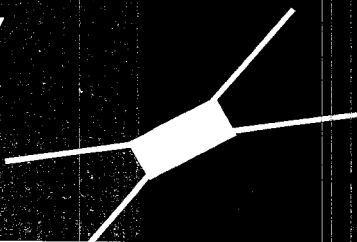
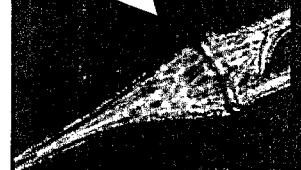
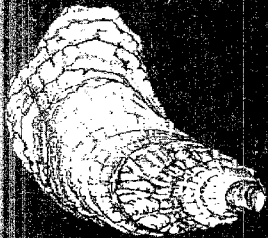
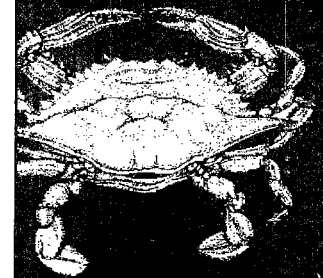


Prospects for Multispecies Fisheries Management in Chesapeake Bay

A Workshop

STAC Publication 98-002



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Prospects for Multispecies Fisheries Management in Chesapeake Bay

A Workshop

**April 1-3 1998
Solomons, Maryland**

Workshop Convenors: E.D Houde, M.J. Fogarty, & T.J. Miller
Sponsored by the Scientific and Technical Advisory Committee



August 1998
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Executive Summary

Fisheries management in Chesapeake Bay, and globally, is based upon single-species plans (FMPs) that often have neglected biological interactions such as predator-prey relationships or the so-called technical interactions (e.g. bycatch, discards) that affect yields, productivity, profitability, and which may have implications for the broad ecosystem management goals of the Chesapeake Bay Program. A workshop was convened in Solomons, Maryland, 1-3 April 1998, to consider the potential and advisability of moving towards multispecies fisheries management or of adopting approaches that are clearly compatible with an ecosystem management philosophy. International experts joined regional scientists and managers to explore multispecies issues in plenary sessions and focused working groups. This report contains the workshop's findings and recommendations.

An overall goal of the workshop was to evaluate the needs for strategic planning, research, and modeling that can allow multispecies approaches to be incorporated into the present day single-species management of fisheries resources in Chesapeake Bay. Three work groups were formed:

1. Chesapeake Bay Multispecies Issues
2. Fisheries and Ecosystem Models
3. Management Needs and Perspectives

Each work group produced a report. Findings and recommendations of work groups then were consolidated and summarized, and are the major product of the Workshop Report.

A finding of the workshop was that Chesapeake Bay fisheries management, while single-species in scope, recently had adopted a risk-averse and habitat-sensitive philosophy that will be helpful, if not sufficient, to support ecosystem management goals of the Chesapeake Bay Program. Because the success of the Program depends upon restoration or maintenance of living resources, there is a substantial need for research and modeling of trophic interactions to understand better predator-prey relationships that affect yields and productivity of Bay fisheries. At the least, identification of key species and critical linkages or dependencies among species should be highlighted in FMPs. The results of multispecies and ecosystems research or models can be adopted by managers as strategic tools to assist in decision-making within a single-species management framework. Multispecies and ecosystem models that include upper trophic levels also are needed by the Modeling Subcommittee of the Chesapeake Bay Program to evaluate potential effects of nutrient reductions on overall Bay productivity, biodiversity, and water quality.

There is no substitute for good monitoring programs of fished species and of key interacting species. Modeling evolves from and depends upon monitoring results, and management depends upon an understanding of status and trends of stocks. Fishery-independent surveys to monitor resources and to obtain biological data, if instituted and coordinated throughout the Bay, would help to improve management. Several participants stressed that fisheries management, whether it be single- or multispecies, regulates activities of people as it attempts to optimize and sustain

harvests, and thus has major socioeconomic consequences to stakeholders. Moving from single-species management towards adoption of multispecies and ecosystem approaches will not be simple. The science that is required is difficult to undertake and the management required also is complex.

The Workshop's recommendations are provided in two categories: 1) Research and Modeling, and 2) Management. They are summarized here and presented in more detail in the body of the report.

Research and Modeling Recommendations

- **Develop Fishery-Independent Surveys.** Coordinated Baywide surveys are needed to estimate key species abundances and to obtain biological data on both economically and ecologically important species.
- **Determine Key Predator-Prey Relationships and Trophic Interactions.** Identify the key species and the temporal-spatial dynamics of their interactions, especially piscivore-forage fish relationships.
- **Develop Multispecies Assessments and Models.** Assessments of key assemblages of organisms and development of multispecies models can provide managers with strategic advice on trends in assemblage abundances and potential consequences of management actions directed at component species.
- **Develop Top-Down (Predation Mediated) and Bottom-Up (Nutrient Mediated) Models.** Modeling from both perspectives is important to allow managers to consider implications of fisheries resources decisions that are made in the Bay Program's ecosystem-management setting.
- **Develop a Better Knowledge Base for Recreational Fisheries.** Better information and evaluation, including socioeconomics, of the recreational fishery, which targets several species in Chesapeake Bay, are sorely needed.
- **Evaluate Estuarine Habitats and the Potential Value of Protected Areas.** Better knowledge of habitats and their ability to support fish and invertebrate communities is required for modeling and for managers to evaluate consequences of management decisions. Estuarine reserves or protected areas need to be investigated as a potential management tool to protect or enhance key species and assemblages.

Management Recommendations

- **Develop Multispecies Assessments.** Multispecies assessments, including the identification of major predator-prey interactions and evaluations of any technical interactions (e.g. bycatch) of importance, should be included in single-species management

plans. Such assessments should be incorporated into FMP revisions that are planned.

- **Improve Catch, Effort and Biological Data.** Reliable data on catch and effort, and on the biological characteristics of managed species, are an important prerequisite for multispecies management and are obviously important for single-species management needs. Effective monitoring programs (fishery-dependent and fishery-independent) may be the single most important need for effective fisheries management.
- **Minimize Technical Interactions.** Technical interactions (e.g. bycatch) can be minimized by developing technologies and by management actions. The socioeconomic, as well as ecological, consequences of controlling technical interactions need to be evaluated.
- **Incorporate Multispecies and Ecosystem Models as Management Tools.** Encourage the development of multispecies and ecosystem models, to be used as strategic 'tools' by managers to better understand the potential consequences of actions in single-species fisheries management in the near-term and the implications for ecosystems in the longer term. Eventually, these models will be useful not only to fisheries managers but also to water quality managers in the Chesapeake Bay Program.
- **Consider Bioeconomics in a Multispecies Framework.** Optimizing social and economic benefits in multispecies fisheries will require socioeconomic research and modeling. Complexities of participation, profitability, and utilization are increased in multispecies fisheries. Achieving fairness in multispecies management will be even more difficult than in traditional single-species management.
- **Scientific Advice is Needed.** Incorporating multispecies approaches will require that scientists provide information to managers on species interactions. Scientists must advise managers on how to utilize or incorporate multispecies knowledge and models into FMPs. There are risks and uncertainties if multispecies approaches are adopted, just as there are risks and uncertainties at the ecosystem level of not being sensitive to complex multispecies issues.
- **Educate the Public.** Fisheries managers must educate the public on advantages and constraints of multispecies approaches to management. The public, while sensing a need to restore habitats and understanding that species interact, is not knowledgeable about the complexities of a multispecies approach. Managers need to convince the public that single-species management, if risk-averse and precautionary, is beneficial in the framework of the Chesapeake Bay Program's ecosystem management goals. At the same time, managers must develop and communicate to the public longer-term strategies that are broadly sensitive to multispecies interactions and the need to insure sustainability.

Conclusions

The Chesapeake Bay Program and fisheries management, in particular, can benefit from adoption of multispecies approaches that consider ecosystem needs. Presently, much can be accomplished within the single-species management framework that is in place, especially if a risk-averse strategy is followed. Explicit recognition of species interactions, bycatch concerns, competing users, complex allocation requirements, and habitat issues is needed to move management towards a multispecies management ideal that will be desirable in the future. In the meantime, multispecies assessments and models should be developed and utilized by managers as strategic tools to guide decisions in single-species management. The need for coordinated Baywide, fishery-independent surveys to assess fish stock abundances and biological parameters is clear. The requirement for reliable monitoring of fish stocks and other key interacting species cannot be overemphasized. Without it, multispecies and ecosystem models cannot be effectively developed, and the success of single-species management is diminished. Finally, multispecies management, if adopted, will be a complex endeavor requiring more regulations of fishers to achieve its goals. This inevitably will produce 'winners and losers' in the harvesting sector while it promotes the overall wellbeing of the Bay ecosystem and its ability to sustain high fisheries yields in the future.

Introduction

Fisheries are highly selective enterprises in which fish and shellfish are caught and removed from aquatic communities. Intensive fishing may lead to excessive removals of key species, changes in abundances of predators and prey, and to habitat damage when destructive gears are employed. Fishers constitute a diverse community, broadly categorized as commercial and recreational fishers, who employ many gears and land favored species, but who also inadvertently catch non-targeted species. The social and economic pressures that control fishing activities are as complex as the ecological consequences of the fishing.

Fishery managers generally direct management at individual species and attempt to optimize or maximize benefits from fisheries for the individual species. In commercial fisheries, that optimization may be expressed as an optimal annual yield or less commonly as some maximum economic yield. In recreational fisheries, goals may be less clearly defined but center upon optimizing the recreational experience, which often includes significant removals of fish, sometimes rivaling those of commercial fisheries. Fisheries historically have been managed as single-species entities, with a goal of achieving sustainability at acceptable levels, but with little consideration of the consequences of species interactions, or the implications of selective harvesting and management to overall fisheries production and ecosystem function.

Scientists, managers, and the public understand that there are important linkages and dependencies among components of ecosystems that affect community structure and ecosystem productivity, but the complexities of such interactions may be overwhelming and potential consequences usually are ignored in fishery management plans. Globally, reliance upon traditional, single-species management still predominates. However, the cognizance that a broader perspective ultimately will be necessary to manage fisheries is evolving. It has become popular to promote ecosystem management (Christensen et al. 1996) and, indeed, the Chesapeake Bay Program strives towards that goal (CBP 1995). Globally, about 70% of marine fish stocks are utilized to full capacity or over-harvested, and >20% of the stocks are over-fished or severely depleted (Garcia and Newton 1997). Given such statistics, some scientists question whether sustainability at satisfactory levels can be attained by managing fisheries in the traditional, single-species mode (Ludwig et al. 1993). Recently developed multispecies and ecosystem models explore the implications of fishing selectively on key species in aquatic ecosystems that are regulated by predator-prey interactions. While progress in development of such models has been impressive, they are seldom used as the basis for single-species management, which still prevails worldwide (Sissenwine and Daan 1991; Daan 1997). The emerging awareness that species interactions (usually predator-prey relationships) and the ability to manipulate them through management decisions might lead to higher-valued, more sustainable fisheries has been one important result of multispecies model development.

Concerns about sustainability in fisheries has led to recommendations for ecosystem approaches to help achieve it, including those in a recent study by the National Research Council of the United States' National Academy of Science (NRC in press). The consensus of such studies is that multispecies models and ecosystem approaches are important to develop long-term

management strategies for fisheries. Recommendations center on improving multispecies or ecosystem models, evaluating them, and using their output as one tool in the management process. However, shorter-term management objectives to control fishing effort in single-species management may solve some overfishing problems, reduce bycatch, reduce environmental damage and, therefore, can be a major tool to achieve some goals embraced by multispecies and ecosystem management advocates.

Single-species management in theory can be reasonably effective. But, fishery scientists and managers now realize that an ecosystem's carrying capacity, production potential and total sustainable yield to fisheries are not simply the sums for individual component species. Changes in abundances of individual species, whether due to habitat and environmental change, or to changes in fishing activity, can lead to shifts in the sustainable yields of species and to changes in the value of yields to fisheries. The biological interactions of certain 'key' species may play critical roles in regulating community structure or channeling production. Bycatch issues (i.e. technical interactions) also are of concern because these non-targeted catches often are unevaluated yet may contribute substantially to fishing mortality and to overexploitation of some species, in addition to shifting the balance of key biological interactions (Alverson et al. 1994; Alverson 1997).

Despite longstanding interest in the development of multispecies and ecosystem models and the contributions in Mercer (1982) and Daan and Sissenwine (1991), comparatively few examples exist of direct multispecies management. Gulland (1991) and Brugge and Holden (1991) note that multispecies and ecosystem models entail consideration of tradeoffs in yield between interacting species, substantially complicating management decisions. Coupled with the greater information requirements associated with these models, this complication has hindered widespread adoption of explicit multispecies and/or ecosystem approaches by managers (Gulland 1991; Brugge and Holden 1991).

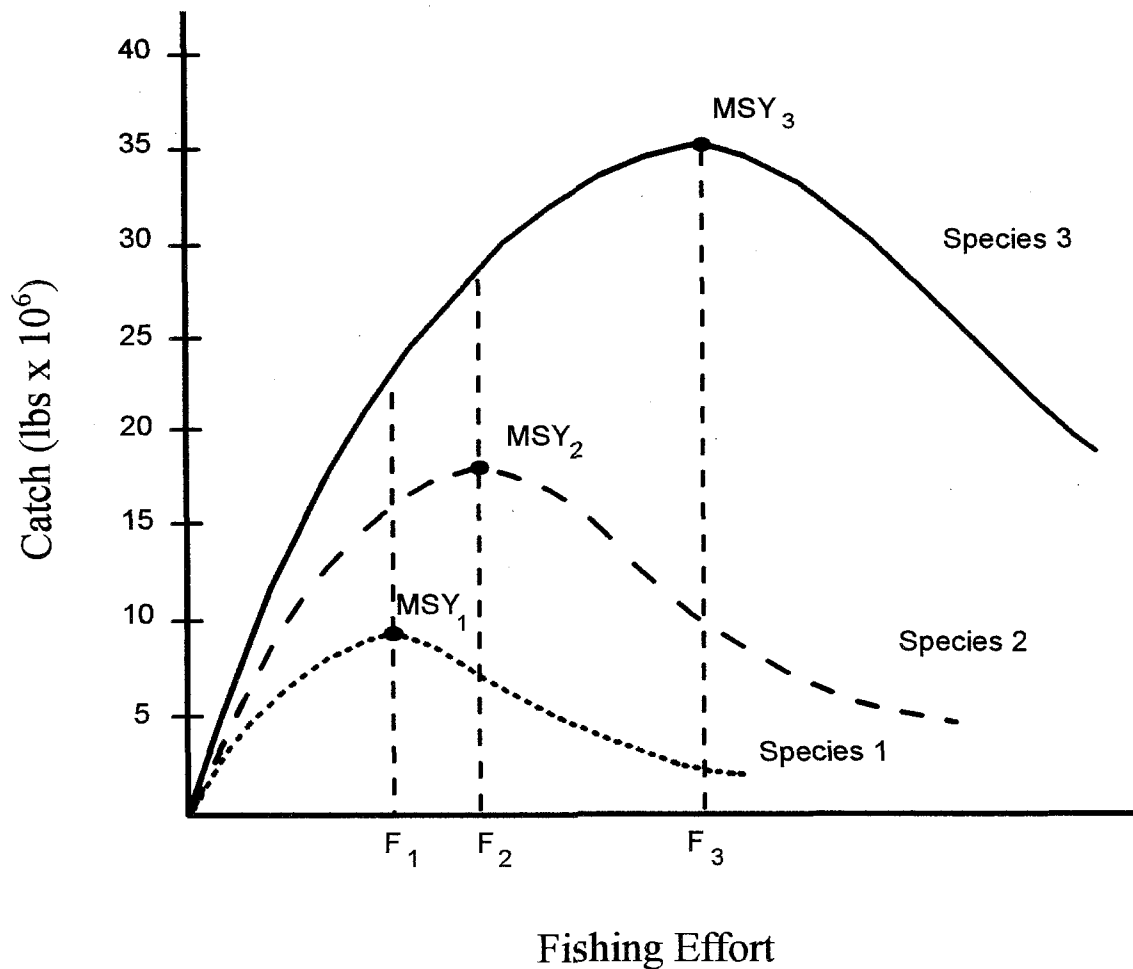
Examples of application of multispecies management approaches include the "Two-Tier" quota system adopted by the International Commission for Northwest Atlantic Fisheries (ICNAF) in 1972 (Fogarty and Murawski 1998). A system-wide quota was adopted that was less than the sum of the estimated maximum sustainable yield levels of the individual species in explicit recognition of discarding, bycatch and biological interactions (predation and competition) based upon aggregate production modeling. A similar strategy is followed in Northwestern Australia with an overall multispecies quota (Sainsbury 1988). In the Bering Sea, an overall system quota also has been implemented. Management of the Southern Ocean under the Commission for Conservation of Antarctic Marine Living Resources (CCAMLR) is based on the principle of "maintenance of the ecological relationships between harvested, dependent, and related populations" although even here, management actions have often been developed on a single-species basis (CCAMLR 1989). It should be noted that long-term spatial closures have been advocated as a means of maintaining ecosystem integrity within areas with a total prohibition on harvest (Fogarty and Murawski 1998). Closed areas and sanctuaries are increasingly proposed as an integral component of an overall management strategy.

It is clear that adoption of long-term fishing strategies has socioeconomic as well as ecosystem

consequences. For example, multispecies fisheries that catch several species in the same gear may have very different impacts upon stocks and upon revenues from the catches, depending on levels of fishing effort and the intrinsic productive potentials of the species (Figure 1). Decisions regarding allocations in multispecies fisheries will affect the various users differently.

Management actions are likely to produce winners and losers among the fishers, in addition to different biological community structures and productive potentials in ecosystems.

The multispecies nature of fisheries is best appreciated when observing the so-called technical interactions that result in a mix of species being caught in a fishing gear, some being primary targets of the fishery, but others being secondary species or of no economic value. Figure 1 illustrates a hypothetical example of technical interactions in a three-species fishery in which constituent species have different yield potentials and values. The multispecies problem extends to inadvertent or unintended catches of non-targeted species, for example seabirds and mammals, or juveniles of targeted and non-targeted species. In this context, the problem becomes most acute when threatened or endangered species are captured in fishing gears. The results of technical interactions can precipitate biological interactions at the ecosystem level when critical predator-prey relationships are altered.



$$\sum_{i=1}^3 C_{F_1} = 45.5 \quad \sum_{i=1}^3 C_{F_2} = 51.5 \quad \sum_{i=1}^3 C_{F_3} = 48.0$$

Figure 1. Multispecies fishery with technical interaction. Hypothetical example of a three-species fishery in which all species are caught in the same gear (e.g. gillnet, poundnet, recreational gear). The productivities and associated maximum sustainable catches (MSY) differ for the three species, as do the fishing effort (fishing mortality rates, F) that are required to obtain their respective MSYs. In the example, summed equilibrium catches ($\sum C_F$) of the three species range from 45.5 to 51.5 million pounds, for F levels in the range that could maximize sustainable yield of one of the species. Fishing at a level to maximize catch of species 3 (F_3) results in low sustainable yields of species 1 and 2, and may risk severe overfishing or stock collapse of those species. If hypothetical species 3 has low value (\$0.10 per lb) relative to species 1 and 2 (\$3.00 and \$1.50 per lb, respectively), then the total catch at fishing effort F_3 will have low economic value ($\sum C_{F_1} = \$52.5$ million; $\sum C_{F_2} = \$50.6$ million; $\sum C_{F_3} = \$26.0$ million). In the example, fishing at F_3 leads to declining abundances of species 1 and 2, low yields of species 1 and 2, low overall profitability in the multispecies fishery, and risk of stock collapses for species 1 and 2. A manager might choose to reduce fishing effort to F_1 or F_2 levels to increase abundance and yields of species 1 and 2, increase profitability in the fishery, and lower the risk of stock collapses in the multispecies fishery.

Chesapeake Bay

The stated goal of the Chesapeake Bay Program is to follow an ecosystem approach to restore and manage Bay resources. Indeed, the success of the Program rests on the restoration or maintenance of living resources. Much of the effort of managers is focused on achieving reductions in nutrient inputs and evaluating effects of such reductions on well-being of living resources in the Bay watershed. Yet, fisheries in the Bay are managed as single-species entities. A presumption, which is supported by hydrodynamics and nutrient effects modeling, is that 'bottom-up' influences of excess nutrients have led to eutrophication and decline of water quality (EPA 1997). Links to fisheries seem probable but have been little studied. It is legitimate to ask whether a 40% reduction in controllable nutrient loading will have a negative effect on fish production in Chesapeake Bay, or whether improvements in water quality attributable to reductions in nutrient loading will have a salubrious effect on Bay fish production. Until recently, little emphasis on habitat dependence or species interactions was included in fishery management plans that have been developed for Chesapeake Bay.

The fisheries of Chesapeake Bay have enjoyed a long and productive history, although many have declined in the 20th century, a consequence of overfishing, habitat loss and probably the deterioration of water quality. Commercial, charter boat, and recreational fishers share, compete for and harvest fisheries resources. Diverse gears are utilized, some of which (e.g. poundnets, gillnets, recreational gear) may capture many species. We do not review the status of the Bay's fisheries in this report, but refer readers to earlier publications (Rothschild et al. 1981, 1994; Richkus et al. 1992) and to a recent literature synthesis on multispecies fisheries issues and concerns (Miller et al. 1996). Here, we note that the Bay's resources include key predators--e.g. striped bass, bluefish, weakfish; key species at lower trophic levels--e.g. phytoplankton filterers such as eastern oyster and Atlantic menhaden; and important trophic intermediaries--e.g. blue crab and bay anchovy. In the case of the oyster, its collapse may have significantly altered the structure and productivity of the Bay community. The precipitous decline of anadromous shads and river herrings also is notable. At the time this report is being written, there is evidence of declines in menhaden and bay anchovy abundances that may be important for trophic interactions between these planktivores and the piscivores that consume them. A resurgence of striped bass has raised the question of whether its predation might control blue crab, anadromous fish, and forage fish abundances. Changes in fisheries stocks have occurred during a period when major declines in seagrasses were observed, when phytoplankton standing stocks increased, and when the Bay became more eutrophic as a consequence of increased nutrient loading.

The synthesis by Miller et al. (1996) was the stimulus for the workshop reported here. In reviewing the multispecies nature of Chesapeake Bay's fisheries, they noted that, while the Bay's total commercial fisheries landings were increasing (Figure 2), many component species were in decline. They also pointed out that the diversity of the catch was much reduced in recent decades, being dominated by menhaden and blue crabs in recent years (Figure 3). The Miller et al. (1996) synthesis documented the problems and complexities of the Bay's fisheries and recommended that the potential benefits of multispecies approaches to research and management be evaluated. This request for a critical evaluation of multispecies issues and approaches in management led to the Solomons workshop in April 1998.

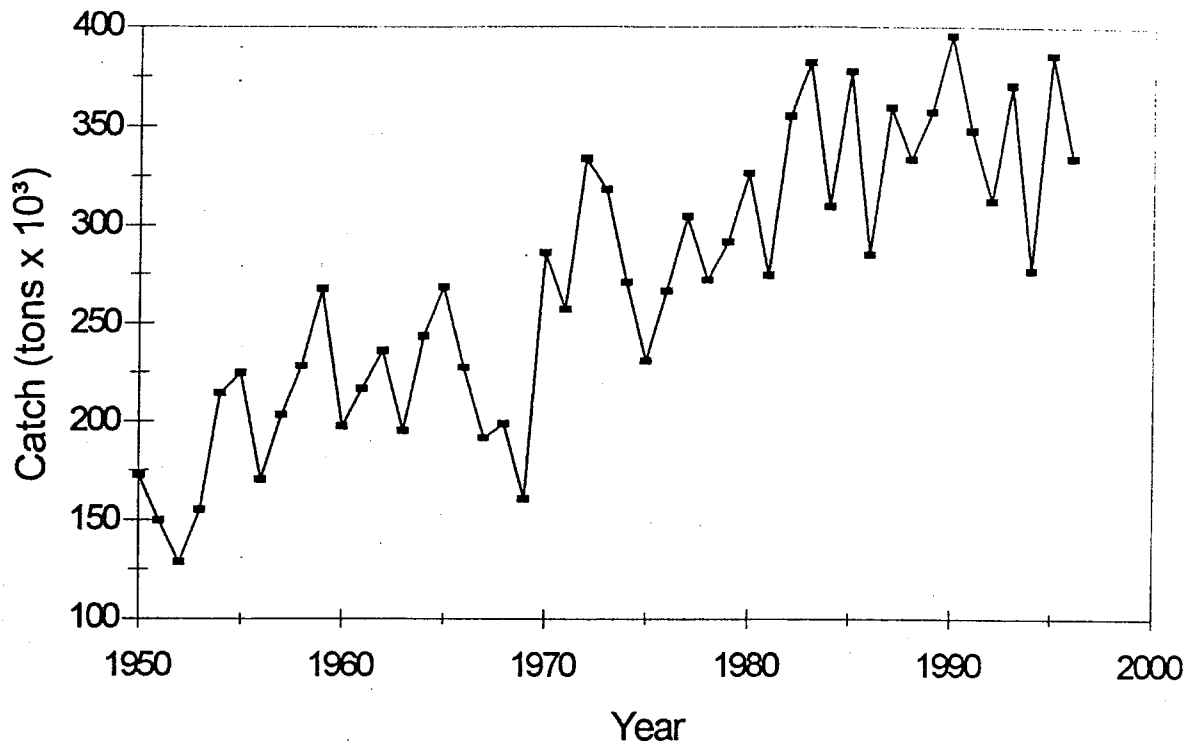


Figure 2. Trends in commercial fisheries catches in Chesapeake Bay. Data from National Marine Fisheries Service, URL: <http://www.st.nmfs.gov/st1/commercial/landings>

Goals and Objectives

The structures and productivity levels of aquatic ecosystems, including Chesapeake Bay, are dependent upon habitat, hydrodynamics, and species interactions as well as external factors related to climate and weather. Within the context of variability generated by those factors, stabilizing or improving fishery yields while maintaining sustainability of fisheries, are objectives shared by fishery and ecosystem managers. A popular view is that single-species fisheries management has largely failed. However, if precautionary and risk-averse, single-species approaches may be successful, although improved understanding of species interactions and ecosystem dynamics ultimately will provide a firmer basis upon which to make management decisions. Gaining that level of understanding, while accepting the uncertainties in ecosystems dynamics and in fisheries exploitation that cannot be predicted, implies that a transition to multispecies management will not take place overnight or be easily accomplished. Nevertheless, a move towards development of multispecies fisheries models will inform us in a strategic sense of how risk-averse we need to be. Indeed, the very fact that complex multispecies interactions exist is reason to be risk-averse and it is preferable to quantify those interactions instead of stating simply that we need to be more conservative.

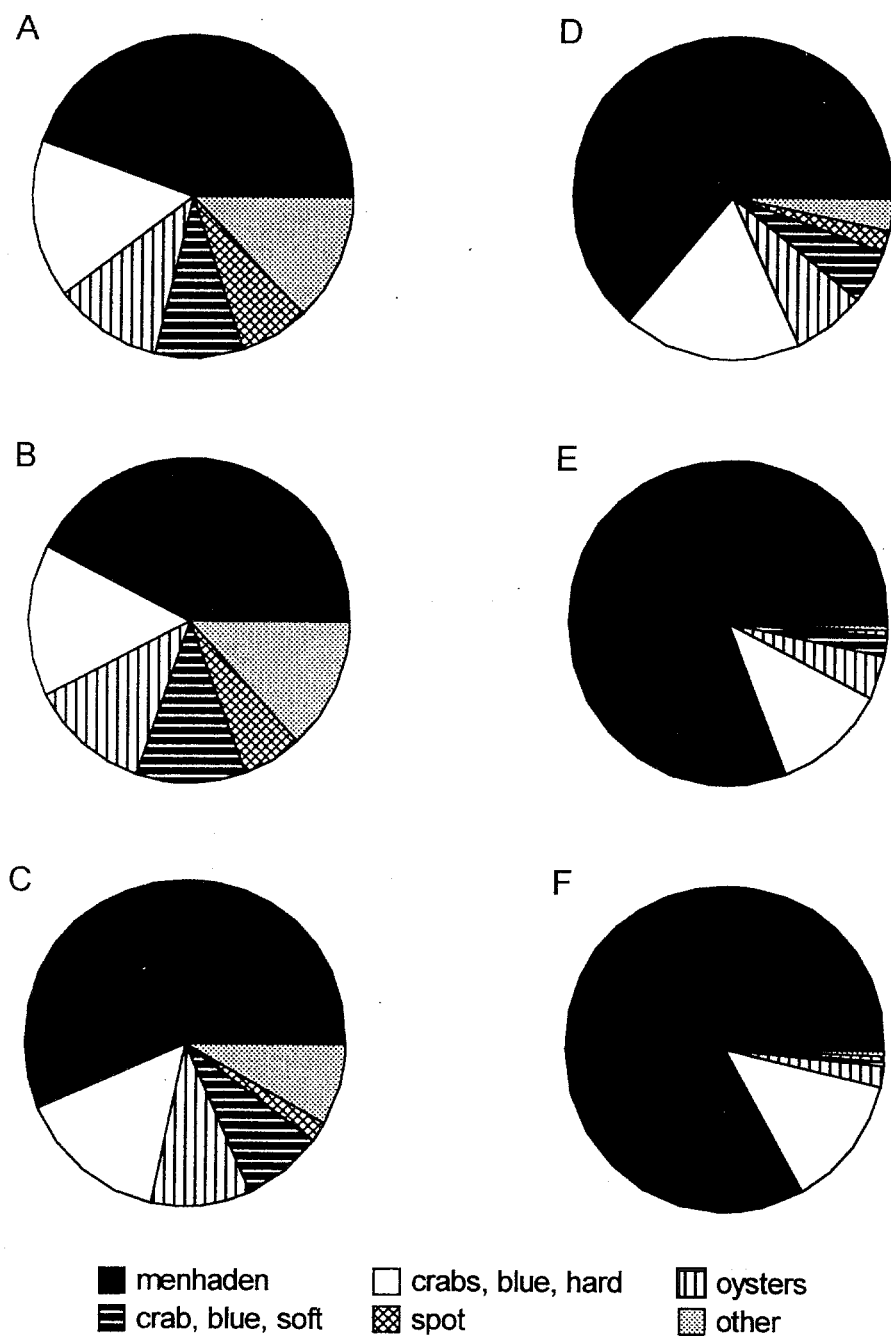


Figure 3. Decadal percentage composition of commercial fisheries catches in Chesapeake Bay. Note the decline in diversity during recent decades, with trend toward dominance by menhaden and blue crab. A = 1930's, B = 1940's, C = 1950's, D = 1960's, E = 1970's, F = 1980's (from Miller et al. 1996).

With these thoughts in mind, the overall goal of the workshop was to evaluate the need for strategic planning, research and modeling that will allow ecosystem and multispecies approaches to be incorporated into the present day single-species management of fisheries resources in Chesapeake Bay. As one participant noted, "the science required to achieve this goal is not rocket science, it's a lot harder."

Understanding biological and technical interactions, combined with complex social and economic pressure that affect fisheries in Chesapeake Bay, will not be attained without major research efforts and management experiments. The Bay Program, through its Living Resources Subcommittee, recently has adopted principles that serve to emphasize the importance of habitat issues and species dependencies (LRSC 1997) as Baywide Fishery Management Plans are developed and revised. The philosophy espoused in that document represents a good start towards adopting an ecosystem view of fisheries and the need to incorporate multispecies approaches in fishery management plans. It bears repeating that a move towards multispecies management will not come easily or quickly, but the multispecies approaches recommended in this report will improve single-species management in the short to medium term and will help to build the foundation for multispecies management in the future.

The workshop had several specific objectives. Some of these are embodied in the following questions that were included in mailed materials sent to workshop participants.

2. Can traditional, single-species fisheries management suffice in the long term? Can we do better?
3. Can the Chesapeake Bay be defined as a unique ecosystem and can its fisheries be managed in that context?
4. What are the species and trophic relationships (biological interactions) of pivotal importance to Bay fisheries management?
5. Are bycatch issues (technical interactions) of concern?
6. What are the critical economic and social issues related to multispecies management?
7. What fisheries and ecosystem models (or types of models) are most appropriate and in need of development to advance fisheries management in Chesapeake Bay?
8. Should a broad plan or strategy be recommended and developed to move Chesapeake Bay fisheries management towards multispecies and ecosystem approaches?

These and additional 'priming' questions (Appendix C) were considered in plenary and workgroup sessions. Not all of the questions were answered, but recommendations that evolved were a product of discussions that initially addressed these questions.

Nine plenary talks were presented by experts on multispecies fisheries issues or on regional applications of multispecies approaches and modeling (Appendix A). These presentations stimulated discussions within the Work Groups and shaped recommendations that evolved. The presentations included 1) an overview of multispecies issues in Chesapeake Bay (T. Miller), 2) a review of the toolbox of fisheries models available to fishery scientists and modelers, which

includes tabulated summaries of fishery assessment questions and information needs (S. Murawski), 3) an examination of ecosystem models, especially network analysis, and potential applications in fisheries (R. Ulanowicz), 4) an examination of technical and economic interactions in multispecies fisheries (J. Kirkley and D. Lipton), 5) an overview and critique of multispecies approaches and models used by ICES working groups (J. Rice), 6) a critical essay on the realistic possibilities for multispecies modeling and its role in fisheries management (N. Daan), 7) a summary of the broad multispecies and ecosystem approaches, and models, used to provide management advice in the NE Pacific fisheries (A. Hollowed), 8) a critical evaluation of predator-prey models used to understand ecosystem production potentials and fisheries production (J. Collie), and 9) a presentation of a model that demonstrates how complex predation, disease, and environmental factors combine to affect yield optimizations of transplanted oysters in estuaries (E. Hofmann). In addition, luncheon talks by J. Collier (Bay Program modeling) and by D. Boesch ("Making it Happen") touched upon the important issues of how to model higher trophic levels and how to choose approaches to develop the science and management necessary to manage fisheries in a complex ecosystem like Chesapeake Bay. A lecture (J. Pope) on the complexities of multispecies issues in research and management summarized the preceding plenary talks, discussed the effects of fishing on biomass size spectra in marine ecosystems, and provided a critical evaluation of potential for multispecies fisheries management.

Workshop Structure

There were 44 invited workshop participants and several observers. Participants (Appendix D) included fisheries researchers and managers from the Bay region as well as national and international experts. Plenary presentations were made by the experts. Summaries of their presentations and J. Pope's summary lecture are included (Appendix A). The agenda and schedule also are appended (Appendix B).

Three Work Groups were constituted. The groups met on each day of the workshop to discuss and debate multispecies concerns. The three Work Groups were:

1. Chesapeake Bay Multispecies Issues.
2. Fisheries and Ecosystem Models.
3. Management Needs and Perspectives.

A set of 'priming questions' was distributed to each of the Work Groups to help initiate and guide, but not restrict, their discussion (Appendix C). Reports and recommendations of the Work Groups are included in the body of the Workshop Report.

General Findings

- The Chesapeake Bay jurisdictions and the Bay Program have made important strides in producing baywide fishery management plans for most of the commercially and recreationally sought species in the Bay. And, there has been noted improvement in collection of fishery-dependent statistics of catches and effort in the commercial fisheries

over the past 15 years.

- The “Guidelines, Philosophy, and Over-Archiving Principles” for fisheries management, which the Bay Program Living Resources Subcommittee has adopted (LRSC 1997), explicitly recognize the importance of habitats and the necessity for precautionary, risk-averse management of the Bay’s valuable fishery resources. The adoption of these guidelines was an important first step in recognizing the need to integrate fisheries management into the ecosystem approaches that are the foundation of the Chesapeake Bay Program.
- Technical interactions (e.g. bycatch, mixed species catches in the same gears, other non-targeted catches, undersized catches, etc.) are common in Chesapeake Bay fisheries, as in fisheries globally. The consequences of technical interactions on overall fisheries productivity and harvest are little understood and only partly documented. The documentation of technical interactions and their impacts goes beyond biological concerns and has important implications for socioeconomic wellbeing of Chesapeake Bay fisheries.
- Biological interactions (e.g. predator-prey relationships and other biological links), while clearly important in Chesapeake Bay, are little understood in any quantitative way with respect to their potential to control fish production or levels of sustainable catches. Workshop participants agreed that identification of key interacting species, research on predator-prey relationships, and multispecies assessments should be included in the research and management regimes for Chesapeake fisheries, even in the context of single-species management that will continue to prevail in the future. Research results and development of both multispecies and ecosystem models (see Table 2.1) will provide managers with tools to guide risk-averse decisions that will promote sustainability.
- Ecosystem-level modeling that includes upper trophic levels also is badly needed as part of the ongoing Chesapeake Bay Program nutrient reduction strategy. The possible effects on fisheries production of reduced nutrient loading need to be anticipated, so that they can be considered in future fisheries management. Potential ‘top-down’ effects on water quality also must be understood. It is in this context that ecosystem modeling, including bioenergetics models and bulk biomass dynamics models, becomes important to all interests in the Bay Program.
- Establishment of a Baywide, fishery-independent survey program for fisheries resources and key forage species is a highly desirable goal for fisheries management in Chesapeake Bay. Such a program, which could be based upon trawling or other survey methods, would allow the distributions, abundances, annual variability and trends in abundance, age/size structures, feeding habits, and recruitment potentials of key stocks, including seasonal migratory species, to be monitored regularly and would form an important basis for future stock assessments. Such surveys also would effectively show the overlaps in species distributions and provide information on interactions among species that could be effectively applied in development of multispecies models.

- Catches and effort in the recreational fishery must be monitored better and characterized temporally and spatially in Chesapeake Bay. Estimates of total removals, species contributions, and sizes/ages in the catch will be valuable for single-species management and eventually also are needed in multispecies management. We suspect that there are strong socioeconomic pressures operating in the recreational fisheries which not only affect targeted species but which also promote a significant technical interaction with the commercial fisheries.
- Several workshop participants emphasized that management of fisheries resources is often management directed at humans and that fish stocks or ecosystems are indirect recipients of benefits (or adverse impacts) that may result from regulations. The social and economic consequences of management, already complex in a single-species context, become even more complex in a multispecies setting. There are winners and losers in the regulatory process, even when a principle of fairness is at the heart of the management philosophy.
- Adopting multispecies and ecosystem approaches to fisheries management, including development of models and interpretation of assessments, will not be easy. Changes or shifts in fundamental ecosystem properties and, indeed, unpredictable fluctuations in abundances of individual stocks, will continue to dominate uncertainties in fisheries management. Single-species management is difficult and multispecies (or ecosystem) management truly may be more difficult than ‘rocket science.’ Nevertheless, substantial progress can be made now towards modeling or understanding technical and biological interactions that can be incorporated into the decision-making processes by managers of Chesapeake Bay’s fisheries resources. Multispecies models can be strategic and thus useful to judge community-level implications of multispecies management in the long-term, rather than identifying year-to-year tactical adjustments that still will be necessary.

Recommendations

Workshop recommendations are presented in two categories:

- Research and Modeling
- Management

Specific recommendations from each Work Group, detailed in their reports, were consolidated to develop this summary list.

Research and Modeling Recommendations

1. Develop Fishery Independent Surveys.

Develop coordinated, Baywide surveys to regularly estimate species abundances, trends, and biological characteristics (e.g. age/size structure, recruitments, growth and mortality rates, food

habits) of economically and ecologically important key species.

2. Determine Key Predator-Prey Relationships and Trophic Interactions.

Determine key predator-prey relationships, especially the roles of piscivores and forage fish species. Do not be lulled into thinking that such relationships are simple. Determine the temporal and spatial dynamics of trophic interactions. Begin such evaluations by focusing on important pairwise interactions (e.g. striped bass-menhaden, striped bass-blue crab).

3. Develop Multispecies Assessments and Models.

Assess the multispecies assemblages of fisheries and ecologically important species with respect to their overall trends in abundances, size/age structure, and biological interactions. Develop multispecies models that explicitly account for predator-prey interactions among key species. These assessments and models can serve to provide medium to long-term strategic advice to managers on trends in assemblages of important species that are harvested and possible implications of management actions directed at component species. Keep in mind that many Chesapeake fisheries depend upon seasonal migrants and fractional components of more broadly distributed stocks that experience multispecies interactions on broader temporal and spatial scales than those experienced in Chesapeake Bay.

4. Develop Top-Down (Predation Mediated) and Bottom-Up (Nutrient Mediated) Models.

As a corollary to Recommendation 3, pursue development of a variety of models of the Chesapeake Bay ecosystem in complementary programs. Develop these models with fisheries management needs in mind to allow managers to consider the implications of such factors as nutrient reduction strategies or predator harvest regulations, based upon single-species fishery management decisions made in the Bay Program's ecosystem-management setting.

5. Develop a Better Knowledge Base for Recreational Fisheries.

Better information and evaluation, including socioeconomics, of the recreational fisheries in Chesapeake Bay are needed. These fisheries target many of the Bay's key species but the levels of removals are poorly known as is their overall impact on the Bay ecosystem.

6. Evaluate Estuarine Habitats and the Potential Value of Protected Areas.

Protect and restore estuarine habitats, and evaluate the results of these activities on recovery of key species and assemblages. Habitat needs are especially important in estuaries and their roles in supporting the life histories of anadromous fishes, oysters, crabs, and forage species must be understood. Estuarine reserves (protected areas) need to be investigated and evaluated as a means to protect or enhance key species and species assemblages important to Chesapeake Bay fisheries. With respect to reserves, questions of habitat type, location, size, and regulations regarding allowable utilization must be addressed.

Management Recommendations

1. Develop Multispecies Assessments.

The multispecies issues or concerns in each single-species management plan must be identified. Multispecies assessments, including the identification of major species interactions and evaluations of any technical (e.g. bycatch) or biological interactions of importance, should be included in single species fishery management plans (FMPs) for Chesapeake Bay. Such assessments should be incorporated into planned revisions of present FMPs. The multispecies assessments will provide managers with important information to guide them in strategic decision-making on single-species management plans.

2. Improve Catch, Effort, and Biological Data.

A major step in incorporating multispecies or ecosystem approaches into FMPs is to collect reliable catch and effort statistics, and the biological data required to successfully undertake risk-averse single-species management. Many participants in the workshop believed that the single most important activity in single-species or multispecies management was an effective monitoring program (fishery-dependent or fishery-independent) that provide managers with stock-status information on a regular basis. Single-species management must have defensible biological reference points (e.g. fishing mortality rates, spawning stock biomasses) or thresholds.

3. Minimize Technical Interactions.

Evaluate and minimize technical interactions (e.g. bycatch, non-targeted fishing mortality, allocation issues) that lead to biological, economic and social concerns. Many technical interactions could be controlled by appropriate management actions, to the overall benefit of fisheries in Chesapeake Bay.

4. Incorporate Multispecies and Ecosystem Models as Management Tools.

Encourage development of multispecies and ecosystem models, to be used as strategic “tools” by managers to better understand potential consequences of actions in single-species fisheries management in the near-term and the implications for the Chesapeake Bay ecosystem in the longer term. These models will be useful not only to fisheries managers but also to water quality managers in the Chesapeake Bay Program. Such models can assist managers in making decisions with respect to status of resources, appropriate levels of biological reference points, and levels of uncertainty associated with the importance of species interactions.

5. Consider Bioeconomics in a Multispecies Framework.

Optimizing social and economic benefits in multispecies fisheries will require socioeconomic research and modeling. Multispecies fisheries and decisions regarding their management have important consequences for participation, profitability, and utilization, especially in multi-user fisheries like those of Chesapeake Bay. Socioeconomic data on commercial and recreational

fisheries are badly needed to develop better single-species FMPs and to work towards multispecies management that minimizes effects of technical interactions while considering effects of biological interactions on the ecosystem. We regulate fishers as a means to manage resources. Achieving fairness in multispecies management will be even more difficult than in traditional single-species management. There will be winners and losers in any management enterprise.

6. Scientific Advice is Needed.

Multispecies or ecosystem approaches to fisheries management demand greater communication between scientists and managers. Scientists must provide information on species interactions and their magnitudes, and they must advise managers on how to utilize or incorporate multispecies knowledge and approaches into FMPs. Scientists also must advise managers of the risks of not incorporating multispecies approaches into FMPs. And, managers will request advice from scientists regarding additional risks and uncertainties associated with adopting multispecies approaches in either single-species or multispecies management.

7. Educate the Public.

Fisheries managers and the Chesapeake Bay Program must begin to educate the public on multispecies fisheries management and its role in the Bay restoration process. The advantages and disadvantages of adopting a multispecies approach should be communicated clearly to citizens. The public senses the need to restore and protect habitat, and it understands that there are critical species interactions upon which living resources depend. However, the complexities of achieving successful multispecies management, however desirable, may not be appreciated by citizens in the Bay watershed. Managers must communicate to the public that risk-averse, single-species management, which is responsive to potential effects of biological and technical interactions, can provide acceptable stewardship of resources while scientists and managers work towards a fuller understanding of multispecies and ecosystem processes that are the basis of management plans to insure sustainable fisheries.

Conclusions

The Chesapeake Bay Program and fisheries management, in particular, can benefit from adoption of multispecies approaches that consider ecosystem needs. Presently, much can be accomplished within the single-species management framework that is in place, especially if a risk-averse strategy, consistent with a precautionary approach now widely recommended (FAO 1995) is followed. In this context, the Living Resources Subcommittee of the Chesapeake Bay Program recently has promoted and adopted principles for fisheries management plans that are consistent with the precautionary approach (LRSC 1997).

Explicit recognition of species interactions, bycatch concerns, competing users, complex allocation requirements and habitat issues is needed to move management towards a multispecies management ideal that will be desirable in the future. In the meantime, multispecies assessment and ecosystem models should be developed, and used to advantage by managers as strategic tools to guide decisions in single-species management. The need for coordinated Baywide, fisheries-

independent surveys to assess fish stock abundances and biological parameters is clear. Key species must be monitored and assessed on a regular basis. The requirement for reliable monitoring of trends in fish stocks and other key interacting species cannot be overemphasized. Without it, multispecies and ecosystem models cannot be effectively developed, and the success of single-species management is diminished. Many Chesapeake Bay fish stocks are migratory and only a fraction of the coastwide population may occur in Chesapeake Bay, a complexity that must be recognized if multispecies models and management are to be realized. Finally, multispecies management, if adopted, will be a complex endeavor requiring more regulations of fishers to achieve its goals. This inevitably will produce 'winners and losers' in the harvesting sector while it promotes the overall wellbeing of the Bay ecosystem and its ability to sustain high fisheries yields in the future.

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Work Group Reports

Work Group 1: Chesapeake Bay Multispecies Issues

Findings and Recommendations

Workgroup 1 was charged with the responsibility of identifying and ranking multispecies issues in Chesapeake Bay. Furthermore, the workgroup was asked to identify additional monitoring or research needs that are required to quantify the multispecies issues that we identified.

The workgroup recognized that because Chesapeake Bay is a functioning ecosystem, albeit impacted by human activity, there are by definition multispecies interactions. Predators and competitors are facts of nature. Moreover, more complicated indirect effects are also undoubtedly present. Oyster reefs provide habitat for a diverse community of animals that are neither predators on, nor competitors of, oysters. Yet, these species clearly interact. However, the workgroup wished to identify principal, ecologically important interactions, and technical interactions among those species that are linked by a common pattern of exploitation.

Question 1: Is there evidence for important multispecies interactions in Chesapeake Bay?

Finding 1: There is unequivocal evidence of technical interactions among commercially and recreationally important fisheries species in Chesapeake Bay that significantly impact fisheries management objectives.

Discussions involving multispecies technical interactions centered around the use and specific characteristics of certain commercial and recreational gear types. The possibility of organizing multispecies management around fisheries gear and catch methods was debated. Several gears/methods came to mind which would require multispecies management. Among these were non-selective gears such as poundnets and haul seines, which are known to take a variety of species over a range of sizes. Also mentioned were multi-targeted fisheries fleets, which are designed to easily switch gears and species focus. Examples in Chesapeake Bay include the seasonal switching among target species and deployed gear evident in landings reports of many waterman. By-catch issues were noted as being of concern, especially regarding the white perch gill net fishery. The recreational fishery was described as being non-selective and multi-targeted by nature as well as having a bycatch component. Gear types which potentially affect critical habitat, including hydraulic clam gear, were recognized as well.

Finding 2: There is a strong likelihood that biological interactions exist among commercially and recreationally important fisheries species in Chesapeake Bay, which significantly impact fisheries management objectives.

When asked to discuss the constituents of possible multispecies ecological interactions, the group responded with several key examples. The mechanisms driving the predator and prey interactions

between striped bass, menhaden, white perch and bluefish were of particular concern. The interactions between striped bass, blue crab and soft clam was another example discussed by group members. There was a general consensus regarding the need for additional stomach analysis, forage rate and fishery- independent data. The accumulation of such information may provide a basis for more clearly linking higher food web organisms to prey fluxes and nutrient levels within the Bay.

Finding 3. There is unequivocal evidence of biological interactions within Chesapeake Bay that significantly impact ecological function.

Both top-down and bottom-up controls may exist within Chesapeake Bay. The manipulation of various species through management regulations may affect related predators or prey. The integrity of the system demands a delicate balance of predator and prey species, whether they be fish, invertebrates or plankton. Multispecies management, in theory, must recognize this balance and coordinate its efforts to maximize the most beneficial relationships between the organisms, while still allowing acceptable growth rates and abundance levels of charismatic large species.

Finding 4: Several ecologically important species are not subject to commercial or recreational exploitation and require additional monitoring and assessment.

The importance of the forage base within Chesapeake Bay and how it relates to multispecies assessment/management was discussed at length. Species that are not commercially or recreationally targeted but are thought to play significant ecological roles in predatory/prey interactions are often ignored in management directives. More information on key forage base species such as bay anchovy, menhaden, silversides and alosids specific to Chesapeake Bay must be gathered. The menhaden, in addition to being an important forage species, is exploited by commercial fisheries in the Bay. Information on the jellyfishes also is needed. Gelatinous zooplankton are important consumers of plankton in Chesapeake Bay and may compete with fish forage species for shared prey resources.

Finding 5: Trophic interactions in Chesapeake Bay are not well characterized.

Understanding linkages between the many components of Chesapeake Bay's complex food web was discussed as being an important step towards multispecies management/assessment. The group identified the need to gain more specific information on energy partitioning and pathways as critical to the development of a more complete trophic model for this system.

Recommendation 1: We recommend that a program be instituted to monitor and assess forage species within Chesapeake Bay.

Recommendation 2: We recommend that a program be instituted to characterize predator-prey interactions among forage species and piscivorous fish.

Question 2: Can we define a multispecies system in space or time?

Finding 6: A substantial portion of the fisheries community in Chesapeake Bay is highly migratory.

There was a general concern over the logistics of managing species which are known to migrate within Chesapeake Bay as well as to adjacent coastal waters. Migratory species are exposed to a variety of biological characteristics and technical interactions among these different habitats through which they move. Multispecies management focusing on gear types or trophic interactions becomes difficult when species move into different management jurisdictions.

Finding 7: Multispecies interactions may be discrete in time and space.

The biological and technical interactions between species were recognized to have potential seasonal and spatial characteristics. Migrations, spawning activity, growth and behavioral changes may alter interactions between and among species groups. Thus, interactions between specific life history stages may occur in restricted geographic areas and over limited time scales. However, these interactions can still exert an important effect on population dynamics. This feature challenges our ability to institute multispecies management and assessment.

Finding 8. Many widely distributed and migratory stocks are assessed on a coast-wide basis. Abundances of the components of the stock which reside in Chesapeake Bay for several important species are poorly described.

Abundance data for fisheries within Chesapeake Bay was characterized by group members as being deficient. Several species have indices which give trend information but in general are lacking critical biomass and abundance data. Fishery-independent abundance data, as well as improved recreational and commercial CPUE data, was felt to be an integral requirement in modeling and management activities. The relationship between state-specific indices, baywide abundances and coastwide abundances is also unclear for all species. Forage-base species biomass was determined to be critical in judging the carrying capacity of top predators in the system, yet is not currently assessed adequately.

Finding 9. Our understanding of resident species is not adequately quantified.

As observed in many of the Chesapeake Bay Program's Fishery Management Plans, the characterization of several resident species was thought to be deficient with respect to critical biological data. Formal peer-reviewed stock assessments of the majority of these resident species have not been completed. The group noted that little data had been collected on yellow perch, white perch and catfish, which were among several species that were described as being ecologically and/or economically important.

Recommendation 3: We recommend that abundance estimates be developed for key species specific to Chesapeake Bay.

Recommendation 4: Distributions of species in space and time must be accounted for when planning and executing diet studies.

Question 3: Are habitat concerns a key issue in multispecies interactions in Chesapeake Bay?

Finding 10: Key habitats including submerged aquatic vegetation and oyster reefs are important to ecological function in Chesapeake Bay and can be impacted by fishery activity.

The group suggested multispecies interactions in Chesapeake Bay were unique with respect to the important role of habitat such as submerged aquatic vegetation and oyster reefs. The interactions associated with these habitats have been identified as critical to the ecological function of Chesapeake Bay. It was felt that habitat must be included in multispecies management or research, assuring the protection and/or restoration of critical areas to support fish and invertebrate populations. Habitat quality was also recognized as being susceptible to bottom-up controls. And, effects of fishing activities, especially of certain gear types on demersal and benthic fisheries, can affect habitat quality.

Finding 11. Fish /shellfish habitats are likely important and are not sufficiently understood.

Habitat usage more clearly needs to be defined for certain species. The relationship between blue crabs and SAV was used as an example by the members of the group. In order to determine how much habitat will support a species, it first needs to be determined how that species uses its habitat. Estuarine reserves were suggested by several group members as a possible tool for gaining a more complete understanding of habitat usage and dependence. It was also suggested that reserve areas could be studied to understand more fully ecological interactions in the Bay foodweb while maintaining foodweb balance in the Bay generally.

Finding 12. Habitat classification should be an integral component of multispecies assessment.

The workgroup came to the conclusion that any management action, whether multi or single species, should contain specific habitat needs for the species being managed.

Recommendation 5: We recommend that marine protected areas be used to quantify the utility of habitat protection.

Question 4: Can we list, categorize and prioritize multispecies concerns or issues in Chesapeake Bay?

Recommendation 6: We recommend that multispecies assessment be developed to provide medium and long-term advice for fisheries management with regard to the

likelihood of enhancing or restoring desirable fisheries communities in Chesapeake Bay.

Recommendation 7: We recommend that initial movement toward multispecies assessment and management focus on single step, pair-wise interactions before addressing more complex issues involving higher order interactions.

Recommendation 8: We recommend that when single species FMP's are updated, they should be required to identify multispecies interactions that likely impact the dynamics of species under consideration.

Recommendation 9: We recommend additional attention be paid to quantifying recreational catches and effort.

Conclusions

The workgroup found compelling evidence for the presence of important biological and technical interactions in Chesapeake Bay. However, the spatial and temporal variability that characterizes the fish and shellfish community will make defining and quantifying any multispecies "system" difficult. Furthermore, the workgroup also recognized a critical need to improve our knowledge and monitoring of ecologically important species that have been outside current fisheries-dependent and independent monitoring for commercial species.

Work Group 2: Fisheries and Ecosystem Models

Introduction

Work Group 2 was requested to evaluate the potential application of multispecies-fishery models to Chesapeake Bay living marine resources. Until now, single species models have been employed to describe the dynamics of exploited fish and shellfish populations and to evaluate management options in the bay. However, these models ignore interspecific interactions at the community level and fundamental considerations of production characteristics at the ecosystem level that must be taken into account in the assessment and management of the bay's resources. Because single-species models do not include feedback from competition and predation from other species, they overestimate the total production of the bay. To date, no multispecies fishery models have been applied to the bay system. To begin this process, Working Group 2 examined a spectrum of multispecies and ecosystem models as potential management tools in Chesapeake Bay.

Our evaluation focused on data requirements, the kinds of information and outputs derived from each model type, and their potential for application in Chesapeake Bay. In this report, for simplicity, we will consider multispecies models as a subset that focuses on interactions among a specified assemblage or ecological community. Typically, lower trophic level dynamics are not considered in these models. In contrast, ecosystem models do explicitly include production dynamics at lower trophic levels. Multispecies models often include detailed resolution of species and (in some cases) age or size structure while many of the ecosystem models considered by the working group tend to aggregate species and age or size categories to manage the overall complexity of the models. Many of the multispecies models that we considered are designed to provide tactical and/or strategic fishery management advice while the ecosystem models are typically not configured to directly address issues in fishery management. Eight model types were considered:

- Biomass Dynamic Models
- Size Spectrum Models
- Multispecies Yield and Spawning Biomass per Recruit Models
- Multispecies Sequential Population Analysis
- Multispecies Bioenergetic Models
- Trophic Production Models
- Network Analysis/Ecopath/Energy Budgets
- Ecosystem Simulation Models

This hierarchy ranges from the simplest multispecies models with minimal data requirements to complex ecosystem models with extensive requirements for physical and biological data. An overview of data requirements and outputs for each model type is provided in Table 2.1.

Overview of Modeling Approaches

Biomass dynamic models have the longest history of the models considered above. The classical Lotka-Volterra predator prey model is a special case of this class of models. Volterra's motivation for the development of his model was in fact an exploited multispecies assemblage in the Adriatic Sea. This model type has minimal data requirements and can potentially be useful in data-limited situations for exploratory analysis.

Size spectrum models examine the slope of the relationship between the numbers at size (for combined species) and body size (usually measured as units of biomass but linear measures of size have been used). Application of this class of models to fishery systems has suggested that the size spectrum is a conservative property that reflects both the intensity of exploitation (including species selectivity in harvesting practices) and intraspecific interactions and species replacements.

Multispecies yield and spawning biomass per recruit models are a direct extension of their single species counterparts with the inclusion of information on predator-prey interactions. These models are typically age-structured although size- or stage-based approaches are possible. They permit examination of the expected yield and adult biomass generated over the lifespan of a cohort for all species considered. Results are expressed per unit recruitment and therefore direct estimates of recruitment are not required

Multispecies sequential population analysis allows a reconstruction of past estimates of population size and mortality rates in an age- or size/stage-structured framework. This approach by itself cannot be used for evaluating management policies. However, it does permit important insights into the magnitude of predation and fishing mortality rates and changes in population size over time.

Bioenergetic models have been employed within the Bay to model interactions between striped bass as predators and anchovy and menhaden as prey. Inclusion of other predator species is also underway. These models have not been employed to specifically address the implications of tradeoffs in fishing mortality rates on predators and prey but, in principle, analyses of this type could be readily undertaken. These models do have important current applications in analyses of changes in growth and condition of key fish species in the bay.

Trophic production models examine the linkages between nutrients, phytoplankton, zooplankton, and fish. These models often use aggregated species groups within these categories. Models of this type have been employed within the bay up through the zooplankton component. To examine the role of fish in this system, it remains to add a component for the upper trophic levels.

Network Analysis provides a static picture of energy flows through an ecosystem and provides a number of important descriptors of ecosystem structure and function. This approach has found important applications within Chesapeake Bay. Existing applications have employed aggregated species groups in an attempt to manage some of the complexity of this approach. The network

analysis approach is interchangeable with other methods including the *Ecopath* approach and more traditional energy flow representations.

Ecosystem simulation models permit a dynamic representation of changes in abundance at different trophic levels in response to changes in physical factors, nutrient levels, interspecific interactions and anthropogenic impacts. An integrated model for the Bay system, including a hydrodynamic component, up through the lower trophic levels has been developed. A complete model incorporating upper trophic levels could, in principle, be developed by linking the existing model with information and model structures of the multispecies approach described above.

Evaluation of Potential Application of Multispecies/Ecosystem Modeling Approaches in Chesapeake Bay

The initial phase of our evaluation centered on assessing the near-term and future applicability of the model types based on a mapping of the data requirements for each to the current status of knowledge of the biological and ecological characteristics of the bay at all trophic levels.

The general consensus of the group was that a critical difficulty for application in multispecies models is a lack of coordination in sampling and data bases that inhibits effective integration for bay-wide analyses. The complexity of the fisheries in the Bay, comprising multiple gear types, commercial and recreational user groups, and multiple management authorities makes coordination difficult but highlights the importance of integration. The group recognized that critical data limitations exist on a bay-wide basis (while noting that components of the required information are available for some locations and time periods). In particular, use of these models requires consistent measures of catch and fishing effort from all segments of the fisheries, along with accompanying biological and ecological information on demographic characteristics (size/age composition, reproductive biology, growth, mortality), trophic interactions, habitat requirements, and abundance for key species within the bay as a whole. Because many of the species considered occupy the Bay on a seasonal basis, factors related to movement and dispersal rates and events in locations outside the bay must also be considered. The group noted that most of these identified data needs also meet the requirements for stock assessments with a traditional single-species focus. The elements of single species analyses can be considered as building blocks for multispecies models with the addition of information on trophic dynamics.

The need to consider technological interactions (e.g. bycatch of species in different fishing gears) was highlighted by the group. Although studies of trophic interactions have been undertaken for components of the Bay system, the issue of technological interactions and their consequences has been given less attention.

The data needs specified above are directed principally at requirements for multispecies models. These issues and others assume importance with respect to the application of ecosystem models in a fishery management context. In particular, because individual species are of critical importance to harvesters and because fishery management has traditionally been implemented for individual species, higher resolution at the upper trophic levels would be required to convert the existing ecosystem models to tools in support of fishery management. This would require much of the

information identified above for multispecies models. Accordingly, our evaluation of data needs and issues for ecosystem models for use in fishery management closely parallels that described above for species-specific information. In addition, because the control variables available to managers, in principle, include the fishing mortality rates and the age or size at capture, inclusion of age or size structure for the exploited component of the system would be useful for some applications. This would require reconfiguring the structure of the ecosystem models and increasing their complexity.

It is the conclusion of the working group that direct consideration of both bottom-up effects due to changes in nutrient inputs and other factors affecting the base of the food web within the Bay, and top-down-effects due to changes in top predators (piscivorous fish) under exploitation is necessary. It is unlikely that any one model will capture all the dimensions of the problem. Accordingly, it is recognized that it will be fruitful to apply a number of different models in a complementary fashion to address specific questions or management needs. Ultimately, the models chosen for use in a particular context will depend on the specific management objectives identified.

RECOMMENDATIONS

Based on the considerations outlined above, the working group made the following recommendations:

- 1) Implement Immediately an Integrated Bay-wide System for:
 - Establishment of fishery-independent surveys to estimate abundance of ecologically and/or economically important species
 - Collecting fishery-dependent information (particularly catch, effort)
 - Determining biological parameters (including growth, maturation, mortality, migration) for species of ecological and/or economic importance
 - Collecting bioeconomics data
- 2) Undertake Coordinated Intensive Study of trophic interactions on a Bay-wide basis including consideration of spatial and temporal dynamics.
- 3) Apply information derived from (1) and (2) above and from existing data sources to develop and/or apply existing "Bottom-Up" and "Top-Down" Modeling Approaches to the Bay ecosystem in complementary analyses.

Table 2.1. Description of model types, data requirements, model outputs and classification considered by the working group. MS = Multispecies; SSB = Spawning Stock Biomass.

MODEL TYPE	DATA NEEDS	MODEL OUTPUTS	MANAGEMENT CLASSIFICATION
Biomass Dynamic	Catch, Effort, (Auxiliary Variables)	Equilibrium Yield, Biomass Trajectories, Biological Reference Points	Multispecies Strategic
Size Spectrum	Numbers (all species combined) within specified size categories	Slope of relationship between number at size and size	Multispecies Descriptive
MS Yield & SSB per Recruit	Growth Rates, Maturity function, Fishing Mortality, Diet Composition, Daily Ration, Feeding Selectivity	Yield and SSB per Recruit Biological Reference Points	Multispecies Tactical
MS Sequential Population Analysis	All specified for MS Yield and SSB per Recruit plus: Age/Size Composition of Catch, Auxiliary Variables	Population Trajectories by age/size and species, predation mortality rates, fishing mortality rates	Multispecies Descriptive
MS Bioenergetic	Predator Density, body size, growth, consumption, metabolic costs, search volume, prey density and availability, temperature, oxygen, light	Aggregate Production, Growth Potential	Multispecies Descriptive
Network Analysis	Primary Production, Secondary Production, Biomass, Exploitation, Predation, Production to Biomass ratio, Diet composition, Daily ration	Production, Energy Flow, Mean Trophic Position for each Species	Ecosystem Descriptive
Trophic Production Models	Nutrient Levels, Phytoplankton Zooplankton and Fish Density, Algal reproductive rate, grazing rate, light, zooplankton reproduction, predation rate, Fish reproduction, natural mortality, fishing mortality		Ecosystem Descriptive
Ecosystem Simulation Models	All of the Above	All of the Above	Ecosystem Descriptive

Work Group 3: Management Needs and Perspectives

The Management Needs and Perspectives Workgroup focused on the transition from traditional single species fishery management plans to multispecies management, examining issues of the effectiveness of single species management, initial steps toward the consideration of multispecies interactions, and impediments to multispecies management.

The limiting factors associated with multispecies management were identified, including species-specific data limitations, uncertainties associated with biological reference points for various species, and the lack of quantification of multispecies interactions (e.g. predator prey relationships). It was recognized that not many single-species management plans contain appropriate biological reference points. However, the construction and implementation of multispecies implementation plans, replete with multiple species-specific biological reference points and multispecies interactions, were viewed as complex, unrealistic undertakings at this time.

The workgroup also discussed the public perception of single species management efforts. Although the public frequently considers single species management efforts to be failures, the workgroup noted that multispecies management should not be attempted solely in response to perceived failures by management on a single species basis. Several workgroup members pointed out the importance of improving single species management prior to incorporating a multispecies management framework.

The workgroup recommended that multispecies management efforts should initially consider biological and technical interactions (e.g. by-catch) as part of a multispecies "assessment" process aimed at improving the single species management plan. The workgroup also recommended that revision or construction of Chesapeake Bay Program single species fishery management plans should incorporate the multispecies assessment approach. For example, interactions between striped bass and menhaden or juvenile blue should be assessed in preparation of the single species plan.

The management workgroup agreed that awareness of the important multispecies interaction, from an assessment perspective, could be used to provide manager advice on management single species. For the initial multispecies assessment process the group recommended following the current Chesapeake Bay Program schedule for revising or constructing Fishery Management Plans.

This workgroup also discussed the practical aspects of fisheries management, recognizing that human activity needs to be managed, rather than the biological resource itself. Therefore, multispecies management efforts would need to address open access systems of fisheries, which would not be compatible with multispecies management regimes. In addition, multispecies management plans would need to address provisions for sustaining some form of commercial

It is recommended that attempts to address multispecies interactions or management be first provided for those species scheduled for FMP development or revision.

- 3) What are the institutional and jurisdictional constraints on multispecies management in Chesapeake Bay?

It is recommended that if the Chesapeake Bay Program implements multispecies management in the future the following issues and constraints need to be evaluated and addressed by the various agencies involved.

- Open access nature of most fisheries
 - Conflicting stakeholder objectives of various stakeholders
 - Inequity among stakeholders, in terms of sharing benefits or costs
 - Differences in management philosophies among jurisdictions may exist
 - Interjurisdictional nature of fish stocks
 - Lack of stakeholder understanding of multispecies management
 - Lack of data
 - Lack of personnel
 - Lack of funding
- 4) How can multispecies (or ecosystem) models be incorporated into the framework of single-species management approaches in Chesapeake Bay?

Multispecies and ecosystem models can be incorporated into current management frameworks by serving as tools to improve:

- The assessments of the status of resources
and
- The identification of biological reference points for management

Recommendations:

- A) Development and testing of ecosystem/multispecies models which contain properties useful in supporting management decisions
- B) Programs to collect the data required for such models

livelihood, traditionally associated with one or more of the species assemblage incorporated by the multispecies fisheries management plan.

The Management Needs and Perspectives workgroup concluded their recommendations on multispecies fisheries management, with the following recommendation on the pre-eminent management need for addressing multispecies management:

We should take every effort to obtain reliable catch, effort and biological data, as well as instituting fishery independent surveys of the major components of the ecosystem.

Results from Discussions of Key Questions on Multispecies Management Needs and Perspectives

- 1) Can single species fisheries management operate successfully in the context of a Chesapeake Bay Program that bills itself as an "ecosystem management" program?

Single species fisheries management plans (FMPs) have been of benefit to managing bay and coastal stocks. They are understandable documents that are accepted by the public. Single species management can become increasingly successful as a component of an overall ecosystem management strategy if these recommendations are followed:

- Single species FMPs must have defensible reference points.
- Major multispecies interactions and ecosystem forcing functions are identified, reviewed and considered in constructing single species FMP.

- 2) Are there "simple" or essential first steps in moving towards a multispecies management approach in Chesapeake Bay?

There are "simple" or essential first steps in moving towards a multispecies management approach in the Chesapeake Bay that should be taken as soon as possible and include:

- The identification of the major forcing functions and first-order interactions (technical, biological) associated with the Bay's flagship species. As part of this process, available data on these interactions need to be identified.
- Obtain multi-stakeholder support of common objectives of the FMP and provide education on the multispecies management process to all groups which use or have an interest in the resources managed under the FMP(s).

- 5) What questions or requests for information would managers direct to scientists with respect to multispecies fisheries management in Chesapeake Bay?

Comprehensive and defensible scientific information will be needed by fisheries managers to develop and implement effective multispecies management strategies. It is recommended that the following scientific information be provided.

- major multispecies interactions and forcing functions
- nature and magnitude of the above interactions
- how to incorporate scientific advice into implementation of management regulations
- risks incurred by not including multispecies interactions in current single-species management
- major sources and magnitudes of uncertainty incurred by including these interactions in multispecies management.

Appendices

- A.** Two-page summaries of plenary presentations
- B.** Workshop Agenda
- C.** Work Group 'Priming Questions'
- D.** List of Participants

APPENDIX A.

Two-Page Summaries of Plenary Presentations

Dr. Jeremy S. Collie	Predator-prey interactions on the New England Continental Shelf
Dr. Niels Daan	The multispecies and ecosystem approach to fisheries management: A hiking trail to Utopia?
Dr. Eileen E. Hofmann	Environmental variability and implications for the oyster fishery: Modeling studies
Dr. Anne B. Hollowed	An overview of efforts to incorporate ecosystem concerns in fishery management advice for Northeast Pacific and Bering Sea groundfish stocks
Dr. James E. Kirkley and Dr. Douglas Lipton	Managing technical and economic interactions in multispecies and multiproduct fisheries
Dr. Thomas J. Miller	Multispecies patterns, processes and concerns in Chesapeake Bay
Dr. Steven A. Murawski	An hierarchy of fishery assessment models
Dr. John G. Pope	A brief summary of the meeting and some personal thoughts
Dr. Jake Rice	Multispecies advice on management of living marine resources
Dr. Robert E. Ulanowicz	Network analysis: Making sense out of many-species interactions

Predator-prey Interactions on the New England Continental Shelf

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The New England continental shelf is a productive ecosystem which supports important demersal fisheries. In addition to the principal groundfish species (cod, haddock, flounder) residing on the offshore banks, pelagics (herring, mackerel) undertake seasonal migrations throughout the shelf region. The New England region is fortunate to have one of the longest and most comprehensive fisheries data bases in North America. While many studies have focused on Georges Bank, a wider perspective is needed to encompass migrants such as the pelagics and spiny dogfish.

Energy budgets constructed by Sissenwine et al. (1984) provided important insights into the structure of the Georges Bank ecosystem. The energy budget is quite "tight", which implies that production at one trophic level may be limited by production at a lower trophic level or consumption at a higher trophic level. The planktonic food web is thought to have been relatively constant over time, in contrast to the fish food web which changed dramatically as a result of exploitation. Production of pre-exploitable fish exceeds the production of exploited fish. The observation that most of the fish production is consumed by other fish, prompted Sissenwine to call Georges Bank a predator-controlled ecosystem.

The first estimates of predation mortality were published by Overholtz et al. (1991), who constructed a simulation model of the pelagic fish ecosystem off the northeastern USA. The most important prey species are herring, mackerel and sand lance; the fish predators are silver hake, spiny dogfish, and Atlantic cod. Predation by seabirds and marine mammals was also included. The age-structured simulation was run from 1988-1992 based on food habits data from 1981-1986. Predation mortality was highest on prey ages 1-2, and was considerably higher than the natural mortality assumed in stock assessments. Overholtz et al. investigated the response of the prey species to increases or decreases in the fishing mortality on the predators. Predicted prey biomasses were sensitive to the choice of predator functional response.

Multispecies virtual population analysis (MSVPA) accounts for changing abundances of predators and prey by calculating prey suitability coefficients based on a type-II predator functional response. Unlike the forward simulation model of Overholtz et al., MSVPA reconstructs cohort abundance, starting with the oldest ages and working backward in time. Tsou & Collie (1997) fit an eight-species MSVPA of the Georges Bank fish community from 1978-1990. In addition to the fishes considered by Overholtz et al., we included yellowtail flounder as prey, haddock as prey and predator, and winter skate as an "other" predator. The MSVPA shows that the amount of food consumed by cod declined with the decrease in cod abundance, and that the diet composition changed with changing prey abundances. Predation was an important source of mortality for age

0-1 herring; for ages 2 and older, fishing was the dominant source of mortality. The 1978 and 1979 herring year-classes suffered above-average mortality due to predation by silver hake, such that year-class size was altered during the juvenile stage.

Another approach to multispecies modeling is aggregate biomass-dynamic models. Collie and DeLong grouped 10 important fish species into four taxonomic groups: roundfish (cod, haddock, silver hake), flatfish (yellowtail and winter flounder), pelagics (herring, mackerel) and elasmobranchs (dogfish, skates). Roundfish and flatfish biomass and catches declined from 1963-1993 due to overfishing. Pelagic biomass has recently increased to record levels and catch is presently low. Elasmobranch biomass increased and peaked in 1990, suggesting that the apparent replacement of groundfish with elasmobranchs may be reversing in recent years. We fit multispecies biomass-dynamic models to 30 years of aggregate biomass and catch data. The most important interactions were negative effects of elasmobranchs on roundfish, flatfish and pelagics; these effects are consistent with observed predation by the elasmobranchs. The only positive effect corresponded to roundfish feeding on pelagics. Roundfish had apparent negative effects on elasmobranchs that could be interpreted as competition. A type-II predator functional response is needed to account for shifts in prey abundance.

Major shifts in the species composition of the fish community have occurred on decadal time scales. In addition to the impact of fishing, fish productivity is affected by large-amplitude environmental changes such as the North Atlantic Oscillation. Gradual changes in the marine environment may be amplified by nonlinear trophic interactions, resulting in abrupt shifts in species abundance. Steele & Henderson (S-H) constructed a simple predator-prey model in which a type-III functional response results in two stable equilibria for certain combinations of parameters. Autocorrelated environmental variability (red noise) and/or harvesting can cause the system to flip between equilibrium states with patterns resembling observed fish abundances. Spencer and Collie (1997) fitted the S-H model and the classic Schaefer model to catch and biomass data for Georges Bank haddock. The S-H model explains the decrease in productivity that occurred around 1970 as a shift to a lower equilibrium caused by high fishing mortality. If the S-H model is correct, low fishing mortality and/or favorable environmental conditions are required to shift the haddock stock back to the higher equilibrium level that existed before 1960. The S-H model requires a lower fishing mortality for stock recovery, but the stock would recover to a higher level than if the Schaefer model were correct.

Many conclusions drawn from the New England continental shelf also apply to Chesapeake Bay. First is the need to spatially define the ecosystem by accounting for the contributions of seasonal migrants and proceeding to models with simple spatial structure. Data needs for multispecies analysis differ from single-species assessments. Long time-series are needed to estimate species interactions. Taxa that are ecologically but not commercially important need to be monitored (e.g. bay anchovy, jellyfish). In the absence of age-structured data, considerable understanding of multispecies interactions can be gained from food webs, energy budgets, and aggregate biomass-dynamic models. In Chesapeake Bay, food-web models need to include the lower trophic levels. In temperate ecosystems, multispecies analyses may not be needed for short-term management, but a multispecies approach is needed to understand decadal shifts in productivity.

Biological reference points are increasingly used to assess the status of fish stocks and to set harvest levels. These reference points are affected by changes in growth and mortality schedules which in turn depend on environmental changes and trophic interactions. Without ecosystem understanding, biological reference points will remain moving targets.

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The Multispecies and Ecosystem Approach to Fisheries Management: A Hiking Trail to Utopia?

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Introduction

Fisheries science has come a long way from traditional single-species oriented research towards integrated, interdisciplinary ecosystem research. Nevertheless, few fisheries problems have been satisfactorily resolved along this way, apart from those where the exploited stocks resolved the management problem by becoming virtually extinct (like the northern cod). Why has fisheries management failed: has our scientific knowledge been inadequate, have scientists given the wrong advice, have managers taken the wrong decision? Unless we try to answer such questions first, there is no guarantee that societies will do a better job in optimizing yields or safeguarding our renewable resources for future generations by letting scientists asking themselves more difficult, topical questions first. I say societies, because managers (and scientists) are not the only (and maybe even not the most important) players in the game. The industry, NGO's, and the public at large are ultimately responsible for the political will to actually do something. Still, in moving from single-species assessment to ecosystem effects of fishing, scientists appear to feed the suggestion that we live in a makeable society: if only we would know all the quantitative interactions within the system, the problem of developing sustainable fisheries in a sustainable ecosystem could be easily solved. However, this may not be the case, because the overwhelming complexity of marine ecosystems suggests that the answers may become even more uncertain. I will present here some views on the prospects of multispecies management and sustainability, which may appear cynical to some but are meant to be constructive.

What Can Be Managed?

In the scientific literature, reference is frequently made to fisheries, resource, multispecies and ecosystem management. Although definitions are rarely given, the variable adverbs of "management" suggests that we are dealing with different entities. However, in my opinion such typology stems from an unrealistic belief in makeable systems: Chesapeake Bay is not an aquarium under complete control of a society, which probably does not even have the legal power to impose all measures thought necessary. In reality, what can be regulated in common property waters is restricted to human activities, and even that presents large difficulties. Thus, although single-species or multispecies resource management objectives may differ, the common denominator is always 'fisheries management', i.e. how can the fishing activities be controlled? In

an 'ecosystem' approach, an important question may be how the management of different human activities (e.g., fisheries, mineral extraction, pollution) can be integrated in some satisfactory way. Nevertheless, fisheries management remains an entity within itself. In my view, the suggestion sensed from the term ecosystem management that society could control all processes within the system to promote some particular, and most likely utopic, configuration is a false one.

Fisheries Management

There is vast evidence of direct effects of fisheries on the stocks they exploit, because catch means an additional source of mortality. The effect of excessive fishing mortality can be easily seen. Even fishermen were worried about changes in the size distribution of the catch and on the total landings when scientists were called in at the end of last century to solve their problem. Scientists could only confirm that there was considerable impact and that a reduction in fishing effort would be required to reverse the process. Overexploitation is not a very new conclusion. Assessment models have become more sophisticated but broadly speaking the multispecies approach has not changed the conclusion. Nevertheless, exploitation rates have only increased even further. In my opinion, the problem is that the development within any fishery is largely an autonomic economic process which cannot be managed simply by catch limits. We lack knowledge of how fishing effort can be effectively reduced and what kind of management system must be developed to facilitate this. This is the bottleneck for fisheries management rather than lack of knowledge about ecological interactions. This is not an easy matter, because it has to do with the distribution of wealth among people. But it may well be that a lottery system for issuing quota shares would find more public support, and this be more effective, than concepts based on 'relative stability' of national fisheries (that major concept underlying the Common Fisheries Policy of the EU).

Inadequate Science

There has been another major flaw in the scientific approach to fisheries management. In most situations we concentrate on individual stocks rather than on fisheries. In fact, TAC management systems do not recognize fishery units, but are based on the premises that catch levels will control fishing mortality and that is what we would like to see reduced. In fact, science has been promoting the utopia of 'fish stock management' rather than 'fisheries management.' However, most fisheries exploit species groups rather than individual stock. As a consequence, measures aimed at the well being of individual species may look appropriate in isolation, but the fishermen are confronted with all kinds of daily conflicts, if they try to catch one species and to avoid another. Such apparently contradictory measures do not contribute to the credibility of science or management. Even in the case of targeted, clean fisheries, the vessels are often multipurpose and will be used elsewhere if they can no longer fish for their original target species. Thus in trying to solve problems for one species, other problems may be created. In practice, the technical multispecies interactions within and between fleets are probably more important for setting up an appropriate management system than biological interactions.

Where To Go?

Socio-economics have a high priority, but ecology remains at the base of fisheries management because ecology determines the constraints of the economic activity. However, in order to facilitate economic factors being integrated our analyses should focus on fisheries, i.e., fleets consisting of units with similar characteristics (e.g., gear types), rather than on individual species.

This is not difficult because fishing mortality can be split relatively easily in partial fishing mortalities caused by different fleets. Fleet-based management has the additional advantage that specific 'ecosystem effects' of that fleet (by-catch of cetaceans, disturbance of the benthic community, etc.) Can be taken into account when defining the appropriate constraints. I am not suggesting to stop single species or multispecies assessment. Ultimately, we will need to evaluate the effectiveness of fisheries management on single species, multispecies complexes and on the ecosystem in order to advise on necessary adjustments of the constraints identified.

Environmental Variability and Implications for the Oyster Fishery: Modeling Studies

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The transplanting of oysters from one ground to another is a common practice in the oyster industry. A coupled oyster *P. Marinus*-predator model was used to investigate the effect of the timing of transplanting on the ultimate yield of Eastern oysters (*Crassostrea virginica*) in Delaware Bay. Simulations were run in which oysters were moved from seed beds to leased grounds in November, January, March, April, and May. The yield of market-size (≥ 76 mm) adults for harvest times from July to November were compared for populations undergoing mortality from predation (crabs, oyster drills) or disease (*Perkinsus marinus*). In all simulations, the abundance of market-size oysters declined between July and November. However, oysters transplanted in November resulted in the largest yield of market-size oysters for all harvest times.

Transplanting in May resulted in the least. The earlier transplant allows the oysters to benefit from the larger spring phytoplankton bloom over the leased grounds in the lower estuary. The effect of varying the season of transplant was most noticeable if oysters were harvested early (July or August). For diseased oyster populations harvested in the fall, the earlier transplant time was most beneficial in enhancing the overall yield of market-sized oysters. In all simulations, transplanting resulted in a higher abundance of market-size oysters over direct harvest from the seed beds. However, a May transplant is only moderately better than a direct harvest and its economic benefits of either option likely are determined by the cost of transplanting and the mortality associated with the process. The decision as to when to harvest relies on balancing the increased price obtained in the fall for oysters with the increased loss due to predation and disease. Awaiting a fall harvest is clearly much riskier if the principle source of mortality is disease rather than predation because disease mortality is concentrated on the market-size oysters and is maximum in the fall.

An Overview of Efforts to Incorporate Ecosystem Concerns in Fishery Management Advice for Northeast Pacific and Bering Sea Groundfish Stocks

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Scientists at the Alaska Fisheries Science Center have endeavored to improve our understanding of processes that influence production and sustainability of groundfish resources of the Gulf of Alaska and Bering Sea. This research effort utilizes information obtained from a variety of sources including: a) fishery independent data from surveys, b) commercial fishery data from observer programs, c) studies of the feeding ecology and trophic interactions of marine fish, d) process oriented research programs focused on factors influencing early life history survival, e) pinniped abundance and foraging ecology studies, and f) stock assessment modeling.

Collectively these programs provide the quantitative data necessary develop, implement and validate impacts of bio-physical forcing on the production of select groups of groundfish stocks. This document provides a brief summary of these programs and an overview of precautionary management practices that are utilized for management of groundfish stocks in the Northeast Pacific and Bering Sea.

Annual harvest quotas are the principal tool used to manage groundfish stocks in the North Pacific and Bering Sea. Quotas are established for individual species or species groups. In many instances time and area limitations are utilized to reduce localized fishery effects. Each year, TAC specifications for target groundfish categories are based on ABC specifications as modified by social and economic factors and, in some cases, to accommodate uncertainty in the stock assessments. The ABC specifications, in turn, are developed under a precautionary approach which provides a risk-averse means of specifying ABC and OFL based on the best available scientific information as summarized in the annual SAFE reports. The ABC specifications are based on definitions which were developed to safeguard against overly aggressive harvest rates, particularly under conditions of high uncertainty or low stock size. The guidelines are robust enough to provide adequate protection to stocks even when recruitment is highly variable or when instances of low recruitment tend to occur in a series. The guidelines are based on the precautionary principle wherein, the ABC/OFL guidelines maintain an appropriate buffer between the fishing mortality rates associated with ABC and OFL (F_{ABC} and F_{OFL} , respectively). Overall, the TAC specifications are set at or below ABC and are considerably lower than the associated overfishing levels. In some cases, the TAC specifications established are substantially below the ABC levels for bycatch or OY considerations, or because of uncertainty in stock assessments. As an added precaution, the ABC/OFL guidelines call for a reduction in fishing mortality rates whenever stock size falls below a target level.

Initial efforts to develop stock assessment models that address ecosystem concerns have targeted walleye pollock because they are the dominant groundfish species in both the Bering Sea and Gulf of Alaska. The pollock resource is an important component of Bering Sea and Gulf of Alaska ecosystems as both predator and prey. Both the Gulf of Alaska and Bering Sea stocks are supported by large interannual variations in recruitment. The dual importance of predation and recruitment variability necessitated top down and bottom up modeling approaches.

Investigations of bottom up forcing on the production of pollock is currently being conducted by scientists within NOAA's Fisheries Oceanography Coordinated Investigations (FOCI), and NOAA's Coastal Ocean Program Regional Study on Southeast Bering Sea Carrying Capacity (SEBSCC). These investigations have produced conceptual models of factors influencing pollock recruitment. Indices of key processes influencing recruitment are monitored annually to produce recruitment forecasts. These forecasts are used to project future trends in abundance and to predict the temporal and spatial changes in the abundance of larval and juvenile pollock within the two systems. Coupled bio-physical models are being developed and refined to examine the role of physical forcing on encounter rates between predator and prey. Stock assessment scientists are currently exploring methods to formally incorporate information obtained from the FOCI and SEBSCC programs into the stock assessment decision process.

Scientists at the Alaska Fisheries Science Center are exploring a variety of top down models including bulk biomass models, multispecies VPAs, and single species models that incorporate trends in predation mortality. The single species models that incorporate predation effects demonstrate trends in age specific natural mortality that could bias stock assessments. These models are also useful in providing estimates of key vital rates such as predator selectivity and catchability that can be utilized in development of bioenergetic models of top trophic level consumers.

The Alaska Fisheries Science Center is striving to develop models to formally address ecosystem concerns regarding the potential impacts of commercial fishing. Top down and bottom up modeling approaches have been advanced to accomplish this goal. The models are made possible by a coordinated research approach that includes a commitment to long term data collection and an interdisciplinary research team. New avenues of research revealed by this effort show single species harvest guidelines based on biological reference points must be reconsidered to address multispecies considerations.

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Managing Technical and Economic Interactions In Multispecies and Multiproduct Fisheries

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The harvesting of multiple species is quite common in fisheries. The harvesting of a single product is even more rare. To date, management authorities have mostly pursued multispecies management under the assumption that species are typically produced in fixed proportions to one another (e.g., if two pounds of species 1 is harvested, four pounds of species 2 is harvested). Alternatively, management has ignored the technical interactions among species and treated each species in a multispecies fishery as though it could be managed as a single species. Failure by management to adequately consider the technical interactions in a multispecies fishery could lead to serious biological, social, and economic problems. In this brief summary, we provide a discussion of possible quantitative approaches which may be used to determine or characterize the technical and economic interactions of a multispecies fishery. We ignore the highly important biological or ecological interactions which also occur in fisheries.

When two or more species are harvested independently of one another or there are no technical interactions, production of those species may be classified as nonjoint-in-inputs. In this case, the catch-effort or production relationships may be specified for each species and the potential interactions may be ignored:

$$C_i = f_i(E_i, N_i) \quad \text{Eq. (1)}$$

where C is catch, E is fishing effort, N is resource abundance, and i indicates the ith species. Alternatively, the relationship between catch (outputs), effort (inputs), and resource abundance

may be written such that outputs are aggregated and there are no unique interactions between any one output and any input:

$$F(C_1, C_2, \dots, C_M) - F(E, N_1, N_2, \dots, N_M) = 0 \quad \text{Eq. (2)}$$

where F is some functional specification of a composite output, C is catch, F is a function specification of a composite input, E is effort, N is resource abundance, and M is the number of species or products caught. When production can be written as in Eq. (2), the technology is said to be separable between inputs and outputs; we may form a single composite input and a single composite output. There are numerous possibilities between Eq. (1) and Eq. (2).

We commence with the full specification in which no restrictions are imposed on the underlying technology and examine one approach which may aid in identifying the technical interactions. Eq. (3) offers a catch-effort specification in which the technical interactions are unknown but assume to be joint in inputs (i.e., a unit of effort affects the catch of all species in some unique manner):

$$F(C_1, C_2, \dots, C_M; E, N_1, N_2, \dots, N_M) = 0 \quad \text{Eq. (3)}$$

The issue is whether or not the application of effort results in increased catches of all species, a subset of the all species, is there a unique interaction between effort and each species and that interaction involves only a single species (i.e., there are no technical interactions), or can effort be allocated among species.

The concept of duality offers one possible approach to parametrically or statistically determine the nature of the technical interactions. Duality permits the specification of an underlying economic objective function (e.g., maximization of profits or revenue or minimization of cost), and with the imposition of various restrictions, permits a statistically-determined characterization of the underlying technical and economic interactions.

We apply a dual revenue function to the New England, Georges Bank, otter trawl, multispecies fishery. More than 20 species (e.g., cod, haddock, yellowtail flounder, winter flounder, witch flounder, cusk, cusp, hakes, pollock, and monkfish) and 100 products (e.g., market cod, cod scrod, and whale cod) are regularly harvested by otter trawl gear on Georges Bank. The revenue function may be specified by several functional forms; we use a second-order approximation in order to minimize the imposition of the form of the technical interactions and to permit a characterization of the technical and economic interactions while also allowing the dependent variables to be specified as landings. The dual revenue function we use is also called a Generalized Leontief:

$$R(P, Z) = \sum_i \sum_j \beta_{ij} (P_i P_j)^{0.5} Z + \sum_i \beta_i P_i Z^2 \quad \text{Eq. (4)}$$

where R is revenue, P is a vector of output or species prices, Z is fishing effort, i and j indicate the i th and j th species, and the β 's are coefficients to be estimated. By taking the first partial derivative of the revenue function with respect to output prices (P), we obtain input compensated (fishing effort held constant) supply functions (Q_i):

$$\partial R(P,Z)/\partial P_i = Q_i = \beta_{ii} Z + \sum_{j \neq i} \beta_{ij} (P_j / P_i)^{0.5} Z + \beta_i Z^2 \quad \text{Eq. (5)}$$

We consider seven species or groupings of species: (1) cod, (2) haddock, (3) yellowtail flounder, (4) pollock, (5) winter flounder, (6) other flounder, and (7) miscellaneous. We thus have seven supply equations to estimate. We impose an error term, assume normal but contemporaneously correlated across equations, for each equation and estimate via seemingly unrelated regression (i.e., the equations appear as a system of equations but the system is not simultaneous). We consider six tonnage groups: (1) 5 to 50 gross registered tons (GRT), (2) 51 to 75 GRT, (3) 76 to 100 GRT, (4) 101 to 125 GRT, (5) 126 to 150 GRT, and (6) 151 plus GRT.

Via the imposition of different possible structures of the technology and parametric testing, we conclude that the Georges Bank multispecies fishery is quite heterogeneous relative to the different size vessels and how they target species. We also find evidence of considerably different structures of the technology relative to jointness, nonjointness, input/output separability, and the ability to manage groupings of species. We conclude that while some species and vessel sizes could be managed independently of other species, it would be more practical for management to consider the full realm of technical interactions and focus on jointly managing all species of the Georges Bank trawl fishery.

Multispecies Patterns, Processes and Concerns in Chesapeake Bay

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Introduction to an Ecosystem

The Chesapeake Bay is the largest estuary in North America. It is 320 km long, 50 km at its widest point and has an average depth of 6.4 m. The Bay covers almost 600,000 ha. It receives half of its water from the Atlantic Ocean. The remaining half of the input is freshwater draining from its 16.5×10^6 ha watershed, which covers parts of Virginia, Maryland, Delaware, West Virginia, Pennsylvania, New York and the District of Columbia. There are 50 major tributaries that drain into Chesapeake Bay. The majority enter on the western or northern side of the Bay. The principal tributaries are the Susquehanna (50% of freshwater input, 25% of total), Potomac, Rappahannock, and James Rivers. The average flushing time for the Bay is 42d.

Prior to European colonization the watershed was extensively forested. Yet today, large portions of the watershed have been cleared for agriculture and development to support the 15 million people who live in the watershed. The development has led to concerns about eutrophication. Nutrient loadings to the Bay have increased since pre-colonial times, with agricultural run-off being principally responsible. The increased nutrient load led to a decline in submerged aquatic vegetation. More significantly, the increased nutrient loading has led to an increased incidence in summer zones of anoxia. Declines in oysters, through over-fishing and disease also have had substantial ecological effects. Exploitation of other commercial fishes and shellfish has caused or exacerbated natural variations in their abundances. Today, then, the Chesapeake Bay is an altered ecosystem.

Multispecies Patterns

Fish and shellfish species that are found in the Bay face a highly seasonal environment. In spring months salinities in the middle of the Bay are 10-15 ‰. In autumn these same areas may experience salinities of 20-25‰. Shellfish must clearly be able to withstand such changes as they cannot move to avoid them. For the fish community, however, many species have adapted life histories that mean that they are not resident in the Bay for their entire life history. Accordingly, we may recognize three broad categories of fishes. (1) Bay -resident species -- these are resident throughout their entire life history and include bay anchovy, silversides, white perch and many more freshwater species such as yellow perch and catfish. (2) Anadromous species C these come into the Bay to spawn, typically in spring months and include striped bass, American shad and river herrings, and sturgeon. (3) Offshore spawning species C these may be resident in the Bay during juvenile and pre-maturation stages, but move offshore to spawn and include menhaden, bluefish, summer flounder, and several species of sciaenids.

Chesapeake Bay supports an important commercial fishery. Landings increased steadily since reliable records were started in the 1930's. Recently, landings may have begun to level off. In 1996 more than 330,000 tonnes, valued at \$160 million, were taken from the waters of Chesapeake Bay. Menhaden dominated the commercial catch, accounting for more than 80% of the total weight, but less than 45% of the total value. Blue crab were second in importance by weight, but first in value. In total, more than 50 species were reported in the commercial statistics. However, the distribution of the catch by species has changed dramatically in the past 100 years. Early in the 20th Century, oysters represented 15% of the catch. Although the data are unreliable, it is likely that oysters represented a much more significant proportion of the catch in the last 20 yrs of the 19th Century. Today, less than 1% of the total harvest is oysters. In contrast, the landings of menhaden have not always dominated the catch. In the 1930's they represented only 45% of the catch by weight.

An analysis of the landings shows evidence of multispecies interactions in Chesapeake Bay. There appears to have been a replacement of oysters by blue crab, such that the overall level of shellfish landings have been fairly constant. Piscivore species have fluctuated out of phase with each other, such that striped bass, weakfish and bluefish are never all at peak abundances in the same year. There is also significant coherence between the striped bass - white perch, alewife-menhaden and weakfish-croaker time series. Together, these and other patterns are indicative of both biological and technical multispecies interactions in Chesapeake Bay.

Multispecies Processes and Concerns

Species interact both ecologically and because of joint exploitation. A species need not be the target of a fishery to respond either by biological forcing or technical interactions to removal of the targeted species. Examples of both biological and technical interactions can be found in Chesapeake Bay.

Several of the Chesapeake fisheries are non-selective or have substantial by-catches. Significantly, however, the menhaden purse-seine fishery, which is responsible for more than 80% of the total landings, is largely free of such concern. Pound nets, which are common all along the 7,400 km shoreline, are non-selective trap nets that are set in shallow water. Long panels of netting set orthogonal to the shore lead fish into a pen. Fishers dipnet the trapped fish. As the fish are not gilled or otherwise selected many species are vulnerable to this gear. Gill nets are extensively used for white perch, striped bass and other species. Mesh sizes are regulated, but inevitably there is a bycatch of juvenile and young adult striped bass in the white perch gill net fishery. There is also a substantial coastal gill net fishery just outside of the Bay which intercepts many returning anadromous fishes, particularly American shad and river herrings. The recreational fishery targets a multitude of species; mixed-species catches are common.

Biological interactions have also been documented for Chesapeake Bay. Several of the important species, e.g. striped bass and menhaden, are linked as predators and prey. Hence, removal of prey species may negatively affect predators, while removal of predators may permit additional removals of prey. At the core of the Chesapeake Bay food web are several small-bodied, forage fish species such as bay anchovy which are not themselves subject to exploitation, but do support larger fish that are exploited. These forage species may respond to changes in the productivity of the ecosystem, being brought about by nutrient control, hence allowing these effects to cascade to higher levels. However, the links are not well established and are worthy of additional research.

An Hierarchy of Fishery Assessment Models

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The provision of scientific advice in support of fishery management has as its fundamental paradigm the quantification of stock status (abundance and harvest rates relative to pre-defined targets) as the basis for predicting the effects of various policy options on attributes of the biological system and fishery. Analysts have at their disposal a vast toolbox of methods to provide such advice, depending on the specific types of fishery assessment questions being asked, and the availability of data with which to parameterize the models (Shepherd 1988; Hilborn and Walters 1992; National Research Council 1998). Fishery management questions, the objects of modeling studies, take three general forms: (1) those concerned with abundance estimation, (2) tactical (short- to medium term) management decisions, and (3) strategic (long-term or equilibrium) management goals or "biological reference points" (Table 1).

Model-based estimates of population abundance are the norm in fishery science since direct estimation of stock size is usually impractical and may not present a consistent integration of abundance measures and catches over time. Abundance estimation models typically combine one or more stage-disaggregated measures of relative stock size, catch (landings and discards) and direct measures or assumptions of losses due to natural processes (predation, disease, senescence). Non-linear fitting models can be used to estimate population parameters and their uncertainty, with emphasis placed on the most recent year of the time series. Model results of current stock status (abundance, fishing mortality rates, predation mortality rates by stage) and functional relationships determining population processes and species interactions (stock-recruitment relationships, feeding relationships among predators and prey, etc.) are the elements from which predictions are made. Reconstruction of population sizes, predation-related deaths and rates of fishing and predation mortality of interacting species have been derived using multispecies extensions of age-based cohort models (e.g. Sparre 1992; Rice et al. 1992).

Tactical management questions focus on the transitional effects of changing fishery control measures. Often, tactical models are used not only to evaluate effects on populations and fishery landings, but on the economic and social benefits and costs of changing management measures. Tactical management prediction models are used to evaluate progress towards pre-defined goals (i.e. biological reference points of harvest rates and target stock sizes), which are determined from various strategic management models. Quantitative methods supporting tactical fishery predictions include short- and medium-term fish prediction models, demand models of volume-price relationships, and quantitative or qualitative behavioral models (exit/entry etc.). Recently, there has been more emphasis on providing short-term forecasts in a probabilistic framework, incorporating uncertainty in initial stock conditions, fishing mortality rates and recruitment (National Research Council 1998).

Strategic goals in fishery management define the desired level of fishery yields and their interannual variability from one or more species supporting regional fisheries. Single-species strategic goals are most often associated with growth- or recruitment overfishing (Beverton and Holt 1957; Hilborn and Walters 1992).

Fishery assessment models have increasingly been used to evaluate strategic trade-offs associated with harvesting groups of interacting species. The precise definition of the assemblage, guild, community, ecosystem or other appropriate grouping of species to evaluate and optimize is invariably problematic (Underwood 1986) and defines the scope of fishery-related analyses that can be undertaken. Such studies are generally categorized as technological (bycatch) interactions or biological interactions among species (Daan and Sissenwine 1991; Miller et al. 1996), although significant interactions of both types may occur simultaneously. Technological interactions, which are easily defined by catch and bycatch data, are used to evaluate the optimum selectivity patterns for species harvested jointly, and to calculate the yields accruing to various fisheries that harvest shared species (either as landings or discards). Economic aspects of technological interactions models may be important when the interactions among incompatible fisheries are strong.

Biological interactions occur when harvested species or other components of the ecosystem exhibit significant predatory or competitive interactions (Table 2). Various methods have been used to test for these interactions, and to model them, including fitting of statistical models to predator and prey abundance time series (Sissenwine et al. 1982; Fogarty et al. 1991), incorporation of consumption in estimates of prey population sizes, and multispecies surplus production models. In several instances, the incorporation of interspecies predation into strategic models has resulted in qualitatively different advice on the long-term benefits accruing from tactical management measures (e.g., increasing net mesh sizes). The effects of fishing on various aggregate metrics of fish production from ecosystems such as the slope of aggregate size compositions (pioneered by Pope and Knights 1982, and subsequently extended by J.G. Pope) and the average trophic positions of regional fishery catches over time (Pauly et al. 1998) provide the potential for new insights into the effects of species- and size-selective fisheries and the overall impacts of fishing effort. These new developments signal a convergence of fishery assessment models with broader trophic and population ecology approaches used to evaluate, trophic cascades, effects of harvesting on co-evolved species, and the genetic implications of intensive fishing.

In the future there will likely be greater emphasis placed on tactical fishery management models explicitly accounting for spatial processes and biological effects, owing to increased use of closed areas in fisheries management (Lauck et al. 1998). Likewise, fishery assessment models will better quantify process and measurement uncertainty and its effects on management advice. The use of "meta-analyses" (comparative analyses populations and ecosystems) in the search for mechanisms influencing biological populations will increase (Myers et al. 1995), as will behavioral models that relate harvest rates to dynamic biological, economic and social factors (i.e. man as a prudent or imprudent predator). Models of fishery and species interactions for systems such as Chesapeake Bay will require the collection of information not heretofore available for the system. This does not mean, however, that data collection programs documenting single species catches, abundance measures and ancillary biological information should be abandoned in favor of alternatives. Rather, these programs should be improved and extended to a wider array of species, and supplemented with other appropriate investigations and information (Table 2).

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Table 1. Fishery Assessment Questions

Type of Question	Time Frame	Form of Answer	Data	Examples of Models
I. Abundance Estimation (How many...?)	<ul style="list-style-type: none"> • Retrospective • Current 	<ul style="list-style-type: none"> • Data • Model Results • Precision Estimates 	<ul style="list-style-type: none"> • R/V Relative Abundance • CPUE • Tagging • Acoustic / Swept Area • Demographics • Catch, • Bycatch • Consumption 	<ul style="list-style-type: none"> • Stage Structured (Age-Size) estimates: Population Size and Exploitation Rate • Aggregate Biomass (Snapshot)
II. Tactical Management (What if...?)	<ul style="list-style-type: none"> • Season / Year • Medium-Term 	<ul style="list-style-type: none"> • Model Results • Precision Estimates 	<ul style="list-style-type: none"> • Results from I. + • Management Scenario • A iTargetj • Recruitment Generator • Behavioral Models • Price Effects 	<ul style="list-style-type: none"> • jYear-Ahead, Medium-term projections • Stochastic; Deterministic • Demand • Benefit-Cost • Diffusion; Spatial
III. Strategic Management (Fishery-Environment Interactions)	<ul style="list-style-type: none"> • Long-Term (Decadal) • iEquilibriumj 	<ul style="list-style-type: none"> • Directionality (Sign change) • Model Results • Uncertainty 	<ul style="list-style-type: none"> • Data & Models in I. & II + • A iTargetj (different?) • Correlation Studies • Interdisciplinary Studies • Meta-Analyses 	<ul style="list-style-type: none"> • Yield per Recruit • Stock-Recruitment • Trophic Interactions • Genetics • GSMS • Fishery Interactions

Table 2. Quantifying Fishery Interactions: Necessary & Sufficient Conditions & Information.

Interaction Type	Information Type								
	Abund. Measures	Dist. Overlap	Size Pref.	Behavioral Overlap	Consump. Estimate	Bycatch Data	Growth Data	Maturity Data	Catch by Stage
Predation									
Intra-	++	++	++	++	++				++
Inter-	++	++	++	++	++				++
Competition									
-Growth									
Intra-	++	+		+	+		++		
Inter-	++	++	++	++	++		++		
-Recruitment									
Intra-	++	++				++		++	++
Inter-	++	++	++	++	++				0
-Distribution									
Intra-	++	++		+		++			
Inter-	++	++		+		++			

Table 2. (Continued).

Interaction Type	Information Type								
	Abund. Measures	Dist. Overlap	Size Pref.	Behavioral Overlap	Consump. Estimate	Bycatch Data	Growth Data	Maturity Data	Catch by Stage
Bycatch									
Intra-	+	++		++		++			++
Inter-	+	++		++		++			++
Not Specified									
Production Function	++					++			++
Aggregate Abundance & Size	++					++	+	+	++
Interaction Terms	++					++			++

A Personal View of the Workshop on Multispecies Fisheries Research and Management Problems

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Introduction

Neils Daan pointed out that you cannot manage ecosystems, you can only manage what humans do to them. In the case of Chesapeake Bay, humans clearly affect the ecosystem by adding nutrients and by fishing. Orientation papers by Ed Houde and Tom Miller brought out these concerns.

Hydrological models of nutrient inputs in the Chesapeake Bay watershed seem well developed. Such models can be coupled to phytoplankton production but as production moves to higher trophic levels, the problems of understanding, modeling and managing increase because we are increasingly dealing with critters with minds and agendas of their own. Moreover, they interact with each other and are directly or indirectly subject to fishing pressure. In short, we are moving from physical/chemical problems and into biological and fisheries problems.

Traditionally fisheries models have concentrated on the biology of each species in isolation and proposed appropriate ways to fish each species. Where fishing has been the major source of change in fish stocks, this single species approach has been reasonably successful in pointing out the major fisheries management problems. From a management perspective such an approach leads to relatively straightforward management decisions. Given combinations of size of first capture and exploitation rate can be seen as being good or bad, with respect to objectives about yield maximization. The management problem is also relatively capable of being communicated to fishermen and to the public. It can be expressed in terms of certain sizes of capture being good or bad or in terms of certain rates of harvest being excessive. Unfortunately, these relatively comfortable single species management tools do not always reflect fisheries or biological reality. When this is the case they may need to be replaced by multispecies approaches. The rest of this note is about what these might be.

Interactions between fishermen and the ecosystem

Comfortable single species management tools do not reflect fisheries or biological reality. This is because, in addition to the direct effects of fishing mortality, other interactions occur between both sets of players. The workshop presentations have made it clear that multi-species interactions are of two types:

- Technical interactions are of obvious interest to fishery managers because they involve different user groups who have different interests in the various fish stocks. Managers clearly need to know enough about technical interactions to be able to allocate the resource appropriately between the various user groups. Indeed, as part of allocation arguments, managers will often hear "whines" about the "misdeeds" of other user groups. Since these problems are of clear concern to managers, data are needed that are appropriate to this problem. Appropriate data are those that describe what species the various user groups catch, the size selectivity of their gear and perhaps where they fish in the Bay. Such data allow the construction of relatively simple, "who does what, and with which, unto whom" models, which, when coupled to the single species models of the relevant species, will help illustrate the allocation alternatives; and

- Biological interactions are less obvious to managers and also potentially more difficult to manage. Biological interactions between species may involve species for which little common utilization occurs. Hence, to consider them may involve allocation problems between users who previously appeared to operate independently of each other. In the case of Chesapeake Bay examples might be interactions between menhaden and striped bass or interactions between oysters and crabs. These examples indicate that considering biological interactions may involve wider and perhaps more difficult tradeoffs than managers are used to handling. However, if real biological interactions exist, then single species management plans aimed to simultaneously maximize the yield of all species will be rooted in unrealistic expectations.

A previous Prime Minister of the UK, Harold Macmillan, said “that politicians have a duty to point out where their constituents aims are unrealistic, For example, to point out that zero inflation and 10% annual pay rises for everyone are not compatible”. On occasion fisheries managers also have to act as opinion leaders. It is their duty to point out to their stakeholders when their aims are unrealistic. A general example is that fishermen cannot expect all their sons to carry on the business and at the same time to use the most modern gear and best electronic kit on their vessels; increases in efficiency imply reductions in participants. A possible example, in the context of Chesapeake Bay, is that it may be incompatible to expect the yields of those species, which have displayed opposite trends through time, to be simultaneously maximized. Similarly, it is possible that the Bay cannot be restored to near pristine conditions and still have the fish yield at current levels. It is usually best for leaders to face up to such realities and tackle them, rather than to ignore them and to foster unrealistic expectations that cannot be satisfied. Thus, if they seem likely to exist, then it is best that biological interactions are studied, quantified and brought into management decisions.

Multispecies models to aid management

Given that multispecies interactions have to be addressed, there is a need for suitable models to provide advice. There is also a need for models that help scientists to visualize the problems, even if they are not directly applicable to management. Management models of biological interactions need to tackle two main problems. These are:

- Predatory interactions amongst the higher trophic levels; contributions by Jake Rice, Ann Hallowed and Jeremy Collie have described some appropriate models.
- The effects of changes in the nutrient base and the production of phyto-plankton and zooplankton, particularly in so far as they provide food to higher trophic levels; Bob Ulanowicz describes one such model and Danny Pauly and Villy Christensen are in the market with an analogous approach.

A problem with all such models is that predation acts by size. The size, age or stage detail needed to satisfy the predation models is typically far more than could be chosen for the food production models. Nutrient and production models tend to be framed in terms of the biomasses of major species or species groups. Combining both types of models would probably result in something that was so complicated that it could neither be fitted to data nor understood. Hence, both types of models are needed. Presently it is best to use the type of model that is most appropriate to a particular question rather than to seek a general model, which will solve all problems.

The bulk biomass type of model provides an interesting integration of both processes. Jeremy Collie showed an example of such a model. These models are interesting because they might address both predation and food competition interactions. However, there is a drawback. It is that the number of model terms potentially increases as something like n^2 , where n is the number of species. Thus a four species model might have 16 parameters to estimate. It is not realistic to expect that all 16 could be

estimated from available time-series of data. In fisheries, biomass or catch rate data time-series are typically quite short (20 or 30 years) but even a hundred-year sequence would hardly suffice to estimate 16 interaction terms. Jeremy Collie got over this problem by a judicious elimination of many of the potential interactions but the potential to do this may not always exist. Moreover, it is not clear to me if nutrients could be easily entered in such a model. Despite these problems, clearly such models can provide a useful overview for the effects of a few major interactions. As well as being a way of directly fitting data, such models do have a further useful role. They may be fitted to the outputs from more complex models to provide a relatively simple summary that can be helpful for providing management advice and exploring management tradeoffs.

Typically species interaction models need extra data in order to fit the extra terms. Predation is one of the easier effects to study because of the availability of the "smoking gun" of stomach contents data, but all species interaction models need their own appropriate data.

Models to aid scientific understanding

As well as developing models that help managers to handle biological interactions, there may also be a need for models, which help scientists to better understand multi-species problems. Size spectrum models seem to have some potential for helping scientists to visualize the problem simply. In the North Sea, the size spectrum of the finfish has been found to be a very conservative feature of the system and one that appears to react simply to changes in exploitation. For example, comparisons between the size spectrum of finfish in 1904 and in 1991 (see figure) shows how the relative numbers of the larger sizes of fish have been eroded over the past century. They also are useful for making comparisons between systems.

Finfish size spectra are of course only the tip of the iceberg of the size spectra of all species. The Sheldon Sutcliffe/Platt and Denman hypothesis postulates that in non-seasonal systems, size spectra contain equal biomass per size octave. In many systems, including Chesapeake Bay, it is likely that such spectra are seasonally perturbed. Pope et al. (1994) have speculated that the Sheldon Sutcliffe/Platt and Denman hypothesis might also be true when size spectra are integrated over a year. It seems likely that studies and comparisons of size spectra of phyto and zooplankton may indicate disruptions and changes caused by changing nutrient inputs. Moreover, size provides an alternative "taxonomy" to species and perhaps, when augmented with the dimension of species guilds, one which might make a useful basis for a network analysis of Chesapeake Bay.

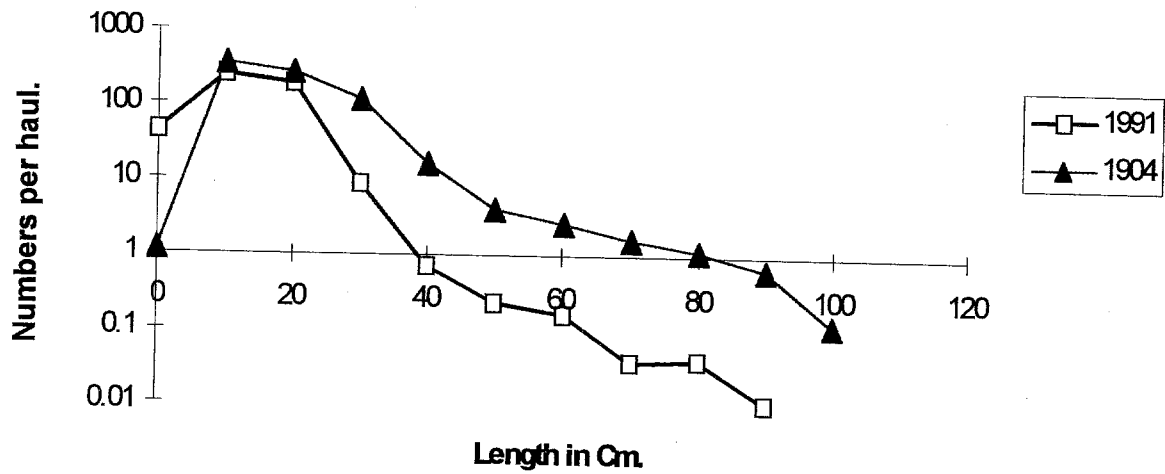
Problems with the wider ecosystems effects of fisheries

The wider ecosystem effects of fisheries can cause an extension to the problem of species interactions. In the North Sea and a number of other areas the ecosystem effects of fishing on parts of the ecosystem which have no direct economic value has become an issue. Examples of such problems are beam trawls designed to catch flatfish, which also kill benthos, discarded fish and fish offal which feed populations of scavenging seabirds, cod and flatfish gill nets, which also catch cetaceans. Any effects of fisheries on the wider Chesapeake Bay ecosystem will add to the factors that its managers will have to consider. Clearly this will be difficult but an ecosystem approach to management will demand nothing less.

Reference

Pope, J. G. , Shepherd, J. G. and Webb, J. 1994. Successful surf-riding on size spectra: the secret of survival in the sea. *Phil. Trans. R. Soc. Lond. B* (1994) 343: 41-49.

Figure 1. Comparison of slope of size spectrum of all survey caught fish species combined: 1904 and 1991 data from the Southern North Sea.



Multispecies Advice on Management of Living Marine Resources:

The ICES Perspective

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ICES advises many national and international management bodies on issue of fisheries and marine science. Provision of advice is done through two Advisory Committees: the Advisory Committee on Fisheries Management and the Advisory Committee on the Marine Ecosystem, based on reports produced by over 35 Working Groups and Study groups. Additionally, a number of Scientific Committees coordinate international research efforts, symposia, data base management, and diverse other science activities, to enhance the knowledge base available to the Working Groups and Advisory Committees. This talk summarizes the recent activities and products of two Working Groups, on Multispecies Assessment and Ecosystem Effects of Fishing, but activities of many other Working Groups and Science Committees contribute to the "ICES Perspective" on ecosystem management.

The Multispecies Assessment Working Group (MAWG) has been meeting since 1980. Its activities have been about equally divided between developing MSVPA to the point of being an operational tool for analytical multispecies assessments, and reviewing progress on developing multispecies assessment tools for boreal ecosystems, where MSVPA was thought to have more limited usefulness.

MSVPA was never considered to be a global ecosystem assessment tool. Its purpose is to estimate the component of natural mortality due to predation, in addition to the other parameters routinely estimated in single species VPA. Hence MSVPA requires all the usual age-disaggregated inputs of single species VPA, plus samples of stomach contents of each predator and estimates of their quarterly rations. It also requires several additional assumptions; particularly significant are the assumptions that suitabilities are constant, and "other food" has known dynamics.

The 1997 meeting of the Working Group produced a benchmark application of MSVPA to the North Sea. It included 12 "species" of predators, including grey seals and a generic seabird, and 7 species of prey. It explored a variety of different scenarios, including strategies for accounting for uncertainty in prey weights, estimation of predator consumption levels, and other technical factors. It gave particularly thorough attention to the question of the stability of estimates of suitabilities with stomach samples from 1981, 1991, and using all stomach sampling. This investigation supported the more preliminary work done at previous meetings; there are statistically significant differences in suitabilities between parameterizations using only the 1981 data and using only the 1991 data. However, the inter-year differences are small, the changes in predation mortality are much smaller than the changes in suitabilities, and the effects on forecast performance are also minor. All these points reinforce the use of MSVPA as reasonable approximation of the species in the model. The application found that predation mortality does vary substantially over years and across ages, but for the species included is as large or larger than fishing mortality on some ages of most prey.

Much of the activity of the Working Group was looking at the information that the MSVPA results had about the structure and dynamics of the top components of the food web. For example, the WG looked at patterns in total biomass and production of these levels over the past 25 years, as well as

properties like the proportion of production taken by fisheries and by predators. Interestingly, MAWG concluded that the weakest inputs to MSVPA were now catch data, rather than stomach data.

MAWG explored multispecies aspects of biological reference points, using several approaches, including the Shepherd - Sissenwine models, and Lotka-Volterra models. The work was preliminary, but showed important differences between reference points estimates in single-species and multi-species frameworks. The differences are particularly important for evaluating rebuilding strategies. MAWG also reviewed future directions for multispecies assessments. It concluded that adding length structure to the age structured MSVPA framework would expand the areas where assessments could be done as multispecies rather than single-species formulations. It saw little short-term promise for assessments based on mass-balance or coupled predator-prey population dynamics models, as bases for advice to fisheries managers, although these approaches have a number of merits as research tools. MAWG also concluded that there would be more loss than gain in trying to add more trophic levels in a single, more complex assessment package, but makes other suggestions for how this important task should be approached.

The Working Group on Ecosystem Effects of Fishing (WGECO) met first in 1990, and its role in ICES is expanding rapidly. At its 1997 meeting it addressed several Terms of Reference on bycatch, on long term trends in target and non-target fish populations, on community metrics which may reflect the impacts of fishing, and on the precautionary approach in an ecosystem perspective.

WGECO concluded that the poor quality of data on discards and bycatches should be an embarrassment to the fisheries and marine science community, and certainly undermines many quantitative investigations. Long term trends in populations of target of non-target species showed all sorts of patterns, but in most cases it was not possible to extricate the impacts of fisheries from environmental forcings. WGECO gives several suggestions for what can be done in future, but stresses most of the contrast in the processes of interest is very small compared to the changes fishing may have caused several decades ago. This point is illustrated with size composition data from several stocks with histories of many decades.

WGECO looked at lots of community metrics as tools for investigating ecosystem effects of fishing. The multivariate methods favoured by community ecologists show lots of interesting patterns, however, there is almost no success in linking these patterns specifically to fishing. On the other hand, the theory linking size spectra to fishing is developed quite well. This tool is proving extremely useful in investigating some aspects of the ecosystem effects of fishing.

WGECO benefited from participation by researchers experienced in several approaches to ecosystem modeling, including ECOPATH, trophic cascades, L-V food web models, and MSVPA. The group drew from this expertise in its discussion of the precautionary approach in an ecosystem context. It was pointed out where a number of additional reference points are required, to ensure conservation is achieved at the ecosystem level, as well conservation of the target species of fisheries. WGECO was able to go further, though, and conclude that it had not been possible to demonstrate, within any of the frameworks, an ecosystem property which would be "at risk", if all the constituent species were being conserved with high probability.

Network Analysis:

Making Sense Out of Many-Species Interactions

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The quantitative tools available to analyze multi-species interactions in fisheries and ecosystems are rather limited in scope. Normally, one associates with the task some sort of simulation modeling. Such models may be as simple as coupled differential equations of populations described in terms of bulk biomass, or they might include some features of population structure, such as are quantified with a Leslie-matrix type approach. Models sometimes are even cast in terms of individual organisms that operate according to rule-based scenarios. But all such efforts at simulation suffer on two counts: 1) Dimensionality, and 2) Non-linearity.

As simulation models increase in either the number of their compartments or the nonlinearity of their component processes, their behaviors tend to become more pathological, that is, increasingly prone to artificial extinctions or unreal population explosions. To keep such models behaving acceptably modelers usually are forced to resort to inherently stable dynamics, such as linear, donor control or ad-hoc cutoff thresholds, that are poor descriptors of actual interactions. One winds up sacrificing model reality for stability.

Do there exist alternatives to simulation modeling available for application to the management of multi-species fisheries interactions? One possibility is the Network Analysis of trophic transformations. Basically, a network of trophic exchanges is a box-and-arrow diagram that presents in visual form the answers to the questions, "Who eats whom?", and "At what rate?" Transfers are usually measured in terms of some chemical element, such as carbon, nitrogen or phosphorus, and typically are presented in units of mass/area/time. Four types of flows comprise most trophic networks: 1) Intercompartmental transfers, like predator-prey exchanges or contributions to some detrital pool, 2) Imports from outside the system, such as primary productions or the advection of allocthonous materials into the system, 3) Useful outputs that can be utilized by some other system of comparable scale, and 4) Dissipations of medium into its energetically lowest state. A typical budget is that of the mesohaline Chesapeake Bay ecosystem by Baird and Ulanowicz (1989), shown as Fig. 1.

Perhaps the key to Network Analysis is the fact that networks of flows can be portrayed in matrix format. The magnitude of the flow from prey i to predator j can be entered into the i th row and j th column of an $n \times n$ matrix, where n is the number of compartments in the system. With the network thus encoded, various algorithms based on linear algebra can be applied to the matrix to reveal underlying features of the web. For example, each column can be summed to compute the total consumption of that particular predator. Dividing each entry in a column by that column's sum yields a matrix of "dietary coefficients". Each column of this matrix contains the percentage distributions of prey items in the predator's diet.

The diet matrix is extremely useful. When the matrix is multiplied by itself, each entry of the product indicates how much medium passes from each component as source to any other compartment as sink over all trophic pathways consisting of exactly two steps. Similarly, multiplying this result yet another time by the original matrix gives the proportions from every source to each sink over all pathways of trophic length 3. In particular, the powers of the diet matrix can be used to answer the question, "Of all medium entering B, how much once was incorporated into A?", or conversely, "Of all the medium that leaves A, how much eventually enters arbitrary compartment B?" (called the "contribution coefficients") The former computations yield the "indirect diet" of a given species, that is, the percentages of a predator's diet that at some time past resided in each of the other compartments (Szyrmer and Ulanowicz 1987.)

Indirect diets can be used to describe niche separation between species that might otherwise appear to compete strongly. For example, in the Chesapeake ecosystem, the bluefish (*Pomotatus saltatrix*) and the striped bass (*Morone saxatilis*) both appear as aggressive piscivores. The indirect diet of the former, however, is rich in benthic components, whereas that of the latter is heavy in pelagic fare (Baird and Ulanowicz 1989.) Contribution coefficients, in their turn, can be used to represent the efficiencies by which plant material wends its way through the ecosystem to become incorporated onto various fish stocks.

The integer powers of the diet matrix also can be used to apportion the flow into any compartment according to the length of the various pathways over which it traversed to reach that taxon. This operation allows one to map the complicated foodweb into an equivalent linear-type foodchain (sensu Lindeman) that reveals how much, on average, is lost with each transfer through the system. Any atrophy of the upper members of this "Lindeman chain" for an aquatic system could be indicative of overfishing or some other system-level stress on the ecosystem as a whole. Conversely, one can use the trophic apportionment of flow into any given compartment to calculate the average trophic level at which that taxon is feeding (usually not an integer.) Decreases in the average trophic level of any commercial fish species typically is an indication that the population is being stressed in that particular habitat.

When a predator consumes a prey item, the transfer exerts a direct negative effect upon the prey population and, at the same time, represents a positive increment to the predator stock. Using similar methods as those employed on the diet matrix, one may propagate the negative trophic effects down the foodweb and simultaneously project the positive influences up the trophic scale. In this way one may quantitatively assess the net trophic impact of any one particular species upon any other taxon. When managing several fish stocks simultaneously, knowing what ecosystem components significantly affect each stock with what positive and negative magnitudes could prove very useful information, indeed.

Control within ecosystems often is exerted via cyclical or feedback pathways. Algorithms are available to enumerate within a network all simple cyclical pathways for transfer of medium (Ulanowicz 1986.) Knowing in which cycles a particular fish population participates could yield clues concerning the controls upon that stock. When all cycles in a system are aggregated, the resulting picture sometimes reveals how particular taxa are functioning in an ecosystem. For example, cycling analysis revealed that in the mesohaline Chesapeake ecosystem the planktivorous fish were serving as a "bridge" to convey material and energy away from a planktonic domain of control and into a complex of feedback between the deposit- feeding benthos and the piscivorous nekton (Baird and Ulanowicz 1989.)

Finally, Network Analysis provides a number of whole-system indices (derived from information theory) that characterize the organizational status of the whole ecosystem and its level of performance in processing energy and material. While whole-system status might appear interesting only to the ecologist, quantifying the specific contributions of particular fishes to how the system as a whole is performing could be most helpful to the fisheries manager. Monaco (1995), for example, compared the contributions of several fishes in three different estuarine habitats to the overall system ascendancy (the primary index of performance) to uncover clues as to how each stock was faring in the separate communities. Elsewhere, Ulanowicz and Baird (in press) employ such contributions to identify which elements (C, N, or P) and which particular sources of these elements limit the production of each component of the ecosystem.

While Network Analysis can be used by itself, it also can provide significant advantages when employed as a complement to conventional modeling techniques. For example, networks of trophic exchanges can be used to "calibrate" or "verify" extremely complicated models of ecosystems or fisheries (ATLSS 1997.) Furthermore, when such complicated simulations behave unrealistically (as they are prone to do), Network Analysis can be invoked as a diagnostic tool to help locate where problems in the model may lie.

Network Analysis shows considerable promise as a tool for furthering our understanding of complicated interactions in multi-species fish communities.

A more complete description of the methods for Network Analysis as well as the algorithms themselves can be obtained over the World Wide Web at
<<http://www.cbl.umces.edu/~ulan/ntwk/network.html>>.

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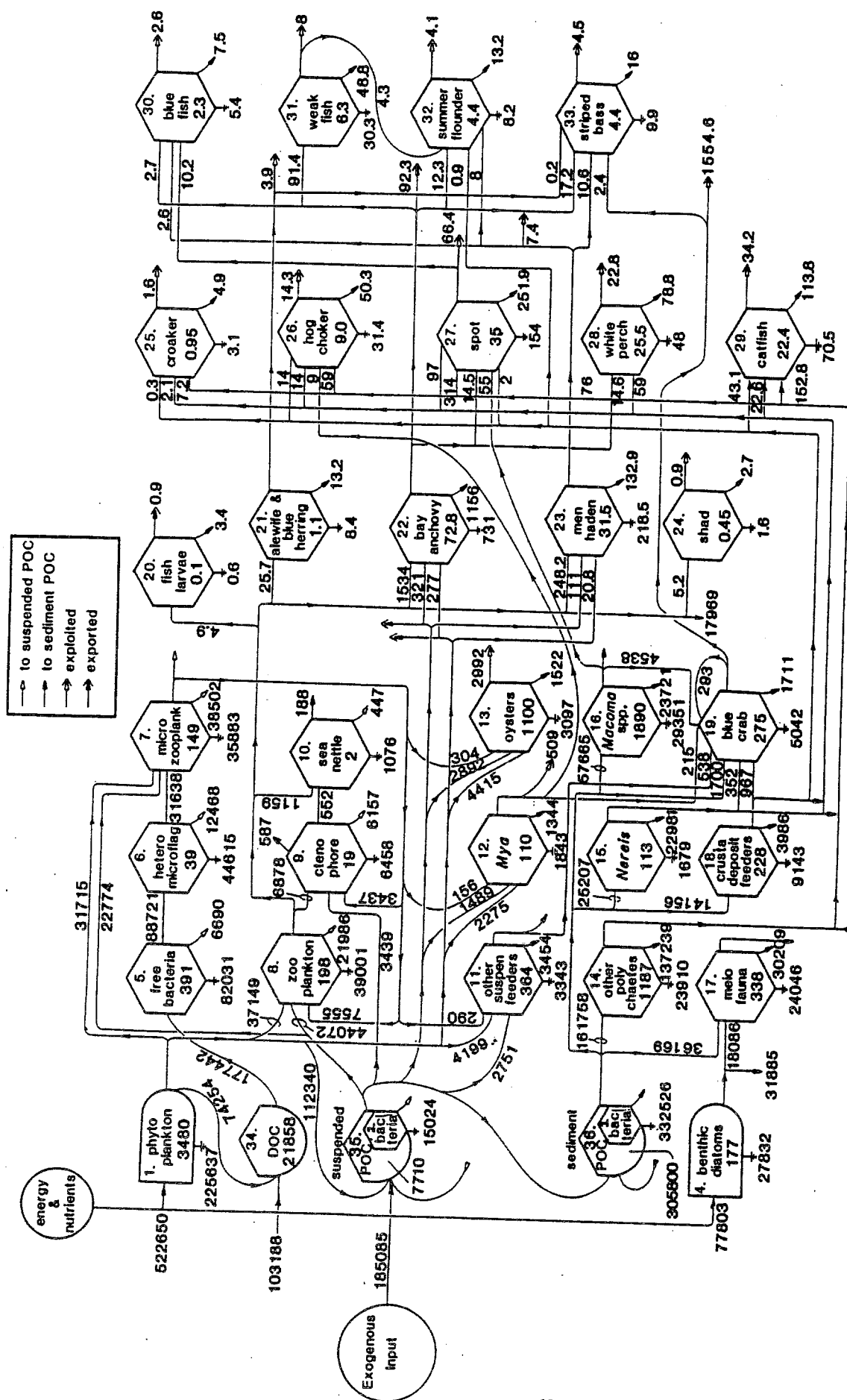


Figure 1. Schematic representation of the annual carbon flows among the 34 principal components of the Chesapeake mesohaline ecosystem. Carbon standing crops are indicated within the compartments in mg/m^2 and the indicated carbon flows are in $\text{mg}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$.

APPENDIX B

AGENDA

Multispecies Fisheries Research & Management Workshop

DAY 1: 1 April 1998

- 9:30 a.m. Welcome and Introduction to Workshop..... E. Houde
- 9:45 Multispecies Patterns, Processes and
Concerns in Chesapeake Bay Fisheries T. Miller
- 10:30 COFFEE BREAK
- 10:45 An Hierarchy of Fisheries Assessment Models..... S. Murawski
- 11:30 Network Analysis: Making Sense Out of Many-Species Interactions R. Ulanowicz
- 12:15 p.m. PREPARED LUNCH
- Luncheon Speaker J. Collier
Chesapeake Bay Program: Ecosystem Modeling
- 1:30 Managing Technical and Economic Interactions in
Multispecies and Multiple-Product Fisheries..... J. Kirkley & D. Lipton
- 2:15 Multispecies Advice on Management of Living Resources
--the ICES Perspective..... J. Rice
- 3:00 COFFEE BREAK
- 3:15 *Plenary Session*: Discussion of Workgroup Objectives
- 3:45 Workgroups Convene
Workgroup 1: Chesapeake Bay Multispecies Issues
Workgroup 2: Fisheries and Ecosystem Models
Workgroup 3: Management Needs and Perspectives
- 5:45 Refreshments and Informal Discussion
- 7:00-9:00 DINNER at Captain's Table Restaurant
-

AGENDA

DAY 2: 2 April 1998

- 8:30 a.m. The Multispecies and Ecosystem Approach to Fisheries Management:
A Hiking Trail to Utopia? N. Daan
- 9:15 Multispecies Research and Management in the Northeast Pacific A. Hollowed
- 10:00 Predator-Prey Interactions on the New England Continental Shelf J. Collie
- 10:45 COFFEE BREAK
- 11:00 Environmental Variability and Implications for the Oyster Fishery:
Modeling Studies E. Hofmann
- 11:45 Workgroups Reconvene
- 12:30 p.m. PREPARED LUNCH
Lunch Speaker D. Boesch
- 3:00 COFFEE BREAK
- 3:15 Workgroups Convene
- 4:30 *Plenary Session: Preliminary Workgroup Reports*
- 5:30 Adjourn for the Day
- 6:00 Reception at Chesapeake Biological Laboratory
- 7:30 DINNER (on your own)

DAY 3: 3 April 1998

- 8:30 a.m. Impressions and Summary Comments J. Pope
- 9:15 Workgroups Final Session
- 10:15 COFFEE BREAK
- 10:45 *Plenary Session: Workgroups Report and Summarize Findings, Workshop
Recommendations, Assignments, etc.*
- 12:00 ADJOURN
-

APPENDIX C

WORKGROUP PRIMING QUESTIONS

Workgroup 1. Chesapeake Bay Multispecies Issues

1. Is there evidence for important multispecies interactions in the Bay?
 - a. Ecological
 - b. Fisheries-related. Both directed landings and bycatch
2. Can we define a multispecies “system” in space or time?
3. Are habitat concerns a key issue in multispecies interactions?
4. Can we list, categorize, and prioritize multispecies concerns or issues for Chesapeake Bay? What fundamental research is required to address the issues?

Workgroup 2. Fisheries and Ecosystem Models

1. What multispecies modeling approach is needed most in Chesapeake Bay? What data, information, and research are required to build the models?
2. Is Multispecies Virtual Population Analysis (MSVPA) required or sufficient as a multispecies approach in Chesapeake Bay?
3. Are ecosystem models likely to be useful in multispecies fisheries management? What models?
4. Are there important distinctions between models developed especially for fisheries management and those developed to understand ecosystem function?
5. Given no new financial resources to undertake basic ecosystem research and fisheries surveys, what categories of models could be developed to benefit fisheries management?

Workgroup 2. Fisheries and Ecosystem Models

1. Can single-species fisheries management operate successfully in the context of a Chesapeake Bay Program that bills itself as an “ecosystem management” program?
 2. Are there “simple” or essential first steps in moving towards a multispecies management approach in Chesapeake Bay?
 3. What are the institutional and jurisdictional constraints on multispecies management in Chesapeake Bay?
 4. How can multispecies (or ecosystem) models be incorporated into the framework of single-species management approaches in Chesapeake Bay?
 5. What questions or requests for information would managers direct to scientists with respect to multispecies fisheries management in Chesapeake Bay?
-

APPENDIX D

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