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Atlantic States Marine Fisheries Commission

Working towards healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015

Linking Multispecies Assessments to Single Species Management

December 2003

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FINAL REPORT

A Report of a Workshop Conducted by
The Atlantic States Marine Fisheries Commission
October 22-23, 2002
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Preface

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Executive Summary

The Atlantic States Marine Fisheries Commission (Commission) hosted a workshop on October 22-23, 2002 in Baltimore, Maryland to investigate how fisheries management agencies can incorporate advice from multispecies/ecosystem assessments into single species management processes. The workshop was attended by about 40 representatives of state and federal fishery management agencies, non-governmental organizations, and the fishing industry. The Commission workshop focused on four different model types, including Multispecies Virtual Population Analysis (MSVPA), spatial models, trophic dynamic models, and Ecopath. The purpose of this workshop was to develop options that can be used by fishery managers to incorporate the advice from multispecies assessments into the decision-making process in the near future (1-5 years) and to identify those models and classes of models that may be useful in interstate management issues. The workshop focused on developing recommendations based on the technical constraints to performing these models, the added value of advice provided by multispecies and ecosystem models, and the requirements and needs of fisheries managers, the fishery resources and various components of the fishing community.

In general, ecosystem approaches address effects of fishing on target and non-target species, habitat, ecological interactions, and system-wide processes, and explicitly address biomass allocations. In order to meet the goals of ecosystem-based fisheries management, it is important that clear priorities be set and biomass allocation be considered. Ecosystem goals should consider both top-down and bottom-up processes in a holistic approach. It is important to provide a complete scientific understanding of ecosystem functioning, as well as the relative importance of different processes.

The recommendations included in this report are intended to provide fisheries managers with information on the benefits and added value obtained through use of multispecies and ecosystem models. This report also provides a generic implementation plan that can be modified by individual fishery management agencies to incorporate these models into existing management structures. The implementation plan (Figure 3) illustrates how several of the recommendations are functionally linked and depend upon progress on, or completion of, another task.

It was assumed throughout this workshop and development of this report that results of multispecies and ecosystem assessments will be used in conjunction with current single species models. Replacement of single species models and/or current management structures is not anticipated in the short-term (1-5 years). Recommendations developed during this workshop include integration and coordination issues, development of basic multispecies/ecosystem models, technical review of models, development of data collection priorities and programs, and implementation of model results in fisheries management structures. Specific recommendations are as follows:

Improve integration of multispecies issues into current management structures.

- Include multispecies issues as an agenda item for all management board meetings in order to initiate discussions and educate managers and stakeholders.
- Include information on general multispecies interrelationships in existing single species FMPs to show links and interdependence among managed species.

- Present multispecies assessment results to all species management boards to provide quantitative information to support single species management decisions.
- Include multispecies assessment information in single species FMPs to provide quantitative information to support single species management decisions.

Improve **coordination and communication** among agencies, researchers, scientists, stakeholders, and fishery managers (ASMFC, Councils, NMFS, Corps of Engineers, Chesapeake Bay Program, USFWS) to address overlapping jurisdictions, encourage coordinated use of multispecies models, and improve data collection activities.

- Identify all relevant jurisdictions for managed species (species groups). Compile existing laws, acts, and regulations. Indicate the benefits of, differences or inconsistencies between, and prescribed actions for managed species or species groups.
- Review existing laws and acts to document and assess mandates for multispecies and ecosystem management.
- Involve economists/social scientists to develop advice and costs/benefits of multispecies management.
- Develop and implement a public education program for fisheries managers and the fishing/general public to show benefits of multispecies/ecosystem assessment information and its use in fisheries management decisions.

Develop basic multispecies and ecosystem models to improve current single species management advice and/or actions.

- Assemble existing data for inclusion in multispecies and ecosystem models.
- Build basic multispecies and ecosystem models using existing data.
- Expand current single species models by including appropriate output from multispecies models, such as predation mortality, etc.
- Evaluate environmental influences on managed fish stocks.
- Evaluate basic implications of management measures to improve single species management.
- Evaluate information gaps to direct sampling and research priorities and development of new data collection programs.

Evaluate and peer review multispecies and ecosystem models.

- Appoint or designate a committee to evaluate current multispecies and ecosystem models.
- Provide advanced training to state and federal stock assessment scientists to increase understanding and ability to conduct multispecies/ecosystem models.
- Conduct formal peer reviews of multispecies/ecosystem models.

Develop realistic priorities for multispecies data collection based on clear objectives and direct application to resource and management needs.

- Appoint or designate a committee to develop priorities, plans, etc.
- Review implementation options from the ASMFC multispecies workshop.
- Review objectives for multispecies data collection.
- Update the inventory of existing data collection programs.
- Evaluate data gaps, precision of data, and ability of existing programs to meet multispecies and ecosystem needs (i.e., ACCSP, SEAMAP, NMFS and state surveys).
- Develop data collection priorities for existing and future programs.

Develop a plan for implementing new data collection programs to support multispecies and ecosystem assessments.

- Develop objectives for new data collection programs to meet requirements for both single species and multispecies assessment models.
- Develop a list of required data collection surveys, including data elements, standards, and estimated costs.
- Develop costs and timeframes for implementation of new programs.

Implement new data collection programs to meet multiple objectives (e.g., both single and multispecies management requirements).

- Supplement current sampling programs to collect additional required data (i.e., diet studies).
- Fully design new data collection surveys to collect a suite of data to support several single species, multispecies, and ecosystem models.
- Secure additional funding to implement new data collection surveys.
- Implement new data collection surveys.

Fully implement multispecies and ecosystem framework in a phased-in approach, including conducting a retrospective analysis.

- Include additional species and information in existing multispecies and ecosystem models (i.e., environmental data, habitat trend information).
- Conduct retrospective analyses to examine the successes/failures of past or existing single species management strategies relative to how they might have been managed using a multispecies strategy.
- Develop complementary system-wide targets and thresholds (biological reference points) allocated by species or aggregate groupings (tiered reference points).
- Include management information into existing multispecies/ecosystem frameworks.
- Include social/economic information into existing multispecies and ecosystem frameworks.

- Evaluate environmental influences on managed and non-managed fish stocks.
- Develop management scenario analyses for full suite of inter-related species.
- Develop predictive simulations for future projections.

Modify existing management structures to more fully address multispecies issues and to address overlapping jurisdictions.

- Research and evaluate existing multispecies management structures for application to the Atlantic coast (ICES, West coast, etc.).
- Evaluate use of management and risk assessment tools to develop a multi-objective decision making process (balance of species and ecological issues).
- Evaluate changes to management structures.
- Implement changes to management structures.
- Apply management tools to assist in making multiple decisions and balancing trade-offs.

Introduction

The Atlantic States Marine Fisheries Commission (Commission) hosted a workshop on October 22-23, 2002 in Baltimore, Maryland to investigate how fisheries management agencies can incorporate advice from multispecies/ecosystem assessments into single species management processes. The workshop was attended by about 40 representatives of state and federal fishery management agencies, non-governmental organizations, and the fishing industry. The purpose of this workshop was to develop options that can be used by fishery managers to incorporate the advice from multispecies assessments into the decision-making process in the near future (1-5 years). The workshop focused on developing recommendations based on the technical constraints to performing these models, the added value of advice provided by multispecies and ecosystem models, and the requirements and needs of fisheries managers.

The Commission workshop focused on four different model types, including Multispecies Virtual Population Analysis (MSVPA), spatial models, trophic dynamic models, and Ecopath (see Appendix A for details on each of these models). In general, these models can provide biological reference points similar to single species Virtual Population Analyses (VPA), but will also provide information on trophic interactions and more detailed spatial scales (Table 1).

Table 1. Comparison of several different types of models, including Multispecies VPA (MSVPA), spatial models, trophic dynamic models, and Ecopath, with traditional single species VPAs.

	MSVPA	**Spatial**	**Trophic**	**Ecopath**
Model Output (Ref. Pts)				
Same outputs as VPA	X	X		X similar
Same outputs as MSVPA	X	X		X similar
Total mortality	X	X spatial	X	X
Natural mortality	X	X spatial		X
Fishing mortality	X	X spatial	X	X
Reproductive contribution	X	X		X
Total biomass	X	X	X	X
Migration patterns		X		
Stock distribution		X		
Local prey depletion		X		
Allocation	X	X		X
Age/growth	X	X		
Consumption	X	X	X	X
Predation mortality	X	X		X
Non-managed species				X
Trophic flux		X	X	X
Realistic bounds			X	
Insight into ignored processes		X	X	X

The major objective of MSVPA is to quantify age-specific predation mortality rates (M2) on exploited fish populations. Predator diets and absolute levels of prey consumption (in biomass) are calculated in the course of quantifying predation mortality rates for each prey. The MSVPA provides absolute mortality and abundance at age similar to single species models. Biological reference points for each species are likewise similar to those from standard single species assessments. The model provides direct management guidance for the targeted species, but may also implicitly evaluate the importance of "other prey" as food items for major predators.

The principal objective of aggregate biomass models is to understand major energy flows (i.e. biomass) within an ecosystem at an summarized, functional group level. These can provide trends in relative abundance and biomass tradeoffs in a broader context. This class of models provides insight into how pelagics might respond after demersals have been overfished, or how piscivores might respond if planktivorous or benthivorous forage fish have been removed. The point is to look at the total biomass/productivity of a system and then allocate it based upon our understanding of production, predation, competition, and whatever external forcing functions (usually fishing, but could be climate) alter the input variables. The model can generate reference points but they are qualitatively different than we typically think of for most fisheries models. Aggregate biomass models are generally not used to provide specific management advice, such as changing *F* or setting quotas. They are used primarily for putting bounds on the system and for heuristic purposes (to understand the system retrospectively).

The goal of spatial dynamic multispecies models is to develop a generalized mechanistic biophysical production model by linking bioenergetic principles of physiology, age-structured population ecology, and community trophodynamics to two-and three-dimensional hydrodynamic circulation models. The major objective of the model is to evaluate predator-prey and cohort-specific recruitment, growth, and mortality in a multi-species trophodynamic linkage under exploitation and environmental changes. The trends, relationships between species, and spatial distribution patterns will provide fisheries managers useful advice such as when and where fishing should be regulated or stopped. The types of model outputs are large and comprehensive including: (1) Production model-type outputs (yield horizon with fishing mortality, MSY, OSY, Fmsy, Fopt); (2) Analytical yield – yield per recruit, spawning biomass per recruit, growth overfishing, recruitment overfishing, maximum sustainable yield, maximum economic yield, etc.) - full suite of traditional management benchmarks for sustainability; (3) Fleet impacts; (4) Impacts of habitat changes on stock and/or community productivity (water quality and benthic substrates); (5) circulation – hydrodynamic effects on stock-recruit relationship (could include climate change scenarios); and (6) Siting of spatial management measures (e.g., marine protected areas). In general, spatial models will provide model outputs similar to the VPA, but allow predictive capability.

Ecopath software is a suite of three ecosystem models: Ecopath, Ecosim and Ecospace. While each of these models focuses on providing different information, all three models rest upon the basic assumption of mass-balance in the system. Furthermore, each considers trophic interactions as fundamental to ecosystem dynamics. Finally, the models incorporate a comprehensive, though hardly complete, set of ecosystem components, including unlimited: species/species groups, fisheries, and time series of both biological (e.g., survey data) and abiotic (e.g., wind speed) data. While the actual outputs may be absolute, they will vary relative to the policy implemented. It is dangerous to consider the output from any ecosystem model as absolute. Therefore, the safest assumption is that the model will accurately capture trends, over time, in species abundance, harvest, *etc*., thus identifying the pitfalls of a particular policy. One of the strengths of Ecopath is that it can provide guidance for both the community within the ecosystem as well as individual species. In general, this advice can be easily implemented by fisheries managers, since the model operates much the way managers would, that is, to vary fishing mortality in order to achieve a desired result.

The recommendations included in this report are intended to provide fisheries managers with information on the benefits and added value obtained through use of multispecies and ecosystem models. This report also provides a generic implementation plan that can be modified by individual fishery management agencies to more fully incorporate these models within existing management structures. The implementation plan illustrates how several of the recommendations are functionally linked and depend upon progress on, or completion of, another task. It was assumed throughout this workshop and development of this report that results of multispecies and ecosystem assessments will be used in conjunction with current single species models. Replacement of single species models and/or current management structures is not anticipated in the short-term (1-5 years).

How Are Multispecies/Ecosystem Models Currently Used?

Marine fisheries management along the U.S. Atlantic coast is currently conducted through single species approaches by the Regional Fishery Management Councils, the Atlantic States Marine Fisheries Commission (Commission), and individual state natural resource agencies. There are significant U.S. federal legislation that influences living marine resources and marine ecosystems going back to the Lacey Act of 1900. Jack Ward Thomas noted the ruling of Judge Dwyer on the Pacific Spotted Owl controversy in 2001 that "not only was an ecosystem management approach legal, it was mandatory if all applicable laws were to be simultaneously obeyed." Some of the more recent federal laws have contained specific reference to ecosystem management, and there have been recent discussions at the federal level to make ecosystem management a mandatory requirement of the Regional Fishery Management Councils.

Important federal legislation involving marine resources includes:

- 1900 Lacey Act
- 1920 Migratory Bird Conservation Act
- 1934 Fish and Wildlife Coordination Act
- 1948 Clean Water Act
- 1950 Federal Aid in Sport Fish Restoration Act
- 1965 Anadromous Fish Conservation Act
- 1970 National Environmental Policy Act
- 1972 Coastal Zone Management Act
- 1972 Marine Mammal Protection Act
- 1973 Endangered Species Act
- 1976 Fisheries Conservation and Management Act
- 1986 Interjurisdictional Fisheries Act
- 1993 Atlantic Coastal Fisheries Cooperative Management Act
- 1997 National Wildlife Refuge System Improvement Act

Although there are examples of successful management programs using the single species approach, this approach gives little (if any) consideration to trophic linkages and dependencies among components of the ecosystem that affect community structure and productivity of the fisheries. Current marine fisheries management practices on the Atlantic coast involve assessments and management at the single species level or as "grouped" species management. Under the single species approach, stock status determination and management measures are based on single species directed fisheries and single species biological reference points. Grouped species management can be based either on fishing gear interactions or taxonomic groupings. Management based on fisheries interactions include summer flounder, scup, and black sea bass management by the Mid-Atlantic Fishery Management Council (MAFMC) and the Commission; squid, mackerel, and butterfish management by the MAFMC; and the Northeast Multispecies (groundfish) Fishery Management Plan (FMP) by the New England Fishery Management Council (NEFMC). In practice, these management programs are really separate species management programs based on individual species stock assessments, biological reference points, and management measures. The NEFMC groundfish management program is grouped based on fishing gear (i.e., large mesh and small mesh), with management measures enacted to affect multiple species. These fisheries are grouped together under one FMP cover only because of interactions between fisheries and/or fishing gears. Another type of management group is based on taxonomy, and includes the snapper/grouper management complex of the South Atlantic Fishery Management Council (SAFMC). This complex includes 73 species, but is again supported by single species assessments and individual species management measures.

There are several examples of international multispecies management programs, including those by the International Council for Exploration of the Sea (ICES). ICES has developed a multispecies Virtual Population Analysis (MSVPA), which includes cod as a predator species and herring and sprat as prey species. The MSVPA is run in order to calculate natural mortality including predation by age class of all predator and prey species. Natural mortality values from the MSVPA are then entered into single species assessments in order to develop short term management advice. Other ICES management actions that are based on ecological dependencies include Barent Sea capelin and sand eel.

ICES multispecies management programs include:

- Use of MSVPA to evaluate natural mortality for cod, herring and sprat
- Accounting for predation and fishery removals in setting cod management measures
- Closed season for sandeel to avoid competition with sea birds

In general, there are few examples of trophic-based multispecies or ecosystem management programs at the international, national, or regional level. However, many Atlantic coast fishery management agencies are actively pursuing development of multispecies and/or ecosystem models. Some agencies, such as the National Marine Fisheries Service, the Chesapeake Bay Program, and the South Atlantic Fishery Management Council, are also currently developing fishery ecosystem plans (FEP) to guide data collection and other activities. In order to more fully utilize the results of these models, fishery management agencies will need to clearly focus discussions on implementation measures. Given that single species assessments and management programs are the norm for most management agencies, it will be important to find innovative ways to improve the integration of these new models into existing management frameworks.

What is Ecosystem Management and How Are Multispecies/Ecosystem Models Used

In general, ecosystem approaches address effects of fishing on non-target species, habitat, ecological interactions, and system-wide processes. These models explicitly address biomass tradeoffs and provide tools that fisheries managers can use to assist in making allocation decisions and to balance various uses. In order to meet the goals of ecosystem-based fisheries management, it is important that clear priorities be set and biomass allocation be considered. Ecosystem goals should consider both top-down and bottom-up processes in a holistic approach. It is important to provide a complete scientific understanding of ecosystem functioning, as well as the relative importance of different processes.

Setting of ecosystem goals will be an important component of implementing these models and integrating model results into current fisheries management structures. Multispecies/ecosystem assessment scientists and models must provide a range of options for managers to consider. The assessment model should be focused on providing information to specific questions framed by fisheries managers. Setting of clear goals and objectives will assist managers in balancing trade-offs among different species.

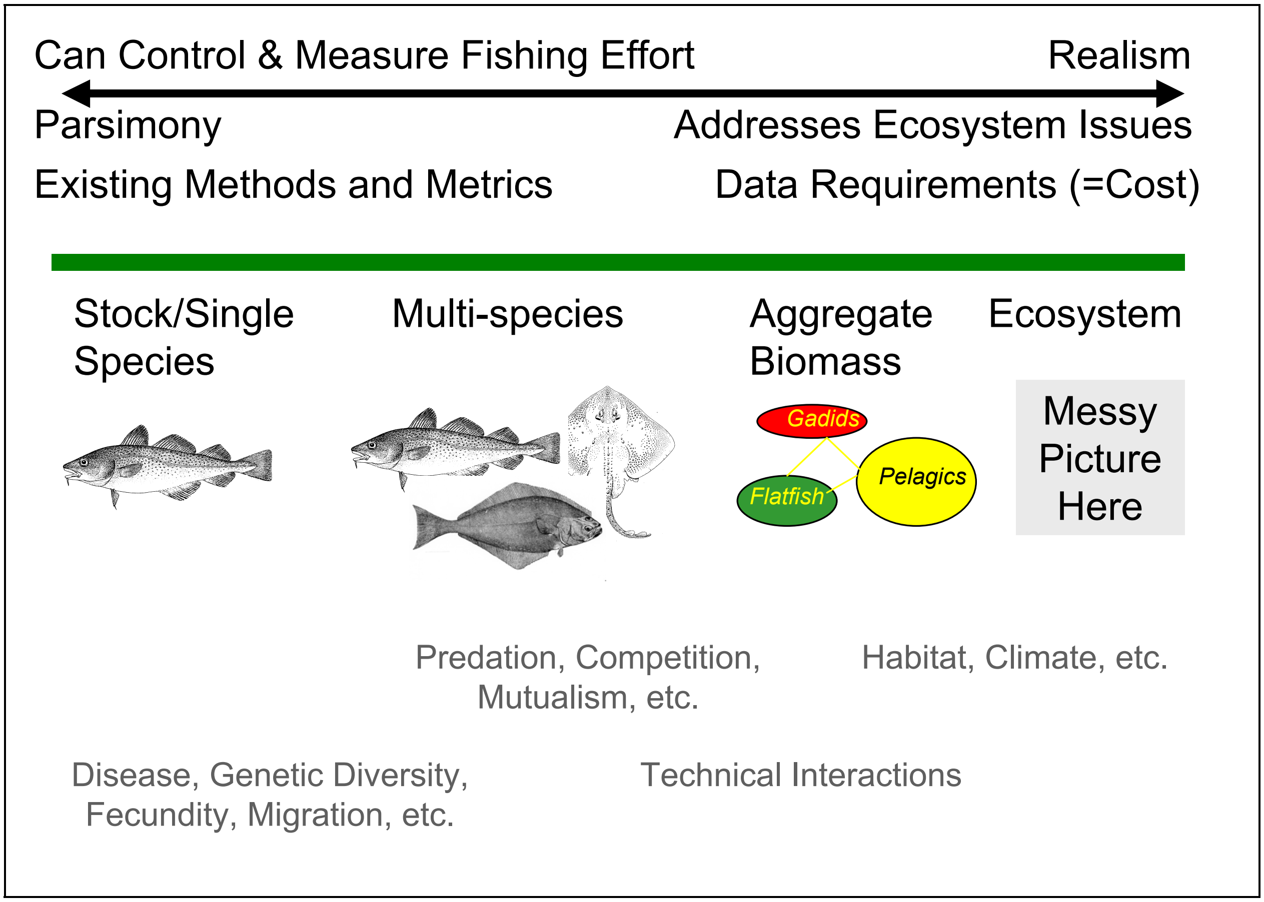
When setting ecosystem goals it is important to determine if managers want to simultaneously:

- Optimize total fish yield of the system,
- Optimize yield of a particular species or groups of species,
- Provide long-term economic viability,
- Conserve biodiversity,
- Maintain a particular ecosystem state,
- Protect certain species, and/or
- Protect ecosystem services.

There are two ways that fisheries managers can use the information provided by multispecies/ecosystem models: 1) tactical management (binding in scope), and 2) strategic management (bounding in scope). Tactical management will provide revised stock assessments based on quantitative information provided through multispecies/ecosystem models. This can include yield adjustments, altered biological reference points, and new control rules. Tactical management can also provide information on impacts on non-target species and specific "what if" and "gaming" scenarios to provide fisheries managers with a predictive capability. This type of management would provide fisheries managers with information to make binding management decisions. Strategic management will provide information for fisheries managers to assess biomass tradeoffs, evaluate alternate stable ecosystem states, evaluate long-term recruitment bottlenecks, and provide general "what if" scenarios and "gaming" for long-term trends. This type of management will provide more qualitative information to allow managers to place bounds around decisions that affect species with trophic interactions.

Multispecies and ecosystem management can be thought of on a continuum ranging from single species assessments to multispecies assessments to aggregate biomass models to full ecosystem models (Figure 1). It is easier to measure and control fishing effort under single species and even multispecies models; however, ecosystem modeling provides increased realism by modeling the full range of biological and environmental interactions. Data requirements increase along this continuum, particularly with inclusion of habitat and climatic factors. Multispecies models, such as the MSVPA, may be easier for managers and the fishing public to understand and accept since they tend to use assessment methods similar to single species assessments.

Figure 1. Summary of continuum from single species stock assessments to ecosystem assessments. The level of complexity and data requirements increases along this continuum (From a presentation provided by Dr. Jason Link during the workshop).



Although single species assessment approaches are very good at providing detailed short-term tactical management, they do not explicitly consider the following:

- Species interactions,
- Changes in ecosystem structure and function,
- Biodiversity,
- Non-fishing ecosystem services and values
- Needs of protected or rare species,
- Ecosystem effects of discarding unwanted bycatch,
- Systemic productivity,
- Shifting environmental conditions, and
- Fishing gear impacts on habitat.

At the other end of the spectrum, ecosystem approaches also do not consider everything. For example, ecosystem approaches do not explicitly consider age/size-based variation in demographic parameters, density-dependent effects, stock-recruitment relationships, and effects of fishing on genetic diversity. Ecosystem approaches, therefore, do not work for all species and all situations. They are particularly relevant for the following:

- Small forage species that consume primary or secondary production and are eaten by numerous predators,
- Ecosystems with highly complex fish communities that effectively preclude stage based assessments (i.e., need aggregation),
- Food webs with low connectivity (indirect linkages) yet strong species interactions, and
- Ecosystems with clear environmental signals that notably affect fish production.

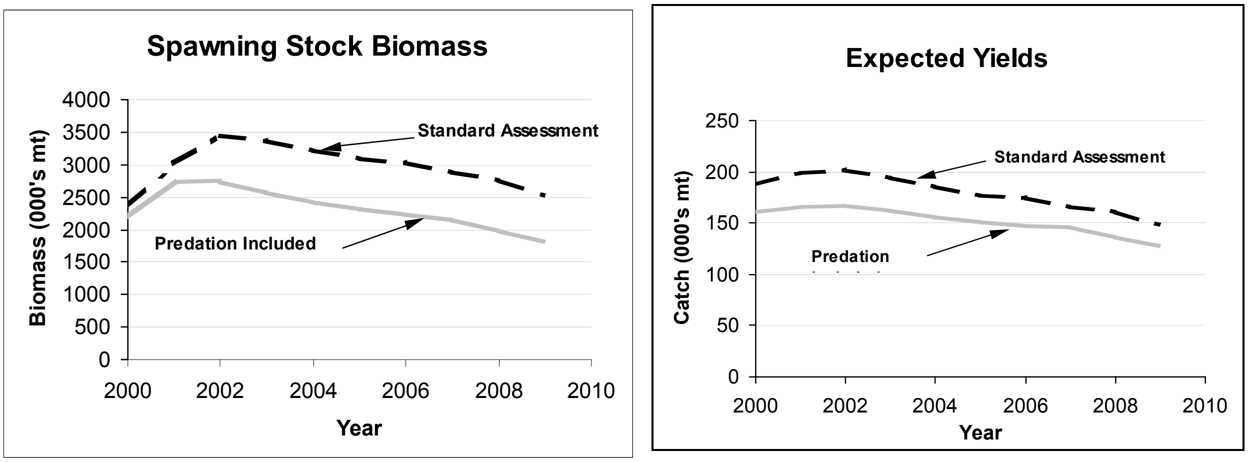
> Atlantic sea herring and silver hake are good candidates for multispecies and ecosystem models because they:
>
> - Spatially overlap with many other species,
> - Provide a forage base for protected species and other commercially valuable species,
> - Compete with protected or commercial species,
> - Are at low or intermediate trophic levels,
> - Have very high trophic efficiency,
> - Are key species in the ecosystem.

There are several multispecies/ecosystem models currently being developed or used to assist fisheries managers, including use of predation mortality estimates in single species assessments (M2), temperature triggered reference points, multispecies VPAs, habitat checklists/thresholds, protected species checklists/thresholds, aggregate biomass limits, ecosystem assessments, and fishery ecosystem umbrella plans. However, many of these are still in the developmental stage and therefore have not been peer reviewed or fully implemented.

> Current multispecies and ecosystem models and fishery management plans being developed:
>
> - ASMFC Multispecies Virtual Population Analysis (MSVPA)
> - ASMFC Spatial Multispecies Model
> - Florida Ecopath/Ecosim Model (West Florida shelf and Tampa Bay)
> - Chesapeake Bay Fisheries Ecosystem Plan (FEP)
> - National Marine Fisheries Service Ecosystem-Based Fisheries Management Plan
> - Chesapeake Bay Ecosystem Models
> - South Atlantic Fisheries Management Council Ecopath/Ecosim model focused on reef fish

Typically single species assessments use a constant annual rate of natural mortality across age classes. Many multispecies and ecosystem models are currently showing that natural mortality varies among age classes, with higher rates typically at younger ages. Annual variations are also common for most species. Inclusion of predation effects in single species assessments may change estimates of expected yields and/or spawning stock biomass as calculated by single species assessments (Figure 2).

Figure 2. Examples of how the integration of predation mortality estimates may change estimates of spawning stock biomass and yields calculated from single species assessments (From a presentation provided by Dr. Jason Link during the workshop).



There are some basic characteristics of all multispecies and ecosystem approaches. Multispecies/ecosystem approaches increase the ability to directly evaluate issues of biomass tradeoffs by assessing a suite of processes that may explicitly control fish stocks and allowing tradeoffs among these processes. Increased information obtained through multispecies/ecosystem approaches will produce tradeoffs which include 1) increased realism versus decreased prediction capabilities, 2) accuracy versus precision tradeoffs, and 3) tradeoffs involving the level of detail in taxonomic hierarchy (species-specific vs. aggregation of species), market categories, and production levels (species-specific vs. total production). Multispecies/ecosystem approaches will provide more conservative reference points either by retrospectively determining that more fish existed or prospectively by determining that less fish will be available. Therefore, fishery management caps and quotas may be more realistically determined. Multispecies/ecosystem models will produce reference points that are qualitatively distinct, but no less valid, than "normal" single species reference points. Control rules developed from multispecies/ecosystem approaches are less straightforward and will need further development to be used in a tactical management context. However, it may be simpler to use advice from these models as strategic management advice. It should be recognized that some considerations are beyond human control. For example, predator switching and climate effects are obviously beyond the control of fisheries managers. Therefore, it may be necessary to wait for a shift in the environmental state or to adapt as conditions alter. The increase in the number of considerations included in multispecies/ecosystem approaches will increase the number of stakeholders involved in the decision-making process.

What Can Be Gained From Multispecies/Ecosystem Models?

Multispecies/ecosystem assessments can provide additional information to support single species assessments and management. The value added varies by specific multispecies model; however, there are many insights that can be provided by all models. These include more detailed information on predator/prey interactions and forage bases, evaluation of overall environmental carrying capacity, and evaluation of the feasibility of managing all species at maximum sustainable yield (MSY). Multispecies/ecosystem modeling can also provide fisheries managers with additional knowledge regarding the trade-offs in single species management decisions (e.g., decisions for one species may influence one or more other species). Specific information can also be provided on fishery production levels in relation to habitat and environmental changes, local predator and prey depletions, and the evaluation of long-term changes in abundance.

Additional detailed information, including temporal and spatial components, is provided by multispecies assessments.

The multispecies and ecosystem models reviewed during this workshop all provide additional detailed information that can be applied to single species assessments and management (Table 2). These models provide the ability to evaluate factors that are typically ignored and may allow scientists and managers to identify causes for a change in the status of a single species. Analyses to allow evaluation of fishing areas, changes in abundance, allocation issues (both user group and biomass), and evaluation of indices of abundance can be enhanced through the results of multispecies models. These models can also provide information over and above that provided by single species assessments, including environmental and habitat information, species interactions, and evaluation of long-term effects of fish harvest on the environment, and the effects of environmental change on harvest.

Multispecies models allow detailed evaluation of fishing area, including evaluation of redistribution of fishing effort and effect of effort changes on the stock. The spatial aspects of these models can provide information on changes in abundance of a species in relation to changes in catch rates and distribution of both the fishing fleet and the fish population. This information can be very useful to fisheries management in modifying fisheries regulations in relation to species shifts. These models also allow an evaluation of allocation of the resource between user groups, as well as between the fishery and forage base. From a technical perspective, these models can evaluate the spatial relevancy of specific abundance indices to be included in single species assessments.

Spatial models and EcoPath allow mapping of spawning habitat and evaluation of production relationships, including links to physical transport and behavior of fish larvae. Detailed information on habitat types (including both benthic and water column), and documentation of habitat changes over space and time can be provided. This information can also be related to changes in production levels of natural resources. Detailed information on environmental factors (e.g., temperature, salinity) can also be incorporated into multispecies models. These models can evaluate changes in fish abundance, distribution and other factors in relation to environmental change. It may also be possible with spatial models and EcoPath to model nutrient loading into estuarine and coastal areas. These models may provide input into best management practices for nutrients (e.g., top down management of trophic cascades versus bottom up management of point and non-point sources of nutrients).

All multispecies and ecosystem models allow detailed evaluation of trophic relationships between species within the ecosystem. This information can be used to evaluate species overlap, predator-prey interactions, competition, and possible prey depletion. Spatial models provide an evaluation of whether fish are not in a local area due to harvest or some physical conditions influencing fish availability. This information is linked to fish migration patterns to investigate local depletion. Use of this information in fisheries management will provide managers with the ability to evaluate species harvest tradeoffs. In other words, how implementation of management regulations on one species may effect other species in the ecosystem.

Spatial models can provide information on real time conditions if data collection supports this level of modeling. This would allow these models to be used for real time predictions, similar to hurricane forecasting models. It was recognized that current data will not fully support this level of modeling effort in the short term. Current data capabilities, however, will support evaluations of tradeoffs between key species, projection and evaluation of short-term changes in abundance, and evaluation of changes in the ecosystem due to the environment or fishery harvest.

Gain perspective of the balance between predator/prey and fisheries effects on fish stocks.

Multispecies assessments will put the impacts of fisheries in a larger perspective by quantifying trophic relationships, including predator/prey interactions. Current single species assessments use a constant rate of natural mortality across all age groups. This approach, however, does not address the fact that the highest levels of mortality for most fish species occur in the early life stages (egg, larval, juvenile). Multispecies models can provide detailed information on the natural mortality rates for all life stages, thus, providing a more realistic benchmark to evaluate the relative impacts of natural mortality and fishing mortality on different life stages. There will, however, be a differential effect depending on whether the dead fish are removed from the nutrient base of the food web (i.e., fish are eaten and incorporated into higher trophic level) or retained through degradation.

Table 2. Summary of added value provided by multispecies and ecosystem models when applied to single species assessments and management.

	Model Type			
Added Value over Single Species	**MSVPA**	**Spatial**	**Trophic**	**Ecopath**
Current Single Species Measures				
Evaluation of fishing area		X		X
Changes in centers of abundance		X		X
Allocation (user group/biomass)	X	X	X (biomass)	X
Evaluate indices of abundance	X	X	X	X
Environmental Influences				
Production in relation to habitat changes		X		X (EcoSpace)
Habitat factors – benthic & water column		X		X (EcoSpace)
Environmental change	X	X	X	X
Evaluate nutrients		X	X	X
Species Interactions				
Tropic relationships	X	X	X	X
Species overlap	X	X	X	X
Local prey depletion		X		X
Species harvest tradeoffs	X	X	X	X
Long-Term Effects				
Real time conditions		X		X
Tradeoffs between species	X	X	X	X
Evaluate long-term changes	X	X	X	X
Ecosystem impacts of harvest		X	X	X

Evaluate the multiple uses of forage and predator species (e.g., forage base).

Multispecies assessments can segment out the various demands placed on a fishery resource. Using Atlantic menhaden as an example, there are multiple demands placed upon this resource as both a forage base and for human use. Menhaden provide a forage base (prey species) for other species of fish, seabirds, and marine mammal populations. It also supports important bait and reduction fisheries. Multispecies assessments can identify and quantify these various uses so that they can be explicitly addressed by fishery managers when assessing stock status and developing management strategies. These models also allow scientists to evaluate various biomass allocation scenarios (e.g., forage base effects of higher allocations of menhaden to fishery uses).

Evaluate carrying capacity of the ecosystem relative to sustaining high population abundance levels.

Multispecies models provide an overall perspective on the maximum quantity of fish an ecosystem can support (i.e., carrying capacity). Currently, single species management strives to maximize abundance levels for all managed species without regard to the ability of the ecosystem to sustain these high abundance levels. By integrating information on habitat, environmental quality, predator/prey relationships, and species abundance, multispecies assessments provide a more realistic picture of the ecosystem's carrying capacity.

Evaluate the feasibility of managing all species at MSY estimated from single species assessments.

Species are currently managed to achieve maximum sustainable yield (MSY), which is the largest average catch that can be taken on a sustainable basis from a stock under average environmental conditions. MSY is determined for each individual species based on information specific to that species alone. Attempting to reach MSY for all managed species is an unreachable mandate and can never be reached due to competition among species. It is not possible in an ecosystem context to use MSY as a target for yields from all fisheries, i.e., removals at the MSY level. The yields from each fishery must be more conservative in the ecosystem context. By incorporating information for all species, multispecies models may redefine MSY within the context of the entire ecosystem (e.g., carrying capacity). Resulting multispecies management may still rely on MSY as a biological reference point, however, the level may be more conservative than under single species management.

Evaluate trade-offs in single species management decisions.

Currently, management decisions are made on a species-by-species basis, with little consideration of the interactions among species. Multispecies models can provide fishery managers with additional information on the impacts that changes to one species' management program may have on other managed species. The integration of this information will require managers to clearly define species priorities, management goals, and objectives. Multispecies assessments will also allow evaluation of tradeoffs between different management goals (i.e., few large fish versus many smaller fish).

Ability to evaluate various management scenarios through forward projection tools for multiple species (i.e., 'gaming' or simulations).

Currently, scientists have the ability to make future projections based on a suite of management options for a single species. This same ability is also available to multispecies modelers. Using forward projection tools, scientists will be able to project the possible consequences of management decisions for multiple species, thereby, providing fishery managers with a powerful tool to evaluate management effects among interrelated species. One limitation of these projection models is that they are only valid for roughly one generation time of the shortest lived animal in the system. Beyond that time the model is based completely on simulated stock values, which widens confidence limits and has little connection to (realistic / measured / expected) abundance values.

What Are Some Constraints To Implementation of Multispecies Models?

Multispecies and ecosystem models can provide a great deal of additional information to support single species assessments and management. However, there are constraints to full implementation of these models, many of which also constrain single species assessments. Some of the major impediments include lack of data, lack of personnel and expertise, and lack of funding.

Data Availability

Multispecies models are constrained by the same lack of basic fisheries data as single species assessments, including fisheries-dependent and fisheries-independent data. Without these basic data elements it is difficult to build more complex models. Regardless of model type, if adequate input data are not provided, the model will fail (e.g., biomass dynamic models without enough contrast in the data, VPA problems due to ageing errors or variable natural mortality). Multispecies and ecosystem models require long time series of data in order to validate model results, similar to requirements of single species assessments. This is especially important when trying to forecast beyond the short term; when evaluating trends in abundance and assemblages over decades.

The types and amounts of data available are a function of current sampling programs. There are many species that are not targeted in current sampling programs, which limits our basic understanding of their ecological importance. For example, blennies are common on George's Bank and represent a large potential pool of prey biomass. Ctenophores also occur in great numbers and may represent a significant predation effect on larval fish. Insufficient understanding of these types of species constrains our understanding of the ecosystem as a whole. If an ecosystem model is going to be used, sampling designs need to be structured to collect the types and amounts of data necessary to run these models.

Comprehensive sampling in time and space provides the most relevant information for these models. The majority of current sampling is conducted for demersal piscivores. Sampling for information on prey field requires midwater trawls, and few surveys run multiple gears to sample both predator and prey groups. Trawl surveys need to collect basic diet data over at least a five year period. Seasonal studies must be sustained over years and space to capture large scale changes in prey field and diets (e.g., the National Marine Fisheries Service's Northeast Fisheries Science Center survey indicates that there is a primary prey shift about every six years). Currently, data are particularly lacking on size structure and biomass for non-managed species, such as anchovies and silversides.

Lack of age-based catch data will limit multispecies and ecosystem models since the basic requirements of these models are similar to single species VPA. These models do not function well with long-lived species with overlapping age and size data. Data included in spatial models must also be spatially indexed on the same scale as the model. Many current data collection programs collect data that are either not spatially indexed or are indexed at a very low level of resolution.

Most multispecies and ecosystem models require very detailed environmental data and habitat mapping. The amount of information required depends on the questions that are being asked. Spatial models require physical and environmental data collected in the same spatial location as fisheries data. Physical and habitat data may be collected during resource surveys where they can be directly matched with the fisheries data. However, some physical and habitat data are collected separate from the fisheries data and will need to be matched with fisheries information at a later time. Habitat mapping is also not available for many locations to support these models. Improvements in understanding the life history requirements with specific focus on identifying habitat areas of particular concern (crucial environmental parameters and actual locations) would also be helpful.

Inclusion of spatial movement data (e.g., tagging data) will provide for more accurate spatial modeling. However, tagging data are not always available for all species being modeled. Social and economic information is also required for expansion of basic multispecies and ecosystem models. There is an overall lack of species-specific social and economic data to support both single species and multispecies models. All multispecies and ecosystem models require detailed and comprehensive diet data. Information on prey size and type of prey preference is particularly lacking.

Uncertainty in Model Parameters

Lack of data in multispecies models and the need for formulation of model assumptions will lead to uncertainty in model parameters. The more complex the model, in conjunction with a high level of missing data, the more uncertainty in model parameters and model results. It will be necessary to establish time series of some of the less common data types in order to support these models. In most cases, model development seems to be two steps ahead of data collection. To counteract this problem in the short term, it might be worthwhile to develop models that will use existing data.

Uncertainty in some age-based multispecies models (MSVPA and spatial models) will also increase when species data are combined, and when adding new types of data (e.g., diet data). Any inherent bias in the single species assessments may become compounded in a multispecies assessment. It should be noted that any improvements in single species models will translate to improvements in multispecies models (i.e., addition of tuning indices, collection of additional data). Due to the manner in which VPA calculations are performed, the greatest uncertainty surrounds the most recent years' data in both single species and multispecies assessments. It is important that multispecies models match the single species models as closely as possible so that any differences in model results can be attributed to predator interactions or environmental influences, as opposed to model formulation.

For most multispecies models, it is necessary to identify the system being modeled prior to analysis. For example, which species are included over what geographic range, how will the species be grouped, what environmental factors are important, etc. It may be necessary to confine model parameters to set bounds that will provide useful answers without making the model too large and cumbersome. In order to do this, it is necessary to have some a priori understanding of the system.

Logistical Support

Building of these more complex multispecies and ecosystem models will require increases in personnel, expertise, funding, and political will. On the Atlantic coast there is a lack of personnel and expertise to conduct single species assessments. This problem will be compounded when trying to move to multispecies and ecosystem assessments. Many of these models include both biological and physical information and will, therefore, require collaboration between biological and physical (hydrodynamic) experts.

The concept of ecosystem management is not new. It has been discussed by various groups over the past two decades. However, during that time period no increases in funding have been appropriated for these activities and little progress has been made. The theoretical basis for these models has been developed, however, funding has not been provided to test and implement these models. It should be noted that over the past two decades limitations in computing resources may have led to some of these delays.

Table 3. Summary of constraints to implementation of multispecies and ecosystem models. It should be noted that many of these constraints also apply to single species assessments.

	Model Type			
Constraints to Implementation	**MSVPA**	**Spatial**	**Trophic**	**Ecopath**
Data Availability				
Fishery-dependent & fishery-independent data	X	X	X	X
Age-based catch data	X	X		X
Habitat maps		X		
Spatially indexed data		X		X ecospace
Co-occurring physical data		X		
Spatial movement data		X		
Social/economic data	X	X	X	
Diet data	X	X	X	X
Long-term data	X	X	X	X
Modeling Uncertainty				
Uncertainty in model parameters	X	X	X	X
High uncertainty in recent years	X			
Compounding uncertainty by analyzing multiple species				
Logistical Support				
Personnel	X	X	X	X
Expertise	X	X	X	X
Money	X	X	X	X
Political will	X	X	X	X
Prioritize data needs	X	X	X	X
Managers need to change perspective	X	X	X	X

In general, the majority of constraints limiting development and implementation of both single species and multispecies assessments can be addressed. Technical constraints are mainly focused on lack of basic fisheries-dependent and fisheries-independent data, as well as more detailed spatially-indexed data. These constraints can be addressed through implementation of coordinated data collection programs like the Atlantic Coastal Cooperative Statistics Program, and the Northeast and Southeast Monitoring and Assessment Programs. Collection of higher quality and quantity of data will also result in improvements to model parameterization and increased confidence in model results. However, for these improvements to be realized, funding levels to support expansions in data collection activities must be made a priority.

How Can Multispecies/Ecosystem Models Be Implemented?

Workshop participants identified a broad range of activities needed for a phased-in approach to implementing multispecies and ecosystem models. The recommendations and timeline developed are generic and cover a ten year period. It is anticipated that most fishery management agencies will be unable to implement all recommendations and some may not be relevant to all agencies. However, these recommendations and generic implementation plan can be modified to meet the needs of each individual agency.

- Improve integration of multispecies issues into current management structures.
- Improve coordination and communication among agencies, researchers, scientists, stakeholders, and fishery managers (the Atlantic States Marine Fisheries Commission, the Regional Fishery Management Councils, National Marine Fisheries Service, U.S. Fish and Wildlife Service, Army Corps of Engineers, Chesapeake Bay Program) to address overlapping jurisdictions, encourage use of multispecies models, and improve data collection activities.
- Develop basic multispecies and ecosystem models to improve current single species management advice and/or actions.
- Evaluate and peer review multispecies and ecosystem models.
- Develop realistic priorities for multispecies data collection based on clear objectives.
- Develop a plan for implementing new data collection programs to support multispecies and ecosystem assessments.
- Implement new data collection programs to meet multiple objectives (e.g., both single and multispecies management requirements).
- Fully implement multispecies and ecosystem frameworks in a phased-in approach, including conducting of a retrospective analysis.
- Modify existing management structures to more fully address multispecies issues and to address overlapping jurisdictions.
- Agencies should review the workshop recommendations and generalized implementation plan (Gantt chart) for possible modification and application to agency specific goals and objectives.

Improve integration of multispecies issues into current management structures.

The majority of existing management structures on the Atlantic coast are based on assessment and management of single species. The few exceptions (e.g., New England Fishery Management Council's groundfish fishery management plan, South Atlantic Fishery Management Council snapper-grouper fishery management plan) are focused on species groupings either based on fishery and/or gear interactions, or taxonomic groupings. Stock assessments, even for these species complexes, are typically conducted to evaluate stock status of a single species and discussions during management forums mainly focus on the species currently being managed with little regard to trophically related species. Even though management strategies adopted for one species may impact one or more related species, there is little consideration given to these interrelationships.

Include multispecies issues as an agenda item for all management board meetings in order to initiate discussions and educate managers and stakeholders.

Agenda items focused on multispecies issues should be included during all management forums, including Commission board meetings and Regional Fishery Management Council meetings. Communication should occur both within an agency and also between agencies, since a change in one species may affect a species managed by another organization. Multispecies discussions should also be facilitated during advisory panel meetings and during technical forums. This would provide a forum to generate broad input into these issues from a variety of sources, including fishery managers, scientists, and the fishing and general public. Feedback between these groups should be encouraged to provide clear direction on research and other analysis activities to support multispecies assessments and use of model results in management decision-making.

Include information on general multispecies interrelationships in existing single species FMPs to show links and interdependence among managed species.

All fishery management plans should include sections describing general multispecies interrelationships in order to identify known trophic interactions and species interdependencies. This section should include a description of known qualitative interactions, status of quantitative multispecies models and data inputs, species necessary to provide a forage base, and species it serves as forage for. This section should provide interrelationships to other managed species, as well as non-exploited species. Many non-managed species can be important prey items and may provide a short term forage base or an alternative food source when more preferred prey types become limited in abundance. Identification of problem areas during drafting of these sections may assist in addressing specific research areas to support more quantitative analyses. Raising awareness of general multispecies and ecosystem issues should also improve the support for generating a more quantitative base of information to more fully support management decision-making.

Present multispecies analyses and results to all species management boards to provide quantitative information to support single species management decisions.

As multispecies and ecosystem models are developed, quantitative model results should be presented to in all management forums, including Commission management boards and Regional Fishery Management Council meetings. Because these models will cover several species it is important that model results be presented to all affected management boards. This will allow specific boards to avoid setting contradictory regulations for trophically linked species and to balance regulations across all affected species. It will also allow boards to address the balance between direct harvest of a species and management to maintain a strong forage base, which may have a broader impact on several managed species.

Include multispecies assessment information in single species FMPs to provide quantitative information to support single species management decisions.

As quantitative multispecies/ecosystem models are developed and the basic understanding of multispecies and ecosystem issues increases, specific analyses should be formally presented to fishery managers and explicitly included in fishery management plans. As managers, scientists, and the fishing public become more familiar with these models they should be encouraged to develop specific management questions that can be addressed through quantitative modeling activities. Quantitative information from these models should be included in FMPs for all interrelated species to encourage managers to balance trade-offs between species and to provide validation for strategies developed through single species management.

<u>Improve coordination and communication among agencies, researchers, scientists, stakeholders, and fishery managers to address overlapping jurisdictions, motivate use of multispecies models, and improve data collection activities.</u>

On the Atlantic coast there are a myriad of agencies involved in fisheries management many of which have overlapping jurisdictions and potentially conflicting mandates. Agencies directly involved in fisheries management include the state natural resource agencies, the Atlantic States Marine Fisheries Commission, the Regional Fishery Management Councils, National Marine Fisheries Service, U.S. Fish and Wildlife Service, Army Corps of Engineers, and Chesapeake Bay Program. There are also many agencies (e.g. Environmental Protection Agency and state permitting agencies) that are indirectly involved in fisheries management through regulation of related activities (e.g., pollution control, habitat regulation, vessel permits). Many of these agencies may also have conflicting management goals and objectives that may influence management of the same species by multiple agencies (e.g., Regional Fishery Management Council mandate to manage all species at MSY). Many researchers and scientists are also pursuing quantitative modeling activities in a variety of forums (e.g., state and federal agencies, universities, private and industry organizations). The high level of activity focused on multispecies/ecosystem issues across a variety of agencies and organizations can result in a lack of coordination and communication. With limited resources, including funding and personnel, it is important to encourage increased coordination both within and between agencies in order to meet common objectives for all marine resources.

Identify all relevant jurisdictions for managed species or species groups; compile existing laws, acts, and regulations; and indicate the benefits of, differences or inconsistencies between, and prescribed actions for managed species or species groups.

A compilation of existing laws, acts, and regulations should be developed to assist fishery management agencies in evaluating inconsistencies between actions adopted for managed species or species groups. This compilation could also assist in identifying overall benefits of transitioning to a multispecies management framework. Identification of differences between jurisdictions should also assist in improving communication among agencies, as well as coordination of agency management goals (e.g., management of all species to maximum levels).

Review existing laws and acts to document mandates for multispecies and ecosystem management.

A review of existing laws and acts should be conducted in order to evaluate legal mandates by specific agencies for multispecies/ecosystem management by specific agencies. This review should include an evaluation of current single species management goals for managing all species to maximum sustainable yield (MSY) and whether this is an appropriate goal in a multispecies/ecosystem management context.

Involve economists/social scientists to develop advice and costs/benefits of multispecies management.

Social and economic issues and analyses should be included in discussions of multispecies assessments and management in order to develop benefits of moving in this direction and assist in promoting the program. These analyses should also provide information on the long-term sustainability of the resource from a biological standpoint in conjunction with economic and social considerations of the constituencies that use the resource in both the short and longer term. These analyses should focus on evaluating MSY versus optimum yield (OY) and maximum economic yield (MEY), which would allow an evaluation of biological versus social/economic sustainability.

Develop and implement a public education program for fisheries managers and the fishing/general public to show benefits of multispecies/ecosystem assessment information

Issue papers should be developed to describe the potential benefits of multispecies management and any legal issues that may need to be addressed. General informational materials should also be developed to encourage user group support for use of new models and new multispecies/ecosystem objectives included in FMPs. Stakeholders should be included in discussions to more fully evaluate social and economic impacts of multispecies/ecosystem management scenarios.

Develop basic multispecies and ecosystem models to improve current single species management advice and/or actions.

In order to develop basic multispecies/ecosystem models, it will be necessary to improve data collection activities for both single species and these more advanced models. Multispecies/ecosystem models also require additional data sources that are sometimes lacking at the single species level (e.g., social/economic information). Improvements in modeling approaches will be necessary to more fully develop and use these models in the fisheries management decision-making process. There will always be a need for more and better data, since the quality of our assessments is a function of the available data.

Assimilate existing data for inclusion in multispecies and ecosystem models.

In order to build basic multispecies/ecosystem models, all fisheries-dependent and independent data on individual species must first be compiled and assimilated. Physical/environmental data, habitat information, predator-prey relationships, diet data, and social/economic information will also be necessary to support these models.

Build basic multispecies and ecosystem models using existing data.

Once existing data are compiled, basic multispecies and ecosystem models should be developed. These models should provide fisheries managers with quantitative information on multispecies interactions that can be incorporated into assessment and management of individual species. Examples of basic model results include information on prey and forage biomass, predation mortality rates by fish age, influence of physical factors on fish distribution and abundance. These basic models should assist in educating fishermen and fisheries managers on the utility of multispecies models while beginning to answer questions that cannot be addressed by single species assessment methods. Basic models will improve over time as data collection activities improve.

Expand current single species models by including appropriate output from multispecies models, such as predation mortality, etc.

Results of multispecies/ecosystem models, such as predation mortality, temperature thresholds, and habitat thresholds, could be directly used in single species assessments to improve understanding of some of the factors that may be affecting a population. Multispecies model results could also be used in single species management in a more qualitative manner through communication of model results directly to all groups conducting related single species assessments. A multispecies VPA could also be used to determine predation mortality rates which vary by year. These results could then be used directly as data inputs to initiate the single species VPA. The single species assessment is used to set fishing regulations, but is also computationally linked to the multispecies assessment. This method is currently being used by the International Council for Exploration of the Sea (ICES). In the initial use of these basic multispecies/ecosystem models it should be noted that the multispecies model is not replacing the single species model, but is used to provide additional qualitative insight into factors that affect individual species.

Evaluate environmental influences on managed fish stocks.

Inclusion of physical and environmental factors in basic multispecies/ecosystem models will allow fisheries managers to evaluate effects of environmental factors on managed fish stocks. Examples include the influence of water temperature and salinity on fish distribution and abundance, the effect of water currents on fish migrations and stock mixing, and the effect of habitat changes on recruitment patterns. These models should provide information on local depletions in relation to environmental changes and fishing activities.

Evaluate basic implications of management measures to improve single species management.

Inclusion of single species management information in multispecies/ecosystem models will allow fisheries managers to evaluate trade-offs between species. In other words, how implementation of a management measure for one species may impact related species. It will be possible to provide both short-term and long-term evaluations. These models will also allow managers to evaluate the feasibility of managing all species at maximum sustainable levels (MSY). Information provided by these models in management of forage species will be particularly important to balance regulations for directed fisheries with the need to maintain a sufficient forage base for other managed and non-managed predator species.

Evaluate information gaps to direct sampling priorities and development of new data collection programs.

As basic multispecies/ecosystem models are developed, data gaps necessary for further expansion of these models should be identified. Many of the information gaps should be similar to those currently being identified for single species assessments and may easily be incorporated into existing data collection programs. Scientists should present these information gaps and associated research priorities to fisheries managers for inclusion in plans to develop new data collection programs. Expansion of these models will require additional data and feedback between scientists and fisheries managers in focusing future development activities.

Evaluate and peer review multispecies and ecosystem models.

Several multispecies/ecosystem models are currently being developed by Atlantic coast fishery management agencies and research institutes (Atlantic States Marine Fisheries Commission, Florida Marine Research Institute, Virginia Institute of Marine Science, National Oceanographic and Atmospheric Agency Chesapeake Bay Office). Most of these models are still in the developmental phase and are not being actively used in the decision-making process. Internal technical reviews are being conducted to evaluate data inputs, model formulation, and basic model outputs. Scientific peer review of these models, both internally and externally, will be an important step to ensure confidence in use of model results in management.

Appoint or designate a committee to evaluate current multispecies and ecosystem models.

Each management agency should appoint or designate a committee to provide oversight into the development of multispecies and ecosystem models. If existing committees are designated to assume this responsibility, such committees should have sufficient time and resources to perform the necessary functions. This committee should provide guidance on model type, data requirements, coordination with other agency activities, and funding opportunities. This committee could also synthesize the advice from the multispecies/ecosystem model for presentation to several single species management boards.

The committee should define the implications of regulations adopted for one species on other interrelated species, and should carefully review single species management decisions for contradictory outcomes.

Provide advanced training to state and federal stock assessment scientists to increase understanding and ability to conduct multispecies/ecosystem models.

Advanced training for state and federal stock assessment scientists and fishery biologists should be conducted to increase the ability of all management agency personnel to perform, or at a minimum to interpret multispecies model results. Single species models can be difficult to conduct and understand, and with additional data and model formulations multispecies models are even more difficult. Some state agencies currently have limited capability to conduct single species assessments. By adding more emphasis to multispecies models, we are "raising the bar," and states with limited single species assessment capabilities may be even less capable of performing and/or understanding multispecies models. Training in single species assessments is currently being conducted through the Commission's Stock Assessment Training Program, and USFWS classes on Fish Stock Assessment, but should be expanded to cover multispecies models as well.

Conduct formal peer reviews of multispecies/ecosystem models.

A formal peer review should be conducted for all multispecies/ecosystem models to ensure that the underlying science, model formulation, and input data are sound. Different evaluation processes may be used, however, the different processes should adhere to similar standards, such as the NMFS Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC), Southeast Data and Assessment Review (SEDAR), and Commission external peer review process currently used to peer review single species assessments. Consideration should be given as to how the process should be organized. Different processes could be organized regionally or by agency, depending on local expertise and specialization (e.g., New England has very different species considerations than the South Atlantic). Models should be peer reviewed prior to use of model results as a quantitative tool to assist fisheries managers.

Develop realistic priorities for multispecies data collection based on clear objectives.

Over the past several decades, a great deal of attention has been focused on identifying priorities for collection of fisheries-dependent and fisheries-independent data to support single species stock assessments and management. Several programs have been initiated to provide coastwide coordination of these activities, including the Atlantic Coastal Cooperative Statistics Program (ACCSP), the Southeast Area Monitoring and Assessment Program (SEAMAP), and the Northeast Area Monitoring and Assessment Program (NEAMAP). Any improvements made to data collection programs to support single species assessments will also provide benefits for multispecies/ecosystem models. However, some data required for multispecies/ecosystem models are not currently addressed through these programs and additional attention will need to be focused on these needs.

Appoint or designate a committee to develop priorities, plans, etc.

A management level committee/subcommittee should be appointed or designated to identify data requirements, develop data collection priorities, and provide guidance to policy related topics regarding management of a multispecies complex. This committee could provide input to the development of systemwide thresholds, targets, goals and objectives, which are more appropriately formed from a holistic view rather than on a species-by-species basis. The committee should be composed entirely of management level personnel representative of all affected organizations (Atlantic coast states, NMFS, Commission, Regional Fishery Management Councils). Appointment of such a committee does not necessarily involve a restructuring of the agency, since the committee could be an existing committee or a new committee that reports to an existing policy-level committee.

Review implementation options from the ASMFC multispecies workshop.

All Atlantic coast fishery management agencies should review the implementation options included in this report for possible future action. However, it should be noted that the list of implementation tasks outlined in this report include many activities that may be outside the scope of any one agency. For example, the Atlantic States Marine Fisheries Commission and the Regional Fishery Management Councils are not directly involved in data collection. These agencies are more involved in fisheries management, but may influence data collection priorities through their management activities. Therefore, it may not be appropriate or relevant for all Atlantic coast fishery management agencies to implement all tasks listed in this report. It may also be infeasible for any one agency to implement all of these recommendations due to time, resource, and funding constraints. It may be necessary for each fishery management agency to develop an implementation plan specific to their organization and consistent with their own agency's priorities.

Review objectives for multispecies data collection.

Current data collection activities are typically focused on collection of data to support single species stock assessments and management activities. Existing data collection programs should be reviewed in regards to the objectives and data requirements for multispecies models. It is possible to modify existing programs and/or implement new programs to meet both the needs of single species and multispecies assessments. Data collection priorities should be based on the specific model or suite of models chosen for use, as well as the specific management questions being addressed.

Update the inventory of existing data collection programs.

An inventory should be conducted of all the Atlantic coast data collection surveys, including an itemization of the specific data collected by each program. The Commission's Management and Science Committee has developed such an inventory for fisheries independent surveys, and ACCSP has inventoried fisheries-dependent data collection programs. These inventories should be updated and reviewed to determine the types of data collected coastwide, regionally, and in each state in order to identify data gaps on both a broad and detailed spatial scales.

Evaluate data gaps, precision of data, and ability of existing programs to meet multispecies and ecosystem needs (i.e., ACCSP, SEAMAP, NMFS and state surveys).

Existing cooperative data collection programs, such as ACCSP, SEAMAP, NMFS and state surveys should be reviewed to determine if they fully meet the data requirements of multispecies/ecosystem modelers. If possible these programs should be modified to meet these requirements. Standardized data elements should be developed for multispecies/ecosystem models. These basic data elements may be collected through existing programs, however, the level of detail may not be sufficient to meet the needs of some multispecies/ecosystem models. If possible, existing programs should be modified prior to implementation of new data collection programs.

Develop data collection priorities for existing and future programs.

Fishery managers should develop clear priorities for data collection in order to more fully utilize multispecies assessments in the management process. Data collection recommendations have been re-iterated during many workshops over the past decade and yet priorities are rarely met due to resource limitations. Coordinating with existing data collection programs, and integration of common priorities, should be encouraged in order to make efficient use of these limited resources. Coordination among agencies should also be encouraged in order to increase leverage for additional funding and personnel to support these activities.

Develop a plan for implementing new data collection programs to support multispecies and ecosystem assessments.

Currently there is no comprehensive plan for collection of information to support the development of multispecies/ecosystem assessments. Attention has been focused on developing plans for both fisheries-dependent and fisheries-independent data collection efforts, with priority for single species assessments. It may be possible to collect some additional data to support multispecies/ecosystem models through these programs. However, new data collection programs with clear objectives may also need to be implemented.

Develop objectives for new data collection programs to meet requirements for both single species and multispecies assessment models.

Once gaps in existing data collection programs are identified, new data collection programs may need to be developed to fill gaps in sampling and meet the priorities identified by fisheries managers. Many of the data requirements for multispecies assessments are the same priorities for single species assessments. Therefore, any new data collection programs should be designed to meet multiple objectives for both single and multispecies management.

Develop a list of required data collection surveys, including data elements, standards, and estimated costs and timeframes for implementation of new programs.

Following clear delineation of data collection objectives, a detailed list of data collection surveys required to meet these objectives should be developed. The program design for each survey should include consistent sampling protocols and data format standards to ensure data from different surveys can be combined and used in regional assessments. In order to effectively implement new programs it will be necessary to develop full implementation plans which include estimated costs and timeframes for implementation. Most new programs will require additional funding, which can only be justified through presentation of a comprehensive implementation plan.

Implement new data collection programs to meet multiple objectives (e.g., both single and multispecies management requirements).

Once an implementation plan for data collection activities to support multispecies/ecosystem models has been developed and approved it will be necessary to implement these programs. Implementation can be conducted through supplementing existing survey programs and/or design of new data collection surveys. New surveys can be designed to meet the needs of both single species and multispecies/ecosystem models. Funding will be required to implement any new surveys to support these efforts.

Supplement current sampling programs to collect additional required data (i.e., diet studies).

Additional data required to support multispecies/ecosystem assessments should be collected through supplementation of existing survey programs, where possible. The most important data in identifying trophic relationships is diet data by species size and/or age with strong temporal and spatial resolution. The NMFS Northeast Fishery Science Center has collected relatively simple volumetric diet data for many years, and found that having more data points of relatively good precision results in better information than few data points with very high precision. Diet studies should be piggybacked on fisheries surveys to capture changes in the forage base and feeding habits of managed predatory species. An evaluation should be conducted to determine whether other data collection requirements for multispecies/ecosystem assessments can be piggybacked on existing fisheries surveys, such as physical, environmental and habitat data.

Fully design and implement new data collection surveys to collect a suite of data to support several single species, multispecies, and ecosystem models.

The design and implementation of new data collection surveys should consider the requirements of both single and multispecies/ecosystem models in order to increase efficiency and fully utilize scarce fiscal resources. There are many different single species, multispecies, and ecosystem models that can support a variety of management decisions. Many data collection programs are currently designed to only respond to either one species and/or a limited number of management issues. However, most data collection programs can be modified or designed to meet the needs of a myriad of assessment models, thereby providing a broad range of information to fisheries managers. It is much more cost and time efficient (in terms of funding, staffing and other resources) to implement data collection programs that can meet the needs of many species and assessment models.

Secure additional funding to implement new data collection surveys.

Implementation of new data collection surveys will require additional funding support. These long term surveys provide fisheries managers with the full size spectrum, spatial distribution, and diet information necessary as inputs to multispecies models. Funding will need to be secured not only for implementation of the survey and data management activities, but also for stock assessment scientists and other analysts to process the data for inclusion in these models.

Fully implement multispecies and ecosystem frameworks in a phased-in approach, including conducting a retrospective analysis.

When modeling any system it is important that relevant parts of the system are identified and included in the model. It is also important to evaluate data availability associated with these model parameters. Given data, funding, and other constraints, it will be necessary to plan a phased-in approach in order to fully implement multispecies/ecosystem approaches. It will also be important to include model components in a meaningful manner, as opposed to inclusion of all factors and then a prior evaluation to determine their importance. A retrospective analysis can provide valuable information on how multispecies/ecosystem models can be used and how these models should be structured. This type of analysis would also provide an evaluation of how well the current single species assessment and management system works, would assist in identifying problem areas, and would provide an indication of whether the system should be changed.

Include additional species and information in existing multispecies and ecosystem models (i.e., environmental data, habitat information).

As our understanding of the system improves through the development of basic multispecies/ecosystem models, additional data on species and trophic interactions, physical and environmental parameters, and habitat factors should be added to the model to improve the analysis. Addition of these data and expansions of existing models will provide information to assist in answering broader management questions at a more detailed spatial resolution (e.g., local depletion issues).

Conduct retrospective analyses to examine the successes/failures of past or existing single species management strategies relative to how they might have been managed using a multispecies strategy.

A retrospective analysis focused on striped bass management should be conducted to determine if multispecies impacts occurred, what those impacts were, and if the impacts were positive or negative. This retrospective analysis should be used to evaluate rebuilding of coastal striped bass stocks in the context of multispecies interactions, social factors, economic factors, environmental factors and effect of regulations. This type of analysis will also show whether these impacts could have been enhanced if management had occurred in a multispecies context and whether management could have been more effective if striped bass were managed as part of a multispecies complex. The overall objective of this analysis is to evaluate impacts on other species and the ecosystem of striped bass rebuilding and to evaluate how the energy in the system has been redistributed.

This study should explore and evaluate several specific parameters, including:

- Restructuring of biomass
- Management effects
- Environmental influences
- Multispecies population dynamics
- Single species assessments
- Prospective simulations
- Identify information gaps

The retrospective analysis should be implemented as a phased-in approach over a ten year period, with the level of modeling detail increasing over time. Phase I (1-3 years) should include data assimilation and basic model building, including an evaluation of historical data to support this analysis. The basic model should include habitat use, environmental effects, general bounds, and implications of management scenarios. Phase II (3-6 years) should include additional biological and environmental data and inclusion of additional species. Phase III (6-10 years) should include management and social-economic information and the development of detailed management scenario analyses. It will also be possible to develop different types of targets and benchmarks, including ecological, biological, and economic. The model should be reconstructed as far back as possible given the available data. It will be important to show the benefits of conducting this analysis in Phases I and II in order to secure funding to proceed to Phase III.

It will be possible to evaluate changes in the striped bass resource in the absence of fishing (i.e., how the population would have responded to the natural environment) and then to impose constraints and evaluate the response of the resource to these constraints. This would allow an evaluation of carrying capacity since the population should increase to a level that can be supported by the ecosystem. In this manner it would be possible to evaluate the error in the current management system in relation to productivity (comparison of energy in past years to energy in the present), economic impacts, and social impacts. The measurement of the gap between where a manager would like to be and where a manager currently is can be viewed as a measure of the success of current management. This would also provide an evaluation of how well the current system works, whether there are problems, and whether the system should be changed from single species management to multispecies management. Once a reliable model is developed it is possible to tune the model to the existing system and then use the model for predictive purposes, such as evaluation of alternative management measures.

Develop complementary system-wide targets and thresholds (biological reference points) allocated by species or aggregate groupings (tiered reference points).

Multispecies assessment results should be integrated into single species management through development of system wide thresholds and targets. Developing system wide thresholds will allow scientists and managers to evaluate the interactions among species and take other species into consideration when developing single species targets. Current multispecies models suggest that MSY values for individual species may change in response to these models. These models will also allow evaluation of the feasibility of reaching MSY for both non-directed and non-managed fisheries, which are not typically considered in single species management. Multispecies/ecosystem models will allow evaluation of whether current MSY levels are feasible when interactions between species groups are considered. Multispecies/ecosystem models will provide information to assist fisheries managers in choosing biological reference points that are conditional on the status of other stocks while balancing the needs of all stakeholders.

Include management information into existing multispecies/ecosystem frameworks.

Under the recommended phased-in approach, multispecies models will be developed focusing on a limited number of species and a limited number of input parameters. As these models become more clearly understood and used in the management decision-making process, they should be expanded in order to improve their usefulness to fisheries managers. Inclusion of management information, such as fisheries regulations, is an important first step in improving these models. With inclusion of management information, these models will be capable of providing an evaluation of the implications of proposed management strategies in relation to the species being modeled.

Include social/economic information into existing multispecies and ecosystem frameworks.

Inclusion of social and economic information in order to expand basic multispecies and ecosystem models will be useful in evaluating the impacts of proposed fisheries regulations and other management activities not only on the species being modeled but on fishing communities and society as a whole. This will allow an evaluation of the impacts of combinations of regulations on multiple species on all facets of society, similar to existing socio-economic models for single species.

Evaluate environmental influences on managed and non-managed fish stocks.

Inclusion of environmental and physical factors in multispecies/ecosystem models will allow scientists to evaluate the effects of physical abiotic factors on both managed and non-managed fish stocks. Detailed information can be provided regarding environmental influences on fish distribution, abundance, migration patterns, recruitment, and many other important factors. This information will be important in evaluating stock status and developing more effective fisheries regulations.

Develop management scenario analyses for a full suite of inter-related species.

In existing single species management forums, analyses are typically conducted to evaluate alternative management scenarios and their potential effects on a single managed fishery. Multispecies and ecosystem assessment models will allow similar management scenario analyses, but on a suite of inter-related species. These models can evaluate the impact of regulations on multiple species, including those that provide a broad forage base for key managed predators. These types of models can provide useful information to fisheries managers on balancing decisions in order to successfully manage multiple inter-related species.

Develop predictive simulations for future projections.

Multispecies and ecosystem models can provide similar predictive analyses as in single species assessments. Depending on the types and amount of information included in these models, projections can be provided on stock abundance, recruitment, environmental perturbations, habitat changes, and many other influences for a complex of species. Multispecies and ecosystem assessments should include short term projections with confidence limits to aid management decisions. Projections are typically not valid past one generation time of the species in the model, since beyond that time period, all data are based on theory and projected numbers instead of measured recruitment or fish abundance at age.

Modify existing management structures to more fully address multispecies issues and to address overlapping jurisdictions.

Research and evaluate existing multispecies management structures for application to the Atlantic coast (ICES, West coast, etc.).

An evaluation of existing multispecies management structures, such as ICES, the U.S. west coast, Canada, and the Gulf Region, should be conducted in order to gain insight into effective methods of implementing multispecies/ecosystem models. Other possible sources of information that could be evaluated include inland fisheries and the migratory bird models of the U.S. Fish and Wildlife Service. Fisheries management agencies should evaluate appointment of a Multispecies Management Board to synchronize the amendment process for species linked by a multispecies assessment. These evaluations should consider the need to simultaneously address harvest decisions and species tradeoffs in order to avoid the creation of regulations for individual species that may have contradictory effects.

Evaluate use of management and risk assessment tools to develop a multi-objective decision making process (balance of species and ecological issues).

Fisheries management agencies should evaluate a multi-objective decision making framework in order to assist in making decisions on species tradeoffs. Multispecies assessment models will provide valuable information to allow managers to evaluate the impacts of management decisions on multiple species. Management decisions will need to focus on balancing these tradeoffs. Risk assessment tools will assist fishery managers in quantifying these impacts and balancing these tradeoffs.

Evaluate options and implement changes to management structures.

Existing management structures are based on a single species approach, with the technical and decision-making bodies typically organized around a single species. Fisheries management agencies should evaluate potential options for changing the current management structure. The focus of this evaluation should be on improving the ability of fishery managers to make decisions that may affect multiple species, and should consider trophic interactions or other considerations.

Apply management tools to assist in making multiple decisions and balancing trade-offs.

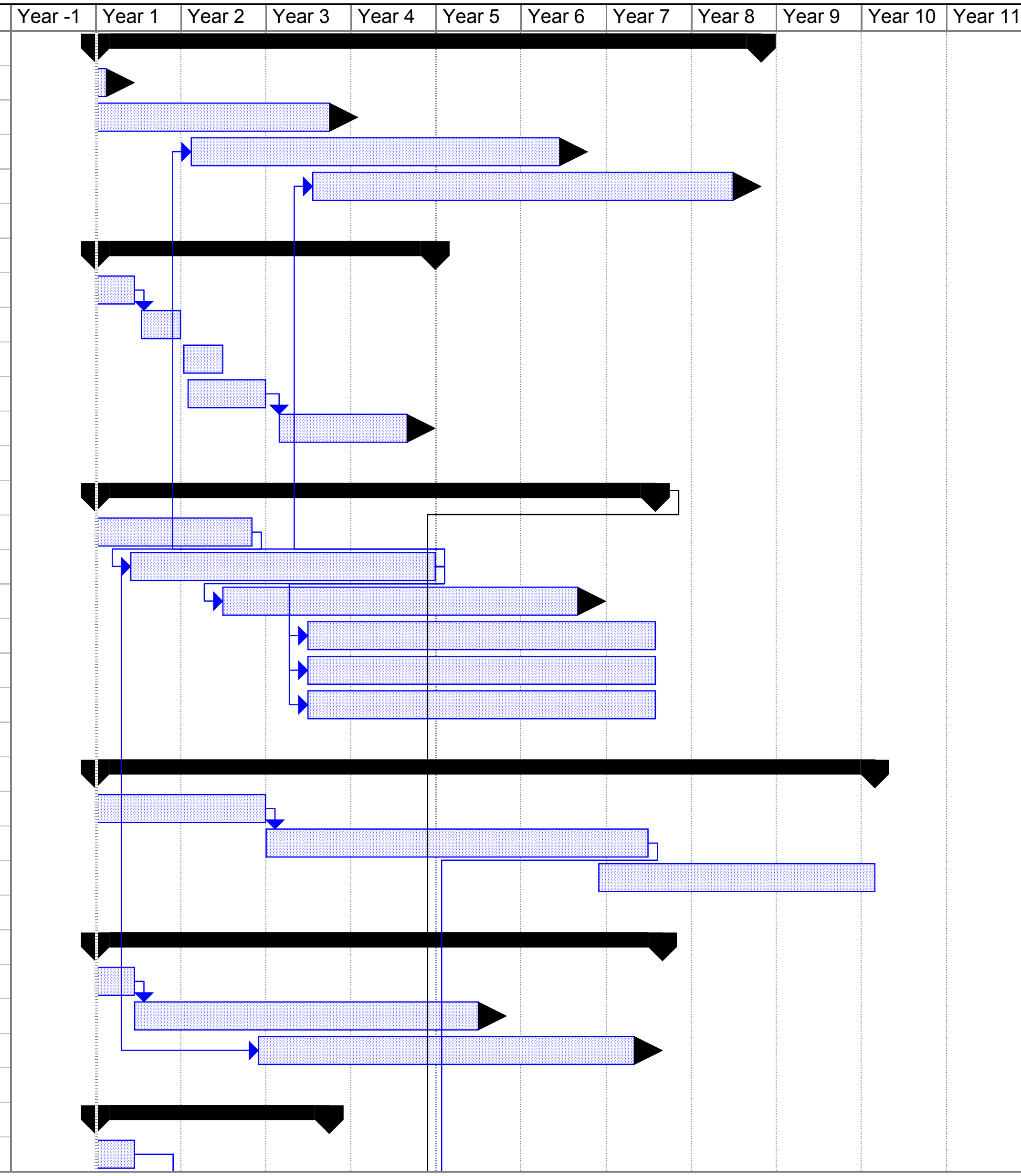
As fisheries managers are supplied with information on species interactions from multispecies and ecosystem models they will need to balance trade-offs between species. This will need to occur under existing management structures based on a single species management approach or under a modified management structure based on species interactions. Application of risk assessment tools will assist fisheries managers in making these multiple decisions, particularly under a single species management framework.

<u>Agencies should review the workshop recommendations and generalized implementation plan for possible modification and application to agency specific goals and objectives.</u>

This workshop developed a generalized 10 year implementation plan (Figure 3). However, given the complexity of multispecies and ecosystem issues, as well as different goals and priorities of the various fisheries management agencies, each agency may need to focus on implementing different portions of this generic plan. Many of the recommendations included in this plan are linked and depend upon progress on, or completion of, another task. Improving the use of multispecies issues in fisheries management will require a well planned and coordinated multi-year effort. Each fisheries management agency should review the recommendations contained in this report, evaluate progress to date, and prioritize activities to develop agency specific implementation plans.

Figure 3. Gantt chart representing a generalized 10 year implementation plan for linking multispecies assessments to single species management. Solid bars represent major tasks, shaded bars represent sub-tasks, horizontal arrows indicate ongoing tasks, and vertical arrows represent linked tasks. Timelines for specific tasks may overlap or extend past the 10 year horizon.

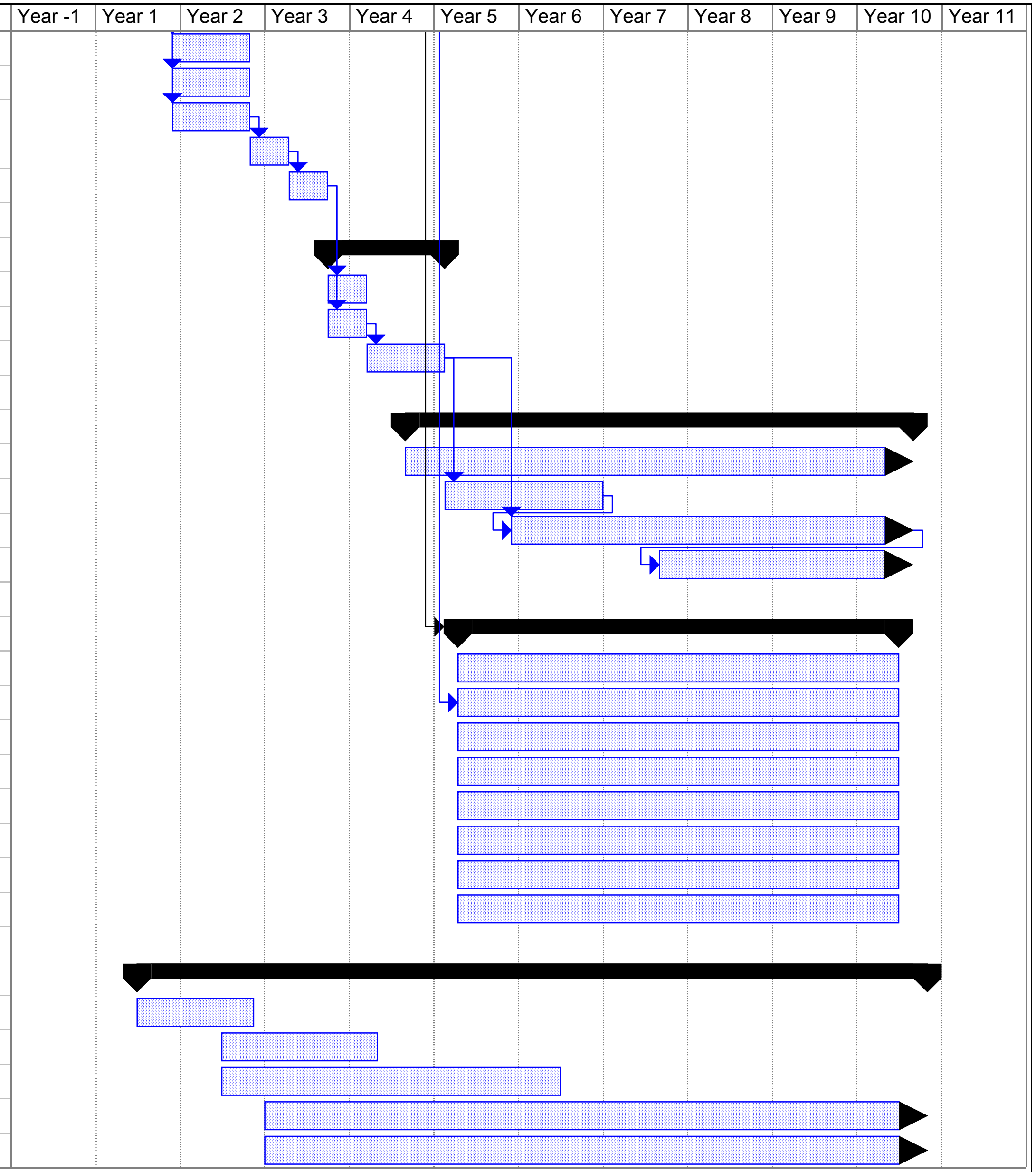
ID	Task Name
1	**Improve Integration**
2	Include agenda items at Board meetings
3	Include interrelationship information in single species FMPs
4	Present results to Boards
5	Include multispecies assessment information in single species FMPs
6	
7	**Improve Coordination and Communication**
8	Compile existing laws
9	Review existing laws
10	Develop costs and benefits
11	Develop public education program
12	Implement public education program
13	
14	**Develop Basic Multispecies Models**
15	Assimilate existing data
16	Build basic models
17	Expand current single species models
18	Evaluate environmental influences
19	Evaluate basic management measures
20	Evaluate information gaps
21	
22	**Retrospective Analysis of MS vs SS Advice**
23	Plan retrospective comparisons (reference line 14)
24	Perform and refine retrospective analysis with updated data (ref 52,57)
25	Expand to other species (ref 52, 54,55, 57)
26	
27	**Evaluate and Peer Review Models**
28	Appoint or identify committee
29	Provide advanced training
30	Conduct formal peer reviews
31	
32	**Develop Realistic Priorities**
33	Appoint or identify committee



Project:
multispecies implementation schedule

Task
Split
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline

ID	Task Name
34	Review workshop implementation options
35	Review data collection objectives
36	Update inventory of data collection programs
37	Evaluate data gaps, precision, etc.
38	Evaluate data collection priorities
39	
40	**Develop Implementation Plan**
41	Develop objectives
42	Develop data requirements
43	Develop costs and timeframes
44	
45	**Implement Data Collection Programs**
46	Supplement current sampling programs
47	Design new programs
48	Secure additional funding
49	Implement new programs
50	
51	**Expand Basic Multispecies Models**
52	Include additional species and information
53	Develop retrospective analysis (also see line 24)
54	Develop system-wide targets
55	Include management information
56	Include social-economic information
57	Evaluate environmental influences
58	Develop management scenario analyses
59	Develop predictive simulations
60	
61	**Modify Existing Management Structures**
62	Research and evaluate existing organizations (ICES)
63	Evaluate use of management and risk assessment tools
64	Evaluate changes to management structures
65	Implement changes to management structures
66	Apply management tools



Project:
multispecies implementation schedule

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

Appendix A.
Multispecies Assessment Model Overviews

Multispecies Virtual Population Analysis (MSVPA)

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Model objectives - The major objective of MSVPA is to quantify age-specific predation mortality rates (M2) on exploited fish populations due to fish predators. In combination with catch information, absolute population size at age and associated mortality rates are calculated for all stocks explicitly included in the model. Predator diets and absolute levels of prey consumption (in biomass) are calculated in the course of quantifying predation mortality rates for each prey.

Input data requirements - Generally, MSVPA data requirements are not much more intensive than for single species VPA assessments with the addition of diet data. Catch at age data is required for all explicitly modeled predators and prey species, length at age, weight at age, spatial overlap data, size and type prey preference parameters, evacuation rates, and biomass of "other food" not explicitly modeled but included in diets. The spatial resolution generally includes the entire stock of each species considered, but this may be modified through application of appropriate seasonal spatial overlap indices. In general, the predation aspect of the model is resolved on a seasonal time scale (e.g., quarterly) and the model encompasses the catch history, generally 10-20 years for most species.

Data sources include fishery dependent indices of catch, weight, and size at age. Fishery independent indices of abundance may be incorporated to "tune" outputs in most recent years. Diet and feeding studies are used to derive prey preference parameters and metabolic rates. Annual diet data collection is necessary to observe shifts in a diet for a given year, but more sporadic sampling can be combined for less detailed analyses.

The MSVPA developed for the ASMFC has a prey 'preference" value based on 3 factors - spatial overlap by season, type preference (simple ranking input), and size preference (dome shaped relationship between predator and prey size). The type and size preferences are constant over time in model, but there may be some functional response of type preference changing at very low prey availability that is being explored in current model development. Prey abundance and feeding information is derived by combining several small feeding studies, and few studies measure prey field. Usually one can infer type preference from diet studies, and broad studies can get size preference relationships as well.

Calculations - The model calculates predation and fishery mortality rates and population size. Ancillary data can then be applied to calculate biomass, spawning stock biomass, evaluate YPR and SSB/R conditions, and a variety of reference points equivalent to those used in single species assessments (e.g. $F_{0.1}$, F_{max}). It is difficult to incorporate uncertainty analyses due to large number of parameters, and extensive sensitivity analysis is therefore more appropriate. A forward projection component incorporating stock-recruit relationships can be used to explore short and mid-term management strategies and outcomes.

Model advice - The MSVPA provides absolute mortality and abundance at age equivalent to single species models. Reference points for each species are likewise similar to those from standard assessments. The model provides direct guidance for the targeted species, but may also implicitly evaluate the importance of "other prey" as food items for major predators. Most directly relevant to fisheries managers as it typically ignores "bottom-up" processes occurring at lower trophic levels.

Standard biological reference points include: fishing mortality by age for all species in model, B_{msy}, F_{msy}, YPR, SSBPR (same calculations as single species), age structured diet consumption (empirical), predation mortality by age. By generating predation mortality values from an individual species you improve both the time series of recruitment and magnitudes of abundance for ages 0 and 1. In single species assessments, recruits are basically unknown, but MSVPA improves stock size estimates by using time variant mortality rates. Secondly, MSVPA can look at system level interactions to recognize tradeoffs between species harvest.

Trophic / Aggregate Biomass Models

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Model objectives - The principal objective of aggregate biomass models is to discern major energy flows (i.e. biomass) within an ecosystem at an aggregated, functional group level. These can provide trends in relative abundance and biomass tradeoffs in a broader context.

Aggregate biomass models are not a single model, such as EcoSim and Multispecies VPA (MSVPA), but rather a class of models. There are several different ways an aggregate biomass model can be constructed, though all methods are founded on the same premise of combining species within trophic levels. Aggregate biomass models are most comparable to single species production models. Like production models, aggregate biomass models do not divide the population among sizes or ages and provide a gross analysis of the population, rather than an age structured analysis. However, whereas traditional production models aggregate a single species across age/size classes, aggregate biomass models combine different species within trophic groups, such as forage species. Collie and DeLong used an aggregate biomass model and derived reference points that are analogous to F_{MSY}, B_{MSY}, and $F_{0.1}$. The reference points are not used for individual species, but are useful to put bounds on the system. In other words, the sum of MSY yields for individual species from species specific models can not be higher than the system MSY derived from an aggregate biomass model. Aggregate biomass models are also used to emphasize flux between the different trophic groups. This does not de-emphasize the importance of the stated variables (whatever is being transferred, e.g. biomass, calories, etc.).
There are two general methods for constructing an aggregate biomass model. Typically, all species from a trophic level/group/guild are combined together into a single data set for input. This is beneficial because all species are included in the model, allowing you to see all the interactions and their implications. However, the large amount of data may make the model cumbersome, or lack of data for many species may make the model difficult to construct. The other option is to identify representative species from each guild and use data only from those species. Although this type of model may be easier to construct, it may not be as informative since it does not allow evaluation of all interactions, and a key species or interaction may be overlooked.

It is necessary to determine whether the species included in the model are important relative to biomass, biomass flux (predator/prey), or other effect. If they're not important, it may be possible to drop them from the analysis to simplify the process. Trophic linkages need to be adequately characterized and those linkages that are most important need to be modeled. Whether or not species are eliminated will depend on the questions that are being answered. One risk of combining species is that "super-predators" may be created. Individual species may have moderate trophic effects, but when they are combined, they have a large impact. This super-predator may then drive your model results. A risk of eliminating species is that important linkages may be overlooked because of lack of information on a given species.

Input data requirements - Generally, the data needed are some assessment of standing stock biomass (either in aggregate or for desired species which can then be aggregated), production rates (e.g. P/B ratios, growth), consumption rates, diet composition, and similar vital rates from which parameters can fit/estimated. The resolution is typically broad taxonomically, and variable and as appropriate spatio-temporally.

Calculations - This class of models calculates various tradeoffs in biomass due to a wide range of simulated or observed perturbations, particularly fishing. Species are secondary to functional taxonomy (e.g. think trophic guilds). Uncertainty can be dealt with in the typical modeling protocols, but typically the results tend to be deterministic.

Model advice - This class of models provides insight into how pelagics might respond after demersals have been overfished, or how piscivorus might respond if planktivorous or benthivorous forage fish have been removed, etc. The point is to look at the total biomass/productivity of a system and then allocate it accordingly based upon our understanding of production, predation, competition, and whatever external forcing functions (e.g., fishing, climate, and nutrient loading) alter the stated variables. The outputs can be set to absolute values, but typically are relative. There can be reference points, but they are qualitatively different than we typically think of for most fisheries models. For instance one could conceivably determine an aggregate B_{msy} for a group such as benthivores or elasmobranchs or whatever. However, the main idea of these models is geared more for strategic management (i.e. long term, broad perspectives to provide broad boundaries for more immediate considerations) rather than tactical management.

Aggregate biomass models are generally not used to provide specific management advice, such as changing F or setting quotas. They are used primarily for putting bounds on the system and for heuristic purposes (to understand the system retrospectively). For example, an aggregate biomass model could be used to determine B_{MSY} for a guild, such as demersal predators. This value could be compared to the sum of B_{MSY} from all single species assessments of demersal predators. The sum of all the single species values can not be larger than the system value. Alternatively, if enough is known about the system to set a cap (*e.g.* a quota) for a guild, the cap can be allocated among the species within the guild to best meet management priorities.

A Spatial Dynamic Multispecies Fisheries Model

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Model objectives - Traditionally, water quality, essential habitats, and fish stocks have each been treated as separate management issues. However, pervasive declines in fishery production and widespread habitat degradation have emphasized the importance of taking a more holistic view. The new Federal paradigm focuses assessment and modeling efforts on linking the production dynamics of fish populations, fishing, the biological community, the physical environment, and essential habitats. The over-arching goal of our modeling efforts was to develop a generalized mechanistic spatial dynamic biophysical age-structured multistock production model by linking bioenergetic principles of physiology, population ecology, and community trophodynamics to two-and three-dimensional finite element hydrodynamic circulation models. This means that we've come very close to explicitly modeling the fine-scale encounter dynamics and behaviors of foraging arena theory (e.g., C.J. Walters). We have implemented a numerical version of the model and used scientific data visualization to display real-time results. The major objective of the model is to evaluate predator-prey cohort-specific recruitment, growth, and mortality in a multi-species trophodynamic linkage under exploitation and environmental changes. For example, Ault et al. (1999) used the model to examine predicted spatial patterns and growth/abundance changes on time scales of up to a few years. Ault et al. (2002) used the model to provide estimates of age/size-structured population abundance and spatial distribution for each cohort of each species under various fishery management scenarios. Meester et al. (2001) used a model variant to explore the design efficacy of marine protected areas.

Input data requirements - The spatial dynamic multistock production model runs in continuous-time (thus incorporating tidal, lunar, quarterly and annual dynamics), and is parameterized by incorporating demographic attributes of growth, survivorship, recruitment, and spatial movements. These are explicitly linked to "habitat features" of the physical and biological environment over the range of the unit stock (Figure 4). We model predator and prey growth using a bioenergetic framework to facilitate explicit coupling with the physical and biological environments. The model, because of its individual-based "cohort" structure allows explicit tracking of life history ontogeny dynamics for post-larval transport and settlement, post-settlement movements, juvenile movements, mature adult movements up to maximum sizes and ages for the age-structured predator and prey species incorporated into the model structures. Classes of variable parameterization include:

In developing the spatial multispecies model, survey information is used to generate initial conditions, usually from spatially indexed catch data or using spatially distributed size and age structure data. Assumptions are made on the spatial integrity of the data and data are redistributed, if necessary based on temperature preferences and other assumptions. Once the model is developed it is important to evaluate whether model results match the available data.

The most reliable data available for these models will be spatially indexed over the unit area being assessed. For example, the Commission spatial model will cover the area of bluefish distribution (i.e., Maine through Florida) and data should be spatially indexed within that range.

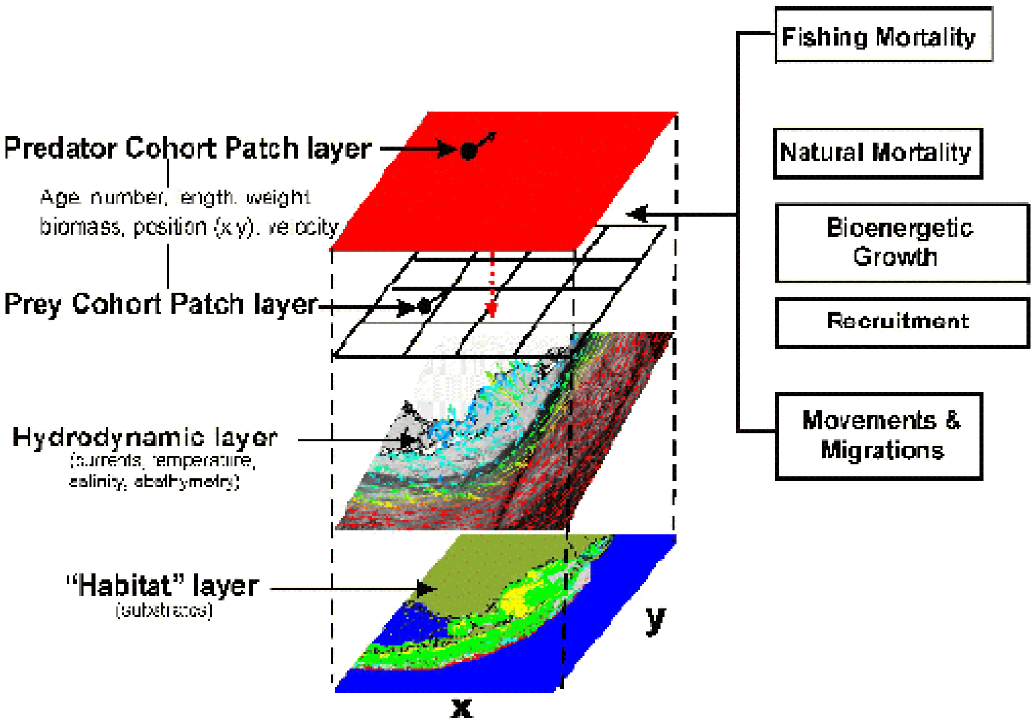

Figure 4.- Conceptual diagram of two-dimensional spatial patch interaction model used for predator-prey community dynamics. Shown also are hydrodynamics and habitat layers overlain by predator and prey cohort objects' spatial domains.

The spatial model links recruitment terms with a growth model, which represents the biogenetics portion of the model. These two components are blended together to allow size to be a function of mortality. An average index is developed across age/size groups and environmental factors are added to allow individuals to vary. Individuals are then aggregated to the population level. These models are no different than other models, such as surplus production and multispecies virtual population analyses, with minor modifications.

The spatial model will include several basic steps, including 1) development of population interactions functions, 2) development of functions for external forcing factors, such as environmental factors, 3) modeling for spatial scale, 4) comparisons of model results against known data sets for calibration purposes, and 5) forward projection of the model. The spatial model developed for the Florida Keys has an average resolution of ½ km^2. The cell size will be larger for menhaden model. The Florida Keys model will be expanded to extend from Maine through north Florida, with the stock centered where the bulk of biomass is located.

A good understanding of the production functions is necessary in order to develop any model. For the spatial model it is important to know where the fish are currently located and in what densities.

If conditions change the model will be able to predict changes in species distribution. These types of models will allow managers to better estimate the effects of controlling fishing effort through area/time closures. For the most part, this level of detail is not available. Therefore, the majority of aggregate models provide a gross simplification of the process. Results from these aggregate models will need to be evaluated to determine whether the average result relative to variability is realistic. A review of data requirements for aggregate models indicates that there is still a great deal of information required to support more detailed models.

In order to advance fisheries management to a more predictive process, such as used in hurricane forecasting, a change in the way fisheries management is conducted would be required (e.g., a change in the "way we do business"). Realtime measurements and timely updates to prediction models are necessary. Realtime data capture would also allow a more realistic evaluation of natural variability. The basic parameters in the model will also include uncertainty. If the precision of the mean estimates can be increased through better data collection, and an indication of the uncertainty in model parameters is presented, then fisheries managers will have to decide whether they will accept a certain level of risk in the model estimates.

Physical.- Key model dynamic layers are run in "real time" and require spatially-explicit currents, water temperature, salinity from coastal hydrodynamics models (at about 0.5 km resolution), or in the open ocean (greater than 30 m isobath), from MICOM (Miami Isopycnal Coordinate Ocean Model at 5 nautical mile resolution). Bathymetry (or bottom topography) and benthic habitat (substrate) data are also fundamental.

Biological (Population-Dynamic).- Biological data is focused on aspects of the "fishery ecosystem" and includes predator abundance, prey abundance, diet data, bioenergetics (consumption, egestion, excretion, assimilation efficiency, and respiration) data; behavioral (biological response to environment in terms of growth and movements, prey-dependent functional response) data, and population dynamics (age- and sex-structured growth (length and weight), mortality, fecundity).

Spatial data (5 nm resolution).- Initial spatial abundance distribution data for each age-class of each species, and fishing effort distribution. Since the ocean circulation model operates at 5 nm resolution, all other data types will be organized to that spatial scale.

Fishery.- Cohort (age)-specific catches in numbers and weight from which fishing mortality rates can be temporally and spatially estimated via the effects of directed and non-directed nominal effective fishing effort.

Calculations - The biological component of the model focuses on a series of key trophodynamic linkages (i.e., predator-prey). The model incorporates a highly detailed spatial model that included hydrodynamic processes (wind and tidal currents, freshwater inputs, salinity, temperature) and habitat structure (depth, bottom type). The present version of the model is "seeded" with small temporal cohorts (small groups of individuals) of larval trout and shrimp, and simulated their physical transport, movements, foraging, bioenergetics (growth, maturation), and mortality (interaction/predation, fishing, and other causes), on very fine time scales of a few minutes per simulation time step. High temporal resolution was used in order to capture spatial movement and factors like the changing vulnerability of shrimp to trout predation caused by shrimp "tide-hopping" behavior—periodic use of tidal currents to aid in inshore-offshore ontogenetic migrations. Uncertainty is encompassed through several stochastic functions which relate to predator-prey abundances, physical-environmental conditions which affect stock demographics, production potential and interaction rates. The model calculates ensemble weights, lengths, abundances, biomasses, natural mortality, total mortality, movements, spatial abundance and biomass (for exploited phase, mature stock and juveniles) distribution for all species and ages in the model. The model can be used to forecast and simulate alternative fishery management strategies that influenced by changes in exploitation rates, but also changes in water quality and habitats. Species included in the model are all considered equally, and thought to be the keystone determinants of system performance. The output is easily configured to render easily interpretable information that facilitate management decision making.

Model advice - The quality of the outputs will depend heavily on the quality (i.e., basic precision and spatial and temporal quantities) of the input data. If the initial abundance and recruitment are known with absolute precision, the model outputs will be absolute under the mechanistic model formulation; otherwise, the outputs will be relative. But the trends, relationships between species, and spatial distribution patterns will provide fisheries managers useful advice such as when and where fishing should be regulated or stopped. The model can be initiated (parameterized) with historical conditions (assuming data are available), and therefore outputs can be compared to and calibrated with historic data. The types of model outputs are large and comprehensive that include: (1) Production model-type outputs (yield horizon with fishing mortality, MSY, OSY, Fmsy, Fopt); (2) Analytical yield – yield per recruit, spawning biomass per recruit, growth overfishing, recruitment overfishing, MEY, MSY, etc.). Full suite of traditional management benchmarks for sustainability; (3) Fleet impacts; (4) Impacts of habitat changes on stock and/or community productivity (water quality and benthic substrates); (5) circulation – hydrodynamic effects on stock-recruit relationship (could include climate change scenarios); and (6) Siting of spatial management measures (e.g., marine protected areas).

In general, spatial models will provide similar model outputs as Virtual Population Analyses (VPA), but allow predictive capability. The VPA is based on historical data and, therefore, is not truly a forecast model. The VPA also does not consider all the factors that may influence model estimates, including environmental factors and predator-prey interactions. The spatial model estimates mean parameters similar to the VPA, but includes the influence of these additional factors. The spatial model will also produce similar model outputs as the Multispecies Virtual Population Analyses (MS VPA), however, different functions are used in these models to model diet and predator-prey information. For example, the spatial model uses a bioenergetic function which includes both consumption and respiration.

In general, spatial models will provide the following outputs:

- Total Mortality: Spatial models will provide estimates of total mortality rates, as well as the distribution of cohort-specific mortality by age.
- Natural Mortality: Spatial models will provide estimates of natural mortality, as well as distribution of natural mortality by age.
- Fishing Mortality: Spatial models will provide estimates of fishing mortality rates by space, including spatial catchability coefficients. These models use fleet distribution to impose

nominal fishing effort in space and will be dependent on the amount of resource under each vessel.

- Migration Patterns: Most spatial models use kinesis models to model migration patterns. These use a migration rate proportional to the relative change in environmental preference. If this information is not available it is possible to use tagging studies for average migration rates. Spatial models allow mapping of annual migration patterns to environmental factors and evaluation of the relationship between environmental factors and food distribution.
- Stock distribution: Spatial models will allow evaluation of stock movement and distribution in response to environmental factors.
- Local prey depletion: Spatial models will allow an evaluation of whether fish are not in a local area or whether physical conditions have influenced fish availability.
- Allocation: Spatial models will allow an evaluation of allocation of the resource between user groups and the fishery and forage base. This is linked to information obtained on movement and local depletion.
- Age and growth: Spatial models will provide basic information on age and growth of a species.
- Reproductive contribution: Spatial models will provide basic information on reproductive capability of a species.
- Total biomass: Spatial models will provide information on total biomass of a species.

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Ecopath with Ecosim (EwE)

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Model objectives – EwE is a software suite of three ecosystem models: Ecopath, Ecosim and Ecospace. While each of these models focuses on providing different information, all three models rest upon the basic assumption of mass-balance in the system. Furthermore, each considers trophic interactions as fundamental to ecosystem dynamics. Finally, the models incorporate a comprehensive, though hardly complete, set of ecosystem components, including unlimited: species/species groups, fisheries, and time series of both biological (e.g., survey data) and abiotic (e.g., wind speed) data. For the purpose of this workshop, the roles of Ecopath and Ecosim only will be considered.

Ecopath
Ecopath has no predictive capabilities; it is primarily a descriptive model similar to food web models of the past. The primary objectives of Ecopath are twofold: one is to provide initialization parameters for Ecosim; the second is to provide a snapshot of the state of an ecosystem at a point in time. While it is an equilibrium model, it is NOT a steady state model, but in fact can incorporate known trends of species or species groups over the period modeled. Secondary objectives include evaluating instantaneous natural (as calculated by a described diet matrix), fishing and total mortality rates (Note: these can be age specific). Other analysis can be done, for example network analysis. Another important, although collateral, result of the construction of an Ecopath model is the collection and warehousing of data previously kept in separate databases, often pointing out deficiencies in the data.

Ecosim
Ecosim is a biomass dynamic model that reconstructs the history of an ecosystem and projects into the future. Ecosim is perhaps best thought of as a series of individual species stock assessments connected through an underlying trophic structure. Key to Ecosim model is the ecological concept of the foraging arena. This provides for the explicit modeling of the behavioral ecology of predator-prey interactions, specifically by limiting the proportion of prey biomass available to a predator at any one time.

The primary objective of Ecosim is to provide a tool to evaluate alternative fishing policies in a multispecies and multifleet context with consideration of a user-defined objective function. The objective function is the maximized sum of variable-weighted multiple criteria often considered in management, including economic, social and ecological factors.

Input data requirements - The primary data requirements for an EwE model are (note that the following 5 requirements are all that is needed to construct an Ecopath model, and are input there exclusively. Numbers 6 – 15 include data may be input directly into either Ecopath or Ecosim indiscriminately for concision and readability):

1. Biomass density (t·km^{-2}, to species/species group);
2. Total mortality (year^{-1}, to species/species group);
3. Consumption to biomass ratio (year^{-1}, to species/species group);
4. Harvest (t·km^{-2}, to species/species group);
5. A diet matrix (% composition, to species/species group).

If some parameters are missing, Ecopath can estimate these. In addition, if various ages or 'stanzas' in the life history of one species are to be modeled, you must provide age-specific information for at least one age for (1), all ages for (2), and one for (3), as well as the K of the Von Bertalanffy growth function.

For more complex simulations, the following data can be included (note some are repetitive to above but are time series):

6. Effort (any measure, by fleet, by species/species group, annual over time);
7. Recruitment (relative, by species/species group, annual over time);
8. Primary productivity (relative, annual over time);
9. Biomass, CPUE, survey indices, absolute abundance, outputs from other models (relative, by species/species group, annual over time);
10. F, M, Z (actual, by fleet, by species/species group, annual over time);
11. Harvest (t·km^{-2}, by fleet, by species/species group, annual over time);
12. Fishery value ($·(t·km^{-2})$^{-1}$, by species/species group, annual);
13. Operating costs, Rent (by fleet, % total revenue, annual);
14. Employment indicator (ratio of jobs/landed value, by fleet, annual);
15. Any other modeled or observed relationship, e.g., wind speed vs. primary production, turbidity vs. SAV growth rates, spawner-recruit relationships (annual or monthly over time)

Not all of the above may be required for any one particular model or policy analysis. The majority of the above data are typically available in the primary literature and in fact are used in traditional stock assessments. Others, such as diet compositions, may be combed from 'gray' literature or unpublished data, assumed similar to those in systems that have been studied well, or, in the worst-case scenario, simply guessed at using professional knowledge and justifiable criteria (e.g., mouth shapes, size and position in fish limits prey types, as does claw morphology in crabs).

Calculations and output - In the data minimal case indicated above, the user will have provided all the necessary information to construct a basic EwE model with the capability to evaluate the present state of the ecosystem and the impact of future fishing policies. In such case, however, with no model validation, expected predictions can at best be expected to capture differences in relative trends over time caused by alternative fishing rates or environmental regimes. Other predictions regarding stock biomass *etc*. should be considered at most with extreme prejudice.

There are several ways of assessing the uncertainty associated with inputs. For example, simple sensitivity routine is included in Ecopath. The routine varies all basic input parameters (1-5 above) in steps from -50% to +50% and checks what effect each of these steps has for each of the input parameters on all of the 'missing' basic parameters. As well, one can enter the 'pedigree', or confidence one has, in each input data point and then run the routine Ecoranger (included in the software) that performs a Monte-Carlo simulation coupled with a sampling-importance-resampling scheme in order to derive Bayes' marginal posterior distributions, or maximum likelihood estimates of the input parameters. The most powerful way of dealing with uncertainty, however, follows below.

With more data the model can be 'validated' or 'tuned', as is done in traditional single species assessments. Typical validation data include those listed in 9 above. Data used to drive models (again, as in single species assessments), include 6, 7, 10 and to a lesser extent 11 and 15. A validated Ecosim model can provide time-dynamic information on: M, F and Z, relative abundance, biomass, recruitment, and harvest among others and in which more confidence can be placed.

Inclusion of data from 12, 13, and 14 above allow for the evaluation of simple to complex fishing policy alternatives. For example, all fleets could be considered to be cooperative and pool all profits, and the optimal fleet configuration and harvest could be calculated that way. Alternatively, fleets could be considered separately and the profits to one fleet maximized. Similarly, the number of jobs provided can be maximized, the mandated rebuilding of a species (e.g., oysters here in the Chesapeake Bay), or ecosystem diversity (measured as a maximum departure from some desired abundance of a species or species group) can be considered. Various weights on all three at the same time can also be modeled. All outputs are given in both graphical and tabular form, and are readily interpretable as management advice.

Model advice

An EwE model is designed to evaluate the relative impacts of alternative fishing policies. That is to say, while the actual outputs may be absolute, they will vary relative to the policy implemented. Furthermore, it is dangerous to consider the output from any model as absolute, the safest assumption is that the model will accurately capture trends, over time, in species abundance, harvest *etc*., thus identifying the pitfalls of a particular policy. Furthermore, modeling cannot replace the need for monitoring, or assessment. That being said, however, EwE can be a useful management tool.

One of the strengths of EwE is that it can provide guidance for both the community within the ecosystem as well as individual species. In general, this advice can be easily implemented by fisheries managers, since the model operates much the way managers would, that is, to vary fishing mortality in order to achieve a desired result. The benefit here is that multiple fleets can be manipulated jointly or independently, and the impacts evaluated on the system as a whole or focused on individual species. If mortality agents outside the modeled system are known, and the mortality they induce to species or species groups is also known, these can be incorporated in the model (see 15 above) and whether the cooperation of outside agencies will be needed can also be determined.

Whether it is useful to use an ecosystem model, such as EwE, in the derivation of reference points, whether biological or otherwise, is as yet unclear. It would be wiser to use such large complex models as but one tool in a management toolbox. In other words, the outputs from single species assessments can be used to help tune an ecosystem model, which can in turn estimate parameters to help fine tune single species assessments, such as varying natural mortality rates over time, and setting constraints on fishing rates relative to the impacts they may have on other species. The single species assessments can then re-evaluate previously generated reference points that now implicitly include ecosystems effects, yet focused primarily on a species of concern. Such ‘handshaking’ between models provides useful cross-validation and should not be disregarded.

Overall, EwE models expand the suite of reference points to include implications on other species, which is especially important in the nearshore areas where human impacts on the environment are much greater than offshore. Based on the ‘handshaking’ approach described above, any improvements to single species assessments will benefit an ecosystem model, and the ecosystem models will expand the scope and provide a complementary role to the single species approach. A final benefit over the MSVPA model is that index based assessments are possible in EwE, and it may be possible to extract an approximate assessment for a species without sufficient data to perform a single species assessment.

The EwE breakout group recognized the need to continue a single species approach and not to abandon single species assessments. There is a place for both approaches, and scientists need both levels of scope to understand the system and species interactions. Single species assessments will continue to provide the detailed information necessary to make specific harvest decisions. Ecosystem models will improve or add to our single species approach by helping us understand changes in other populations or environmental effects on target species abundance. Some members of the group wouldn't use Ecopath as a direct management tool, but would use it to look for warning signs that are not in SS. (an over- or under-abundance of other spp related to the target species).

Appendix B.
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