affected by prey availability and by competition with fish having similar feeding habits.	4) Test release groups at times or in areas of high food availability vs low food availability. If growth or survival is food-dependent, release schedules should be adjusted to minimize competitive interactions.
5) Survival or growth of release groups is inversely related to the number of fish released at one time/place (i.e. density-dependent survival or growth occurs).	5) Test by evaluating relative survival or growth of small and large release groups.
6) Hatchery stocks will spawn at the same locations and times as wild stocks.	6) Test by surveying for marked fish on the spawning grounds and in alternative spawning areas.
7) Mortality rates of released juvenile, anadromous fish are higher in fresh water parts of the estuary than in saline waters.	7) Release uniquely marked fish of same size/age at the same time in different locations. Evaluate survival by recapture of marked fish to determine relative survival rates of the release groups.
8) Hatchery stocks are genetically similar in heterozygosity to native populations.	8) Carry out comparative genetic evaluation of hatchery stock and wild stock.

A P P E N D I X   A

AGENDA FOR WORKSHOP

AGENDA

Monday, 2 February 1987

15:00-evening. Arrival of workshop participants at the Donaldson Brown Center

15:00-17:30. Registration of participants

19:00. Dinner

Tuesday, 3 February 1987

07:00-09:00. Breakfast.

08:00-09:30. Continued arrival and registration of workshop participants and agency representatives at Donaldson Brown Center

General Session

(Workshop Participants, Agency Representatives, Research Administrators)

09:30	Welcome; Workshop Objectives and Goals	Edward Houde
09:35	Introductory and Welcoming Remarks	Verna E. Harrison, Assistant Secretary, Maryland Department of Natural Resources
09:45	A Look Back at Research and Management	L. E. Cronin
10:05	Water Quality Monitoring in Chesapeake Bay	William Eichbaum, Assistant Secretary, Office of Environmental Programs, Maryland Department of Health and Mental Hygiene
10:25	Problems and Promises for Shellfishes in Chesapeake Bay	Herbert Austin
10:45	Finfishery Resources and Trends in the Chesapeake Bay	Louis Rugolo
11:05	Estuarine Circulation and Physical Processes of Importance to the Ecology of Chesapeake Bay	William Boicourt
11:25	Coffee	

Tuesday, 3 February 1987 - cont'd.

11:45	Autochthonous Sources of Particulate Organic Matter in Chesapeake Bay and its Coastal Plume	Thomas Malone
12:05	Benthic-Pelagic Coupling	W. Michael Kemp
12:25	The Baltic-Ecosystem -- a Changing Basis for the Fisheries	Bengt-Owe Jansson
12:50	Lunch	
14:00	San Francisco Bay: Environmental Issues and Contrasts with Chesapeake Bay	James Cloern
14:25	Predator-Prey Relationships and Multispecies Assessments	Niels Daan
14:50	Remote Sensing as a Research Tool for Linking Environmental Factors and Bay Productioon	Mary Tyler
15:10	Bioenergetics Modeling: Species Interactions and Potential Productivities -- Great Lakes Experience	Donald Stewart
15:30	The Anatomy of the Ecosystem's Network of Chesapeake Bay	Robert Ulanowicz
15:50	Time Series Recruitment Process and Coordinated Interdisciplinary Research	John Hunter
15:15	Where Did all the Coho Go?	William Pearcy
16:35	Coffee	
16:55	Modeling Man's Impact on Fish Populations	Michael Sissenwine
17:15	The Role of Bioeconomic Modeling in Developing Research and Management Programs	Lee Anderson
17:35	An Overview of Contaminant Research Needs in the Chesapeake Bay	Paul Mehrle

Tuesday, 3 February 1987 - cont'd.

17:55	Effects of Large-Scale Hypoxia on Fishery Resources: Comparisons from the Gulf of Mexico	Donald Boesch
18:15	Session Wrapup	Edward Houde
18:25	Adjourn	
19:00	Dinner (invited workshop participants)	
20:15	"Science, Research and Management of the Chesapeake Bay" (after Dinner remarks)	Ian Morris, Director, CEES, University of Maryland
20:30	Discussion, Relaxation, Refreshments	

Wednesday, 4 February 1987

07:00	Breakfast	

Working Group Meetings
(Workshop Participants)

09:00	Organization, Assignments and Guidelines for Working Groups	Edward Houde
09:20	Working Group Deliberations (Individual working groups will meet separately. For those inividuals with multiple interests/expertise, participation in more than one working group is encouraged.)	
11:00	Coffee	
11:20	Continue Working Group Deliberations	
13:00	Lunch	
14:15	Preparation of Working Group Recommendations and Reports	
16:00	Coffee	
16:20	Continue Preparation of Working Group Recommendations and Reports	
17:30	Adjourn	

Wednesday, 4 February 1987 - cont´d.

18:00	Happy Hour	
19:00	Dinner	
20:30	Maryland Sea Grant Film "The Twilight Estuary"	

Thursday, 5 February 1987

07:00	Breakfast	

Plenary Session

(Workshop Participants, Agency Representatives, Research Administrators)

09:00	Call for Reports	Edward Houde
09:05	Working Group Reports and Discussion	Working Group Chairmen and Rapporteurs
11:40	Closing Discussion and Remarks	Edward Houde
12:00	Adjourn	

APPENDIX B

SYNOPSES OF ORAL PRESENTATIONS

Long-Range Research Needs for Chesapeake Bay Living Resources

WORKSHOP OBJECTIVES, ORGANIZATION AND GOALS

Edward D. Houde
Chesapeake Biological Laboratory
The University of Maryland
Center for Environmental & Estuarine Studies
Solomons, Maryland 20688-0038

Many results and recommendations of EPA's Chesapeake Bay Program and subsequent deliberations indicated that the health of living resources should be a criterion for judging effectiveness of water quality and cleanup efforts in the Bay. Extensive, Bay-wide programs have been instituted to monitor water quality, plankton productivity and benthic processes. Little of the new effort includes fisheries research or monitoring, despite a clear need to relate the water quality work to potential production, harvest and management of living resources.

There is a large component of fisheries research, management and monitoring that is carried out independent of bay-wide ecological research and monitoring. Much of that effort, which is carried out by the states of Maryland and Virginia or their contractors, is crisis-oriented, directed at a few stocks or species and designed to respond to immediate management needs. Little of it is long-range, Bay-wide, or concerned directly with the relationship between the Bay's potential productivity and living resources production. Newly-instituted stock assessment programs, jointly pursued by Virginia and Maryland, will improve fisheries statistics/stock assessment and provide the basis for better future management. There remains the need for long-range ecological and bioeconomic research on living resources. The workshop will consider this area of need.

There are many concerns for Chesapeake Bay living resources. Nutrient inputs from point and non-point sources have increased over the years and are thought to negatively influence fisheries production, although the linkages and magnitude of such effects are unknown. Summer hypoxia is increasing and also may negatively impact living resources. Seagrass beds, a presumed critical nursery habitat for many fish and invertebrates, have declined greatly. A complex mix of pollutants, toxicants and low pH is believed to be at least partly responsible for failed recruitments and declining abundances of anadromous species. Overharvesting, especially notable on oysters and striped bass, has depleted these resources and poses a threat to their recovery given the present degraded condition of Chesapeake Bay.

Of the major resources harvested from the Bay, only blue crabs, menhaden and bluefish landings have not declined from peak landings recorded decades ago. The sharp declines in landings of anadromous species contrast with more modest declines, or fluctuating landings, of marine spawners. The species which have not declined or have declined least spawn offshore or near the Bay mouth, suggesting that the Bay itself or its tributaries are degraded and unable to support successful reproduction. But, fishing mortality has been high, climatic events of "one in a century" proportions (e.g. tropical storm Agnes) have occurred and poorly understood economic/-social factors have acted during the past 25 years to confound, or at least confuse, the picture. Long-range research programs that focus on Chesapeake Bay productivity and its complex linkages to living resources and, ultimately, to management of those resources are required.

Such long-range research is needed to inform us of the levels of resource productivity and harvest that we can expect now and under changed Bay conditions. Can we restore resources to their former level of abundance -- e.g. could the Bay presently sustain the oyster resource at levels that once allowed 10 million bushel harvests? Or, given a large hatchery input of striped bass in the future, will there be sufficient forage present to sustain it, especially when other predators, e.g. bluefish and weakfish are present at moderate to high levels of abundance? The questions and problems are fundamental ones about system productivity and its complex relationship to living resources. Answers to these questions may be closely tied to the anthropogenic insults that the Bay has been forced to bear in recent years. Furthermore, the future of living resource harvests will depend partly on social decisions and willingness to bear the costs of research as well as the costs of management.

Seven working groups have been designated to address major problem areas. Six areas are generic in the sense that they deal with ecosystem or fisheries research needs that exist in many estuaries and coastal systems. The seventh is specific in the sense that it relates directly to Chesapeake Bay species and their habitat needs. The seven groups are:

1. Nutrients, Anoxia, and Fish Production
2. Predator-Prey Relationships and Systems Energetics
3. Effects of Fishing
4. Recruitment Variability
5. Pollutants, Toxicants and Disease
6. Restoration Strategies
7. Review of Species-Specific Needs and Living Resources Habitat Criteria.

Each working group, via its designated chairman, will produce a draft report before the workshop adjourns listing recommendations and providing rationale for research. When possible or desirable, research needs should be prioritized and framed to test hypotheses. Recommendations will be forwarded to the supporting agencies, primarily Maryland's Department of Natural Resources and the U.S. Department of Agriculture. The Workshop Proceedings is intended to serve as a guideline for long-range research that will link water quality monitoring, system productivity studies and lower trophic level ecology to living resources research.

To be most useful, our advice and recommendations should consider the following points. The space and time scales, as well as the extent of monitoring or surveys in support of living resources research, need be designated. Both specific and interdisciplinary research/science must be identified. While we should not take a narrow point of view, we should consider societal needs and recommend scientific programs or approaches that will ultimately provide products for use by managers. The feasibility, logistics and costs, when known, ought to be included in our deliberations. Finally, infrastructure needs, either at the scientific program or at an agency/commission level must be considered.

Scientists from several disciplines are represented at the workshop. We think that the combined expertise, in a working group setting, will be effective in identifying research programs likely to benefit understanding the Bay and its living resources. Workshop participants bring experience from the Pacific Coast, San Francisco Bay, the Great Lakes, Baltic Sea, North Sea, Gulf of Mexico, and Northwest Atlantic in addition to the Chesapeake Bay. There are analogies and sometimes contrasts in living resources or ecosystem problems among these regions. Solutions to ecosystem and living resources problems have not come easy in any of the regions. But, the assemblage of expertise, awareness of problems and experiences with both fruitful and failed approaches should allow our workshop participants to recommend many elements of a plan to successfully address long-range research needs in Chesapeake Bay.

Lastly, we should not forget the many Chesapeake Bay programs, conferences, symposia and workshops that have preceded us. They have provided the foundation for our workshop and have identified a need for the kinds of research that we will recommend. Our effort will be unique in the context and the extent to which we concentrate on long-range, living resources research. Our predecessors have provided the impetus that is required by specifically identifying the well-being of living resources as the criterion by which Chesapeake Bay management success will be judged.

A LOOK BACK AT RESEARCH AND MANAGEMENT

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I assume, and hope, that "long-term" means long enough to answer the question addressed through research, and that "living resources" includes all organisms of economic value (commercial or recreational), of ecological importance in sustaining the system, of aesthetic significance, or abundant in the Chesapeake Bay system. If these assumptions are correct, this Workshop can be the most valuable we have ever had.

There is a considerable history of management efforts and research related to Chesapeake Bay, heavily skewed toward the harvested species. There was a long period of discovery beginning with Captain John Smith's colorful but useful notes on a new world. Knowledge greatly expanded as new gear (dredges, gill nets, pound nets, purse nets, trawls, crab pots, hydraulic escalator dredges plus scientific collecting gear) revealed more and more from previously unsampled habitats. Diversity and fantastic abundance were well documented. From 1630 to 1930 and beyond, description continued. The FISH HAWK survey of 1918-22 produced the fine document "Biological Study of the Offshore Waters of Chesapeake Bay" and "Fishes of Chesapeake Bay." In 1919, Churchill wrote the excellent monograph "Life History of the Blue Crab."

Problem solving and management efforts did not begin in significant scale until late in the last century. Brooks distinguished zoological studies and management recommendations for oysters, made in 1891, are still largely correct and useful -- but the management steps recommended are still not fully achieved.

Management efforts were first directed to protecting human health, then the health of valued species, then to reducing over-fishing. Eventually, species management has been attempted in part, including desirable organisms and some obnoxious ones. Only recently has the management of the biological system received attention. Dr. Hargis has identified the post-1940 era as the "quantum jump period" in Bay related research.

I once reviewed efforts toward "rehabilitative management" to see if we have ever intentionally restored a species to a selected previous level, using the American shad, striped bass, soft-shell clam, oyster and blue crabs for the review. Despite many constructive efforts, I concluded that there was no case of successful rehabilitative management. I blame ignorances, pollution, and politics -- and the removal of the ignorance is what we are about in this Workshop.

There are substantial dissonances between open unrestricted research and management activities. There are also many instances of successful rapport, and a compelling need for high courtesy and 60:60 tolerance between the persons involved.

Since 1940, I have participated, I think, in scores of workshops and conferences related to the management of living resources. A case is provided by the efforts of the Chesapeake Research Consortium to identify the principal research needs, consolidate them, rank them, and explain them. Over 400 questions were reduced to 10 principal topics -- through workshops, experienced judgement and the skilled writing of knowledgeable people.

Do workshops and related efforts have significant value? I am certain that they can. They effect participants directly and others in more subtle ways. They are rarely acknowledged, and the effects are less than we optimistically hope, but the value is real and substantial.

What is missing in our research effort? Personally, I think that the greatest weakness is in the rarity of excellent structured research programs, with clear objectives, cooperative action by scientists and managers, sequential design in appropriate disciplines, completion - and fully adequate funding. We must, for best management, also have appropriate small projects, room for smart mavericks and thorough fundamental knowledge of the Bay system.

On the basis of a long look back, I recommend to the Workshop:

1. AS FULLY AS POSSIBLE, CONSIDER THE LIVING RESOURCE TO INCLUDE ALL ECONOMICALLY USEFUL SPECIES, ECOLOGICALLY IMPORTANT ORGANISMS, AESTHETICALLY OR INTELLECTUALLY SIGNIFICANT FLORA AND FAUNA AND ALL OF THOSE WHICH ARE ABUNDANT.

2. AVOID TRIVIAL QUESTIONS AND INTERESTS. THINK NO SMALL OR SELF-SERVING THOUGHTS. IDENTIFY THE TRULY IMPORTANT QUESTIONS AND DESIGN ADEQUATE RESEARCH. THE COST IS WORTH IT.

3. AVOID THE FALSE PREMISE AND THE CHEAP ALTERNATIVE. THE FIRST DESTROYS FAITH AND THE SECOND IS NEVER CHEAP IN RESEARCH.

4. DESIGN THE NECESSARY RESEARCH AND SEQUENCE FROM FUNDAMENTAL TO TECHNICAL, INVOLVING AS MANY DISCIPLINES AS ARE NECESSARY. REVIEW PROGRESS AND IMPROVE THE DESIGN.

5. AS SCIENTISTS AND MANAGERS, APPROACH MANAGEMENT-RELATED RESEARCH COOPERATIVE AND CORDIALLY, EACH WITH 60:60 TOLERANCE FOR THE OTHER.

If the quality is high and the value is clear, both public support and funding are, I am convinced, possible. I look forward to seeing exceptionally fine statements on long-range research needs for Chesapeake Bay living resources.

PROBLEMS AND PROMISES FOR SHELLFISHES IN CHESAPEAKE BAY

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Long-term research programs directed at the living marine resources of the Chesapeake Bay are needed in order to provide managers with the data and information required to make informed decisions. All too often management decisions must be made quickly without proper information. Even when scientists have an opportunity to comment it is on short notice. The States, and their responsible agencies and/or universities must commit themselves to long-term programs of research and monitoring.

There are four major shellfisheries in the Chesapeake Bay; soft and hard clams, blue crab and oyster. Of these, the soft clam is found only in Maryland in harvestable quantities. On the other hand the hard clam is principally a Virginia fishery. Both States support a major fishery for blue crabs and oyster. Of these four, the blue crab is the only Bay migrant, therefore, opening the opportunity for bi-state management and research.

Soft Clams

Soft clam fishery problems in Maryland are principally in the market sector. Stock levels are currently good due to recent recruitment levels. The soft clam is not the focus of active management in Maryland. It responds rapidly to large-scale environmental events, and reaches sexual maturity and legal size (2") in one year. Research should be directed at understanding how the dynamics of climatic scale environmental changes produce recruitment fluctuations.

Hard Clams

Virginia packers report that clam stocks are sufficient to meet current demands, but that legislated inefficiency in the fishery make their supply very unreliable. Most clams are harvested by patent tong or "scratchin" (also called "signin"). Demand is greatest during winter, but only patent tongs along the western shore fish during winter.

Current research in Virginia includes methods for containerized relaying from polluted waters. It is estimated that in 1986 26 million clams were moved this way. Further research into this technology is needed. Virginia is preparing to develop a State Fisheries Management Plan for the hard clam. The Marine Resources Commission (MRC) has indicated that an immediate data need is going to be a recruitment index.

Blue Crab

The blue crabs' spawning success is largely dependent upon natural environmental events, including temperature on the spawning grounds, salinity on the extruding grounds, and wind regime at the mouth of the Bay. It has generally been accepted that the stock in the Bay is 1) self sustaining with no outside recruitment, 2) completely density independent, and 3) pollutant effects have no impact on the stock or recruitment. These assumptions are believed to have been true under previous levels of fishing effort although there is uncertainty at present.

Fishing effort is increasing with no apparent way of quantifying the level. Figure 1 shows the empirical and "smoothed" Virginia landings for the period 1960 through 1985. These are "biological" rather than "calendar" year landings. The raw data suggest a fairly stable fishery, with some interannual fluctuation. The smoothed data clearly show a fifteen year decline with an upturn in the trend since 1980. Marine Resources Commission personnel have indicated that there has been a significant, but undocumented increase in effort since then. Catch per unit effort (CPUE) data are simply not available, but they must be if future assessments are to be effective.

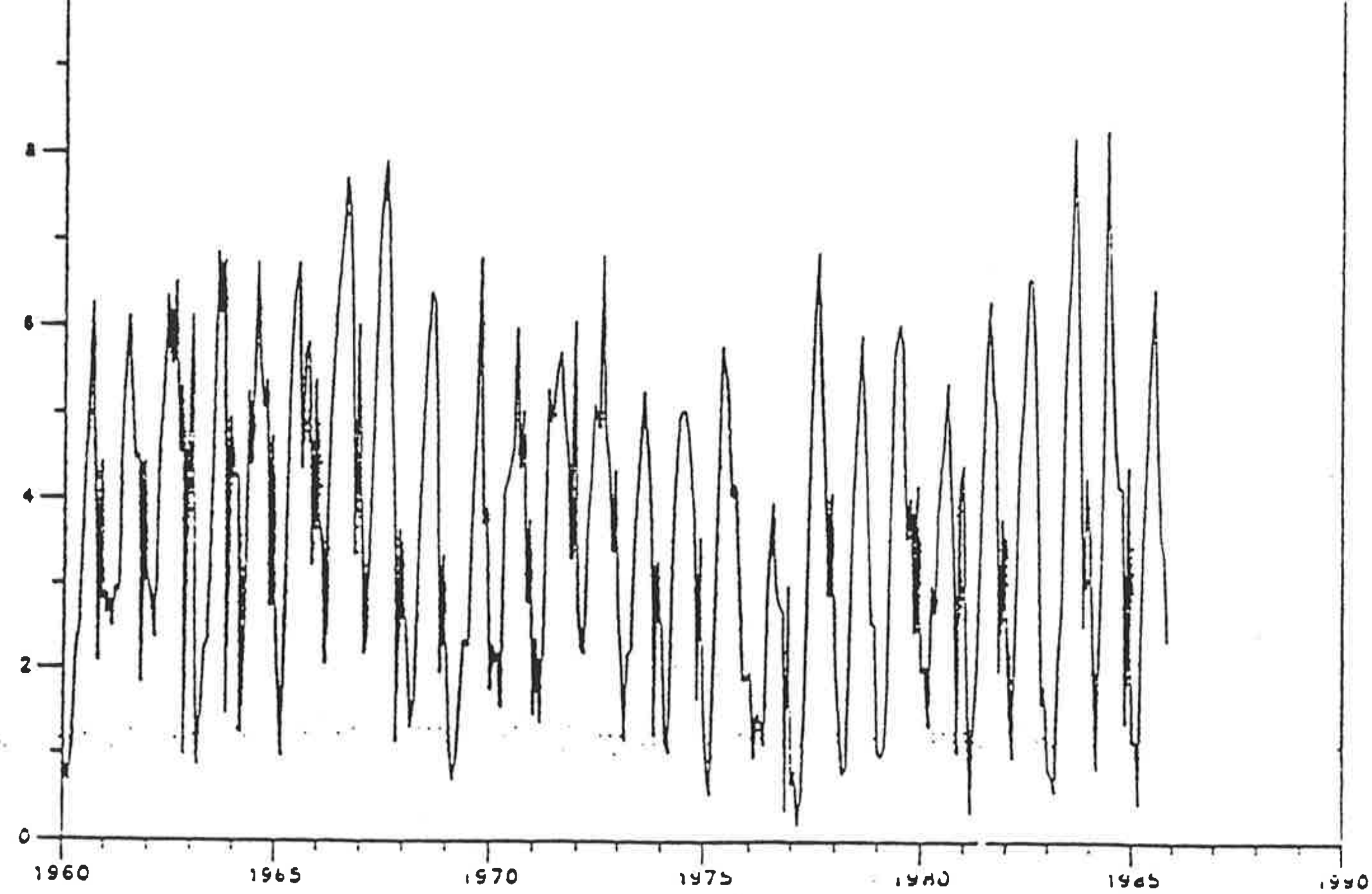
In addition to developing a better measure of CPUE, a realistic juvenile index should be agreed upon. Larval and post-larval abundance fluctuations are important measures to understand the biotic-physical environmental variability, but a juvenile (post-larval) index should prove more reliable. Juvenile blue crabs are found throughout the Bay. Although they are concentrated in eel grass beds, leading one to support the need for grass beds as a habitat, they are also found in large numbers over the open Bay and tributary sand-mud bottoms. The contribution of these habitats should be examined and a Juvenile Habitat Index developed. Such an index would also be useful when regulatory permits for dredging or shoreline modification are considered.

Oyster

The oyster and its industry have more problems and promise than all the other shellfish combined. A substantial repletion program in both states supports the commercial "public ground' fishery. Where and when to spread shell and/or seed is often a political decision, not one based upon probability of success for survival of seed or likelihood of a spatfall ("strike"). Virginia has established a Repletion Committee which has as one of its ten members, a scientist. His input is often not heeded.

Both Maryland and Virginia have a shortage of shell for repletion. Additional sources, such as old shell reefs, often under a meter or more of sediment, should be mapped and dredged.

The Virginia Institute of Marine Sciences (VIMS) has monitored spatfall in the fall since 1946, and in the summer since 1963. Virginia's oyster



Crab Landings data, 1960-1985

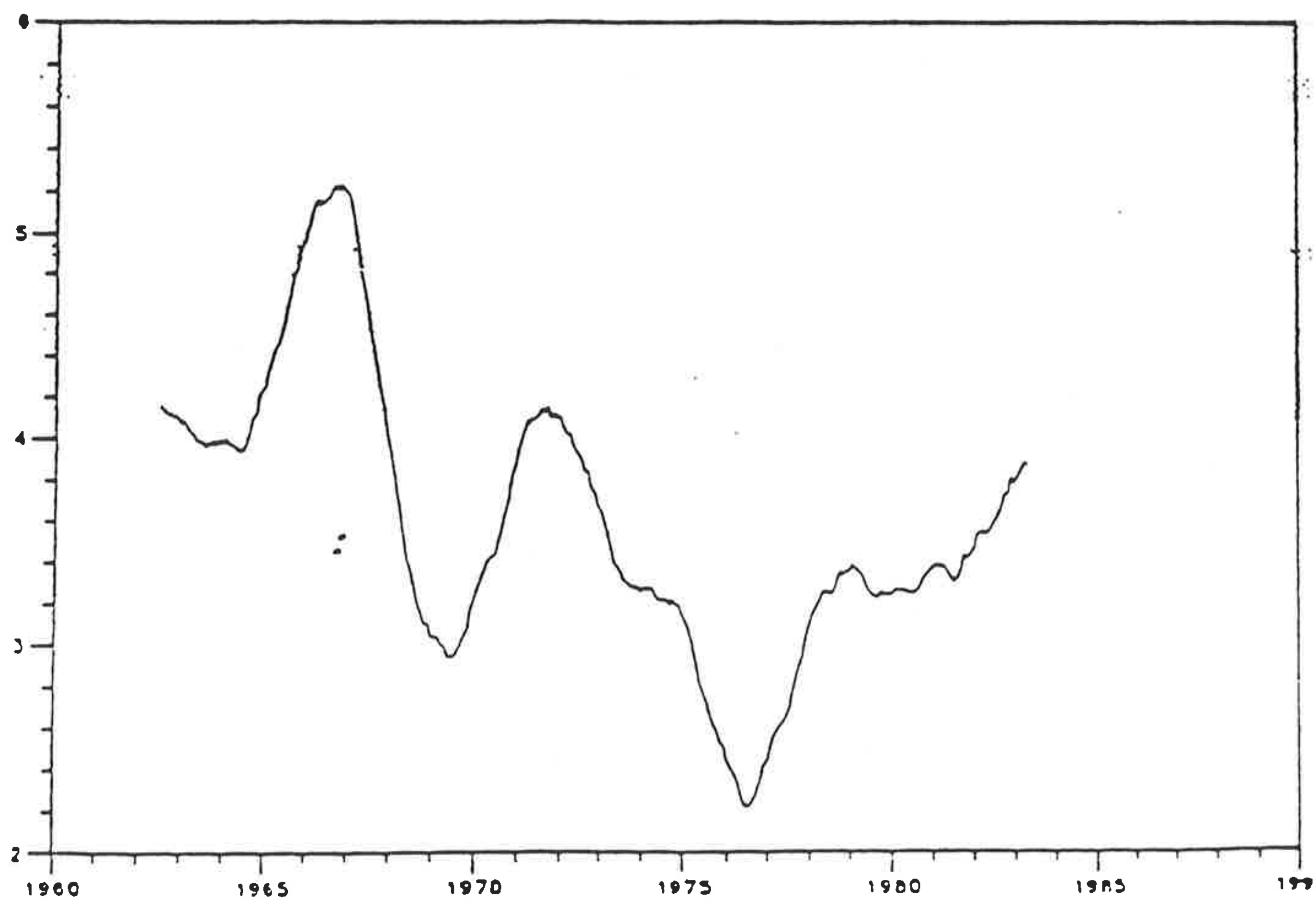


FIG. 1

Crab Landings data, 1960-1985

industry experienced a catastrophic decline in landings during the early 1960's. This was concurrent with a decline in spatfall. The cause(s) of the decline in spatfall has been linked to the reduced brood stock following the stock decline due to MSX, introduction of chlorination in 1960, and predation. Figure 2 shows the changes in summer spatfall and subsequent fall survival. The early 1980's have experienced spatfall levels similar to the pre-1960's; survival however, has been poor. The causes of the reduced strike and subsequent survival must be investigated further.

Many scientists and managers are beginning to believe that a seed hatchery is the only way to provide and maintain seed in economical abundance. Current research at VIMS shows this may work, but additional study will be needed before hatcheries can be available to even supplement nature.

Summary

In all cases we need to develop a better understanding of the natural and man-made forces acting on recruitment. Additionally, stock-recruitment relationships are poorly known. How the environment affects stock-recruitment is completely unknown. Development of recruitment and juvenile habitat indices has been expressed as a need from the managers.

Commercial catch per unit effort data need to be collected. Both States are making efforts in this direction but more needs to be done.

Figure 3 shows the 1986 distribution of spatfall and market oysters in the Rappahannock River, Virginia. A vertical line at river mile 21 is the current legislated patent tong up-river limit. The annual monitoring data suggest that a proper management option is to close the lower river (below mile 15). Unfortunately, the Marine Resources Commission cannot do so without the agreement of the legislature. A monitoring of the annual distribution and abundance of recruitment is important for all stocks as it will allow management flexibility for the MdDNR and VaMRC.

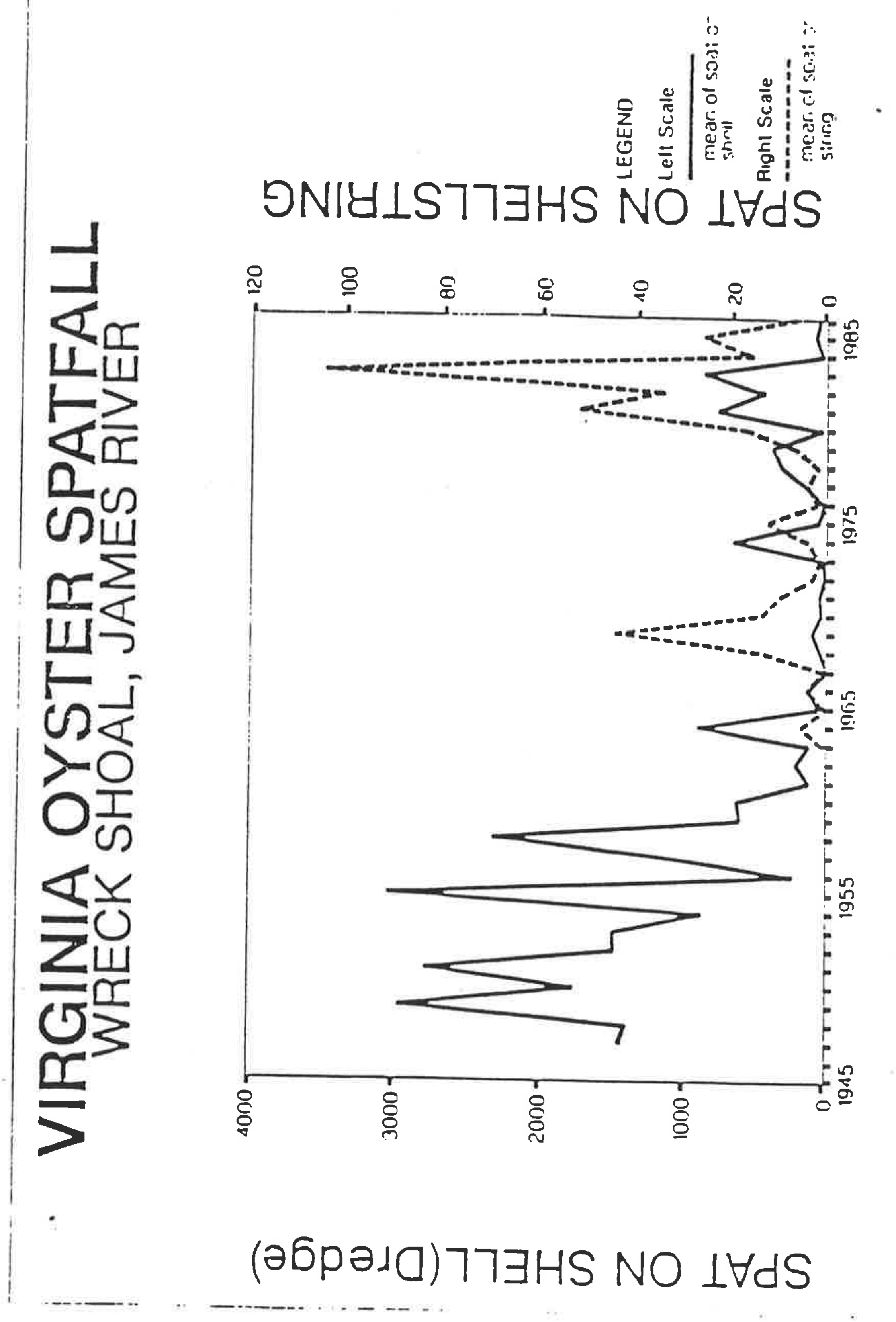

VIRGINIA OYSTER SPATFALL
WRECK SHOAL, JAMES RIVER
SPAT ON SHELL(Dredge)
SPAT ON SHELLSTRING
YEAR
LEGEND
Left Scale
Right Scale
0
1000
2000
3000
4000
20
40
60
80
100
120
1945
1955
1965
1975
1985

Fig. 2

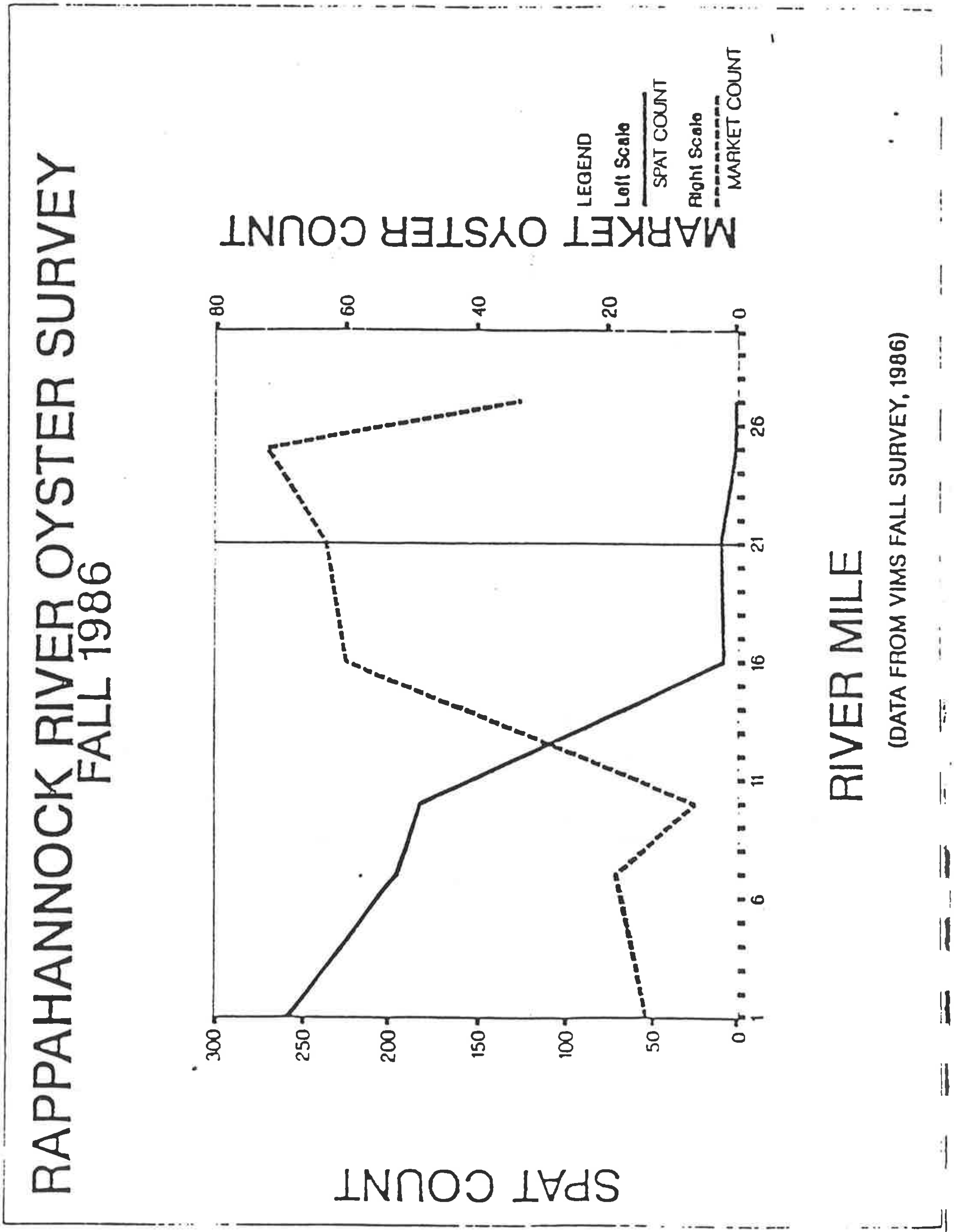

RAPPAHANNOCK RIVER OYSTER SURVEY
FALL 1986
SPAT COUNT
MARKET OYSTER COUNT
300
250
200
150
100
50
0
80
60
40
20
0
1
6
11
16
21
26
LEGEND
Left Scale
SPAT COUNT
Right Scale
MARKET COUNT
RIVER MILE
(DATA FROM VIMS FALL SURVEY, 1986)

Fig. 3

AUTOCHTHONOUS SOURCES OF PARTICULATE ORGANIC MATTER IN THE CHESAPEAKE BAY AND ITS COASTAL PLUME

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The response of planktonic communities to nutrient enrichment in coastal ecosystems is a major problem in marine ecology which has broad implications in terms of both water quality and fisheries. The production of organic matter by phytoplankton depends on external sources of nutrients (new or allochthonous inputs) as well as on internal nutrient recycling. The supply of new nutrients and fish yields are correlated on a global scale. However, new nutrient inputs from natural and anthropogenic sources often result in a decline in water quality and lower fish yields. The extent to which one of these effects predominates over the other depends in part on the rates and pathways by which organic matter produced by phytoplankton is metabolized by heterotrophic components of the system. A critical factor here is the degree to which the photosynthetic production of organic matter is separated in time and space from the aerobic decomposition of this organic matter. The more closely phytoplankton production and heterotrophic consumption are coupled, the lower the probability that increases in phytoplankton production will lead to a decline in water quality.

Major routes of heterotrophic consumption involve both metazoan and microbial pathways, the relative importance of which may be related to the degree of coupling between phytoplankton production and heterotrophic consumption. Until recently, the roles of microbial pathways initiated by bacteria were considered to be insignificant relative to metazoan pathways in terms of both energy flow and nutrient cycling. This view must now be re-evaluated as a result of the discovery that bacteria metabolize an equivalent of 20-60% of phytoplankton production in coastal and oceanic waters.

In Chesapeake Bay, it is generally assumed that increases in anthropogenic nutrient inputs have caused phytoplankton production to increase and that this increase has led to a decline in water quality over the last 3-4 decades. An increase in the temporal and spatial extent of oxygen depletion during summer is believed to be one feature of this decline. This scenario has several weaknesses which bare on issues of water quality and living resources. 1) Inputs of new nutrients account for only ca. 10% of phytoplankton production so that the impact of nutrient inputs on an annual time scale depends more on how nutrients are recycled and lost from the system than on the magnitude of the inputs per se. 2) The pathways and rates by which the products of photosynthesis (dissolved and particulate) are consumed and metabolized are not well documented. More specifically in terms of water quality, cause-effect linkages between nutrient input, phytoplankton production, and oxygen demand below the pycnocline have not been documented or quantified. 3) Finally, nutrient input and the fate of these inputs depends to a great extent on fresh water run-off and wind-mixing, both of which exhibit large episodic, seasonal, and interannual variations.

A study, funded by the Maryland and Virginia Sea Grant Programs, was initiated in 1985 to provide data on the potential roles of microbial and metazoan food webs and on benthic-pelagic interactions as they relate to water quality and living resources. Today, I would like to address two problems concerning the fate of organic matter produced by phytoplankton: 1) how important are bacteria relative to phytoplankton as sources of particulate organic matter and 2) how important are phytoplankton as sources of organic matter for bacterial growth?

Seasonally averaged phytoplankton production varied from 740 to 1480 mg C/m2/day. Flow of the Susquehanna River is the main source of new nutrients (N, P, Si) for phytoplankton growth in the mesohaline reach of Chesapeake Bay. As a consequence of this input and of nutrient recycling, phytoplankton growth is not nutrient limited on a seasonal time scale. Thus, seasonally averaged phytoplankton biomass is correlated with fresh water flow (new nutrient supply), but phytoplankton production is not. Bacterial production in this reach of the Bay is roughly equivalent to phytoplankton production. Assuming a conversion efficiency of 50%, the metabolic requirements of bacteria are usually ca. 25-125% of phytoplankton production except during May when bacteria metabolize an equivalent of 500% of phytoplankton production. These are exceptionally high levels of bacterial production and may be indicative of a shift from a metazoan-dominated food web to a microbial-dominated food web as the Bay has become more eutrophic.

In contrast in the mid-Bay, phytoplankton growth in the coastal plume is low (300 to 1000 mg C/m2/day) and nitrogen limited during much of the year. Under these more oligotrophic conditions, bacterial production was generally less than 20% of daily phytoplankton production. Again, assuming a 50% conversion efficiency for bacteria, this translates into a bacteria demand of 20 to 40% of phytoplankton production.

Measurements of bacterial uptake of dissolved organic carbon released by phytoplankton indicate that phytoplankton exudates account for 10-30% of the daily metabolic requirement of bacteria in the plume. While such measurements have yet to be made in the Bay, high bacterial production relative to phytoplankton production indicates that there are large lags between phytoplankton production and the release of dissolved organic substrates, i.e. that most bacterial production is not dependent on the uptake of recently released dissolved organic matter. Such lags are suggested by the seasonal time courses of phytoplankton biomass and bacterial production. Phytoplankton biomass reaches a seasonal maximum during March-April as a consequence of the advection of biomass into the Bay and of large accumulations of biomass due to high input of new nutrients and low grazing rates. During May, phytoplankton biomass declines dramatically as bacterial production increases rapidly relative to phytoplankton production and as dissolved oxygen is depleted below the pycnocline. These patterns may reflect the release of dissolved organic matter as phytoplankton mortality increases in response to oxygen depletion.

In conclusion, our results to date indicate that an understanding of how nutrient enrichment, water quality, and living resources are related depends on the pathways and time courses by which organic matter produced by phytoplankton are metabolized. The magnitude of bacterial production raises many questions which may have important implications with respect to living resources. 1) What are the pathways and rates by which phytoplankton production enters the pool of dissolved organic substrates utilized by bacteria? 2) Does the microbial food web compete with or enhance energy flow to metazoan consumers? 3) Does a shift in energy flow through microbial relative to metazoan food webs signal a change in water quality and/or fish yields? 4) What factors govern the relative importance of these two trophic systems? Of central importance to this problem are the effects of interactions among metazoan and microbial food webs on energy flow to metazoan consumers and the quality of their environment and the effects of variations in fresh water run-off and wind mixing on these interactions.

BENTHIC-PELAGIC COUPLING: POTENTIAL IMPORTANCE FOR FISHERIES IN CHESAPEAKE BAY

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In aquatic systems such as Chesapeake Bay, autotrophic processes of primary production tend to be restricted to the upper portion of the water column, while much of the heterotrophic activity is concentrated at or near the sediment surface. The various mechanisms by which these two zones are functionally connected have been collectively referred to as pathways of "benthic-pelagic coupling." Two of the major connections include: the delivery of autochthonous organic matter from the water column to the benthos where it is concentrated, used and stored; and the regeneration and transport of nutrients from sediments back to the euphotic zone where they are assimilated again in primary production. In addition, benthic-pelagic (B-P) coupling provides a means by which materials may be transported horizontally (across salinity and depth gradients) while being used reciprocally in autotrophic and heterotrophic processes. Many other behavioral and trophic interactions are also a part of the network of B-P couplings, including: vertical migrations; foraging by demersal fish; suspension-feeding by benthic animals; and spawning and recruitment of benthic invertebrates with pelagic larvae.

In estuaries, it is these mechanisms of B-P coupling which help to maintain effective connections among key processes, including: nutrient inputs, geochemical cycles, primary production; foraging and grazing by invertebrates and nekton; fisheries production and yield. In terrestrial systems such as temperate forests, the phloem and xylem of trees facilitate vertical coupling of autotrophic and heterotrophic processes, while leaf-fall and aeolian dispersion of seeds are analogous to sinking of algal cells and detritus, and larval dispersion of benthic invertebrates. In aquatic systems, B-P coupling depends primarily on gravity and hydrographic transport mechanisms, both advective and diffusive.

It has been established that the relative importance of B-P coupling in the trophic and nutrient dynamics of lacustrine and marine ecosystems is inversely proportional to mean water depth (Harrison 1980). Thus, the relative magnitude of vertical fluxes between water column and benthos (in proportion to planktonic rates of carbon and nutrient cycling) generally declines as one moves from the estuary to the open ocean. In general, the deeper the water column the greater the percentage of autochthonous organic matter which is consumed in the pelagic zone. Conversely, in shallow waters the fraction of plankton production which reaches the sediment surface (and is remineralized by benthic metabolism) is relatively large. The nature of other B-P trophic interactions such as herbivorous grazing on phytoplankton is also affected by depth. In deeper water columns crustacean zooplankters are the dominant herbivores, and algal material reaches the sediments only through passive sinking of both zooplankton feces and intact algal cells. In shoal waters, however, populations of benthic macrofauna, which filter large volumes of water per day, can be the most important grazers of phytoplankton production (Officer et al. 1982).

Although the relative magnitude of B-P fluxes varies greatly with depth, several generalizations can be made for typical estuarine and coastal marine systems such as Chesapeake Bay. It appears that 30-70% of the particulate organic matter produced by phytoplankton is delivered to the benthos (Hargrave 1983). Most of the estimates of particulate deposition are based on sediment-trap measurements. Interpretations of data from sediment-trap methods are confounded by poorly understood hydrodynamic properties of the traps themselves. However, in the few cases where sediment-trap rates have been compared to values estimated from geochemical and paleontological methods (mean rates over decades), good agreement has been found. In addition, independent data on benthic nutrient regeneration and respiratory metabolism are consistent with generalization about deposition rates, where approximately one- to two-thirds of the total system respiration and nutrient recycling is attributable to benthic processes for most estuarine systems (Nixon 1981; Boynton and Kemp 1985).

In some shallow well-mixed estuaries, such as San Francisco Bay, it appears that phytoplankton abundance can be regulated by grazing losses to the filter-feeding benthos (Cloern 1982). Recent evidence suggests that dense populations of the filter-feeding clam, Corbicula, once abundant in the upper Potomac River estuary, effected efficient removal of algal biomass from a large area (Cohen 1984). Similar data are not available for the main Chesapeake Bay or for other tributaries. However, it has been estimated that oyster populations in the estuary during the early 1900's were sufficient to filter the entire Bay volume in three days (Biggs 1981). Thus, declines in oyster abundance over the past 80 years may have had marked influence on the trophic dynamics of the Bay ecosystem and the balance between pelagic and benthic food chains and associated fish populations.

By definition, the primary orientation of B-P couplings is in the vertical plane. However, these same B-P mechanisms, combined with hydrographic forces, provide a means for gradual transport of nutrients and organics in the horizontal plane as well. The major period of annual nutrient input to Chesapeake Bay occurs in early spring with the river freshet while the major season for primary and secondary production occurs in the summer. Spatially, most of the primary uptake of dissolved nitrogen and phosphorus occurs in the oligohaline reaches (0-5 ^{o}/oo salinity), whereas the region of maximum productivity is seaward in the mesohaline portion (10-15^{o}/oo). It appears that this temporal and spatial asynchrony between annual delivery of new (as opposed to recycled) nutrients and incorporation into phytoplankton and higher trophic groups is the consequence of B-P couplings which involve a sequence of: nutrient uptake; particulate deposition; resuspension, downstream transport, and redeposition; decomposition and nutrient regeneration; followed again by nutrient uptake and algal growth (Kemp and Boynton 1984). This mechanism, thus, provides a means whereby nutrients delivered annually to the Bay can be retained long enough for efficient incorporation into ecological food-webs and upper trophic levels of fish (Kemp and Boynton 1984).

Within the mesohaline reaches of Chesapeake Bay an analogous mechanism appears to be operating to transport nutrients and organic material laterally across the width of the estuary. In response to a combination of wind, gravitational and rotational forces, the pycnocline which separates upper and lower layers tends to oscillate between tilting orientations upward to east and to west. This results in advective transport of nutrient-rich bottom waters up into the euphotic zone in the shoals flanking the Bay channel. As a consequence, these shallower waters are highly productive. Sediment-trap collections in this region were significantly correlated to rates of plankton production in the shoals but not to production in the deep water overlying the main channel (Malone et al. 1986). The mode for lateral transport of particles here may be similar to that described above for longitudinal coupling. The winnowing of bottom sediments, which enter this portion of the Bay directly through shore erosion (where a gradient from coarse to fine sediments can be found along a lateral depth transect from shallow to deep stations), offers corroboration for this hypothesized mechanism. The importance of these pathways of B-P coupling for fish production in the Bay remains to be investigated.

While the connection between nutrient inputs and fish production may seem remote for large estuaries such as Chesapeake Bay, mass-balance considerations dictate that the large annual harvests of fish products could not be maintained without these inputs. For lakes, relationships between nutrients and fish have been demonstrated through both correlative and experimental analyses. Significant relationships have been observed between nutrient inputs and algal production (or biomass) and between algal production and fisheries yield for lacustrine (Schindler 1981) and estuarine systems (Boynton et al. 1982; Nixon 1987). One provocative observation is that estuaries appear to have greater fish yield per unit primary production than do lakes (Nixon 1982). There are many possible explanations for such a difference, one of which is more efficient B-P coupling in estuaries. Strong correlations between benthic macrofaunal abundance and fish yields have been reported for lakes (Hanson and Leggett 1982). In addition, higher rates of primary production per unit nutrient loading tend to occur in shallower lakes where B-P couplings are more direct (Schindler 1981). Many of these observations suggest the importance of B-P couplings in modulating the connection between nutrient input and fisheries yield.

What are the potential effects of eutrophication on B-P coupling, fish production, and related processes in Chesapeake Bay? As indicated from the positive relationship between primary production and fisheries yields for various coastal systems described above, nutrient enrichment may enhance both processes under certain conditions. It has been shown that benthic macrofaunal abundance can be increased by experimental fertilization (Nixon 1984). However, in regions susceptible to depletion of oxygen in bottom waters, eutrophication will lead to decreased macrofauna (Cederwall and Elmgren 1980). Zooplankton responses to eutrophication seen less predictable, but any changes in their abundance or species composition would affect delivery of algal production to the benthos. In mesohaline Chesapeake Bay, benthic macrofaunal populations are seasonally controlled by fish predation (Holland et al. 1980), which may be intensified by losses of benthic habitat from oxygen depletion (Kemp and Boynton 1981). Nutrient recycling processes associated with these organisms may also be affected by changes in benthic macrofauna. It is likely therefore, that eutrophication would result both in shifts between plankton and benthic food chains and recycling pathways and in scarcity of foods for demersal fish.

Over the past two decades much has been learned about the quantitative features of B-P coupling, especially in terms of deposition of particulate organics and recycling of nutrients. Much less is known about the qualitative elements of these processes -- for example, how B-P couplings are affected by changes in environmental conditions and how important food chains are dependent on these interactions. Long-term data records for key processes (e.g., nutrient inputs, primary production, B-P coupling, food-chain dynamics, and fish production) will be most useful if they are combined with specific experiments to elucidate ecological mechanisms controlling fisheries yield.

THE BALTIC ECOSYSTEM - A CHANGING BASIS FOR THE FISHERIES

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The semi-enclosed Baltic Sea has a surface area of 373,000 km^2, a volume of 22,000 km^2 and an area of the watershed 10 times that of Chesapeake Bay, maintaining a population of 92 million people. The main topographical characteristics are the rocky archipelagoes along the Swedish and Finnish coasts, the division into several basins and the mean depth of 56 m. The surface salinity has a mean of 7 ppt, decreases slowly from south to north but is very stable at any one point. The input of rivers induces an inflow from the North Sea of heavy, saline water, which creates a stable primary halocline at ca. 60m depth. Greater pulses of inflowing water stochastically break the stagnant conditions in the deep water, regulated by the distribution of high and low pressures over the Atlantic. The absence of tides makes wind important, inducing upwelling and downwelling events, and strong coastal jets, which redistribute the injected concentrations of nutrients over the whole Baltic within weeks.

The biological communities have a low diversity with some 50 species of macroscopic animals, ca. 40 species of seaweed but a fairly diversified meiofauna. In the pelagic system the spring bloom of phytoplankton transfers 50% of the synthesized organic matter to the benthos through sedimentation, which constitutes 40% of the annual demand of potential energy of the benthic system. The other conspicuous bloom is the autumn bloom of nitrogen-fixing algae, which fixes approximately 130,000 tons of nitrogen in the Baltic each year.

The economically most important fish are sprat, herring, cod and salmon. The first three have benefited from eutrophication although the areas for development of cod eggs, in water of 10-11 ppt at 70-80m depth are threatened by anoxia.

The originally well-functioning, oligotrophic system was changed through man's activities. Today a total of 1.2 million tons of nitrogen and 78,000 tons of phosphorus are poured into the system annually. Of the nitrogen, 56% comes from land run-off and 34% as atmospheric fallout. Approximately 9 tons of PCB is injected into the system each year from the atmosphere, originating from industrialized Europe.

The eutrophication is responsible for several changes:

1) Ca. 100,000 km^2 (25%) of the Baltic soft bottoms are usually anoxic.

2) The potential fish food at depth in the well-mixed layer (above the primary halocline) has increased four fold.

3) The stocks of herring and cod have increased.

4) The lower limit of the important brown algae belt (Fucus-belt) has been displaced upwards 3-4m due to decreased water transparency.

The DDT- and PCB-levels are decreasing. Nevertheless, the seal populations are close to extinction due to PCB, although those substances are banned in the Baltic countries.

The fisheries have been productive but have started to decline. The total catch of one million tons is ca. 1% of the total world catch although the Baltic is only 0.001 of the total ocean area. The urgent development of ecological-economic fishery models is strongly advocated.

SAN FRANCISCO BAY: ENVIRONMENTAL ISSUES AND CONTRASTS WITH CHESAPEAKE BAY

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Like the Chesapeake Bay, San Francisco Bay is a large estuarine ecosystem that has been radically altered by the activities of man. These changes accompanied the rapid population growth of California since 1850, and resulted from the expansion of the urban/commercial centers on the estuary as well as agriculture in the drainage basin. Major ecological changes include:

1. Radical alteration of the Bay's geomorphology through (a) hydraulic mining in the tributaries that introduced massive quantities of sediment and permanently altered bottom topography; and (b) the near-complete elimination of tidal fresh- and salt-water marshes to create salt-evaporation ponds, new farmland, or for urban expansion.

2. Significant changes in the seasonal timing and magnitude of freshwater inflow from the major rivers - the Sacramento and San Joaquin. Separate state and federal water projects retain much of the snow melt and surface run-off in a system of reservoirs, and redistribute this water to sustain irrigated agriculture in California's Central Valley. As a consequence, total annual freshwater inflow to San Francisco Bay has been reduced to less than half of the historic level; by the year 2000 this value will be reduced to about one third of the historic inflow.

3. Biological communities of San Francisco Bay have been dramatically altered by the introduction of exotic species via commercial shipping or the aquaculture of shellfish transplanted from the U.S. east coast. About 90% of the biomass of benthic infauna comprises exotic species, and there have been equally successful introductions (some intentional) of finfish and pelagic invertebrates.

4. Although San Francisco Bay historically supported a diversity of commercial fisheries (e.g. sturgeon, salmon, striped bass, shad), the only remaining commercial fisheries are for Pacific herring and anchovy, neither of which is taken for direct human consumption. No shellfish are taken commercially, and recreational shellfish collection is highly restricted.

5. San Francisco Bay receives contaminants from a diversity of municipal, industrial, and agricultural wastes that have altered water quality. Waste inputs now constitute 4% of the freshwater inflow to the estuary, and this contribution will double by the year 2000.

Given this background of diverse impacts from human activity, three environmental issues are of primary concern. First are questions related to the ecological significance of freshwater diversion. Of particular concern is the effect of altered river-driven circulation on (a) the transport of contaminants and (b) the distributions of larval and adult fish. Second are questions concerning the nature, sources, and ecological significance of toxic wastes. Although we recognize the existence of multiple sources of contaminants discharged into San Francisco Bay, few of these are quantified. Moreover, the ecological responses (historic or contemporary) to contaminant discharge remain virtually unstudied. A third concern is the recent decline in the abundance and condition of striped bass, the major sport fishery. In contrast to Chesapeake Bay, San Francisco Bay does not now exhibit symptoms of eutrophication -- phytoplankton blooms do not deteriorate water quality and there are typically no incidences of hypoxia. This departure from the condition of Chesapeake Bay suggests that some estuaries may be somewhat resilient to the effects of eutrophication. However, San Francisco Bay has apparently not been resilient to other stresses -- freshwater diversion, urban growth, alterations of biological communities, and waste inputs.

INTERSPECIFIC PREDATION AMONG EXPLOITED FISH SPECIES AND FISHERIES MANAGEMENT

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Introduction

Undoubtedly there are extensive differences between Chesapeake Bay and the North Sea. The former is estuarine with a relatively small gate to the Atlantic ocean and heavily influenced by land use around its coasts. The latter is a shelf sea also largely enclosed by land masses, but both the Channel and the open area between Scotland and Norway allow considerable exchange with Atlantic water. The river Rhine is the largest single contribuant of fresh water, if the sewage carried down by this river may still carry that adjective, but quantitatively the input is negligible. Likewise, the fisheries supported by the two areas are rather different. The Chesapeake Bay yields species of both marine and fresh water origin with menhaden being a single dominant species, a considerable amount of shellfish and supports a relatively large sport fishery. The North Sea harvest is almost completely commercial and includes a large variety of strictly marine species only. I can only expect that the priorities of various management issues are different as well. Therefore I am not sure how relevant a discussion of some recent developments in the North Sea area is in the context of the goals of this workshop, but I hope that it will fit somewhere in shaping long term research needs for your areas.

Within the time available I cannot go into much scientific detail and I will restrict my account at this stage to some generalities. Before addressing the specific problem of interspecific predation among exploited fish populations, some general aspects of the North Sea system need be considered in order to explain the main management problems we are facing and why a particular line of research has been chosen.

The North Sea

Traditionally the North Sea served primarily as a medium for transport and a resource for fish production, two hardly conflicting functions. More recently other functions have become important issues as well. Oil and gas industries have been developing and some people consider the North Sea as a natural waste box, simply an extension of the river Rhine, whereas others value highly the unspoiled ecosystem and want to protect it entirely against abuse. Undoubtedly, at some stage an integrated North Sea management policy must be formulated and the first steps in trying to achieve this are presently taken. However, in daily practice, fisheries management is still an isolated economical and political issue and remains the leading force behind scientific research.

Before the 1970's access to the North Sea fish resources was unrestricted and a large number of countries exploited the North Sea. It was realized at an early stage that no country could effect sound management policy by itself and that in order to establish effective fisheries management both scientific advice and enforcement of regulations had to be agreed internationally. Therefore already in 1904 the International Council for the Exploration of the Sea (ICES) was set up, which served as a forum for discussion of marine research matters in general but focused attention on fisheries problems in the entire Northeast Atlantic Ocean. From 1946 onwards the Northeast Atlantic Fishery Commission (NEAFC) formed its political counterpart responsible for the implementation of management. Presently, the task of NEAFC has been largely overruled due to the introduction of exclusive economic zones of 200 miles, through which most fish stocks in the area came directly under the jurisdiction of one or two countries. Since all member countries of the European Economic Community (EEC) ratified unrestricted fishing rights in each other's water, the EEC took up the responsibility for fisheries management in EEC waters. There are hardly any tasks left for NEAFC, because in the North Sea only the EEC and Norway need bilateral agreements to divide up the fish pie. There has been no change in the provision in internationally agreed advice, which is still submitted by ICES, which has no financial means to influence research carried out in the area directly. However, in practice it's influence is considerable, because ICES recommendations to undertake specific coordinated research programs are generally highly respected by the national research councils responsible for setting research priorities.

Fisheries Management Policy

During the time when NEAFC was responsible for fisheries management, a large number of regulatory measures were introduced such as legal mesh sizes, minimum landing size, allowed bycatch ratios, etc. However, NEAFC never succeeded in controlling total fishing effort employed by individual countries. When EEC assumed the jurisdiction over waters of member countries, a long-term policy was formulated which included indirect control of fishing effort by means of catch quota for all important exploited fish stocks. The long-term objectives were largely based on biological considerations as provided by ICES, but the agreed Total Allowable Catches (TAC) might have been adopted in the light of economical and political considerations.

In many instances the TAC approach adopted appears to be far from being totally appropriate. Most member countries turn out to have severe problems in enforcing TAC regulations, which results in falsification of catch statistics and thus strikes at the roots of the scientific advice. But even when TAC's could be enforced large problems remain, particularly with respect to species which are caught in mixed fisheries. For those species a TAC might prevent fish from being landed after the quota is reached, but it does not necessarily prevent these fish being caught. Since survival of discarded fish is virtually zero, the primary aim of a TAC to control fisheing mortality cannot be attained. However, now that the system has been adopted and TAC's are annually decided for each species and each stock in EEC waters separately, it appears to be extremely difficult to convince the EEC that TAC's ought to be replaced by something better.

Management Objectives

ICES has developed a system of assessment working groups, which define the appropriate catch level in the next year on the basis of catch predictions for different levels of fishing mortality, taking into account long-term yields and trends in biomass and recruitment. These working groups follow a long standing tradition in fisheries science and concentrate on single species models in trying to explain interactions between fishing effort and fish yield. The management objectives derived from this approach refer to maximizing or optimizing yields. Actually, this approach assumes that interspecific interactions between species are subordinate to interactions between a particular stock and the fishery thereupon. This would seem a reasonable assumption when stocks are moderately exploited, because this condition implies that the overall impact on the ecosystem is relatively small and therefore the environment may be considered constant. However, when fish stocks are heavily exploited, the balance between species is more likely to be distorted and the effect of interactions between stocks should be more pronounced.

The North Sea fish stocks were already "overfished" in the yield per recruit sense during the first half of this century. Since the Second World War exploitation rate increased even further for all species, but only the yield of pelagic species (herring and mackerel) decreased according to expectations. For most demersal species yield increased, contrary to predictions of the yield per recruit model. This has been the incentive for Andersen and Ursin to develop their North Sea ecosystem model, by means of which they tried to find explanations for such discrepancies in terms of species interactions. As an assessment tool the North Sea model was less appropriate, but it gave birth to a family of simplified multispecies assessment models, which were directly linked to Virtual Population Analysis (VPA) as routinely used by ICES assessment working groups: the Multi-species Virtual Population Analysis (MSVPA) provides a simultaneous assessment of several exploited fish stocks on the basis of catch data, the additional feature being that it allows for variable intra- and interspecific predation among these species between years. Apart from the usual catch-at-age arrays, application of this model requires rather detailed knowledge of the food composition and the feeding rates of the predators in a particular reference year. Starting from this reference year the number of individuals of various species age-groups consumed can be calculated for other years as affected by changes in the densities of the various prey classes.

Stomach Sampling Project

At the time when the theoretical basis for MSVPA was developed, the kind of information available from general feeding studies did not allow further application of the model and after careful evaluation of the input requirements, ICES strongly endorsed a stomach sampling program to be carried out in 1981 to obtain the crucial information. The five potentially most important predator species were selected and coordinated surveys were specifically undertaken to sample stomach of these predators by size class. Eight countries participated in the collection of samples and the entire North Sea was covered during each quarter. The samples were then sent to five species coordinators for analysis in order to ensure complete homogeneity within species. In total some 50,000 stomachs were collected. In the analysis special attention was paid to fish prey: all items were sorted in size classes in order to allow subsequent application of age size keys, also collected during the surveys, to estimate the age distribution of prey by age distribution of predator. The catch rates by size class of predator during the surveys allowed raising according to the density distribution in order to obtain reliable estimates of the average food composition over the entire North Sea by quarter. Sampling and analysis logistics were strictly defined by the demands set by the model. Consumption rates could not be estimated directly from the sampling program, but the average amount of food present in stomachs could be linked to experimental data about stomach evacuation time and the ultimate estimates were compared to theoretical energetic requirements for validation.

Multispecies Virtual Population Analysis

It took several years before the data could be applied in trial runs with the model and the first results of MSVPA became available only in 1984. It turned out that food composition varied strongly by season and this variation was apparently directly related to changes in availability of juvenile fish of the right size class to be preyed upon by the predators. Since VPA was routinely based on annual catch figures, it was originally envisaged to lump quarterly food composition data to annual values. The large variation between quarters, however, led to the decision to run MSVPA on a quarterly basis, which implied a complete revision of the input catch data for all species. Although the actual figures for predation mortality have thus been revised over the years since the first trial runs due to gradual improvements in the huge data base entering the model (7 prey species, 5 predators, 10 age-groups, 11 years, 4 quarters, catch numbers, mean weights, stomach contents and prey weights yield approximately 20,000 input data points!), the general conclusion from 1984 that predation mortality on juvenile fish (mainly 0- and 1-group, but also 2-group of most species is significantly affected) is very much higher than the levels of natural mortality applied before in single species VPA, when natural mortality was assumed constant for all age-groups of a particular stock at rather arbitrarily chosen values.

Validation of Multispecies Virtual Population Analysis

MSVPA allows part of the natural mortality which is caused by predation among exploited fish species to be estimated dynamically for each individual prey age class in each year. For the reference year from which stomach content data are available the procedure is quite straight forward and there can be little doubt that predation mortalities on juvenile fish are extremely high. However, residual natural mortality is entering the model as an arbitrary constant and total natural mortality rates may well be even higher than estimated from the sum of predation and residual mortality. In principle MSVPA can be further extended to incorporate other important predators as well (e.g., birds and mammals). However, this would require reliable estimates of trends in biomass and dietary information for such predators and that is the real problem for unexploited species.

An important aspect of MSVPA is that it actually allows validation of some of its underlying assumptions, because diet composition is calculated for each predator in each quarter and year. Thus, if independent information on diet composition were available for other quarters than only in the reference year, model predictions could be tested against real observations. First trials in this respect with a limited data set for 1982 indicated that the predation model resulted in much higher correlations between predicted and observed diets in 1982 than between the observed diets in 1981 and 1982 directly. In order to make a more extensive validation a new stomach sampling program has been undertaken in 1985, but the results are not yet available.

Implications for Management

The high predation mortalities on juvenile fish in the exploitable phase emerging from multispecies assessment have drastically changed our views on short-term losses and long-term gains from mesh assessments, because in the critical size range increased escapement through the meshes will hardly affect survival. Similarly, the adverse effects of industrial fisheries, operating small-meshed nets and taking a by-catch of protected species, on the human consumption fisheries on these species are much less severe than envisaged earlier on the basis of single species assessments.

On the other hand extensive comparisons between catch predictions based on MSVPA and single species assessments did not reveal significant differences as long as exploitation rates were not changed drastically from one year to another. Management policies will in general aim at some continuity in the fishing industry and therefore TAC's commonly largely refer to "status quo" situations in terms of exploitation rate. Under these circumstances multispecies assessment does not seem to result in significant gains compared to single species assessment.

More difficulties emerge when long-term management objectives are considered. Clearly, yield per recruit is heavily depending on the biomass of predatory species and consequently there is no single maximum for any level of fishing mortality. This means that management is in fact faced with a choice: preference for a large catch of herring may require a different strategy for the exploitation of the cod stock than when the cod is valued highest. Attractive as this may sound to managers, within the European situation it would seem absolutely impossible that English, Danish and Dutch ministers of fisheries would agree on species priorities. At this time fisheries science does not seem to be advanced enough to provide quantitatively reliable alternatives in this respect.

Conclusion

Any model will only provide sensible answers to questions which were explicitly addressed in the modelling phase. The MSVPA was developed to estimate predation mortalities among exploited species and the effect of predation in modulating recruitment after the early phase of life. The answers obtained indicate that, although predation in the post-larval phase is considerable, the modulating effect on year class strength is a matter of fine tuning rather than that predation is causing large variations in recruitment. Thus, the MSVPA did not help a great deal to answer the dominating question in fisheries: what are the causes in interannual changes and long-term trends in recruitment? I suppose then that we in the North Sea are in no better position than you are in Chesapeake Bay and that we also need a long term research program to solve this question.

We have as yet no proof that species interactions lead to differential changes in average recruitment, but it would seem to me that, irrespective of influences of the abiotic environment on annual survival rates, the carrying capacity of a system for a particular species must have some biotic foundation. Therefore, it would seem important to pay more attention to interactions between species extending into the early egg and larval phases. Whether in the end we can afford to restrict ourselves to a multispecies approach to solve the recruitment problems or we have to adopt a more extensive ecosystem approach remains open to speculation. One thing we have learned from the North Sea exercise, however, is that model development and data collection should be carefully tuned to each other to produce the highest scientific yield.

Remote Sensing as a Research Tool for Linking Environmental Factors and Bay Production

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The recent application of satellite technology to the synoptic detection and monitoring of global ocean features has resulted in the birth of a new subfield of oceanography by which large and small scale surface properties of the ocean can be tracked with exacting detail. Sea surface temperature and turbidity are two properties which the satellite platforms measure reliably and accurately. More recently, the ability to measure "ocean color" which is translatable into surface pigment concentrations (chlorophyll) contributed by photosynthetic phytoplankton has enabled widescale mapping of these algal standing stocks. This is of prime importance to the fisheries as the location of the food source often governs the spatial distribution of the higher trophic levels. Attempts at relating the standing stocks to ocean productivity have generated enthusiasm as to the power of the imaging tools to answer pressing scientific questions. The correlation of these pigments with physical features as revealed by temperature or turbidity (upwellings, fronts, intrusions, rings, etc.) has intensified the interdisciplinary approach to oceanography because the physical processes controlling or defining algal blooms or turbidity plumes may be delineated. Indeed, in many cases, the differences in ocean color may actually be used as a biological or geochemical indicator of water mass origin when physical parameters give diffuse or conflicting signals.

Recently, in collaboration with NOAA, we have demonstrated that reliable and accurate measurements of small scale pigment and suspended sediment distributions in highly turbid estuarine environments is feasible and desirable using newly developed algorithms. Satellite imagery was obtained from NOAA 6 and NOAA 7 AVHRR (1.1 km resolution) and Nimbus 7 CZCS (0.8 km resolution). The radiance data were processed for pigment concentrations using the vector analysis technique developed for turbid waters. The resulting imagery is color encoded according to concentration. The satellite imagery can greatly aid in answering basic scientific questions on algal migration, bloom origins, dissipation, tidal spatial reconfiguration and population dynamics as well as trace the fine scale kinetics of sediment plumes.

Estuaries in particular are most difficult systems in which to work. These highly dynamic environments make the interpretation of shipboard data a challenge. While climatic forcing ultimately controls estuarine flow patterns, phenomena which last on the order of days to minutes such as wind events, tidal currents, and breaking of internal waves influence the horizontal as well as vertical distributions of organisms and nutrients by altering or completely disrupting seasonal stratification patterns.

A major frustration that an estuarine oceanographer, therefore, faces is to determine how representative the sample is of the area. Since the time and space scales of estuarine processes are significantly different than those in the open ocean, it is critical that sampling schemes are designed to adequately characterize the heterogeneity and transience of the system. The integration of reliable remote sensing techniques with *in situ* observation can provide the sensitivity and synoptic coverage needed to assess the variability of the system.

While the satellite remote sensing in estuaries can never replace *in situ* observations, it is becoming increasingly apparent that its use can improve the interpretation of the ground truth. The satellite is capable of documenting interannual variations to establish trends as well as discerning the effects of tidal events on the system. This is a powerful, readily available source of data which should be a routine tool in any basic or applied research program.

BIOENERGETICS MODELING: SPECIES INTERACTIONS AND POTENTIAL PRODUCTIVITIES -- GREAT LAKES EXPERIENCE

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The economic value of activities related to sport and commercial fisheries in the Great Lakes is now over $4 billion per year, and over 95% of those values derive from salmonine sport fisheries. Prior to the 1960s most fishery values were associated with commercial operations. Drastic changes in Great Lakes fish communities were brought about by human activities beginning early in this century: 1) rainbow smelt were introduced, and the alewife and sea lamprey invaded the upper Great Lakes via the Welland Canal; 2) lamprey predation and intensive fishing decimated larger commercial fishes including lake trout, the primary piscivore, permitting the alewife to attain high abundance; 3) smelt and alewife contributed to extreme reductions and extinctions of native species by intense competition and perhaps predation on eggs and larvae; 4) the alewife went through a population explosion and massive die-off in 1967 which had high social and economic costs. In the mid-1960s Lake Michigan was yielding little of its natural productivity to human benefits.

Control of sea lampreys by chemical treatments permitted reintroduction of lake trout and, in addition, an intensive restocking program was started for coho salmon, chinook salmon, rainbow trout and brown trout to bring the alewife population under control. The tremendous success of this salmonine enhancement program led to public pressure for ever-increasing densities of predators, and managers complied, apparently without concern for production limits and stability of the forage base. Presently about 15 million salmon smolts per year are stocked into Lake Michigan.

A bioenergetics-modeling synthesis of total predation by the entire salmonine assemblage suggested: 1) that a significant proportion of annual prey production was now being consumed, 2) that consideration of time lags and species-specific forage demands should be an integral part of management plans for salmonine stocking, a recommendation now being followed by resource managers, and 3) that the uncoupled predator-prey system was inherently unstable and eventual collapse of the alewife stock was very possible. Between 1980 and 1984, alewife populations in Lake Michigan declined about 85%.

Decline of alewives led to explosive increases in bloaters and yellow perch, and notable increases in smelt and deepwater sculpins, indicating strong interactions among these species. The reduction in size-selective predation by alewife led to major changes in the zooplankton community towards pre-1950's conditions, with recovery of efficiently-filtering *Daphnia* species. Increased grazing on the phytoplankton by *Daphnia* more than doubled water clarity in the off-shore epilimnion, clearly demonstrating the strong influence which fishes can have on all lower trophic levels.

Lake Michigan remains a management-dependent system dominated by exotic fishes. Irreversible changes have occurred, but management actions have brought the system back to a state which yields high social and economic benefits. Energetics-modeling simulations are being used to further our understanding of predator-prey dynamics and ways in which they influence system production limits at all trophic levels. Modeling results have had immediate applications in the ongoing decision-making processes of resource managers and, hopefully, will help to sustain the flow of benefits.

THE "ANATOMY" OF THE ECOSYSTEMS NETWORK OF CHESAPEAKE BAY

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The usual method of studying ecosystems' response to perturbation has been to create simulation models of the system dynamics. Models require copious data on species stocks and intercompartmental flows. It is possible to extract much information useful for deciding management issues from the structure of the exchanges itself, without having to invoke the manifold a-priori assumptions required for simulation. One modeler has likened modeling to studying the "physiology" of the ecosystem, whereas flow analysis is akin to inspecting the system's "anatomy."

Flow analysis can be made at several hierarchical levels. For example, one may calculate the total exchanges between any pair of species over all direct and indirect pathways. In this manner, one may portray the "extended diets" of species of interest. For example, the striped bass is known to ingest bay anchovies, menhaden, crabs and alewives directly. But these prey in turn consume a host of other invertebrates and plants, some of whom feed on still others, etc. Matrix and vector operations allow one to calculate the extent to which any organism of interest depends upon any other compartment for direct and indirect sustenance. Although adult striped bass do not feed on zooplankton directly, the latter item has been incorporated into about 67% of the striped bass prey.

Similar matrix operations allow one to determine the average topic distance over which each feeding organism obtains its food. In the Chesapeake system, despite the existence of some feeding pathways with as many as eight trophic links, no carnivore feeds, on the average, at trophic level 5 or higher. If this assignment represents "the apportionment of integral trophic levels among the species," then the inverse operation is also possible. That is, knowing the various trophic pathways along which food reaches a particular species, one can divide the activity of that species among the integer trophic levels in proportion to the intensities of the pathways of various lengths. The end result is to transform the arbitrarily complicated network of exchange into a "straight chain" of ever-decreasing transfers -- the classical Lindeman trophic pyramid. The effects of stress are most likely to be exhibited as changes in the upper trophic elements of the chain. Any abrupt change in the trophic assignment of a particular species would probably indicate a strain on that organism.

Control in the ecosystem is usually indicated by feedback cycles of material and energy. Such cycles inherent in the web of exchanges can be enumerated and extracted from the network by an appropriate backtracking algorithm. The pattern of feedback in the Chesapeake system is bipartite, with recycling among the pelagic species decoupled from feedback among the benthic and nektonic components. The entire suite of filter-feeding organisms engages in no feedback, but rather performs the function of shunting material and energy from one domain of control to the other.

Finally, it is possible to characterize the development stage of the overall network by techniques borrowed from information theory and flow analysis. In particular, if one has access to the configuration of the system at two or more different times, it becomes possible to verify quantitatively the existence of heretofore qualitative phenomena such as eutrophication and ecosystem "health."

A preliminary quantification of carbon exchange among the 35 major components of the mesohaline ecosystem during the summer has been made. Work is currently underway to estimate the seasonal changes in network configuration, create an annual composite network, and compare the structure of the Chesapeake network with a similar study of the Baltic Sea being conducted by the ASKO Laboratory of the University of Stockholm.

WHERE DID ALL THE COHO GO?

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After catches of coho salmon declined in the 1940's and 50's, largely because of destruction of natural stream habitat, a large-scale hatchery program was initiated to restore the runs. At first there was an encouraging positive relationship between smolts released and production (catch plus escapement) of adults. This was followed by a period of variable survival when smolt releases were fairly constant, and then a period of poor survival despite increased releases of smolts from private salmon ranchers. In recent years an inverse relationship exists between smolts released and adult production.

Several hypotheses have been proposed to explain the poor survival of coho salmon in recent years. These relate to:

1. changes in the ocean environment and productivity
2. density dependent growth and mortality
3. poor quality of smolts released by hatcheries
4. increased predation on hatchery fish

The survival of coho salmon in the ocean is positively correlated with the intensity of coastal upwelling during the period of smolt migration to the ocean. Poor upwelling has prevailed since 1975. Thus, declining ocean production of salmon may be related to decreased food availability or to changes in distribution of smolts that affect predation rates.

There is some evidence for decreased survival in weak upwelling years when large numbers of smolts are released. But when stock-recruitment relationships were analyzed for wild and hatchery stocks and for strong and weak upwelling years separately, no significant density dependence was detected. However, adult size and abundance are inversely related during periods of high adult production, suggesting that growth may be affected by abundance.

Survival may be affected by the poor quality and physiological condition of the smolts when released from hatcheries by suboptimal migrational tendencies of the smolts, or by their increased vulnerability to predation. These factors require further research.

Interannual variations in predation rates are difficult to evaluate, but recent studies suggest that seabirds may prey intensively on the smolts released into estuaries by private salmon ranchers. Higher survival of smolts barged and released offshore compared with survival of those released into estuaries supports the hypothesis that predation during early ocean life is an important determinant to survival.

TIME SERIES, RECRUITMENT PROCESSES, AND COORDINATED INTERDISCIPLINARY RESEARCH

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The subject of this talk is the origins, organization, and accomplishments of California Cooperative Oceanic Fisheries Investigations (CalCOFI), an interdisciplinary, interagency research program. I begin with a discussion of the origin of CalCOFI, then describe the present organization, explain why I believe it still survives after 40 years, and provide some highlights of recent accomplishments that document the importance of time series information, the heart of the CalCOFI program. My sources for historical information were papers by Clark, Croker, Baxter, Reid, Powell, and Radovich (all published in 1982).

The CalCOFI program began in 1947 in response to the political and scientific controversy evoked by the remarkable failure of the California sardine. The California Legislature passed an act creating a committee [Marine Research Committee (MRC)] which was composed of leaders of the lead resource agencies and industry representatives who held the majority vote. The responsibility of the MRC was to guide research on the origin of the sardine failure and administer research funds generated by a landing tax, self-imposed by the industry. The organization and the research programs fostered by the MRC became the program known today as CalCOFI. By 1960 the mandate of the program was broadened to include investigations of the factors controlling variations in population size and availability in oceanic fishes of the California Current. CalCOFI has continued to this day despite the passage of the 1976 Fishery Conservation and Management Act (extension of Federal jurisdiction to 200 miles) which led to the demise of the MRC in 1978. The basis of the present program is a cooperative agreement between three agencies -- the National Marine Fisheries Service, California Department of Fish and Game, and the University of California, Scripps Institute of Oceanography. These agencies conduct cooperative surveys, contribute $10,000 per annum each to pay for editorial and publication costs of CalCOFI Reports, hold monthly coordinating meets, and support an annual workshop meeting which is widely attended by the general research community. Other than support for CalCOFI Reports, all costs incurred in support of the program are borne individually by the three agencies.

The MRC played a crucial role in the early years by providing seed money for scientific projects and funds that helped support the cost of the surveys during lean years. Total funds allotted for research by MRC over its 31 years was 3.5 million (about 65 to 180K$ per year). Perhaps more important was persuasion of Federal and State legislators by industry representatives on appropriate funds to support University and Federal programs.

I believe the factors that have maintained the organization to this day, long after the loss of the financial and political support of the MRC, were faith, face, and determination; faith among a few members in each organization in the ultimate value of time series and interdisciplinary research; fear of the loss of face in being the organization responsible for the demise of CalCOFI; and the determination to convince their respective organizations that the effort was worthwhile. I also believe the cloistered annual workshop meetings and the journal (CalCOFI Reports) in which findings of primarily regional nature could be rapidly published were also instrumental in the continuation of the program. Another important ingredient was that each organization had an acknowledged expertise and role in particular fields (monitoring of the catch, California Department of Fish and Game; oceanography, Scripps Institution; and ichthyoplankton, National Marine Fisheries Service). Thus each group could pursue their own organizational commitments and interests within the loose framework of the CalCOFI program.

Three key elements led to the scientific success of the program: maintenance of quality records of age composition and length of the commercial catch of key species; a grand ichthyoplankton and oceanographic survey design that encompassed the entire spawning habitat of key species (sardine and anchovy) for all seasons; and most importantly, the commitment of all groups to the belief that only through long time series of fishery data, survey abundance estimates, and environmental measurement could the causes of variation in fish stocks be determined.

I have selected a few recent accomplishments of the CalCOFI program to illustrate the importance of time series information. Presentation of all the scientific accomplishments of CalCOFI, which are documented in about a thousand publications, is beyond the scope of this report. Chelton et al. (1982) used the 30 year CalCOFI time series to demonstrate that interannual variations in the flow of the California Current plays a dominant role in controlling zooplankton biomass over the vast area (240 x 100 M) sampled in the CalCOFI program. Increased zooplankton is associated with cold temperatures and increase equatorward flow, and low abundance with warm temperatures and weak flow. Clearly, these major long-term trends in the environment may have critical importance to stock dynamics, but their effects are still largely in the realm of speculation. Recent work indicates, however, that weak flow and low standing stocks of zooplankton result in slower growth of juvenile anchovy and sardine and this reduction in size reduces the reproductive output of anchovy (Butler 1987). Another important aspect of the time series is historical documentation of contaminants in the preserved specimens taken in past surveys. Such a study was conducted by MacGregor (1974) who measured the amount of pesticide DDT and its metabolic products (DDE and DDD) in myctophid fish, Stenobrachius leucopsarus. This research done in the early 70's documented the increase in DDE in fishes from the early 50's until in 1970 when dumping of DDT wastes ceased. The anchovy management plan, is a major fishery accomplishment of the CalCOFI program. In the present plan the time series of fishery data and the ichthyoplankton survey data are coupled with a new precise method of estimating spawning biomass (The Egg Production Method). Development of the egg production methodology (Lasker 1985), and subsequent coupling to the time series (Methot 1986) were all part of the CalCOFI program. A modified version of the egg production methodology (Wolf and Smith 1986) is currently being used to monitor an apparently recovering sardine population which was open to controlled fishing this year for the first time since 1973.

Neither the causes of recruitment variation in sardine and anchovy nor the effects of long-term trends in the oceanic climate on these stocks have been conclusively identified. However, the long-term monitoring of the stocks and the environment which is an inherent part of the CalCOFI program has permitted hypothesis testing, a rare event in the speculative field of recruitment research. A time series of size-specific mortality rates of anchovy (Lo 1985) and sardine (Butler 1987) has been very useful for hypothesis testing. Use of these data along with environmental information has led to rejection of some past hypotheses and creation of others, and a more sophisticated and accurate interpretation of the dynamics of the stocks (Methot ms). Most recent findings indicate that anchovy larval mortality over the first 20 days of life is correlated with stable ocean conditions, but larval abundance at the end of this stage is not correlated with that of the recruits (Peterman et al. 1986). Cannibalism and starvation have also been documented as important sources of anchovy mortality over this period. On the other hand, larval sardine mortality rates and sardine recruitment are correlated with anchovy biomass but larval sardine mortality is not correlated with stable ocean conditions (Butler 1987). I believe future advances will require continuation of monitoring the abundance of all early life stages as well as the environment and clearly, monitoring the catch and routine annual estimates of recruitment are essential ingredients of any program on recruitment. In addition, back calculation of cohort abundance and mortality rates using otoliths, within the context of known egg production rates, offers a unique opportunity for evaluating the effect of the environment on cohort survival and ultimately recruitment.

In conclusion, the CalCOFI time series as well as most other oceanic time series (Longhurst et al 1972) indicate that the ocean is a highly variable environment and that changes may be sudden and dramatic or covert and sustained for long periods. Obviously, these changes can only be revealed and measured by deliberate and sustained ocean monitoring.

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MODELLING MAN'S IMPACT ON FISH POPULATIONS

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Not surprisingly, the effect of man on living marine resources that is modelled quantitatively most often is fishing. There is a large literature spanning 50 to 100 years. Some of it is very sophisticated ecologically and mathematically.

There is also an extensive literature on the effects of other anthropogenic activities (i.e. pollution) on the aquatic environment and living marine resources. One of the goals of such research is to assess how these activities affect fisheries. But most of the studies describe biological effects on individual organisms or ecologically important, non-target (non-fished) species. Relatively few studies quantitatively model the effects of pollution or habitat alteration on resource populations and fisheries yield.

Pollution-oriented "biological effects studies" will be more valuable if they are interfaced with population dynamics models. For this reason, it is illustrative to review some of the population dynamics models which are the cornerstones of fisheries science and show how they can be easily modified to take account of effects of pollution stress. The approach indicates why it is essential that studies of biological effects provide information on the effects of pollution stress on demographic parameters (e.g., growth rate, survival rate, reproductive rate) if the effect of pollution on fisheries is to be assessed.

OVERVIEW OF CONTAMINANT RESEARCH NEEDS IN THE CHESAPEAKE BAY

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The Chesapeake Bay is one of our nation's most valued resources. It provides millions of pounds of commercial seafood, abundant sport fishing, major wildlife habitat, excellent recreational opportunities and it functions as a major center for shipping and navigation. Associated with the opportunities and resources which the Bay supports are extensive industries, agriculture, urbanization, and projected population expansion. The integrated uses of the Chesapeake Bay and its watersheds have placed substantial pressure on the Bay's ecosystem. Recognition of these pressures and resulting adverse impacts such as decreased shellfish and finfish populations, deteriorated water quality, and increased chemical contaminants has stimulated much concern and research efforts by Federal and State agencies and private conservation organizations. The U.S. Environmental Protection Agency (EPA) initiated an intensive five-year effort in 1976 to study the environmental quality and management of the Chesapeake Bay natural resources.

One of the major stressors identified by the EPA Chesapeake Bay Program (CBP) was toxic chemicals. These stressors included over 300 identified organic compounds (pesticides, PCB, petroleum hydrocarbons, etc.), inorganic chemicals (cadmium, copper, lead, etc.), contaminated sediments, and sewage treatment effluents. The CBP documented the seriousness of the contaminated resources and predicted that the sources and quantities of chemical contaminants in the Bay and its extensive watersheds will continue to grow. Control of both existing and future point and nonpoint sources of contaminants needs to be addressed by resource managers to preserve and enhance the Bay resources. It is naive and unrealistic for scientists and resource managers to expect or try to achieve in all cases "zero discharge" of chemicals into the environment and more particularly into the Chesapeake Bay. We need a better understanding of the impacts of contaminants on Bay resources and better estimates of "safe" exposure concentrations of contaminants and contaminant mixtures to indigenous species. A more thorough understanding of safe levels will make management and control of contaminant inputs more realistic. Contaminant research needs in the Chesapeake Bay are very broad and encompass many different sources and classes of toxic chemicals in salt water and freshwater environments. Future research needs should focus on contaminants previously identified, and special emphasis should be given to those contaminant sources which need more thorough hazard assessment, such as agricultural chemicals, contaminated sediments, and hazardous waste sites.

With regard to agricultural chemicals, it is estimated that world pesticide and fertilizer use will more than double by the year 2000. This increase in pesticide use will be accomplished by a shift in the types of chemicals utilized; this has already been reflected in agricultural practices in the Bay area. The three major classes of insecticides -- organochlorines, organophosphates, and carbamates -- will continue to be used, but a dramatic shift towards less persistent organophosphorus and carbamate compounds, as well as synthetic pyrethroid chemicals, will be evident, with less organochlorine compounds being applied. Although insecticide usage per acre is not expected to increase significantly in the future, major shifts in use patterns are projected which may result in adverse impacts on fishery and wildlife resources. An example is a major shift toward the use of pyrethroid insecticides for major crops. These compounds are generally highly toxic both to target organisms and to non-target aquatic organisms. A 100% increase in insecticide use on soybeans is also projected for the near future. As shifts to new generations of organophosphates and pyrethroid insecticides occur, we are faced with data gaps in assessing the potential for impacts on non-target aquatic species and ecosystems. The biggest increase in pesticide usage will be for herbicides, because farmers are employing more conservation tillage methods (no-till, minimum till) which require more frequent, heavy usage of herbicides. Conservation tillage techniques provide not only advantages such as reduced energy output and soil conservation but also disadvantages of increased chemical use and increased breeding places for pests. The toxicity, bioconcentration, and ecological community-level effects of these new generation pesticides need to be evaluated. Although non-point source pollution from agricultural levels in the Chesapeake Bay watershed has been and continues to be addressed, it is an area of research which deserves special attention because of changing agricultural practices, sedimentation, and a lack of ecological-oriented contaminant research.

Research activities and contaminant assessment technology in the future must be expanded and integrated with other Chesapeake Bay programs to address the potential contaminant impacts on aquatic resources in the Chesapeake Bay. The acute and chronic toxicity data bases on effects of chemical contaminants on representative aquatic species should be expanded to gain a better understanding of the water quality factors that affect toxicity. In addition, more emphasis should be given to predicting toxic responses from physical-chemical characteristics of contaminants through quantitative structure-activity relationships (QSAR). Because of the multitude of contaminant problems in the Bay, more short-term predictive techniques are needed. More fundamental research on absorption and desorption kinetics of pesticides to soils and sediments is needed to assess the bioavailability of chemicals in agricultural and hazardous waste site run-off and to predict environmental concentrations causing adverse effects in the natural environment. Most importantly, considerable research emphasis must be given to contaminant effects at the population and community levels. Development of ecological assessment tools which utilize laboratory and field measurements are desperately needed in contaminant assessment procedures, as are development of models for predicting the fate and ecological effect of contaminants in aquatic habitats. Inherent in all contaminant research needs is the continued development of analytical chemistry techniques for the detection of minute amounts of contaminants in water, fish, sediment, plants, and other biota so as to measure effective environmental concentrations of contaminants. The hazard assessment of contaminants to aquatic life requires integrated research efforts with other Chesapeake Bay research efforts which are dynamic and need continued updating and fine tuning. The following are areas of long-term research which need to be addressed in conjunction with other Bay research efforts to assess more adequately the hazards of contaminants to aquatic resources in the Chesapeake Bay:

1. Determine the acute and chronic toxicity of contaminants to indigenous species of the Chesapeake Bay and assess the water quality factors (salinity, alkalinity, pH) that affect toxicity.

2. Assess the chronic toxicity and bioconcentration of contaminant mixtures in sensitive life stages of finfish and shellfish.

3. Develop biological indicators of contaminant stress for use in field investigations to predict fish health and community-level effects.

4. Assess the chronic no-effect concentrations of contaminants and contaminant mixtures in relation to measured environmental contaminant concentrations.

5. Continue to assess the influence of acid deposition and contaminant interactions on early life stages of striped bass and other species in salt water and freshwater habitats.

6. Develop techniques to predict contaminant toxicity and bioconcentration using quantitative structure-activity relationships (QSAR).

7. Develop/adapt chemical techniques to measure environmental concentrations of contaminants in environmental sample matricies.

8. Continue environmental monitoring of contaminants in fish, water, and sediment in critical habitats of the Chesapeake Bay and its watersheds with emphasis on relating research results to environmental concentrations of contaminants.

THE ROLE OF BIOECONOMIC MODELING IN DEVELOPING RESEARCH AND MANAGEMENT PROGRAMS

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At one level I could accomplish my purpose by presenting a list of economics of fisheries management and economics of pollution control questions that are directly related to Chesapeake Bay Living Resources. However, due to the emphasis of other papers in this symposium, I will use a different framework. Rather, I will look at the formulation of a biological research plan from the point of view of an economist. I believe this approach is valid and useful for at least two reasons. First, the emphasis in today's discussion has been on research for management rather than research for the sake of inquiry. Second, to obtain funding for such a research program, either from State or Federal authorities, justification in terms of return to investment will be necessary. [If the reference to justification of government dollars is offending, the issue can be put differently. There is only so much scientific expertise that is knowledgeable about Chesapeake Bay problems and currently working in the area, and so many hours to work in a year. Therefore, it is useful to provide some advice on which problems should be given more effort and which problems should be attacked first.]

In earlier discussions, people have cited the decline of Chesapeake Bay productivity by showing how total catch in weight has fallen steadily and drastically over the last 100 years. While this is certainly a sign of an unhealthy Bay, it really gives little help in planning a research agenda to improve the health of the Bay.

In one sense, the Bay can be viewed as one of many valuable resources in our economy. When we use other inputs in conjunction with the Bay, we produce valuable outputs. That is, when we use labor, gasoline, boats, etc. with the Bay, we produce such things as commercial fishing, recreational fishing, swimming, boating, housing, transportation, and waste assimilation services. There may even be "existence values" produced by knowing that particular species are preserved in the ecosystem. Each of these services has a value, some of which are higher than others. Economists have been studying market and non-market evaluation for many years, but it is beyond the scope of this brief discussion to discuss it in detail here. However, see Bockstael et al. (N.D), Vincent et al. (1986) and Moser and Dunning (1986) and the references cited therein. The point that is important for formulating research schemes, however, is the absolute and relative values of thee various uses.

The real problem with the health of the Bay is that the values that are generated from its use are not as high as they might be. Two important reasons for this decline in potential value are open-access to the fisheries wherein stocks are overfished, and the externality relationships between the amount of waste produced by industry, and the value of other services such as commercial and recreational fishing, and swimming. If somehow we can readjust the types of inputs that are used with the Bay, we could increase the value of outputs produced now and/or in the future.

Bearing this in mind, what topics or issues should a research program focus on? What should be studied? I would suggest that research should be focused on those species which directly affect use values of the Bay, species that indirectly affect use values through ecological or economic interdependencies and the chemical and physical processes which affect both these groups of species. Which should be studied first? The answer is, "Those species and those processes which affect the more valuable uses."

While the theoretical thrust of the above is appealing, I admit there can be problems in application and therefore the point should not be pushed too stringently. Obviously, care must be taken not to exclude topics too easily just because direct links or current values cannot be shown. But all else equal, what the above implies is that the clearer the relation to a valuable use the higher the value of that use, the more emphasis should be given to the study of those species or those chemical or physical processes.

Once the areas for study have been determined, it is also necessary to determine what particular aspects of those areas should be scrutinized. I would propose the following two types of questions:

1. What will happen to the use values generated from the Chesapeake Bay under a status quo situation?

2. What will happen to the value of output if changes in parameters which are directly or indirectly under the control of management agencies are changed?

For example, if effort is reduced in one particular fishery, how will this affect user values or if a certain type of pollution at a certain concentration in a certain location is changed, how will this affect the values produced?

The emphasis in the above should be on studying things that will be relevant to potential management decisions. Not all of the important parameters or variables in the system are under the control of a management agency and so not all research will be equally valuable. For example, knowing how the system will respond to changes in rainfall will not be directly relevant to management because we cannot control rainfall. I realize the effects of management can be different according to the amount of rainfall in a year so I am not necessarily ruling out scientific studies on the effects of rainfall.

The things that are under the control of management agencies are determined by two important facts. First, depending on the nature of the laws, management agencies may legally control only certain variables. The second important determinant is the degree of actual control. This has to do with the enforceability of particular laws. A law on the books that allows for control of pollutants but which cannot be practically enforced will not change the amount of pollutant and hence will not change the value of end uses. All else equal, therefore, in a choice between studying two questions, emphasis should be given to those questions which study how higher valued goods and services change with changes in parameters under legal and actual control of government agencies. Again, I do not recommend a hard and fast application of this rule because of measurement problem, but it is a good frame of reference. As a final point I would like to emphasize that this approach requires interdisciplinary research. As a simple example, consider studies of the effect of the reduction of a certain type of pollutant. This will require ecological studies to determine the repercussions through the ecological system up to a point where issues such as the effect on catch per day of recreational fishing can be determined. Simultaneously, however, there will need to be economic studies of how catch per day affects the number of participants and value of each user day. The research plan that I am proposing, then, will require interdisciplinary natural and social science research.

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HYPOXIA IN THE FERTILE FISHERIES CRESCENT, THE NORTHERN GULF OF MEXICO: EFFECTS ON LIVING RESOURCES AND COMPARISONS TO THE CHESAPEAKE BAY

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The continental shelf and estuarine waters of the northern Gulf of Mexico yield between one-fourth and one-third of the fisheries biomass landed in the U.S. annually, yet the inner shelf is the site of extensive and severe hypoxia in bottom waters during summer months. Assessments of the causes of recurrent hypoxia and the effects on living resources are made difficult because of the paucity of historical data and the lack of concerted observations or research on the subject. This presentation reviews what is known about the occurrence of shelf hypoxia in the Gulf and hypothesizes potential impacts on fishery resources. Comparisons are made with the potential impacts of seasonally persistent hypoxia in the Chesapeake Bay.

The occurrence of areas of depleted dissolved oxygen at the seabed on the open continental shelf off Louisiana has been known from at least 1973. Hypoxic or anoxic bottom waters were thought to occur in isolated and somewhat ephemeral pools and were thought related to the decomposition of organic matter from the Mississippi and Atchafalaya Rivers and coastal marshes. The Mississippi River is the largest river in North America and is the sixth largest in the world in terms of freshwater discharge. The Atchafalaya River distributes 30% of the Mississippi's flow (approximating the Columbia and Yukon Rivers in the amount of water discharged into the sea), which debauches on to a broad, shallow continental shelf in comparison to the deeper water discharge of the Mississippi proper.

In 1985 systematic investigation of shelf hypoxia was begun. This investigation has shown 1) that the oxygen depleted zones were extensive and continuous (areas exceeding 8,000 km^2 and bottom dissolved oxygen levels below 2 mg/l during mid-summer in both 1985 and 1986); 2) that hypoxic conditions persisted over the entire summer, shifting offshore and onshore in response to wind forcing; 3) that oxygen was depleted by decomposition of organic material produced <u>in situ</u> by plankton which is stimulated by river-borne nutrients; and 4) that oxygenation of bottom waters is prevented by strong density stratification mainly due to the halocline.

In 1985, bottom-water hypoxia was observed during initial sampling in June and persisted into August, when intense mixing of shelf waters due to the passage of hurricanes broke down density stratification. In 1986, hypoxic conditions first appeared in mid-April and appeared to be intensified as a result of phytoplankton blooms associated with diluted plumes of discharged river water. Gradual dissipation of stratification due to decreased freshwater discharge, surface cooling and wind mixing resulted in alleviation of bottom hypoxia in September. The existence of a well-defined coastal boundary layer of warm, lower salinity water seems to contribute to the persistence of hypoxic conditions throughout the summer by maintaining inner shelf stratification and recycling nutrients.

An important question is whether nutrient enrichment due to human activities, particularly in the Mississippi River, has caused eutrophication which has exacerbated oxygen depletion on the shelf in space and time. Evidence is presented that average spring and summer nitrate concentrations in the Mississippi River discharge have doubled over the last 30 years, but that silicate levels have decreased during this period, probably as a result of sediment trapping in upstream reservoirs. Nitrogen concentrations in Mississippi River water have doubled during the last 30 years as a result of increased application of fertilizers and point-source discharges in the Mississippi River drainage basin, which constitutes 40% of the U.S. (excluding Alaska). The discharge of nitrogen from the Mississippi River system into coastal waters exceeds 1000 metric tons per year, dwarfing such loadings into the Chesapeake and Hudson estuaries and the southern California Bight, for example.

The effects of oxygen depletion resulting from coastal water eutrophication in the northern Gulf of Mexico on the rich fisheries of the region are potentially substantial. Although the impact on the important fisheries is unquantified, it has been demonstrated that benthic fish and penaeid shrimps are virtually absent over large areas of the shelf where dissolved oxygen levels are below 2 mg/l.

Particularly threatened are demersal penaeid shrimps, the nation's most valuable fishery. Critical conditions may exist for juvenile brown shrimp, *Penaeus aztecus*, early in the summer when this species migrates offshore from estuarine nursery grounds. Juvenile shrimp are confronted with a nearly continuous, longshore band of bottom water in which oxygen concentrations are too low to support their metabolism. White shrimp, *Penaeus setiferus*, on the other hand are probably most threatened as larvae and postlarvae late in the summer. Hypoxic zones coincide with the inner shelf spawning grounds of this species. The effects of hypoxia on these stocks are virtually impossible to infer from catch or landing statistics because of the greatly varying fishing effort and because of the well-known importance of other factors, such as salinity conditions in the nursery estuaries, on the stocks.

A P P E N D I X   C

WORKING GROUP SCHEDULES AND ASSIGNMENTS

Long-Range Research Needs for Chesapeake Bay Living Resources

Working Group Schedule and Participants
4 February 1987

Schedule

09:00 Organization, Assignments and Guidelines for Working Groups
E.D. Houde

Working Groups

1. Nutrients and Fish Production
   Chairman: T. Malone

2. Predator-Prey Relationships and System Energetics
   Chairman: R. Ulanowicz

3. Effects of Fishing
   Chairman: J. Boreman

4. Recruitment Variability
   Chairman: H. Austin

5. Anoxia, Pollutants, Toxicants and Disease
   Chairman: J. Sanders

6. Restoration Strategies
   Chairman: R. Harrell

7. Review of Species-Specific Needs and Living Resources Habitat Criteria

   a) Oysters, Clams
   b) Blue Crabs
   c) Menhaden, forage species
   d) Anadromous species complex
   e) Bluefish and sciaenid complex
   f) Flounders, eels, others
   (Chairmen of subgroups to be designated)

09:20 - 11:00 Working Groups #1 - #6 Convene and Deliberate

11:00 - 11:20 Coffee

11:20 - 13:00 Working Groups #1 - #6 Continue Deliberations and Formulate Recommendations

13:00 - 14:15 Lunch

A 14:15 - 16:00	Chairmen and rapporteurs of Working Groups #1 - #6 prepare outlines of reports and lists of recommendations
B 14:15 - 16:00	Working Subgroups 7a - 7f Convene and Deliberate
16:00 - 16:20	Coffee
16:20 - 17:30	Working Subgroups 7a - 7f Continue Deliberations and Formulate Recommendations
A 17:30	Adjourn
B 17:30 - 19:00	Chairmen and rapporteurs of Working Subgroups 7a - 7f prepare outlines of reports and lists of recommendations
18:00	Happy Hour
19:00	Dinner
20:15 -	Finalize typing, word processing, copying of Working Group Draft Reports

Working Group Assignments

4 February 1987

I. Nutrients, Anoxia and Fish Production
<u>Chairman</u>: Tom Malone
<u>Members</u>: Boesch, Cloern, D'Elia, Malone, Tyler, Kemp, [Boynton & Nixon input]

II. Predator-Prey Relationships and System Energetics
<u>Chairman</u>: Bob Ulanowicz
<u>Members</u>: Brandt, Jansson, Mihursky, Stewart, Roman Ulanowicz, Purcell

III. Effects of Fishing
<u>Chairman</u>: John Boreman
<u>Members</u>: Anderson, Boreman, Chittenden, Merriner, Richkus, Daan

IV. Recruitment Variability
<u>Chairman</u>: Victor Crecco
<u>Members</u>: Boicourt, Crecco, Pietrafesa, Hunter, McConaugha, Prager

V. Pollutants, Toxicants and Disease
<u>Chairman</u>: Jim Sanders
<u>Members</u>: Haire, Hall, Fogarty, Jordan, Krantz, Mehrle, Strand, Tsai, Cronin

VI. Restoration Strategies
<u>Chairman</u>: Reggie Harrell
<u>Members</u>: Harrell, Orth, Powers, Kennedy, Pearcy, Wooley, Rugolo, Chesney

VII. Species-Specific Needs and Living Resources Habitat

7a. Oysters, Clams

<u>Members</u>: Boesch, Cloern, Jordan, Krantz, Sanders, Kennedy

7b. Blue Crabs

<u>Members</u>: Boicourt, Cronin, Fogarty, Kemp, McConaugha, Orth

7c. Menhaden, Forage Species

Members: Haire, D'Elia, Hunter, Merriner, Tyler, Roman, Purcell, Prager

7d. Anadromous Species Complex

Members: Crecco, Boreman, Hall, Harrell, Mihursky, Richkus, Strand, Tsai, Wooley

7e. Bluefish and Sciaenid Complex

Members: Brandt, Daan, Chittenden, Mehrle, Pietrafesa, Stewart, Rugolo

7f. Flounders, Eels, Others (e.g. Sturgeons)

Members: Houde, Pearcy, Ulanowicz, Chesney, Jansson

A P P E N D I X   D

SPECIES-SPECIFIC RESEARCH NEEDS

Subgroup a Report

OYSTERS, SOFT CLAMS, AND HARD CLAMS

Victor S. Kennedy (Chairman), Donald F. Boesch, James E. Cloern,
Stephen J. Jordan, George E. Krantz, James G. Sanders

The major research need is for population assessment and recruitment data. At present, there is almost no information on the amount of standing stock of the three species in Maryland's portion of Chesapeake Bay. In addition, the factors that limit recruitment are not known. Are such factors most important at the larval, spat, juvenile, or adult life stages?

To supplement the population/recruitment questions, additional questions can be posed:

1. What is the abundance of natural brood stock now available in different areas of the Bay? Is it increasing or declining? Is there an optimal brood stock concentration that ensures adequate spawning? Is population age distribution a factor in determining this optimal concentration, i.e., does one age group contribute more viable gametes than another age group?

2. The supply of seed bivalves is a limiting and critical factor in rehabilitation and management, especially for oysters. In the Bay, there are areas that consistently produce adequate quantities of seed oysters. Why are those regions more successful than others? Again, for oysters, how much cultch is now available in the Bay, and how much is optimal? What cultch concentrations are required on different bottom types or in different locations? Can any area of the Bay be made into a good seed area, given suitable firm bottom and adequate cultch for settlement?

3. For all three bivalve species, the best areas available for settlement and growth need to be determined and protected. It is not clear why some areas are conducive to setting but are not suitable for rapid growth and fattening, and vice versa, but the reasons must be clearly understood to utilize areas effectively. The development of good seed and good growing areas depends upon a clear understanding of the environment and on the life stage-specific biological responses of the bivalves to the environment.

Turning now to other important questions which can be explored in concert with research into stock and recruitment, there are five major areas of research that need to be addressed:

1. Larval Biology. The biology, ecology, and behavior of bivalve larvae are poorly understood. Their small size and the difficulties of sampling field populations continually and accurately are primarily responsible for this. We need to understand larval dispersal patterns, the

influence of water movements, salinity changes, temperature, light and pressure on larval behavior in the water column; factors concentrating or dispersing larvae; factors influencing settlement, either positively or negatively; the relationship of larval abundance to settlement success; larval food requirements and whether these are being met; the impact of predators, parasites and disease on larval abundances and ultimately on settlement success.

2. Feeding and Nutrition. The food supply and nutritional requirements of all life history stages of the three bivalve species need to be determined. Have there been changes in food species in the Bay over time, similar to changes in submerged aquatic vegetation? Have conditions favored less nutritious or less acceptable species at the expense of suitable food species? If there have been such changes, are they influencing gametogenesis and larval vigor? Are the variations in suitability of different areas of the Bay for settlement or growth related to differences in food quality? Have the bivalves themselves played a role in causing changes in primary producer-nutrient relationships in the Bay?

3. Genetics. Selective breeding of bivalves is an infant science. For aquacultural purposes of oysters in Chesapeake Bay, what trait or traits need to be selected? Are there interactions between traits such that improvements in one (e.g., shell growth) result in loss in another (e.g., meat yield)? How much of an improvement over natural selection can we expect to attain by experimental selection for desirable traits and how much will it cost in terms of time, energy, space and money? How responsive are oysters or other bivalves to genetic manipulation? Do positive results in selecting for a desirable trait in larvae (e.g., in terms of rapid growth) persist in later life?

4. Disease. The role of disease in the ecology of the three bivalve species, and the impact of non-catastrophic disease on population levels and environmental resistance, need further investigation. Interactions among diseases and methods of disease transmittal need to be established. Larval diseases, both in the hatchery and in the field, have not been studied to any extent.

5. Pollutants. Estuaries are particularly exposed to pollution. Pollutants tend to be concentrated in estuaries, either by circulation patterns or by adsorption onto sediments. Thus, quantities of anthropogenic chemicals, among them chlorine compounds, heavy metals, and petrochemicals, may come into contact with the bivalves. The influences of these materials and methods to evaluate effects on all life history stages remain to be evaluated. In addition to direct effects, we need to know the influence of pollutants on the food species of larvae and adults, and on contamination of the settlement substrate. Synergistic effects of various pollutants have not been studied to any extent.

6. Hypoxia and Anoxia. The increase of this problem in the Bay is of particular concern because all three species have a pelagic larval component

in their life history. It is not clear how larvae might be affected if carried into low-oxygen waters. In addition, the movement of such water over established oyster and clam beds is of concern, especially for soft clams which, unlike oysters, cannot close their shells and live anaerobically for a few days until the low-oxygen water is replaced by more oxygenated conditions.

Finally, some socioeconomic matters need to be addressed:

7. How can increased harvests be phased to be consistent with market demand <u>and</u> restoration objectives? What are the costs and economic benefits of restoration? Would improvements in bay water quality result in heavier utilization of bivalve resources by the public or would demand increase? Are new or innovative management strategies needed? If so, are they socially and politically feasible?

Subgroup b Report

BLUE CRAB

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Despite wide interannual fluctuations in abundance the blue crab consistently ranks number one or number two in commercial catches within the bay in both total pounds landed and dollar value. To be managed effectively, several key aspects of its population dynamics must be investigated.

As a cornerstone to good management, there is a need to develop methods for assessing stock abundance of the blue crab. Several methods for assessing stock abundance are currently being evaluated and should be encouraged, including fishery-dependent and fisheries-independent methodologies. Major hurdles to blue crab stock assessment in Chesapeake Bay are the lack of standardized data collection methods among the state jurisdictions and the extensive movements of all life history stages in patterns that are poorly understood. One promising fisheries-independent assessment technique may be the development of a megalopa-juvenile crab index in the lower Bay. While successful stock assessment ultimately will be the basis for evaluating the success of a management plan, other critically important research should proceed concurrently. These very general, but key questions include:

* What are the critical life history stages that determine annual recruitment success?
* What are the physical and biological factors that affect recruitment?
* Is there a stock-recruitment relationship?

To answer these and other questions, research plans will have to assess the spawning effort, distribution patterns and mortality rates for larvae, juveniles and adults, transport and/or migration rates for key life history stages, age structure of the population, and growth rates. Research plans should include both field and laboratory observations. Field research must measure both biological and physical factors (i.e., need for physical oceanography). Laboratory studies should include physiological processes, growth, predator-prey interactions and behavioral responses.

Key management questions that require research to obtain answers are:

* What level of exploitation should be allowed?
* How should this be allocated between the commercial and recreational fisheries?
* Do current fishing gears (pots, scrapes, dredges) adversely affect juvenile survival as well as the habitat (e.g. submerged aquatic vegetation) of blue crab and other organisms?
* Is the present, intensive total fishing pressure damaging in any way to the optimal harvest of blue crab in Chesapeake Bay?
* Do sanctuaries, gear and season restrictions, catch limits and other present and potential management efforts have a sound basis in biology or economics?

Subgroup c Report

MENHADEN AND FORAGE SPECIES

John V. Merriner (Chairman), Christopher F. D'Elia, Michael Haire, John R. Hunter, Michael H. Prager, Jennifer E. Purcell, Michael R. Roman, Mary G. Tyler

There is a major need to develop fishery-independent data sets on forage species to permit tracking of abundances and applications to stock assessments. These species are a major link between the primary producer/-zooplankton level and the large piscivorous species. New techniques must be tested and a protocol established for Bay-wide application. There is a general paucity of data on forage species populations/abundances and their trends/vital statistics.

A major research question is, "Are these abundant fishes (e.g., Anchoa and Brevoortia) having significant effects upon the phyto- and zooplankton populations, on local and larger scales: Top down predator effects?"

A second question relates to energetics. How much production is routed through these fishes? Does it cycle within the Bay or is it exported within forage or in secondary consumers (bluefish, weakfish ---)?

There is an important gap in our knowledge of forage species life history and larval ecology data. Age-specific growth, mortality and energetics data of important forage species including Anchoa, gobies/blennies, hogchokers, etc. are needed to understand secondary production in the Bay. We have a poor understanding of the distribution, abundance and natural history of foragers as well as their size /filtration efficiencies and impact of feeding on prey.

Do Anchoa, menhaden, and other forage species exert significant predation or compete with other key species of economic/ecological/aesthetic importance, particularly blue crab, oyster, soft clam --- as well as other fishes?

Menhaden, Anchoa and other forage species could serve as model species to evaluate transport phenomena from the shelf to Bay and within the Bay. Also, because menhaden and anchovy can be spawned experimentally, they can be utilized for laboratory tests of tolerances, contaminant uptake, physiological responses, and energetics relationships.

Trophic interactions of piscivores and forage species generally are not thought to control piscivore abundance, but could a threshold exist? Striped bass and menhaden, for example -- Are the increases in Atlantic menhaden since the late 1970s the result of declines in predation, changes in fishing mortality or variation in environmental factors that have favored recruitment?

Subgroup d Report

ANADROMOUS SPECIES

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Anadromous fishes in Chesapeake Bay and its tributaries have declined in abundance, in some cases precipitously. Despite considerable research effort, the causes of decline in striped bass are still not known with any degree of certainty. Even less is known about causes of decline in shads, river herrings, and white perch. Several research and monitoring efforts are needed so that management and restoration can be carried out in an informed way.

RESEARCH NEEDS

1. Representative and standardized juvenile indices for shad, white perch, yellow perch, river herring, and striped bass, for all major tributaries of the Bay.

It has been documented for many fish species that year-class strength is established by the time the juvenile stage is reached. Juvenile indices thus provide an indication of reproductive success in any given year and an estimate of potential future recruitment into commercial and recreational fisheries. Long-term records of juvenile abundance have proven invaluable in studying factors influencing reproductive success and also in guiding management actions. For example, the Maryland striped bass juvenile index has been used in most major studies of the population dynamics of striped bass and currently serves as the trigger for major changes in regulation of striped bass fisheries. Establishment of similar long-term records of juvenile abundance for all of the important anadromous fish species would facilitate characterization of their population dynamics and management of their fisheries.

2. Monitor selected critical habitats for water quality, contaminants, and environmental (chemical, physical, biological) conditions, and use data to determine the processes that affect survival of critical life stages.

Several hypotheses concerning the means by which environmental change, both natural and anthropogenic, affects reproductive success and recruitment have been raised in recent years relative to anadromous fish in the Chesapeake Bay. To date it has not been possible to rigorously address these hypotheses due to the lack of adequate data, particularly long-term records of important variables taken in a consistent manner. Establishment of monitoring programs to collect important environmental data in major spawning areas on the appropriate time/space scale, together with long-term monitoring of reproductive success, would result in data records sufficient to resolve issues critical to management of these species.

3. Develop a Bay-wide juvenile index for striped bass that is validated.

Questions have been raised about the degree to which the existing striped bass juvenile indices are quantitatively representative of year-class size. The existing indices appear to be adequate to confirm the occurrence of very good and very bad reproductive success, but there are many questions about the degree to which they accurately represent the relative magnitude of year-classes in the mid-range. In addition, Maryland and Virginia indices are not consistent with each other. The development of an index which can be validated as representative of relative year-class strength Bay-wide would contribute substantially to the management of striped bass in Chesapeake Bay and along the coast as well.

4. Establish relative or absolute abundance indices for the adult stock for each anadromous species.

Understanding population dynamics and effects of environmental variation on the dynamics requires knowledge of population size and changes in both relative and absolute abundance. The lack of these types of data has proven to be a major stumbling block in the study of the major anadromous species in the Bay. Establishing species interactions and trophic relationships, which may be important for successful management of anadromous species in the Bay, is virtually impossible without knowing, at a minimum, the relative abundance of these species (relative to each other and among years).

<u>CRITICAL AREAS</u>

Freshwater/oligohaline areas throughout the Bay.

<u>CRITICAL LIFE STAGES</u>

Egg through post finfold life stages.

Subgroup e Report

BLUEFISH AND SCIAENID COMPLEX

Mark E. Chittenden (Chairman), Stephen B. Brandt, Niels Daan,
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There is a lack of specific knowledge on fishes in this group, most of which range over much of the U.S. Atlantic Coast. Topics addressed below are needs for research.

I. Comprehensive evaluation and synthesis of existing data.

A large amount of biological and fisheries data exists for these species but it is largely unevaluated. Its quality should be determined and preliminary analyses undertaken before comprehensive new research programs are instituted.

II. Studies on stock identification and stock mixing in various fisheries.

These fishes are distributed along much of the Atlantic Coast. Stock identification/mixing studies should be conducted throughout their range. Little is known of their population structure and how populations mix either spatially or in fishery catches.

III. Define on a spatial and temporal basis species compositions and distributions along with species-specific transport and movement patterns.

These studies should focus initially on the Bay and its tributaries, but eventually expand to include the continental shelf. Critical habitat and distribution patterns will be defined by such studies, a prerequisite to other ecological research. Spawning areas and nurseries need comprehensive description, as do exchanges between the rivers, Bay, and shelf. Area-specific comparative abundances, biomasses, and production need to be assessed by fishery-independent and fishery-dependent methods. Physical and behavioral mechanisms for active or passive transport, especially at egg/larval and juvenile stages, need to be described. Results will elucidate how recruitment is dependent on the shelf and estuarine environment and how fluctuations in abundance may be related to physical or biological processes.

IV. Life history/population dynamic studies

Much of the basic life history/population knowledge needs to be developed on an area, age, and fishery-specific basis. Because allocation of species in this group frequently is a source of conflict between recreational and commercial fishermen, the need to accurately parameterize fishery models to predict effects of fishing is critical.

a) To determine effects of fishing and develop yield per recruit or spawner per recruit models, we need:

   1) methods of age determination and validation followed by growth modeling
   2) age and size composition data of the catch, based on regular monitoring
   3) mortality rates (total, natural, fishing) and longevity
   4) age at entry to exploited area/phase of life; age leaving exploited phase
   5) maturity schedules, fecundity, and sex ratios

If the above information is obtained, probable effects of size limits, minimum mesh sizes, closed areas and closed seasons could be determined from fishery modeling.

b) To evaluate recruitment variability and possibly recruitment overfishing, we need:
   1) Area-specific abundance indices for egg/larval, juvenile, adult stages along with appropriate environmental and hydrographic data
   2) early life survivorship/growth patterns
   3) spawning periodicity, duration information
   4) evaluation of nursery areas, their location with respect to spawning areas and understanding of how young reach the nurseries from distant spawning locations
   5) physiological/ecology studies to determine responses to low temperatures and other environmental factors, especially in Atlantic croaker. Such research would provide laboratory-derived cause and effect support for correlative environmental models.

c) For multispecies models that include bluefish and sciaenids, we need:
   1) a knowledge of trophic dynamics: "who eats what, how much, when and where."

Subgroup f Report

FLOUNDERS AND EELS

Edward D. Houde (Chairman), Edward J. Chesney, Jr., Bengt-Owe Jansson, William G. Pearcy, Robert E. Ulanowicz

<u>Summer Flounder</u>:

Critical life stage in Chesapeake Bay -- juveniles and prerecruits.

<u>Research Needs</u>

1) Stock Identification. With what stock(s) is the Chesapeake Bay group of predominantly juvenile fish associated? Age and size-structure need to be monitored. Electrophoresis and mtDNA studies are recommended. Results will be important for long-term management.

2) How critical is the Chesapeake Bay as a juvenile nursery for summer flounder? Are coastal areas more important? Is summer flounder estuarine-dependent? Would loss of Chesapeake Bay habitat be critical to coast-wide recruitment? <u>Approach</u>: Fisheries-independent surveys of prerecruit abundance in the Bay and coastally.

<u>Eels</u>

Critical life stage in Chesapeake Bay -- prerecruits.

<u>Research Needs</u>

1) Recruitment Information. Prerecruitment indices should be developed to forecast CPUE and catch. The fishery is totally dependent on external recruitment. A fishery-independent method to estimate prerecruit abundance is the critical factor in developing an effective management plan. Maryland DNR has a management plan under development.

2) General Population Dynamics and Fishery Models. Mortality rates (natural and fishing) are unknown. Fishery-dependent and independent estimates of abundance of fished age-classes are needed. Yield models must be developed. Long-term trends in abundance should be monitored which would document recruitment variability and changes in fishing mortality. Effects of water quality on abundance must be determined. Socio-economic models and research will be particularly relevant because eels are fished both for bait (blue crab fishery) and as a high-value export product for human consumption. There is a need to determine if apparent, recent shifts in age-structure are caused by fishing.

3) Effects of Hypoxia. Will an increasingly hypoxic main stem of the Bay affect abundance, particularly of males and of recruiting elvers? What

effects does hypoxia in the Bay or tributaries have on growth, production and distribution of eels, which are predominantly benthic in habit? Are significant mortalities associated with hypoxic or anoxic conditions? Approach: Seasonal fishery-independent surveys of bay main stem and tributaries relative to DO levels.

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