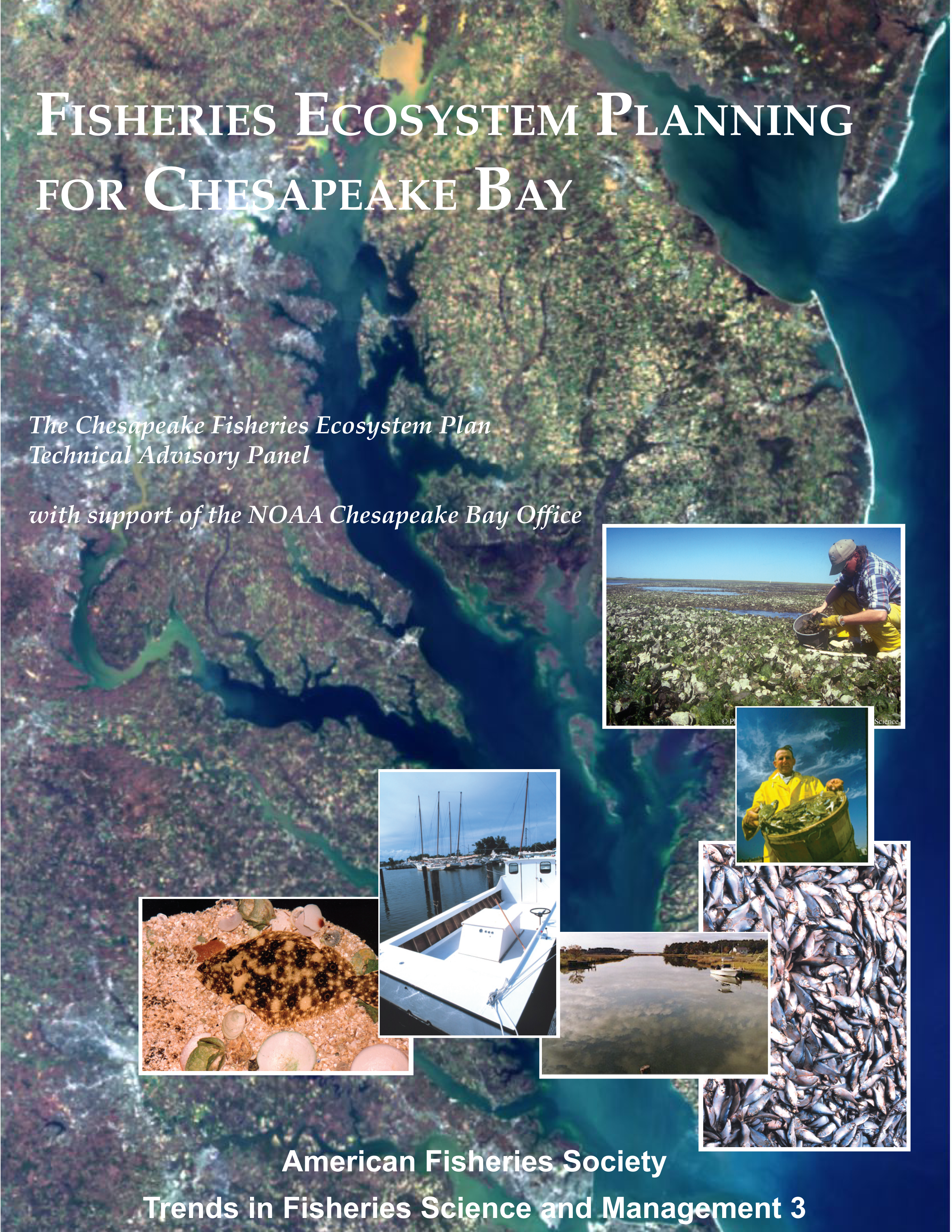

FISHERIES ECOSYSTEM PLANNING FOR CHESAPEAKE BAY

The Chesapeake Fisheries Ecosystem Plan
Technical Advisory Panel

with support of the NOAA Chesapeake Bay Office

American Fisheries Society
Trends in Fisheries Science and Management 3

Fisheries Ecosystem Planning for Chesapeake Bay

Developed by the
Chesapeake Fisheries Ecosystem Plan Technical Advisory Panel
with support of the NOAA Chesapeake Bay Office

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Preface

Fisheries Ecosystem Planning for Chesapeake Bay provides strategic guidance for ecosystem-based approaches to fisheries management and information on the function and structure of the Chesapeake Bay ecosystem. This comprehensive planning document and prototype fisheries ecosystem plan (FEP) was developed in response to key recommendations by the NMFS Ecosystem Principles Advisory Panel (NMFS 1999). The FEP Technical Advisory Panel was appointed by the NOAA Chesapeake Bay Office. The Panel addressed principles in the NMFS (1999) report, described components of the Chesapeake Bay ecosystem, and formulated recommendations for management and research required to develop ecosystem-based fisheries management plans. The principal authors of each chapter or element of the FEP are identified below. However, the FEP is a consensus document, representing the product of Panel deliberations, ultimate agreement, and consensus. The Chesapeake Bay Program has adopted the FEP as its guidance document for preparation of ecosystem-based fisheries management plans.

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Chapter 4
Margaret McBride and the FEP Panel

Chapter 5
Margaret McBride and the FEP Panel

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Fisheries Ecosystem Plan Technical Advisory Panel

The Fisheries Ecosystem Plan Technical Advisory Panel developed the Chesapeake Bay Fisheries Ecosystem Plan (FEP). This dedicated effort has been completely voluntary for all participants other than NOAA employees. Margaret McBride (NCBO) and Ed Houde (UMCES) served as co-chairs; they coordinated FEP development and were the principal panel reviewers of all draft FEP elements. Tom Miller, Dave Secor, and Lisa Kline conducted indepth panel reviews of the draft FEP document prior to the external technical review. Current affiliations of the panel members may not be the same as those listed below. See the Biosketches section for the background and most recent affiliation of each member.

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A Fisheries Ecosystem Plan for the Chesapeake Bay

State of the Bay and its Fisheries

Since European settlement, the Chesapeake Bay's rich estuarine ecosystem has supported major fisheries and the livelihoods of residents who adopted a water-dependent way of life. Over recent decades, however, many of the fish and shellfish that sustained these fisheries for over 3 centuries have declined dramatically in abundance or productivity; in some cases, stocks collapsed during the 20th century. Fishing and other anthropogenic stresses or modifications to the estuary and its watershed are the known or presumed causes of most long-term fishery declines. Despite such trends, fisheries on many species continue to produce high and apparently sustainable yields.

Given the importance of the fisheries both economically and ecologically, the Chesapeake Bay Program (CBP) has adopted two important goals: the continuation of high yields from healthy fisheries and the restoration of ailing fisheries. Recognizing the complex interactions among species, water quality, and habitats in the Bay ecosystem, the CBP has adopted a plan to institute multispecies fisheries management in Chesapeake Bay during the first decade of the new millennium (CBP 2000b). This challenging mandate has spurred efforts to develop ecosystem approaches that complement conventional fisheries management in the Bay.

The long-term decline in Chesapeake fisheries stems from several problems troubling the ecosystem. The CBP has identified excess nutrients, mostly from nonpoint sources (runoff and atmospheric deposition), as the major cause of water quality decline. Accelerated eutrophication due to excess loads of nitrogen and phosphorous precipitated a shift in the state of the ecosystem, transforming it from a relatively clear, seagrass-based system to one that is relatively turbid and phytoplankton-based, with resultant changes in habitats and biological communities.

The Bay has experienced both heavy fishing pressure and alteration or destruction of habitats (e.g., dams and impediments to migrations of anadromous fish). Such changes have precipitated shifts in species dominance and altered the population size structure of fished species that are important predators or prey. In addition, sedimentation, fishing, and disease have caused the collapse of oysters and the loss of oyster reefs (Rothschild et al. 1994; Boesch et al. 2001; Jackson et al. 2001), leading to further eutrophication and worsening water quality. Such changes have altered habitats and biological communities in the Bay and, consequently, its potential as a viable fisheries ecosystem.

Despite threats to the ecosystem, the Chesapeake Bay continued to support annual fisheries landings of more than 250,000 metric tons into the early 1990s (Miller et al. 1996; Houde et al. 1999). Regardless of this positive note, the number of principal species in the landings declined continuously through the last half of the 20th century, with changes in the status and nature of the fisheries continuing to the present. Since the mid-1990s, the overall level of landings has declined as catches of Atlantic menhaden *Brevoortia tyrannus* and blue crab *Callinectes sapidus*—the two dominant species in landings—dropped to levels lower than recorded in the previous decades.

***Definition of a fisheries ecosystem:** the complex interactive community of organisms (including humans and their institutions) and their shared environment (including habitats and ecological processes) that contributes to, influences, or determines the fishing industry.*

Virtually everyone advocates better fisheries management to assure sustainable fisheries. The Bay Program recognizes that successful efforts to reduce nutrient loads, improve water quality, re-establish submerged aquatic vegetation, and restore migratory fish spawning habitat should bring about healthier, more abundant stocks of fish, crabs, and oysters, ultimately leading to higher fisheries yields from the Bay (CBP 2002). To date, single-species fisheries management has formed the mainstay of the Bay's fisheries programs in which regulation of amounts caught and fishing effort form the primary management tools. Such single-species management is the norm globally, although the fisheries community widely recognizes that more effective fisheries management could result from a multispecies approach (Daan and Sissenwine 1991; Hollowed et al. 2000) that explicitly considers interactions among predators and prey and their effects on sustainable fisheries yields.

Recently, broader application of ecosystem principles has been debated and recommended nationally and internationally (e.g., Alaska Sea Grant 1999; NMFS 1999; Sinclair et al. 2002) to improve marine fisheries management in response to widespread recognition that fishing creates many unintended effects on ecosystem structure and function (Goni 1998). On a global scale, the move towards incorporating ecosystem approaches is gaining momentum. Collie and Gislason (2001) proposed biological reference points applicable in multispecies fisheries management, while Sainsbury and Sumaila (2003) emphasized the need to develop ecosystem-level reference points and indicators of the state of fisheries in an ecosystem context. Link et al.

(2002) have demonstrated that such reference points can be developed and applied to a fisheries ecosystem.

Adding ecosystem objectives to fishery management plans initiates the process of managing fisheries using an ecosystem-sensitive approach. In this regard, Gislason et al. (2000) recommended adoption of six conservation objectives. Management plans should require maintenance of

1) Ecosystem diversity,
2) Species diversity,
3) Genetic variability within species,
4) Directly impacted species,
5) Ecologically-dependent species, and
6) Trophic-level balance.

These objectives, perhaps now implicit in the CBP's approach to Bay resource management, can be formalized in a fisheries ecosystem plan (FEP). On both national and international scales, support is emerging for FEP development (NMFS 1999; Sissenwine and Mace 2003), although how such plans would be structured and implemented remains under debate.

When the CBP formally adopted multispecies management as a goal in its *Chesapeake 2000* agreement (CBP 2000a), it emphasized the need for greater understanding of species interactions, habitats, and water quality before effective multispecies plans can be implemented. Full consideration of such factors in management plans will provide an ecosystem approach to fisheries management. This approach builds on single-species management within an ecosystem context (Mace 2001; Link 2002b). Multispecies management will be strengthened greatly by development of a Chesapeake Bay fisheries ecosystem plan—a strategic umbrella document that describes the major structure, functions, and key species of the ecosystem within which fisheries are pursued and emphasizes adherence to ecosystem principles in the regulatory process (NMFS 1999).

> *An FEP is an umbrella document containing information on the structure and function of the ecosytem in which fishing activities occur, so that managers can be aware of the effects their decisions have on the ecosystem, and the effects other components of the ecosystem have on its fisheries (NMFS 1999).*

A Fisheries Ecosystem Plan for Chesapeake Bay

In the 1990s, it became apparent that the conventional, single-species management emphasis in Chesapeake Bay was not fully responsive to the broader, ecosystem-based management goals of the CBP. Habitats, water quality, and predator-prey interactions, for example, were considered only sparingly and generically in fishery management plans developed under the program's auspices. Recognizing the desirability of ecosystem-based management, the Scientific and Technical Advisory Committee (STAC) of the CBP supported a review of species interactions, multispecies models, and the potential for multispecies fisheries management in the Bay (Miller et al. 1996). A workshop followed to evaluate both need and feasibility (Houde et al. 1998). These initial efforts were instrumental in gaining support to integrate ecosystem approaches into Chesapeake Bay fishery management plans.

At the national level, during reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act, Congress requested that the National Marine Fisheries Service appoint a panel of experts to evaluate ecosystem-based approaches for fisheries management (NMFS 1999). Although the principles and recommendations delivered by that panel primarily address fisheries in the Exclusive Economic Zone, they have broader relevance to the management of aquatic living resources. The panel recommended that each management jurisdiction (regional fishery management councils) develop fisheries ecosystem plans (FEPs) that could serve as umbrella documents to guide individual FMPs. The panel report (NMFS 1999) spurred the NOAA Chesapeake Bay Office to advocate and sponsor development of an FEP for Chesapeake Bay in a pilot effort to both demonstrate feasibility and build a framework for ecosystem-based fisheries management in the Bay.

Under NOAA/STAC sponsorship in July 2000, a Chesapeake Bay FEP workshop convened to explore the concept of an FEP for Chesapeake Bay, ultimately recommending that development of such a document move forward (NCBO 2001). The NCBO appointed a Technical Advisory Panel of regional experts in November 2000 to develop the FEP. The FEP presented here is in many ways a model plan for management agencies nationwide to study and evaluate as they anticipate similar efforts within their jurisdictions. This initial effort was considered feasible due to the value of Chesapeake Bay fisheries, the

Goal Statement by the FEP Panel

The FEP Technical Advisory Panel will produce a fisheries ecosystem plan that clearly describes the structure and function of the Chesapeake Bay ecosystem, including key habitats and species interactions. The FEP will serve as an umbrella document to support ecosystem-based approaches in individual fishery management plans. It will include recommended actions to implement ecosystem-based approaches to fisheries management for Bay resident and coastal species. And, it will recommend specific research to enhance knowledge of the ecosystem and its fisheries to support long-term management objectives.

state of knowledge of Bay fish stocks and environment, the CBP emphasis on ecosystem-based management, the CBP Chesapeake Information Management System (CIMS) that houses 18 years of environmental data on the ecosystem, and the explicit requirements for multispecies and ecosystem approaches adopted in the *Chesapeake 2000* agreement (CBP 2000a).

Fisheries Ecosystem Plan Goals

Ecosystem approaches and ecosystem-based fisheries management have broad connotations for resource managers and the public. Many ecosystem-level issues (Link 2002a) could be considered in developing an FEP; however, expectations of an FEP for the Bay must remain realistic and practical. The document presented here is a strategic rather than tactical plan to adopt ecosystem approaches and apply them to fisheries management. It can serve as a guide for the CBP Fisheries Management Planning and Coordination Workgroup and the Fisheries Steering Committee as they develop the particulars of FMPs or amend those now in effect.

The FEP calls attention to critical features and processes of ecosystems vital in managing fisheries resources (Link 2002b), but is neither an ecosystem management plan nor a prescribed recipe to assemble an FMP. The FEP does not attempt to integrate all major elements of the fisheries ecosystem it discusses. Rather, it recognizes the critical role of each element in serving the needs of Chesapeake Bay fisheries and its value to the continuation of ecosystem services generated by species important to sustainable Bay fisheries (Holmlund and Hammer 1999).

Ecosystem Principles

The Chesapeake Bay FEP Panel also accepted the eight ecosystem principles of the NMFS (1999) Ecosystem Principles Advisory Panel. These broad principles guided development of the Chesapeake Bay FEP and can shape fisheries management actions in the Bay and coastal regions. Listed here in abbreviated form, the principles from the NMFS (1999) report are presented in full text in Appendix 1.

1) The ability to predict ecosystem behavior is limited.
2) Ecosystems have real thresholds and limits which, when exceeded, can effect major ecosystem restructuring.
3) Once thresholds and limits have been exceeded, changes can be irreversible.
4) Diversity is important to ecosystem functioning.
5) Multiple scales interact within and among ecosystems.
6) Components of ecosystems are linked.
7) Ecosystem boundaries are open.
8) Ecosystems change with time.

In addition to the eight principles, the FEP broadly adheres to relevant sections of the Code of Conduct for Responsible Fisheries developed by the Food and Agriculture

The Seven Guiding Principles

The FEP Technical Advisory Panel adopted seven guiding principles that constitute its *Vision* of a Chesapeake Bay fisheries ecosystem plan.

1) The *Vision* essentially encapsulates the goals, rationale, and justification for a fisheries ecosystem plan in Chesapeake Bay which

- Focuses on needs for fisheries management and is cognizant of present fishery management plans and goals;
- Sets high standards for conservation of critical ecosystem components;
- Emphasizes the ecosystem as the productive engine that must be conserved to insure valuable fisheries into perpetuity;
- Emphasizes protection of the Bay ecosystem's structure and function;
- Provides recommendations to fisheries managers to guide implementation of the FEP; and
- Adheres to the precautionary approach already espoused by fishery managers in the CBP (CBP 1997).

2) The FEP emphasizes fisheries and their management in an ecosystem context—and humans are an integral part of ecosystems. The FEP recognizes that human activities on Chesapeake Bay, including fisheries, provide important economic and recreational opportunities and strives to make recommendations insuring that fisheries not only co-exist with other human activities, but operate without endangering the productive capacity of the Chesapeake Bay ecosystem.

3) The FEP recognizes that key habitats and key trophic (predator–prey) relationships are critical and essential to preserve the capacity of Chesapeake Bay to sustain its important fisheries. As such, the FEP is broad in scope and considers the value of species that are not fished but are essential to food webs. The FEP appreciates the role that habitats play in

- Supporting exploited species at all life stages (fished and unfished);
- Supporting key prey or predator species at key life stages; and
- Preserving water quality.

4) The FEP includes descriptions of the Chesapeake Bay ecosystem, its boundaries, its key components (habitats and organisms), important predator–prey complexes, and the important social and economic drivers that shape the commercial and recreational fishing industries.

5) The FEP recognizes the external influences on the Chesapeake Bay ecosystem, many of which cannot be controlled by Bay fishery managers. For example, weather, climatic events and trends, and long-term shifts in ecosystem productivity that may be regional or continental in scale should be considered in developing or amending FMPs. Coastal migratory species that are seasonally resident in the Bay cannot be managed solely by regulations in Chesapeake Bay Program FMPs, but must be managed in coordination, or in compliance, with broader jurisdictional authorities. Although fishery managers and their agencies may not be able to control such external influences on their own, some factors

The Seven Guiding Principles (continued)

(such as pollutant and contaminant degradation) can be controlled by coordinated agency efforts in the Bay Program. Together, fisheries and other environmental agencies can make ecosystem-sensitive decisions to improve the Bay ecosystem while promoting sustainable fisheries.

6) The FEP addresses the need to develop and apply indicators of ecosystem health as tools to recognize shifts in ecosystem state or productive capacity for fisheries. Such indices or “reference points” can bind the goals of the FEP to the broader goals of the Chesapeake Bay Program. To the extent possible, FEP goals remain compatible with CBP goals and objectives.

7) The FEP is intended to be practical and does not propose actions with little possibility for implementation. It provides clear strategic advice to fishery managers, but does not offer step-by-step implementation recommendations for individual FMPs. Priority lists of recommendations for an ecosystem-based approach in achieving FEP goals are presented in each element of this report.

Organization of the United Nations (FAO 1995a). Sissenwine and Mace (2003) emphasize that, to be successful, ecosystem-based management of fisheries requires responsible actions to ensure sustainable human benefits, without risking adverse changes in marine ecosystems. Although referring primarily to global fisheries, many of the principles of the FAO Code (Article 6) can guide the responsible development and implementation of Chesapeake Bay FMPs that emphasize ecosystem approaches and recognize human needs (Appendix 2).

The objective of the FEP Panel was to produce a strategic plan to improve fisheries and fishery management in Chesapeake Bay and a framework to accomplish *Chesapeake 2000* commitments. The FEP builds upon the capabilities of existing institutions and policies, including humans and human activities as components of a functioning ecosystem. Importantly, it advises fishery managers on the necessary elements of ecosystem-based management, while providing recommendations for the research needed to support this approach.

Precaution and Ecosystem-Based Management

The concept of the precautionary approach for fisheries management evolved in the 1990s. Its principles are embodied in the FAO reports (FAO 1995b) that require recognition of uncertainties in fisheries management, fisheries research, and fisheries technology. Precautionary approaches are particularly relevant in an ecosystem-based plan such as the Chesapeake Bay FEP. The Bay ecosystem is the productive engine that must be conserved and upon which fisheries depend.

Desired Outcomes from the Chesapeake Bay FEP

1) Production of a valuable reference document for fisheries managers and other resource managers in the Chesapeake Bay Program that serves as
    - A strategic guide for the CBP on ecosystem-based approaches for fisheries management.
    - A "living" document for use by the Living Resources Subcommittee's Fisheries Management Planning and Coordination Workgroup in fisheries management plan development, amendment, and revision.
2) Achievement of consensus on FEP recommendations for management and research emphasizing
    - New research and management initiatives and strategies to support ecosystem-based fisheries management.
3) Development of a strategy for incremental FEP implementation with
    - Emphasis on both long-term objectives and visible short-term actions;
    - Coordination of ecosystem-based management actions (CBP, Atlantic States Marine Fisheries Commission, Mid-Atlantic Fishery Management Council, and the South Atlantic Fishery Management Council) to sustain mutually valuable regional and coastal fisheries.
4) Emphasis on fisheries as a driver for Bay restoration with
    - Promotion of fish health and productivity and sustainable fisheries as an indicator of ecosystem health.
5) Continuation of FEP Panel Advice to the Chesapeake Bay Fisheries Steering Committee with
    - Timely and responsive advice by the FEP Panel to promote ecosystem approaches, solve problems, and guide actions leading to implementation of *Chesapeake 2000* mandates.

Precautionary management requires "prudent foresight" and adoption of measures that avoid "undesirable or unacceptable outcomes," as well as incorporate "uncertainty into assessments and management" (FAO 1995b). Fisheries management agencies globally are accepting the precautionary approach as a basis for prudent, risk-averse management that sustains fisheries and the ecosystems that support them. The Living Resources Subcommittee of the Chesapeake Bay Program has adopted the approach, in principle, for Bay fisheries management (CBP 1997).

As a corollary of the precautionary approach, the concept of "shifting the burden of proof" has become a popular expression to promote risk-averse decision making. Shifting the burden implies that when the status of stocks is uncertain and research or management advice is not absolute, the burden of proof should not be borne by managers and scientists to demonstrate unequivocally that a fishery, or its supporting ecosystem, will be unharmed by increased fishing effort or questionable fishing practices. Rather, the precautionary approach should apply, recognizing that managers are faced with imperfect information and inherent variability within the ecosystem. Fishermen must bear the burden of proof until scientific and management advice can assure that target species, associated species, and marine habitats will remain productive and sustainable under a management regime (Dayton et al. 2002).

Scope of the FEP Effort

The FEP consists of elements that describe

1) Major components of the Chesapeake Bay fisheries ecosystem;
2) Processes important in ecosystem functioning;
3) Issues relevant to Bay fisheries; and
4) Current management status of Chesapeake Bay species.

A summary and recommendations for each element and a chapter on Pathways for Implementation outline the framework for an implementation plan. This Pathways Chapter is directed to fishery managers in the Chesapeake Bay region, who are the primary audience for the FEP. Others who will benefit from the ecosystem-based approaches in fisheries management proposed in the FEP include fishermen, the Chesapeake Bay Program, and residents within the watershed committed to conservation and sustainable use of the Bay and its resources.

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Appendix 1

Ecosystem principles for consideration in the development and implementation of fishery management plans (from NMFS 1999).

1) The ability to predict ecosystem behavior is limited.

   Uncertainty and indeterminacy are fundamental characteristics of the dynamics of complex adaptive systems. Predicting the behaviors of these systems with absolute certainty is impossible, regardless of the scientific effort invested. We can, however, determine the boundaries of expected behavior and improve our understanding of the underlying dynamics. Although ecosystems are neither totally predictable nor totally unpredictable, they can be managed within the limits of their predictability.

2) Ecosystems have real thresholds and limits, which can effect major system restructuring when exceeded.

   Ecosystems are finite and exhaustible, but generally have a high buffering capacity and are fairly resilient to stress. As stress is applied to an ecosystem, its structure and behavior may not change noticeably at first. Only after exceeding a critical threshold does the system begin to deteriorate rapidly. Since little initial change in behavior occurs with increasing stress, these thresholds are quite difficult to predict. The nonlinear dynamics causing such behavior constitute a basic characteristic of ecosystems.

3) Once thresholds and limits have been exceeded, changes can be irreversible.

   When an ecosystem is radically altered, it may never return to its original condition, even after the stress is removed. This phenomenon is common in many complex, adaptive systems.

4) Diversity is important to ecosystem functioning.

   The diversity of components at the individual, species, and landscape scales strongly affects ecosystem behavior. Although the overall productivity of ecosystems may not change significantly when particular species are added or removed, their stability and resilience may be affected.

5) Multiple scales interact within and among ecosystems.

   Ecosystems cannot be understood within a single time, space, or complexity scale. At a minimum, both the next-larger and next-lower scales of interest must be considered when analyzing the effects of perturbations.

6) Components of ecosystems are linked.

   The components within ecosystems are linked by flows of material, energy, and information in complex patterns.

7) Ecosystem boundaries are open.

   Ecosystems are far from equilibrium and cannot be adequately understood without knowledge of their boundary conditions, energy flows, and internal cycling of nutrients and other materials. Environmental variability can alter spatial boundaries and energy inputs to ecosystems.

8) Ecosystems change with time.

   Ecosystems change with time in response to natural and anthropogenic influences. Different components of ecosystems change at different rates and can influence the overall structure of the ecosystem itself and affect the services to society such as fish catch, income, and employment.

Appendix 2

General principles of the Code of Conduct for Responsible Fisheries (Article 6, FAO 1995) as abbreviated by Edeson (1999).

- Conserve aquatic ecosystems, recognizing that the right to fish carries with it an obligation to act in a responsible manner.
- Promote the interests of food security, taking into account both present and future generations.
- Prevent overfishing and excess capacity.
- Base conservation and management decisions on the best scientific evidence available, taking into account traditional knowledge of the resources and their habitat.
- Apply the precautionary approach.
- Develop further selective and environmentally safe fishing gear in order to maintain biodiversity, minimize waste, and minimize catch of non-target species.
- Maintain the nutritional value, quality and safety in fish and fish products.
- Protect and rehabilitate critical fisheries habitats.
- Ensure fisheries interests are accommodated in the multiple uses of the coastal zone and are integrated into coastal area management.
- Ensure compliance with and enforcement of conservation and management measures and establish effective mechanisms to monitor and control activities of fishing vessels and fishing support vessels.
- Exercise effective flag state control to insure the proper application of the Code.
- Cooperate through subregional, regional, and global fisheries management organizations.
- Ensure transparent and timely decision-making processes.
- Conduct fish trade in accordance with the principles, rights, and obligations established in the World Trade Organization Agreement.
- Cooperate to prevent disputes and resolve any disputes in a timely, peaceful, and cooperative manner, including entering into provisional arrangements.
- Promote awareness of responsible fisheries through education and training, as well as involving fishermen and fish farmers in the policy formulation and implementation process.
- Ensure that fish facilities and equipment are safe and healthy and that internationally agreed standards are met.
- Protect the rights of fishermen and fish workers, especially those engaged in subsistence, small-scale, and artisanal fisheries.
- Promote the diversification of income and diet through aquaculture.

CHAPTER 2

Managed Fisheries of the Chesapeake Bay

Cause for Common Concern

The Chesapeake Bay system has a complex jurisdictional framework within which to manage its fisheries for regionally important species. Not only do many of these species cross jurisdictional boundaries within the Bay, but several species supporting the Chesapeake's most valuable fisheries are also coastal and not confined to the Bay. This mobility creates a major issue in the adoption of ecosystem-based approaches in the Chesapeake since these species spend a significant amount of time, or critical life stages, outside the Bay mouth (Table 1). Within the Bay area, the differing objectives of each state may bring about inconsistent management actions for fisheries on ecologically interdependent species that have no regard for jurisdictional boundaries. Where Bay fisheries are subject to regulation under a hierarchy of different management regimes, coordinated actions that account for a species' range and life history become necessary.

The commonwealths of Virginia and Pennsylvania, along with the state of Maryland, the Potomac River Fisheries Commission, and the District of Columbia separately regulate the fisheries for year-round residents, such as catfish and white perch *Morone Americana* (Table 2, Figures 1 and 3). Individual states also manage the fishery for blue crab *Callinectes sapidus* even though this species spends its egg and larval stages outside the Bay mouth and may disperse to other estuarine systems. Fisheries for coastal species that are seasonal Bay residents (e.g., striped bass *Morone saxatilis*, bluefish *Pomatomus saltatrix*, and Atlantic menhaden *Brevoortia tyrannus*) are managed by the Atlantic States Marine Fisheries Commission (ASMFC) through the Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA) and by the regional fishery management councils authorized through the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). State regulations for fisheries on such coastal species must comply with ASMFC or council fishery management plans (FMPs) (Figure 2).

Coastal species that venture beyond state territorial waters (up to 3 mi offshore) into the exclusive economic zone (EEZ) (3 to 200 mi offshore) fall under the authority of the New England Fishery Management Council (NEFMC, Figure 2a) (e.g., lobster), the Mid-Atlantic Fishery Management Council (MAFMC, Figure 2b) (e.g.,

Table 1. Estimates of 3-year (1998–2000) average preliminary reported landings from Delaware, Maryland, and Virginia combined for species managed under FMPs in effect under the CBP, ASMFC, MAFMC, and SAFMC. The CBP does not have regulatory authority. The Gulf of Mexico Fishery Management Council and the SAFMC jointly manage fisheries for Spanish *Scomberomorus maculatus* and king mackerel *S. cavalla*. The ASMFC and MAFMC jointly manage black sea bass *Centropristis striata*, and summer flounder *Paralichthys dentatus,* while the ASMFC and SAFMC manage red drum *Sciaenops ocellatus*. American shad *Aolsa sapidissima*, hickory shad *A. mediocris*, alewife *A. pseudoharengus*, and blueback herring *A. aestivalis* are managed under the CBP Alosid FMP.

Species	Landings (MTS)	CBP	ASMFC	MAFMC	SAFMC
American Eel	**283.7**	•	•		
Atlantic Croaker	**6,296.2**	•	•		
Atl. Menhaden	**-**		•		
Atl. Sturgeon	**-**		•		
Bay Anchovy *	**-**				
Black Drum	**-**	•			
Black Sea Bass	**417.4**	•	•	•	
Blue Crab	**23,345.3**	•			
Bluefish	**307.9**	•	•	•	
Catfish *	**-**				
Horseshoe Crab	**-**	•	•		
King Mackerel	**-**	•			•
Oysters	**403.7**	•			
Red Drum	**2.5**	•	•		•
Shad/R. Herring	**-**	•	•		
Spanish Mackerel	**-**	•	•		•
Spot	**1,596.3**	•	•		
Spotted Seatrout	**-**		•		
Striped Bass	**1,944.1**	•	•		
Summer Flounder	**1,462.4**	•	•	•	
Tautog	**-**	•	•		
Weakfish	**532.5**	•	•		
White Perch *	**842.7**				

•	*FMP in effect*
*	*No FMP in effect*
CBP	*Chesapeake Bay Program*
ASMFC	*Atlantic States Marine Fisheries Commission*
MAFMC	*Mid-Atlantic Fishery Management Council*
SAFMC	*South Atlantic Fishery Management Council*

Table 2. Chesapeake Bay commercial (♦) and recreational (♣) fisheries regulated under state/local authorities as of May 2001.

Species	**DCFWD**		**MD DNR**		**PFBC**		**PRFC**		**VMRC**	
	Com	*Rec*	*Com*	*Rec*	*Com*	*Rec*	*Com*	*Rec*	*Com*	*Rec*
American eel			♦	♣		♣	♦	♣	♦	♣
Amer./hickory shads		♣	♦	♣		♣			♦	♣
Atlantic croaker			♦	♣			♦			
Atlantic menhaden										
Atlantic sturgeon	♦	♣	♦	♣	♦	♣	♦	♣	♦	♣
Bay anchovy										
Black drum			♦	♣			♦	♣	♦	♣
Black sea bass			♦	♣			♦	♣	♦	♣
Blue crab			♦	♣					♦	♣
Bluefish			♦	♣			♦	♣	♦	♣
Catfish		♣	♦	♣		♣	♦	♣		
Horseshoe crab			♦							
Oyster				♣						
Red drum			♦	♣			♦	♣	♦	♣
River herring			♦	♣	♦	♣				
Scup									♦	♣
Spanish mackerel			♦	♣			♦	♣	♦	♣
Spot							♦		♦	
Spotted seatrout			♦	♣			♦	♣		
Striped bass		♣	♦	♣			♦	♣	♦	♣
Summer flounder			♦	♣			♦	♣	♦	♣
Tautog			♦	♣			♦	♣	♦	♣
Weakfish			♦	♣			♦	♣		
White perch			♦	♣		♣	♦	♣		

DCFWD	*District of Columbia Fisheries and Wildlife Division*
MD DNR	*Maryland Department of Natural Resources*
PFBC	*Pennsylvania Fish and Boat Commission*
PRFC	*Potomac River Fisheries Commission*
VMRC	*Virginia Marine Resources Commission*

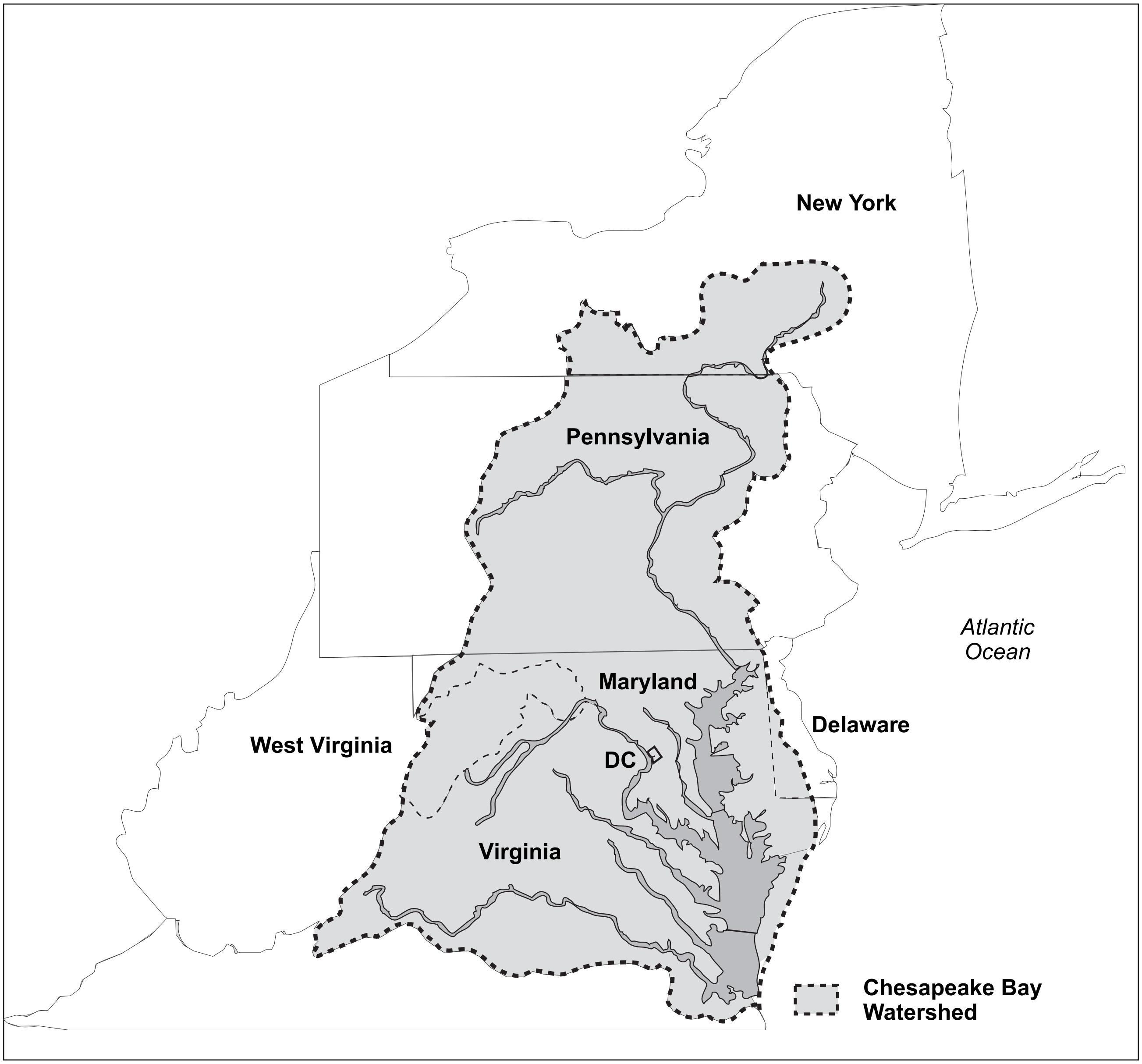


Figure 1. The Chesapeake Bay watershed.

black sea bass *Centropristis striata* or summer flounder *Paralichthys dentatus*), or the South Atlantic Fishery Management Council (SAFMC, Figure 2c) (e.g., red drum *Sciaenops ocellatus* or Spanish mackerel *Scomberomorus maculatus*). This composite of management regimes may prove inefficient and cumbersome when trophically interdependent species, such as Atlantic menhaden and striped bass, are managed under separate authorities with incompatible or competing management objectives (Hinman 2001).

Existing Management Regimes

Chesapeake Bay Program

The Chesapeake Bay Program (CBP) began to develop FMPs for selected finfish and shellfish within the framework of the *1987 Chesapeake Bay Agreement*, setting a schedule for adoption of FMPs for individual species. Presently, the Fisheries Management Planning and Coordination (FMPC) Workgroup of the Living Resources Subcommittee has completed 15 plans that encompass 21 species and the Chesapeake Executive Council has approved these plans. The plans provide compatible, coordinated management for the conservation and wise use of the Bay's fishery resources. The CBP does not hold regulatory

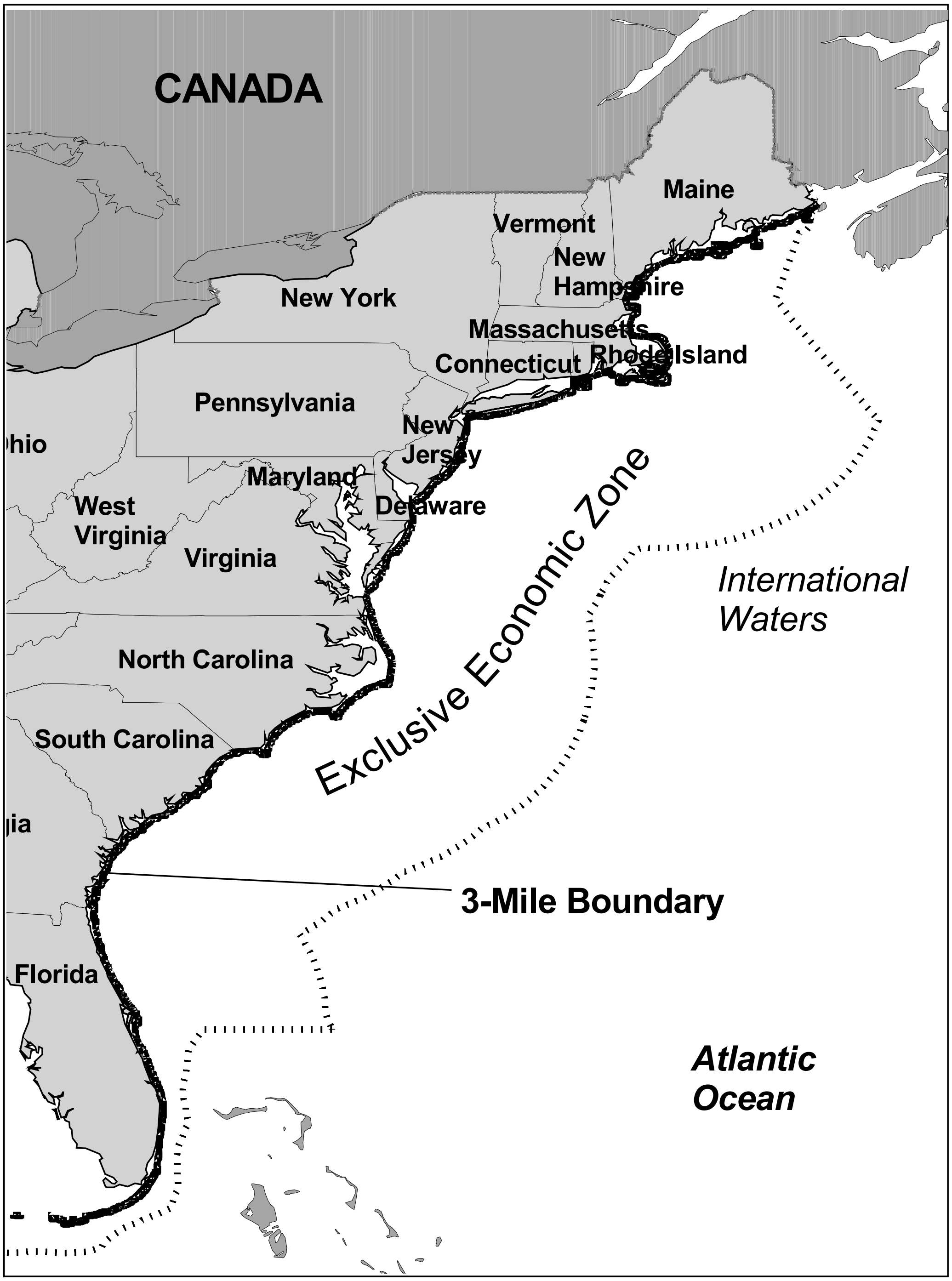


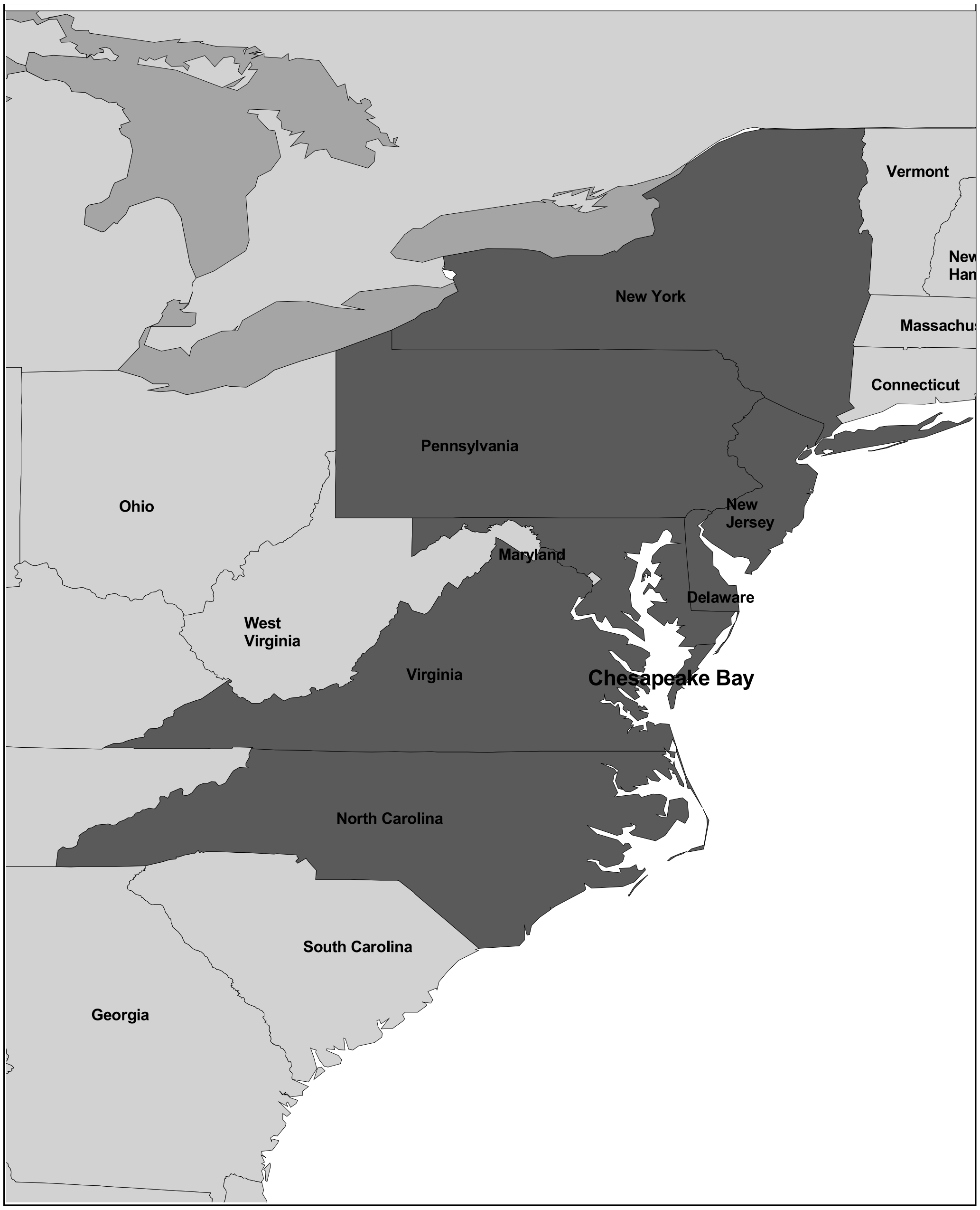
Figure 2. Atlantic coast of the United States with state territorial seas extending 3 nautical miles from the coast, the Exclusive Economic Zone extending 200 nautical miles from the coast, and international waters extending beyond 200 nautical miles.


New England Fishery Management Council

Figure 2a. States with voting representation on the New England Fishery Management Council (Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut).

authority, however, and compliance by Bay states remains voluntary.

Nine of the 14 most valuable species fished in the Chesapeake are not year-round residents. These species are managed under ASMFC regulatory authority, or under joint authority by ASMFC with either MAFMC or SAFMC (Table 1). Although the Bay Program has no management authority over seasonal Chesapeake Bay residents that range along the coast, the states do have authoritative



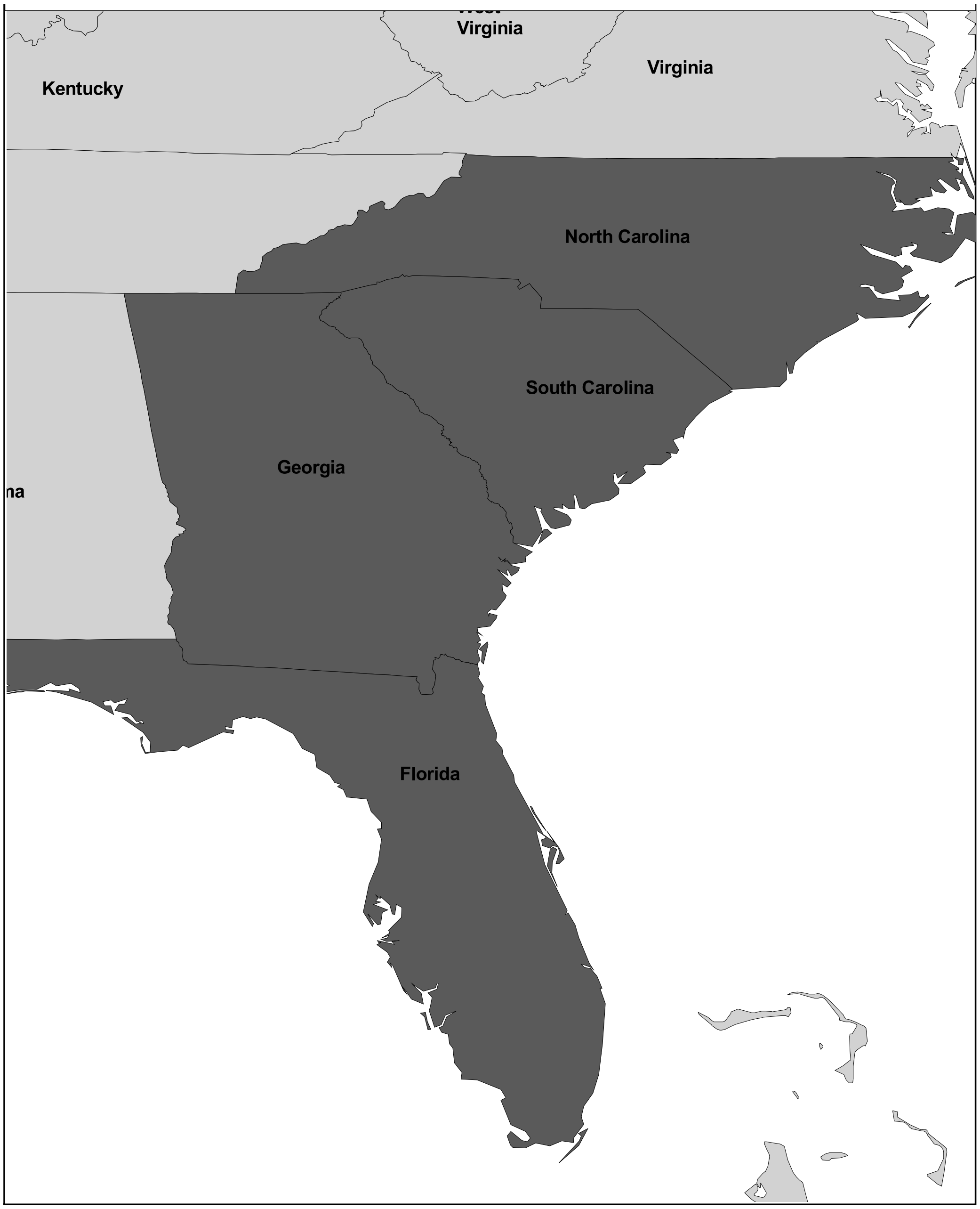
Mid-Atlantic Fishery Management Council

Figure 2b. States with voting representation on the Mid-Atlantic Fishery Management Council (New York, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, and North Carolina).

jurisdiction when these migrants move within their boundaries. Management of migratory species by the hierarchy of responsible agencies is critical since these fished species represent a vital component of the Chesapeake Bay's culture and economy.

Atlantic States Marine Fisheries Commission

The focus of ASMFC activities centers on management of coastal migratory species. The fisheries commission



South Atlantic Fishery Management Council

Figure 2c. States with voting representation on the South Atlantic Fishery Management Council (North Carolina, South Carolina, Georgia, and Florida).

emerged from an agreement in 1942 by the 15 Atlantic coastal states (Maine through Florida, including Pennsylvania) to participate in cooperative management and conservation of shared coastal fishery resources within state waters (inland waters and state territorial seas) (Figure 2). Each state has three representatives on the commission: the director for the state's marine fishery management agency, a state legislator or designee, and an individual appointed by the state governor to represents fishery interests.

The commission's main policy arenas include interstate fisheries management, research and statistics, habitat conservation, sport fish restoration, and law enforcement. The ASMFC operates under authority of the Atlantic Coastal Fisheries Cooperative Management Act (Atlantic Coastal Fisheries Act), which became law in 1993. The act brings together the

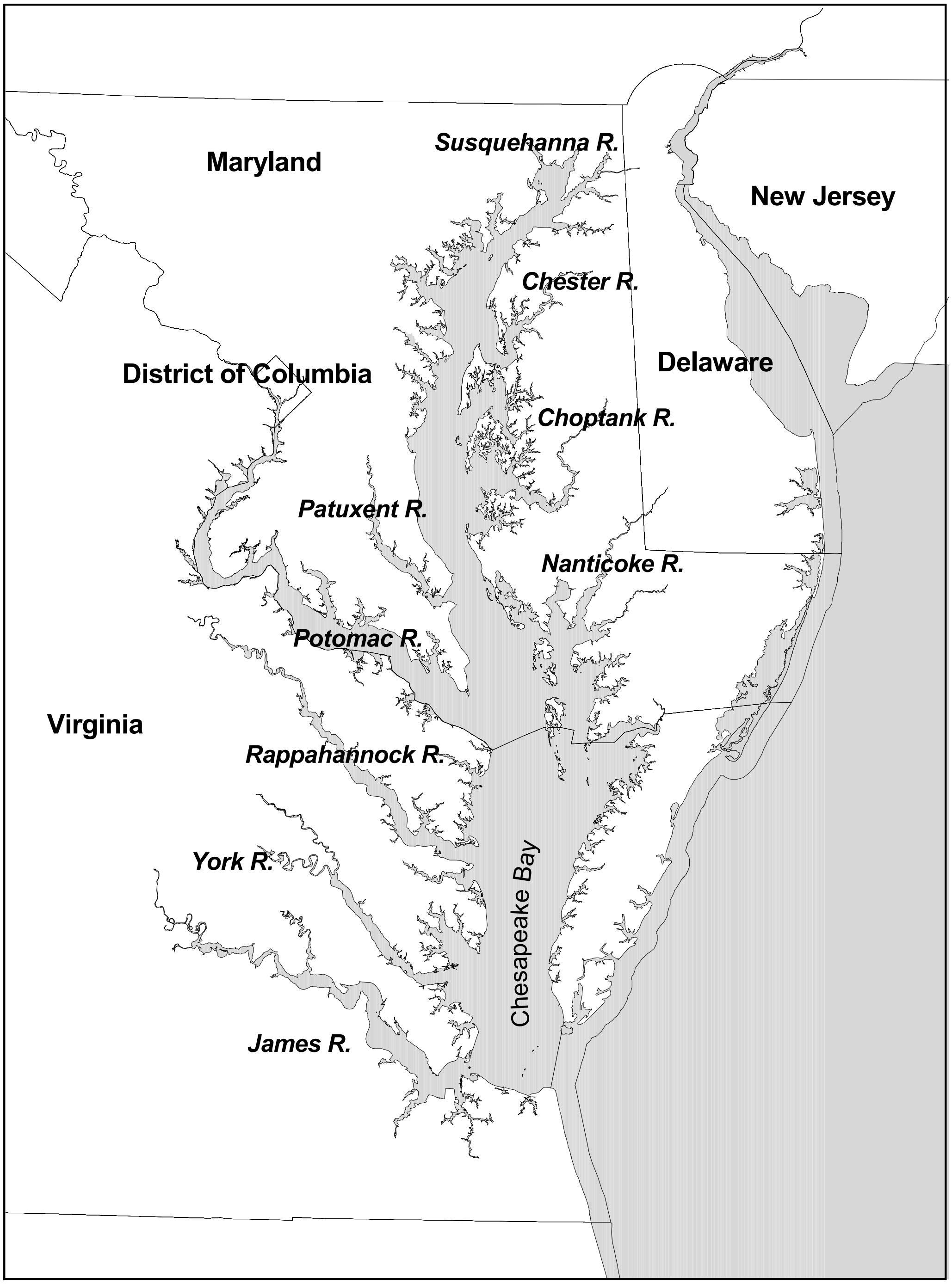


Figure 3. Major tributaries of the Chesapeake Bay along with the Maryland/Virginia state boundary.

ASMFC and its member states, NOAA Fisheries, and the U.S. Fish and Wildlife Service in a cooperative management process, and provides a mechanism to ensure Atlantic coastal state compliance with conservation measures included in ASMFC-approved FMPs. Prior to the passage of this act, state implementation of ASMFC FMPs was voluntary, except for striped bass. Today, all ASMFC states must comply with conservation provisions of an FMP or face a moratorium imposed by the Secretary of Commerce on fishing for (or landing) the managed species within waters of that state.

Regional Management Councils Established Under the Magnuson Act

The Magnuson Fishery Conservation and Management Act (MFCMA) of 1976 established authority to manage U.S. fisheries within the U.S. EEZ (extending from 3 nautical miles [5.556 km] offshore to 200 nautical miles [370.4 km]) and created eight regional councils to manage the living marine resources within this zone (Figure 2). The MFCMA was enacted principally to control and reduce heavy foreign fishing, promote the development of a domestic fishing fleet, and link fishing communities more directly to management. The geographical range for several Chesapeake fished species extends into management regions of the New England, mid-Atlantic, and South Atlantic fishery management councils.

Regional Management Councils

New England Fishery Management Council (NEFMC)

The NEFMC jurisdiction extends from Maine to southern New England. Some NEFMC-managed species range to the mid-Atlantic, while striped bass (managed by ASMFC) ranges as far north as Canada (Figures 2 and 2a). Notably, the council has developed and implemented the Northeast Multispecies (groundfish) Fisheries Management Plan (NEFMC and NMFS 2003) that covers a complex of 13 species. None of NEFMC's managed fisheries, however, has relevance to Chesapeake Bay.

Mid-Atlantic Fishery Management Council (MAFMC)

The MAFMC is responsible for conservation-based management of fisheries in federal waters (the EEZ), which occur primarily off the mid-Atlantic coast (Figures 2 and 2b). States with voting representation on the mid-Atlantic council include New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, and North Carolina (North Carolina is represented on both the mid-Atlantic and south Atlantic councils). Black sea bass, bluefish, and summer flounder are Chesapeake Bay species under joint MAFMC and ASMFC management authority.

South Atlantic Fishery Management Council (SAFMC)

The SAFMC establishes conservation measures to ensure viability of marine resources in federal waters off the coasts of North Carolina, South Carolina, Georgia, and east Florida to Key West (Figures 2 and 2c). Its FMPs are designed to produce optimum yield while preventing overfishing. Red drum and Spanish and king mackerels are Chesapeake Bay-dependent species for which fisheries are managed under joint SAFMC and ASMFC management authority.

District of Columbia

The District of Columbia's Research and Management Branch of the Fisheries and Wildlife Division (DCFWD) conducts annual surveys and studies of migratory and resident fish in the district's waterways. Data are used to estimate population and age and growth trends. Commercial fishing is not legal within D.C.'s waterways, which include portions of the Potomac and Anacostia rivers. Recreational fishing is also prohibited for American shad, chain pickerel *Esox niger*, hickory shad, longnose gar *Lepisosteus osseus*, northern pike *E. lucius*, and striped bass unless posted otherwise. Regulated recreational fisheries include striped bass, largemouth bass *Micropterus salmoide*s, smallmouth bass *M. dolomieu*, channel catfish *Ictalurus punctatus*, walleye *Sander vitreus*, and yellow perch *Perca flavescens*. Recreational fishing controls include minimum size limits, possession limits, creel limits, seasonal closures, and gear restrictions.

Maryland Department of Natural Resources

The Maryland Department of Natural Resources (MD DNR) was created as a state agency in 1969 to manage commercial and recreational use of the fresh- and saltwater finfish and shellfish resources within state waters (Figure 3). Commercial fisheries in Chesapeake Bay regulated by MD DNR include black sea bass, striped bass, bluefish, catfish, blue crab, horseshoe crab *Limulus polyphemus*, Atlantic croaker *Micropogonias undulatus*, black drum *Pogonias cromis*, red drum *Sciaenops ocellatus*, American eel *Anguilla rostrata*, summer flounder, river herring, Spanish mackerel, oyster, white perch, spotted seatrout *Cynoscion nebulosus*, tautog *Tautog onitis*, and weakfish *C. regalis*. Fishing control measures for commercial fisheries in the Chesapeake Bay include licensing, seasonal closures, minimum size limits, along with day, time, area, and gear restrictions. Maryland's regulated recreational fisheries in the Bay include those for black sea bass, striped bass, bluefish, catfish, blue crab, Atlantic croaker, black drum, red drum, American eel, summer flounder, river herring, Spanish mackerel, oyster, white perch, tautog, spotted seatrout, and weakfish. Fishing control measures for recreational fisheries include minimum size limits, bag limits, possession limits, seasonal closures, closed areas, gear restrictions, harvest quotas, landing quotas, day and time restrictions, and creel limits.

Pennsylvania Fish and Boat Commission

The Pennsylvania Fish and Boat Commission (PFBC) enforces rules and regulations governing fishing, boating, and the protection of fish, reptiles, and amphibians. The commission maintains a fisheries research station and a research vessel on Lake Erie. It also works with conservation groups to improve aquatic habitat for all species. Regulated recreational fisheries for Chesapeake Bay-dependent species include those for American shad, river herring, American eel, striped bass, catfish, and yellow perch. Fishing control measures include seasonal closures, minimum size limits, and daily catch limits. Pennsylvania has no commercial fisheries.

Potomac River Fisheries Commission

Virginia and Maryland, under the authority of the Potomac River Fisheries Commission (PRFC), share fisheries management in the tidal Potomac River (below the Woodrow Wilson Bridge). The PRFC operates under the Potomac River Compact of 1958, authorized by Congress. The commission is a semiautonomous agency; its work and policies, however, coordinate closely with the Resource Assessment Service of the MD DNR and the Virginia Marine Resources Commission (VMRC). Fishery agencies of both states provide law enforcement on the Potomac River for the commission. Regulated commercial fisheries include blue crab, oyster, American eel, Atlantic croaker, black drum, black sea bass, bluefish, catfish (blue *I. furcatus*, channel, and white *Ameiurus brunneus*), red drum, shad (American and hickory), Spanish mackerel, spot *Leiostomus xanthurus*, spotted seatrout, striped bass, sturgeon (Atlantic and shortnose), summer flounder, tautog, weakfish, white perch, and yellow perch. Fishing controls for commercial fisheries include closed seasons, minimum size limits, daily possession limits, gear restrictions, and annual quotas per licensee. Regulated recreational fisheries in the tidal Potomac include striped bass, largemouth bass, smallmouth bass, black drum, black sea bass, bluefish, catfish (bullhead , channel, and white), Atlantic croaker, American eel, pike/chain pickerel, red drum, American shad, Spanish mackerel, spotted seatrout, summer flounder, tautog, weakfish, and perch (white and yellow). Fishing controls for recreational fisheries include permit requirements, size limits, possession limits, gear restrictions, closed seasons, moratoria, and bait restrictions.

Virginia Marine Resources Commission

The Fisheries Management Division of the Virginia Marine Resources Commission (VMRC) administers current and long-term state policies affecting saltwater fisheries—both recreational and commercial—in Virginia's tidal waters (Figure 3). The division's goal is to provide maximum benefit and long-term use of Virginia's finfish and shellfish resources through conservation and enhancement. Its objectives include data collection and estimation of fishery statistics to determine stock status, participation in management bodies pertinent to Virginia fisheries—including PRFC, ASMFC, and MAFMC, and development of FMPs for important species in Virginia waters. Fishery management plans for oyster, blue crab, shad and river herring, striped bass, weakfish, bluefish, spotted seatrout, black drum, red drum, spot, and Atlantic croaker have been implemented. Regulated commercial fisheries include blue crab, oyster, American eel, American shad, black drum, black sea bass, bluefish, king mackerel, red drum, scup *Stenotomus chrysops*, Spanish mackerel, striped bass, summer flounder, and tautog. Fishing controls for commercial fisheries include minimum size limits, possession limits, and landings quotas. Regulated recreational fisheries in Virginia waters of Chesapeake Bay include blue crab, oyster, American eel, black drum, black sea bass, bluefish, king mackerel, red drum, scup, American shad, Spanish mackerel, striped bass, summer flounder, and tautog. Fishing control methods for recreational fisheries include minimum size limits, possession limits, and seasonal closures.

Enforcement of Fisheries Regulations

Laws protecting Bay fishery resources are enforced through a hierarchy of regimes, depending on the species fished and the location of fishing. The NMFS Office of Law Enforcement forms the compliance element of NMFS that enforces federal laws and regulations for fishery resources within the U.S. EEZ under the authority of the MSFMCA. Species in this category that support important Chesapeake Bay fisheries (Table 1) include black sea bass, bluefish, red drum, summer flounder, and Spanish and king mackerels.

The ASMFC Law Enforcement Program assists member states in coordinating their law enforcement efforts through data exchange and problem identification. This program ensures that law enforcement provisions of commission FMPs are adequate. It is coordinated through the ASMFC Law Enforcement Committee, which includes law enforcement representatives from the 15 Atlantic coastal states, the District of Columbia, NMFS, the U.S. Fish and Wildlife Service, and the U.S. Coast Guard. Managed Bay species falling under this enforcement regime include American eel, American shad and river herrings, Atlantic croaker, Atlantic menhaden, Atlantic sturgeon *Acipenser oxyrhynchus*, black sea bass, bluefish, horseshoe crab, red drum, Spanish and king mackerels, spot, spotted seatrout, striped bass, summer flounder, tautog, and weakfish.

Each regulatory agency within the Chesapeake Bay has a component to enforce laws and regulations to protect aquatic natural resources as part of its fisheries management program. These enforcement arms include the waterways conservation officers and deputy officers that support PFBC activities, Maryland natural resources police to enforce MD DNR regulations, and the Law Enforcement Division of the VMRC.

Table 3. Status of Chesapeake Bay managed fisheries (or important species) characterized by relative abundance, relative exploitation, management jurisdiction, most recent Baywide or coastal stock assessment, and status/date of most recent fishery management plan. See species synopses for more detail.

Species	Relative Abundance	Relative Exploitation	Management Jurisdiction	Stock Assessment	FMP
American Eel	Medium	Full	ASMFC/MAFMC	None	Adopted 1999
Shad/R. Herring	Low	Low	ASMFC/MAFMC	Shad 1997	Amended 1998
Atlantic Croaker	High	Medium	ASMFC/MAFMC	2001	Adopted 1987
Atl. Menhaden	Medium	Full	ASMFC/MAFMC	1988 & 1990	Amended 2001
Atl. Sturgeon	Extirpated	Moratorium	ASMFC/MAFMC	None	Amended 1998
Bay Anchovy	Not Estimated	Unknown	Not Managed	None	None
Black Drum	Not Estimated	Unknown	Not Managed	None	None
Black Sea Bass	Low	Over	ASMFC/MAFMC	1998	Amended 1998
Blue Crab	Low	Over	VA & MD	1997	Adopted 1997
Bluefish	Low	Over	ASMFC/MAFMC	2000	Amended 1999
Catfish	Healthy	Unknown	Not Managed	None	None
Horseshoe Crab	Not Estimated	Unknown	ASMFC/MAFMC	None	Amended 2001
Oysters	Low	Over	VA & MD	None	Adopted 1994
Red Drum	Not Estimated	Over	ASMFC/MAFMC	2000	Amended 2002
Spanish & King Mackerel	Moderate	Full	ASMFC/MAFMC	Spanish 1999	Adopted 1990
Spot	Medium	Medium	ASMFC/MAFMC	None	Adopted 1987
Spotted Seatrout	Not Estimated	Unknown	ASMFC/MAFMC	None	Amended 1991
Striped Bass	High	Limited	ASMFC/MAFMC	1995	Amended 2003
Summer Flounder	Medium	Over	ASMFC/MAFMC	2000	Amended 2003
Tautog	Low	Over	ASMFC/MAFMC	2001	Amended 1996
Weakfish	High	Low	ASMFC/MAFMC	2002	Amended 2003
White Perch	Not Estimated	Unknown	Not Managed	None	None

CBP	*Chesapeake Bay Program*
ASMFC	*Atlantic States Marine Fisheries Commission*
MAFMC	*Mid-Atlantic Fishery Management Council*
SAFMC	*South Atlantic Fishery Management Council*

Maryland and Virginia regulations do not apply to fisheries on the Potomac River; regulations enacted by the PRFC are enforced through joint efforts by Maryland and Virginia enforcement agencies under provisions of the Potomac River Compact (1958). The District of Columbia relies on the metropolitan police department's

Harbor Patrol for enforcement of its fisheries regulations.

Enforcement of Environmental Laws/Regulations

States and local agencies are granted the authority to protect water quality and fish habitat within their jurisdictions under provisions of the Clean Water Act (1982). They must write and enforce environmental protection policies at least as stringent as those mandated under the act. The EPA Office of Enforcement, Compliance and Environmental Justice (Region III including Bay states and the District of Columbia) oversees and coordinates laws and regulations issuance, permitting, compliance assistance, enforcement, and environmental justice issues among state and regional agencies. Within its oversight capacity, it reviews and approves policies, sometimes enforcing or prosecuting violators to promote equal public health and environmental protection for the mid-Atlantic region (J. Viniski, Environmental Protection Agency, personal communication). State and local offices (e.g., Maryland Department of the Environment (MDE), Virginia Department of Environmental Quality (VA DEQ), and the DC Environmental Health Administration) play key roles in carrying out enforcement goals and are responsible for conducting compliance along with civil and criminal enforcement actions within their boundaries. These offices are usually the primary contacts for the regulated community and the public for permitting, enforcement, and pollution response (VA DEQ 2003). In settling environmental enforcement cases, state and local offices require violators to achieve and maintain compliance with environmental laws and regulations and pay civil penalties as appropriate (MDE 2003).

In 1998, the Chesapeake Bay and many of its tidal tributaries were added to the list of impaired waters maintained under the Clean Water Act, thus requiring development of total maximum daily loads (TMDLs) to comply with the act. A TMDL defines the maximum load of a single pollutant from contributing point and nonpoint sources that a water body can assimilate without causing violations of water quality standards set by individual states and approved by EPA. These allocations are then regulated through enforcement of permit limits by EPA and state environmental protection agencies (MDE and VA DEQ) principally directed at point source dischargers along with implementation of best management practices (BMPs) for nonpoint sources (CBP 2003).

Species Synopses/ Management Status

Pertinent information characterizing managed species of the Chesapeake Bay follows within the text as well as in the species boxes of this section. Table 3 presents key summary information that describes recent levels of abundance and exploitation as well as the management status for each of the managed species.

American Eel

The American eel has a complex, catadromous life history with several unique stages. The species reproduces in the Sargasso Sea, but spends most of its life and is exploited in fresh, brackish, and coastal waters along the Atlantic Coast from the southern tip of Greenland to northeastern South America. Juvenile American eel form an important food source for various finfish (e.g., striped bass). Fish-eating birds and mammals also prey on the eel (Sinha and Jones 1967). American eel, in turn, prey on small fish and invertebrates in estuarine ecosystems (CBP 1993; ASMFC 2000a).

Concern exists about effective management of American eel to ensure stability of the coastwide population (ICES 2002). Management of Chesapeake Bay

American Eel *Anguilla rostrata*


Duane Raver/USFWS

Life Cycle: Catadromous

Life History Categories:

S_{CB}	Resides in Chesapeake Bay
S_{CST}	Resides in coastal waters outside Bay
S_{EST}	Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Full

Relative Abundance: Medium

ASMFC Management:

FMP	Adopted 1999
Management Unit	Migratory stocks from Maine through Florida
Monitoring	Fishery dependent
Stock Assessment	Not conducted
F	Not estimated
SSB	Not estimated

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	592.5	Not reported
1996	458.9	Not reported
1997	414.2	Not reported
1998	461.2	Not reported
1999	488.2	Not reported
2000	652.2	Not reported
2001	394.0	Not reported
2002	280.5	Not reported
2003	460.8	Not reported

CBP Management:

FMP	Adopted 1991
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	323.6	Not reported
1996	276.3	Not reported
1997	280.7	Not reported
1998	298.7	Not reported
1999	287.9	Not reported
2000	249.8	Not reported
2001	250.6	Not reported
2002	179.4	Not reported
2003	254.8	Not reported

Shad/River herring *Alosines*


Duane Raver

Life Cycle: Anadromous

Life History Category:

S_{CB} Resides in Chesapeake Bay
S_{CST} Resides in coastal waters outside Bay
S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Low (No commercial fishery in Chesapeake Bay; offshore winter gill net fishery)

Relative Abundance: Low

ASMFC Management:

FMP	Amendment 1, adopted 1998
Management Unit	All migratory stocks from Maine to Florida
Monitoring	Fishery dependent and fishery independent (recruitment)
Managed Species	Hickory shad (*A. mediocris*) Alewife (*A. pseudoharengus*) American shad (*A. sapidissima*) Blueback herring (*A. aestivalis*)
Stock Assessment	
American shad	Completed 1997
F	F_{30}
SSB	Not estimated

Estimated Removals from Atlantic Coast (species combined)

	Commercial (MT)	*Recreational (MT)*
1995	895.2	Not reported
1996	813.0	Not reported
1997	1,028.6	Not reported
1998	1,138.9	Not reported
1999	1,005.8	Not reported
2000	900.0	Not reported
2001	1,163.3	Not reported
2002	751.0	Not reported
2003	694.2	Not reported

CBP Management:

FMP	Adopted 1989, Amendment 1, 1998 (adheres to ASMFC)
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined – species combined)

	Commercial (MT)	*Recreational (MT)*
1995	182.7	Not reported
1996	142.0	Not reported
1997	362.0	Not reported
1998	273.1	Not reported
1999	215.1	Not reported
2000	175.3	Not reported
2001	270.6	Not reported
2002	83.8	Not reported
2003	28.3	Not reported

fisheries is conducted through FMPs of the ASMFC (ASMFC 2000a) and the CBP (CBP 1991a). The status of the Chesapeake Bay eel stock remains unclear, but local fishermen and research surveys have reported downward trends in the size and numbers of eels caught (CBP 1991a). Data to characterize the sustainability of eel fisheries in the Chesapeake Bay are not available. The CBP has adopted the ASMFC's conservative approach to manage the fishery for American eels. The potential exists to harvest large quantities of elvers (small eels that have only recently entered the Bay from the ocean) to supply aquaculture industries (CBP 1991a). A minimum 1/2-in mesh size for eel pots, therefore, has been established throughout the Bay to support the 6-in minimum size limit adopted to protect young eels.

Alosines (American Shad, Hickory Shad, Alewife, Blueback Herring)

American shad, hickory shad, alewife, and blueback herring, collectively termed “alosines,” are important anadromous species that historically supported large commercial fisheries along the east coasts of the United States and Canada. American shad once supported the most valuable finfish fishery in the Chesapeake Bay (CBP 1989; see Externalities Element). Alosines are planktivores (that sometimes eat very small fish) at all life stages and play an important ecological role in freshwater, estuarine, and marine food webs (Facey et al. 1986; MacKenzie et al. 1985; Weiss-Glanz et al. 1986). Through their return migrations as adults, they may also play a significant role in the transfer of nutrients from the marine system to freshwater rivers (Durbin et al. 1979; Garrnan 1992).

Stocks of alosines in the Chesapeake and along the Atlantic coast are low relative to historic levels and no longer support robust commercial fisheries. These declines have been attributed to overfishing, habitat loss due to impediments (dams and blockages), spawning migrations, and poor water quality. Recent indications, however, suggest that greater numbers of American shad and hickory shad are returning to Chesapeake Bay spawning tributaries. Factors contributing to the increases are dam removals, stocking of hatchery-reared shads, construction of fish passages, and restrictions on Atlantic coastal intercept fisheries. Stock assessments coastwide have been limited by incomplete catch data, the inability to identify the river of origin, and inconsistent fishery-independent data.

Management by the ASMFC of migratory, coastwide alosine fisheries promotes interjurisdictional coordination. No commercial fisheries for American shad are allowed in the Bay or its tributaries. In Maryland, the commercial fishery for alosines has been closed since 1980; on the Potomac River, a 5% bycatch is allowed in commercial pound net fisheries. The Virginia fishery has been closed since 1994. Recreational tributary fisheries are closed baywide, although catch-and-release fisheries are allowed along the Susquehanna River (ASMFC 1999).

Atlantic Croaker and Spot

Atlantic croaker and spot are both offshore spawners that belong to the drum family, Sciaenidae. Both species migrate seasonally between estuarine and coastal waters as juveniles and adults, using the Chesapeake as juvenile nursery habitat. Adults of both species use the Bay’s productive benthos, feeding opportunistically on bottom macrofauna. Croaker also migrate seasonally offshore and to the south during the fall and winter.

Croaker and spot play key roles in the trophic dynamics of the Chesapeake Bay, as predators of benthic invertebrates and as prey for striped bass, bluefish, weakfish, sharks, and summer flounder. As bottom feeders, they consume polychaetes, crustaceans, and mollusks as well as plant and animal detritus. These species support important recreational fisheries in the Chesapeake Bay. Commercial landings for both species are much lower than historic highs, although the abundance of croaker since the early 1990s has remained relatively high.

The ASMFC developed FMPs for both species in 1987. Its 1990 reevaluation of management measures emphasized

Atlantic Croaker *Micropogonias undulatus*

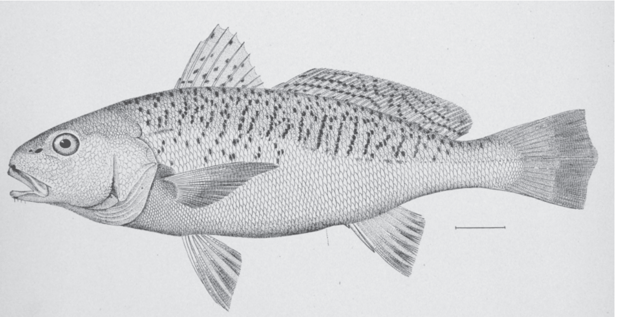
Life Cycle: Nearshore coastal-estuarine spawner

Life History Category:

- S_{CB} Resides in Chesapeake Bay
- S_{CST} Resides in coastal waters outside Bay
- S_{EST} Resides in other estuaries along mid-Atlantic seaboard

Relative Exploitation Level: Medium

Relative Abundance: High



NOAA

ASMFC Management:

FMP	Adopted October 1987
Management Unit	Migratory stocks from Maine to Florida
Monitoring	Fishery dependent
Stock Assessment	Conducted 2001 (NC State University)
F	0.77
SSB	Not estimated

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	3,420.5	1,829.8
1996	4,650.9	1,917.3
1997	6,462.2	3,520.1
1998	6,070.3	3,588.5
1999	6,547.4	3,320.3
2000	6,527.7	4,395.3
2001	6,877.6	5,026.7
2002	11,796.6	4,153.5
2003	12,931.2	4,180.5

CBP Management:

FMP	Adopted December 1992 (Atlantic croaker and spot)
Management Unit	Watershed to Bay mouth
Monitoring	Fishery independent
Baywide Stock Assessment	Not conducted
F	Not estimated
SSB	Not estimated

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	3,420.5	1,487.5
1996	4,650.9	1,607.5
1997	6,462.2	3,011.4
1998	6,070.3	3,206.8
1999	6,547.4	2,718.2
2000	6,527.7	3,429.4
2001	6,877.6	4,060.5
2002	6,332.6	3,736.5
2003	5,655.6	3,512.4

Atlantic Menhaden *Brevoortia tyrannus*

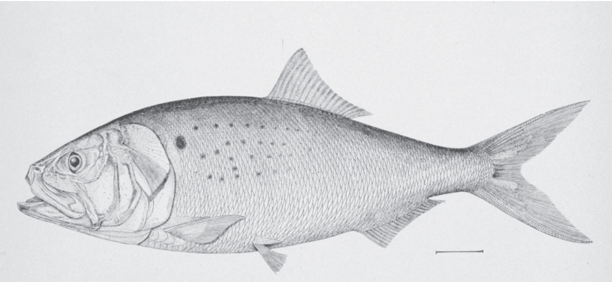
Life Cycle: Migratory coastal spawner

Life History Category:

S_{CB} Resides in Chesapeake Bay
S_{CST} Resides in coastal waters outside Bay
S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Full

Relative Abundance: Medium



NOAA

ASMFC Management:

FMP	Amendment 1 adopted Spring 2001
Management Unit	Coastwide (Florida to Nova Scotia)
Monitoring	Fishery dependent
Stock Assessment	Conducted 1988 and 1990
F_{max}	1.04
F_{rep}	1.33
SSB_{target}	37,400 MT
$SSB_{threshold}$	20,570 MT

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	364,687.3	Not reported
1996	305,792.9	Not reported
1997	291,133.4	Not reported
1998	277,420.7	Not reported
1999	208,011.2	Not reported
2000	207,151.9	Not reported
2001	261,027.9	Not reported
2002	210,984.2	Not reported
2003	203,106.8	Not reported

(Primarily reduction and bait fisheries)

CBP Management:

FMP	Adheres to ASMFC FMP
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	319,535.3	Not reported
1996	265,034.8	Not reported
1997	227,732.9	Not reported
1998	232,782.2	Not reported
1999	174,126.6	Not reported
2000	168,738.9	Not reported
2001	223,062.0	Not reported
2002	167,736.4	Not reported
2003	171,504.7	Not reported

the need to

1) Develop and implement bycatch reduction devices (BRDs) in trawl fisheries;
2) Promote increased yield-per-recruit to ages over 1 year through delayed entry into both fisheries;
3) Implement a research and monitoring program; and
4) Conduct a coastwide stock assessment for Atlantic croaker.

The ASMFC's FMP provided the basis for the Chesapeake Bay Atlantic croaker and spot FMP (CBP 1991b).

Atlantic Menhaden

The Atlantic menhaden, a member of the family Clupeidae, is a schooling fish in coastal and estuarine waters ranging from Nova Scotia to northern Florida. Adults migrate extensively along the entire Atlantic seaboard. Spawning occurs principally at sea, with some spawning in bays and sounds in the northern portion of its range. Eggs hatch at sea. After about 2 months at sea, the larvae ride with ocean currents to estuaries where they metamorphose, develop into juveniles, and spend their first year of life feeding on the estuary's rich supply of plankton. This species is important both economically and ecologically in Chesapeake Bay and coastwide (Ahrenholz 1991). The Atlantic menhaden commercial purse-seine fishery is one of the most important—and the most productive—on the Atlantic coast. It provides product for reduction into fish meal, fish oil, fish solubles, and bait for other fisheries. Coastwide landings have ranged from 200,000 to 400,000 metric tons (MT) annually since the mid-1970s. Always an important fishing region for menhaden, the Chesapeake has recently become the center for the fishery as focus shifted from more northerly waters (ASMFC 1992; see Externalities Element). Ecologically, the adult Atlantic menhaden is a filter feeder that grazes on planktonic organisms, principally phytoplankton. Thus, menhaden forms an important link in the coastal marine food chain, transferring planktonic material into animal biomass and influencing the conversion and exchange of energy and organic matter within the coastal ecosystem (Peters and Schaaf 1981; Lewis and Peters 1984; Peters and Lewis 1984). Menhaden is a favored forage species for many predatory fish, including bluefish, striped bass, weakfish, and king mackerel. Piscivorous marine mammals and seabirds also prey on Atlantic menhaden (see Food Web Element).

Due to Atlantic menhaden's ecological importance, concern has grown over the effect of intensive fishing and potential for population decline. Although the spawning stock is currently considered healthy, recruitment levels have dropped over the past 15 to 20 years and are now contributing to a decline in stock size (numbers and biomass). Spawning stock biomass (SSB) may wane in the next few years unless the trend in recruitment reverses. Causes of recruitment declines remain unknown, although scientists have cited changing environmental conditions in ocean or estuary nursery areas, possible increases in predation mortality, and heavy fishing on adult stock as contributing factors.

The fishery for Atlantic menhaden is currently managed through Amendment 1 of the ASMFC's Atlantic Menhaden Fishery Management Plan (ASMFC 2001d) with the management unit defined as the entire coastwide resource. This amendment defines a more rigorous and accountable process for future management of Atlantic menhaden, pursuant to requirements of the Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA 1993). It also adopts a new definition of overfishing (incorporating both fishing mortality and SSB reference points) by which the Atlantic Menhaden Management Board will judge the status of the resource.

The amended plan requires mandatory reporting of catch and effort from all menhaden purse seine fisheries. The management board will institute additional changes to Amendment 1 as necessary using a proposed adaptive management strategy.

Atlantic Sturgeon

The Atlantic sturgeon is an ancient fish dating back 70 million years. The sturgeon can live for more than 60 years and has grown as large as 4.5 m and 370 kgs. Unlike most fish, the Atlantic sturgeon is covered with five rows of bony plates called scutes and has a hard snout and four whisker-like sensory barbles that project near the mouth. The fish is typically a bottom dweller and uses its snout to root along the bottom for benthic organisms such as mollusks, insects, and crustaceans, which it sucks up with its protrusive mouth. These anadromous fish are found from Quebec to the Gulf

Atlantic Sturgeon *Acipenser oxyrhynchus*

Life Cycle: Anadromous

Life History Categories:

- S_{CB} Resides in Chesapeake Bay
- S_{CST} Resides in coastal waters outside Bay
- S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Coastwide moratorium (since 1999)

Relative Abundance: Extirpated or at historic low

ASMFC Management:

FMP	Amended June 1998
Management Unit	Migratory stocks from Maine to Florida
Monitoring	Bycatch
Stock Assessment	Not conducted
F	$F_{0.0}$
SSB	Not estimated

Estimated Removals from Atlantic Coast

Duane Raver

Commercial (MT)	*Recreational (MT)*
N/A	N/A

CBP Management:

FMP	Adheres to ASMFC FMP
Management Unit	Watershed to Bay mouth
Monitoring	By-catch
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

Commercial (MT)	*Recreational (MT)*
N/A	N/A

Black Drum *Pogonias cromis*

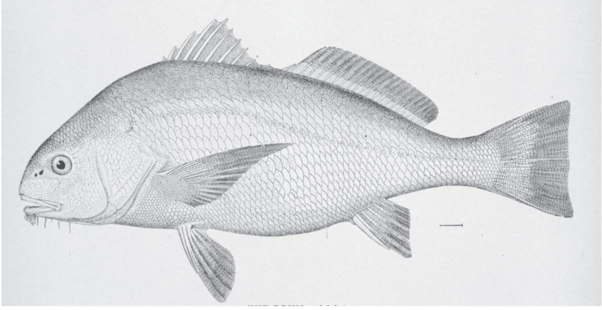
Life Cycle: Inshore coastal and estuarine

Life History Categories:

S_{CB}	Resides in Chesapeake Bay
S_{CST}	Resides in (inshore) coastal waters outside Bay
S_{EST}	Resides in other estuaries along mid-Atlantic seaboard

Relative Exploitation Level: Not determined

Relative Abundance: Not estimated



NOAA

ASMFC Management:

FMP	No FMP
Management Unit	No FMP
Monitoring	Fishery dependent
Stock Assessment	Not conducted
F	Not estimated
SSB	Not estimated

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	122.8	380.0
1996	135.0	309.6
1997	142.2	276.7
1998	61.1	294.2
1999	152.0	320.2
2000	104.9	815.2
2001	83.0	592.6
2002	252.0	377.2
2003	131.2	722.6

CBP Management:

FMP	Adopted 1993
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	32.5	77.0
1996	31.6	44.4
1997	69.3	16.4
1998	35.5	41.4
1999	30.8	3.9
2000	28.4	7.8
2001	28.5	0 .2
2002	14.0	11.2
2003	52.0	49.5

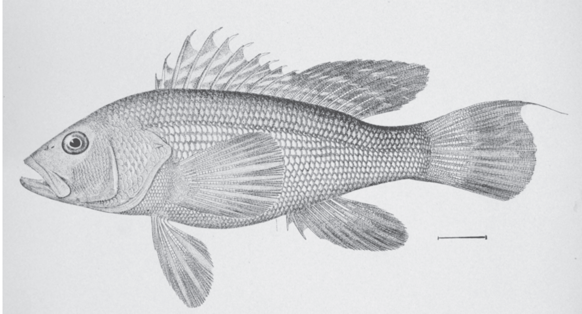
of Mexico and swim through the Chesapeake in April and May on their way into tributaries, which they use as spawning grounds and nurseries (CBP 2004).

Since colonial times, the Atlantic sturgeon has supported commercial fisheries of varying magnitude. High demand for the sturgeon's flesh and eggs (sold as caviar) led to severe overfishing. This demand, combined with blockage of access to historical spawning grounds, left the coastal stock on the verge of extirpation. The fishery in coastal waters under the jurisdiction of the ASMFC is closed. Every jurisdiction has a moratorium or closure in place that bans possession of Atlantic sturgeon. No directed fisheries for the species exist (ASMFC 1998).

Black Drum

The black drum, a member of the family Sciaenidae, occurs in coastal waters and estuaries from Argentina to the Gulf of Mexico and along much of the U.S. Atlantic coast. Black drum use areas near the Chesapeake Bay and off Cape Charles, Virginia as spawning and nursery grounds. Adults spawn from April through early June. After spawning, they move further into the Bay to feed on benthic mollusks and

Black Sea Bass *Centropristis striata*



NOAA

Life Cycle: Inshore coastal and estuarine

Life History Categories:

- S_{CB} Resides in Chesapeake Bay
- S_{CST} Resides in coastal waters outside Bay
- S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Overexploited, but recovering

Relative Abundance: Low, but increasing

ASMFC Management:

FMP	Amendment 12, 1998; Amendment 13, 2002
Management Unit	Cape Hatteras to U.S.-Canada border
Monitoring	Fishery dependent
Stock Assessment	June 1998
F	0.26
F_{max}	0.33
SSB	Not estimated

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	1,127.3	3,091.4
1996	1,795.8	2,104.2
1997	1,526.7	2,167.8
1998	1,430.1	686.5
1999	1,569.3	884.2
2000	1,432.0	1,951.3
2001	1,562.5	1,807.8
2002	1,798.6	2,111.6
2003	1,629.1	1,174.7

CBP Management:

FMP	Adopted 1997; Amendment 1, 2003
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent and fishery independent
Baywide Stock Assessment	Conducted 1997

M	0.375	F	0.865
$F_{0.1}$	0.36	F_{MAX}	0.64
F_{REP}	1.17	$F_{10\%}$	1.21
$F_{\%MSP}$		F_{HIGH}	1.76
F_{LOW}	0.48		
Absolute Abundance		83,955 MT	

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	301.8	Not reported
1996	606.2	Not reported
1997	462.5	Not reported
1998	513.4	Not reported
1999	535.0	Not reported
2000	432.2	Not reported
2001	368.1	Not reported
2002	476.9	Not reported
2003	371.9	Not reported

crustaceans and are often associated with oyster bars.

Black drum abundance varied greatly in Virginia during the late 1980s, possibly due to shifts in migratory patterns or to variable stock abundance (MD DNR 1999b). Evidence suggests that black drum inhabiting the Gulf Coast and those inhabiting the Atlantic Coast do not come from the same stock (CBP 1994b). The major portion of the Atlantic coast commercial catch comes from the Chesapeake region.

At present, neither an ASMFC nor a SAFMC FMP exists for black drum. Since limited data were available on black drum stock status within the Chesapeake Bay, the CBP developed and adopted its black drum FMP (1994) largely from information on black drum in the Gulf of Mexico. The broad objectives of this FMP are to stabilize the commercial and recreational harvest and protect the Chesapeake Bay stock. Chesapeake Bay jurisdictions will continue biological monitoring programs to provide data for use in assessing stock status, estimating levels of fishing mortality, conducting cohort analyses, and determining movements within Bay waters.

Black Sea Bass

The black sea bass is a member of the family Serranidae, or true sea basses. Species distribution extends from Maine to the Florida Keys and into the Gulf of Mexico (USFWS 1978). Mid-Atlantic and south-Atlantic stocks of this species are considered distinct (Shepherd 1991). The lower Chesapeake Bay serves as an important nursery and feeding ground for young black sea bass. Spawning is temperature dependent and occurs in the coastal ocean at depths of 60–140 ft (Musick and Mercer 1977). In the Mid-Atlantic Bight, spawning begins around June and occurs primarily in the region between Chesapeake Bay and Montauk, Long Island. Juveniles occur in saline areas of estuaries along the coast and may enter Chesapeake waters (at approximately 5.8 cm total length) during spring, summer, and fall months and remain until December (Geer et al. 1990; Bonzek et al. 1991, 1992). By the time the fish have reached 25.4 cm, most have left inshore waters for coastal and ocean habitats (D. Boyd, Virginia Marine Resources Commission, personal communication).

Recent stock assessment results indicate that black sea bass is overfished, occurring at low levels of abundance (NEFSC 1997). Since most black sea bass catches take place in the EEZ (under federal jurisdiction), management of the species occurs under a joint FMP through authority of the ASMFC and MAFMC.

Blue Crab

The blue crab is a bottom-dwelling decapod found in estuaries, lagoons, and coastal habitats of the western Atlantic, Caribbean, and Gulf of Mexico. This portunid (swimming) crab is economically important throughout its range. It once

Blue Crab *Callinectes sapidus*

Life Cycle: Larvae released near Bay mouth
Larvae transported to continental shelf
Postlarva at nearshore Atlantic Shelf

Life History Categories:

S_{CB} Resides in Chesapeake Bay
S_{CST} Resides in coastal waters outside Bay (during larval stage)
S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Over
Relative Abundance: Low

ASMFC Management:

FMP	No FMP
Management Unit	No FMP
Monitoring	No FMP
Stock Assessment	No FMP

Estimated Removals from Atlantic Coast

Commercial (MT)	*Recreational (MT)*
N/A	N/A

CBP Management:

FMP	Adopted 1997, Amendment 1, 2003
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent and fishery independent
Stock Assessment Baywide	Conducted 1997

NOAA

M	0.375	F	0.865
$F_{0.1}$	0.36	F_{MAX}	0.64
F_{REP}	1.17	$F_{10\%}$	1.21
$F_{\%MSP}$		F_{HIGH}	1.76
F_{LOW}	0.48		

Absolute Abundance	83,955 MT

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	34,812.8	Not reported
1996	33,138.1	Not reported
1997	38,356.6	Not reported
1998	29,431.5	Not reported
1999	30,029.4	Not reported
2000	22,788.5	Not reported
2001	22,260.2	Not reported
2002	22,865.8	Not reported
2003	20,906.3	Not reported

supported the largest single-species crab fishery worldwide, although more recently ranked third in world harvests (FAO 2002; Secor et al. 2002). Blue crab landings from the Chesapeake Bay accounted for over 50% of the national total during the late 1970s through the early 1990s (Orth and van Montfrans 1990). This species has the highest value of any Chesapeake Bay commercial fishery and supports a major, but poorly evaluated, recreational fishery. Blue crabs are harvested as hard shell crabs, peeler crabs (just prior to molting), and softshell crabs (immediately after molting).

The size of the blue crab stock is initially controlled by successful entry and settlement of blue crab postlarvae (the survivors of the larval phase) into Bay nursery habitats. Numbers of blue crab fluctuate annually. To prevent recruitment overfishing of stocks with variable abundance, taking fewer individuals in some years may prove necessary (Holmes 1994).

The viability of the blue crab fishery in Chesapeake Bay presently is threatened. A dramatic decrease in the combined Maryland and Virginia blue crab landings has taken place since the early 1990s. This decline, along with increased fishing effort and decreased catch per unit effort (CPUE) in the commercial fishery since 1945, likely relates to recruitment overfishing (CBP 1997). Factors such as wasteful fishing practices, degraded water quality, and related reductions in suitable habitat (e.g., submerged aquatic vegetation), however, have also been linked to this decline (CBP 1997). In addition, the debate over the effect of striped bass predation on the blue crab stock grows, with Chesapeake Bay striped bass at their highest numbers in decades along with continued dwindling of the blue crab population (Orner 2001). During 2000, baywide abundance indices for age 0, age 1+, and adult females (as indexed in the Chesapeake Bay Winter Dredge Survey) were the lowest in the survey's 10-year time series (CBSAC 2001).

Development of the 1989 Chesapeake Bay Blue Crab FMP (CBP 1989) unified the management approach among Bay jurisdictions. This FMP recognized the importance of the resource, identified areas of concern, and recommended strategies to stabilize fishing effort. Since 1989, new regulations have been implemented, commercial reporting improved, and additional data collected.

In 1996, the Bi-State Blue Crab Advisory Committee (BBCAC) was created through the Chesapeake Bay Commission (CBC) to facilitate dialogue and coordinate blue crab fishery management options among three Bay jurisdictions: Maryland, Virginia, and the Potomac River Fisheries Commission. The BBCAC is not a regulatory body; it consists of a select group of state legislators from Virginia and Maryland and is charged with providing advice to the governors, legislatures, and resource management agencies of Chesapeake Bay jurisdictions. The CBC conveys the findings and recommendations of the BBCAC (obtained with the assistance of its Technical Advisory Committee) to the states. Each jurisdiction then considers management regulations with the goal of implementing complementary regulations baywide. A second FMP for blue crab was implemented in 1997. Its goal is to manage blue crabs in the Chesapeake Bay in a manner that conserves the baywide stock, protects its ecological value, and optimizes the long-term use of this important resource.

Bluefish

The bluefish is the only species in the family Pomatomidae. This large predator is an offshore spawner that inhabits the continental shelf waters of warm temperate zones in most

Bluefish *Pomatomus saltatrix*

Life Cycle: Migratory coastal spawner

Life History Categories:

- S_{CB} Resides in Chesapeake Bay
- S_{CST} Resides in coastal waters outside Bay
- S_{EST} Resides in other estuaries along Atlantic seaboard

Duane Raver

Relative Exploitation Level:	Overexploited
Relative Abundance:	Low

ASMFC Management:

FMP	Amendment 1 approved July 1999
Management Unit	Migratory stocks from Maine to Florida
Monitoring	Fishery dependent
Stock Assessment	Updated in 2000
F	0.28
SSB	Not estimated

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	3,628.8	6,489.4
1996	4,112.7	5,327.9
1997	4,064.8	6,487.2
1998	3,739.5	5,594.7
1999	3,329.5	3,743.6
2000	3,646.7	4,810.8
2001	3,944.7	6,001.0
2002	3,115.6	5,158.1
2003	3,358.4	5,958.6

CBP Management:

FMP	Adopted 1990 (Adheres to ASMFC FMP)
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	292.7	245.6
1996	279.4	337.9
1997	335.4	738.2
1998	444.7	295.9
1999	289.0	227.2
2000	279.9	216.8
2001	417.9	448.0
2002	267.1	301.2
2003	195.5	302.2

oceans of the world. Along the Atlantic coast, it ranges from Nova Scotia to Florida and visits the Chesapeake region from spring to autumn. Adults overwinter off the southeastern coast of Florida and begin a northerly migration in the spring, with local movements in and out of bays and sounds. During the northward migration, a spring spawning period takes place from Florida to southern North Carolina. A second spawning occurs off the mid-Atlantic coast during the summer. Juveniles from both spawning waves enter the lower Bay and its tributaries. Although, no current stock assessment of bluefish within the Chesapeake Bay exists, this species is abundant in the lower Bay and common most years in the upper Bay. In the early autumn, bluefish migrate out of the Bay and move south along the coast. This species is a voracious predator of fish and squid and may compete with adult striped bass, mackerel, and large weakfish (Hartman and Brandt 1995). Bluefish adults have few predators other than humans. The bluefish commercial fishery in the Chesapeake accounts for about 15–20% of total U.S. landings of this species. The bluefish also represents a popular and important sport fish in the Bay.

The MAFMC and the ASMFC adopted an initial coastal FMP for bluefish in 1989, with NMFS adopting the plan in 1990. Signs of stock overexploitation and decreasing stock abundance prompted FMP development. The plan included a harvest quota for the fishery with 80% of the catch allotted to the recreational sector and 20% to the commercial sector. This coastal bluefish FMP was amended in 1999 to set forth a 9-year stock-rebuilding schedule. Specified management measures of the amendment include commercial quotas, minimum fish sizes and minimum mesh sizes, gear regulations, and recreational possession limits, size limits, and seasonal closures. In response to new coastal management measures introduced through Amendment 1 of the coastal bluefish FMP (MAFMC 1998), the CBP bluefish FMP was also amended in 2001 to address CBP ecosystem-based multispecies management objectives.

Horseshoe Crab

The horseshoe crab is a benthic or bottom-dwelling arthropod that uses both estuarine and continental shelf habitats. It ranges from the Yucatan Peninsula to northern Maine. Not a true crab, it is more closely related to arachnids (spiders). Along the Atlantic coast, horseshoe crabs are most abundant between Virginia and New Jersey, with Delaware Bay forming the center of its distribution. Migrating adults move inshore from deep bay and coastal waters in late spring to spawn. Spawning in the Chesapeake Bay area usually begins during late May when horseshoe crabs move onto beaches to mate and lay eggs (ASMFC 1998b).

Horseshoe crabs represent an important food source for the migrating shorebirds that prey on this crab's eggs and newly hatched larvae. Juvenile Atlantic loggerhead turtles, blue crab, and a host of other finfish also prey on this species (Botton 1984; Keinath et al. 1987). Human exploitation of the sites used by horseshoe crabs and shore birds contributes to habitat loss for these species, with the rate of coastal wetlands and beach areas lost corresponding to the density of human population (Gosselink and Baumann 1980). Activities that alter physically protected sand beaches ultimately have a negative impact on the horseshoe crab population, since the crabs use these environments for spawning.

Historically, horseshoe crabs were harvested for fertilizers as well as

Horseshoe Crab *Limulus polyphemus*

Life Cycle: Estuarine and continental shelf

Life History Categories:

- S_{CB} Resides in Chesapeake Bay
- S_{CST} Resides in coastal waters outside Bay
- S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level:	Not estimated
Relative Abundance:	Not determined

NOAA

ASMFC Management:

FMP	Addendum II approved 2001
Management Unit	Yucatan Peninsula to Maine
Monitoring	Fishery dependent
Stock Assessment	Not conducted
F	Not estimated
SSB	Not estimated

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	1,096.0	Not reported
1996	2,340.3	Not reported
1997	2,713.9	Not reported
1998	3,100.5	Not reported
1999	2,379.8	Not reported
2000	1,703.9	Not reported
2001	1,059.9	Not reported
2002	1,257.3	Not reported
2003	1,190.4	Not reported

CBP Management:

FMP	Adopted 1994 (Adheres to ASMFC FMP)
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	9.3	Not reported
1996	693.1	Not reported
1997	805.6	Not reported
1998	1,457.0	Not reported
1999	1,082.2	Not reported
2000	375.2	Not reported
2001	259.1	Not reported
2002	360.1	Not reported
2003	309.9	Not reported

poultry and livestock food. Current commercial interest in horseshoe crabs is driven by their use as bait in pot fisheries for American eel, conch, and catfish. Fishing effort is generally concentrated in the mid-Atlantic, specifically New Jersey, Delaware, Maryland, Virginia, and adjacent federal waters. Fishing mortality also stems from the use of horseshoe crab blood in biomedical research (ASMFC 1977). No known recreational fishery for horseshoe crabs exists. In 1994, jurisdictions within Chesapeake Bay adopted the Chesapeake Bay and Atlantic Coast horseshoe crab FMP (CBP 1994c). Objectives of this plan included protection of the ecological role of horseshoe crabs, development of a spawning stock monitoring program, improvement of commercial data, and delineation of spawning regions and areas used by migrating shorebirds.

In 1998, the ASMFC adopted the Interstate Fishery Management Plan for Horseshoe Crab (ASMFC 1998b). This FMP acknowledges that the necessary information is lacking for a comprehensive coastwide stock assessment. Nonetheless, data on the horseshoe crab were reviewed to investigate recent trends and patterns in stock abundance and fishery performance (ASMFC 1998c). Although the ASMFC technical review teams noted differences in the appropriateness of the surveys used in the assessment, they concluded that a

Eastern Oyster *Crassostrea virginica*

Life Cycle: Planktonic larvae
Sessile benthic invertebrate

Life History Categories:

S_{CB} Resides in Chesapeake Bay
S_{CST} Resides in shallow coastal waters outside Bay
S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Overexploited

Relative Abundance: Low

NOAA

ASMFC Management:

FMP	No FMP
Management Unit	No FMP
Monitoring	Fishery dependent
Stock Assessment	Not conducted (Coastal)
F	Not estimated
SSB	Not estimated

CBP Management:

FMP	Adopted 1994, Draft Comp. Oyster Plan 2003
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent and independent
Baywide Stock Assessment	Not conducted

Estimated Removals from Atlantic Coast

	Commercial (MT)	Recreational (MT)
1995	2,755.3	Not reported
1996	3,072.7	Not reported
1997	2,320.9	Not reported
1998	2,582.2	Not reported
1999	2,359.4	Not reported
2000	1,887.5	Not reported
2001	1,489.4	Not reported
2002	1,166.0	Not reported
2003	1,131.8	Not reported

Estimated Removals (MD and VA combined)

	Commercial (MT)	Recreational (MT)
1995	723.9	Not reported
1996	475.6	Not reported
1997	786.0	Not reported
1998	1,217.3	Not reported
1999	1,263.8	Not reported
2000	1,148.2	Not reported
2001	672.6	Not reported
2002	301.3	Not reported
2003	107.3	Not reported

conservative risk-averse management strategy is necessary based on increases in catch and effort coupled with several surveys showing localized declines in relative abundance. Additionally, horseshoe crabs are less resilient to overharvesting due to their slow maturation rate. More research and monitoring were deemed necessary, with specific monitoring programs recommended for future stock assessments.

Eastern Oyster

The Eastern oyster *Crassostrea virginica* also known as the American oyster, was once so plentiful in the Chesapeake Bay that annual landings were in the millions of bushels (see Externalities Element). As recently as 100 years ago, oyster reefs were so massive that they posed a navigational hazard to ships (CBP 2003). These filter feeders perform functions vital to the Bay ecosystem by

1) Consuming phytoplankton and detrital particles with sequestered nutrients by filtering up to 5 L of water per h;
2) Providing habitat for communities of animals, such as worms, snails, sea squirts, sponges, small crabs, and fish through the convoluted and varied surface of oyster reefs; and
3) Supplying food for birds, such as the American oystercatcher *Haematopus palliates* when the oysters lie exposed on intertidal flats.

Today's oyster population in the Chesapeake Bay has dropped to about 1% of its historic level. Kennedy (1991), Rothschild et al. (1994), and Jackson et al. (2001) have documented factors contributing to this decline:

1) Historic fishing practices, which removed huge volumes of large oysters and oyster shells and destroyed reef habitat and suitable sites for oyster spat settlement;
2) Two parasites lethal to oysters within the first two years of life MSX *Haplosporidium nelsoni*, which thrives in the higher salinities of dry years, and Dermo *Perkinsus marinus*, which tolerates low salinity and is, therefore, more damaging to oyster populations baywide;
3) Loss of habitat due to sedimentation and accelerated eutrophication that leads to severe depletion of oxygen in deeper waters and may impede development of oyster larvae. Pollutants such as metals are toxic to vulnerable juvenile oysters;
4) Siltation from developed land, farm fields, and forest logging, which may smother oysters or prevent them from feeding; and
5) A host of natural predators, such as sea anemones, sea stars, sea nettles, sea squirts, and other filter feeders that eat oyster larvae. Flatworms, small crabs, and some demersal fishes consume newly set oyster spat.

In 1989, the CBP developed the Chesapeake Bay Oyster Fishery Management Plan (CBP 1989), which included strategies to address problems of harvest decline, recruitment, disease mortality, leased ground production, habitat issues, shellfish sanitation, market production, and the repletion program. The oyster commercial harvest continued to decline, however, so special committees were organized to review the situation. A second Chesapeake Bay Oyster Fishery Management Plan (CBP 1994d) superceded the 1989 FMP; its management unit extends throughout the Bay (excluding Virginia's intertidal seaside bars). The 1994 FMP posed strategies to address baywide concerns including disease, repletion programs, habitat and water quality, management to increase oyster production, and data collection to assess population abundance and removals.

CBP has recently developed a new Oyster Management Plan (CBP 2005) that presents an overall strategy for restablishing native oyster populations to the Bay. The ultimate goal of CBP partners is to restore and maintain the valuable ecological services provided by native oyster populations, while continuing to support an oyster fishery. The overall management strategy consists of three main components. The first delineates sanctuaries to increase the ecological function of oyster beds. Sanctuaries will lead to increased biomass through natural spat settlement and oyster seed stocking because the oysters are protected from harvest. The second implements harvest strategies to build a sustainable oyster industry in both Maryland and Virginia. The third recognizes disease constraints and implements management strategies that reduce the impact of disease.

In response to the decline in the native oyster population, the states of Maryland and Virginia have proposed intentional introduction of a nonnative oyster species, Suminoe oyster (also known as Asian oyster) *Crassostrea ariakensis*, which is believed to have greater resistance to the pathogens responsible for MSX and dermo. Considerable controversy exists over this proposed course of action and many questions remain concerning possible implications. In 2003, the U.S. Congress mandated that an environmental impact statement (EIS) be prepared to examine both the risks and benefits of introducing this species to the Bay. In 2004, NOAA began a nonnative oyster research initiative to provide the scientific data required for this EIS.

Red Drum

A member of the family Sciaenidae, red drum occurred historically from Massachusetts to the northern coast of Mexico, but has not been reported north of New Jersey in recent years. This Bay and inshore spawner grows larger than all Bay sciaenids except black drum. Juveniles are most abundant in estuarine waters and inlets. In the Chesapeake region, red drum occurrence is limited to young of year, yearling, and mature fish at least 6 years of age (CBP 1993).

The ASMFC and the SAFMC jointly manage red drum. The FMP defines the management unit as those stocks that inhabit state waters from New Jersey through Florida. The primary goal of the FMP is to achieve and maintain optimum yield. A spawning potential ratio (SPR) allowing 40% of

Red Drum *Sciaenops ocellatus*

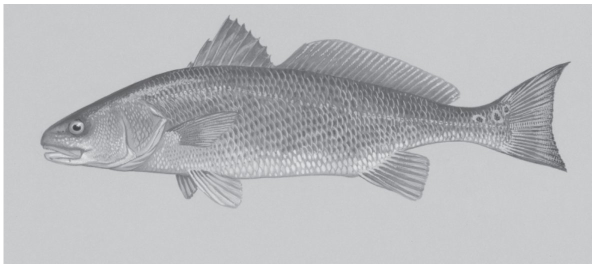
Life Cycle: Nearshore spawners
Estuarine juveniles
Offshore adults

Life History Categories:

S_{CB} Resides in Chesapeake Bay
S_{CST} Resides in coastal waters outside Bay
S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Overfished

Relative Abundance: Not estimated



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ASMFC and SAFMC Joint Management:

FMP	Amendment 2, 2002
Management Unit	Coastal waters Florida to Maine
Monitoring	Fishery dependent and independent
Stock Assessment	Conducted 1999; Updated 2000
F	Individual state estimates
SSB	Not estimated

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	115.4	777.8
1996	53.4	618.5
1997	26.3	368.4
1998	137.2	602.0
1999	175.3	557.7
2000	129.1	734.3
2001	70.3	626.9
2002	40.5	534.8
2003	42.8	711.6

CBP Management:

FMP	Adopted 1993 (Adheres to ASMFC FMP)
Management Unit	Watershed to Bay mouth
Monitoring	Fishery independent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	1.4	30.1
1996	.9	0 .7
1997	1.8	0 .8
1998	3.1	15.8
1999	5.9	42.1
2000	5.6	43.4
2001	2.4	23.5
2002	3.5	77.3
2003	1.7	26.0

the female red drum from each year class to survive and become reproductive would facilitate obtaining optimum yield. Currently, the coastwide stock is considered overfished. Both northern and southern components of stocks have reached an interim goal of 10% SPR (ASMFC 2002). The overall population remains overfished, however, and will remain so until SPR values reach 30%. The primary management measures are bag and size limits. A maximum size of 27 in total length is allowed within the management area. States north of the management area are requested to prohibit the possession and sale of red drum over 27 in.

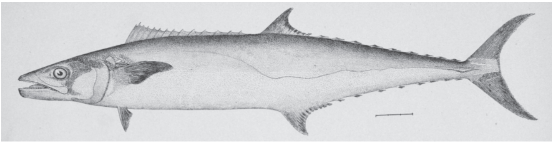
Spanish and King Mackerel

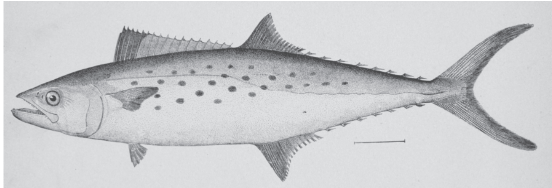
Spanish mackerel and king mackerel are migratory offshore spawners and members of the mackerel family, Scombridae. Spanish mackerel inhabit coastal waters of the western Atlantic Ocean from the Gulf of Maine to Florida and the Gulf of Mexico. King mackerel inhabit coastal waters from

Mackerels

King Mackerel *Scomberomorus cavalla*

Spanish Mackerel *Scomberomorus maculatus*


King Mackerel


Spanish Mackerel

NOAA

Life Cycle: Migratory offshore spawning
Coastal pelagic schooling

Life History Categories:

S_{CB} Resides in Chesapeake Bay
S_{CST} Resides in coastal waters outside Bay
S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Fully

Relative Abundance: Moderate

ASMFC Management:

FMP	Adopted 1990
Management Unit	Florida to New York (excluding Pennsylvania)
Monitoring	Fishery dependent
Stock Assessment (Coastal)	Annually since 1999 (Spanish mackerel only)
F	Below F_{Max} & Below F_{OY}
$B_{2002/2003}$	1.78 x B_{MSY}

Estimated Removals from Atlantic Coast (Spanish mackerel only)

	Commercial (MT)	*Recreational (MT)*
1995	2,900.3	376.6
1996	2,588.5	497.3
1997	3,364.9	664.0
1998	2,859.9	456.3
1999	1,448.1	538.5
2000	2,510.1	823.8
2001	2,576.7	843.6
2002	2,414.3	2,204.2
2003	2,795.4	2,960.4

CBP Management:

FMP	Adopted 1994 (Adheres to ASMFC FMP)
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined – Spanish mackerel only)

	Commercial (MT)	*Recreational (MT)*
1995	80.1	281.7
1996	130.0	36.5
1997	77.0	10.1
1998	62.3	28.7
1999	125.4	36.9
2000	89.5	47.1
2001	89.6	25.7
2002	9.4	0.0
2003	2.4	4.4

the Gulf of Maine to Brazil and the Gulf of Mexico. These species occur most commonly from Chesapeake Bay southward and are found only occasionally in the upper, low salinity region of the Bay. Both species visit the middle and lower Chesapeake Bay to prey on seasonally abundant estuarine fish, including menhaden and anchovies. Coastal and estuarine waters form important nursery grounds for the juveniles of both species (CBP 1999).

Both species support major commercial and recreational fisheries in the Atlantic Ocean and the Gulf of Mexico. Since Spanish mackerel occurs more frequently in nearshore environments, this species represents the more important of the two to fishermen in the Bay states. During the 1880s, up to 86% of the coastwide catch of Spanish mackerel came from the Chesapeake. Recent landings from the Bay have been much lower, with landings from Maryland and Virginia accounting for only 8.5% of the Atlantic coast landings from 1990 through 1998. The recreational fishery for Spanish mackerel along the Atlantic coast is significant, with the species becoming important in the Chesapeake recreational fishery during the 1990s. The Spanish mackerel recovered from coastwide overfishing during the 1990s. Technically, the species may not be fully recovered, but catches in the Chesapeake Bay and coastwide are increasing under strict management regulations. King mackerel also has supported important commercial fisheries along the south Atlantic and Gulf coasts for most of the 20th century. In the Chesapeake Bay, the commercial fishery for king mackerel has remained small. Catches in Maryland and Virginia are relatively low, averaging less than 1% of the total coastwide catch (MD DNR 1999f). Virginia has a small recreational fishery for king mackerel.

In federal waters (3 to 200 mi from the coast), the Coastal Pelagic Resources Fishery Management Plan—jointly developed in 1982 and since amended 13 times by the SAFMC and the Gulf of Mexico Fishery Management Council—regulates Spanish and king mackerel fishing. The ASMFC subsequently adopted an FMP (ASMFC 1990) for Spanish mackerel in state territorial waters to track the federal Coastal Migratory Pelagic Resources Fishery Management Plan (GOM/SAFMC 1983). State regulations should track changes in the federal FMP. Partial stock assessments from 1999 by both the GMFMC and SAFMC indicate that Spanish and king mackerel stocks are not overfished and occur at moderate levels of abundance.

The management strategy of the Chesapeake Bay king and Spanish mackerel FMP is to support measures adopted under the coastal pelagic resources FMP for compatible and coordinated interjurisdictional management. Individual Chesapeake states adopt minimum size and creel limits consistent with regulations in effect in federal waters. In addition, Maryland and Virginia close their respective king and Spanish mackerel recreational and

Spotted Seatrout ***Cynoscion nebulosus***

Life Cycle: Seasonal migrant. Primarily estuarine. Spawns near Bay mouth and nearby coastal waters.

Life History Categories:

- S_{CB} Resides in Chesapeake Bay
- S_{CST} Resides in coastal waters outside Bay
- S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Medium

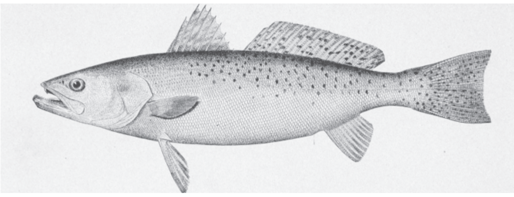
Relative Abundance: Medium

ASMFC Management:

FMP	Adopted 1984; Amendment 1 approved 1991
Management Unit	Maryland to Florida (state territorial waters)
Monitoring	MRFSS, State fishery dependent surveys
Stock Assessment	Not conducted
F	Not estimated
SSB	Not estimated

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	361.1	1,005.3
1996	136.9	404.8
1997	147.4	634.0
1998	178.6	584.2
1999	311.5	1,121.3
2000	209.9	889.8
2001	74.6	530.8
2002	109.9	485.9
2003	98.4	600.6



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CBP Management:

FMP	Adopted 1990 (Adheres to ASMFC FMP)
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	13.1	81.6
1996	8.8	35.0
1997	12.4	133.7
1998	18.9	44.9
1999	34.0	131.8
2000	18.2	88.7
2001	12.9	12.1
2002	9.5	13.1
2003	2.8	100.5

commercial fisheries when such closures are in effect in federal waters (CBP 1994e).

Spotted Seatrout

Spotted seatrout is a member of the family Sciaenidae, which is primarily an estuarine species that ranges from Cape Cod to Mexico. Only rarely does this fish occur north of Delaware. It migrates seasonally into the Chesapeake Bay throughout Bay waters, but is most abundant in the seaward portion. Spotted seatrout prefer shallow water over sandy bottoms, submerged aquatic vegetation, shell reefs, or bottom structures. Spawning occurs from May through July near the Bay mouth and in nearby coastal waters (CBP 1990b).

The spotted seatrout does not support an important commercial fishery in the Maryland portion of the Bay. Virginia landings have declined since their high point in the 1940s. Chesapeake Bay survey data indicate that the recreational catch exceeds the commercial harvest (CBP 1990b).

The ASMFC spotted seatrout FMP was approved and adopted by the commission in 1984 (ASMFC 1984). Amendment 1 was approved in 1991 (ASMFC 2002). Actions to meet spotted seatrout management objectives included

1) Continue efforts to achieve full implementation of the FMP;
2) Continue and increase collection of commercial and recreational landings data, including effort data;
3) Develop and implement methodology to obtain prerecruit indices to monitor stock status;
4) Coordinate research and monitoring activities at state and regional levels along with periodic review; and
5) Update the FMP to incorporate new data and research findings.

The Chesapeake Bay weakfish and spotted seatrout FMP (CBP 1990b) follows the guidelines established by the ASMFC and MAFMC for coastwide management of fisheries for these species, providing fair allocation of the resources, promoting efficient harvesting practices, encouraging biological and economic research, and pursuing standards of environmental quality and habitat protection (CBP 1990b).

Striped Bass

The striped bass is a member of the family Moronidae—the temperate basses—and has been one of the most sought after commercial and recreational finfish in the Chesapeake Bay since colonial times. Atlantic coast striped bass range from the St. Lawrence River in Canada to the St. Johns River in Florida and from western Florida to Louisiana in the Gulf of Mexico. This large predator is found in the coastal ocean and estuaries and has been widely introduced into freshwater lakes and reservoirs. Striped bass is an anadromous species and migrates along the coast, but fish from the southernmost (North Carolina to northern Florida) and northernmost (Nova Scotia) extremes of its range are relatively isolated and likely do not undertake coastal migrations. The east coast migratory population is composed of three major stocks: Hudson, Chesapeake, and Roanoke (Richards and Rago 1999). In these stocks, adult fish return to tidal tributaries to spawn in spring months and then a portion of the adults migrate back to the coastal ocean after spawning (Dorazio et al. 1994). The Chesapeake Bay forms the largest nursery for juvenile striped bass on the Atlantic coast.

Striped bass is strongly estuarine-dependent. The Chesapeake Bay serves as both spawning and nursery grounds for 70–90% of the Atlantic population (Van Winkle et al. 1988). This aspect of their natural history makes them vulnerable to anthropogenic influences. The recent history of striped bass in the Bay, however, represents a management success story (Richards and Rago 1999). Following record high catches in the early 1970s, reported catches from commercial and recreational fisheries declined precipitously until the late 1980s. The declines in striped bass landings, abundance, and recruitment levels were attributed primarily to overfishing, which may have made the population more

Striped Bass *Morone saxatilis*

Life Cycle: Anadromous

Life History Categories:

S_{CB}	Resides in Chesapeake Bay
S_{CST}	Resides in coastal waters outside Bay
S_{EST}	Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Limited - Fisheries in EEZ remain closed

Relative Abundance: High; Fully recovered

ASMFC Management:

FMP	Adopted 1981; Amendment 6. 2003
Management Unit	Migratory stocks from Maine to North Carolina
Monitoring	Fishery dependent
Stock Assessment	Adopted 1981; Amended 1995
F_{Target}	0.30
$F_{Threshold}$	0.41
SSB_{Target}	17,500 MT
$SSB_{Threshold}$	13,600 MT

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	1,737.0	5,710.7
1996	2,133.7	6,043.5
1997	2,791.9	7,342.6
1998	3,045.3	5,856.0
1999	2,916.6	6,346.2
2000	3,138.0	8,065.4
2001	2,949.7	8,881.5
2002	2,878.6	8,458.1
2003	3,213.9	10,411.3

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CBP Management:

FMP	Adopted 1989 (Adheres to ASMFC FMP)
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent and Fishery independent
Baywide Stock Assessment	Conducted
F	0.27
SSB	Not estimated

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	896.7	1,366.8
1996	1,452.9	1,315.8
1997	1,841.3	2,166.6
1998	2,149.3	1,583.0
1999	1,945.8	1,306.3
2000	2,229.0	1,862.7
2001	1,859.2	1,875.3
2002	1,780.8	1,847.9
2003	1,949.2	2,539.5

Summer Flounder *Paralichthys dentatus*

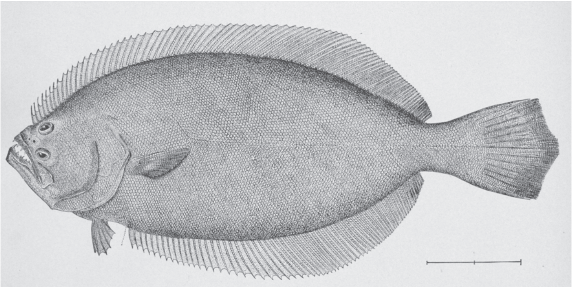
Life Cycle: Migratory offshore spawner
Coastal and estuarine nursery areas

Life History Categories:

- S_{CB} Resides in Chesapeake Bay
- S_{CST} Resides in coastal waters outside Bay
- S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Overfishing occurring

Relative Abundance: Medium



NOAA

ASMFC Management:

FMP	Amendment 13 approved 2003
Management Unit	Coastal waters from NC to U.S.-Canadian border
Monitoring	NMFS Fishery independent state seasonal surveys
Stock Assessment	2000 (NEFSC SAW)
F	0.27
F_{max}	0.26
Biomass	27% > threshold
Threshold	76,650 MT
Target	153,300 MT

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	6,990.4	2,259.4
1996	5,740.9	4,473.2
1997	3,895.3	5,393.8
1998	4,982.5	5,680.3
1999	4,758.2	3,803.3
2000	4,994.3	7,491.0
2001	4,858.7	5,288.8
2002	6,453.5	3,641.9
2003	6,497.8	5,290.3

CBP Management:

FMP	Adopted 1991; Amendment 1, 1997 (adheres to ASMFC)
Management Unit	Watershed to Bay mouth
Monitoring	Fishery independent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	1,582.0	557.1
1996	1,036.8	542.8
1997	1,075.2	837.2
1998	1,186.5	1,115.6
1999	996.0	577.2
2000	1,001.0	773.3
2001	1,206.4	1,355.0
2002	1,426.8	846.4
2003	1,746.9	642.1

susceptible to stresses from pollution and natural environmental variability. In response to this downturn, Congress passed the Atlantic Striped Bass Conservation Act in 1984. Maryland and Delaware imposed fishing moratoria on striped bass from 1985 through 1989; Virginia imposed a 1-year moratorium in 1989. The Chesapeake Bay fishery reopened in 1990, after 3-year average recruitment levels exceeded an established threshold value, although fishing mortality remains tightly controlled in the present fishery. A coastwide FMP, from Maine to North Carolina, is in effect for striped bass under the ASMFC (ASMFC 1981, 1996a). The primary objective of the CBP striped bass FMP (CBP 1989b) is to follow ASMFC annual guidelines and requirements including controlling fishing mortality, developing regulations to allocate and control safe harvest levels, determining stock assessment and research needs, and examining the effects of environmental parameters (water quality, habitat) on striped bass stocks. The coastal striped bass stock is fully exploited; combined commercial landings from Maryland and Virginia have remained stable since the mid-1990s. The reported recreational catch (coastwide) has also remained stable since that time (NMFS 2001).

Summer Flounder

Summer flounder is a member of the flatfish family Paralichthyidae. It inhabits estuarine and coastal waters from Nova Scotia to southern Florida. The Chesapeake is a nursery ground for summer flounder. Most individuals visit the Bay as juveniles from spring through autumn, migrating offshore for the winter. Some overwinter in the Bay, however. Spawning occurs in the coastal ocean during the offshore migration from late summer to midwinter.

More than 90% of the summer flounder landed in Maryland and Virginia come from offshore otter trawls in coastal waters of the EEZ (CBP 1991c). Within the Chesapeake Bay, summer flounder is fished commercially, but catches are low with preliminary 1990 landings at 37,648 MT. Maryland commercial landings (within Bay and coastal) averaged 85,335 MT annually between 1995 and 1999 (MD DNR 1999h). Commercial landings in Virginia Bay waters and the coastal ocean have historically remained an order of magnitude higher than those in Maryland waters (CBP 1991c). The recreational fishery for summer flounder harvests a significant proportion of the total catch. In some years recreational landings have exceeded commercial landings (NEFSC 2001). Estimated recreational landings constituted about 34% of the total landings from 1981 to 1990, averaging 6,400 MT during that period and peaking at 12,700 MT in 1983. Recreational landings averaged 3,200 MT from 1990 to 1995. Since 1997, recreational landings have increased, usually exceeding commercial landings. The preliminary 1999 recreational catch estimate for the Bay and nearshore coastal waters combined was 4,218,414 MT(MD DNR 1999h).

The ASMFC and MAFMC jointly manage summer flounder as a coastal resource under the summer flounder, scup and black sea bass FMP adopted by both bodies in 1998. Fishing mortality is controlled through a coastwide total allowable catch (TAC), allocated among states into commercial and recreational components. The stock is rapidly rebuilding under ASMFC/MAFMC management. Spawning stock biomass had declined 72% from 1983 to 1989 (18,800 MT to 5,200 MT) but has since increased more than fivefold to 29,300 MT in 1999, with an accompanying expansion of the age structure. The stock is considered at a medium level of abundance relative to historic levels. According to the ASFMC (2004), “the resource is no longer overfished but overfishing is occurring. Stock biomass increased substantially in 2003 and is 27% above the biomass threshold.”

The CBP FMP for summer flounder was adopted in 1991 with a progress report following in 1999 (MD DNR 1999h). Chesapeake Bay jurisdictions are currently in compliance with MAFMC/ASMFC recommendations for the summer flounder stock. Management objectives for Bay jurisdictions include the following actions

1) Developing management measures to achieve a 41% reduction in recreational landings;
2) Continuing to manage the commercial fishery according to the MAFMC coastwide quota system;
3) Continuing to monitor the summer flounder resource in the Bay and along the coast; and
4) Implementing measures to collect more discard information.

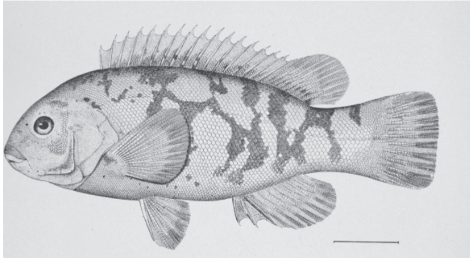
Tautog

The tautog is a long-lived, slow-growing member of the family Labridae. The species ranges from Nova Scotia to South Carolina and inhabits the colder and predominantly saline waters of bays and estuaries. A year-round resident of the Chesapeake Bay, tautog is locally abundant at the Bay’s mouth and lower section from autumn to spring. The species enters the Chesapeake when water temperature drops to about 40° F and can range as far up the Bay as the Chester River during the winter. During the summer (and perhaps also in January and February), a distribution shift to colder offshore locations takes place. Spawning occurs from late April to early August, both in the lower Bay and offshore. Tautog is of minor commercial value, but very popular with anglers. Because this fish is easily located by fishermen and slow to replenish, tautog is susceptible to overfishing and requires a conservative management strategy.

Put in place in 1996 (with size regulations and trip limits imposed to reach a target coastal rate of fishing mortality), the ASMFC FMP for this fish was amended in 1999 to reduce fishing effort further. Recent management measures appear to have lowered fishing mortality to interim target levels, but further reductions are needed. On a coastwide basis, the tautog is considered overexploited (ASMFC 1999a). Additional data describing the stock are required to manage tautog adequately in the southern extent of its range.

The Chesapeake Bay and Atlantic Coast Tautog Fishery Management Plan was adopted in 1998 (CBP 1999). It follows the guidelines established by the ASMFC (1996b) for coastwide management of the Atlantic tautog stock to ensure that high levels of recreational fishing and increased commercial interest in tautog since the 1990s would not lead to further stock depletion (MD DNR 1999d).

Tautog *Tautoga onitis*


NOAA

Life Cycle: Year-round resident
Seasonal inshore-offshore migrations

Life History Categories:

- S_{CB} Resides in Chesapeake Bay
- S_{CST} Resides in coastal waters outside Bay
- S_{EST} Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Overexploited

Relative Abundance: Low

ASMFC Management:

FMP	Adopted 1996; Addendum III
Management Unit	Coastal states from Massachusetts to North Carolina
Monitoring	Fishery dependent and independent (by state)
Stock Assessment	2001 Tautog Tech. Committee
F_{Target}	0.41
SSB	7,514 MT

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	170.4	2,071.7
1996	161.4	1,444.6
1997	127.4	999.7
1998	115.3	671.2
1999	94.7	1,148.8
2000	112.2	1,541.5
2001	138.2	1,247.3
2002	159.4	2,463.6
2003	155.1	1,069.6

CBP Management:

FMP	Adopted 1998 (Adheres to ASMFC FMP)
Management Unit	Watershed to mouth of Bay
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	15.6	330.8
1996	13.5	365.0
1997	15.0	260.5
1998	9.3	136.6
1999	12.4	109.3
2000	8.5	110.9
2001	8.3	90.7
2002	12.7	100.3
2003	7.3	159.7

Weakfish

Weakfish is a member of the drum family Sciaenidae. This fish occurs from Nova Scotia to Florida but is most abundant from North Carolina to Long Island. Weakfish migrate northward in spring and summer and southward in the fall. Most of the Atlantic coast harvest takes place during these annual migrations. Weakfish occur throughout Chesapeake waters. Adults school and frequent shallow sandy bottom areas with salinities above 10 ppt. The weakfish is a piscivore with menhaden and bay anchovy representing important prey species. Spawning occurs in nearshore and estuarine waters along

Weakfish *Cynoscion regalis*

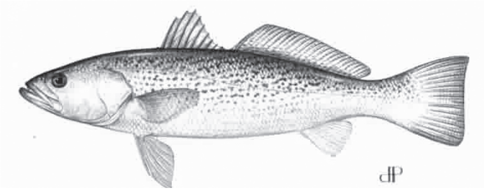
Life Cycle: Seasonal coastal migrations
Inshore spawning

Life History Categories:

S_{CB}	Resides in Chesapeake Bay
S_{CST}	Resides in coastal waters outside Bay
S_{EST}	Resides in other estuaries along Atlantic seaboard

Relative Exploitation Level: Uncertain

Relative Abundance: Uncertain



Diane Peebles

ASMFC Management:

FMP	Adopted 1985; Amendment 4, 2003
Management Unit	Coastal waters from Massachusetts to Florida
Monitoring	Fishery dependent and fishery independent
Stock Assessment	SAW 2000, Updated 2002
F_{Target}	0.31
$F_{Threshold}$	0.50
$SSB_{Threshold}$	>14,400

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	3,219.9	841.7
1996	3,148.0	1,326.9
1997	3,310.3	1,675.0
1998	3,819.1	1,834.8
1999	3,132.2	1,425.8
2000	2,449.7	1,884.6
2001	2,267.8	1,235.0
2002	2,165.0	994.6
2003	908.2	392.3

CBP Management:

FMP	Adopted 1990; Revised 2003 (Adheres to ASMFC FMP)
Management Unit	Watershed to Bay mouth
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	705.1	156.9
1996	780.2	163.6
1997	794.1	282.6
1998	956.4	538.4
1999	860.7	401.3
2000	712.7	531.4
2001	593.2	424.3
2002	569.4	213.0
2003	229.9	109.0

the coast throughout its range. The Chesapeake Bay constitutes important nursery ground for larvae and juveniles.

Historical records of the Atlantic coast commercial fishery for weakfish extend back to the late 1800s (Mercer 1983). These records indicate high abundance at the turn of the century. Coastwide landings escalated during the 1940s. After 1980, Atlantic coast landings began a fluctuating downward trend that continued through 1995. The weakfish stock from Maryland to North Carolina has been overfished (Boreman and Seagraves 1984). The commercial weakfish fishery in the lower Bay remains important, but has generally declined since the 1940s. In this fishery, pound nets, gill nets, and haul seines are commonly used gear types. Weakfish also supports a major recreational fishery in the Bay.

The ASMFC FMP for Atlantic weakfish was adopted in 1985. The entire coastal population is managed as a unit, including estuarine and coastal fisheries within state waters. Adopted in 1990, the Chesapeake Bay Program Weakfish and Spotted Seatrout Fishery Management Plan follows the guidelines established by the ASMFC for coastal management of these stocks with compatible state regulatory actions. The draft revision of the CBP weakfish FMP (CBP 2002) reports that a 1999 assessment of the Atlantic weakfish stock reflected that the status of the coastal stock has improved, moving from overexploited to fully exploited. Spawning stock biomass has increased and fishing mortality is decreasing. The age structure of the stock is expanding, but has yet to reach the wider range estimated historically (CBP 2002).

Major Issues, Problems, and Concerns

Overfishing and Declining Abundance

Several factors have contributed to declines in fish and shellfish populations in the Chesapeake. Pollution and habitat loss threatened the viability of many species. At the same time, overfishing during the past century by both commercial and recreational fishermen has reduced the spawning potential of some stocks (Chesapeake Bay Foundation 2001). Historically, the Chesapeake produced an abundance of fish and shellfish. High productivity nurtured a belief that the Bay's resources were inexhaustible and that any declines represented annual variability or presumed natural cycles. Such a belief, in turn, may have led to a management philosophy that allowed fish stocks to be overexploited, resulting in depletion. Fishing effects, when combined with natural fluctuations, led to the boom-and-bust patterns of abundance evident in catch records (Chesapeake Bay Foundation 2001).

Anadromous fish have been particularly vulnerable to overfishing and habitat loss. Their seasonal migrations from the coastal ocean to estuarine waters often make them highly susceptible to fishing. Over the past two centuries, their critical (spawning, feeding, and nursery) habitats have been systematically blocked, altered, or polluted by anthropogenic land-based activities. Major anadromous species such as striped bass, American shad, river herrings, and sturgeons historically supported valuable Bay fisheries, but all were severely depleted by fishing or declined due to habitat degradation. Since habitat alteration was believed to be the major factor affecting these species, determining the extent to which overfishing was a factor proved difficult until recently. The recovery of striped bass, after imposition of coastwide catch limits and moratoria in some states for several years, clearly confirmed that overfishing can constitute the deciding factor in the decline of anadromous fish stocks (Richards and Rago 1999; Secor 2000a, b).

Reinforcing this lesson is recent experience with species such as weakfish, summer flounder, and Atlantic croaker, which may be less vulnerable to habitat degradation than anadromous species as they do not usually migrate to spawn in the upper parts of estuaries where habitats often are more degraded. These stocks were overfished during the past quarter century. All of these stocks have rebounded in the past decade in response to reduced fishing pressure coastwide, although technically weakfish and summer flounder may remain overfished (Chesapeake Bay Foundation 2001).

Another example, the Eastern oyster was the most valuable fishery in the Bay for much of the 19th and 20th centuries. Severe overfishing, followed by habitat loss and disease, diminished the oyster population to less than one percent of historic levels (Rothschild et al. 1994). Subsequent to the oyster's decline, blue crab became the Bay's most valuable fishery; by 1988, this species had surpassed the oyster in annual value (NMFS 2003). Blue crab has absorbed a fivefold increase in fishing effort over the last 50 years (Chesapeake Bay Foundation 2001) as watermen have increasingly focused on it as other species declined. The challenge now is to prevent the historic pattern of boom-and-bust for blue crab to maintain this valuable fishery into the future, although recent trends in the blue crab fishery and abundance cause concern (Rugolo et al. 1997; Miller and Houde 1998; BBCAC 2001).

Overcapitalization

Globally, overcapitalization is a major problem associated with open-access fisheries, posing a threat to fish populations because it easily can lead to overfishing (Roberts et al. 1991). Overcapitalization occurs when more fishing capacity (i.e., boats, gear, or investment in equipment) exists than is required to catch the available resource in an economically efficient, sustainable manner. The greater the number of fishing vessels participating, the more likely that individual fishing enterprises will become unprofitable or marginal. Combined with limited quotas—a common harvest control measure in the Bay—overcapitalization can lead to pressure to catch fish faster. The resulting competition for market share can create a "race for the fish" or derby fishery that produces market gluts, poor product quality, and safety concerns. Shortened fishing seasons are another potential consequence of overcapitalization that may remove fresh fish from the market for prolonged periods. Managers and policymakers should develop or encourage socioeconomic and other management incentives that discourage overcapacity and reward conservative and efficient use of marine resources and their ecosystems (NRC 1999).

In the Chesapeake Bay, fisheries for blue crabs, oysters, and Atlantic menhaden are among those showing signs of overcapitalization. An analysis of the technical efficiency and productivity in the Chesapeake Bay blue crab fishery found that the catch–effort relationship peaked and flattened in the early 1960s. As a consequence, additional effort entering the fishery resulted in no gains in total landings of blue crabs and caused a precipitous decline in CPUE. Additional analysis showed that the fishery could reduce effort by about five times with no change in overall total landings (J. Kirkley, Virginia Institute of Marine Science, personal communication). This analysis illustrates how a large number of latent units of effort in the blue crab fishery led to increased effort beyond the capacity of the stock to yield enough product to fishery participants. This pattern led to overfishing or economic collapse. A solution rests with substantial reductions in fishing capacity.

Wasteful and Destructive Harvesting Practices

Harvesting practices are wasteful when they decrease economic yield from the fishery or make the resource unavailable for future harvest. Wasteful practices in the blue crab fishery, for example, include harvesting small crabs or buckrams (recently shed crabs with a shell in the process of hardening), which does not maximize economic value of the resource. In addition, harvesting sponge crabs (adult female hard crabs that have extruded their eggs onto the abdomen or abdominal flap) and females at other life stages may result in poor-quality product and a potential loss of reproductive capacity for the population.

Lost and abandoned crab pots not only represent a direct economic loss to fishermen, but also pose attractive refuge sites that trap and eventually may kill significant numbers of crabs and finfish. Weak and dead crabs, in turn, attract other crabs into abandoned pots. This problem of self-baiting is commonly known as “ghost fishing.” Additionally, abandoned pots may trap and drown air-breathing animals, such as terrapins. Biodegradable materials and escape panels—partial solutions—have been the subjects of preliminary investigation in Maryland. As well as posing a hazard to aquatic life, abandoned pots can become navigational hazards for boats.

Aerial photography indicates that commercial clam harvesting with hydraulic dredges scars eelgrass and widgeon grass beds (Orth 2002). Clamming has been a traditional fishery in the Chesapeake Bay for generations. In the winter of 1996–1997, clammers moved into shallower waters and began harvesting clams from submerged aquatic vegetation (SAV) beds, causing extensive damage. Clam dredges rip up the bottom akin to an aquatic rototiller. Recognizing the potential damage, the Maryland state legislature and the Virginia Marine Resources Commission delineated SAV boundaries and prohibited the use of hydraulic clam dredges or modified oyster dredges in areas with SAV beds. To comply with the new laws, clammers must be able to discern the grass beds—not always possible in the sometimes dark and turbid waters of the Chesapeake.

Diseases and Harmful Algal Blooms

MSX and Dermo

Many economically important fish and shellfish species in the Chesapeake Bay have been affected by disease outbreaks in recent decades, some accompanied by mass mortalities (Sindermann and Rosenfield 2001, unpublished manuscript). Two fatal oyster diseases caused by single-celled protozoan parasites—Dermo and MSX—have devastated oyster populations throughout the Bay. Mortality rates reached 60–90% beginning in the 1950s. Infections from both pathogens have persisted since that time, although geographic variation in occurrence and intensity takes place due to seasonal and annual changes in salinities and temperatures. The ecology of the organisms is poorly known and no means for control currently exists. Although these diseases do not render oysters unsafe for human consumption, they have a debilitating effect on the Bay and other coastal regions by reducing oyster growth rates and productivity, typically killing these bivalves before they become reproductive or reach harvestable size.

Dermo was first documented in the 1940s in the Gulf of Mexico where it was associated with extensive mortality (VIMS 1998). Originally, scientists thought the causative agent was the fungus *Dermocystidium marinum.* Even after reclassification, the disease is still commonly referred to as Dermo. *Perkinsus marinus* is an intracellular protozoan parasite infecting the hemocytes of the Eastern oyster. This pathogen proliferates most rapidly at temperatures above 25° C (77° F). Dermo is not harmful to humans. The disease is transmitted from oyster to oyster. Parasites released from disintegrating dead oysters generally cause infections. Because the disease transmits easily from oyster to oyster, it is imperative to avoid moving infected oysters into an area containing uninfected ones. Holding oysters at salinities under 9 ppt will retard disease development and restrict disease-associated mortality. VIMS (1998) suggests that grow-out areas remain fallow for 1 to 2 years before planting seed stocks.

Scientists first documented Multinucleated Sphere X, known better as MSX, in 1957 in Delaware Bay where it caused massive oyster mortality. Two years later, it appeared in the lower Chesapeake Bay where it also caused extensive mortality. The parasite has been found in *C. gigas* from Korea and Japan as well (VIMS 1998). In the Eastern oyster, the disease is caused through infection by *Haplosporidium nelsoni.* Under heavy infection pressure, oysters develop resistance to MSX disease. Native oysters survive better after the infection has established itself in an area for a few years. Low salinities and low temperatures suppress MSX disease, causing infections to be locally patchy and seasonal in the Bay (Connecticut Department of Agriculture 1997). Control measures for this disease include use of MSX-resistant oyster strains and maintenance of oysters in disease-free (low salinity) areas. If oysters must be moved to high salinity areas for growth and conditioning, the timing of the move should avoid the early summer infection period. Effective combinations of low and high salinity to minimize disease and maximize growth have not been thoroughly determined. Avoiding importation of infected oysters into grow-out areas (VIMS 1998) also remains important.

Softshell Neoplasia

In 1983, softshells (also known as softshell clams) *Mya arenaria* in the Bay began dying from a proliferative cell disease—neoplasia. Impacts of this disease on the Bay's clam populations have been severe with mass mortalities. The conditions allowing the disease are still present (McGladdery and Stephenson 1996; Sinderman and Rosenfield 2001). Hemic neoplasia has been well documented in bivalves since the early 1970s (Peters 1988). Most neoplasms have not demonstrated infectivity as they occur at generally low prevalences (usually <10%) within the population sampled. An infectious etiology was suspected in the Chesapeake clam mortalities, however, and recent reverse transcriptase activity reinforces the possibility of a retrovirus trigger (House et al. 1998). From both the environmental and the clam transfer perspective, therefore, the most urgent question is whether the neoplasia is infective or noninfective (Smolowitz and Leavitt 1997).

Many other diseases that cause ecological and economic harm to Chesapeake Bay fishery resources also exist. Crustaceans have their own array of pathogens that can cause mortality. For example, blue crabs in the Bay are subject to a lethal disease caused by the amoebic parasite *Paramoeba perniciosa* and to another caused by a parasitic dinoflagellate *Hematodinium perizi*. Prevalence of *P. perniciosa* in blue crabs of the Chesapeake region reached 20% during the most recent outbreak (Sinderman and Rosenfield 2001).

Hematodinium perezi

The primary disease organism affecting blue crabs in the coastal bays of the Delmarva Peninsula is the parasitic dinoflagellate *H. perezi*. It affects crabs in most of the coastal bays, particularly at the end of summer when water temperatures cool. It does not tolerate low salinities. The disease spreads to the lower reaches of the Bay in the fall (Shields 1997). Commercial fishermen first noticed its effects (dead, dying, listless, or slightly discolored crabs) in 1994. It has occurred yearly to varying degrees. Infections are seasonal, peaking in late autumn and early winter and have been sufficiently severe on occasion to curtail crabbing in some areas. No known methods of prevention or control of *H. perezi* exist at present (Wesche 2000). Grey crab disease and a chitinoclastic bacterium that causes black spots also occur in the coastal bays but have not presented significant problems.

Photobacterium damselae (subspecies *piscicida)*

Striped bass in Chesapeake Bay were killed during the early 1960s by an outbreak of the bacterial pathogen *Pasteurella piscicida* (Snieszko et al. 1964), now known as *Photobacterium damselae* subspecies *piscicida*. The striped bass stock now has a high infection level of the chronic, and eventually lethal, bacterium *Mycobacterium marinum*. Severe skin lesions and mortalities of juvenile Atlantic menhaden during the past decade have been attributed, at least in part, to an ulcerative disease caused by the fungus *Aphanomyces* spp. (Sindermann and Rosenfield 2001).

Pfiesteria

Scientists attribute ulcerative lesions and mass mortalities or "fish kills" of Atlantic estuarine species to exposure to *Pfiesteria*-like dinoflagellates and their toxins. The implicated organism, *Pfiesteria piscicida,* is a recently identified genus and species in a newly recognized dinoflagellate family. Three potentially toxic *Pfiesteria*-like dinoflagellates (*Pfiesteria piscicida, Gyrodinium galatheanum,* and *Cryptoperi-diniopsis* spp.) occur in tributaries of the lower Chesapeake Bay (Kane et al. 1998). Several environmental cues, including nutrient-related stimulation, are responsible for the dinoflagellates' growth, sexual reproduction, encystation, and toxin production.

Research delved into the possible relationships between *Pfiesteria* and nutrients. The consensus of the panel of experts led by Dr. Donald Boesch (Boesch 1998) indicated that probable links between nutrients and *Pfiesteria or Pfiesteria*-like dinoflagellates do exist. The panel concluded, "In the long term, decreases in nutrient loading will reduce eutrophication, thereby improving water quality, and in this context will likely lower the risk of toxic outbreaks of *Pfiesteria*-like *dinoflagellates* and harmful algal blooms" (Magnien 2001). Within the Bay region, 24 fish species are known to be affected by exposure to *Pfiesteria*-like dinoflagellates or their toxins, including striped bass, Atlantic menhaden, American eel, Atlantic croaker, channel catfish, red drum, and white perch (Kane et al. 1998).

In general, observations of ulcerative fish lesions in many different waterways worldwide have increased over the last half-century (Boesch 2001). Although multiple etiologies (causes of disease) are likely involved, increased incidence of fish mortalities and lesions indicates heightened environmental stresses including contaminant pollution and nutrient enrichment. Both create stress and accelerate eutrophication of aquatic systems (Kane et al. 1998).

Gear Conflicts

Gear conflicts among fishermen and other stakeholders are common in fisheries and occur in Chesapeake Bay. The presence of crab pots, conch pots, eel pots, or fish pots of any type in an area where hook-and-line (primarily recreational) fishermen operate presents the potential for gear conflicts or even a safety hazard. Conflicts between commercial net or pot fishermen and recreational boaters are problematic in some areas of the Bay, generally near major cities and ports. From a recreational boater's viewpoint, pot floats and lines interfere with access to and use of the Bay. From a commercial waterman's perspective, recreational boaters interfere with fishing when they inadvertently run over and cut off pot floats. Other instances of gear conflicts include competition for trotline space in some Maryland tributaries.

Climate Change and Sea Level Rise

Experts generally agree that over the next century, the earth as a whole will be warmer, wetter, and subject to more extremes. Storms, freshwater inflows from land and rainfall, water temperature, currents, winds and solar radiance, and sea level rise jointly affect coastal environments and marine resources. All of these influences vary with climate and could potentially shift significantly due to climate change (Boesch and Wright 1999; Boesch 1998). Regional warming will likely narrow the annual temperature range experienced by the Bay. Winters and transitional seasons will likely be warmer with summer temperatures probably not changing appreciably. Because the Chesapeake Bay is rather delicately positioned in a transitional biogeographic region, such an altered temperature regime could influence which species occur in the Bay. Persistent long-term rise in mean annual temperature may alter the seasonal distribution patterns of ecologically and economically important fishery species of the Bay.

Future warming will likely result in a shorter winter season, allowing earlier spring immigration and later fall emigration of many coastal species using the Bay. As warming progresses, the effects on subtropical and cold-temperate species will differ. Subtropical species will benefit from warmer temperatures and may increase their use of the Bay as feeding, spawning, or nursery ground. Warm temperate species, such as penaeid shrimp or the toxic dinoflagellate *Pfiesteria piscicida,* could become more common (Boesch and Wright 1999). Conversely, warming may limit the use of the Bay by cold-temperate species whose southern range ends in the mid-Atlantic region. The commercially important soft clam, for example, may no longer survive or be prolific in the Bay (Wood et al. 2002).

The combined effects of global sea level rise and regional land subsidence has caused a relative sea level rise of about 3.3 mm/year (over the past 60 years) throughout many parts of the Bay. This rise has caused shoreline erosion and inundation of low-lying islands and salt marshes. Simply extrapolating past trends (ignoring any global warming influences) suggests an additional rise of 33 cm (about 1 ft) in the Bay by the end of the century. If, however, the medium sensitivity forecast by the Intergovernmental Panel on Climate Change—of 5 mm/

year by the century's end (based solely on thermal expansion in the ocean)—proves accurate, this effect must be added to ongoing trends. This scenario suggests that throughout much of the Bay, the relative rise will at least double, rising more than 2 ft by 2100 (Boesch and Wright 1999).

Some scientists have predicted that global warming will increase the frequency and severity of hurricanes and tropical storms. The recent consensus of climate modelers, however, is that such projections remain shrouded in uncertainty (Boesch and Wright 1999). Any potential increase in watershed precipitation and associated freshwater runoff into the Bay should be well anticipated through the development of contingency plans.

This issue is a "sleeper"—a concern that has received scant attention but could profoundly affect efforts to restore and manage the Bay ecosystem. Studies by NOAA have shown that average annual precipitation has increased by more than 20% in the Susquehanna basin over the past 100 years with seasonal high flow records set in 1996 and 1998 (NOAA National Weather Service). Regional climate models indicate that the Bay's watershed should experience increased winter and spring precipitation as global warming continues, which will amplify freshwater inflows. The quantity and timing of these flows greatly influence the Bay's salinity, stratification, circulation, and sediment and nutrient inputs. Higher spring flows bring more nutrients, which promote algal growth and deplete dissolved oxygen in the deep areas of the Bay (Boesch and Wright 1999; Wood et al. 2002).

Uncertainty precludes confident projections of the effects of climate change on the Chesapeake ecosystem and its fisheries. An assessment of possible changes is needed, however, since managers require significant lead time to plan and initiate precautionary or mitigating strategies that protect ecosystem integrity and ensure the sustainability of Bay fisheries. Since CO_2 has been accumulating in the atmosphere for over a century, contemporary trends in ecologically important variables (e.g., water temperature, sea level change, and stream flow) may prove instructive in assessing climate change impact on the Bay and its fisheries. For both economic and ecological reasons, it is appropriate to account for the potential consequences of future climate changes in Bay management strategies—from tidal wetland protection and nutrient reduction to fisheries management (Boesch and Wright 1999; Wood et al. 2002).

Toxicants in Bay Seafood

A toxicant is a compound or chemical that is harmful to living organisms at defined levels (CBP 2000). A contaminant is a chemical substance or compound not found naturally in an ecosystem that has the potential to become toxic and cause harm. In practice, the terms toxicant and contaminant often are used interchangeably. Toxicants originate from many sources. Discharge from large industries and waste treatment plants (e.g., factory discharge pipes, smokestacks) are point sources and represent concentrated toxic inputs. The Clean Water Act, Clean Air Act, and other targeted efforts to curb industrial pollution have caused contaminated effluent to decline dramatically. Impressive improvements continue (CBP 2000).

Though reducing contaminant discharges from point sources may be costly, such reductions are generally more efficient than reducing harmful inputs to the Bay from diffuse, nonpoint sources such as farms, automobiles, highways, and chemicals applied to suburban yards. The impacts of nonpoint sources once seemed relatively small compared with those from industry or other point sources. But, while large industrial sites have decreased both production levels and outputs of toxicants, nonpoint sources have continued to increase along with population growth in the watershed (now over 15 million people). In addition, nonpoint sources are much more difficult to control since few permits or other regulatory limits restrain the many activities that produce them, many of which are simply part of daily life (CBP 2000). Nevertheless, the CBP has documented nonpoint sources of nutrient enrichment as the major contaminant problem in the watershed and many of the Program's efforts focus on reducing nitrogen and phosphorus from nonpoint sources (CBP 2000).

Many toxicants occur at very low concentrations. Due to the number of steps in fish food webs, toxicants often reach higher levels compared to other food types. These concentrations often exceed those in the water, particularly for substances that do not break down readily. This tendency makes aquatic biota good indicators of pollution in a water body (MDE 2002). In December 2001, the MDE released extensive fish consumption advisories based on recent EPA guidance for daily intake of fish from Chesapeake Bay tributaries for recreational anglers and their families. Based on samples of 13 varieties of fish, crabs, and other species from 14 tidal water bodies across the state, these advisories warned consumers to limit consumption of these species, which may contain dangerous levels of toxicants. Importantly, the state issued the new advisories in the wake of EPA reductions in the concentrations of toxicants required for public health advisories (based on increased estimates of average human consumption rates), not because concentrations of toxicants have increased in the state's fish and shellfish. Even so, the overall variability in response of individuals exposed to persistent bioaccumulative toxic (PBT) chemicals dictates a more conservative approach, producing guidance that will protect a large portion of the population (EPA 2003).

Nonindigenous Species

With the introduction (accidental or deliberate) of a species that is not endemic, altered predator–prey relationships and increased competition among organisms for forage and space threaten economic and environmental harm. In some instances, such introduced species may also harbor diseases to which native species have no resistance. More than 160 nonnative species in the Bay have been identified as probable exotics (Ruiz 1998; Reshetiloff 1998). Many of these invasives present current or potential threats to Chesapeake Bay fisheries.

The mute swan *Cygnus olor* exemplifies this problem. Native to Asia, this aquatic waterfowl was introduced to the Bay in 1962 when five birds escaped captivity to the Miles River. The mute swan competes intensely with some native waterfowl species and consumes large quantities of the SAV critical for Bay restoration. A highly prolific species, the Bay's mute swan population had increased to almost 4,000 birds by 1999. Mute swan survey data, combined with a population model developed by MD DNR, suggested that this number could double within 4 years (Harvey 2000). Aerial survey data collected in 2002, however, indicated that the mute swan population had stabilized. This stabilization of the adult population can be attributed to an aggressive egg addling program by MD DNR, removal of adult swans from national wildlife refuges, and authorized scientific collections. To address this problem in Maryland, MD DNR created the Mute Swan Task Force in 2000 to compile information on mute swans and their interactions with native habitats, native species, and humans and to create a basis for a statewide management plan adopted in April 2003 (MD DNR 2003b).

An evolving issue is the potential introduction of the Suminoe oyster to restore the ecological role of oysters in the Bay and to supplement market demand for the native Eastern oyster. Overharvest and disease have reduced the native oyster to a fraction of its historic level. The Suminoe oyster's good taste, rapid growth, and high resistance to the protozoan diseases that have decimated the native oyster population make it attractive to the Bay's seafood industry as an alternative to the native. This oyster may prove beneficial as a filtering organism, boosting the ecological service that the native oyster once provided to the ecosystem.

Introduction of this species, however, must proceed with caution. In many cases, exotic species have caused unanticipated ecological problems. Introduction of Suminoe oyster should be planned only after thorough evaluation of its positive and negative potentials for the Bay's fisheries and ecosystem. Appropriately, the Chesapeake Bay Program is considering the Suminoe oyster issue carefully.

The *Chesapeake 2000* agreement committed to identify and rank nonnative, invasive aquatic and terrestrial species that are causing, or have the potential to cause, significant negative impact to the Bay's aquatic ecosystem by 2003. The agreement also requires development and implementation of management plans for invasive species deemed problematic to the restoration and integrity of the Bay's ecosystem by 2003. In response, the CBP established the Invasive Species Workgroup, under the Living Resources Subcommittee. By September 2001, the workgroup had identified six species of particular concern: mute swans *Cygnus olor*; nutria *Myocastor coypus*, phragmites reed *Phragmites australis*, purple loosestrife, *Lythrum salicaria*, water chestnut *Trapa natans*, and zebra mussel *Dreissena polymorpha*.

A workshop "Invasive Species in the Chesapeake Bay Watershed" was held in May 2002 to develop regional management control strategies for invasive species (CBP and Maryland Sea Grant 2002). Research at Chesapeake Bay area scientific laboratories focus on such questions as, How are organisms transported from one ecosystem to another? What ecological mechanisms may determine the "invasiveness" of a species? What are the biological effects of introduced species on their newly-invaded niche? Answering these and other questions is fundamental for managers and policymakers to determine appropriate responses to and plans for control of future invasive species to the Bay region.

Liability and Legal Issues

Stakeholders often greet shifts in fisheries management philosophy or approaches with resistance and mistrust due to perceived or real threats to traditional uses. Transferring the emphasis from traditional single-species management to an ecosystem approach, if incremental, is not likely to impose sudden and overwhelming changes in resource allocation or access by fishermen. Even the fairest of management regimes, however, may be challenged if stakeholders believe that the new regime threatens the resource or the ecosystem or, alternatively, diminishes historical access.

This FEP represents a broad-based approach that emphasizes habitats, predator–prey relationships, and externalities beyond human control in formulating or revising FMPs for Chesapeake Bay. In implementing such a plan, fair allocation and access are essential, requiring stakeholder involvement at the outset. The Ecosystems Panel (NMFS 1999) emphasized the principle of fairness in its consideration of how ecosystem approaches might be applied on a broader national scale. Yet, fairness does not ensure the equal treatment of all stakeholders or that they will share equally in bearing the burden of new regulations—regulations that could result in liability issues and lawsuits with adoption of the FEP.

At the national level, lawsuits and liability issues have become a major burden of NMFS and the regional fishery management councils. Most of these lawsuits are challenges by the environmental community, regarding perceived failures to consider ecosystem needs adequately in the FMPs. Other lawsuits challenge the science that forms the basis of the management decisions. A few address allocation issues by fishermen; others result from jurisdictional disputes over management authority and responsibility. With incremental implementation of the Chesapeake Bay FEP, the hope is that challenges to management measures over environmental issues will remain uncommon since the FEP recommends the precautionary approach (see Uncertainty Element) to address ecosystem issues and concerns. Allocation and access issues may arise but can be minimized by including stakeholders prominently in the entire management process. Jurisdictional issues are probable since the legal boundaries of the Chesapeake Bay are clearly defined, while the ranges of distribution for its fishery resources are not (see Ecosystem Boundaries Element).

How can liability issues be minimized after adoption and implementation of an FEP beyond ensuring stakeholder involvement? Apprising stakeholders of FEP management outcomes and resultant benefits to the ecosystem can help. Additionally, the various jurisdictions that share management responsibility for the Bay's fisheries resources should adopt the FEP approach, at least in theory. An incremental and gradual adoption of FEP principles and measures can minimize the probability of disputes or litigious responses. The goodwill of the public (particularly traditional resource users such as commercial and recreational fishermen), and cooperation among agencies responsible for developing FMPs and agencies managing other components of the Bay ecosystem, are both essential. Mechanisms that promote communication and collaboration among these entities will reduce the likelihood of disputes that lead to litigation.

Fish to Closely Monitor . . . and Perhaps Manage

A balanced, healthy, and productive ecosystem depends upon the integrity of complex communities of ecologically valuable species and the maintenance of their functional role. Within the ecosystem context, all species are of interest. Each has roles as predator, prey, or competitor—even if these roles are not well understood. Although it is impractical to have management plans for all fish species considered ecologically valuable to the Chesapeake Bay (Appendix 1), several finfish species remain unmanaged although they

1) Support significant commercial and recreational fisheries and
2) Constitute forage fish for commercially and recreationally valuable predator species

To fulfill one commitment of the 1987 Chesapeake Bay Agreement "to develop, adopt, and begin to implement baywide management plans for ecologically valuable species," the Ecologically Valuable Species Workgroup of the CBP Living Resources Subcommittee developed a Chesapeake Bay Strategy for the Restoration of Ecologically Valuable Species (CBP 1993). Brief synopses of three such species follow.

Bay Anchovy

A small, schooling pelagic fish, bay anchovy is a highly productive year-round resident and is the most

Bay Anchovy *Anchoa mitchilli*

Life Cycle Year-round Bay Resident.

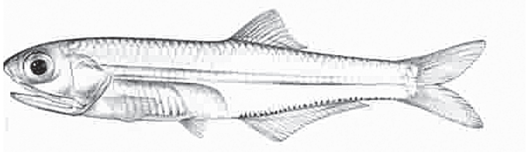
Life History Categories

S_{CB}	Resides in Chesapeake Bay
S_{CST}	Resides in coastal waters outside the Bay
S_{EST}	Resides in other estuaries along mid-Atlantic Seaboard

Relative Exploitation Level	No Directed Fisheries
Relative Abundance	Not Estimated

ASMFC Management

FMP	Not Managed
Management Unit	Not Managed
Monitoring	Not Monitored
Stock Assessment (Coastal)	Not Conducted
F	No Directed Fisheries



Diane Peebles

SSB Not Estimated

Estimated Removals from Atlantic Coast

Commercial (MT)	*Recreational (MT)*
No Directed Fisheries	No Directed Fisheries

CBP Management

FMP	Not Managed
Management Unit	Not Managed
Monitoring	Fishery independent (by state)

abundant species of finfish native to the Bay. It also forms an important component of the Bay's food web. This fish can live up to 3 years but seldom grows longer than 90 mm. Although not commercially exploited, bay anchovy constitutes a major prey of harvested species such as bluefish, weakfish, and striped bass and may represent up to 90% of piscivorous fish diets seasonally (Hartman and Brandt 1995; Baird and Ulanowicz 1989). Populations of bay anchovy fluctuate annually. Recruitment appeared generally low during the 1990s, but indications of recovery have surfaced since 1997 (Wood and Houde 2002; Jung and Houde 2000; Jung 2002). Bay anchovy spawn in late spring and summer—a period when low dissolved oxygen below the pycnocline may limit distribution of all life stages and prove lethal to eggs and larvae. Losses from entrainment and impingement in power plant cooling systems may affect the abundance of this fish, as does the intensity of consumption by predator species.

Catfish

North American catfish (Family Ictaluridae) are freshwater species that commonly range into estuarine waters. They can tolerate low salinities and occur in tidal freshwaters of the Chesapeake, including the upper Bay and its tributaries. Three species of bullhead catfish are native to the Bay: white catfish, brown bullhead *A. nebulosus*, and yellow bullhead *A. natalis*. Regionally, two introduced species—channel catfish and blue catfish—have become economically important as fished species. Channel catfish survive

Catfish *Family Ictaluridae*

Life Cycle Freshwater-Estuarine

Life History Categories

S_{CB}	Resides in Chesapeake Bay
S_{EST}	Resides in other estuaries along mid- Atlantic seaboard

Relative Exploitation Level: Not Estimated
Relative Abundance: Healthy

ASMFC Management

FMP	No FMP
Management Unit	No FMP
Monitoring	Fishery dependent
Stock Assessment (Coastal	Not Conducted
F	Not Conducted
SSB	Not Conducted

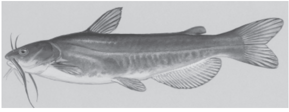
Estimated Removals from Atlantic Coast (Species Combined)

	Commercial (MT)	*Recreational (MT)*
1995	3,359.4	Not Reported
1996	1,957.0	Not Reported
1997	1,850.9	Not Reported
1998	2,260.2	Not Reported
1999	6,642.6	Not Reported
2000	4,418.0	Not Reported
2001	4,633.2	Not Reported
2002	3,733.1	Not Reported
2003	3,134.7	Not Reported

CBP Management

FMP	No FMP
Management Unit	Not developed
Monitoring	Fishery dependent

Blue catfish
Ictalurus furcatus

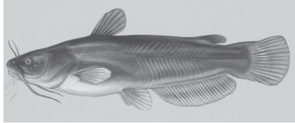


White catfish
Ameiurus catus

Channel catfish
Ictalurus punctatus

Flathead catfish
Pylodictis olivaris

Brown bullhead
Ameiurus nebulosus



Duane Raver

Yellow bullhead
Ameiurus natalis

Stock Assessment (Baywide) Not Conducted

Estimated Removals (MD & VA State Waters Species Combined)

	Commercial (MT)	*Recreational (MT)*
1995	1,045.4	Not Reported*
1996	1,551.4	Not Reported*
1997	1,347.2	Not Reported*
1998	1,820.6	Not Reported*
1999	1,689.7	Not Reported*
2000	1,381.6	Not Reported*
2001	1,620.9	Not Reported*
2002	1,469.7	Not Reported*
2003	1,387.8	Not Reported*

*But Significant

in the upper Chesapeake and tributaries throughout the Bay system. Blue catfish, a large species once considered rare, has become increasingly abundant in several Bay drainages. A third introduced species, the large flathead catfish *Pylodictis olivaris*, shows only limited distribution in the Bay. Species of current commercial importance include channel catfish in Maryland, Virginia, and the Potomac River and blue catfish in Virginia rivers. Brown bullhead supports a small, specialized market; yellow bullhead is not targeted commercially but may be landed as bycatch with other catfish species. Commercial fishermen in the Chesapeake Bay region worry about market competition with farmed catfish. Nationally, catfish ranks third in angler preference (U.S. Department

White Perch *Morone americana*

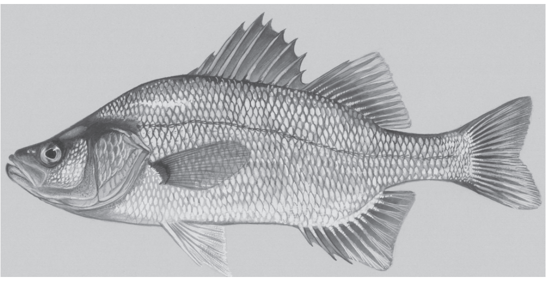
Life Cycle: Semi-anadromous

Life History Categories:

S_{CB}	Resides in Chesapeake Bay
S_{ES}	Resides in other estuaries along mid-Atlantic seaboard

Relative Exploitation Level: Not estimated

Relative Abundance: Not estimated



Duane Raver

ASMFC Management:

FMP	No FMP
Management Unit	No FMP
Monitoring	Fishery dependent
Stock Assessment (coastal)	Not conducted
F	Not estimated
SSB	Not estimated

CBP Management:

FMP	Not developed
Management Unit	Not developed
Monitoring	Fishery dependent
Baywide Stock Assessment	Not conducted

Estimated Removals from Atlantic Coast

	Commercial (MT)	*Recreational (MT)*
1995	749.4	210.6
1996	822.3	380.7
1997	1,151.6	523.1
1998	844.8	278.7
1999	988.5	193.2
2000	1,161.2	313.6
2001	1,140.2	130.5
2002	947.8	298.9
2003	1,001.7	545.1

Estimated Removals (MD and VA combined)

	Commercial (MT)	*Recreational (MT)*
1995	608.4	187.4
1996	689.3	358.9
1997	1,022.5	481.5
1998	716.4	253.5
1999	750.0	154.3
2000	953.3	285.7
2001	969.3	113.4
2002	768.1	229.4
2003	719.3	375.7

of Interior 1989). In the Chesapeake Bay, recreational catches of this fish may be underestimated because the survey does not sample the upper tidal, freshwater portions of rivers where much recreational catfish angling takes place (Piavis et al. 1994).

Recently, *Catfish Populations in Chesapeake Bay* (CBP 1998b) explored the current state of knowledge of the Bay's catfish and established a reference baseline from which future management actions may evolve. The CBP FMP Workgroup recommended that adoption of an FMP for catfish be delayed because commercially and recreationally exploited stocks appear healthy, target levels for landings and biological reference points remain unknown, and no management recommendations could be made without stock assessments (CBP 1998b). The workgroup stated that a stock assessment would be beneficial while stocks are healthy because catfish are heavily exploited. Catfish assessment will trigger monitoring of the fishery and allow management strategy development before landings grow beyond sustainable levels. Because intolerance to high salinities naturally restricts catfish migration across state lines, a baywide interjurisdictional FMP may not be required.

White Perch

White perch is an abundant year-round resident in all tributaries of the Bay. From spring through autumn, it lives on flats and in channels, retreating to deep channels in the winter. White perch is among the most important recreational and commercial fish in the Chesapeake, especially in Maryland waters where more than 80% of Bay landings occur. Commercial landings of white perch in the Bay peaked in 1969 at 1.3 million kgs and have since declined. The commercial fishery uses several gear types, including haul seines, fyke nets, and pound and gill nets. Catches tend to be greatest during the spring spawning season and from September through November when white perch are schooling to feed on migrating menhaden, shad, and river herring (MD DNR 2003a).

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Appendix 1

The Chesapeake Bay Program (CBP 1993) has defined ecologically valuable finfish species and species groups of the Chesapeake Bay as those species or groups of species having significant functions in the ecosystem by

1) Regulating populations of other species (prey and predators);
2) Regulating the quantity and quality of habitat for other species (e.g., oysters, submerged aquatic vegetation);
3) Processing large amounts of material (nutrients, organic and inorganic matter) by physical and chemical means (phytoplankton, bacteria, filter feeders); or
4) Producing organic matter (phytoplankton, SAV, marsh, shoreline plants).

Ecologically valuable fish species were chosen based on a minimum CPUE of 0.1 in Maryland seine and bottom trawl samples (Carmichael et al., 1992) or through consultation with biologists for those species not represented in seine and trawl samples (notably reef fish).

By species groups, ecologically valuable fish include

Marine Spawners:

American eel *Anguilla rostrata**
silver perch *Bairdiella chrysoura*
Atlantic menhaden *Brevoortia tyrannus*
spotted seatrout *Cynoscion nebulosus**
spot *Leiostomus xanthurus**
Atlantic croaker *Micropogonias undulatus**
summer flounder *Paralichthys dentatus**
harvestfish *Peprilus paru*
black drum *Pogonias cromis**
bluefish *Pomatomus saltatrix* *
red drum *Sciaenops ocellatus**
Atlantic needlefish *Stronglyura marina*

Estuarine Resident:

bay anchovy *Anchoa mitchilli*
spotted seatrout *Cynoscion nebulosus**
weakfish *Cynoscion regalis**
sheepshead minnow *Cyprinodon variegatus*
banded killifish *Fundulus diaphanus*
mummichog *Fundulus*

heteroclitus
striped killifish *Fundulus majalis*
eastern silvery minnow *Hybognathus regius*
pumpkinseed *Lepomis gibbosus*
rough silverside *Membras martinica*
tidewater silverside *Menidia peninsulae*
Atlantic silverside *Menidia menidia*
spottail shiner *Noropis hudsonius*
summer flounder *Paralichthys dentatus**
winter flounder *Pseudopleuronectes americanas*
cownose ray *Rhinopter bonasus*
northern pipefish *Syngnathus fuscus*
hogchoker *Trinectes maculatus*

Anadromous:

blueback herring *Alosa aestivalis*
hickory shad *Alosa mediocris*
alewife *Alosa pseudoharengus*
American shad *Alosa sapidissima**
white perch *Morone americana*
striped bass *Morone saxatilis**
yellow perch *Perca flavescens*

Tidal Freshwater:

carp *Cyprinus carpio*
gizzard shad *Dorosoma cepedianum*
tessellated darter *Etheostoma olmstedi*
banded killifish *Fundulus diaphanus*
eastern silvery minnow *Hybognathus regius*
white catfish *Ameiurus catus*
brown bullhead *Ameiurus nebulosus*
channel catfish *Ictalurus punctatus*
pumpkinseed *Lepomis gibbosus*
tidewater silversides *Menidia peninsulae*
largemouth bass *Micropterus salmoides*
spottail shiner *Notropis hudsonius*

Reef Fish:

black sea bass *Centropristis striata**
striped blenny *Chasmodes bosquianus*
skilletfish *Gobiesox strumosus*
naked goby *Gobiosoma bosc*
oyster toadfish *Opsanus tau*

* *Chesapeake Bay Program FMP in effect*

CHAPTER 3

Structural Elements of the Fisheries Ecosystem Plan

The structural elements in the following sections were first identified by the Ecosystem Principles Advisory Panel's report to Congress in 1999. The elements, although described separately by section, collectively characterize the Chesapeake Bay ecosystem in a way that allows managers to make informed natural resource management decisions. This Fisheries Ecosystem Planning document does not attempt to integrate all the major elements that follow; rather, it recognizes the critical role of each element in serving the needs of the Chesapeake Bay ecosystem.

Each element provides recommendations that may be implemented immediately; other recommendations must be addressed from a longer-term perspective. The incremental process in implementing the following elements and recommendations will require the joint cooperation of organizations with relevant jurisdiction.

Each element was developed to be referenced individually. Collectively, however, the elements form the structure and foundation necessary to support ecosystem-based approaches in the restoration of the Chesapeake Bay.

Ecosystem Boundaries: Defining the Management Unit

Introduction

When instituting ecosystem-based fisheries management, the first step is to define the boundaries of the ecosystem. This is not a trivial task. The ecosystem, as defined by Tansley (1935), includes "not only the organism-complex, but also the whole complex of physical factors forming what we call the environment." Many other definitions have been offered since Tansley's; virtually all acknowledge that ecosystems are hierarchically arranged and definable on many scales. Tansley's classification, as well as most subsequent definitions, infers that ecosystems contain the community of populations in addition to the biological and physical components and processes maintaining that community. This simplified designation captures the essential requirements for a Chesapeake Bay fisheries ecosystem plan (FEP), specifically acknowledging the need to consider how fishery catches or changes in abundance of any species may affect the integrated system of plants, animals, habitats, or the processes that support and maintain it.

Like virtually all ecosystems, Chesapeake Bay is open to and influenced by exchanges and flows from surrounding environments. As an estuary, the Bay is strongly influenced by the mixing of freshwater which flows from the upper reaches of the watershed and oceanic waters pushing upbay through the mouth. These waters deposit sediment and deliver nutrients and plankton to the ecosystem from distant sources. The ecosystem is also strongly influenced by seasonally migratory animals, including striped bass *Morone saxatilis*, river herring, Atlantic menhaden *Brevoortia tyrannus*, and piscivorous birds, such as osprey and cormorants, which use the Bay as a seasonal feeding ground and nursery area.

Despite the open and dynamic nature of the Chesapeake Bay ecosystem, defining boundaries that incorporate the processes and habitats that characterize and sustain the ecosystem must constitute a first step in crafting an effective ecosystem-based fisheries management plan. An informed approach must consider this problem within the context of the Bay's geological history, physical geography, and estuarine characteristics (features, processes, and boundaries).

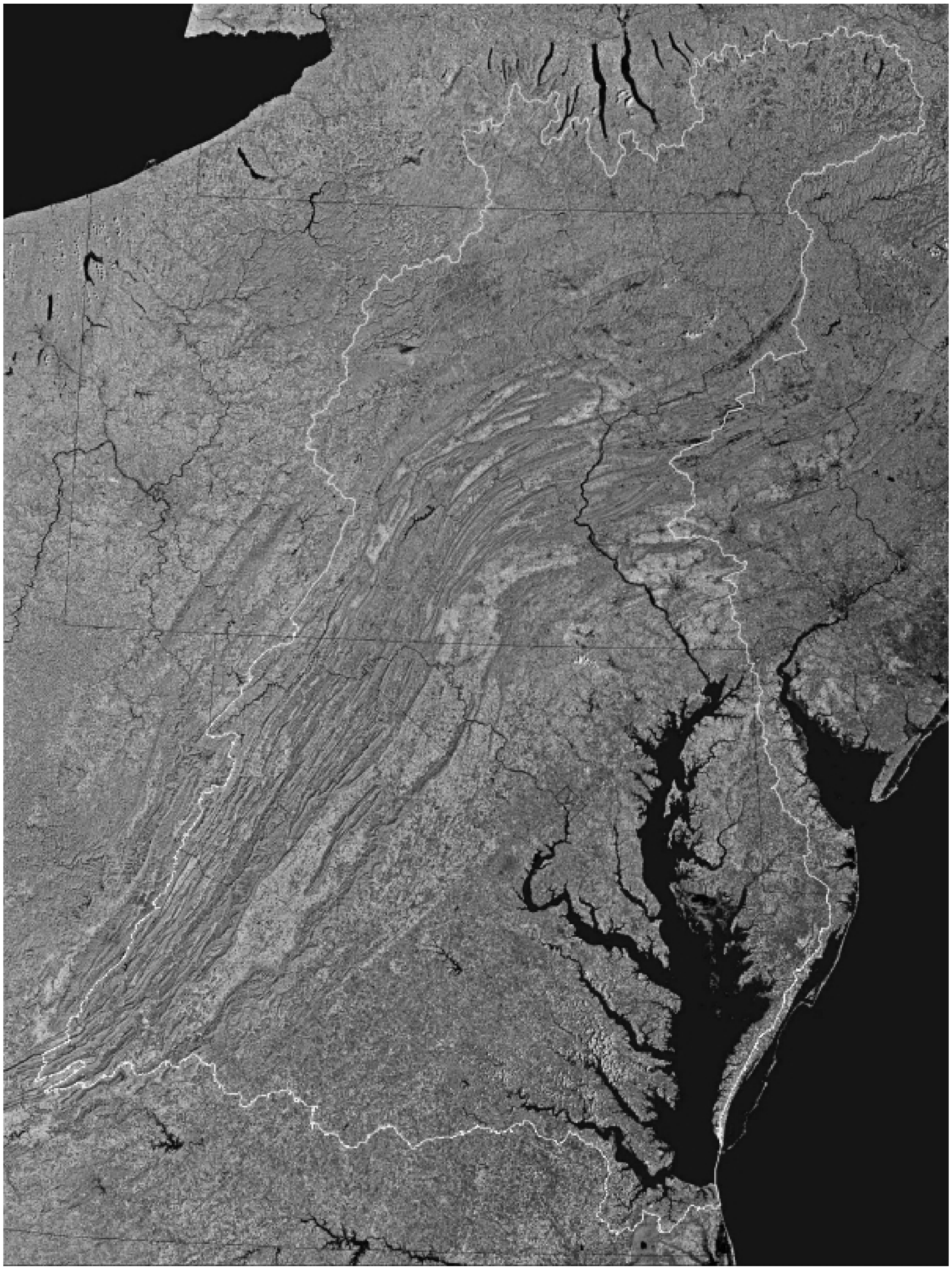

Figure 1. Chesapeake Bay watershed map. Source: United States Geological Survey (http://chesapeake.usgs.gov/chesbay.poster.html).

Geological History

One of the oldest features influencing the geological characteristics and geomorphology of Chesapeake Bay occurred 35 million years ago. At that time, a giant meteorite slammed into what now forms the southern portion of the Bay and stamped a roughly circular crater twice the size of Rhode Island (6,400 km^2) and as deep as the Grand Canyon (1.3 km). Recent research indicates that the courses of the Susquehanna River and its three primary tributaries in Virginia (the

James, York, and Rappahannock rivers), as well as the location of the Bay mouth, were influenced by the impact of this crater (Poag 1997).

On the geologic time scale, the Chesapeake estuary is a rather contemporary geomorphological landform. As recently as 18,000 years ago, an extensive ice sheet covered the northern half of North America, forcing global sea level more than 100 m below its current stand and placing the Atlantic Ocean's shoreline hundreds of kilometers seaward of its current location. During this period, open conifer woodlands of cooler-climate pines and spruce covered the mid-Atlantic region (Adams and Faure 1997). The nascent beginnings of Chesapeake Bay were then present in the form of steep river valleys carved by the Susquehanna River and its major tributaries, which extended across the present continental shelf and deposited sediment onto the continental slope.

The modern form of the Bay began to emerge about 10,000 years ago when climatic warming initiated the present interglacial period and resulted in melting of the North American ice sheet. As a result, global sea level slowly rose, the Susquehanna River valley began to flood, and deciduous forest gradually replaced the mid-Atlantic boreal forest (Overpeck et al. 1992). Finally, by the time sea level rates started to slow about 6,000 years ago, the Chesapeake had evolved into a classic drowned river valley, although it took on its current configuration only about 2,000 to 4,000 years ago (Schuebel 1986).

Physical Geography

The Chesapeake Bay is located along the mid-Atlantic coastline of the United States (36° N 76° W), covering approximately 11,400 km^2 and extending 332 km. The Bay's watershed drains a region of 165,800 km^2 (Figure 1). The mainstem Bay (excluding its tributaries) has a surface area of 6.5×10^9 m^2, an average depth of 6.46 m, and a mean low water volume of approximately 50×10^9 m^3 or 50 km^3 (Schubel and Pritchard 1987).

The Bay's geographic location is one of its defining characteristics. Located at the border between temperate and subtropical climate zones (Figure 2), the Bay ecosystem experiences a pronounced annual temperature range (Figure 3) and is subject to

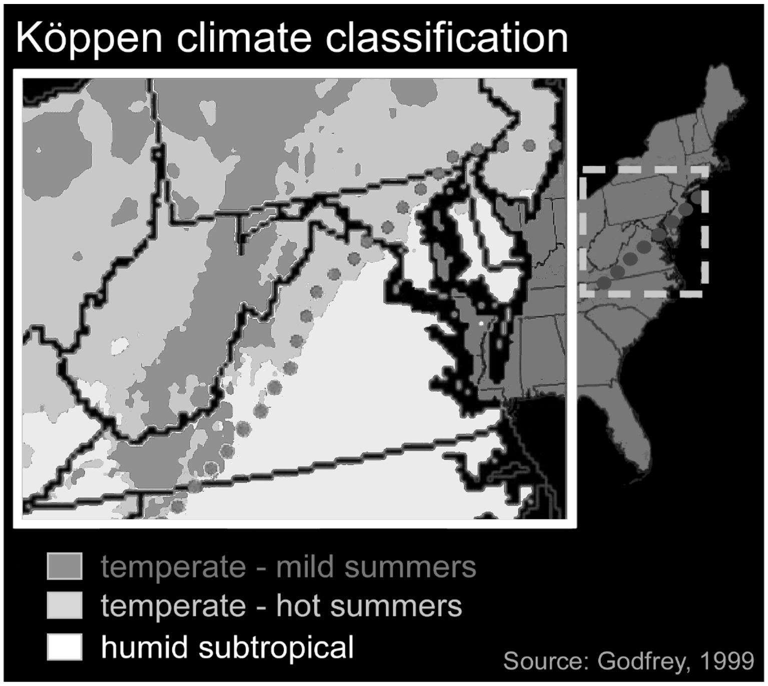

Figure 2. Köppen classification map emphasizing the Bay's proximity to the temperate-subtropical climatic boundary (indicated by dotted line).

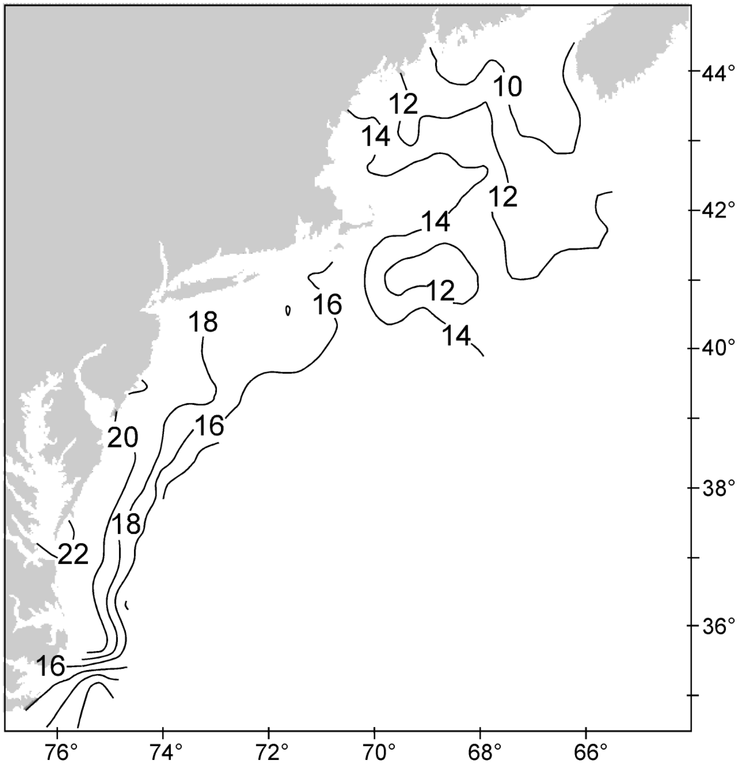

Figure 3. Annual range of temperature (Celsius) along the mid-Atlantic and northeast Atlantic coastline. Source: Mountain and Holzwarth 1989.

strong intraseasonal and interannual climatic variability. Air temperatures can reach 100°F (>37°C) and water temperatures can exceed 85°F (~30°C) during summer months. In the winter, Canadian arctic air masses often lower regional air temperatures to well below freezing and Bay waters can approach 32 degrees F (0° C). Significant regional snowstorms occur on occasion, dumping snow to a depth of over 60 cm (2 ft or more).

These climatic conditions strongly influence the ecosystem by affecting water temperature, available sunlight, length of the annual growing season, estuarine circulation patterns, and other environmental characteristics. Since such variables strongly influence the distribution of marine organisms within the Bay

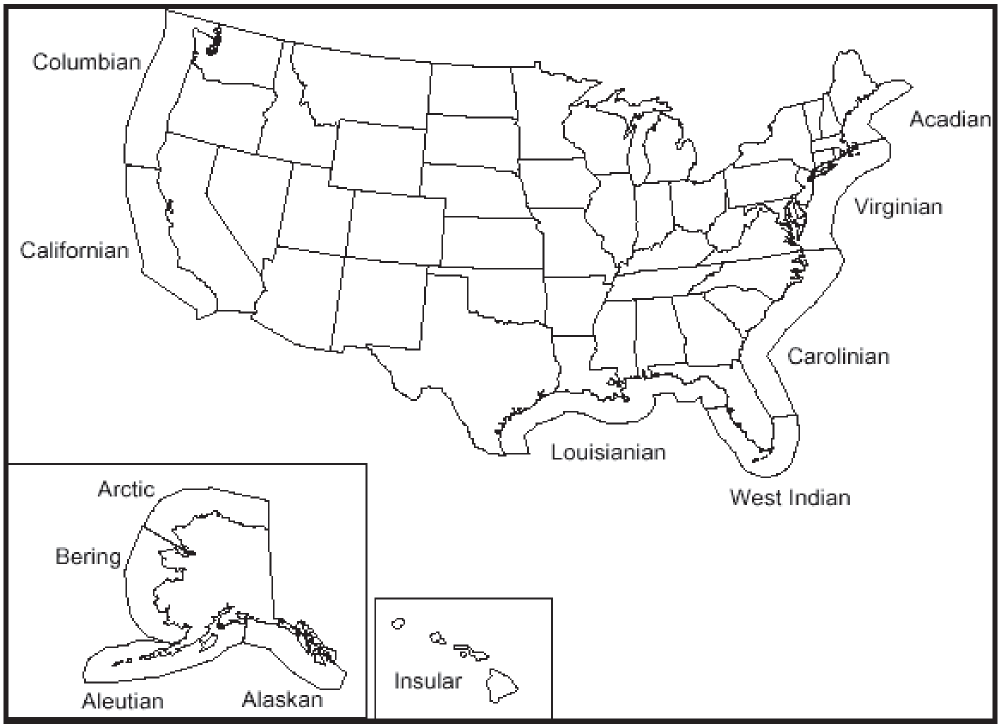

Figure 4. Marine biogeographical provinces bordering the United States. Source: Gibson et al. 2000.

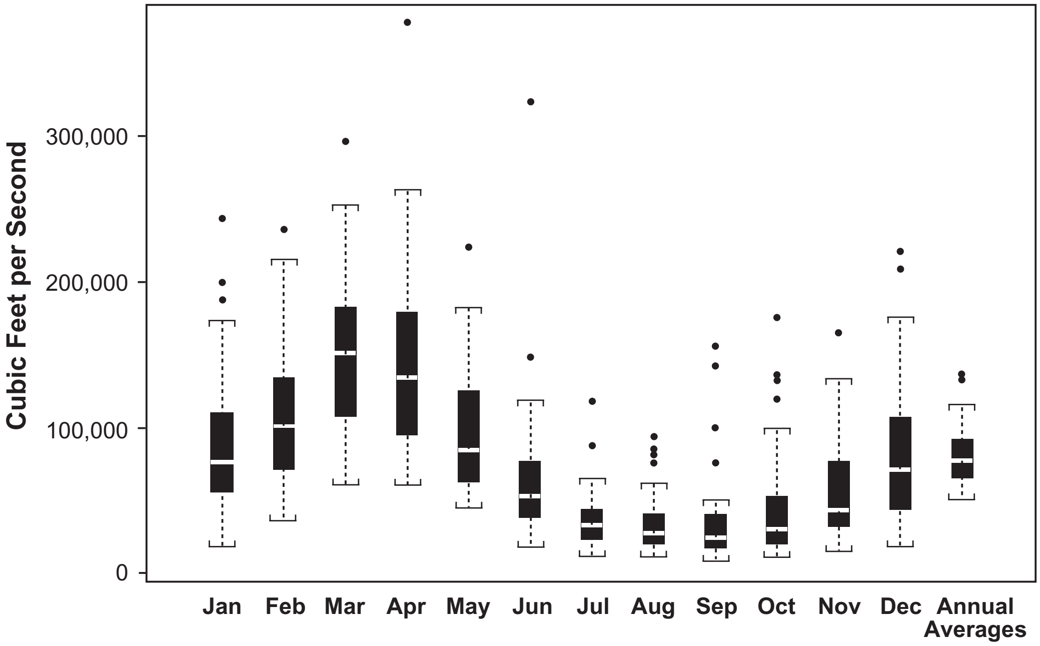

Figure 5. Box and whiskers plot of monthly and annual average (1951–2000) flow across the mouth of Chesapeake Bay. White bars indicate mean values. Filled boxes span the data's interquartile range (from the first quartile containing 25% of the data points closest to but lower than the mean, through the third quartile containing 25% of the data above the mean). Whiskers (staple marks) bracket 1.5 times the interquartile range (including 75% of the centrally distributed data points). Outlier data points extend beyond the whiskers. Source: Bue 1968.

and adjacent coastal waters, the border between the Virginian and more southerly Carolinian coastal marine biogeographical provinces also occurs in the vicinity of Chesapeake Bay (Figure 4) (Gibson et al. 2000). The Bay's juxtaposition between these climatic and biogeographical provinces allows a relatively diverse group of fish species to use this highly productive ecosystem as feeding and nursery grounds. On the other hand, the high annual temperature range and strong interannual variability in hydroclimatic conditions dictated by this geography mandate that relatively few fish species remain as year-round Bay residents (Figures 3, 5, and 6).

Chesapeake Bay Features, Processes, and Boundaries

As an estuarine ecosystem by definition, the Chesapeake Bay is a partially enclosed mixing zone where marine and terrestrial organisms, nutrients, and particles meet and interact (Pritchard 1967; Fairbridge 1980). The Bay has dynamic gradients and ecological boundaries in both horizontal and vertical dimensions as a partially mixed estuary featuring bilayer estuarine circulation (net downstream flow at the surface and upstream flow near the bottom).

The Bay's salinity gradient is perhaps the most obvious feature influencing its biology. Since the ocean serves as the salinity source, salinity values

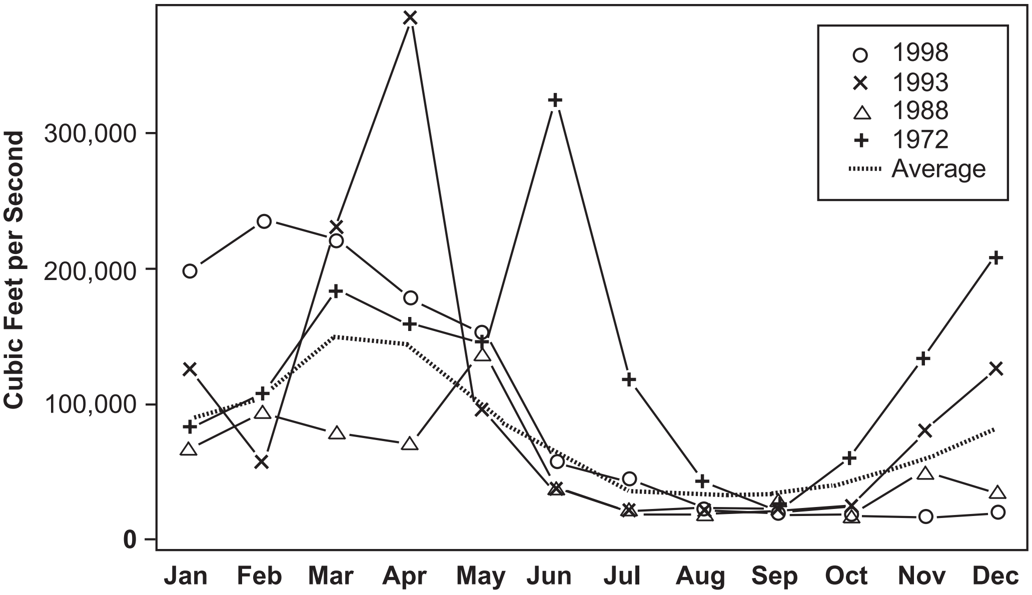

Figure 6. Monthly discharge across the mouth of Chesapeake Bay for selected years compared to the long-term (1951–2000) average. Source: Bue 1968.

generally increase from the upper Bay and the fall lines of its tributaries to the Bay mouth, regardless of depth. One important exception to this rule is the enhanced upstream incursion of coastal ocean waters on the northern side of the Bay mouth (Figure 7). Several factors account for the persistence of this feature, including

1) The eastward (apparent) deflection of the south-flowing coastal current attributed to the Coriolis force,
2) The difference between the much greater freshwater input from western shore tributaries relative to those on the Eastern Shore, and
3) The depth profile (deeper depths to the east) across the Bay.

Less obvious is the vertical salinity gradient that changes with depth from less dense, fresher surface waters to the heavier, more saline, deep waters. Salinity gradients in horizontal and vertical dimensions are highly sensitive to freshwater input and, to a lesser degree, to wind-induced mixing and the seasonal insolation cycle (maximum sunlight during summer, minimum during winter). The balance of these forces is largely determined by seasonally variable climatic conditions. Cooler, windier, and wetter conditions in winter result in a vertically well-mixed water column and in the downstream displacement of the salinity gradient, relative to warmer and drier months. These conditions shift as winter turns to spring. During spring warming, freshwater input increases and wind-driven mixing subsides. The water column starts to stratify with formation of a less dense, low-salinity lens overriding saltier, cooler, and denser deep waters.

With the arrival of summer, precipitation decreases and the effects of flow on the Bay's water

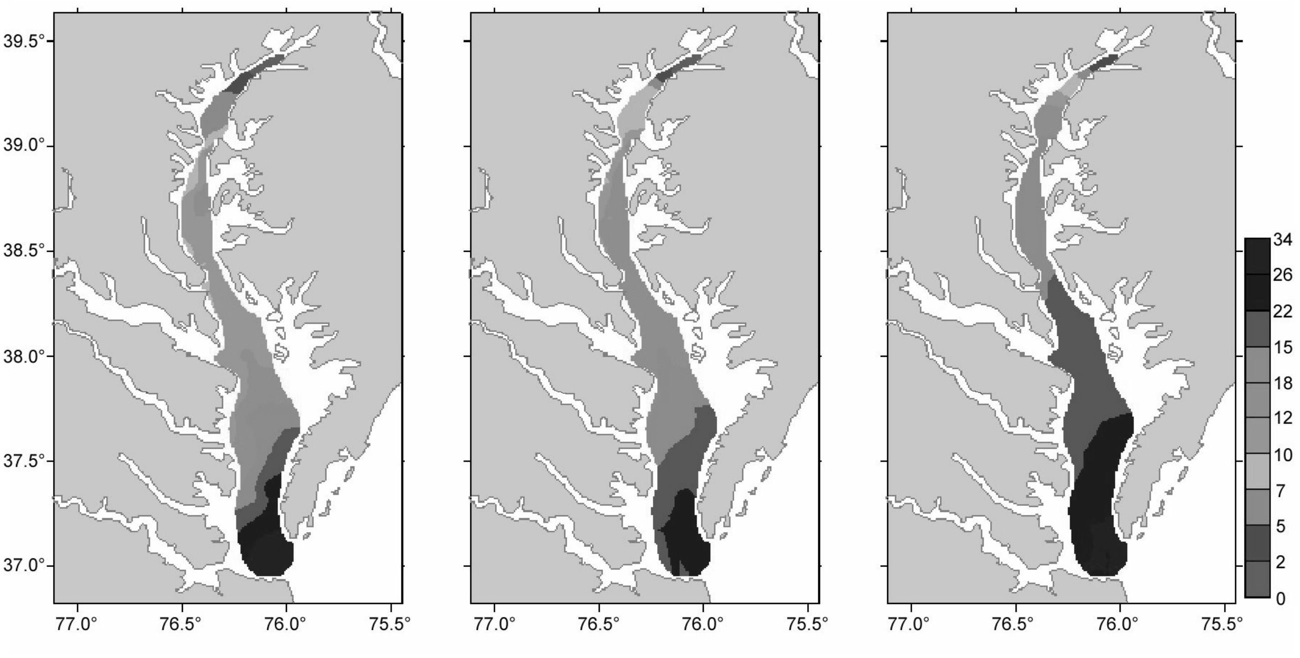

Figure 7. Chesapeake Bay salinity map for spring, summer, and fall of 1997. Source: TIES midwater trawl survey (www.chesapeake.org/ties/mwt/present.htm).

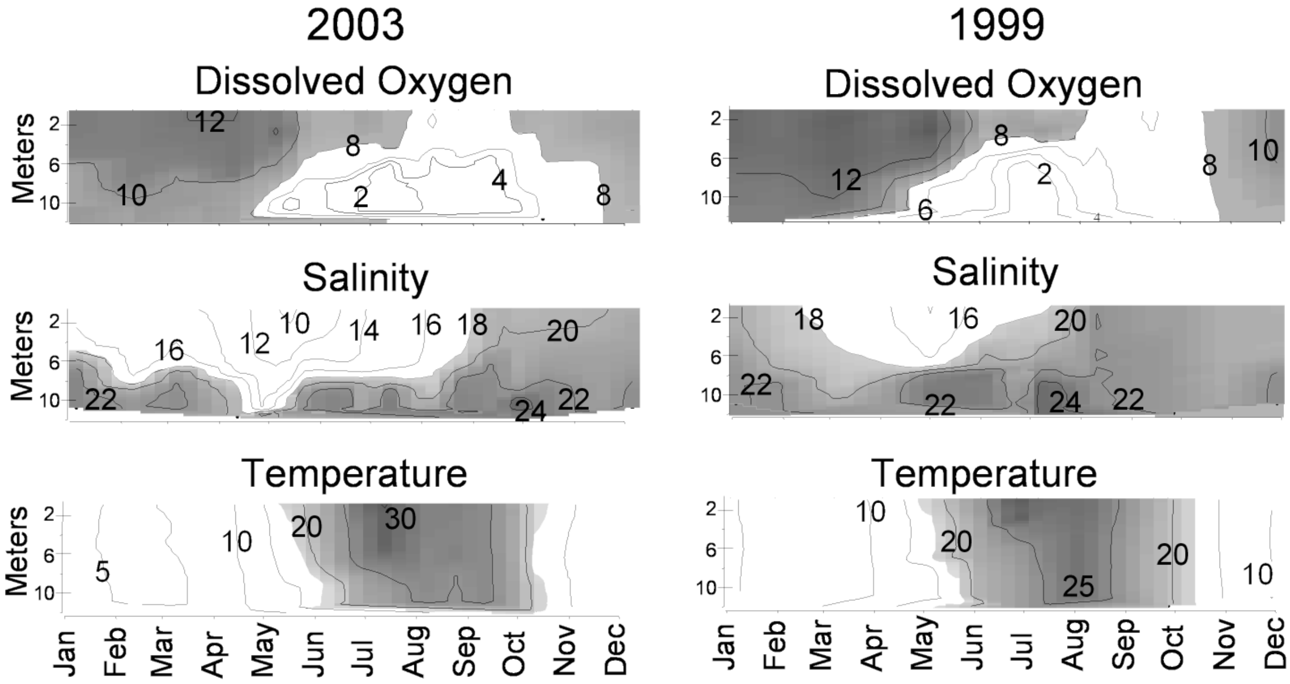

Figure 8. Annual water column dissolved oxygen, salinity, and temperature contour plots for a centrally located station (CB 6.1) monitored by the Chesapeake Bay Program. Plots are presented for 1993 (a high-flow year) and 1999 (a drought year). Note that in 1993, both stratification and hypoxia were more intense and persistent.

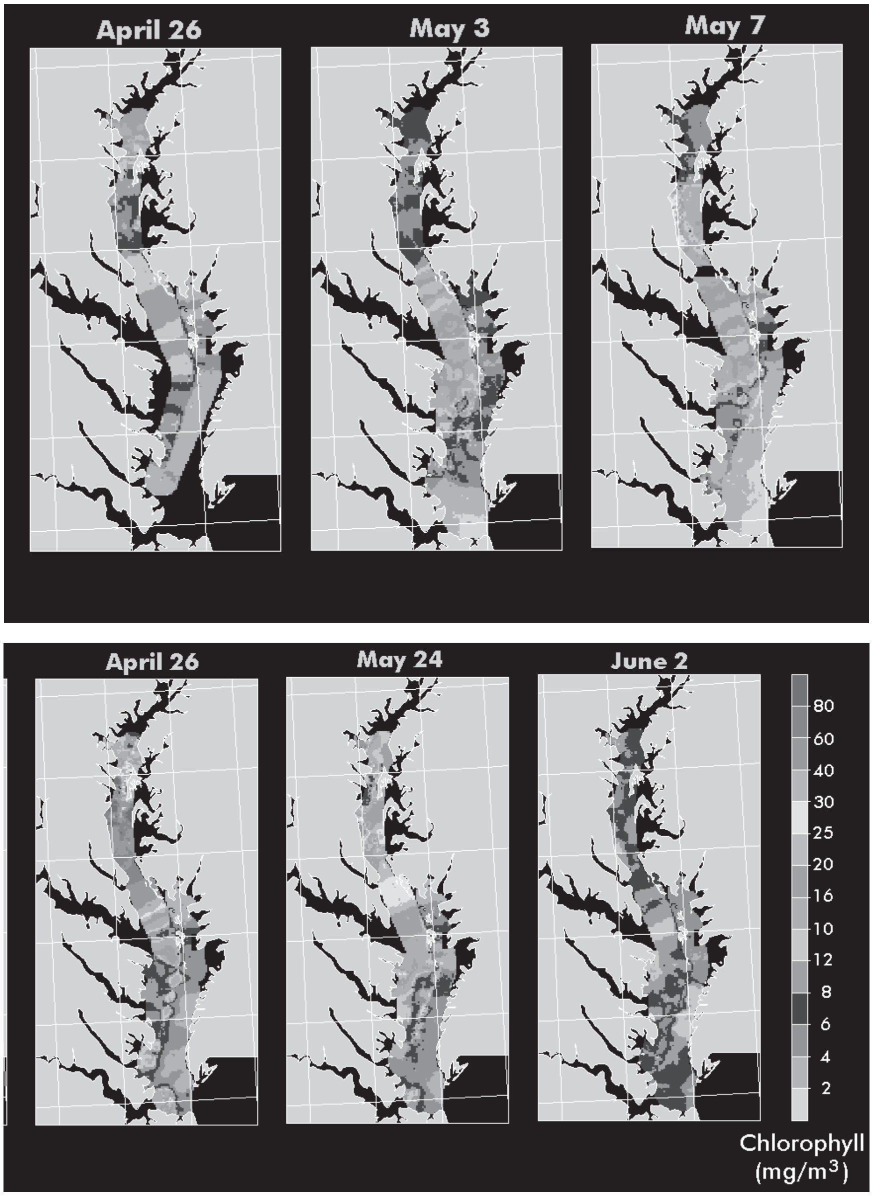

Figure 9. Spring phytoplankton bloom development in 1993. Source: Ocean Data Acquisition System website (http://noaa.chesapeakebay.net/odas_sas.html#Ref972000).

column structure diminishes. The Bay thermally stratifies during this season; vertical mixing of the water column becomes minimal as winds remain low during much of the summer with heating of surface waters. In autumn, the Bay's water column becomes well-mixed once again as temperatures cool and wind mixing increases (Figure 8).

Superimposed upon these generally consistent seasonal-scale patterns are anomalous, shorter-term events, which can markedly affect the system. For example, cool, northern air masses occasionally travel through the region in summer. Often preceding these cool air masses are the thunderstorms, high winds, and cooler temperatures associated with passage of cold fronts that can generate enough mixing to break down thermal stratification temporarily. A more extreme example occurred with passage of Tropical Storm Agnes on June 21 and 22 in 1972 (Astling et al. 1976). Coinciding with a wet spring and recent regional precipitation, Agnes dumped 12.7 cm (5 in) or more of rain over the entire watershed; one-third of the watershed received more than 30.5 cm (12 in) (Davis 1976). As a result, the fresh/saltwater interface moved 35 km further downstream than normal leaving the entire water column of the mainstem completely fresh to the Bay Bridge outside Annapolis, Maryland. (Schubel et al. 1976).

Events of much longer time scales also have occurred in the history of the Chesapeake. For example, climate regimes of decades or longer have affected the Bay's ecosystem. Although such patterns can be brief (e.g., the 20-month drought of 1998–2000), they can also persist for decades (e.g., the hydroclimatic regimes that presented generally cool, dry conditions during the 1960s, and a warmer, wetter climate during the 1970s and 1990s (Austin 2002; see also the Externalities Element). Ongoing efforts to extend the historical window on the Chesapeake ecosystem are providing insight into even longer-scale variability. Recent studies suggest that strong hydroclimatic variability is a natural and persistent characteristic of the Bay and that 14 pronounced wet–dry cycles and two megadroughts have occurred over the past 500 years (Stahle et al. 1998; Cronin et al. 2000).

Because climate variability is an ecosystem characteristic, interseasonal and interannual changes in physiologically important variables, such as temperature and salinity, do not typically have long-term effects on the Bay's living resources (with the possible exception of the extreme effects due to Tropical Storm Agnes). Perhaps the most important impacts of hydroclimatic variability result from variability in the quantity of nutrients delivered to the Bay by freshwater flow. Phosphorous concentrations generally limit primary production in marine waters with nitrogen becoming the limitation in fresh water. The Bay, however, is normally characterized as a eutrophic system since nutrient supply is generally abundant throughout much of the estuary relative to biotic demands, especially during the winter and spring. While production may be thermally constrained during winter, increased insolation and plentiful nutrients bring about a springtime bloom in primary production (Figure 9). During this bloom, phytoplankton take up nutrients and convert them to biomass, which greatly increases the phytoplankton standing stock and decreases available nutrients in the photic zone (the upper portion of the stratified water column with sufficient light to support photosynthesis).

Much of the phytoplankton biomass that accumulates during the spring bloom eventually settles to deeper waters, either directly or packaged within zooplankton fecal matter. Benthic organisms subsequently consume this organic matter or it degrades through oxidation. Since waters are stratified in late spring and summer, mixing does not replenish oxygen levels in the deep waters and dissolved oxygen levels can fall below biologically important thresholds over broad areas. Several studies have suggested that these hypoxic or anoxic zones form significant ecological boundaries that influence the distribution of important fishery species, as well as overall ecosystem dynamics and production (e.g., Diaz and Rosenberg 1995; Keister et al. 2000; see also Habitat, Habitat Requirements, and Habitat Management Element).

Unlike interannual variability, changes in climatological mean conditions persisting over decades or longer may have pronounced effects on the ecosystem and its living resources. While predicting long-term climate variability is currently beyond our scientific ability, continued accumulation of radiatively active gases (greenhouse gases) in the atmosphere will likely lead to century-scale drift from long-term mean climatic conditions and a rise in mean sea level throughout the mid-Atlantic region. This increase, in turn, will likely alter hydrographic conditions and physiochemical processes throughout the Bay (Najjar 1999; National Assessment Synthesis Team 2000), changing the ecosystem's ecologically important physical features and processes. Such changes, in turn, could alter the ecosystem's species composition, species diversity, trophic interactions, and productivity (Wood et al. 2002).

Defining the Chesapeake Bay FEP Management Unit

Defining boundaries of the Chesapeake Bay ecosystem is partly constrained by the intention that these boundaries facilitate effective fisheries management. The boundaries, therefore, must permit protection (or enhancement) of those areas, habitats, and processes critical to maintain (or replenish) economically important fish and shellfish populations harvested within the Bay. Clearly, many potential management unit boundary systems exist.

One appropriate strategy to determine which solution is most appropriate for the Bay is comparing and contrasting the feasibility and adequacy of boundary systems spanning a gradient—extending from the smallest practical option to a larger, more complex alternative. Several systems are discussed below.

The Mainstem Bay Boundary System

The Chesapeake Bay is a geographical entity defined by distinct geological or geomorphological features. Often referred to as the "mainstem Bay," this geographical unit is bounded by the basin's shoreline and the mouths of its tributaries. A line across the Bay mouth—from Cape Charles, Virginia on the Delmarva Peninsula to Cape Henry, Virginia near Virginia Beach—demarcates the seaward boundary of the mainstem Bay.

Although these geographical boundaries generally delineate the mainstem Chesapeake, they do not adequately define an effective fisheries management unit for the Bay ecosystem. One primary benefit of establishing the mainstem Bay as the management unit, however, is that this definition provides a well-defined, geographically based, and relatively confined management area featuring boundaries that change relatively slowly over the long term. These qualities minimize logistics-related costs and complexities in managing and maintaining the unit. While the simplicity of geographic boundaries is advantageous in these ways, this definition does not always adequately represent the physical and biological dynamics that characterize the Chesapeake as an estuary or as an ecosystem.

The Estuarine Boundary System

The Chesapeake Bay closely matches Pritchard's (1967) classic definition of an estuary as "a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh waters derived from land drainage." Since ecological conditions within the Bay are strongly shaped by the physical and chemical dynamics of tidal mixing, the estuarine boundaries incorporate the mainstem Bay and also extend upstream to each tributary's fall line where tidal energy becomes insignificant. Because the chemical and biological influences of the Chesapeake plume continue beyond the Bay's mouth, estuarine boundaries also extend into the coastal ocean.

Estuarine boundaries are superior to the more limited geographical boundaries of the mainstem Bay, as they incorporate many of the ecologically significant processes, habitats, and populations upon which several of the fishery species depend. While an ecosystem approach is certainly focused upon fisheries management, its explicit purpose is to recognize that sustainable fisheries depend upon a healthy and productive ecosystem. Because of the influence of land use and terrestrially based point and nonpoint source inputs (nutrients, sediments, toxicants, etc.), however, the Chesapeake Bay management unit should perhaps extend beyond estuarine waters to include the entire watershed.

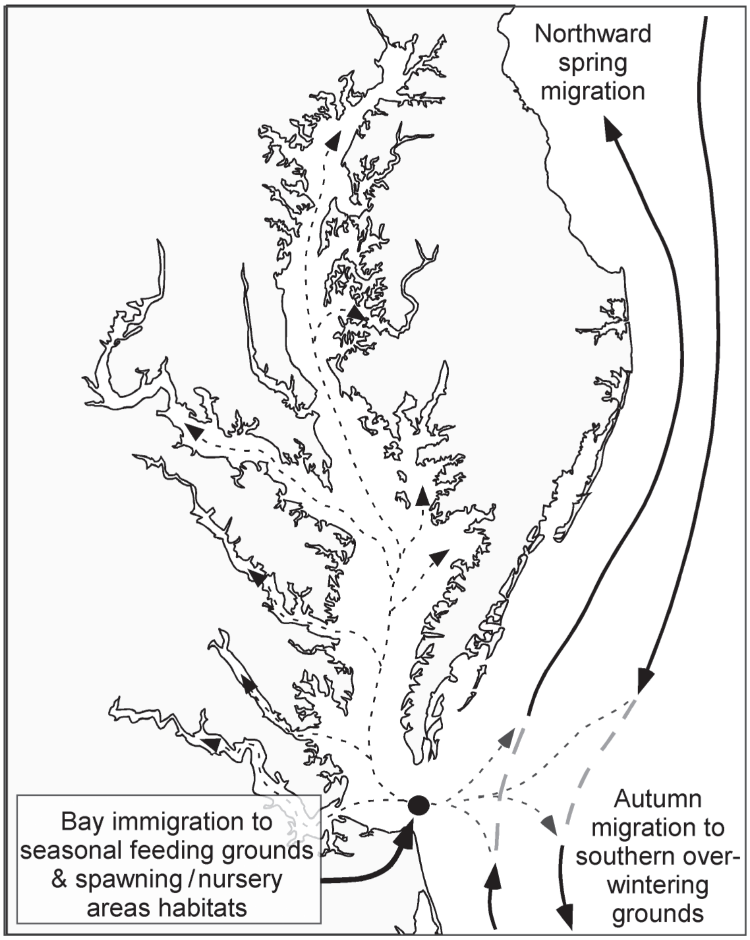

Figure 10. Generalized diagram illustrating the importance of Chesapeake Bay to anadromous and coastal shelf-spawning, estuarine-dependent fish. Not all species use the the Bay's tributaries.

The Watershed-to-Mouth (WtM) Boundary System

Precedence for a watershed-to-mouth (WtM) boundary system for Chesapeake Bay has existed for more than 20 years. Since the signing of the 1987 Chesapeake Bay Agreement, the Chesapeake Bay Program (CBP) and its partners have successfully reduced nutrient and sediment inputs into the Chesapeake Bay and its tributaries. The CBP's use of a WtM boundary system has facilitated this progress by allowing management of point source pollutants at the water's edge as well as key nonpoint sources scattered throughout the watershed, such as those from agriculture (Boesch et al. 2001). Adopting the WtM boundary system for an FEP is appealing, as it would permit management of the most important processes, habitats,

Table 1. Year-round residency status and value of the most valuable commercially exploited species within Chesapeake Bay. All data pertain to the 2000 Chesapeake Bay fishery (Maryland and Virginia Bay including coastal landings) as described by the National Marine Fisheries Service (NMFS). Species such as sea scallops, which are valuable but caught primarily outside the Bay, were not included. Source: NMFS *(*http://www.st.nmfs.gov/st1/commercial/*)*

NMFS Species or Species Group Classification	Significant Time or Critical Life Stage Spent Outside WtM Boundary	2000 Commercial Harvest Value ($ U.S.)
Blue crab - All fisheries	Yes: Planktonic early life stages	54,957,123
Atlantic menhaden	Yes: Adults, eggs, larvae	28,088,828
Eastern oyster	No	7,671,056
Striped bass	Yes: As adults	7,481,956
Atlantic croaker	Yes: Adults, eggs, larvae	6,167,501
Clams or bivalves	No	3,687,762
Summer flounder	Yes: Adults, eggs, larvae	3,131,418
Spot	Yes: Adults, eggs, larvae	2,340,952
Black sea bass	Yes	1,810,138
Weakfish	Yes: Adults, eggs, larvae	1,003,861
White perch	No	998,104
Catfishes and bullheads	No	978,626
Spotted seatrout	Yes: Adults, eggs, larvae	779,034
American eel	Yes: Adults, eggs, larvae	608,473
Proportional summary	***9 / 14 = 64%***	***$104,559,146 / $119,704,832 = 87%***

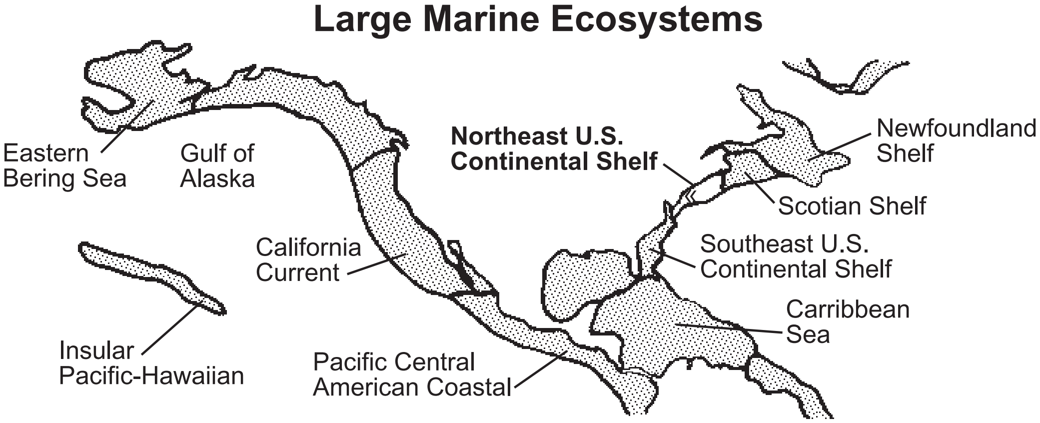

Figure 11. Map of the large marine ecosystems (LMEs) surrounding the continental United States. LME boundary data source: NMFS 2001.

and human activities affecting the ecosystem's health and fisheries production by using a pre-existing, interstate, multijurisdictional infrastructure that emphasizes ecosystem management.

Like many other boundary options, however, the proposed WtM management does not account for the many economically and ecologically important fishery species that spend much of their lives or critical life stages seaward of the Chesapeake Bay (see Setzler-Hamilton 1987 for a review). Species such as striped bass *Morone saxatilis*, American shad, Atlantic menhaden *Alosa sapidissima*, and spot *Leiostomus xanthurus* use the Bay and its tributaries as nursery areas for their young and as seasonal feeding grounds during the annual adult spring (northward) and fall (southward) migrations (Figure 10). Only five of the fourteen most valuable fishery species in the Bay are year-round residents (Table 1). Since many of these commercially and recreationally important species are fished during their Atlantic coastal feeding migrations or on their Mid-Atlantic or South Atlantic bight wintering grounds, they cannot be entirely managed or protected within the Chesapeake Bay WtM management unit.

Need for Coastal Ocean Management

Ecosystems are hierarchical, self-organizing systems. A major decline in any fished population, therefore, may have a powerful effect on the Bay. For example, strong fluctuations in key predator fish (e.g., striped bass, weakfish *Cynoscion regalis* or bluefish *Pomatomus salatrix*) or forage fish (e.g., menhaden or bay anchovy *Anchoa mitchilli*) populations could precipitate cascading changes throughout the food web through predator–prey feedback and multispecies interactions that alter ecosystem structure and dynamics. This possibility is acknowledged in the most recent Chesapeake Bay agreement, which calls for creation of

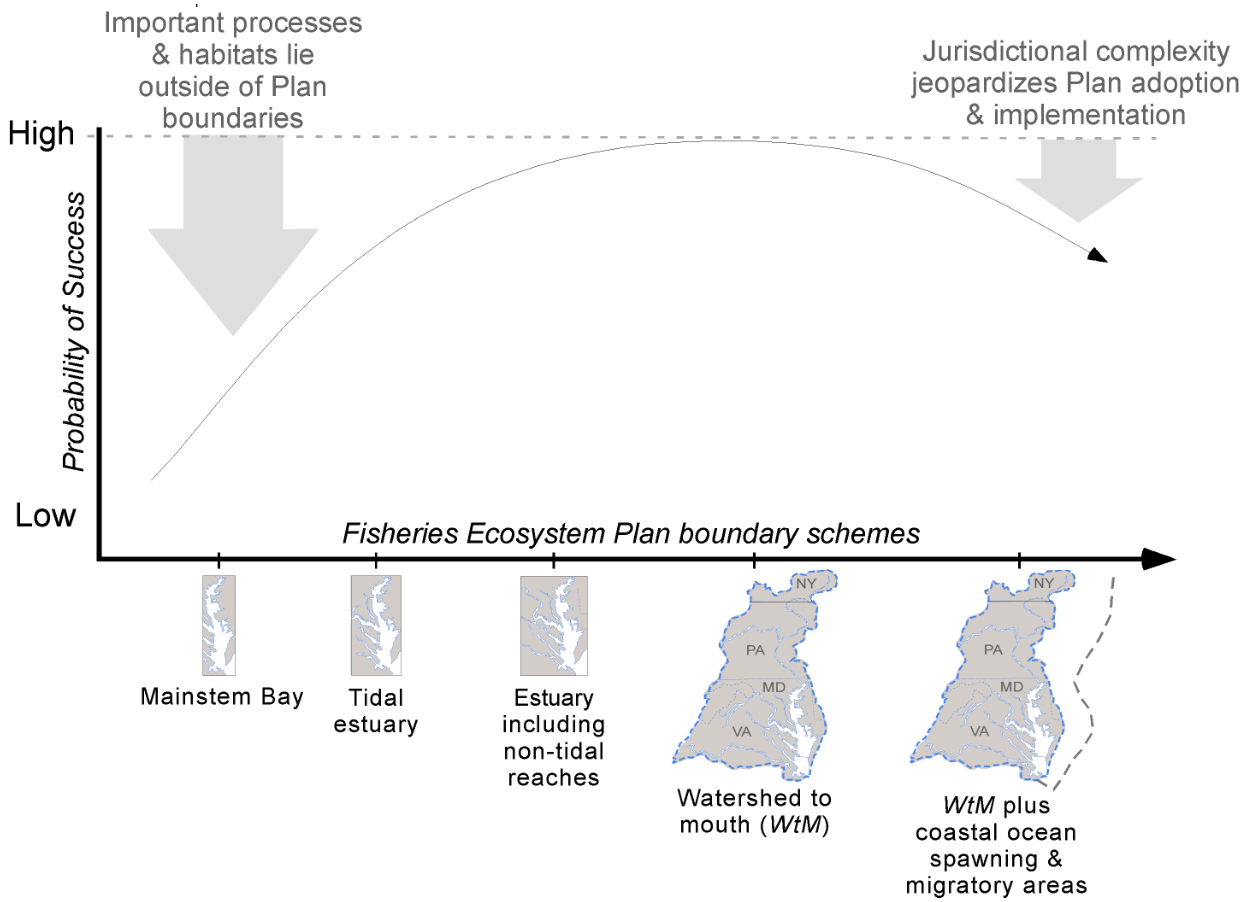

Figure 12. Conceptual diagram illustrating the relationship between probability of FEP success and management unit size. Large boundaries are desirable since they include more ecologically important habitats and fishery zones. Smaller boundaries are logistically less complex and require fewer management resources. The ideal boundary balances the need for "ecologically complete" boundaries against the costs and managerial complexities of a larger management unit.

multispecies fisheries management plans by 2005 (CBP 2000).

The northeast U.S. continental shelf large marine ecosystem (LME) is one of 50 global ecosystem management units designated to promote planning for intergenerational sustainability of ecosystem goods and services (Sherman et al. 1988; Sherman and Duda 1999). This LME (Figure 11) is an example of a management unit that incorporates estuarine and most coastal ocean waters important to many Chesapeake fishery species (Table 1). While appealing from an ecological perspective, the economic costs, jurisdictional issues, and other managerial complexities of implementing a plan for an area as large as the northeast U.S. continental shelf LME would likely prove prohibitive and certainly not tractable for a Chesapeake Bay FEP. Ideal boundaries for a Bay management unit are those that balance the benefits of protecting ecologically important areas—both inside the Bay and along the coastal ocean—against the economic costs and managerial complexities associated with their inclusion (Figure 12). Using the WtM boundary to define the Chesapeake Bay fisheries ecosystem management unit, while enlisting coordinated cooperation of management entities with jurisdiction over coastal waters of the Mid-Atlantic Bight (Atlantic States Marine Fisheries Commission, Mid-Atlantic Fishery Management Council, and South Atlantic Fishery Management Council), may prove a satisfactory solution. Imperative is formally recognizing, within the implementation strategy for a Chesapeake FEP, the development of a cooperative management structure that facilitates coordination among these different agencies.

Zone-based Management

Secondary zoning within the estuary may become an important part of ecosystem-based fisheries management in Chesapeake Bay. Such zones could help maintain general ecosystem integrity or protect productive, unique, or sensitive estuarine areas supporting specific populations. To convey its importance for maintaining fisheries production and ecosystem integrity, each zone should be clearly associated with a particular fishery species, sensitive and productive habitat, or important ecosystem process.

These zones need not be strictly limited to the waters of the Chesapeake. One advantage of the WtM boundary system is that it allows for special zonation of terrestrial areas. For example, this type of zoning could be used to limit or regulate activities that might degrade water quality in areas featuring oyster beds or seagrass meadows. While the WtM boundary system, by definition, stops at the Bay mouth, regulated zones or protected areas in the coastal ocean may be appropriate and necessary to ensure sustainability of Chesapeake fisheries. In fact, the recently expanded deepwater spawning sanctuary for blue crabs now includes coastal ocean waters immediately adjacent to the mouth of the Bay.

Defining the boundaries of the FEP's management unit forms the primary focus of this section. The Habitat Requirements Element provides a more complete discussion of protected areas.

Major Findings

The Chesapeake Bay fits the classic definition of an estuary as "a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh waters derived from land drainage" (Pritchard 1967). However, as this definition stresses, the Bay's inherent characteristics are largely determined by the strong influence of, and open connections with, land and sea. While acknowledging the lack of any fully self-contained ecosystem, delineating precise boundaries for this ecosystem has proven particularly problematic.

Guidance in defining boundaries for the Chesapeake Bay FEP comes from the primary missions of this Chesapeake Bay FEP: to provide a foundation for managing sustainable fisheries and to recognize explicitly that sustainable fisheries depend upon a healthy and productive ecosystem. Because of the influence of land use and terrestrially based point and nonpoint source inputs (nutrients, sediments, toxicants), the Chesapeake Bay management unit should extend landward of estuarine waters to include the entire watershed. Although extending the ecosystem management unit's boundaries beyond the mouth of the Bay may be impractical at this time, any Chesapeake Bay ecosystem-based fisheries management scheme must explicitly recognize that many ecologically and economically important species depend upon Atlantic coast habitats and are subject to fishing pressure within these waters.

After careful consideration, the FEP Advisory Panel has adopted a "watershed-to-mouth" boundary system for the Chesapeake Bay management unit. The WtM is not a new concept; in fact the precedence for this boundary system was established more than 20 years ago. In accordance with the nutrient reduction goals set in the 1987 Chesapeake Bay Agreement, the WtM management unit forms a successful management unit for the agreement's primary management entity—the Chesapeake Bay Program. Because the WtM management unit includes the entire watershed, the Bay Program has been able to address both point and nonpoint sources of nutrients and other detrimental effects to the Bay watershed. Adopting the WtM boundary system for this FEP should prove advantageous because it can build upon interjurisdictional management relationships fostered by the multistate and multiagency CBP. Perhaps more importantly, it encompasses most important processes, habitats, and human activities affecting the productivity, biological diversity, and sustainability of the Bay ecosystem and its fisheries.

One important shortcoming of the proposed WtM management unit is that it does not account for the fact that many economically and ecologically important Chesapeake fishery species spend much of their adult lives or critical life stages seaward of the WtM boundary. Species such as striped bass, American shad, Atlantic menhaden, and spot use the Bay and its tributaries as nursery areas for their young and as seasonal feeding grounds during their annual spring (northward) and fall (southward) migrations. Only four of the fourteen most valuable Bay fishery species are year-round residents. Since many of these commercially and recreationally important species are harvested during their Atlantic coastal feeding migrations or on their Mid-Atlantic Bight or South Atlantic bight wintering grounds, they cannot be managed or protected entirely within a WtM management unit. Management at broader regional levels also is required.

Perhaps the best solution is to use the WtM boundaries to define the FEP management unit while developing further coordination among management entities with jurisdiction over coastal waters of the SouthAtlantic bight and Mid-Atlantic Bight. Under this scenario, effective ecosystem-based fisheries management will require formal recognition and eventually implementation of a cooperative management structure that facilitates coordination among regional management agencies, including those with jurisdiction over coastal Atlantic U.S. waters.

Panel Recommendations

Management Recommendations

1) Make the protection and enhancement of sustainable fisheries of Chesapeake Bay estuarine species within an ecosystem management framework the primary focus of the FEP.
    - Estuarine species should be defined as those inhabiting or using habitats within the tidal waters of Chesapeake Bay and its tributaries.

2) Adopt the watershed-to-Bay-mouth (WtM) boundary system to define the Chesapeake Bay FEP management unit.
    - Acknowledge the need for watershed-wide management of pollution and contaminant sources (nutrients, toxicants, sediment, etc.) and land use patterns to preserve or enhance ecosystem integrity and fisheries production.
    - Strongly consider use of the Chesapeake Bay Agreement's interjurisdictional, cooperative structure.
3) Develop a cooperative management framework linking fisheries management agencies and efforts within Chesapeake Bay to those with jurisdiction over coastal waters.
    - Solicit cooperative engagement of coastal Atlantic management agencies to protect Bay fisheries for species that spend significant portions, or critical life stages, in the coastal ocean.

4) Determine the need for, and feasibility of, establishing a secondary boundary system to allow zone-based management and protection of Chesapeake Bay and coastal Atlantic habitats and areas that ensure sustainability of Chesapeake fisheries.
    - Ensure that each secondary boundary or management zone is associated with at least one representative ecologically and economically important species dependent upon that zone. Such a designation will communicate the need for special management attention within these zones.
    - Do not confine special management zones to the waters of the Bay. Such zones can help regulate estuarine habitat-degrading activities (occurring on land or in estuarine or coastal waters) or protect spawning areas of certain species harvested in the Chesapeake from exploitation or degradation.

Needed Research and Development

5) Conduct retrospective analyses or design surveys to identify important habitats, spawning areas, and feeding grounds for Chesapeake Bay fishery species along the Atlantic coast and

within the Bay.

- Develop a prioritized list of critical habitats and their geographical boundaries identifying Bay and coastal habitats that support critical life stages of ecologically or economically important Chesapeake Bay populations. Retrospective analyses of existing data may prove useful in developing such lists for many species, but in the absence of such information, new surveys will be required to obtain appropriate data.

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Food Web Interactions and Modeling

Introduction

The Chesapeake Bay food web has experienced significant historical alterations due to overfishing, anthropogenic stress, and natural disturbances. Although conventional single-species management approaches do not typically address predator–prey dynamics, these dynamics form the heart of interactions among species affecting abundance and production. Such interactions have dramatic and substantial effects on community structure, ultimately affecting fisheries yields in the Bay, and must be considered when developing or amending ecosystem-based fishery management plans (FMPs).

Fishing mortality—an important fraction of total mortality for most exploited species—represents human predation on fishery resources. Multispecies fisheries management incorporates not only fishing mortality information but also key predator–prey linkages and their contributions to natural mortality. Understanding such food web dynamics allows quantification of the energy and biomass transfers in the food web that dictate sustainable levels of fishery exploitation. Food web relationships are not independent of habitat and water quality issues; they may vary with changes in the productive capacity of the environment, the abundance of planktonic and benthic prey, and the structure of food webs that support fisheries.

Researchers have a good understanding of some food web relationships in the Chesapeake Bay. Atlantic menhaden *Brevoortia tyrannus*, Atlantic croaker *Micropogonias undulatus*, bay anchovy *Anchoa mitchilli*, blue crab *Callinectes sapidus*, and spot *Leiostomus xanthurus* are integral links between and within benthic and planktonic components of the Bay food web. Heavily exploited, predatory fish consume forage species, such as menhaden and bay anchovy; these predators may also rely on juvenile blue crabs as part of their diet and may ultimately affect the abundance of recruiting crabs.

We must expand our understanding of food web interactions, quantify their effects, develop new food web models, and implement existing models to provide the requisite information that will permit managers to define sustainable catch levels and estimate fishing mortality rates of species in the webs. In this fisheries ecosystem plan (FEP), we have included preliminary diagrammed food webs of managed species, indicating strong and weak interactions between predator and prey. These webs can guide managers as they explore policy options to develop ecosystem-based regulations—allowing high yields of piscivorous fish, for example, while conserving forage fish resources and important predator–prey relationships. Managers can now use fundamental knowledge of food web structure and relationships in a precautionary manner, but major research is needed to ensure effective multispecies fisheries management in the Bay.

This FEP element addresses the importance and limitations of developing food web models for the Chesapeake, considers the degree of connectivity between particular species (or trophic groups) and their predators and prey, and describes subwebs of the Bay's economically valuable species. In addition, the element describes and discusses the utility of several recognized multispecies and ecosystem models that managers could adopt for ecosystem-based fisheries management in the Bay.

A food web is defined as a "network of consumer-resource interactions among a group of organisms, populations, or aggregate trophic units" (Winemiller and Polis 1996).

Food Web Dynamics

Importance

Sustainable use of exploited species will depend, at least in part, upon inclusion of multispecies fisheries management approaches based largely on food web dynamics (Christensen 1996; Daan 1997; Christensen and Pauly 1998; Pauly et al. 1998). Managers have not yet applied a multispecies approach to fisheries management in the Chesapeake, despite its potential utility (Houde et al. 1998) as well as the availability of a food web model for the mesohaline (middle) portion of the Bay (Baird and Ulanowicz 1989), which could provide a framework for additional modeling focused on management needs.

Fishing affects ecosystems by removing biomass from the complex of species that feed upon each other in the web (Pauly et al. 2000). It also shifts the relative abundance of exploited species at different trophic levels. Such changes—from fishing, other anthropogenic stresses (e.g., habitat alteration and pollution), or environmental change—may lead to shifts in the productivity and sustainable yields of species. These shifts, in turn, may affect the value of fisheries, species biodiversity, or the structural integrity of the ecosystem (Winemiller and Polis 1996; Pauly et al. 2000; Jackson et al. 2001; Link 2002a). For instance, researchers have postulated that changes in the abundance of key fishery species, such as the oyster and blue crab, may have altered community structure and pathways of production in the Bay (Jackson et al. 2001; Silliman and

Bertness 2002). Massive fishery-induced reductions in the abundance of eastern oyster *Crassostrea virginica*, a suspension feeder on phytoplankton, have contributed to abnormally high phytoplankton production, eutrophication, and seasonal hypoxia that reduce secondary production and species diversity (Jackson et al. 2001). In coastal salt marshes, declines in blue crab abundance (Lipcius and Stockhausen 2002), due partly to heavy fishing pressure, may have allowed marsh periwinkle *Littoraria irrorata* to become more abundant and overconsume salt marsh grasses—a process which ultimately could lead to the destruction of salt marshes important for blue crab production (Silliman and Bertness 2002).

An ecosystem's carrying capacity, production potential, and total sustainable yield to fisheries cannot simply be calculated as the sums of yields for individual component species (Link 2002a) using traditional, single-species stock assessment techniques. Rather, fisheries production of an ecosystem depends significantly on food web dynamics (Pauly et al. 2000; Link 2002a). To evaluate the impact of a species' fishing mortality upon food web interactions and ecosystem processes, therefore, the ecosystem's chief food web interactions must be defined and quantified (Pauly et al. 2000). Similarly, researchers must consider the effects of other controlling factors, such as habitat quality and environmental conditions (see Habitat Requirements and Externalities elements), within the context of ecosystem-based management.

Predation is key in determining the abundance and size structure of populations, as well as the organization and functioning of communities in the Chesapeake and other ecosystems (Lipcius and Hines 1986; Hines et al. 1990; Seitz et al. 2001). Predation affects all life stages of marine organisms and constitutes the primary source of natural mortality for fish in well-studied marine ecosystems (Bax 1991, 1998), even for those species with high fishing mortality during their exploitable life stages.

The relative importance of predation and fishing mortality varies among species, but is typically skewed towards predation for younger (and smaller) individuals and towards fishing mortality for older individuals. For instance, predation largely accounts for the mortality of young juvenile blue crabs whereas fishing becomes responsible for 80% of the mortality of older juveniles and adults. Predation may also play a major role in controlling food web dynamics in marine ecosystems, altering the effects of reductions or increases in fishing mortality of species (Andersen and Ursin 1977; Laevastu and Favorite 1988; Bax 1991, 1998; Christensen 1996; Trites et al. 1999; Pauly et al. 2000; Link 2002a).

With a heavily fished population at low abundance, predation may limit population recovery despite potentially high recruitment of incoming year classes (Sissenwine 1984; Bax 1991, 1998; Christensen 1996; Link 2002a). In such cases, the predator may have remained at high population levels or it may be a fished species that has recovered after management-induced reductions in fishing mortality. For example, Lipcius and Stockhausen (2002) hypothesized that predation pressure by Atlantic croaker (at high abundance in Chesapeake Bay for nearly a decade) or by striped bass *Morone saxatilis* (which dramatically resurged during the last decade following rigorous management measures) may be responsible for the lack of recovery of the depressed blue crab population in the Bay. Similarly, restoration of the Bay's native oyster population may be hampered by disease in older juveniles and adults or by blue crab predation; either of these forces could prevent oyster recovery given that overfishing, habitat degradation, and disease have driven the population to extremely low levels (Rothschild et al. 1994).

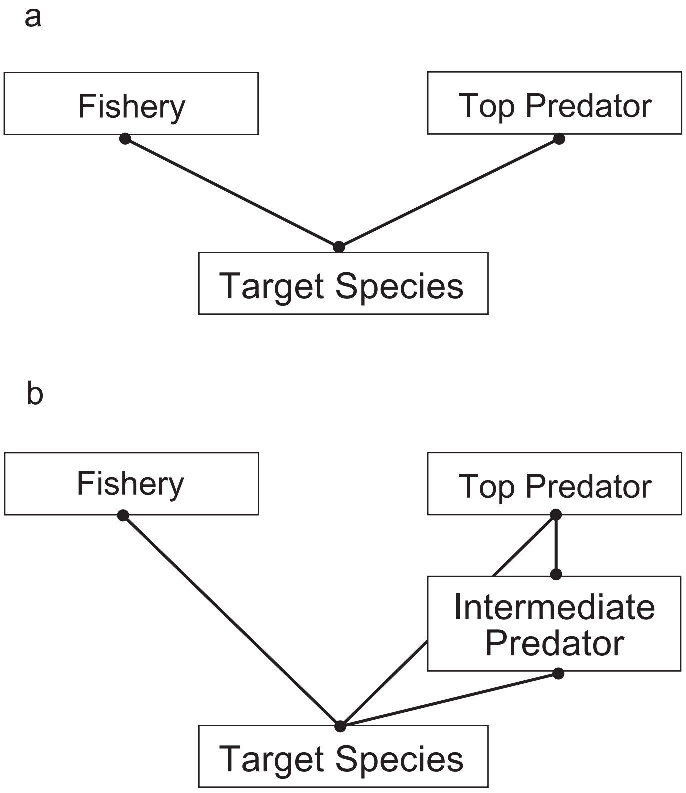

Figure 1. Hypothetical simple (a) and moderately complex (b) food webs with top and intermediate predators that are not fished, a target fishery species, and human fishing at a trophic level equivalent to that of the top predator (adapted from Yodzis 2001).

For some species, natural mortality through predation—especially on young stages—may prove more significant in controlling population abundance than fishing mortality on recruited stages. Such species may be subject to little or no fishing pressure, but serve as forage species for a spectrum of natural predators (Overholtz et al. 2000). Historically, watermen have fished some forage species (e.g. Atlantic menhaden), which form a major component of the Chesapeake fisheries ecosystem. During the past 50 years, when overfishing has caused declines of top predator species, fisheries have increasingly targeted species at lower trophic levels (Pauly et al. 1998). Significant reductions in the abundance of these species may cause fundamental changes in community structure and the ecosystem (Pauly et al. 1998; Jackson et al. 2001). This process, referred to as "fishing down food webs," may disrupt natural predator–prey relationships. The effects of such fishing include shifts in trophic-level structure, along with changes in population abundance and age structure of target species. Selective fishing on forage species can precipitate indirect impacts on other species in the food web as predators transfer their emphasis to alternative prey.

In some cases, predation may not play a major role in controlling abundance, as in shoaling pelagic species (Overholtz et al. 1991, 2000; Jennings and Kaiser 1998), which fluctuate in response to variable ocean conditions. Such variability in controlling mechanisms accentuates the need to define the major food web interactions in an ecosystem before we can understand the relative impacts of natural and fishing mortality upon food web dynamics and ecosystem processes.

Limitations

Despite the growing awareness that fisheries management requires a multispecies approach, considerable debate remains over the reliability of predictions of changes in target species abundance derived from multispecies approaches. Yodzis (2001) provides an illuminating example of the problems associated with predictions of fishery-induced alterations in food webs, examining a situation in which fisheries cull a top predator to increase production of a target species by reducing the natural predation on this species. In this case, fisheries catch a target species consumed by the top predator (Figure 1a). If the cull significantly reduces the population of the top predator, then the abundance and yield of the target fishery species should increase.

This simple view of food web dynamics is based on the assumption that removing a top predator from the system will increase the abundance of prey it would have consumed, which then becomes available to the fishery. If, however, the addition of an intermediate predator complicates the food web (Figure 1b), the potential for indirect effects confounds the ability to determine either the direction of the system response to the removal of the top predator or its magnitude (Yodzis 2001). In this scenario, the reduced top predator population will eat less of the target species, which should result in an increase in its abundance. The top predator will also eat fewer of the intermediate predators, however, which should decrease target species abundance. In this circumstance, the net result of reducing the top predator upon the target fishery species shown in this relatively simple food web remains uncertain. Ultimately, the abundance of the target species might increase, decrease, or be unaffected, depending on the strengths of the various predator–prey links (Punt and Butterworth 1995; Abrams et al. 1996; Yodzis 2001).

Stability is not limited to pristine systems; it is also a feature of disturbed systems (Sheffer et al. 2001; Carpenter 2002) and contributes to the difficulty in restoring disturbed ecosystems such as Chesapeake Bay.

Another complication arising from the complexity of food web dynamics is the possibility that ecosystems have alternative stable states (Sheffer et al., 2001; Carpenter 2002). Given that the Chesapeake Bay food web has undergone dramatic, historical alterations due to anthropogenic changes—such as overfishing (Jackson et al. 2001) and eutrophication (Boesch 2000)—and natural disturbances (R. N. Lipcius and R. D.

Seitz, unpublished manuscript), restoring the food web to its "pristine" state may prove impossible. Even if managers agree on the preferred food web, its composition, and its biomass structure, such a food web may be unattainable due to the stability of the degraded ecosystem characterized by the distorted food web (Sheffer et al. 2001; Carpenter 2002; Peterson and Lipcius 2003). Stability refers to a situation in which a disturbed or degraded ecosystem is in an "alternative stable state" (Sheffer et al. 2001; Carpenter 2002), which will not easily shift back to the undisturbed state due to feedback mechanisms maintaining the structure of the disturbed stable state. Stability is not limited to pristine systems; it is also a feature of disturbed systems (Sheffer et al. 2001; Carpenter 2002) and contributes to the difficulty in restoring disturbed ecosystems such as Chesapeake Bay.

Management, therefore, should consider the possibility that some desired food web configurations may not be achievable (Peterson and Lipcius 2003), at least in the short term, without massive intervention (Carpenter 2002). For instance, the seaside lagoons of the Eastern Shore harbored extensive seagrass beds that supported a lucrative Bay scallop fishery until the Storm King hurricane of 1933 devastated the ecosystem. The resultant turbid conditions not only precluded restoration of the seagrass beds, but also hindered the reestablishment of a productive scallop fishery in the seaside lagoons for over 6 decades (R. N. Lipcius and R. D. Seitz, unpublished manuscript).

Three basic approaches exist for the analysis of food webs (Paine 1966; Winemiller and Polis 1996). One is topological, providing a static description of predator and prey links between species or trophic groups. In the following section, we offer a basic topological analysis of the connectivity of species and trophic groups in the Chesapeake Bay food web. A second approach uses quantitative analysis of energy and matter flow through the food web via predation (e.g., Ecopath with Ecosim, Pauly et al. 2000), a modeling approach that researchers have started using in the Bay. The final approach is functional, identifying the species and trophic links that determine community structure. The functional approach typically depends on field experiments that deal with specific links between important consumers (predators) and resources (prey) in the food web (see Silliman and Bertness 2002).

Topological and energy flow analyses are instructive (Pauly et al. 2000; Link 2002b), but not always capable of explaining the dynamics of populations and communities. The dynamic influence of a particular species or trophic group is not necessarily proportional to the energy flow between trophic links (see review of the three analysis types in Winemiller and Polis 1996). For instance, keystone species may initiate trophic cascades (i.e., significant effects of changes in one species upon

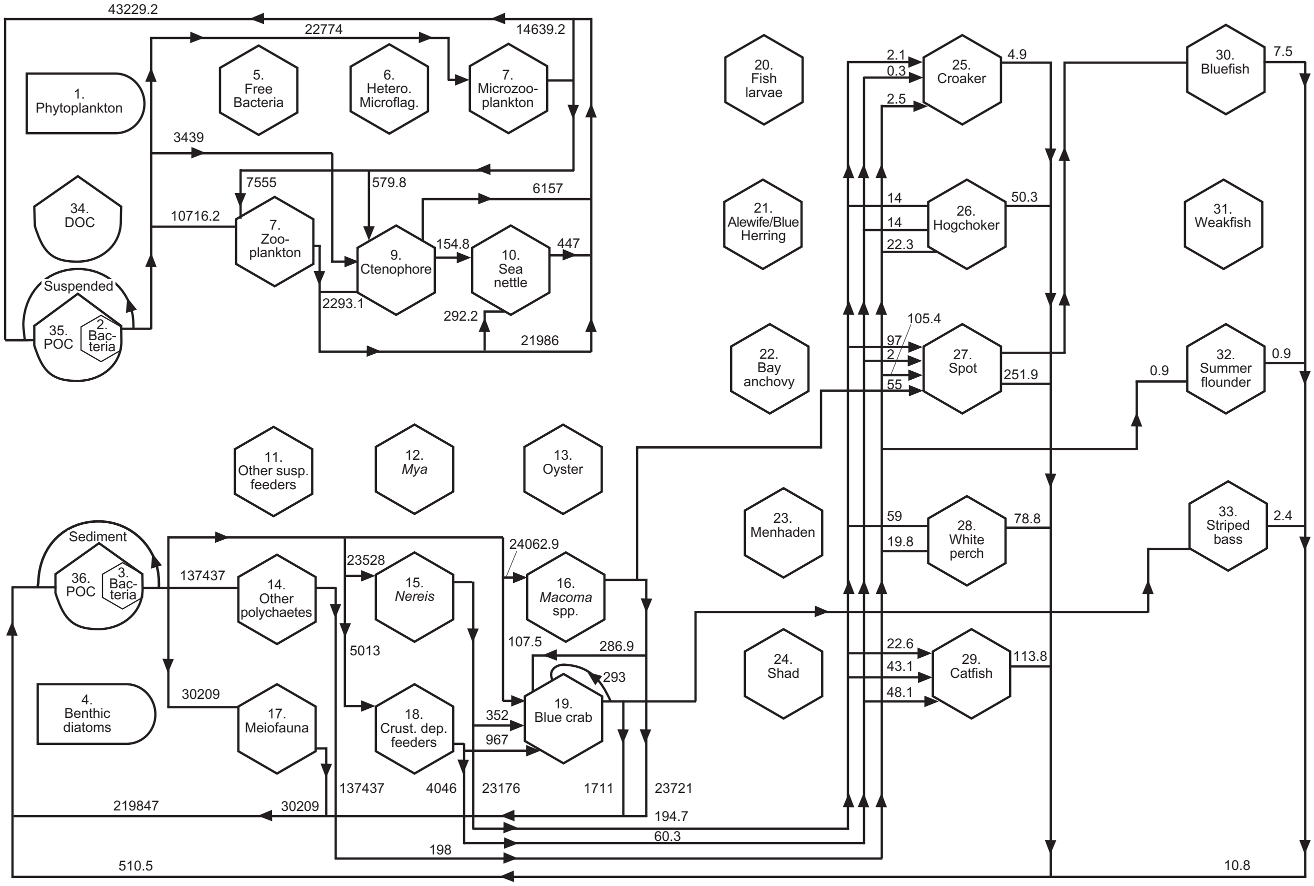

Figure 2. Food web components of middle (mesohaline) Chesapeake Bay, indicating composite cycling of carbon. This web is generally representative of the major food web components used in previous network (energy flow) analyses of the Chesapeake food web (Baird and Ulanowicz 1989; Monaco and Ulanowicz 1997; Hagy 2002) (adapted from Baird and Ulanowicz 1989).

others in the food web without direct links), forming a key force in structuring marine, aquatic, and terrestrial communities. Yet, their influence often appears disproportionately high relative to their biomass (Power et al. 1996).

Recent research suggests that the blue crab is a keystone species in the Chesapeake. First, the blue crab enhances salt marsh grass production and the associated marsh community by feeding upon marsh periwinkles, which at high densities can reduce salt marsh productivity (Silliman and Bertness 2002). Second, the blue crab may strongly influence seagrass production and community structure through consumption of seagrass grazers (e.g., amphipods and isopods), which increase seagrass productivity by grazing upon seagrass epiphytes (M. Harris, E. Duffy, and R. N. Lipcius, unpublished manuscript). The influence of these complex mechanisms on community structure in Bay habitats indicate that an experimental, functional approach to food web analysis is needed to identify the major controlling factors of food web dynamics. Unfortunately, the experimental field manipulations typically required to evaluate the dynamics and functional roles of species in a food web often prove logistically intractable at spatial and temporal scales that capture the full dynamics of an ecosystem. In such cases, topological analyses or modeling may become the only options. A balanced inclusion of the three approaches to food web analysis may best address the food web dynamics of large ecosystems. Moreover, collective uncertainties in food web investigations demand caution in the application of food web analyses to fisheries management.

Chesapeake Bay Food Web

General Features

The Chesapeake Bay food web (Figure 2) contains several features typical of most estuarine food webs:

1) Predominance of generalist feeders, both benthic and pelagic, that typically consume prey in proportion to their availability (Baird and Ulanowicz 1989; Monaco and Ulanowicz 1997; Hagy 2002);
2) Moderately interconnected trophic pathways between predators and prey (Monaco and Ulanowicz 1997; Dunne et al. 2002);
3) Modified food web structure due largely to anthropogenic alterations (Monaco and Ulanowicz 1997; Jackson et al. 2001; Hagy, 2002);
4) High fisheries production (Nixon 1982); and
5) High phytoplankton primary production, much of which is not consumed and is transformed to detritus, particularly in the middle Bay (Monaco and Ulanowicz 1997; Hagy 2002).

Although the ratio of primary production in the water column to that in the benthos is 6:1, production in the Bay relies heavily on inputs from detritus and the microbial loop (i.e., organic matter cycles through bacteria to protozoan consumers with subsequent grazing by microzooplankton) to fuel secondary production at higher trophic levels, including most fishery species (Monaco and Ulanowicz 1997). Production of predatory fish in the Bay may depend significantly on benthic deposit feeders, detritus, and the microbial loop, in addition to pelagic primary production (Baird and Ulanowicz 1989; Monaco and Ulanowicz 1997; Hagy 2002), as in many marine ecosystems characterized by high bacterial biomass (Pomeroy 2001). Benthic suspension feeders use phytoplankton production, allochthonous inputs (e.g., external nutrient sources from freshwater inflows), and benthic production (Monaco and Ulanowicz 1997). Consequently, benthic suspension feeders and deposit feeders form critical conduits between the pelagic and benthic components of the food web, since deposit and suspension feeders (such as worms and clams) are eventually consumed by predatory demersal fish and benthic invertebrates. These predators subsequently become prey for larger, pelagic, predatory fish.

The species and trophic groups comprising the Bay's food web have been assigned to specific trophic levels (Table 1) and their importance identi-

Trophic Group	Hagy	Baird & Ulanowicz	Monaco & Ulanowicz
DOC, POC	1.0	1.0	1.0
Phytoplankton	1.0	1.0	1.0
Picoplankton	1.0	1.0	1.0
SAV	1.0	1.0	1.0
Microphytobenthos	1.0	1.0	1.0
Bacteria	2.0	2.0	2.0
Suspension feeders	2.1	2.1	2.2
Eastern oyster	2.1	2.1	2.2
Atlantic menhaden	2.1	2.8	2.7
Meiobenthos	2.3	2.7	-
Rotifers	2.4	2.2	-
Deposit feeders	2.4	3.0	2.8
Microzooplankton	-	2.2	2.6
Mesozooplankton	2.5	2.2	2.2
Ciliates	2.6	2.8	-
Heteroflagellates	3.0	3.0	-
Blue crab	3.1	3.5	3.2
Spot	3.1	4.0	-
Atlantic croaker	3.1	4.0	-
Hogchoker	3.1	3.9	-
American eel	3.1	-	-
Catfish (Bay species)	3.2	4.0	-
White perch	3.4	4.0	-
Bay anchovy	3.5	2.8	2.7
Lobate ctenophore	3.5	3.0	3.2
Alewife/Blueback herring	3.6	3.2	-
Shads	3.6	3.2	-
Striped bass	3.6	3.9	3.8
Weakfish	4.0	3.8	3.8
Bluefish	4.1	4.6	3.8
Sea nettle	4.6	3.4	-
Summer flounder	-	4.0	3.8

Table 1. Trophic levels of Chesapeake Bay food web components after Hagy (2002), Baird and Ulanowicz (1989), and Monaco and Ulanowicz (1997). Numbers refer to the average trophic level of each group, standardized to 1.0 for primary producers and sources of organic carbon (DOC and POC), 2.0 for primary consumers, 3.0 for secondary consumers, and so on.

fied through network analysis of energy flow (Baird and Ulanowicz 1989; Monaco and Ulanowicz 1997; Hagy 2002). Baird and Ulanowicz (1989) and Monaco and Ulanowicz (1997) categorized the principal consumers and trophic groups in terms of energy flow and cycling in the Bay food web. More recently, Hagy (2002) extended the earlier analyses and reached fundamentally similar conclusions. Although the relative importance of a particular species or trophic group as a consumer may differ based on occurrence in the upper, middle, or lower Bay (Hagy 2002), generalities do exist in the Bay's food web. The following conclusions are summarized from the extensive investigations of Baird and Ulanowicz (1989), Monaco and Ulanowicz (1997), and Hagy (2002). Some species may be categorized poorly, however, due to incomplete diet data or an inadequate understanding of ontogenetic diet shifts. Consequently, the assumed trophic position of individual species should be examined carefully during FMP development or in food web modeling and investigations.

Food Web Generalities for the Bay. The following list cites some of the generalities that apply to the Chesapeake Bay food web.

1) Of the pelagic consumers, bay anchovy and menhaden transfer the most production from plankton to predatory fish and have the highest secondary fish production.

2) The lobate ctenophore (e.g., comb jelly) is a major consumer of mesozooplankton (larger zooplankton such as copepods and cladocerans) and microzooplankton (smaller zooplankton such as nauplii and rotifers) particularly in the middle Bay. This consumption diverts production from forage fish and,

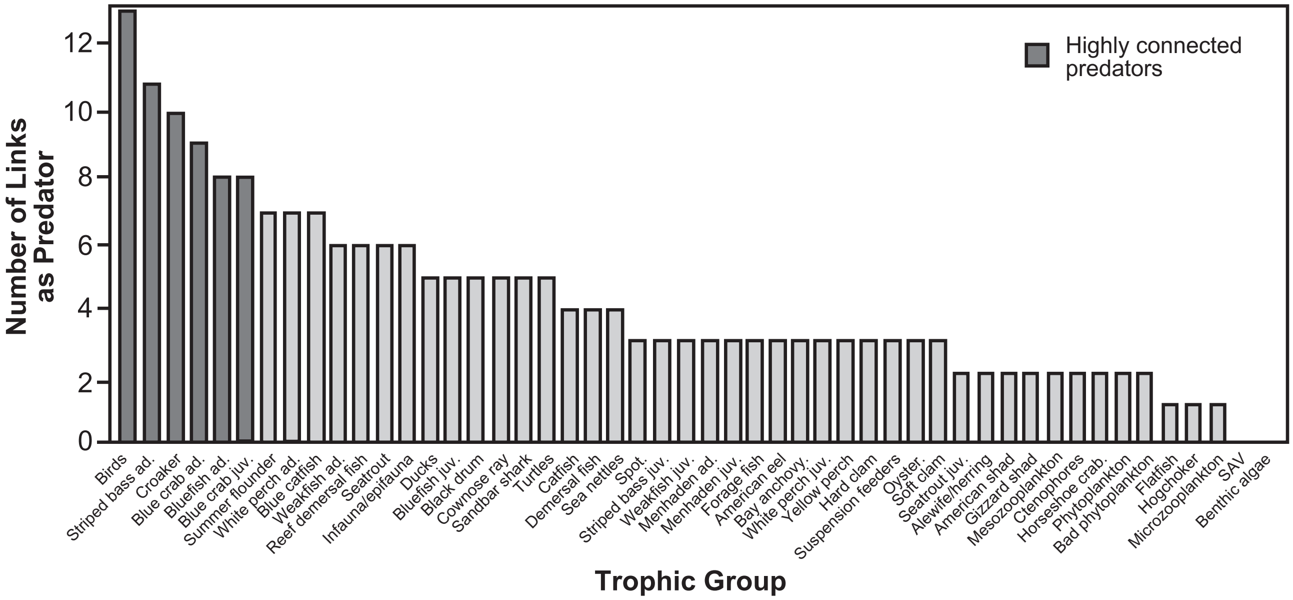

Figure 3. Number of links from the species or trophic group listed on the X-axis to prey of that species or trophic group. For example, striped bass adults prey on 11 species or trophic groups; blue crab adults prey on nine species or trophic groups, including blue crab juveniles.

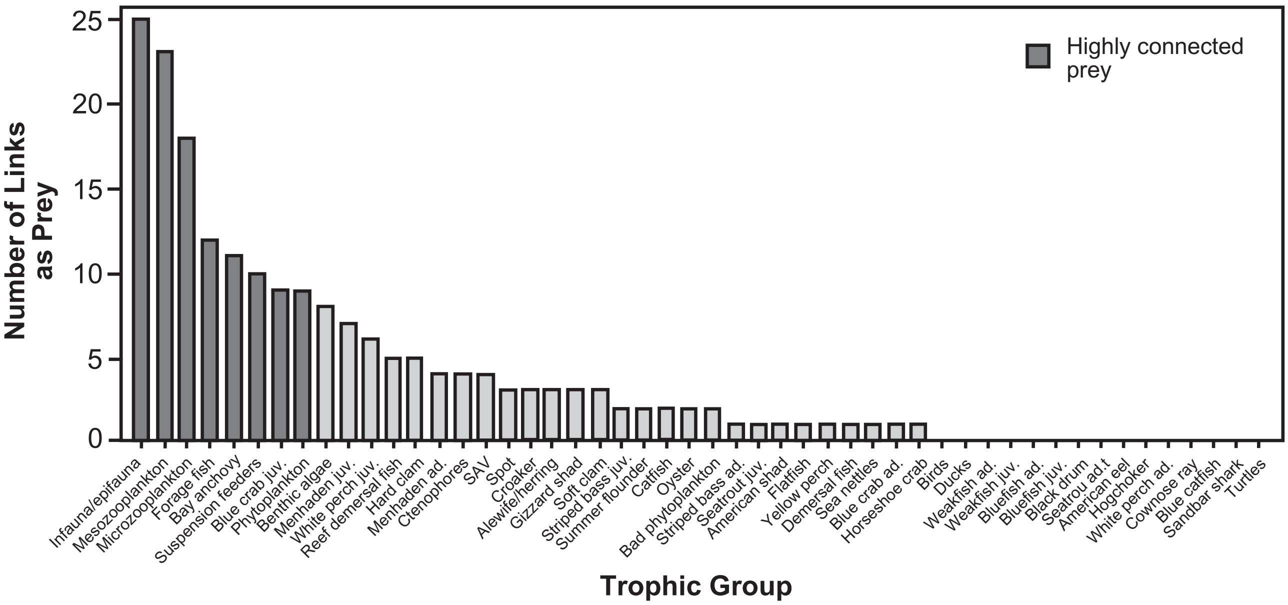

Figure 4. Number of links from the species or trophic group listed on the X-axis to predators of that species or trophic group. For example, 23 species or trophic groups prey on mesoplankton and 11 on bay anchovy. Data are derived from the diet matrix (August 2002) of the Chesapeake Bay Ecopath model.

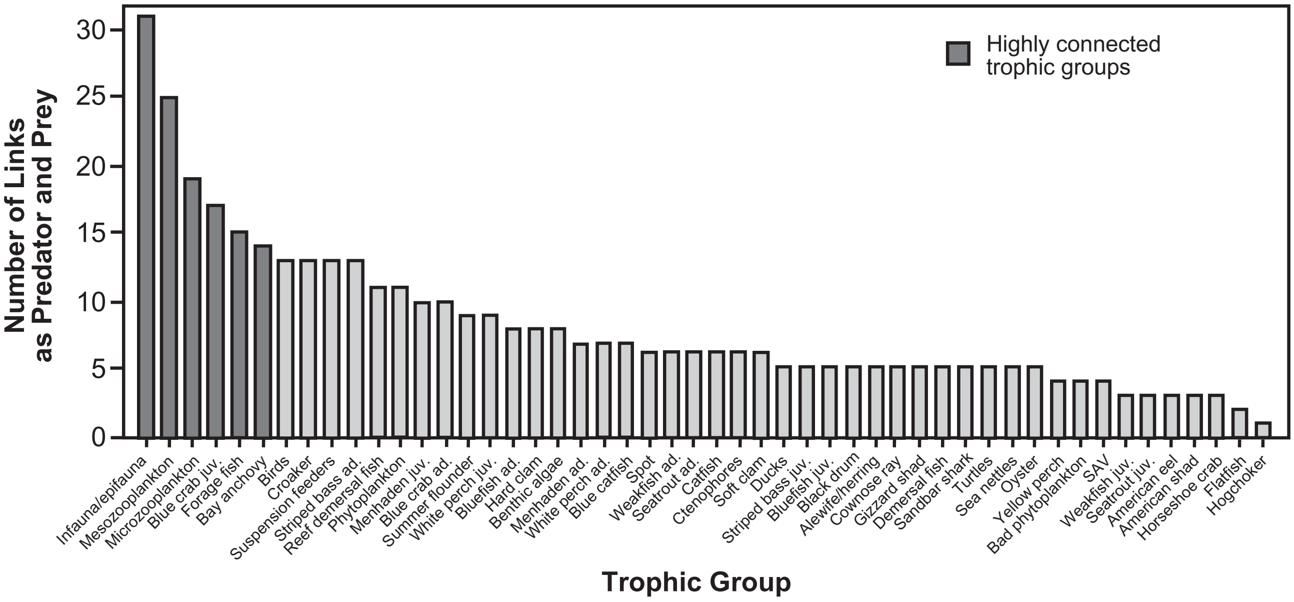

Figure 5. Number of links from the species or trophic group listed on the X-axis to predators and prey of that species or trophic group. For example, 25 links occur from mesoplankton to species or trophic groups that are either predators or prey of mesoplankton along with 17 links from blue crab juveniles to either predators or prey. Data are derived from the diet matrix (August 2002) of the Chesapeake Bay Ecopath model.

ultimately, fisheries yield. Ctenophores also prey on bay anchovy eggs and larvae, reducing the potential for fish production. In network analyses, sea nettle (the medusa *Chrysaora quinquecirrha*) predation on ctenophores appears to compensate for the negative effect of ctenophore predation on bay anchovy. Sea nettles can be viewed positively in terms of energy flow to fish production within the web, therefore, despite their moderate predation on bay anchovy. Other forage fish species that form important links from the plankton to the benthos and predatory fish include the alosines—alewife *Alosa pseudoharengus,* blueback herring *A. aestivalis,* and American and hickory shads *A. sapidissima* and *A. mediocris*.

3) Benthic suspension feeders and deposit feeders, particularly bivalves (e.g., Atlantic rangia *Rangia cuneata*, Baltic macoma *Macoma balthica*, northern quahog *Mercenaria mercenaria*) and various polychaetes (e.g., deep-burrowing *Chaetopterus variopedatus*), consume much of the Bay's detrital, planktonic, and microbial loop output. In the middle Bay, seasonal hypoxia causes low benthic production (Hagy 2002). Network analyses, however, indicate that production remains sufficient to satisfy the demands of demersal (i.e., epibenthic) and benthic (i.e., infaunal) predators. Demersal fish (hogchoker *Trinectes maculatus,* spot, Atlantic croaker) and blue crab are among the chief consumers of the benthos, collectively consuming nearly 90% of benthic production. The most productive of the piscivores include weakfish *Cynoscion regalis*, striped bass, bluefish *Pomatomus saltatrix*, channel catfish *Ictalurus furcatus*, Atlantic croaker, and spot, in no order of importance.

Connectivity of Predators and Prey

Topological analysis is a useful instrument to determine the structure of particular trophic groups in the food web, illustrating the connectivity between a particular species or trophic group and its predators and prey (Winemiller and Polis 1996). The connectivity (i.e., number of linkages between trophic groups) of the Bay's food web is moderate relative to other terrestrial, aquatic, and marine food webs (Dunne et al. 2002; Link 2002b), suggesting that it is reasonably resilient to modest perturbations such as the loss of a few species (Dunne et al. 2002). Such a loss to the integrity of the food web becomes most pronounced when highly connected species (i.e., species possessing multiple linkages to other predators and prey) are removed from the web (Dunne et al. 2002) and may have severe impacts on food web integrity, carbon cycling, and resilience to environmental perturbations (Dunne et al. 2002). Consequently, scientists and fishery managers must recognize those predators and prey having the highest degree of connectivity with other trophic groups in the food web.

To evaluate the degree of connectivity of the various species and trophic groups of the Bay food web, the NOAA Chesapeake Bay Office (NCBO) EcoPath Working Group used the August 2002 diet matrix of the Chesapeake Bay Ecopath model to define the number of links between species and trophic groups (Figures 3–5). The most highly connected predators (top 12%; 6 of 50) were piscivorous birds (e.g., American osprey), striped bass adults, Atlantic croaker, blue crab adults, bluefish adults, and blue crab juveniles (Figure 3). Each had links to 8 to 13 species or trophic groups upon which they prey. Of the prey, the most highly connected trophic groups (top 12%; 6 of 50) were those near the base of the food web, including benthic deposit and suspension feeders, invertebrate grazers, mesozooplankton, microzooplankton, littoral forage fish (e.g., silversides), and bay anchovy (Figure 4). Each of these groups had 10 to 25 links to predators. When considering all trophic links, both to predators and prey, the most connected trophic groups (top 12%; 6 of 50) were again those near the base of the food web, specifically infaunal and epifaunal deposit and suspension feeders, invertebrate grazers, mesozooplankton, microzooplankton, blue crab juveniles, littoral forage fish, and bay anchovy (Figure 5). These groups had 14 to 31 links to predators and prey.

The results bear strong similarity to those of energy flow analyses (Figure 2), indicating that relatively few species and trophic groups drive energy flow and connectivity in the Chesapeake food web. Some species that may be critically important in food webs were not highly connected (e.g., menhaden, ctenophores) due to narrow dietary preferences. The low to moderate connectivity of planktonic consumers, such as menhaden and ctenophores, may result from the aggregation of species as trophic groups serving as their prey. If one considers ontogeny and increase in size at progressive life stages of species such as menhaden and lobate ctenophores, then their connectivity may increase. For example, larvae and early juveniles of menhaden primarily consume zooplankton, while ctenophores in the larval stage may have a broader diet than larger individuals. Such patterns may hold for many species, but the connectivity analyses may not fully account for them.

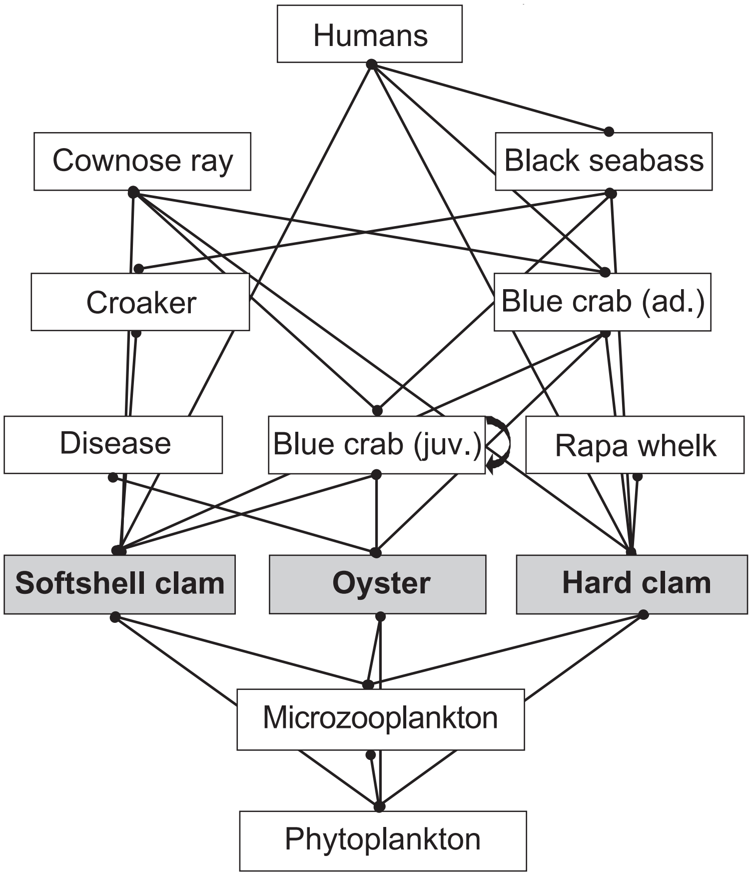

Figure 6. Subweb of the hard clam, soft-shell clam, and native oyster.

Managers should value all species categorized as important in either the energy flow or the connectivity analyses. Additionally, the connectivity between certain species might not be

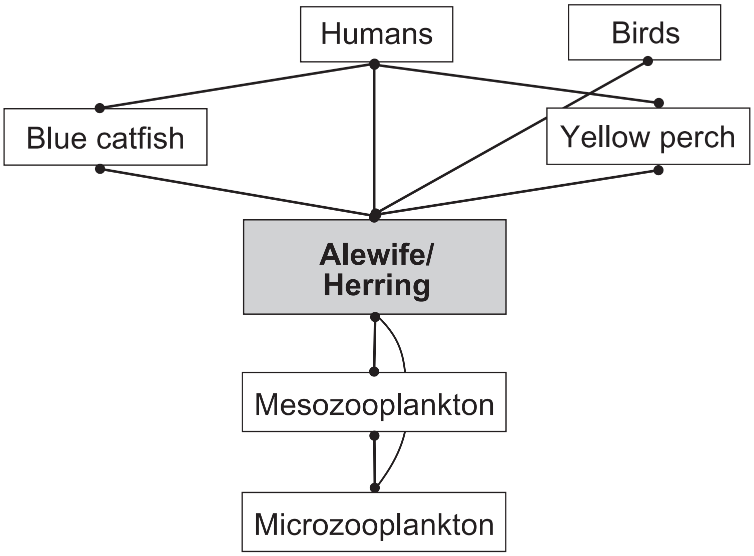

Figure 7. Subweb of the alewife/herring complex.

clear due to reduced abundance of the species. The most notable example—the native oyster—historically played a dominant role as a consumer of phytoplankton.

The Chesapeake Bay food web has undergone substantial historical alterations, due in large part to overfishing (Jackson et al. 2001) (see Externalities Element). Most likely, the current major role of detritus in trophic dynamics results from considerable degradation of the Bay food web and the accompanying shift from an ecosystem that functioned largely through benthic algal and seagrass production to one heavily dependent on the microbial loop, phytoplankton production, and detritus (Jackson et al. 2001). Recognizing that the Bay's food web has endured dramatic change due to anthropogenic stress, we must now accept the possibility that certain components of the food web may not be easily restored.

Subwebs of Fishery Species

Subwebs of each of the economically valuable species in the Bay can guide the identification of the species' important predators and prey. The subwebs do not portray the relative importance of links between predators and prey. Additional factors and processes, external to traditional

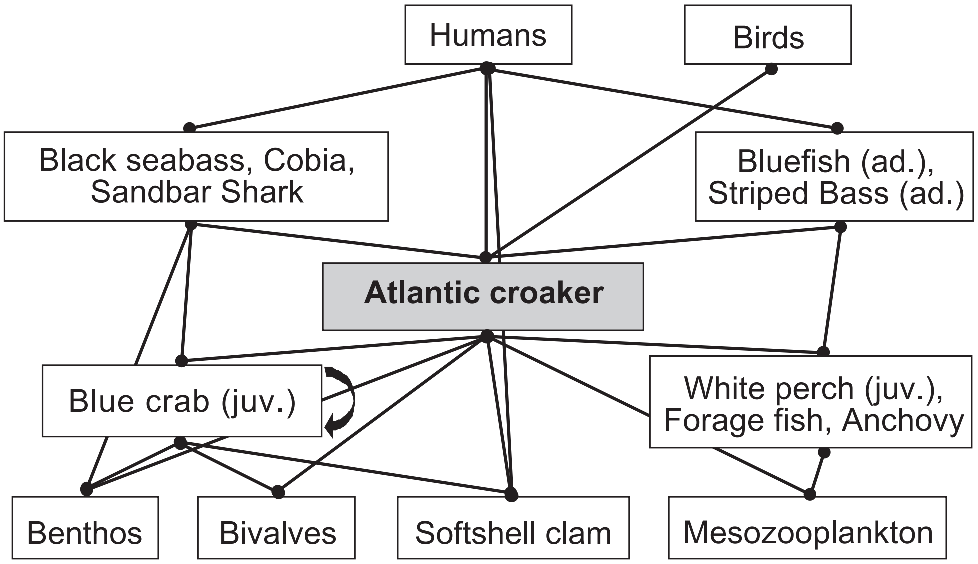

Figure 8a. Subweb of the Atlantic croaker.

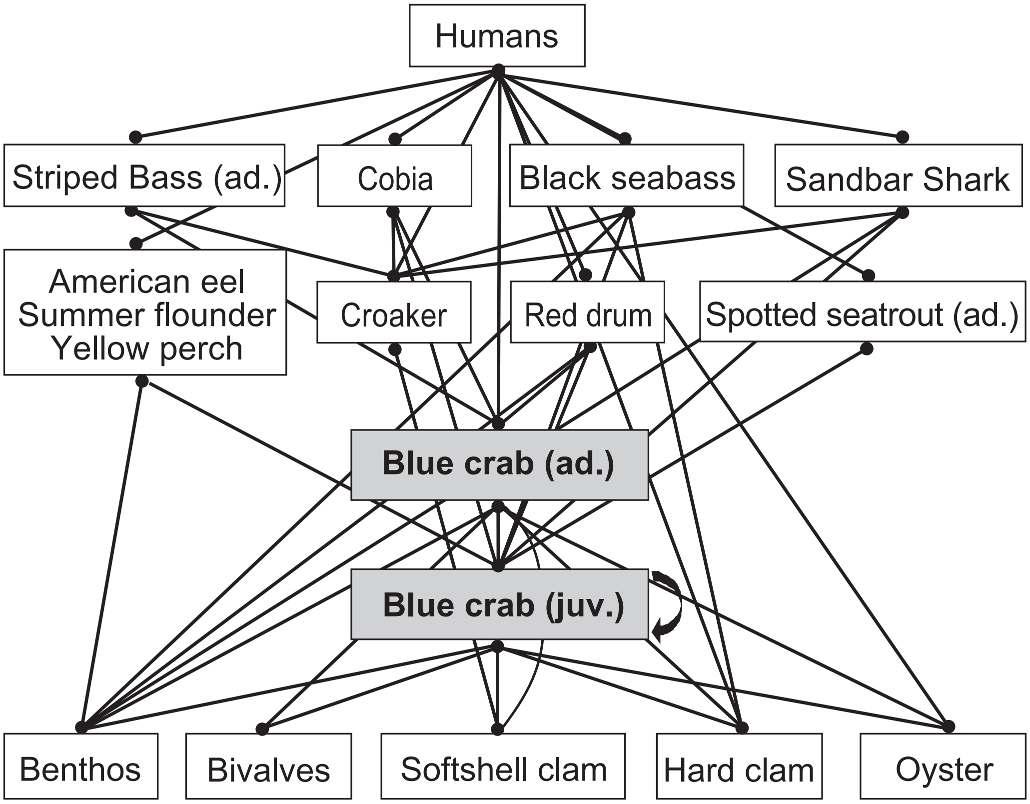

Figure 8b. Subweb of the blue crab.

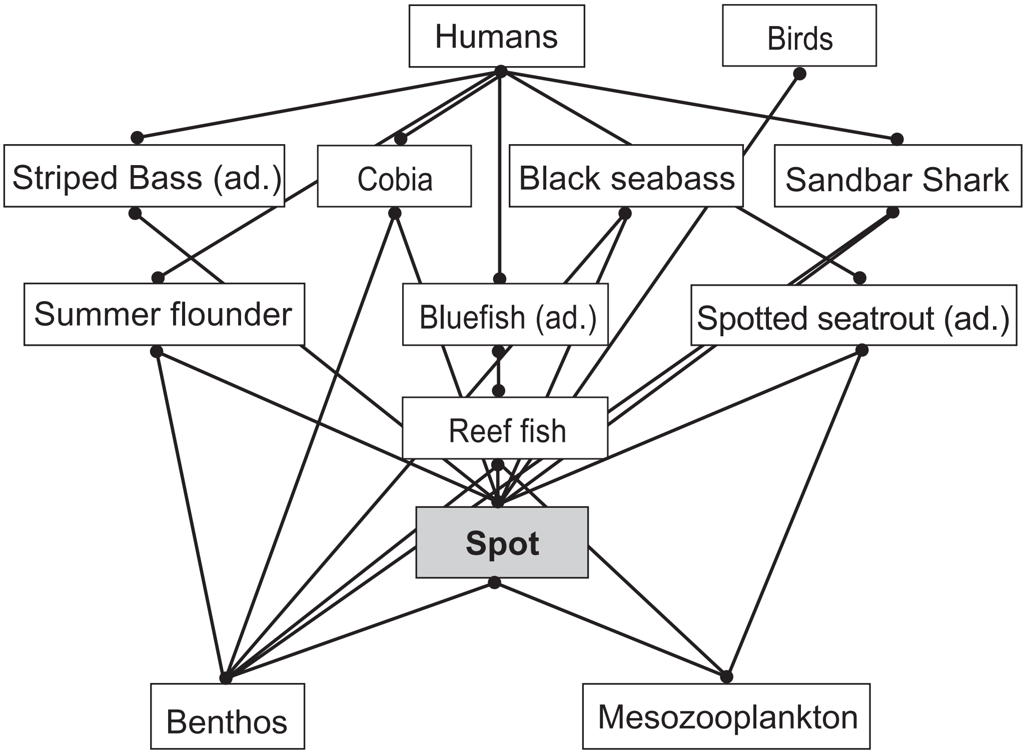

Figure 8c. Subweb of the spot.

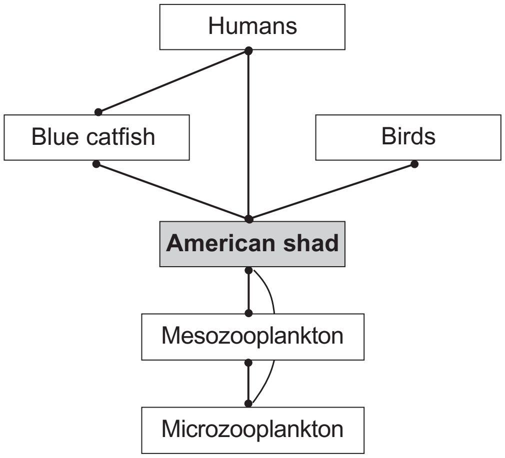

Figure 9a. Subweb of the American shad.

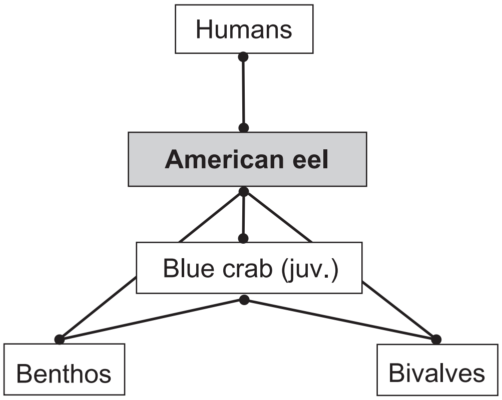

Figure 9b. Subweb of the American eel.

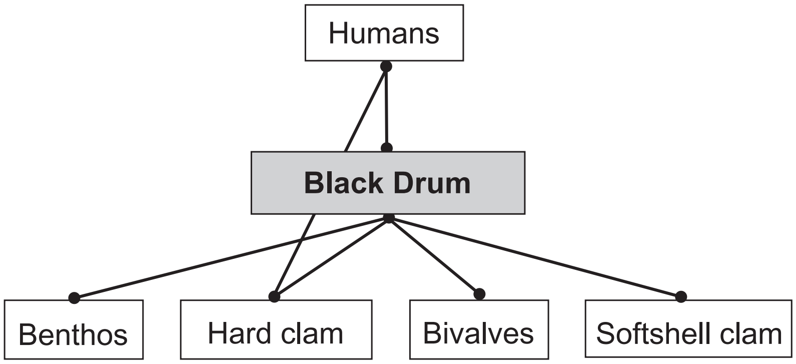

Figure 9c. Subweb of the black drum.

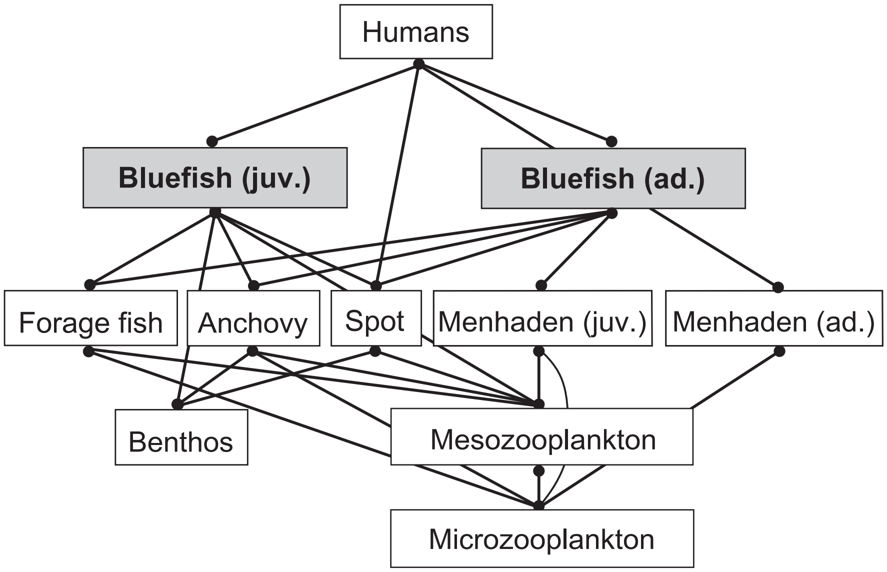

Figure 9d. Subweb of the bluefish.

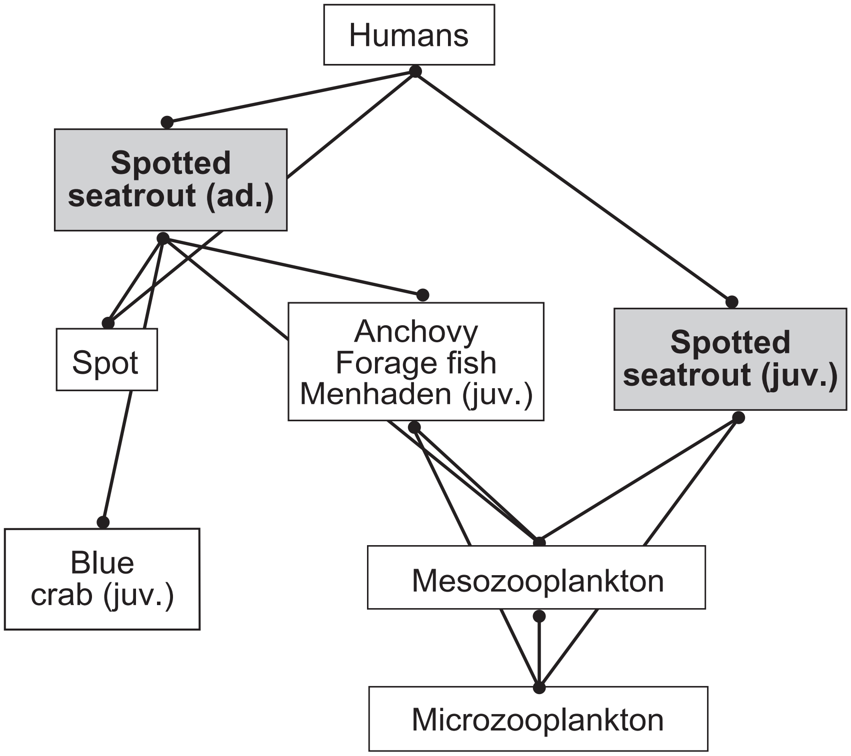

Figure 9e. Subweb of the spotted seatrout.

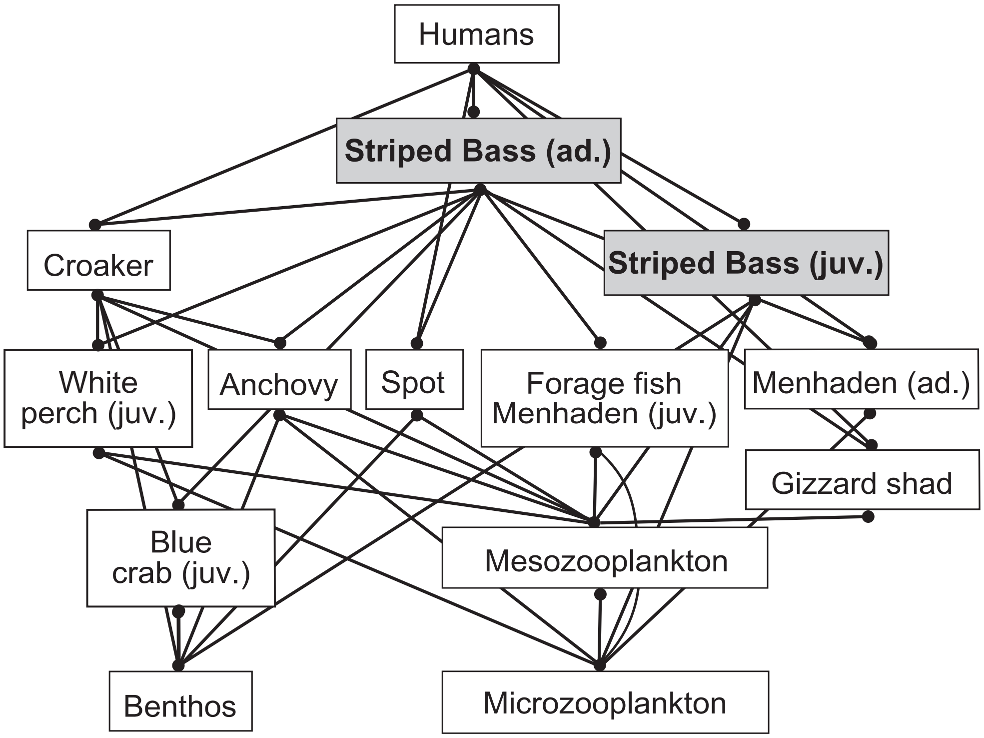

Figure 9f. Subweb of the striped bass.

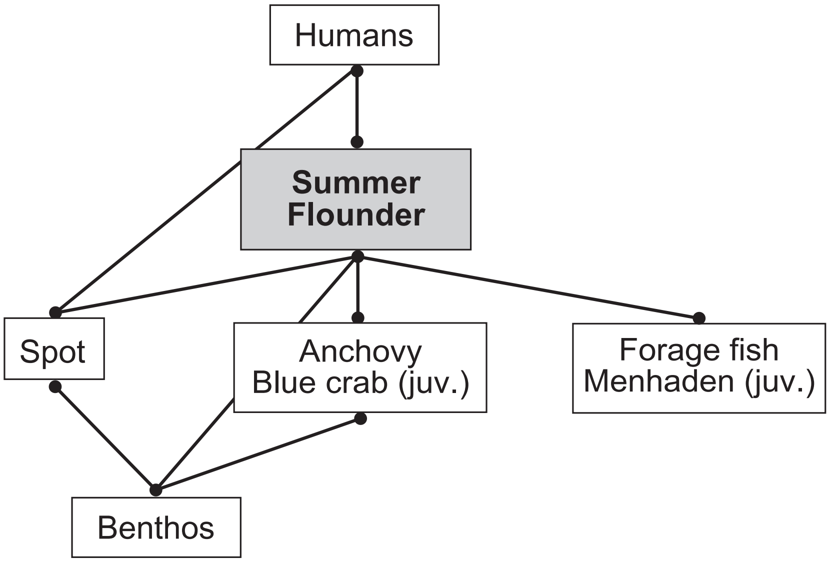

Figure 9g. Subweb of the summer flounder.

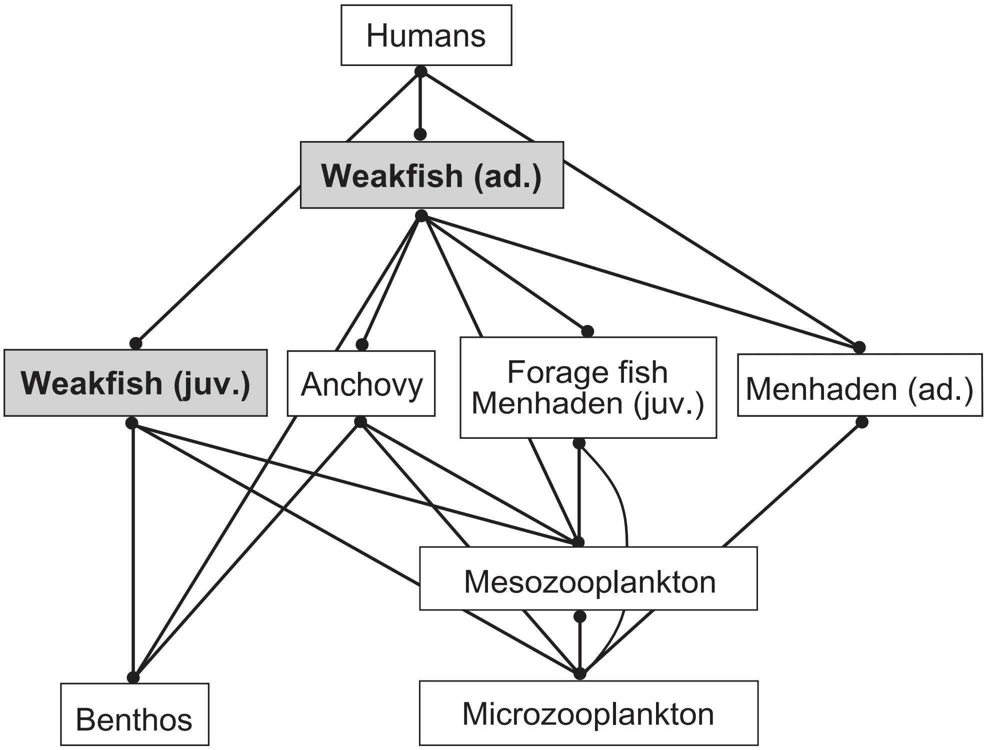

Figure 9h. Subweb of the weakfish.

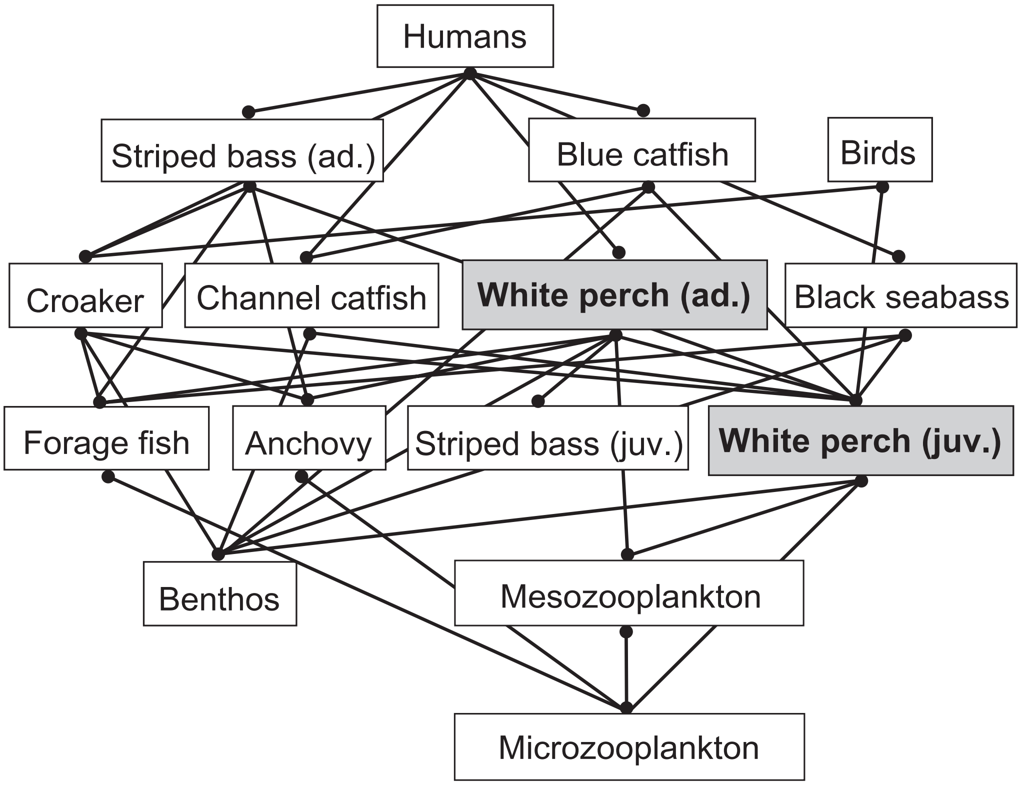

Figure 9i. Subweb of the white perch.

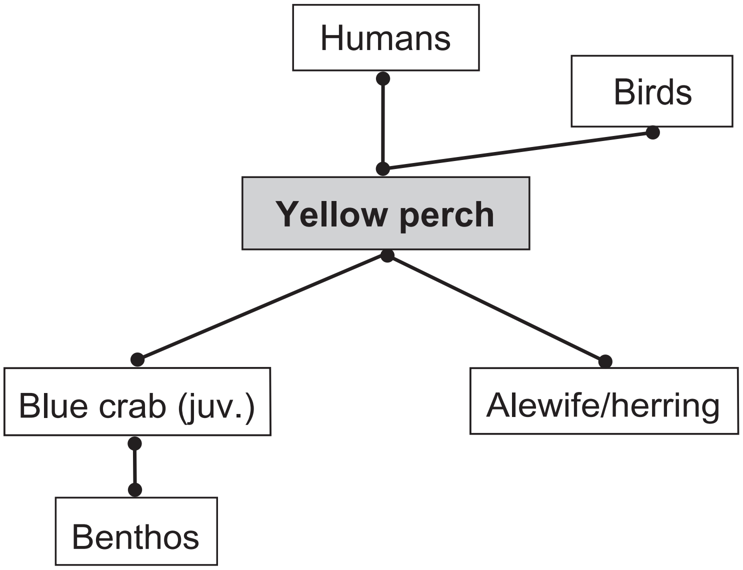

Figure 9j. Subweb of the yellow perch.

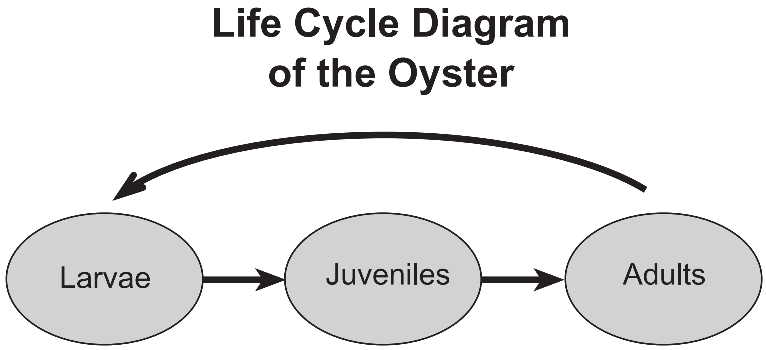
Life Cycle Diagram of the Oyster

Figure 10. Simplified life cycle diagram of the Eastern oyster. highlighting its key life stages.

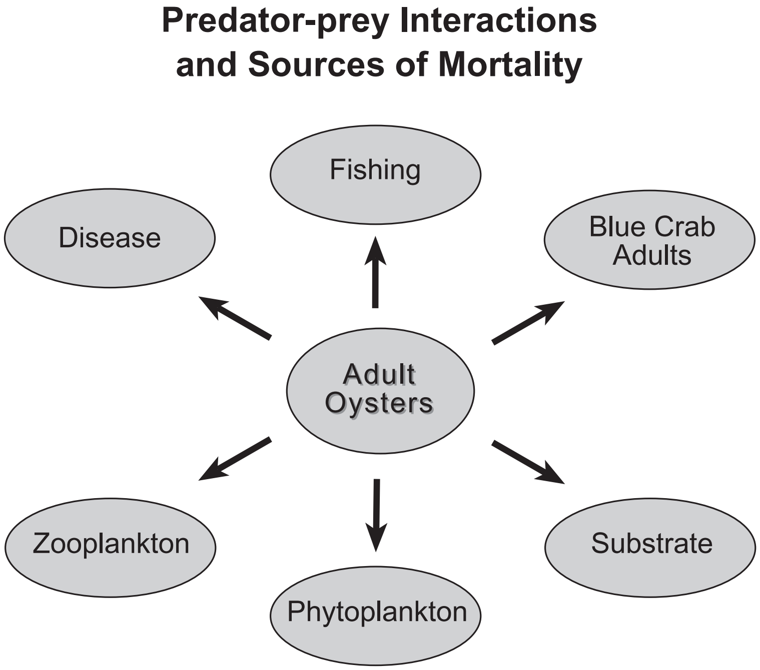
Predator-prey Interactions and Sources of Mortality

Figure 11. Adult stage of the Eastern oyster with major sources of mortality (disease, fishing, blue crab predation), prey (plankton), and habitat needs (substrate).

predator–prey relationships, may prove critical in the dynamics of the species, such as disease in the case of the native Eastern oyster. These factors should be considered in the comprehensive analysis of all sources of mortality affecting a species and in development of ecosystem-based management plans.

The diet matrix of the NOAA Chesapeake Bay Office EcoPath Working Group provided the information to create the subwebs. The first subweb, shown in Figure 6, consists of benthic suspension-feeding bivalves near the base of the food web (Table 1) that support major fisheries, including the northern quahog, softshell (also known as softshell clam) *Mya arenaria*, as well as the eastern oyster.

The next subweb (Figure 7) includes finfish near the base of the food web, specifically the alewife-blueback herring complex. Following is the suite of subwebs that includes most of the intermediate trophic links, and those with a high degree of connectivity, such as Atlantic croaker, blue crab, and spot (Figures 8a, 8b, and 8c). Finally, we detail the food webs of higher-level predators, including most of the top predatory fishes, specifically American shad, American eel *Anguilla rostrata*, black drum *Pogonias cromis*, bluefish, spotted seatrout *Cynoscion nebulosus*, striped bass, summer flounder *Paralichthys dentatus*, weakfish, white perch Morone *americana*, and yellow perch *Perca flavescens* (Figures 9a–9j).

For all subwebs illustrated above, the NCBO EcoPath Working Group is modifying the predator and prey linkages as new information is gathered and incorporated into the current Ecopath model. Updated subwebs may be downloaded at http:noaa.chesapeakebay.net/fepworkshop/netfep.htm. Further details on the prey and predators are available on the web site.

Incorporation of Food Web Dynamics into FMPs

The following list provides general guidelines for incorporating food web dynamics into FMPS.

1) Develop and define the life cycle diagram of the target species.

   The life cycle diagram explicitly recognizes the critical life stages and sources of mortality. For example, Figure 10 diagrams a simple life cycle diagram for the Eastern oyster. Although simplistic, elaboration of such diagrams in terms of habitat requirements and sources of mortality allows one to discern if key processes or sources of mortality have been ignored in

   the analysis of the food web and its predator–prey relationships (Caswell 2000).

2) Identify the major predator-prey interactions and sources of mortality for each life stage by expansion of the life cycle diagram (Figure 11).

3) Identify critical habitat relationships for each life stage.

   Expansion of the life cycle and food web diagrams should consider habitat needs (see Habitat Requirements Element), including possible use of protected or closed areas in management and conservation of exploited species. Figure 12 shows an example of stage-specific predator-prey interactions with probable modification in protected areas for striped bass/blue crab/bivalve linkages.

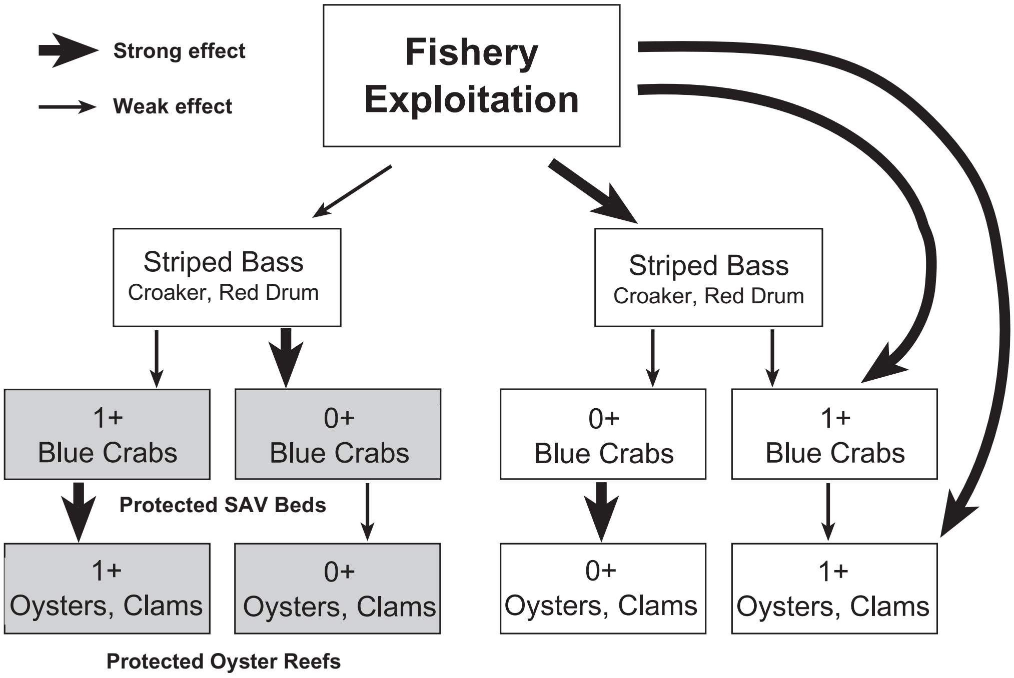

Figure 12. Potential food web interactions in no-take protected (shaded) and open-to-fishing (clear) habitats for a benthic component of the Chesapeake Bay food web that emphasize predator-prey relationships of striped bass/blue crab and other demersal fishes. This example, while hypothetical, indicates the kind of process that fisheries managers should follow in developing multispecies fisheries management plans that account for predator–prey interactions in complex ecosystems such as the Chesapeake.

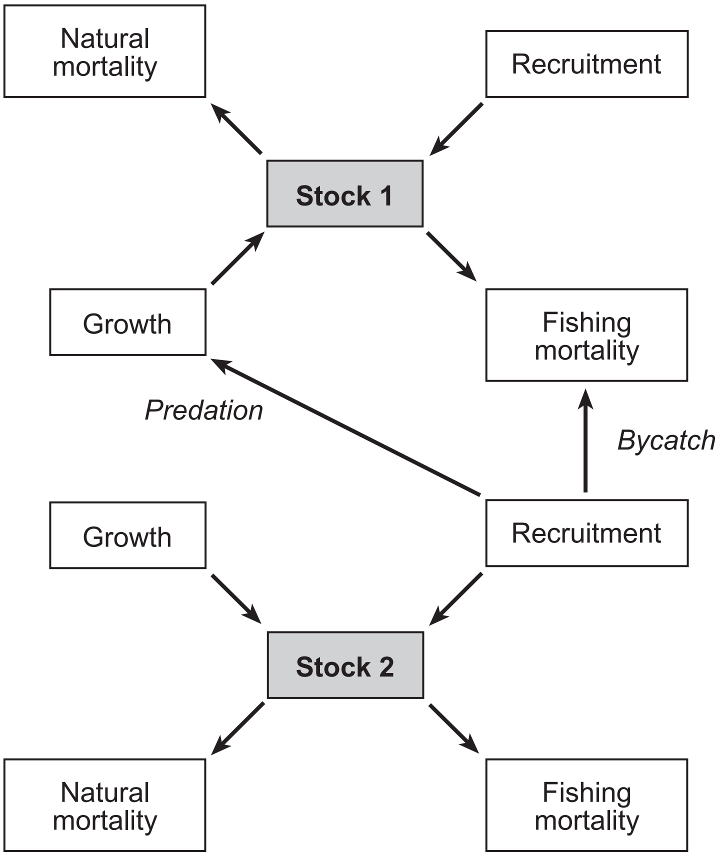

Figure 13. A conceptual description of two fish stocks (S_1 and S_2) linked through both biological and technical interactions. A predator-prey relationship is shown in which S_1 preys upon the juveniles of S_2. Increased predation by S_1, therefore, leads to an increase in its growth rate and a decrease in the rate at which the juveniles of S_2 are captured incidentally by the fishery that targets recruitment rate for S_2. Thus, an increase in the fishing mortality rate will again lead to a decrease in the recruitment rate for S_2. Adapted from Miller et al. (1996).

Although such detailed linkages are difficult to evaluate and fully understand, they do reflect ecological reality; therefore, considering subsets of the food web remains important in developing and implementing ecosystem-based fisheries management.

4) Compare and contrast analyses of food web dynamics with food web modeling.

This exercise entails a thorough and comprehensive comparison of the findings from food web analyses (i.e., topological, energy flow, functional) with those from modeling efforts, as described below.

Multispecies Modeling Approaches

Historically, fisheries management has relied on single-species models that ignored the effects of biological and technical interactions on population abundance (Figure 13). Traditional fisheries models focus on the interplay between exploitation level and sustainability, generally not considering in detail the biology and ecology of the managed species. In recent years, however, researchers have started to overcome this deficiency by considering the feasibility of ecosystem-based approaches to fisheries management. One important element of ecosystem-based management is development and incorporation of multispecies models into management programs. Like single-species models, multispecies models yield information about sustainability but are structured to do so by more accurately reflecting biological and ecological reality.

Over the past several years, the number and types of multispecies models that provide insight on fisheries issues have grown significantly (Hollowed et al. 2000). This growth has been fueled by the need to better inform fisheries policymakers and managers; however, recent concerns about fishing effects on the structure of ecosystems has also prompted research on multispecies modeling and implied predator-prey relationships.

From a theoretical perspective, basing fisheries stock assessments on multispecies (rather than single-species) models appears more appropriate, since multispecies approaches allow explicit modeling of more of the processes that govern population abundance. This increased realism, however, requires additional parameters (particularly for models that assess the impact of biological interactions), which in turn creates the need for more types of data. In the absence of these additional data, or if unreliable data are used to meet the requirements of multispecies stock assessments, more uncertainty in management outcomes will undoubtedly arise compared to single-species stock assessment methods. Consequently, multispecies models are not replacements for single-species models, but rather tools that provide additional types of stock assessment insight when used in concert with single-species models (National Research Council 1999).

In recent years, interest has grown in multispecies fisheries management in the Chesapeake region, as evidenced by the development of fisheries steering groups, the convening of multispecies technical workshops (Miller et al. 1996; Houde et al. 1998), and the requirement for development and implementation of multispecies fisheries management plans by the *Chesapeake 2000* agreement (CBP 2000). In this section, we describe and evaluate some multispecies models commonly applied to understand the effects of both biological and technical interactions; these models have

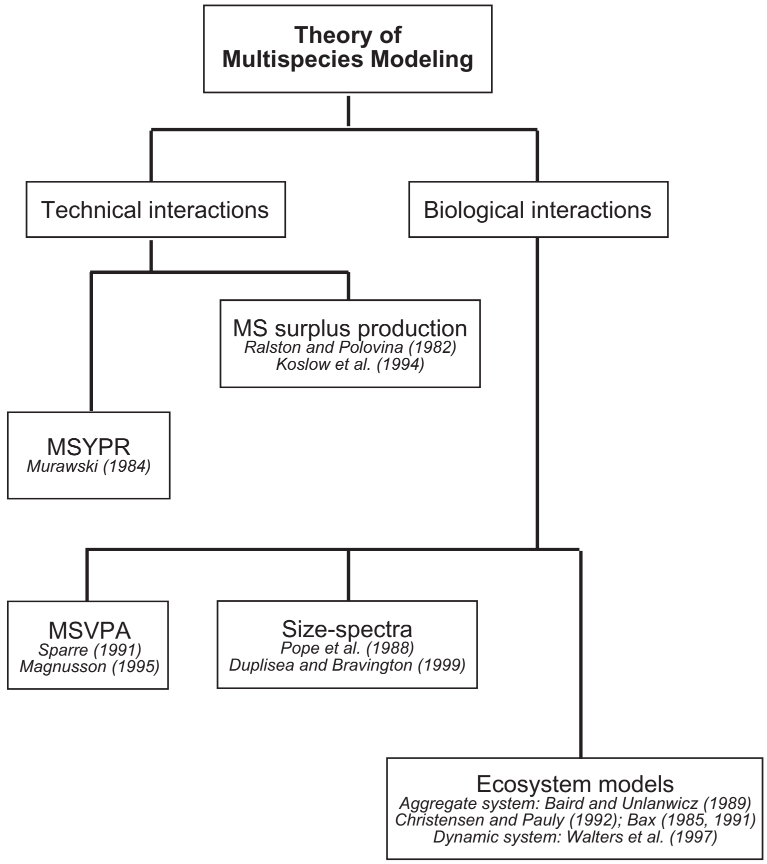

Figure 14. General overview of multispecies fisheries models. Adapted from Hollowed et al. (2000).

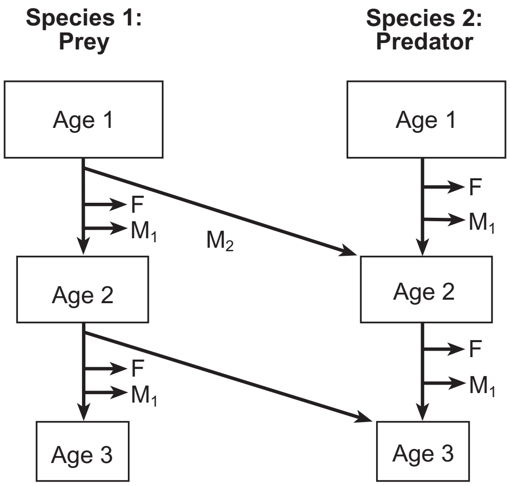

Figure 15. General schematic of two-species MSVPA with arrows indicating losses due to fishing (*F*), predation (M_2), and residual (M_1) mortality (Jennings et al. 2001).

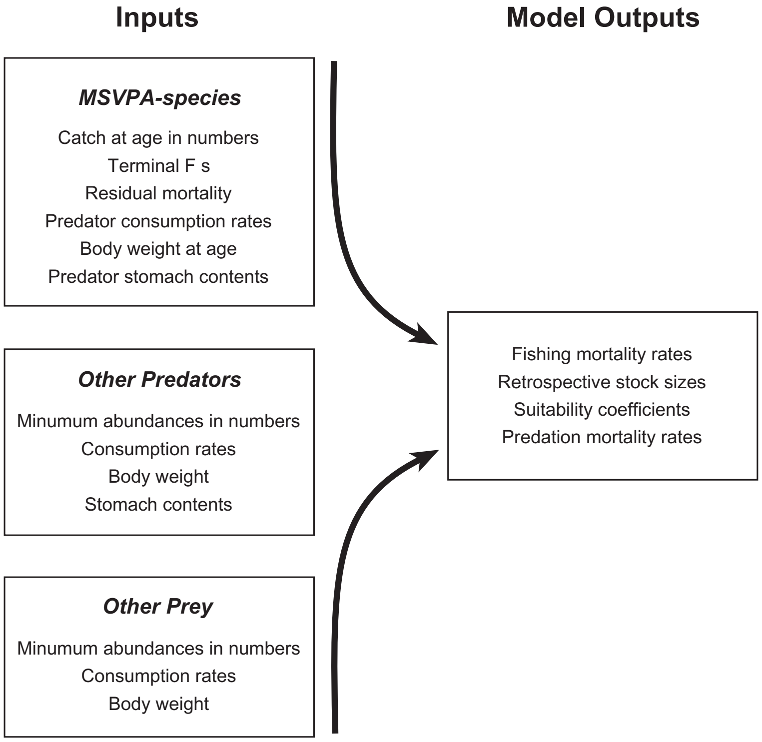

Figure 16. Types of data needed to perform an MSVPA based on the role each species assumes in the analysis. “MSVPA-species” are those predators and prey for which retrospective stock sizes are reconstructed using the MSVPA model and “other predators” and “other prey” represent species for which VPA-type results are not desired, but the researchers know or surmise that these species significantly influence the trophic dynamics of the food web under study. From Latour et al. 2003.

potential for development and application in the Bay.

This overview should inform fisheries managers and policymakers about the capabilities of more commonly applied multispecies modeling techniques. For biological interactions, we review multispecies virtual population analysis (MSVPA), size spectrum analysis, and ecosystem models (Ecopath with Ecosim). For technical interactions, we review multispecies yield per recruit (MSYPR) and multispecies surplus production models (Figure 14).

Biological Interactions

Multispecies Virtual Population Analysis

Single-species virtual population analysis (VPA), as developed by Fry (1949) and Gulland (1965), is a stock assessment technique that uses commercial-catch-at-age data to calculate retrospective stock sizes and fishing mortality rates *(F)* of recruited, age-based cohorts. This approach often is referred to as cohort analysis. For a given cohort, the number alive in the previous year is calculated by adding the number caught by the fishery in the current year to the estimated number that died from natural causes during that same time period. Inherent in this technique are two important features: each cohort is treated separately (i.e., the variables associated with a cohort are calculated independently of those from other cohorts); and an estimate of the natural mortality rate (*M*) is required as input for the model. When *M* is not known, the traditional approach is to estimate it roughly from life history parameters or to use an educated guess.

The dependence of VPA on a reasonable estimate of *M* has motivated researchers to focus on natural mortality estimations. Although natural mortality occurs from various causes, predation is generally believed to be the dominant source of mortality. This belief, along with preliminary quantitative work on feeding and food consumption of North Sea cod *Gadus morhua* (Daan 1973, 1975), provided the foundation for the development of models that accounted for species interactions. Anderson and Ursin (1977) developed an ecosystem model that gave a conceptual framework for modeling predator-prey interactions. Although this complex model could not adapt to real-world management applications, it ultimately facilitated the extension of VPA to multispecies virtual population analysis (MSVPA).

Helgason and Gislason (1979) and Pope (1979) independently combined the theoretical predation relationships of the Anderson and Ursin (1977) model with the VPA methodology of Gulland (1965) to develop MSVPA. The primary feature of the method is the split of the natural mortality rate into two components. That is,

$$M = M_1 + M_2 \qquad (1)$$

in which M_2 represents the predation mortality between and within the exploited species in the ecosystem—as determined by suitability parameters that reflect predator preference for a particular prey species—and M_1 represents the mortality due to all factors not explicitly included in the model (Figure 15). For a review of the MSVPA approach, see Sparre (1991), Magnusson (1995), and Jennings et al. (2001).

The data requirements for an MSVPA vary according to the role each species assumes in the model and the preferred model output (Figure 16). If species' stock sizes are reconstructed using the MSVPA model, with these species referred to as "MSVPA-species," the data requirements include catch-at-age in numbers, fishing mortality rates in the terminal year and for the oldest age class, residual mortality rates, predator consumption rates, body weights at age, and predator stomach contents. With MSVPA, modeling species as "other predators" or "other prey" is possible in cases for which the stan-

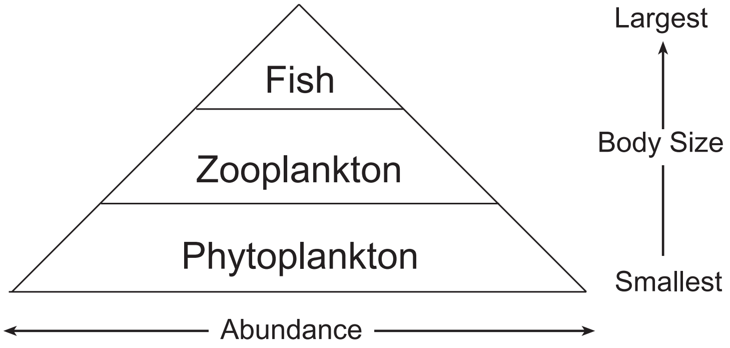

Figure 17a. Trophic pyramid relating the abundance of general species groups within an aquatic ecosystem. The width of the pyramid is proportional to abundance; the height is proportional to body size (Jennings et al. 2001). With biomass used as a metric rather than abundance, the pyramid would be greatly compressed with little difference among trophic levels (Sheldon et al. 1972; Kerr and Dickie 2001).

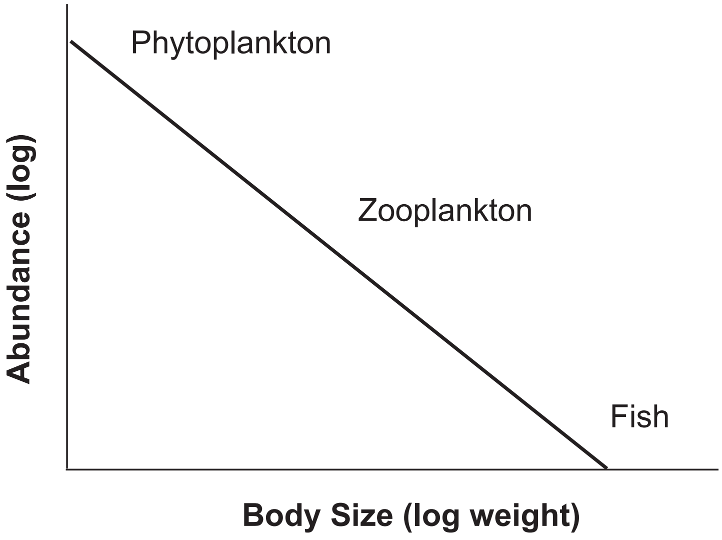

Figure 17b. Plot of normalized biomass (i.e., number density) as a function of body size. The slope of the line is a qualitative representation of the structure of an aquatic ecosystem (Jennings et al. 2001). As with Figure 17a, using biomass instead of abundance results in a "flat" slope, although a small negative slope sometimes occurs.

dard VPA results are not desired, but the researchers know or surmise that these species significantly influence the trophic dynamics of the food web under study. For "other predators," data requirements include minimum abundances in numbers, body weights, consumption rates, and stomach contents; for "other prey" only minimum abundances in numbers and body weights are typically required.

MSVPA in Chesapeake Bay

To date, MSVPA has not been used for stock assessments of fish populations in Chesapeake Bay, although it is recognized as a possible approach (Miller et al. 1996; Houde et al. 1998). An expanded MSVPA model for assessment of the Atlantic menhaden stock in the coastal waters of the eastern United States is currently under development (Garrison and Link 2002) to supplement existing single-species assessments of the Atlantic menhaden stock and to allow fisheries managers to evaluate possible alternatives to the current management scenario. The MSVPA model addresses four major topics through evaluation of

1) The nature and magnitude of linkages among menhaden and its key predators;
2) The current use of menhaden as a directed fishery, its ecological role as a forage fish, and sustainability of the stock;
3) The possible optimal size (or age) composition of Atlantic menhaden to support its ecological role as a prey species and the goals of the directed fishery; and
4) The biological reference points for menhaden recommended for management derived from single-species assessments along with determination of whether adjustments are necessary with predation included in the assessment.

Two major extensions to the base model also are being developed. First, a stochastic feeding model is being incorporated into the MSVPA framework to account for the effects of changes in menhaden population abundance on the diets and consumption patterns of predators. This model will require additional input data on the relative abundance of alternative prey species. Second, the growth and population dynamics of predators (striped bass, bluefish, and weakfish) will be modeled more explicitly to explore and evaluate the effects, if any, of prey quality. This extension will incorporate the effects of prey availability, diet composition, and feeding rates.

In recent years, fishing effort on menhaden has shifted from northerly waters to southern areas; as a result, the Chesapeake Bay has become a center of menhaden fishing. Although recent coastwide stock assessments have characterized the menhaden stock as healthy, concern exists that this characterization does not apply to menhaden in the Bay. Recruitment of Bay menhaden has declined since the 1990s and young-of-year abundance has been low. Low menhaden abundance may cause nutritional stress in predators, such as striped bass. Recent studies suggest that striped bass in the

Bay suffer from poor nutrition, evidenced by an increase in the number of diseased fish exhibiting lesions from mycobacteriosis. The Maryland Department of Natural Resources (MD DNR) Pound Net Survey (2002) revealed that 17% of the striped bass had lesions or sores.

The MSVPA analysis of menhaden represents one of the first multispecies modeling efforts of a fish species indigenous to Chesapeake Bay (discussed later is another modeling effort—the Chesapeake Bay Ecopath with Ecosim model). The MSVPA will document quantitatively the simultaneous effects of predation and fishing on the menhaden stock. Although best interpreted on a coastwide scale, these results should provide information to better evaluate the role of menhaden as a forage fish in the Bay. An MSVPA analysis reflecting Bay-specific input data for menhaden, striped bass, bluefish, and weakfish would provide additional insight into management of these species.

Size-spectrum Analysis

A fundamental characteristic of aquatic food webs is conservation of mass through energy conservation via production, respiration, growth, and predation (Jennings et al. 2001). Body size determines these processes, leading to trophic pyramids with the smallest species at the bottom and the largest species on top (Figure 17a).

By turning this pyramid on its side, a plot results that linearly relates log numbers (or production) to log body size (Figure 17b). Based on the aforementioned law of conservation, perturbations to the ecosystem via removals will cause a change in the line slope. In theory, therefore, it is possible to detect and interpret changes in the structure of an exploited ecosystem by comparing slopes of biomass or abundance (i.e., normalized biomass) in relation to body size. This approach is formally known as size-spectrum analysis.

Size–spectrum analysis has since been adapted and applied in ecological studies ranging from characterization of marine benthic invertebrate assemblages (Schwinghammer 1981, 1983; Saiz-Salinas and Ramos 1999) to harvesting strategies and community structure of fish populations (Pope et al. 1988; Macpherson and Gordoa 1996; Duplisea and Bravington 1999; Kerr and Dickie 2001). Researchers have also used the results of a size-spectrum model (e.g., quadratic regression equations depicting the major biomass domes in a particular ecosystem [Thiebaux and Dickie 1993]) to develop estimates of annual production for the taxonomic groups represented by these domes. The study by Sprules and Goyke (1994) represents a specific example of this application, in which the researchers computed an estimate of annual production for zooplankton in Lake Ontario. Sprules et al. (1991) show that examining the complete biomass size spectrum is possible; they described the pelagic biomass size spectrum including phytoplankton, zooplankton, planktivorous fish, and piscivorous fish from nine major regions of Lake Michigan in both spring and summer and also estimated the potential annual production of several trophic groups.

Within fisheries, the use of spectral methods has rarely been applied when developing management strategies. One exception is the recent study by Duplisea and Bravington (1999) in which they used spectra models to explore the implications of different harvesting strategies on total yields and community stability and persistence in marine ecosystems. Their analysis indicated potential for application of the method, but counterintuitive fishing strategies emerged for some harvesting questions in a few instances. For example, one might expect that the best strategy for maximizing total yield would specify the harvest of fish at lower trophic levels (i.e., remove biomass from the system by fishing before it is lost to predation up the food chain). Duplisea and Bravington (1999) showed, however, that total yield would be maximized if larger fish were exploited preferentially (i.e., intentionally fishing the larger fish in the ecosystem), since this strategy reduces predation on smaller fish and, therefore, increases their production. Although other researchers within the International Council for Exploration of the Sea (ICES) community have explored the size–spectrum approach as an option for fisheries and ecosystem management (Rice and Gislason 1996; Gislason and Rice 1998; Jennings et al. 2002), additional research is needed to fully characterize its potential.

Size–spectra in Chesapeake Bay

Researchers have not yet used size–spectra analyses and models to develop management strategies for Chesapeake fish. Recently, however, Jung (2002) conducted biomass size–spectrum analyses using midwater trawl catch data to estimate biomass, production, contribution to predators, and recruitment numbers (young of year) for forage fish (primarily bay anchovy). Jung also included analyses of higher trophic-level pelagic and benthopelagic fishes, some of which are piscivores (e.g., weakfish) in the Bay. Jung's analysis indicated that annual, seasonal, and regional differences in size spectra occur in response to changing environmental conditions and these environmental conditions primarily affected recruitment and young of year biomass production. The results may prove useful in development of biomass spectrum models that address fishery management issues.

Multispecies fisheries management is designed, by definition, to incorporate ecosystem processes into management plans. Knowledge of the magnitude of predation on bay anchovy and other forage fish is important, therefore, if multispecies plans for these predator species (e.g., bluefish, weakfish, striped bass) are developed.

Ecosystem Models

Ecosystem models form another approach to characterize biological interactions in multispecies fisheries. In effect, these models are mathemati-

Table 2. A subset of the potential policy questions motivated by the *Chesapeake 2000* agreement prioritized into the present (P), the near future (NF), and the longer-term future (LTF) based upon the Chesapeake Bay EwE model's ability to address each issue.

Policy Issue	P	NF	LTF
1. How can we bring back oysters tenfold and what are the consequences?	X		
2. How can we increase populations of crabs through predator manipulation or fishery reductions?	X		
3. How many striped bass can Chesapeake Bay support; is game fish restoration prudent given low stocks of forage fish?	X		
4. What are the effects of forage fish in Chesapeake Bay ecosystem dynamics?	X		
5. What defines a healthy Chesapeake Bay or what are trophic limits to production?	X		
6. How might changes in primary productivity affect upper trophic levels?		X	
7. How could SAV be restored and what trophic effects might occur?		X	
8. Can we assess the effectiveness of closed/protected areas?		X	
9. How might land management practices affect the estuarine food web?			X
10. Can we manipulate freshwater input to increase oyster survival?			X
11. How should we fish menhaden for optimal ecosystem function?			X

cal representations of whole ecosystems, typically used to elucidate the effects of fishing pressure on the system. Although many of these models are extremely quantitative and employ sophisticated mathematical theory, researchers have used the models primarily for policy exploration and the models have yielded results best interpreted qualitatively. As such, ecosystem models can serve a useful purpose in developing management strategies. Using these models for tactical applications is difficult, however, because accurate parameterization depends on the availability of demographic data for ecologically valuable species (as opposed to species that are commercially or recreationally valuable); such data are often unavailable. This limitation is important. Nevertheless, in recent years ecosystem models have received increasing attention from fisheries researchers and managers who used them successfully to summarize knowledge and determine properties related to structure and function of aquatic ecosystems worldwide.

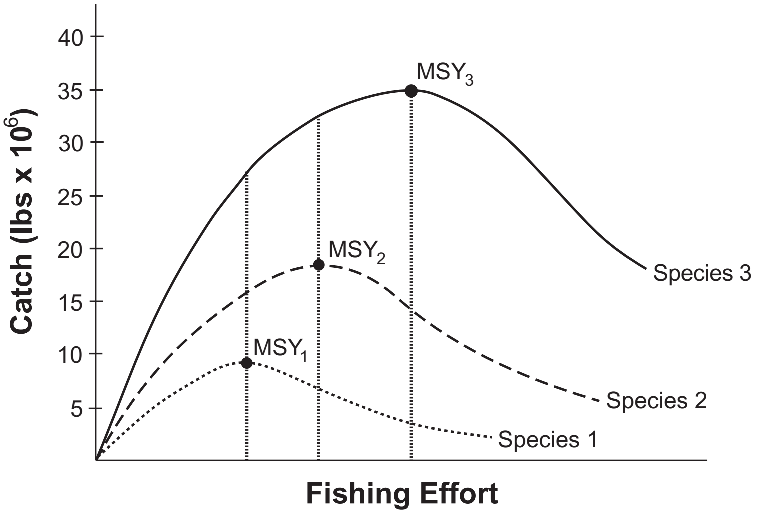

Figure 18. A hypothetical graph showing a three-species fishery in which all species are caught in the same fishing gear. The productivity of each species differs, leading to different levels of maximum sustainable yield (MSY). The fishing effort (i.e., levels of fishing mortality, *F*) that yields the respective MSYs also differs for the three species. To illustrate the importance of technical interactions, suppose that the multispecies fishery exerts a fishing effort that leads to a mortality rate of F_3. Fishing at F_3 will cause the abundance of species 1 and 2 to decline to a level at which substantial risk of stock collapse exists. From a fisheries management perspective, reducing fishing effort to either F_1 or F_2 to lower the risk of collapse is desirable. This management stratetgy is fairly obvious given the graph above; however, independent examination of catch/effort data for each species might not yield as certain a conclusion. Adapted from Houde et al. (1998).

One widely used class of ecosystem models is that which packages Ecopath with Ecosim (EwE) and Ecospace (Christensen et al. 2000). The development of this modeling technique stems from early work on the ecosystem dynamics of a coral reef in Hawaii (Polovina 1984). Application of the EwE approach begins with the construction of an Ecopath model (Christensen and Pauly 1992; Pauly et al. 2000), which creates a mass-balanced snapshot of the resources and interactions in an ecosystem represented by trophically linked biomass pools. The biomass pools generally consist of either a single species or a group of species that represent an ecological guild. Researchers can also split them into ontogenetic age or size categories (juvenile, subadult, adult, etc.) if necessary. The data requirements for Ecopath are fairly simple and often obtainable from traditional single-species analytical stock assessment techniques (e.g., VPA). The parameterization of an Ecopath model rests on the satisfaction of two master equations. Equation 2 (below) describes how the biomass production for each group is allocated within the ecosystem over an arbitrary time period term. Using the principle of conservation of matter within a group, equation 3 (below) balances the energy flows of a biomass pool.

Production = catch + predation + net migration + biomass accumulation+ other mortality (2)

Consumption = production + respiration + unassimilated food (3)

In general, an Ecopath model requires input of three of the following four parameters: biomass, total mortality, consumption and biomass ratio, and ecotrophic efficiency for each species or biomass pool in a model. The ecotrophic efficiency represents the proportion of the production used in the ecosystem, incorporating all production terms apart from “other mortality” (for more details on Ecopath, including the equations, see Christensen and Pauly 1992; Walters et al. 1997; Pauly et al. 2000).

Although Ecopath can describe an ecosystem, it cannot project the effects of different management strategies on the structure and function of an ecosystem. Only Ecosim—a time-dynamic simulation module that facilitates policy exploration—can accomplish these types of projections. Ecosim re-expresses the static mass-balanced equations inherent to Ecopath as a system of coupled differential equations (Walters et al. 1997). This system of equations represents the spatially aggregated dynamics of entire ecosystems and is combined with delay-difference, age- and size-structured equations to represent populations with complex ontogenies and selective harvesting of older animals. Summarized, the important computational aspects of Ecosim are

1) Parameter estimation based on the mass-balance results from Ecopath;
2) Variable speed-splitting methods to simulate the dynamics of both fast (e.g., phytoplankton) and slow (e.g., large predatory fish) biomass groups;
3) Explicit incorporation of top-down (i.e., predation) vs. bottom-up control (i.e., food limitation); and
4) Flexibility to incorporate age- and size-structure of biomass groups.

One obvious deficiency of EwE is its assumption that the resources, interactions, and subsequent dynamics of an ecosystem are spatially homogeneous. Ecospace—a dynamic spatial version of Ecopath that includes all of the key features of Ecosim—overcomes this deficiency. The details of Ecospace are not presented here, but Walters et al. (1999) and Pauly et al. (2000) thoroughly describe them. Researchers have formulated several EwE models and used them for policy exploration. Trites et al. (1999) developed an EwE model of the Bering Sea to examine possible explanations for the changes that occurred in the ecosystem between the 1950s and 1980s. Kitchell et al. (1999) used the EwE approach to study the effects of fishing down top predators in the central Pacific. Shannon et al. (2000) used EwE to compare the effects of fishing in the southern Benguela upwelling system under different combinations of bottom-up and top-down control. On a larger scale, Stevens et al. (2000) summarized the direct effects of fishing on chondrichthyans by examining global information on the responses of shark and ray populations to fisheries. They developed Ecosim models of three previously published Ecopath models to simulate changes in biomass of all groups in response to the rapid declines of shark species.

EwE in Chesapeake Bay

In 2001, the NOAA Chesapeake Bay Office (NCBO), in collaboration with the University of British Columbia (UBC), initiated a workshop series to provide the foundation for construction of an EwE model of Chesapeake Bay. Researchers are developing a large-scale model (~50 species/functional groups) to serve as a "base" and "continuously living" model for future fisheries policy exploration (Table 2).

Technical Interactions

Although technical interactions are not inherent to food web dynamics, they are important and relevant to the topic of multispecies fisheries management (Figure 18 provides a detailed description of technical interactions).

Multispecies Yield-Per-Recruit

Managers can use single-species yield-per-recruit (SSYPR) models to determine fishing mortality rates that achieve optimal trade-off between the size of the individuals harvested and the number of individuals available for capture. If fishing mortality is too high, then yield will not be optimal since too many individuals will be harvested before having a chance to grow. Conversely, if fishing mortality is too low, the yield will also not be optimal because not enough individuals will be harvested (even though each individual will be large when captured).

Conducting an SSYPR analysis requires an estimate or assumed value for the natural mortality rate, information on growth in weight, and data on selectivity (i.e., age or size at recruitment). Such models generally assume that recruitment—and hence the age-structure of the population—are constant over time and that fishing and natural mortality remain constant once the fish become vulnerable to fishing gear. These assumptions are important and their violation may have adverse effects on model performance; however, practical application of an SSYPR model usually characterizes the effects of different ages at first capture and varying rates of fishing mortality.

Fishing gear (e.g., trawls, gill nets) used to exploit fish populations are somewhat indiscriminant. If several fish species occupy the same geographic location at a particular time, these fish may be captured in proportion to their relative abundance, subject to the selectivity of the gear. The overall fishing mortality rates of the different species captured can then be interpreted as a function of gear selectivity and culling practices. Typically, the highest F values are associated with the target species (and size classes); a gradient of F values that depends on selectivity and post-capture survival (assuming it is not uniform) is associated with bycatch or discarded species.

Researchers use multispecies yield-per-recruit (MSYPR) models to study situations in which several stocks are simultaneously exploited by a single fishing gear. The calculations associated with the approach follow those of single-species models except that the results are summed over all species (see Murawski 1984 for a detailed description of the equations associated with MSYPR). Given this summation, researchers can simulate various regulatory scenarios that reflect different levels of total fishing effort (and thus F values) and the selectivity of different gear types.

Using MSYPR, it is also possible to accommodate a situation in which several independent fisheries harvest one or more species and stocks (e.g., exposure to multiple fisheries due to seasonal migrations; the use of different gear types). In this instance, the fishing mortality rates for each species/stock must be adjusted to reflect the relative contribution by each fishery (see Murawski 1984 for details).

Multispecies Yield-Per-Recruit in Chesapeake Bay

To date, researchers have not used MSYPR models to study the effects of technical interactions in Chesapeake Bay. Several types of fishing gear have been used historically to harvest several fish species in the Bay simultaneously—most notably pound nets and haul seines (Chittenden 1989). Species typically captured in pound nets and haul seines include striped bass, Atlantic croaker, Atlantic menhaden, and weakfish, making these species candidates for an MSYPR analysis. The results of any MSYPR analysis should be interpreted cautiously, however, since a reasonable risk exists that the assumptions inherent to the model will be violated. As such, characterizing the potential for and effects of assumption violation should become an important component in any MSYPR analysis of Chesapeake Bay fisheries.

Multispecies Surplus Production

Single-species surplus production (SSP) models are typically used to identify the rates of fishing mortality that generate sustainable yields—including the maximum sustainable yield (MSY)—given a population's rate of growth in terms of changes in biomass over time. Due to their simplicity and relatively modest data requirements (catch and fishing effort), SSP models generally provide a starting point for fisheries stock assessments. The general surplus production model in discrete time takes the form:

$$B_{t+1} = B_t + f(B_t) - Y_t \qquad (4)$$

in which B_t represents the exploitable biomass of a particular species at time t; $f(B_t)$ is a general function describing surplus production (often assumed to be the difference between production and natural mortality) as a function of biomass at time t; and Y_t is the yield to the fishery at time t.

Schaefer (1954) formulated the first widely used equation for $f(B)$ from earlier research by Graham (1935). An application of the classical logistic equation for population growth, the Schaefer model is relatively simple and yields a symmetric relationship between surplus production (dB/dt) and biomass. Pella and Tomlinson (1969) proposed a generalized extension of the Schaefer model to alleviate the inherent requirement of having a symmetrical relationship between surplus production and biomass. Studies of surplus production related to stock size have shown that non-symmetrical relationships often exist, implying that use of this generalized model may prove desirable.

One of two general modeling strategies is possible when extending the production model approach to estimate multiple stocks production in a multispecies fishery. The first—a temporal multispecies production (TMP) model—evaluates production by applying a single-species model using the assumption that multispecies fisheries behave as a single-species stock. The term "temporal" is used to define this approach because the production analysis is usually based on combined time series of catch-and-effort data for all species under consideration (i.e., the parameters of $f(B)$ are estimated from that time-series data). Ralston and Polovina (1982) used this approach to investigate the total production of 13 demersal fish species from the Hawaiian archipelago. In general, they concluded that the approach could prove useful for production analysis in a multispecies fishery.

The second modeling strategy evaluates production over space rather than time. A spatial multispecies production (SMP) model treats the various locations within the total fished area (e.g., islands, reefs) as replicate fisheries and assumes the production from each location is the same (i.e., the parameters of $f(B)$ are estimated from spatial fisheries data). The assumption remains that the spatially explicit fisheries are in equilibrium. As with the SSP and TMP models, the results of an SMP analysis become unreliable if this assumption is violated.

Koslow et al. (1994) used this approach to study two Caribbean reef fisheries in southern Jamaica and Belize, concluding that SMP models should be used with caution in reef fisheries management due to the high probability of assumption violation. Specifically, Koslow and others noted the nonequilibrium condition of the fisheries, the heterogeneous mix of species both within and between Jamaica and Belize, the diversity of fisheries targeting various spawning, sedentary, and migratory fish, and the possible differences in productivity among sites as factors contributing to the limited success of the analysis.

Multispecies Surplus Production in Chesapeake Bay

To date, TMP and SMP models have not been used to develop management strategies for Chesapeake Bay fisheries. The modest data requirements of these models relative to other multispecies modeling approaches, however, imply some fairly immediate possibilities for development. Since watermen have used pound nets and haul seines to harvest several fish species in the Bay, development of both TMP and SMP models could utilize landings data from these gears. Importantly, the MSY of the species complex in a multispecies production model is not simply the sum of the MSYs of the individual species.

Modeling Summary

We have reviewed five valuable approaches for investigating various multispecies fisheries questions. Specifically, we considered MSVPA, size-spectra, and EwE models to evaluate the effects of biological interactions, as well as MSYPR and multispecies production models to make inferences about technical interactions. In addition to the techniques described here, other modeling techniques have proved useful in evaluating impacts on marine communities. Hollowed et al. (2000) reviewed a larger body of multispecies models and described their strengths and weaknesses (as compared to single-species models) in determining the causal mechanisms responsible for shifts in marine ecosystem production. A brief summary of their general conclusions follows.

Hollowed et al. (2000) concluded that multispecies models have a distinct advantage over single-species models since they depict natural mortality and growth rates more realistically. An exception to this lies in the use of single-species models for short-term predictions of large fish species, as trends in predation mortality are not often immediately obvious. With respect to their ability to generate reliable long-term predictions, multispecies models are a work in progress primarily because of their sometimes strong sensitivity to parameter estimates and assumptions about recruitment. Additionally, multispecies models may have the potential to describe the indirect effects of fishing on individual species. Until they are more fully tested and validated, however, relying on general rather than specific model predictions (i.e., qualitative rather than quantitative results) seems more prudent. Undoubtedly, multispecies models that incorporate biological interactions have improved our understanding of fish population dynamics. In some cases, lessons learned from these models have even led to improvements in the single-species models used to characterize the fishing impact on individual species.

Major Findings

Food Web

The Chesapeake Bay food web has undergone significant historical alterations, primarily due to anthropogenic influences such as eutrophication, overfishing, and habitat degradation over the past three centuries. Eutrophication may drive bottom-up control of food web dynamics, whereas fishing upon top predators likely dominates top-down control.

Food web interactions—the outcome of predator–prey relationships—can have dramatic and substantial effects on the ecosystem's community structure, including productivity of species supporting important fisheries. The form and magnitude of the effects from altering food web interactions are somewhat unpredictable, both in form and magnitude, due to the high connectivity within and between the benthic and planktonic components of the Chesapeake Bay food web. Connectivity among the food web components must be better understood to avoid individual and aggregate population collapses or extinctions of Bay species.

Major links between and within benthic and planktonic components of the Chesapeake food web include Atlantic menhaden, Atlantic croaker, bay anchovy, blue crab, forage fish (e.g., bay anchovy), spot, and Atlantic croaker. Researchers have only identified a few keystone (e.g., blue crab) or dominant (e.g., oyster) species in Chesapeake Bay. Further research must identify such species as they may exercise control over community structure and productivity out of proportion to their abundance and dominant species may be the major contributors to energy flow and biomass production in aquatic ecosystems.

Some food web interactions that are not normally regarded as predator–prey or consumer–prey interactions may be consequential in the food web and population dynamics of key species (e.g., disease in oyster, bycatch mortality for endangered or threatened sea turtles and birds of prey).

Modeling

The five modeling approaches reviewed in this element may prove useful in addressing many multispecies fisheries questions. Specifically, MSVPA, size–spectra, and EwE models can evaluate the effects of biological interactions; MSYPR and multispecies production models can make inferences about technical interactions.

In addition to models described here, other modeling techniques could be used to evaluate the impacts on marine communities. Hollowed et al. (2000) reviewed a larger body of multispecies models and described their strengths and weaknesses (as compared to single-species models) for determining the causal mechanisms that induce production shifts in marine ecosystems.

Hollowed et al. (2000) concluded that multispecies models have a distinct advantage over single-species models in that they depict natural mortality and growth rates more realistically.

An exception lies in the use of single-species models for short-term predictions of growth and mortality in large fish species in which trends in predation mortality are not always obvious. Regarding reliable long-term predictions, multispecies models should be considered works in progress due to their strong sensitivity to parameter estimates and assumptions about recruitment. In addition, multispecies models may have the potential to describe the indirect effects of fishing on individual species quantitatively. Until these models are more fully tested and validated, however, relying on qualitative rather than specific model predictions remains prudent.

Multispecies models that incorporate biological interactions have improved our understanding of fish population dynamics. In some cases, the lessons learned from these models have led to improvements in the single-species models used to characterize the impact of fishing on individual species.

Panel Recommendations

Management

1) Develop life cycle diagrams and food webs for target species; use them to define important food web linkages and validate food web models.

Identify the major predator–prey interactions, including all significant sources of food and mortality without ignoring atypical sources (e.g., disease, bycatch) and noncommercial species. Document beneficial aspects of food web interactions, such as the potential benefits of bycatch as food for endangered, threatened, and overexploited species (e.g., sea turtles). Consider vital prey species that potentially are affected by increases in the abundance of the target species. In examining food web interactions of the target species, explore the likelihood that food web (energy transfer) approaches may fail to identify dynamically important linkages (e.g., trophic cascades and keystone species).

2) Distinguish between anthropogenic and natural processes that affect water and habitat quality and thus trophic interactions, such as pollution effects on water quality, watershed influences, hydrodynamics, and variation in environmental processes.

Both anthropogenic and natural causes—or some combination of the two—can alter food web dynamics. It is important to recognize the causes of variability before undertaking management actions intended to either shift the balance among predator and prey species or promote the productivity of prey resources by appropriate controls of fishing on target species.

3) Use multiple models and varying data sources to explore the Chesapeake Bay ecosystem and the ways in which fishing may affect the food web dynamics and production of target species.

Each modeling approach may serve a unique purpose. Run alternative food web models (e.g., Ecopath with Ecosim) when developing FMPs to understand linkages between food webs, fish habitat, environmental changes, and fisheries production. To detect robust responses to changes in target species abundance, develop several models within each class of food web model (e.g., multispecies stock assessments, ecosystem models), when possible, to facilitate model comparison.

Needed Research and Development

4) Conduct field investigations to determine and quantify major predator–prey interactions and significant sources of food and mortality.

Predator–prey dynamics are at the heart of interactions among species that affect abundance and production. Such interactions have dramatic and substantial effects on community structure and may influence the yields of Bay fisheries. At present, managers can use the fundamental knowledge of food web structure in a precautionary manner, but major research must proceed to ensure that multispecies fisheries management in the Bay is confidently implemented.

5) Conduct modeling and field investigations to determine food web (energy transfer) approaches to identify and quantify the effects of dynamically important linkages (e.g., trophic cascades and keystone species).

Do trophic cascades and keystone species exist in Chesapeake Bay? Evaluate existing Bay-area fishery-independent and fishery-dependent databases as sources for inputs to multispecies models. Integrate these databases to reflect a baywide scale.

6) Investigate the connectivity among components of the food web to better understand and avoid the risk of individual or aggregate extirpation of Chesapeake Bay species.

The form and magnitude of effects of alterations in food web interactions are somewhat unpredictable due to the high degree of connectivity within and between the benthic and planktonic components of the Chesapeake Bay food web.

7) Investigate anthropogenic (e.g., hypoxia) and natural (e.g., climate and weather) processes that affect water or habitat quality and, therefore, trophic interactions.

Understanding how natural processes control or destabilize food web relationships (in addition to fishing effects) is important. Research on variability in food consumption by target species, in relation to environmental factors and under varying environmental conditions, will help address this issue.

8) Compare and contrast the various modeling approaches of food web dynamics. Several modeling approaches (e.g., EcoPath and EcoSpace, multispecies virtual population analysis) are available to address food web dynamics. Researchers should apply and evaluate more than one model concurrently.

Testing and comparing modeling approaches to assess model performance and to understand the causes of differences in model results remain important. Thorough comparative modeling research will lead to rigorous and robust model applications for evaluating food web relationships.

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element 3

Habitat, Habitat Requirements, and Habitat Management

Introduction

Merriam-Webster's Collegiate Dictionary defines habitat as "the place or environment where a plant or animal naturally or normally lives and grows." In moving from a single-species perspective to a fisheries ecosystem framework, habitat may be more appropriately thought of as the array of locations and environments potentially utilized by species of interest as well as members of their significant food web. In federal fisheries regulations, habitat includes the waters and substrate used for spawning, breeding, feeding, or growing from the earliest life history stages to maturity, including associated physical, chemical, and biological properties (U.S. DOC 1996) such as turbidity, dissolved oxygen concentration, salinity, and suitability for prey species. Both individual species' habitat requirements and the characteristics of habitats determine the extent to which various habitats within an ecosystem are utilized and contribute to the health and production of fish stocks. Behavioral responses of harvested species, as well as those of their predators and prey, can also be extremely important. Habitats that these species avoid, for example, are unlikely to contribute to the health and production of managed stocks.

Fisheries management has increasingly emphasized how the quality, quantity, and arrangement of habitats within aquatic ecosystems affect both the integrity of ecological systems and the potential sustainable yield of fished species. This emphasis has emerged from developments in fisheries science, basic ecology, and management tools and regulations. This habitat requirements element will

1) Recommend actions that may improve habitat management;
2) Propose a framework and discuss tools for linking fisheries and habitat management;
3) Review important habitat issues that should be considered in fishery management plans (FMPs) for aquatic systems in general, and Chesapeake Bay specifically; and
4) Discuss the potential utility of marine protected areas (MPAs) as a management tool for the Bay.

A species-by-species review of the habitat requirements and preferences of managed species, and members of their significant food web, is beyond the scope of this element. The Habitat Requirements for Chesapeake Bay Living Resources (Funderburk et al. 1991) and individual FMPs provide such information.

Habitat as the Core of an Ecosystem Approach

Habitat links individual species with the Chesapeake ecosystem as a whole. The abundance, spatial arrangement, and quality of habitats affect several important factors: encounter rates between predators and prey, availability of refuges from predation, growth rates, incidence of disease, and many other processes that potentially influence the sustainable yield of exploited populations (Tilman and Kareiva 1997; Case 1999; Stunz and Minellom 2001). Habitat characteristics and locations can determine which species within the Bay system interact directly, and which species influence each other only through their indirect effects on other species or habitats.

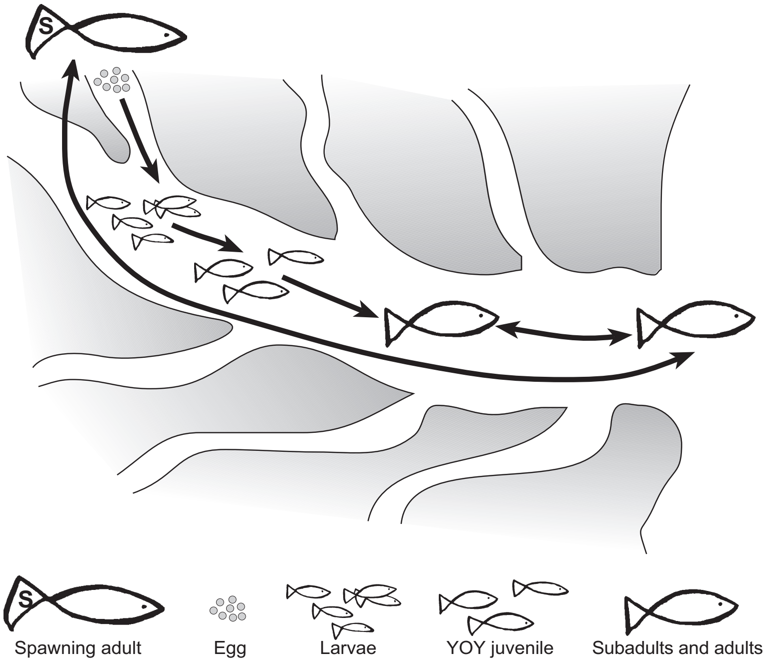

Figure 1. Many managed species in Chesapeake Bay use different habitats and have different physiological responses to habitat characteristics during their life cycles. Such habitat and physiological shifts during ontogeny mean that a species can use a wide variety of Bay habitats; habitat features that affect survival at one life stage can influence the use of other habitats by other life stages. For example, striped bass (shown above) spawn in tidal fresh reaches of Bay tributaries, use tidal fresh and low salinity waters as larvae, migrate into mesohaline waters as young-of-year juveniles, and use mesohaline, polyhaline, and coastal ocean habitat as adults.

The activities of fished species and members of their significant food web also create important linkages among habitats within the Chesapeake system. Fished species and their prey influence the transfer of carbon and nutrients from the plankton to the benthos, redistribute nitrogen among benthic or water column sites by feeding in one location and releasing waste in another, and use many different habitats during development and seasonal migrations (Figure 1). All of these activities create mechanisms through which one habitat can influence the abundance of key species that reach another habitat at a later time. Many managed species within the Chesapeake ecosystem, and some of their important prey, spend a portion of their life cycles outside Bay waters, with many using both freshwater and saline habitats.

Species also alter habitats in ways that influence their suitability for other species. Some species, such as the eastern oyster *Crassostrea virginica,* are essentially ecosystem engineers (Jones et al. 1994) due to their influence on the ecosystem's habitat quality. Before their low levels of abundance, oysters counteracted the negative effects of nutrient loadings both by removing large quantities of phytoplankton from the water column and by influencing nutrient regeneration (Newell and Ott 1999). By affecting the abundance and distribution of such ecosystem engineers, fisheries can indirectly shape ecosystem "health."

These linkages among habitats, and the way that habitat links species, suggest that a holistic, system-wide approach to habitat management is needed for effective ecosystem and fisheries management. Coastal waters, especially those downstream of cities and intense agricultural activities, are subject to multiple stressors caused directly and indirectly by human activities (Breitburg et al. 1998; Cloern 2001; Jackson et al. 2001; Breitburg and Reidel 2005). Intense fishing pressure, increased sediment loads, exotic species (including pathogens), and altered hydrodynamic regimes often plague waters near centers of dense human habitation. In addition, individual stressors can have multiple direct and indirect effects. Excess nutrient loadings into Chesapeake Bay and other coastal waters are associated with

1) Low dissolved oxygen concentrations;
2) Loss of aquatic vegetation;
3) Decreased water clarity;
4) Changes in zooplankton assemblages that encourage increased abundances of gelatinous predators and competitors of early life stages of fishes; and
5) Harmful algal blooms (Cloern 2001; Howarth et al. 2000).

As the number and severity of stressors increase, the potential for serious cumulative and interactive effects also grows. The loss of high vertical relief and shoreward extensions of oyster reefs is largely attributed to overfishing (Rothschild et al. 1994) and exotic parasites (Burreson et al. 2000). This loss increases the vulnerability of both oyster populations (Lenihan and Peterson 1998) and fishes (Breitburg 1992; Lenihan et al. 2001) to episodes of low dissolved oxygen, which are exacerbated by excess nutrient loading to the Bay. Multiple stressors acting simultaneously can make it difficult to identify the cause of population declines and can reduce the efficacy of actions to ameliorate individual problems (Breitburg and Riedel 2005).

An important goal of ecosystem-based management is to maintain, and in many cases increase, the quality and quantity of habitat in the Chesapeake system as a whole.

With cumulative and interactive effects of stressors, habitat restoration efforts that address only a single habitat or single stressor are likely to fail. For example, high sediment loads that bury shell plants (shell placed on the bottom as substrate for oyster habitat) may impede efforts to construct successful oyster reefs, poor water clarity and high nutrient concentrations often hamper the success of submerged aquatic vegetation (SAV) plantings (Batiuk et al. 2000), and the absence of restored populations of filter-feeding organisms hinders water quality improvement through nutrient reduction (Newell and Ott 1999).

Defining Essential Fish Habitat

The Magnuson-Stevens Act defines essential fish habitat for federally managed fish species as ". . . those waters and substrate necessary for spawning, breeding, feeding, or growth to maturity." NOAA Fisheries provided additional regulatory guidance to ensure consistency in the interpretation of this definition: "Waters" include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; "substrate" includes sediment, hard bottom, structures underlying the waters, and associated biological communities; "necessary" means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and "spawning, breeding, feeding, or growth to maturity" covers a species' full life cycle.

A piecemeal focus may also lead to gradual erosion of habitat quality and quantity. For centuries, human activities have both directly and indirectly stressed estuarine ecosystems, such as Chesapeake Bay. The ecosystems we now exploit and attempt to manage are greatly altered from their condition prior to human influence. Although many Bay habitat types are seriously degraded, evaluating the contribution of a small parcel of seascape or even a specific habitat type to the size or productivity of a managed species population is quite difficult. The challenge of identifying and quantifying the habitat benefits and risks at small spatial scales can make the protection of individual sites difficult despite the importance of cumulative losses. To provide a minimum level of viable habitat for sustainable Chesapeake fisheries, a system-wide "no-net-loss" policy for habitat quality and quantity should be adopted.

Implementation of such a policy will require both whole-system and small-scale evaluation and management. An important goal of ecosystem-based management is to maintain, and in many cases increase, the quality and quantity of habitat in the Chesapeake system as a whole. Accounting for the potential contribution of individual habitats and sites to system integrity and function is necessary to accomplish this goal. Even where direct links between habitat and fisheries sustainability and production are difficult to quantify in absolute terms, the relative value of sites and habitat types can often be assessed. The value of habitats depends not only on the habitats' characteristics, but also on the qualities of the habitat matrix within which they exist, their location within the aquatic landscape, and the behaviors and distributions of aquatic organisms. The section Considering the Aquatic Landscape, found later in this chapter, accounts for these issues. The relative contributions of particular sites and habitats may also change as surrounding habitats improve or degrade. Where mitigation is required to meet no-net-loss guidelines, mitigation efforts should remain within the same salinity zone and tributary watershed and, where possible, within the same subwatershed. In most cases, mitigation should address the same habitat type(s) negatively affected. In all cases, mitigation should proceed with methods and in locations that maintain or increase total habitat quality and quantity, without substituting sites and habitat types that serve as population sinks for those that tend to act as sources.

Adopting a more unified and coordinated management of fish removals and fish remains critical despite oversight by several agencies. Fishing activities can degrade the physical habitat and make species more susceptible to fishing pressure and individuals more vulnerable to fishing gear (Baden et al. 1990), reducing the productivity and resilience of populations (Bowen 1997).

Essential Fish Habitat as a Framework

Fisheries management regulations in the United States began incorporating habitat considerations into fisheries management with the enactment of the 1996 Sustainable Fisheries Act (SFA). This act added essential fish habitat (EFH) provisions to the Magnuson-Stevens Fishery Conservation and Management Act. The SFA requires that essential fish habitat, defined as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity" (U.S. DOC 1996), and including associated physical, chemical, and biological properties of habitats, be identified and described for each federally managed species in the preparation of FMPs. The goal of the EFH provisions is to ensure sustainable production of harvestable products. In other words, habitat preservation and rehabilitation in the SFA should preserve and enhance economic benefits due to removal of fish from the environment, as opposed to environmental protection per se (Baird 1999). Thus, the value of habitats for their ecosystem services is not considered directly within the EFH context as specified in the federal SFA.

The SFA requires that any federal agency taking actions that may adversely affect essential fish habitat must consult with the National Marine Fisheries Service (NMFS) to determine the effects of such actions on both habitat and the managed species. In addition, NMFS must recommend to federal and state agencies the necessary steps to avoid, minimize, or offset any adverse effects of agency activities to EFH (50 CFR Part 600, subparts J and K) (Schmitten 1999).

Coordination of fisheries and habitat management in Chesapeake Bay would be facilitated by adoption of regional essential fish habitat regulations.

Current EFH provisions of the SFA apply to federally regulated waters, species with federal management plans, federal agency actions, and actions of state or local government agencies using federal funds. The waters of Chesapeake Bay are under state jurisdiction; therefore, state and local jurisdictions undertake or regulate many of the activities that potentially affect fish habitat. As some Bay species do not have federal management plans (e.g., blue crab *Callinectes* *sapidus* and oyster), many activities that affect fish habitat in Chesapeake Bay are not regulated under EFH provisions of the federal SFA. Several commercially important species, therefore, do not have the benefit of EFH protection when dependent upon Bay habitat during critical life stages.

State and federal agencies currently regulate activities that reduce and degrade habitat. Many of these agencies do not have a specific mandate to protect or restore EFH; some conduct activities potentially damaging to habitat (Peterson et al. 2000). The large number of agencies with responsibilities affecting fish habitat, along with the multiple factors potentially affecting habitat value, argue for a more tightly coordinated or integrated management structure that can address ecosystem issues in a holistic manner (Peterson et al. 2000; Breitburg and Reidel 2005).

Essential Fish Habitat Regulations for the Bay

Coordination of fisheries and habitat management in Chesapeake Bay would be facilitated by adoption of EFH regulations. Federal EFH guidelines provide a good starting point for developing regional EFH regulations, but federal regulations should be modified to design protective, enforceable regulations for Chesapeake Bay, and clear, defensible criteria for determining the level of protection afforded different habitat categories. As regional EFH regulations are developed, improving the federal model in ways that provide the appropriate level of protection for fished species, as well as protection for the Chesapeake ecosystem on which they depend, becomes extremely important. The Chesapeake Bay EFH regulations

1) Would apply to the preparation of Chesapeake Bay fishery management plans for those species not covered by federal management plans;
2) Would apply to state waters and recipients of state and local government funds;
3) Should require habitat assessments, consultation with fisheries management agencies, and avoidance of habitat damage by state and local government agencies; and
4) Would supercede federal regulations within Chesapeake waters where regional EFH regulations are more protective.

Development and adoption of regulations for Chesapeake Bay adapted from federal EFH provisions will provide several benefits to fisheries management. First, these regulations would require that agencies using state and local funds (not only federal dollars) assess the impact of their regulatory actions on essential fish habitat and that they consult with the appropriate state and regional fisheries management agencies before proceeding. Thus, regional EFH provisions would provide a framework for coordination of fisheries and habitat management. Although individual species FMPs prepared by the Chesapeake Bay Program (CBP) Fisheries Management Planning and Coordination Workgroup describe habitat requirements, habitat protection is not universally mandated nor uniformly applied. Second, EFH-type provisions emphasizing ecosystem-level considerations will become an important tool in moving towards ecosystem-based management of Bay fisheries.

Regional EFH regulations should not duplicate federal regulations; they should move beyond the SFA provisions and address problems for which federal EFH provisions have been criticized. For example, no enforcement mechanisms would prevent destruction or degradation of EFH under current regulations (Sarthou 1999). In addition, the difficulty of distinguishing among the various EFH categories requires modification of the current federal classification scheme in development of regional EFH regulations.

Implementing Essential Fish Habitat in an Ecosystem Context

Concerns exist that EFH provides an insufficient framework for promoting ecosystem-based fisheries management. The EFH framework and an ecosystem perspective are not inherently contradictory, however, as long as evaluation of habitat importance includes factors such as the interdependence of habitats, value of habitat complexity, and arrangement of habitats within the estuarine landscape. Baird (1999) has suggested that the term “sustainable” in the SFA requires an ecosystem-based approach since it mandates consideration of “marine environments in a holistic context with sufficient dimensionality and geographic extent to preserve system functionality for fish production.”

Important characteristics of ecosystem-based EFH regulations for Chesapeake Bay should include the explicit designation and protection of essential habitat for prey of managed species, as well as for managed species themselves, and consideration of the interacting effects of the various habitat locations, features, and types. The FMPs should clearly address habitat requirements, preferences, and uses by managed species and members of their significant food web. The plans should also account for habitat diversity, complexity, and

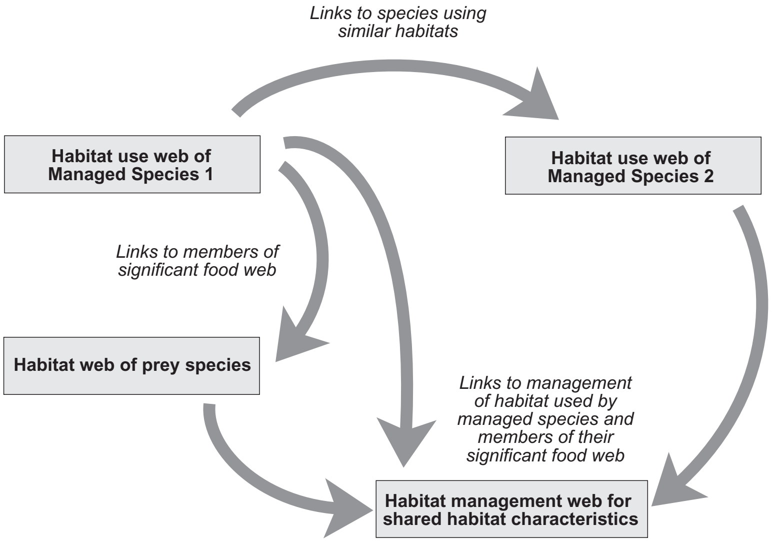

Figure 2. Integrated habitat use and habitat management webs as a management tool. A database that linked information on habitat use and tolerances, food web interactions, and habitat management could support fishery management activities and link fishery management and habitat management efforts. Appendix 1 at the end of this element provides an illustration of linked integrated habitat use and habitat management webs.

spatial organization affecting habitat value, along with the importance and consequences of temporal variability and dynamics in formulating management practices and policy.

Habitat Management and Habitat Requirements

Interagency coordination, as well as identification of habitat uses and requirements of managed species and their prey, could be improved through a data management system and protocol that explicitly links biological data, physical data, and habitat management. Figure 2 and Appendix 1 illustrate a model for such a system, with linkages among habitat use, setting criteria for managed species, food webs, and water quality by management agencies. Such a system would improve information access and updating capabilities for fisheries managers. Most importantly, it could create a formal mechanism in which preparation of FMPs and other routine activities of fisheries agencies automatically trigger re-evaluation of activities by agencies responsible for habitat protection and by those whose actions potentially affect habitat quality.

The data management system for these interconnected habitat requirement and habitat management webs should allow quantitative analyses that facilitate evaluation of the relative contribution of different habitats and habitat characteristics to the growth and survival of managed species in a method analogous to identification of strong and weak links in food webs. It should also allow links to information for geographic referencing, but not depend on geographic information software for operation.

Recent fishery management plans prepared and adopted through the CBP describe managed species' habitat needs, as well as regulations and restoration efforts that protect habitat quality. A more formal framework, based on habitat requirements of managed species and their food webs that leads directly to habitat management and use modification, would constitute an important step in improving Chesapeake fisheries ecosystem management.

Goal and Criteria Setting

Historical Baselines and Trajectories

Human activities have so altered coastal ecosystems that many bear little resemblance in structure or function to their condition prior to human influence (Jackson et al. 2001). These alterations began during aboriginal use of aquatic habitats, but accelerated during colonial periods and modern global exploitation (Jackson et al. 2001). Consequently, Chesapeake Bay habitats prior to European colonization appeared quite different than those of today. Historically, bottom waters contained higher quantities of dissolved oxygen, sea grasses covered much larger swaths of Bay bottom, clearer waters allowed light penetration deeper into the water column, oyster reefs created extensive hard-bottom habitat with complex vertical relief, and storm-related salinity fluctuations were muted (Curtain et al. 2001).

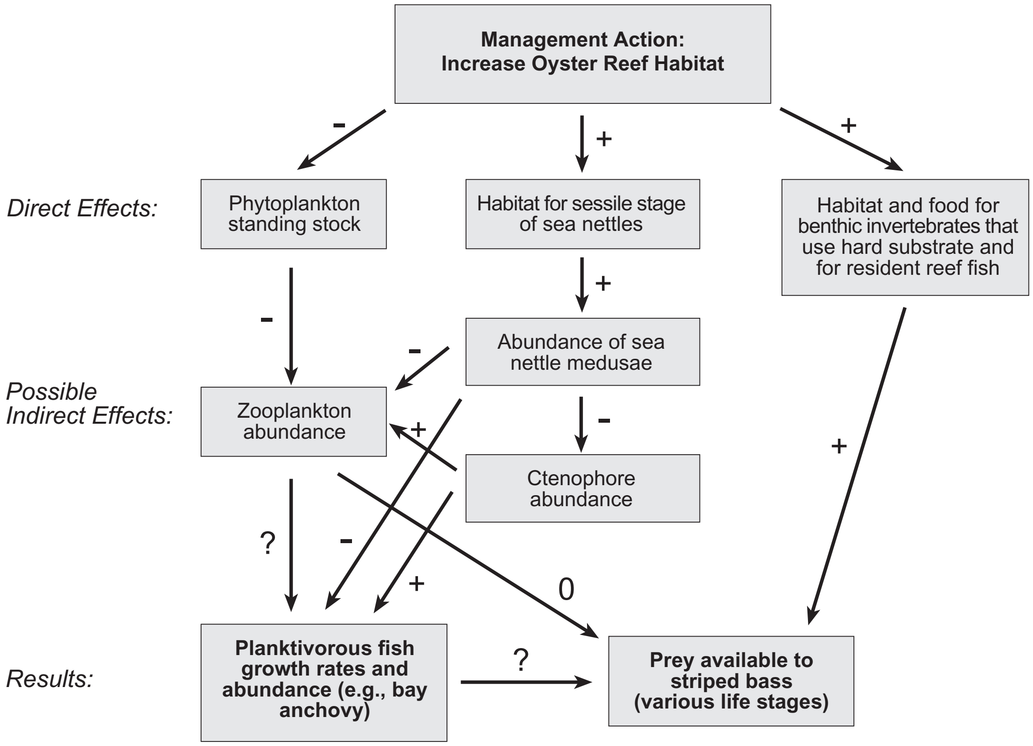

Figure 3. Predicting the results of any specific habitat restoration effort can be difficult because of the large number of indirect effects resulting from trophic interactions and the effect of one habitat characteristic on another. The example above illustrates a few of the potential ways that oyster reef restoration may affect fish populations. The net effect will depend on the relative strength of the various direct and indirect pathways shown, as well as those omitted from this simplified diagram. Historically, the Bay once supported more extensive, healthy oyster reefs and abundant fish; such information can help set restoration goals, especially where reliable predictive models are not available.

As a starting point, no “pristine” habitats now exist in the Chesapeake and virtually all habitats are degraded within the tidal waters of the watershed. The current state of the Bay means that in situ measures of habitat use and trends provide only comparisons among current habitat options. Habitat use, habitat preferences, and the relative potential for growth of managed species in different habitats might follow quite different patterns if the choices for fish and shellfish were not so degraded, or if the relative severity of Bay habitat degradation differed.

Thus, historical baselines and trends may provide better benchmarks for goal setting than comparisons of current habitats. Essential fish habitat assessments in federal guidelines currently use four designation levels, ranging from all habitats in which a species occurs (Level 1) to those habitats yielding highest sustainable yield (Level 4) (NOAA 1997). Providing a lower level of protection to habitats currently yielding low productivity does not account for the possibility that these habitats are yielding low production or abundance primarily due to human degradation.

Where possible, historical baselines and trends should be used to define goals for the restoration and maintenance of habitat extent, health, and distribution since concerted management and restoration efforts can partially or completely reverse some anthropogenic impacts to Bay habitats. Researchers can use a combination of field data, historical accounts, and scientific judgment to develop descriptions of habitats as they likely existed before extensive alteration. As the negative effects of habitat loss and alteration on fish habitat are reduced, baseline conditions and historical trends can point out desired trajectories for change (e.g., more oyster reefs, less severe oxygen depletion) even if a complete return to a non-impacted system proves unachievable.

The difficulty of precisely predicting the impact of individual restoration efforts in a complex system further highlights the value of using historical trends and baselines in goal-setting (Figure 3). Like most ecosystems, estuaries are characterized by complex food webs and landscapes with a variety of habitat types, sizes, and configurations. Any action will likely have multiple pathways through which it ultimately affects a managed species. Detecting and quantifying the effects of habitat on fish population size and production remains difficult due to high interannual variation, interactions among stressors that make isolating individual stressor effects difficult, and spatial heterogeneity in habitat causing disproportionate effects of habitat change on populations (Rose 2000). Data are likely to be incomplete or uncertain even when managers must make decisions. The use of multiple models, data sources, and analytical tools for understanding and predicting linkages among habitats, food webs, and fisheries production, therefore, constitutes an important safeguard for effective management.

Problems associated with precisely predicting how habitat management will affect biomass and production of managed stocks also provide incentive to maintain healthy habitat and toharvest species at precautionary and sustainable levels. The alternative approach (i.e., attempting to manage the Chesapeake ecosystem for maximum fisheries yield) is not an achievable or desirable goal given the understanding of coastal ecosystem organization and function for the foreseeable future. This latter approach may bring unintended consequences that lead to further degradation of the system's ecological integrity. In many cases, we do not have the information or analytical tools to determine accurately how to enhance fish stocks through habitat management. In other cases, management that maximizes landings of particular species can have negative consequences for ecosystem health as well as for populations of other fished species. In Europe, for example, the highest harvests of fishes that feed on zooplankton occur in severely eutrophic systems (de Leiva Moreno et al. 2000). Promoting high production of important prey species for commercially and recreationally fished piscivores, however, is not appropriate justification for abandoning nutrient reduction goals and continuing habitat degradation through high nutrient loadings to the Chesapeake Bay.

Adoption of a Precautionary Approach

The difficulty of making precise outcome predictions for either management actions or potentially harmful activities argues strongly for adoption of a precautionary approach to habitat management (Auster 2001). Such an approach encourages managers to designate fish habitat as essential when faced with scientific uncertainty (Schmitten 1999). It also shifts the burden of proof from establishing the importance of a particular habitat to providing strong evidence that a particular habitat is unimportant (Dayton et al. 1998). The use of historical baselines and trajectories should form a fundamental component of a precautionary approach to goal setting, management, and restoration of Chesapeake Bay habitats.

The inherent difficulties in determining causes of population declines of exploited species also mandates use of a precautionary approach. Overfishing, natural variability in physical or biotic factors, and habitat degradation can cause fluctuations in population size. While reducing fishing mortality may allow declining populations to rebound, protecting and restoring habitat in the Bay may make populations less sensitive to fishing and other pressures. Persuasive data from a range of marine systems suggest that rebuilding ecosystems represents the best strategy for preserving fisheries along with other essential services provided by aquatic ecosystems (Pitcher and Pauly 1998; Pitcher 2001).

Characterizing Chesapeake Bay Habitats

Habitats within tidal portions of the Chesapeake system have been classified by function (designated uses), physical characteristics, and the presence and type of biogenic structure. In addition, the NOAA Marine/Estuarine Classification Workshop proposed a hierarchical classification scheme that covers major marine and estuarine environments, which could be extended to include specific habitats within the Bay (Allee et al. 2000). A habitat's physical characteristics include both structural features (bathymetry and abiotic bottom type) and water quality characteristics (such as salinity, temperature, dissolved oxygen, turbidity, flow, and stratification). Biogenic habitat in Chesapeake Bay includes SAV and oyster reefs. The reefs form the most extensive, structurally complex, hard substrate in the Bay; worm tubes and shells of other benthic invertebrates on the reef create a complex matrix used by fish and their prey. Both physical and biotic factors can limit species distributions and growth through behavioral responses, physiological tolerances, metabolic costs of suboptimal conditions, and influence on trophic interactions.

Adoption by researchers and managers of a single, uniformly utilized habitat classification scheme that includes the seasonally shifting boundaries of salinity zones and other important features of the water column; incorporates physical and biotic features that define benthic habitat; and uses geographical referencing where possible, would aid in both management and understanding of Bay resources. Development and adoption of such a classification scheme would not preclude use of additional systems. Most likely, no single classification scheme will serve all management goals and multiple schemes will remain useful.

Critical Habitats and Issues of Particular Concern

Most managed species in Chesapeake Bay and their prey are habitat generalists. Many species use several habitats throughout their lives, feeding in several salinity zones or on upper water column and benthic prey. Other species use a range of habitats sequentially during ontogeny. In addition, habitats do not function independently of one another. Habitat management and restoration are most successful when habitat degradation and loss are addressed simultaneously, with focus on the role of location in habitat function.

Some habitats—Habitat Areas of Particular Concern (HAPCs) (NOAA 2001)—require special consideration for protection and restoration either because of their importance to critical processes within a species' life cycle or the severity of their degradation. A partial list of such areas, along with discussion of critical habitat issues, follows. Additional habitats and habitat issues may prove equally important as those described here and should be identified during FMP preparation.

The multiple effects of individual stressors, as well as the potential for interactions among stressors, are important in considering factors causing habitat degradation. Both make predicting the consequences of anthropogenic effects on fish habitat less reliable. For example, high nutrient loadings to coastal waters affect fish habitat in several ways, including reductions in dissolved oxygen concentrations, reductions or loss of SAV, and changes in prey abundance and distribution (NAS 2000; Cloern 2001). Nutrient concentrations and ratios can influence the toxicity of trace elements (Sanders and Reidel 1987) while fishing pressure can exacerbate eutrophication-driven food web changes. Both of these stresses alter the ratio of planktivores to demersal piscivores in coastal systems (Caddy 2000).

Individual species' FMPs should

1) Identify habitat requirements and the use of all life stages of managed species and members of their significant food web;
2) Identify critical habitat areas and issues of concern (including, and in addition to, those below) that may affect fished species and their significant food webs;

3) Consider potential effects of habitat areas and issues of particular concern on harvest levels due to direct and indirect effects of habitat on fished species; and
4) Determine whether current habitat criteria and restoration targets are adequate to protect and sustain exploited stocks.

Dissolved Oxygen

During summer, roughly half of the subpycnocline waters of the Bay and its tributaries have reduced oxygen (hypoxia) due to high nutrient loadings from anthropogenic sources, strong density stratification, and slow flushing rates (Mackiernan 1987; Smith et al. 1992). Low concentrations of dissolved oxygen in Chesapeake Bay, and elsewhere, have been associated with fish kills, reduced growth rates, increased incidence or severity of disease, altered trophic interactions, increased predation mortality, increased susceptibility to fishing gear, reduced recruitment of harvested species and members of their significant food web, and reduced abundance within the hypoxic volume of water (Breitburg et al. 2001; Breitburg 2002). In addition, regional population declines of harvested finfish in other estuaries have been linked to life history characteristics that make species susceptible to recruitment declines from blocked migration pathways or high mortality of early life history stages (Chittenden 1974; Pliksh s et al. 1993; Thiel et al. 1995; Mackenzie et al. 1996). Warm summer water temperatures may make animals in the Bay particularly susceptible to dissolved oxygen effects since high temperatures reduce the solubility of oxygen in water and increase the metabolic demand in ectotherms. Low oxygen in bottom waters also reduces or eliminates cool-water refuges that potentially increase growth rates in some species (Coutant 1985; Secor and Gunderson 1998). On occasion, the combined action of winds and internal lateral tides (Sanford et al. 1990; Breitburg 1990) can force the advection of oxygen-depleted bottom waters into nearshore shallow habitats, causing high mortality of organisms within the shallow surface layer (Breitburg 1992). Under calm conditions, the collapse of algal blooms and macrophyte respiration and decomposition in shallow vegetated habitat can bring about in situ oxygen depletion in shallow waters.

The most important effect of low dissolved oxygen in the Bay is likely the reduction, considerably below historical levels, of benthic and lower-water-column habitat available to fish and shellfish. When organisms avoid unsuitable or stressful habitats with low oxygen levels, species diversity in the area declines (Figure 4). Other undesirable effects have also been attributed to low oxygen in Chesapeake Bay, including

1) High mortality of fish eggs that sink into oxygen-depleted bottom waters,
2) Fish kills affecting adults and juveniles,
3) Altered trophic interactions that may increase predation mortality of fish larvae and favor gelatinous

species, and

4) Increased mortality of disease-infected oysters (Breitburg et al. 2001; Breitburg 2002).

Low oxygen in deep channels of the mainstem Bay and tributaries may also fragment habitat for mobile benthic species, inhibiting cross-Bay or cross-river movement. Of species tested to date, striped bass along with Atlantic and shortnose sturgeons are the three in the Chesapeake system most sensitive to low oxygen (Batiuk 2002). Reducing the extent and severity of oxygen depletion in Bay waters will

1) Increase habitat available to managed species and members of their significant food web,
2) Reduce the negative effects already described, and
3) Potentially increase the resilience of the system as a whole.

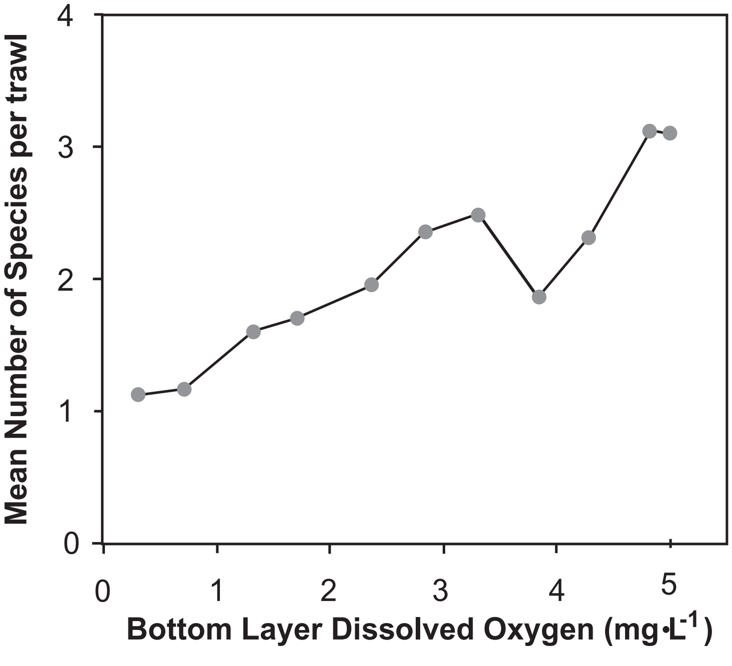

Figure 4. Mean number of fish species collected in trawls near the Calvert Cliffs Nuclear Power Plant (modified from Breitburg et al. 2001). The number of species collected per trawl increased with increasing dissolved oxygen concentration.

Reversing the trend in low oxygen extent and severity is consistent with the precautionary approach of using historical baselines to guide restoration and constitutes an important management goal. Reducing nutrient loadings sufficiently to improve oxygen concentrations substantially in affected bottom waters, however, may reduce the productivity of Bay waters as a whole. An analysis of semi-enclosed European seas indicates that the proportion of planktivorous fish in fisheries landings is highest in semi-enclosed seas characterized by seasonal hypoxia (de Leiva Moreno et al. 2000). On a local scale, however, oxygen depletion can reduce overall landings causing substantial economic losses (Breitburg 2002). Dissolved oxygen criteria for Chesapeake Bay (US-EPA 2003) have been adopted. One of the main goals of nutrient reduction efforts in Chesapeake Bay is improvement of bottom-layer dissolved oxygen.

Loss of Submerged Aquatic Vegetation

Historically, SAV contributed greatly to the high primary and secondary productivity of the Chesapeake Bay (Kemp et al. 1984), but declined dramatically during the 1960s through the 1970s (Orth and Moore 1983). Hurricane Agnes in 1972 triggered the sharpest drop. Researchers have attributed the underlying causes of decline (as well as the failure to rebound to historic levels) to high nutrient and sediment loads coming into the Bay and associated reductions in light penetration (Orth and Moore 1983; Kemp et al. 1983; Hurley 1991). The current acreage of SAV in the Bay occurs at only about 10% of its potential at depths of 2 meters or less (Moore et al. 2000).

Submerged aquatic vegetation provides a host of valuable functions: food, feeding habitat, refuge from predation, and nursery habitat for many organisms, including managed decapod, finfish, and waterfowl species and their prey (Hurley 1991). Generally, faunal densities remain higher within vegetated habitat than in nearby unvegetated areas (Heck and Orth 1980; Orth et al. 1984). Laboratory and field studies also indicate that SAV may reduce predation mortality of juvenile fish (Stunz and Minello 2001), blue crab (Wilson et al. 1987, 1990a; Micheli and Peterson 1999), and clams (Blundon and Kennedy 1982).

Submerged vegetation forms important habitat for blue crabs and may reduce predation on juveniles, molting adults, and feeding adults. The highest settlement densities of blue crab postlarvae occur in seagrass beds near the mouth of the Bay (Metcalf et al. 1996; Hovel and Lipcius 2002; Orth and van Montfrans 2002). In addition, eelgrass *Zostera marina* and marsh creeks may form important overwintering habitats for juveniles (Wilson et al. 1990a). Field experiments reveal that SAV substantially reduces predation on juvenile blue crabs (Wilson et al. 1987, 1990b) and also results in higher growth rates (Perkins-Visser et al. 1996) compared to unvegetated habitat.

In the upper Chesapeake, Kemp et al. (1984) found higher fish abundance and diversity in SAV beds than in unvegetated sites. Similarly, in the lower Bay, Orth and Heck (1980) observed higher density and diversity of fishes in SAV compared to unvegetated locales. Heck and Thoman (1984) noted higher fish abundance at both upper and lower Bay sites in vegetated habitat with the exclusion of spot from the samples. Similar patterns occur elsewhere. For example, most fish in a study of New England estuaries showed maximum abundance and biomass at sites with high eelgrass density and biomass (Hughes et al. 2002). Unclear, however, is whether low seagrass complexity at these sites led directly to low fish abundance or whether fish and seagrass abundances both responded to the same factors.

The contribution of SAV to bivalve survival and growth also remains unclear. Recent unpublished field experiments on softshell (also known as softshell clam) *Mya arenaria* in Maine and northern quahog *Mercenaria mercenaria* in North Carolina found that predation (primarily by crabs and other crustaceans) on softshell clam is higher in grass beds than in adjacent unvegetated areas and that grass beds did not increase northern quahog survival (Beal 2000). Other field experiments in the state, however, indicate that predation mortality of northern quahog is higher on sand flats than in seagrass beds (Irlandi and Peterson 1991). Laboratory experiments point to the potential for physical structure, such as that provided by SAV, to reduce predation by crabs (Blundon and Kennedy 1982). Growth rates of northern quahog in Maine experiments were lower in grass beds than in unvegetated habitat (Beal 2000). Some North Carolina experiments by Beal (2000) and experiments by Irlandi and Peterson (1991), however, indicate that northern quahog growth was higher in grass beds than in unvegetated habitat. Irlandi and Peterson (1991) suggest that growth in sand flats may be reduced by predator activity (e.g., siphon nipping, interfering with clam feeding). These contradictory findings on the importance of SAV habitat to bivalve growth and survival will hamper efforts towards joint SAV habitat and clam fishery management. Further study should help determine when and where it is appropriate to make extrapolations of results from other systems to the Bay, or even extrapolations of results from one region of the Chesapeake system to another.

Loss of Shallow-Water Habitat and Access to Intertidal Habitat and Beaches

Extreme shallow-water habitat can serve as important refuge from predation for juvenile fish and crabs, as well as for adults of small fish species (Ruiz et al. 1993). For example, many small fishes that provide forage for large predator fishes (including silverside species *Atherinopsidae* spp. and mummichogs *Fundulidae* spp.) abound in the shallows of the Chesapeake Bay. Several managed Bay species, including horseshoe crabs *Limulus polyphemus* and terrapins *Malaclemys terrapin*, deposit eggs on sandy beaches and tidal flats within the system. These species require access through shallow-water habitats onto intertidal and beach areas. Lost and blocked access to such habitats due to development, bulkheading, and rip-rap of shorelines decreases the amount of and access to these habitats by managed species and their important prey (CBP 1994).

Blocked Migration Routes

Physical structures that blocked or impeded spawning migrations played an important role in the decline of migratory fish populations in the Bay (Chesapeake Executive Council 1988). Alteration and impoundment of streams within the watershed began during the Colonial period, increased with the construction of dams during the Industrial Revolution, and continued with additional dam construction, road building, and emplacement of other impediments to water flow through much of the 20th century. Nearly a thousand blockages to historical spawning and nursery areas in Maryland and Virginia had been documented when the "Strategy for Removing Impediments to Migratory Fishes in the Chesapeake Bay Watershed" was signed in 1988 (Chesapeake Executive Council 1988). Major dams that block migrations along the mainstem portions of tributaries exist on the Susquehanna, Patapsco, Patuxent, Potomac, Rappahannock, and James rivers. Smaller dams occur throughout the Chesapeake watershed.

Commercially fished migratory species potentially affected by these impediments include American shad *Alosa sapidissima*; river herrings, alewife *A. pseudoharengus* and blueback herring *A. aestivalis*; hickory shad *A. mediocris*; American eel *Anguilla rostrata*; striped bass *Morone saxatilis*; white perch *M. americana*; and yellow perch *Perca flavescens*. The relative importance of migration impediments compared to other factors contributing to population decline remains vague for most affected species since the potential for interacting effects of multiple stressors is high. Habitat effects on reproduction, growth, survival, and behavior may strongly influence the level of fishing pressure that populations can withstand (Breitburg and Riedel 2005). The role that impediments to spawning migrations have played in the decline of Bay alosids (including river herrings, American shad, and hickory shad) elicits particular concern. The affected alosids spawn in freshwater streams; historically, they used habitats now upriver of dams, road culverts, and other structures that prevent or impede migrations. These blockages eliminated important Chesapeake spawning habitat, including all shad runs in the Susquehanna watershed in Pennsylvania (USFWS 2001a, 2001b).

Efforts to remove impediments to migratory fish passage, as well as to minimize the effects of those remaining, continue throughout the Chesapeake watershed. Such efforts include the removal of small barriers, installation of fish ladders, passageways, lifts, and other methods to transport fish around dams, as well as modification in the operation of some dams (USFWS 2001a, 2001b; Commonwealth of Pennsylvania 2001). The "Strategy for Removing Impediments to Migratory Fishes in the Chesapeake Bay Watershed" lists elements of a comprehensive strategy (Chesapeake Executive Council 1988). From 1988 through 2005, 2,958 km of habitat historically used by migratory and resident fishes were reopened through dam removal and fishway construction. This brings restoration efforts about two-thirds of the way towards meeting the goal of opening 4,517 km of habitat by 2014 (http://www.chesapeakebay.net/status.cfm?sid=114).

Oyster Reef Habitat

The hard substrate of the oyster supplies important habitat for many invertebrates and fish. Oyster reefs provide feeding habitat for benthic-feeding fishes, prey for piscivores that feed on resident oyster reef fish, refuges from low dissolved oxygen, physical structure that concentrates fish larvae and juvenile piscivores by altering flow, and physical structure required by cryptic, benthic-breeding, and territorial fish species (Coen et al. 1999; Breitburg et al. 2000). Chesapeake Bay oyster reefs have among the highest densities of fish recorded outside of tropical coral reefs and generally house higher numbers of species and individuals than nearby unstructured, soft-bottom habitat. Overall, studies in the Piankatank, Patuxent, and Fisherman's Island reefs have recorded 57 species of finfish on oyster reefs (Coen et al. 1999; Harding and Mann 1999; O'Beirn et al. 1999; Breitburg and Miller 1999; J. Nestlerode, unpublished data). In many ways, the function of oysters to Chesapeake fishes is similar to that of corals in tropical waters. Oyster reefs transform the surrounding sand and mud habitat into a structurally complex environment replete with hiding nooks, abundant prey, and nesting sites for some species.

Oyster reefs in the Bay and its tributaries can occur in waters of varying salinity. The fish that these reefs house vary by species and abundance, depending upon the local salinity. Species more abundant on oyster reefs than on the surrounding soft bottom in at least one of the three study areas include white perch, silver perch *Bairdiella chrysoura*, black sea bass *Centropristis striata*, striped bass, Atlantic silverside *Menidia Menidia*, blue crab, and terrapin. Permanent residents on oyster reefs, such as blennies, gobies, toadfish, and skilletfish *Gobiesox strumosus*, use the habitat for reproduction and shelter from predators, as well as for feeding (O'Biern et al. 1999; Harding and Mann 1999; Breitburg and Miller 1999; Coen et al. 1999). Some fish species, including white perch and juvenile striped bass, are more abundant on high-relief reefs than in flat low-lying shell areas (Breitburg and Miller 1999). In areas subject to low dissolved oxygen during summer, the upper parts of reefs—as well as reefs that extend towards shore into shallow water—can provide more highly oxygenated habitat that permits survival of benthic fishes and crabs (Breitburg 1992; Lenihan et al. 2001). Increased benthic prey also means greater feeding opportunities and potentially higher growth rates for fish that use oyster reefs. Due to filtration by oysters, near-bottom visibility over oyster reefs can exceed the visibility over surrounding soft bottom—indirectly affecting the feeding rates of fish that use sight to forage.

Large-scale efforts to construct and restore oyster reefs in the Bay are underway. The primary emphasis is to maximize the survival of oysters and enhance reef structure. Beyond this, an ecosystem-based approach can capitalize on the value of oysters as ecological engineers that provide structural habitat for many other species while potentially improving water quality. This philosophy should feature prominently in decisions of design, siting, and management of restoration efforts.

The extent to which oysters can be simultaneously managed for their three valuable roles (as finfish and crab habitat; as a species that potentially affects water quality; and as a harvested species) will depend both on gear restrictions and fishing levels (Breitburg et al. 2000). Patent tongs, for example, destroy the value of the habitat around each grab (1 m^2), because they are very efficient at removing bottom material to a depth of several centimeters. Although a single pass with an oyster dredge has minimal effect on bottom habitat, repeated dredging of an area is destructive as it removes harvestable oysters from the bottom, breaks up shell matrix, and disturbs or damages the resident faunal community (Powell et al. 2001). Shaft (or hand) tongs, the predominant gear for harvesting oysters in Maryland, are likely do less damage per unit of harvest than dredges or patent tongs (S. Jordan and M. Homer, U.S. Environmental Protection Agency and Maryland Department of Natural Resources, personal communication). Divers remove individual oysters by hand and effects should be minimal except for the removal of oysters (S. Jordan, personal communication).

Sanctuaries, or no-harvest zones, should provide sustainable benefits for both oyster populations and reef habitats. Although both Maryland and Virginia continue closing selected areas to oyster harvesting, only a small fraction of historical oyster habitat will ultimately be closed to harvest. Decreasing oystering intensity on a large scale may increase oyster populations and improve habitat value. Over time, the less intense harvesting may lead to increased sustainable oyster landings in the Bay.

Effect of Fisheries and Fishing Gear on Habitat Extent and Quality

The potential for fishing gear to affect benthic habitats negatively by reducing structural complexity and vertical relief elicits considerable concern. (e.g., Auster 1998; Watling and Norse 1998; NRC 2002). Trawling and dredging also potentially reduce the value of habitat to fishes by altering the composition of macroinvertebrate prey (Thrush et al. 1998). The most vulnerable communities tend to be those in physically stable environments characterized by low mobility, long-lived species (NRC 2002).

Trawling and dredging effects on the value of soft-bottom habitat to harvested species and members of their significant food web in the Chesapeake remain unknown. Most finfish fisheries in the Bay use methods that do not cause extensive disruption of bottom habitat. Nevertheless, evaluation of some current practices, such as those in the crab dredge fishery, is warranted given the negative effects of bottom fishing in other locations. Potential impacts of trawling and dredging should also be thoroughly evaluated before allowing any regulation changes that would increase their use in Bay fisheries.

The historical and potential effects of fishing gear on habitats with high-relief biogenic structure (e.g., oyster reefs and SAV) are better understood. Oyster overharvesting and the historical use of destructive fishing gear in the Bay have reduced both the vertical relief and the extent of habitat created by oyster reefs (Rothschild et al. 1994). Reducing the structural complexity of oyster reefs potentially lessens their value as fish habitat. In addition, low vertical relief may make oysters more susceptible to the direct effects of low dissolved oxygen and increase their mortality from disease following exposure to low-oxygen waters (Lenihan and Peterson 1998; Lenihan et al. 1999).

Mechanized fishing (e.g., hydraulic dredging) of clams can damage and destroy SAV beds by uprooting plants and breaking off upright shoots (Manning 1957; Peterson et al. 1987; Hurley 1991). Current regulations in both Maryland and Virginia prohibit mechanical harvesting of clams within SAV beds, although both states permit crab scrapes within SAV. The effect of crab scrapes on SAV habitat is unknown, although powerboats used for crab scraping can cause damage (Blue Crab Fishery Management Plan Workgroup 1997).

Contaminated Water and Sediment

Human activities have elevated sediment and water column concentrations of many contaminants in the Bay (CBP 1999). Contaminants create two distinct threats to managed species. First, toxic chemicals can reduce the value of habitat either from direct effects on the species themselves or through effects on species they use for prey or shelter. Second, accumulation of toxic contaminants in fish and shellfish tissues can pose health risks to seafood consumers, compromising the viability of commercial and recreational fisheries even when contaminant levels prove insufficient to affect the abundance, growth, or health of the fish and shellfish.

Studies of several estuarine and marine species and their habitats indicate that both organic and inorganic contaminants may increase disease prevalence and virulence in fish and shellfish. Increased intensity and prevalence of microbial diseases and parasite infections are common in coastal systems with high levels of chemical and sewage contamination (Kennish 1997). Suppression of immune system responses from exposure to contaminants has been demonstrated experimentally in both invertebrates and fish and is supported by evidence from field-collected animals (Arkoosh et al. 1998, 1999; Dyrynda et al. 1998). This decreased immune response can lead to increased disease occurrence and severity (Arkoosh et al. 1998; Fisher et al. 1999; Anderson et al., 1995; Chu 1996).

The CBP has identified three regions of concern (areas where chemical contaminants "probably" affect living resources): the Patapsco (including Baltimore Harbor), Anacostia, and Elizabeth rivers (CBP 1999). In addition, the CBP (1999) has also distinguished ten areas of emphasis in which data indicate a "significant potential" for contaminant-related problems. The areas of concern are the Middle, Back, Magothy, Severn, upper and middle Patuxent, upper and middle Potomac, Chester, and lower James rivers. These regions compare with eight areas classified with a low probability for adverse effects and 20 areas with insufficient or inconclusive data.

Some sediments in Baltimore Harbor are heavily contaminated by several organic and inorganic chemicals toxic to some fish, bivalves, and crustaceans (MDE 1996). Parts of the Anacostia River have also shown sediment toxicity (DC Environmental Regulation Administration 1996). In the Elizabeth River, both water and sediment exposure can cause pathology in fish and invertebrates (Elizabeth River Project 1996). Some areas in the tidal reaches of the Bay have contaminant concentrations that may result in chronic sublethal effects due to subtle alterations in the food web (Breitburg et al. 1999).

The accumulation of toxic chemicals in fish and shellfish also poses a serious human health concern. Large individuals of some fish species contain mercury concentrations (Gilmour and Riedel 2000) that trigger health advisories. Oysters from parts of the Patuxent River have substantially elevated levels of copper, silver, and cadmium. The NOAA National Status and Trends program found these levels average an order of magnitude higher than levels elsewhere in the U.S. (Riedel et al. 1998). The Indicators of Ecosystem Health Element of this book deals with the effects of contaminants on fisheries and human health .

Dynamic Water Column Habitats

Most of the discussion of habitat above focuses on benthic habitats and water quality issues. The pelagic portion of the water column, however, comprises most of the habitat used by finfish and larval stages of benthic invertebrates within the Chesapeake. Several physical, chemical, and biological factors affect the value of this habitat for feeding, growth, and reproduction. These factors, in turn, are influenced by climate, as well as by management decisions controlling land use, dams, and stream channelization.

Although water, as a medium, appears uniform to the eye, the pelagic realm varies both vertically and laterally causing spatial differences in utilization and production. For example, light penetration is influenced by nutrient and sediment loads and can affect prey production, feeding success, and behaviors. Turbulence is influenced by flow rates, wind, and bottom topography and can affect feeding success of fish larvae (Mackenzie et al. 1996; Dower et al. 1997). Salinity is a major factor affecting the distribution of individual species, the species composition and diversity of assemblages, physiological rate processes, and the intensity and prevalence of pathogens. Land use, water use, water management, and rainfall all affect salinity. The location of particular salinity zones, and the salinity at any given spot, varies within short-scale (e.g., daily) periods, seasonally, and yearly. Light, turbulence, and salinity all vary vertically and laterally within the Bay and its tributaries.

Physically defined features of the water column—estuarine turbidity maximum regions, fronts, and pycnoclines—may constitute important sites of high production or abundance. North and Houde (2001), for example, found that 91% of striped bass and 67% of white perch post-yolk-sac larvae in upper Chesapeake Bay occurred within 10 km of maximum turbidity readings in 1999. The estuarine turbidity maximum also functions as an entrapment zone for zooplankton prey of fish larvae (Roman et al. 2001). Salt fronts may physically bar downstream transport of eggs and larvae (Secor and Houde 1995). Also, a persistent cyclonic gyre evident in the lower Chesapeake Bay may retain larval anchovy or attract feeding adults (Hood et al. 1999; Rilling and Houde 1999).

The location and importance of pelagic habitats and habitat features form important factors in the management of Chesapeake Bay fisheries. The dynamic nature of the pelagic realm, however, may require management strategies and tools different from those used for spatially fixed benthic habitats. Analogous to delineation of 100-year floodplains, GIS mapping and restrictions may need to be based on the 10-, 20-, or 50-year boundaries of features such as salinity-delineated spawning habitats or estuarine turbidity maximum larval habitat. Fishing restrictions that limit take from "source" habitats should consider protection of high-production pelagic locations to preserve or enhance baywide populations. Physical features of the water column should be considered in the siting and size of MPAs.

Habitat avoided is habitat functionally lost to the system.

Considering the Aquatic Landscape

The field of landscape ecology offers important lessons when expanding the perspective from fished populations to fisheries ecosystems. Not only do particular habitat types play an important role in sustaining and restoring the resilience of ecosystems and exploited populations, but so also do habitat diversity, complexity, and spatial organization. These features can affect the function and value of fish habitat. Characteristics of aquatic habitats, as well as spatial organization and complexity of the landscape, can influence the health and functioning of ecological systems. Structural complexity is critical to ecosystem function as it imparts resistance to and resilience from disturbance (Christensen et al. 1996). Structurally complex habitats generally support greater numbers of species than do structurally simple habitats (Noss and Csuti 1997).

The surrounding landscape also strongly shapes the function of any particular location or habitat in an aquatic system (Christensen et al. 1996; Micheli and Peterson 1999; Peterson and Estes 2001). The size and arrangement of habitat patches, topographic irregularity, and ratio of edge to interior of habitat patches all contribute to the complexity of the estuarine landscape. These features can influence the movement of animals among habitats, and the value of habitats for feeding, shelter from predators, and refuges from physical disturbance. The degree of isolation or connectedness of habitat patches can be especially important to predator-prey interactions, influencing densities and species composition of key animals (Peterson and Estes 2001). In addition, habitat structure may alter the efficacy of parasite transmission by affecting the parasite itself, or by shaping the distribution or dispersion of hosts (Sousa and Grosholz 1991).

The maintenance and restoration of habitat complexity in Chesapeake Bay should be a high-priority management strategy to benefit ecosystem health, while promoting and sustaining fisheries productivity. Prioritization and siting criteria for habitat protection and restoration, along with species' habitat requirements in FMPs, should account for factors such as the importance of connections among habitats, structural complexity, arrangement of habitats within the landscape, and temporal change.

Connections among Habitats

The physical proximity of habitats affects their use in several ways. First, the presence of degraded habitat can render adjacent habitat less useful. For example, hypoxic water overlying otherwise suitable sediment can make soft-bottom benthic habitat unsuitable for species sensitive to low dissolved oxygen. Second, a habitat can improve the health and stability of adjacent habitats. For example, intertidal oyster reefs can reduce erosion of adjacent salt marsh habitat (Meyer et al. 1997). Third, physical proximity of habitats can strongly influence predator–prey interactions by creating refuges from predation and the effects of disturbance by providing migration corridors for animals. For example, vegetated underwater corridors may reduce predation by birds, allowing blue crabs to move freely among habitat patches, thereby influencing the spatial pattern of their predation on clams (Micheli and Peterson 1999; Micheli 1997). Similarly, oyster reef habitat extending to nearshore waters provides an emigration route for benthic fish to escape deepwater habitat with severely hypoxic bottom waters (Breitburg 1992).

Structural Complexity in Habitats

The sections on oyster reefs and SAV discuss the high diversity and abundance of harvested species and members of their significant food web in complex biogenic habitats. Even within these habitats, however, factors that increase topographic or spatial complexity may increase habitat value. Vertical relief in oyster reefs creates low-flow refuges for fish larvae (Breitburg et al. 1995), feeding sites for juvenile striped bass (Breitburg 1999), and refuges for fish and crabs from bottom-layer hypoxia (Lenihan 2001). Similarly, seasonal increased habitat complexity in SAV beds, manifested by increased shoot density, creates highly fragmented habitat that increases survival of juvenile blue crab (Hovel and Lipcius 2002).

Habitats within the Landscape

On a large spatial scale, habitat arrangement within the landscape can influence both managed species and the health of other Bay habitats. For example, patch size and the distance between patches of habitat may affect the migration routes of highly mobile Bay species. Oyster reef location can affect the water quality of downstream areas. The importance of such large-scale landscape patterns within the Bay and its tributaries has generally not been evaluated

Temporal Change

Ecosystems, including the arrangement and configuration of their habitats, are dynamic. Habitat structure can change with succession in response to the presence or absence of physical disturbances, such as storms and organism activity. Management that attempts to maintain unchanging functions and configurations of ecological systems is likely to be both futile and ineffective (Christensen et al. 1996).

Evaluating Habitat Requirements and Value

Managing for Optimal Habitat

Limits to physiological tolerances and absolute habitat requirements of biota have frequently been used to set criteria for habitat management. Measures such as LC50s or more conservative LC5s (i.e., the concentration at which 50 [LC_{50}] or 5 [LC_5] % of animals die within a specified time-exposure period) are useful because they provide clear and defensible guidelines for criteria setting. Growing evidence suggests, however, that mobile animals not only avoid habitat based on detectable mortality risk, but also avoid habitat based on levels of chronic, sublethal stress (Figure 5).

Habitat avoided is habitat functionally lost to the system. The behavioral responses of animals can provide clear guidelines on habitat suitability that ultimately may prove more useful for species protective than tolerance data. Behavioral responses, however, depend upon perceived options available to an organism. Severely degraded habitat can lead to sublethal effects (e.g., reduced growth or compromised immune responses) or mortality in the absence of such options. The utilization of such suboptimal habitats, and the effect of these habitats on managed species, may depend on the extent and severity of habitat degradation. If optimal habitat remains scarce, species may use the suboptimal alternatives more readily regardless of consequences to growth and long-term survival (Eby 2001).

Tools for Assessing Habitat Value

Habitat Suitability Models

These models predict the relative or absolute suitability of habitats for the growth, survival, and reproduction of species and are based on the match between factors (such as a species' habitat preferences, physiological tolerances, and bioenergetics traits) and characteristics of the habitats, themselves. Researchers use two general types of habitat suitability models. The first—habitat suitability index (HSI) models—typically use field and laboratory data, combined with statistical models, to evaluate and rank the relative suitability of habitats for particular species, species groups, or biological processes of interest (e.g., Rubec et al. 1998; Vadas and Orth 2001). The second general type—including growth potential models (e.g., Brandt and Kirsch 1993; Demers et al. 2000), other bioenergetics models (e.g., Niklitschek 2001), and individual-based models (e.g. Rose et al. 1999; Breitburg et al. 1999)—use simulation modeling to predict growth, survival, and other biological processes in habitats with specific characteristics. The spatial detail of both model types can vary from qualitative comparisons of two habitat types to sophisticated maps identifying predicted distributions and growth rates within a fine-scale, three-dimensional, spatial grid. Mapping can utilize

1) Programming tailored to specific applications (Tyler 1998);
2) Commercial packages such as the ArcView Spatial Analyst module (Rubec et al. 1998); or
3) Programs designed specifically for habitat suitability index development that combine analytical and GIS capabilities (e.g., Valutazione della Vocazionalita Faunistica: Habitat Suitability Assessment, Ranci Ortigosa et al. 2000). Habitat suitability models developed by the Department of Interior and NOAA now exist in user-friendly software format on the web (http://webmesc.mesc.nbs.gov/hsi/hsi.html).

Useful applications of habitat suitability modeling in the Bay watershed include

1) Habitat suitability indices for stream fish in the Roanoke River (Vadas and Orth 2001);
2) Growth potential models for striped bass (Brandt and Kirsch 1993), bay anchovy (Luo and Brandt 1993), and Atlantic menhaden *Brevoortia tyrannus* (Luo et al. 2001);
3) Bioenergetics models predicting the effects of temperature and dissolved oxygen on the growth of Atlantic and shortnose sturgeons *Acipenser oxyrinchus* and *A. brevirostrum* (Niklitschek 2001); and
4) Individual-based models used to examine bay anchovy population dynamics (Wang et al. 1997; Rose et al. 1999, Cowan et al. 1999), as well as the effect of low dissolved oxygen on the predation mortality of estuarine fish larvae (Breitburg et al. 1999).

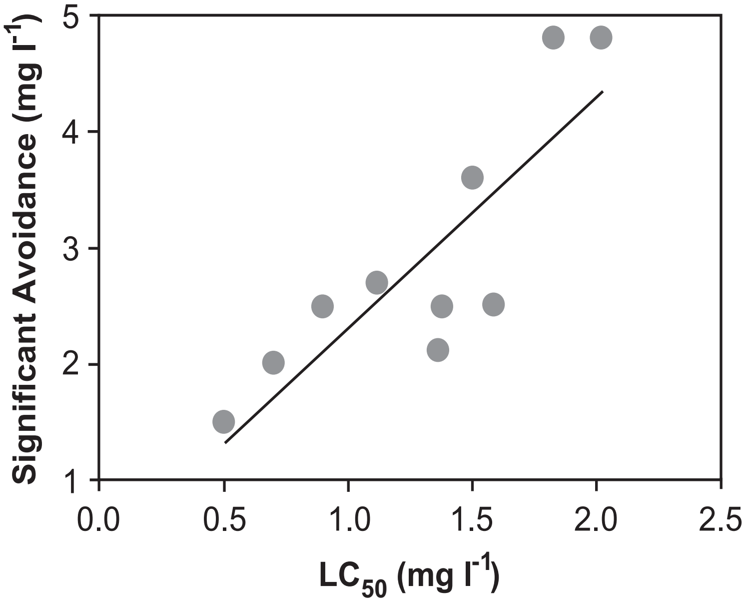

Figure 5. Relationship between lethal dissolved oxygen concentrations and those avoided by marine and estuarine fishes. Dissolved oxygen concentrations avoided are about twice the level of those that result in mortality (adapted from Breitburg 2002).

Linking Habitat Requirements, Locations, and Characteristics.

Habitat suitability maps, combined with additional habitat and biological data, can produce a GIS-based Spatial Decision Support System (SDSS) (Rubec et al. 1998). Such a system may allow managers to identify habitats with the potential to support high growth and reproduction of key species—species managed for fisheries, their important prey, and those important as keystone species or ecological engineers within the ecosystem. Such a system could also identify the location of sensitive habitats. Incorporating model results, biological and habitat data, and citations into a relational database can provide better access to information and a means to link environmental information with fisheries data (Rubec et al. 1998), facilitating incorporation of habitat information in FMPs and promoting sound habitat management in Chesapeake Bay.

Usefulness of Approach.

The advantage of HSI and other models is their ability to calculate species distributions in areas without extensive field sampling and predict fisheries management parameters (such as growth rates) that are difficult to match with habitat characteristics from field data on highly mobile species. The validity and usefulness of such models, as with all modeling efforts, greatly depend on the quality and detail of data available to parameterize models. Such models assume fixed relationships among biological and physical parameters, however, and do not allow novel shifts in behavioral responses with habitat change. To remain useful as management tools, suitability models and indices will require frequent updates to include changes in the Bay landscape, water quality, climate, and biota. Additionally, most current techniques do not generate reliability bounds, influencing their use in priority setting and management decisions. If Bay management agencies embark on an extensive program of habitat suitability modeling, widespread use of such a program could be greatly enhanced by standardized, readily available, accessible programs for use by the research and management communities. This, along with a graphical interface that allows researchers and managers to develop habitat suitability models for additional species, makes it easy to modify existing habitat suitability models with new information.

All approaches for evaluating habitat value have strengths and weaknesses. The benefits of statistical, analytical, simulation, and conceptual approaches vary with the specific questions asked and the richness of information available to answer the questions. Field data, experimental data, and model results jointly can produce habitat characteristics yielding highest growth and reproduction, habitat types and locations with the highest historical yields, and behaviorally favored habitat characteristics, for use in goal and criteria setting for habitat restoration. A range of approaches allows full exploration of the issues critical to incorporate habitat value into fisheries and habitat management.

Habitat Restoration, Habitat Protection, and Spatial Management

Two aspects of habitat management are important in promoting sustainable fisheries. The first—protection and restoration of habitat important to fisheries species and the ecosystem that sustains them—formed the focus of much of this chapter. The second aspect, mentioned briefly above, is the use of spatially defined management units to protect all or part of the fisheries system within the boundaries of these units.

Habitat restoration, habitat protection, and spatial management should all play important roles in the management of fisheries in the Chesapeake Bay and its tributaries. The long list of habitat areas and issues of special concern highlight the potential role that restoration and protection can play in providing an ecosystem environment for managed species that supports healthy, sustainable populations. In the face of multiple stressors affecting both the aquatic environment and the managed species, predicting the exact consequence of a single negative action or protective measure may prove difficult. The best chance of ecosystem-based fisheries management, therefore, may lie with a precautionary approach that combines conservative estimates of sustainable harvests (see Total Removals Element) with strong measures for habitat restoration, protection, and spatial management.

Habitat restoration—including reductions in nutrient loading that could lead to improved bottom-layer dissolved oxygen and reestablishment of SAV—forms a cornerstone of the CBP agreements. The current Bay agreement also calls for a 10-fold increase in oyster reef habitat. Progress in increasing the extent or quality of Bay habitats, however, remains minor relative to that needed to turn the clock back a half-century. Clearly, additional effort is needed to restore the health and spatial extent of Bay habitats used by managed species and members of their significant food web.

Spatial Management Strategies

Increased attention to spatial management, including greater emphasis on establishing protected areas, may help restore the health and sustainability of Bay fisheries. Closed areas, no-take zones, and other spatial restrictions on fishing or exploitative use are not new to the Bay. But, their use is relatively limited in the suite of management options that recognize the importance of habitat in sustaining marine and estuarine fisheries. Marine protected areas represent a hierarchy of spatial management measures—from wilderness areas (where no removals are allowed and no impact on habitat is tolerated) to areas with only minor restrictions on use. Three recent studies have concluded that MPAs, including marine reserves (no-take zones), have a role in management of U.S. coastal fisheries, especially if combined with conventional management approaches (NMFS

1999; NRC 1999, 2001). Such areas can be included effectively in an ecosystem-based approach to fisheries management in Chesapeake Bay that will promote overall goals of sustainability and habitat protection and restoration.

A major and valid reason to implement MPAs is to hedge against the uncertainties of science and management in temporally variable and spatially complex ecosystems. Properly designed MPAs can

1) Protect key communities and populations,
2) Preserve or restore important habitats,
3) Shield unique features of ecosystems from fishing effects,
4) Protect the nursery function of specified habitats,
5) Increase the spawning potential of protected organisms,
6) Reduce or eliminate bycatch,
7) Safeguard threatened or endangered species, and
8) Promote education and science (NRC 2001).

Economic costs to traditional users of fishery resources, however, may result from initial designation of MPAs. Evidence suggests that MPAs lead to increased abundance and greater sizes of protected species within the boundaries of reserves; the benefits to surrounding areas are less certain without understanding of dispersal or migration patterns of key organisms in a protected community. Some cases have documented the export of benefits to surrounding regions, including estuarine fisheries in Florida (Roberts et al. 2001).

Design Issues

Planning and design considerations are critical for successful implementation of MPAs. All interested parties (i.e., stakeholders and the fishing community) must become involved in all stages of the planning and designation process. In Chesapeake Bay, properly designed MPAs have the potential to protect habitats associated with nursery functions for important fisheries such as blue crab (e.g., SAV beds), and other habitats that increase productivity and provide wide-ranging benefits to demersal communities (e.g., oyster reefs). In a few cases, MPAs already have been implemented or are being tested in Chesapeake Bay, such as the blue crab migration corridors (Seitz et al. 2001, Lipcius et al. 2003) and the seasonal closures that protect spawning by anadromous fishes (e.g., striped bass FMPs). Expanded spatial approaches for Bay fisheries management will require careful planning and consideration of siting (location and size), zoning, networking, enforcement, and monitoring and evaluation needs.

Spatial management using MPAs can protect biological communities, thus promoting the multispecies management goals of the CBP (CBP 2000). With the exception of blue crab and oyster reef sanctuaries, no formal plans currently exist to develop or add MPAs to the suite of conventional management tools for management agencies in the Bay region. Goals and objectives for MPAs must be clearly specified and potential sites identified, while considering zoned use to alleviate conflicts and spatially partition acceptable habitat uses. The potential to develop networks of complementary MPA sites in the Bay that increase prospects for success should also be evaluated. All stakeholders must become involved in the design process; otherwise, MPAs may not receive broad support. A realistic view of the probable benefits and costs in the short and long terms should be adopted.

Performance Issues

The performance of MPAs depends on the particular migration and dispersal behaviors of organisms at each relevant life stage (Fogarty et al. 2000). In a fisheries context, MPA designations usually anticipate that benefits will be exported from the protected zone to a wider surrounding area (Figure 6). Researchers should evaluate this expectation through reviews, experiments, and modeling during the design phase. Expectations for performance may differ for single-species protection compared to multispecies or community protection. Monitoring and regular performance evaluations are required if MPAs are adopted as a major part of a Chesapeake Bay management regime. Socioeconomic data must document the costs and benefits. Mechanisms that allow changes in MPA policies and designations if performance does not meet expectations must be in place. The enforcement of boundaries and MPA regulations can help make a spatial management approach more effective.

Chesapeake Bay

Several examples in the Bay illustrate protected areas and their spatial emphasis on management with some representing a component of conventional management. The best example is the closure of spawning tributaries to fishing during the striped bass spawning season. The recent designation of migration corridors to protect pre-spawning blue crabs in Virginia Bay waters provides another example (Seitz et al. 2001; Lipcius et al. 2003). Newly constructed oyster reefs closed to fishing in Virginia and Maryland waters are being evaluated for their potential enhancement of reef community productivity and biodiversity.

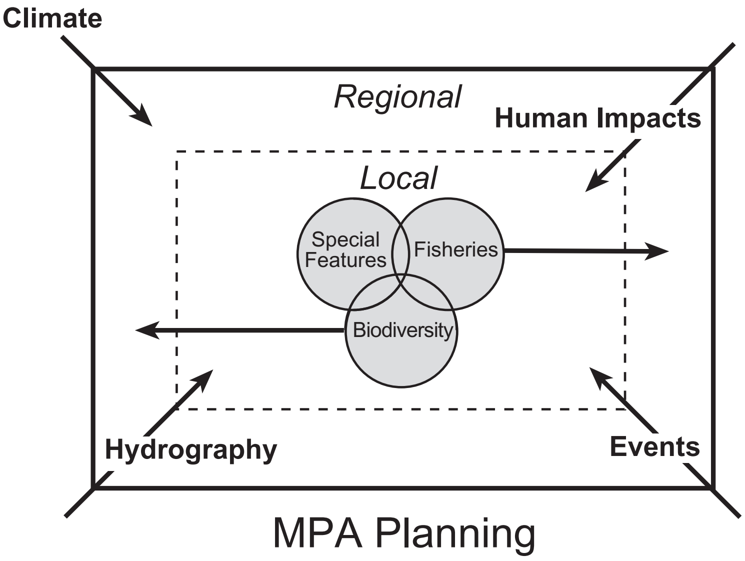

Figure 6. Issues for consideration in designing and planning marine protected areas (MPAs). In most cases, benefits to fisheries from MPAs are presumed to accrue from export of early life stages or recruited stages to regional or broader areas outside the MPA boundaries. Here, “events” are natural environment events (e.g., storms). Human impacts include contaminants, introduction of invasive species, or alteration or destruction of habitats.

Areas in the Bay have been designated as National Estuarine Research Reserves (NERRs). Although most of these areas occur in wetlands and small subestuaries, they do protect habitat, promote research, and educate the public. A significant fraction of the Chesapeake Bay shoreline and its waters have been protected historically from fishing through restricted civilian access to military bases and property. In effect, these areas function as MPAs, although their contribution to Bay fisheries productivity and protection remains unevaluated.

MPA Benefits

Chesapeake Bay MPAs can make an important contribution to ecosystem-based fisheries management. These areas balance agency-specific problem solving in single-species fisheries with broader habitat-sensitive approaches that conserve the structure and function of a fisheries ecosystem. The MPA approach recognizes the spatial heterogeneity of habitats and, importantly, the need for management that values such heterogeneity (Houde and Roberts 2004). In this sense, MPAs appear quite compatible with broad CBP goals for habitat protection and water quality. Nevertheless, MPA-based management should be instituted only when it can support the overall goals of long-term sustainability and continued economic benefits from Bay fisheries. Additional benefits, such as increased biodiversity, provide the impetus to consider MPAs in a balanced, ecosystem-based approach for managing the Bay and its resources.

Major Findings

Habitat is the medium within which individual species interact with the Bay ecosystem. The abundance, spatial arrangement, and quality of habitats influence encounter rates between predators and prey, the availability of refuges from predation, growth rates, incidence of disease, and a host of other processes related to the sustainable yield of fished populations. The kinds of habitat and locations determine which species within the Bay interact directly, and which influence each other only through their indirect effects on other species or habitats.

Many managed species within the Bay ecosystem and some of their important prey also depend on habitats in other ecosystems because they spend some of their life cycle outside Bay waters. Many use both freshwater and coastal habitats during their lives.

The activities of fished species and members of their significant food web create important linkages among habitats within the Chesapeake ecosystem. Fished species and their prey

1) Influence the transfer of carbon and nutrients from the plankton to the benthos,
2) Redistribute nitrogen among benthic or water column sites by feeding in one location and releasing waste in another, and
3) Utilize a range of habitats during

development and seasonal migrations.

Linkages among habitats suggest that a holistic, ecosystem-wide approach to habitat management, rather than a habitat-by-habitat or site-by-site approach, is needed for successful management of many Chesapeake fisheries. Restoring and protecting SAV, oyster reefs, anadromous fish spawning areas, and overall water quality in the Bay, and in the freshwater and coastal ecosystems that support some life stages, must simultaneously occur as part of a Bay strategy supporting an FEP.

Panel Recommendations

Management

1) Adopt regional Essential Fish Habitat regulations that apply to state waters as part of the preparation and revision of Chesapeake Bay fishery management plans (FMPs) for species not covered by federal management plans.

Regional EFH regulations should require habitat assessments and prevention of habitat damage (not simple consultation on potential damage) by state and local government agencies as well as recipients of state and local government funds. Regulations should also include ecosystem-level considerations, such as essential habitat of prey species and habitat characteristics that influence the suitability and function of other habitats and the Bay ecosystem as a whole.

2) Prevent further habitat degradation, including loss of habitat from the cumulative effects of small projects, by adopting a “no-net loss” policy.

This policy would apply to projects with impacts that are too small in scale or severity to assess individual impact on managed populations or their important prey. It would also prohibit setting criteria for acceptable habitat quality that allows degradation of habitats in ways that reduce their value for fish. Mitigation should take place within the same salinity zone and watershed and, in most cases, apply to the same habitats as those negatively affected.

3) Include descriptions and evaluations in FMPs detailing the need for protection and restoration of essential habitat for all life stages of managed species, their important prey, and the structural species on which they depend.

Consider habitat diversity, complexity, and spatial organization that affect habitat value as well as the importance and consequences of temporal variability and dynamics in formulating management practices and policy for fisheries in Chesapeake Bay. Clearly define the Habitat Areas of Particular Concern for each managed fishery in the Bay.

4) Improve coordination among agencies responsible for fisheries and habitat management.

Develop mechanisms by which new habitat requirements information automatically triggers examination and possible revision of habitat management and criteria. Agencies responsible for fisheries management must automatically evaluate actions that may degrade habitat. Improve interagency coordination (as well as identification of habitat uses and requirements) of managed species and their prey through a data management system and protocol that explicitly link biological data, physical data, and habitat management.

5) Evaluate use of MPAs in ecosystem-based fisheries management in the Bay.

An evaluation should include: development of a prioritized list (with justifications) of fisheries and habitats that could benefit from MPAs; development of a strategy and long-term plan for design and implementation of MPAs that supplement conventional fisheries management; and identification of long- and short-term research needs for MPA design and implementation.

6) Adopt a precautionary approach to habitat management.

A precautionary approach encourages managers to designate fish habitat as essential when faced with scientific uncertainty (Schmitten 1999) and to shift the burden of proof from establishing the importance of a particular habitat to providing solid evidence that a particular habitat is unimportant (Dayton et al. 1998). Historical baselines and trajectories should form fundamental components of a precautionary approach to goal setting, management, and restoration of Bay habitats and their associated fisheries.

7) Couple evaluation with habitat management strategies and habitat restoration activities.

Evaluate the effectiveness and consequences of actions and policies from both economic and management standpoints. Evaluations that compare alternative approaches, restored and control sites, and trends before and after management actions can modify management and restoration efforts, increasing their effectiveness and reducing expenditures on ineffective strategies.

8) When possible, use historical baselines to define goals for the restoration and maintenance of habitat extent, health, and distribution.

Anthropogenic influences have drastically altered the Bay; some of these changes are irreversible. Use field data, historical accounts, and scientific judgment jointly to develop habitat descriptions as they likely existed prior to human alteration. Reduce and reverse the negative effects of habitat loss and modification of fish habitat. By using baseline conditions, desired trajectories for change (e.g., more oyster reefs, less severe oxygen depletion) can be established even where a complete return to a non-impacted system is not achievable.

Needed Research and Development

9) Improve understanding of the multiple pathways by which habitat degradation and restoration can affect managed species and members of their significant food web.

Estuarine ecosystems are characterized

by complex food webs and landscapes composed of a variety of habitat types, sizes, and configurations. Any action that potentially degrades habitat is likely to have multiple pathways by which it can affect managed species. Multiple models, data sources, and analytical tools to understand and predict linkages among habitat, food webs, and fisheries production are important for effective management (see Food Web Element).

10) Improve understanding of how multiple stressors—some of which affect habitat—influence managed species and members of their significant food web.

As the number and severity of stressors increase, the potential for serious cumulative and interactive effects also increases. Simultaneous actions of multiple stressors that degrade habitat quality can make identifying the actual causes of population decline more difficult and can reduce the efficacy of restoration. Harvest-habitat interactions are of particular concern.

11) Enhance the ability to predict and distinguish habitat avoidance from other measurable endpoints, such as reductions in growth and survival.

Avoidance of unsuitable or stressful habitat results in decreasing species richness. Avoided habitat also represents a loss to the potential for sustainable Chesapeake Bay fisheries.

12) Determine how the spatial arrangement of habitats influences their value to managed species and members of their significant food web.

Both the size and location of habitats that support living resources are important to support production and recruitment to fisheries as well as their interactions with key prey and predator species. The spatial arrangement of habitats, presence of corridors, and connectivity among habitats remain important research issues.

13) Develop an MPA strategy and long-term plan for the design and implementation of MPAs that can supplement conventional fisheries management.

Closed areas and restricted access are not new to fisheries management in the Bay. This tool can be applied more extensively, however, for the benefit of some fisheries and the habitats that support them. Both field tests and modeling approaches are recommended to learn how emphasis on spatial management through MPAs can benefit Bay fisheries.

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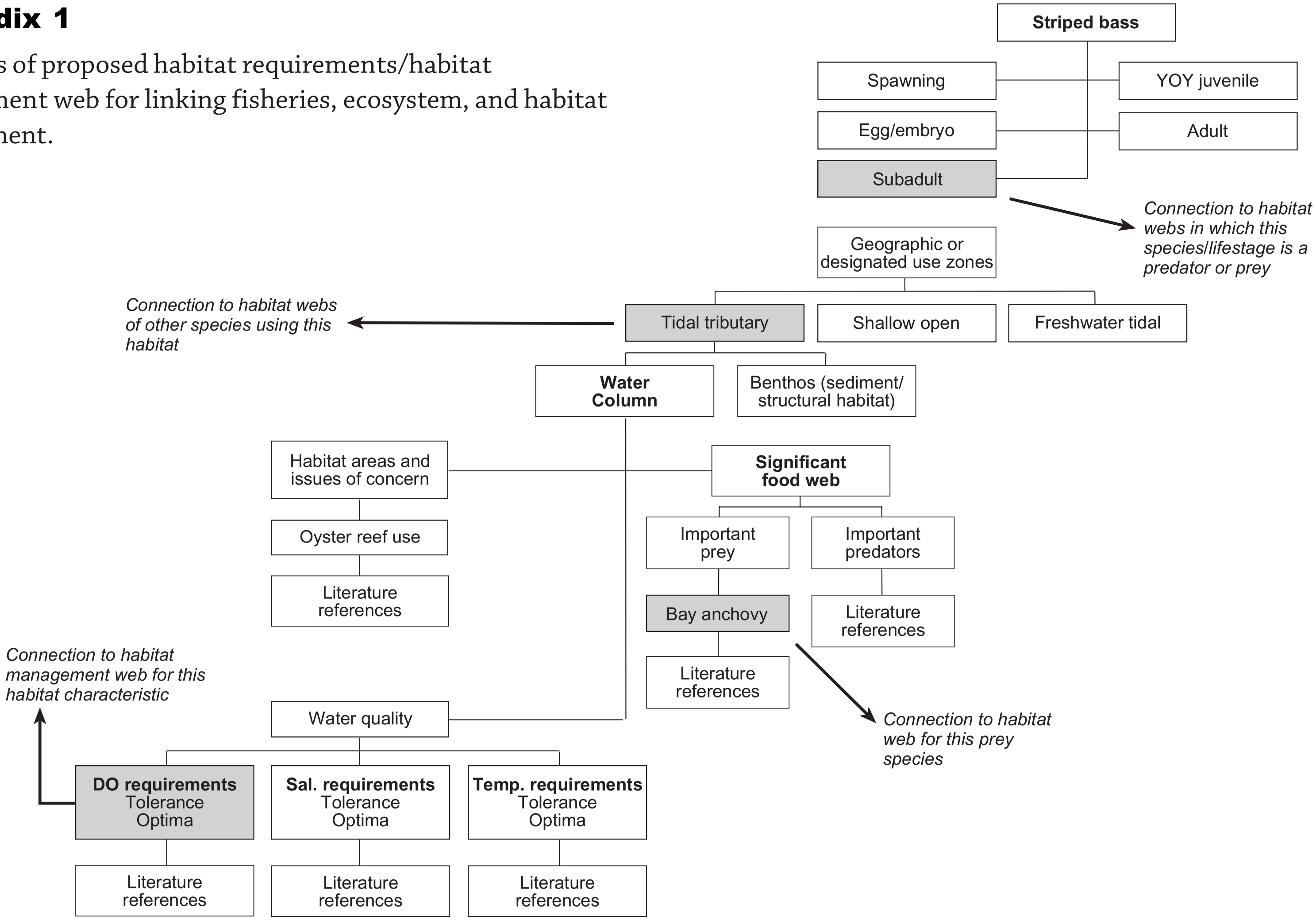
Appendix 1

Examples of proposed habitat requirements/habitat management web for linking fisheries, ecosystem, and habitat management.



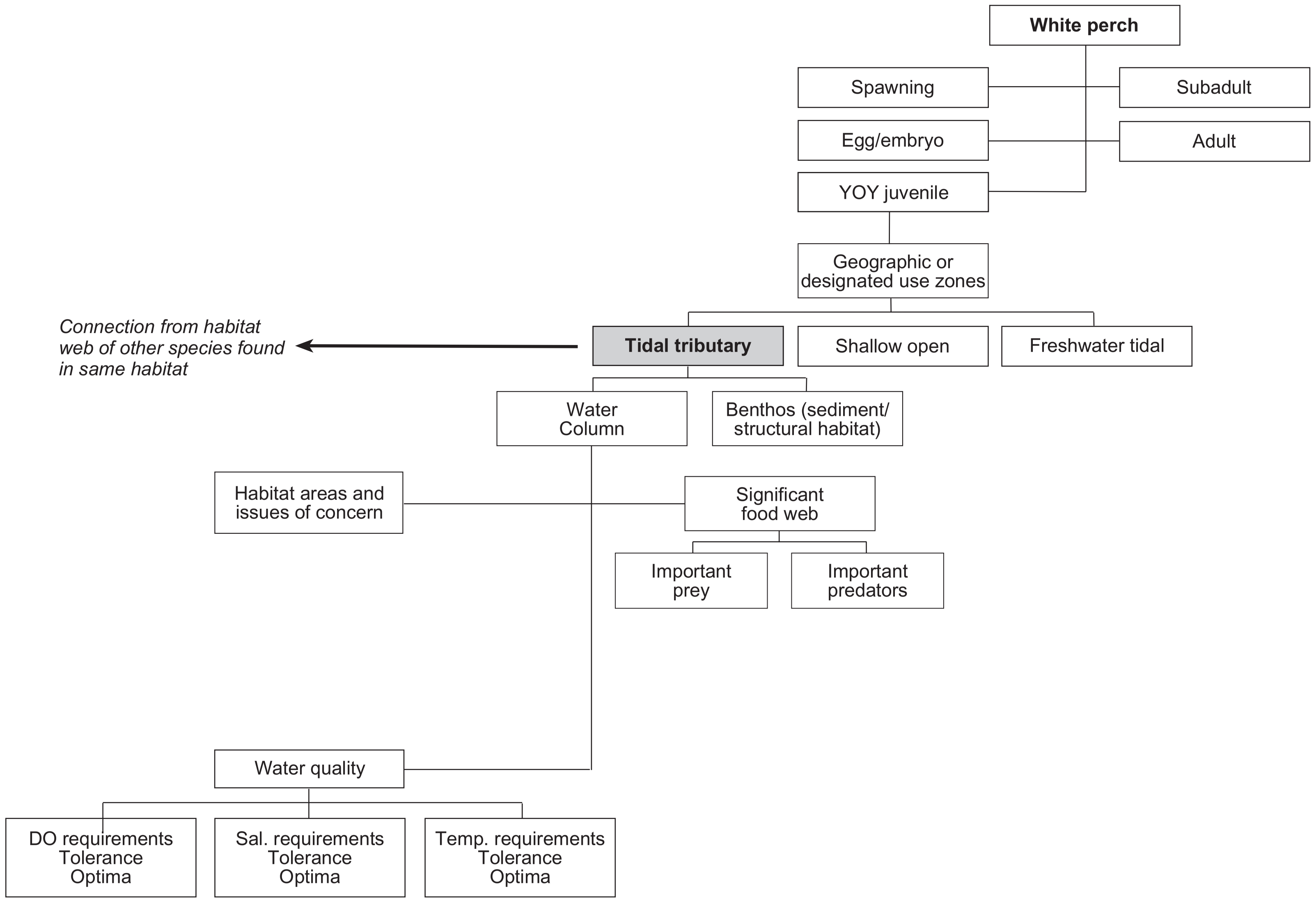
Connection to habitat webs in which this species/lifestage is a predator or prey

Connection to habitat webs of other species using this habitat

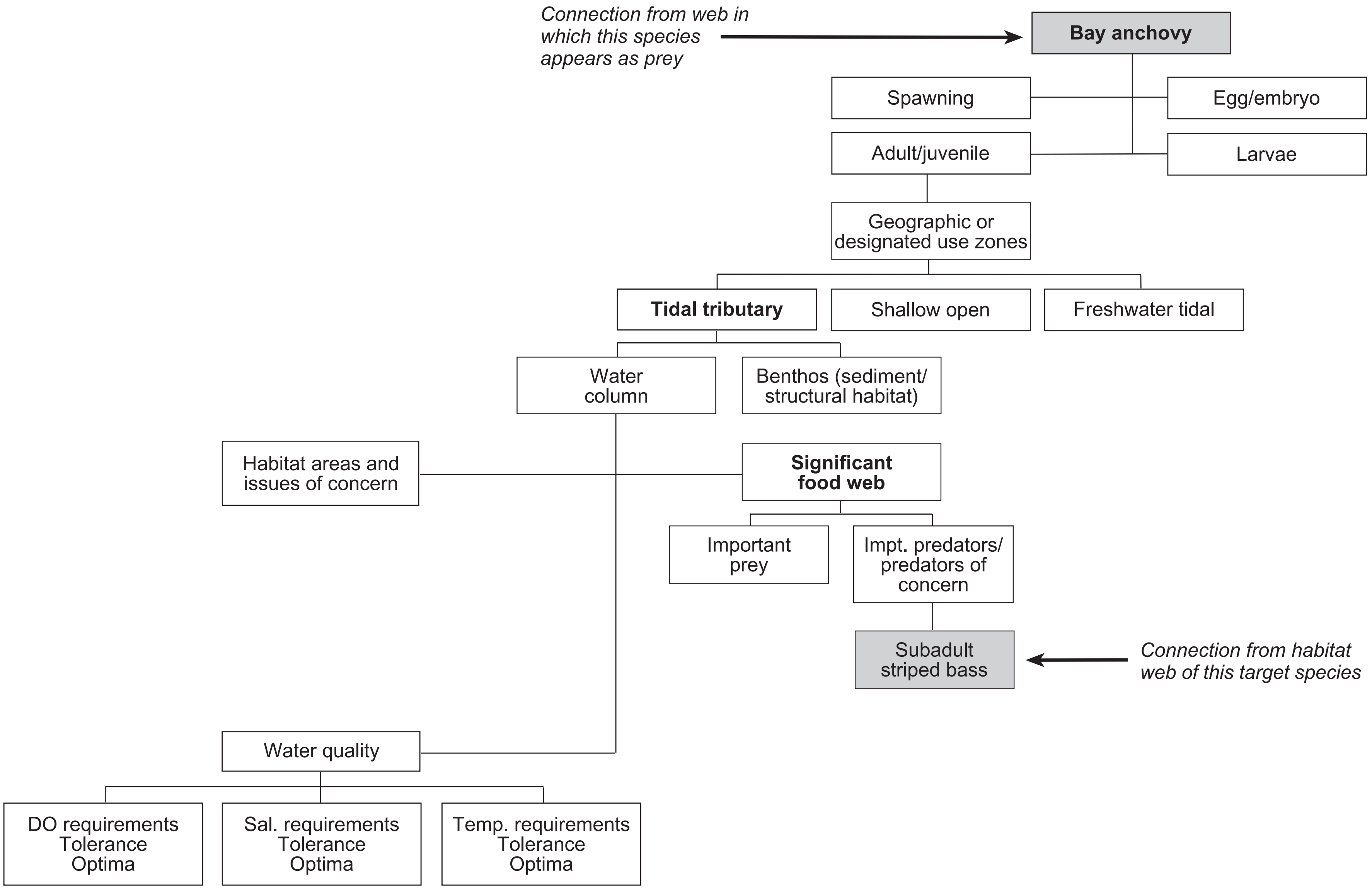
Connection to habitat web for this prey species

Connection to habitat management web for this habitat characteristic

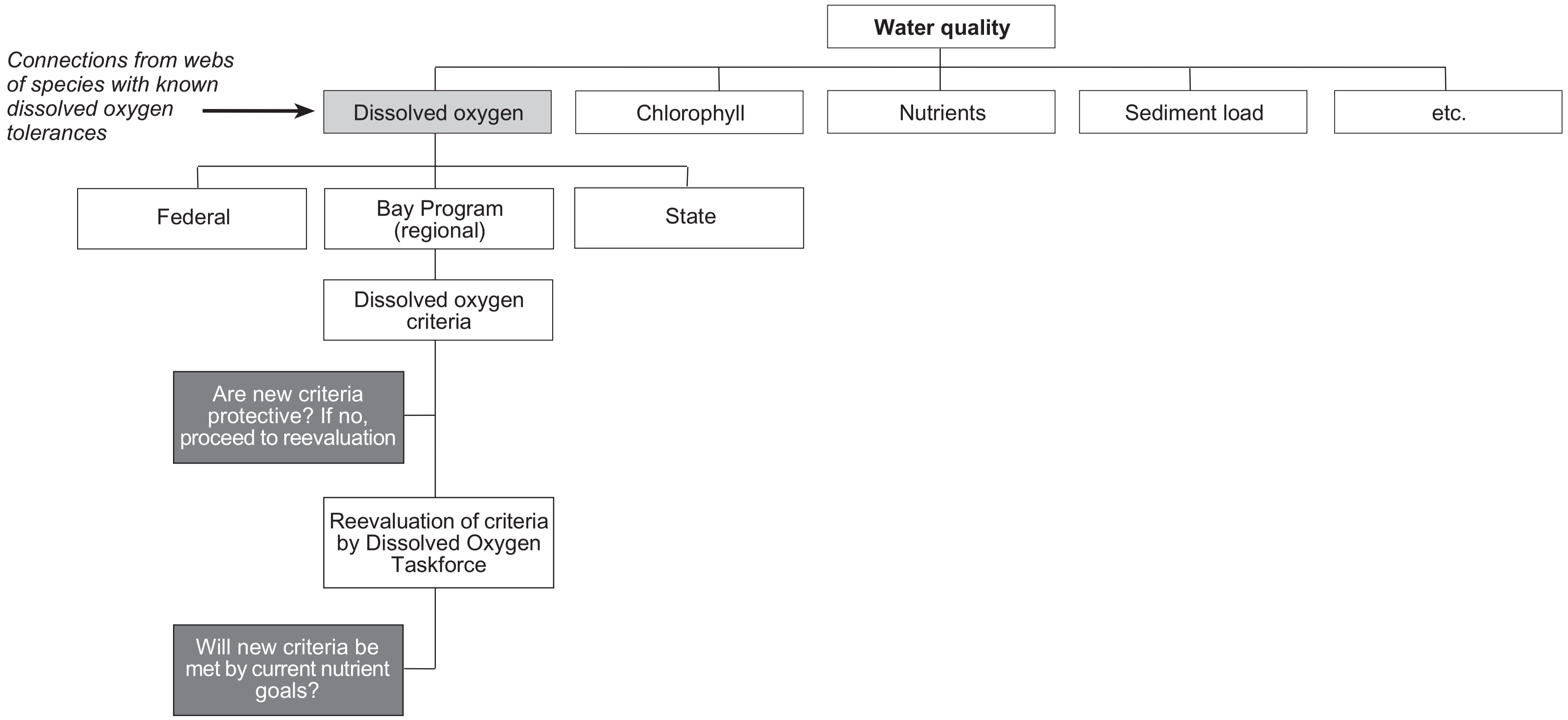
Habitat Web 1: Habitat use and requirements of all life stages of a managed species. Habitat webs could be constructed for each managed species to summarize habitat use and tolerances for each life stage. This example shows information available on water column use within tridal tributaries by subadult striped bass. Important life history events could be mapped separately from other adult acitivities. Highlighted boxes indicate links to other layers of the habitat requirement/habitat management web example on the following pages. In a computer version, a user could click on boxes to access species using the same habitat or sharing similar tolerances, habitat information for predators and prey, and details on management of the habitat. Fisheries managers would update this layer, as well as habitat webs of important predators and prey, during the FMP process and as new information arises.



Habitat Web 2: Connections to habitat webs of other target species (e.g., white perch) that use tidal tributaries. Link is through the highlighted box in the diagram. If link was made through the "dissolved oxygen" requirements box, one could identify species with similar, higher, or lower tolerances to dissolved oxygen that use tidal tributaries.



Habitat Web 3: Connection to habitat web of important prey species (bay anchovy). Connection can be made through either of the highlighted boxes. By inputting and expanding information on other bay anchovy predators in tidal tributaries, one could identify species potentially competing with subadult striped bass for bay anchovy prey.



Habitat management web: As information is updated in the habitat webs of managed species and their significant prey, tolerances and other habitat requirements would be compared to criteria and goals in the management web. In this example, a link is indicated between dissolved oxygen requirements of subadult striped bass and dissolved oxygen criteria adopted through the CBP. If existing criteria were not protective, this process would trigger an automatic reevaluation to determine whether updated dissolved oxygen goals could be achieved under current nutrient reduction targets. If not, nutrient reduction goals would be reevaluated as well. Ideally, review and action by federal and state agencies with regulatory control affecting dissolved oxygen would also be triggered. Expert opinion and cooperation among agencies with regulatory control affecting dissolved oxygen would determine whether a reevaluation would be immediate or at a previously determined time. Links would be made between management webs and habitat webs of both managed species and their important prey.

Patterns of Total Removals

Introduction

Fisheries ecosystems have limits to their production. Over the years, many cases have documented the overharvesting of species that has led to declines in their fisheries (Smith 1994; Myers et al. 1997; Reynolds et al. 2002). The undesirable impacts brought about by overharvesting some species may not be reversible or may require extended recovery time (Hutchings 2000). Defining the limits of single-species exploitation is not simple given the statistical variability in data, biological variability in populations, and economic variability of seafood markets. Researchers can use both empirical and theoretical approaches, however, to determine safe landings limits (Quinn and Deriso 1999). The blue crab *Callinectes sapidus* in Chesapeake Bay, for example, is currently managed under empirically defined abundance and exploitation thresholds that control fishing effort and mortality rates (Miller 2001). Despite the difficulty in defining abundance thresholds, fisheries management policies must identify—and stay within—rational exploitation thresholds to ensure sustainability (National Research Council 1998).

Concerns over the perceived shortcomings of traditional fisheries management—one dominated by single-species approaches—have led to multispecies alternatives (Miller et al. 1996). Multispecies approaches in fisheries management stem from biological and technical interactions among species. Some of these approaches account for biological interactions, such as predation, in fisheries management. These multispecies approaches aim to balance fishery catch, predation mortality, and natural mortality of all exploited (and relevant unexploited) species within an assemblage of species. Other multispecies approaches recognize that individual fisheries seldom catch only the sought-after species. Moreover, different fisheries exploit different portions of a species' life history. These multispecies models account for technical interactions among different fisheries in management considerations.

Regardless of the initial factors motivating development of these approaches, when fisheries exceed exploitation limits in an ecosystem context, substantial and perhaps irreversible ecosystem changes may occur. Defining removal limits for fisheries managed from a multispecies perspective, therefore, remains just as important as for those under single-species management. In the multispecies scenario, however, managers must consider the level of removals of all species combined, regardless of the sector from which they are taken. Throughout this element, the aggregate level of removals is termed the total removals from the fishery ecosystem

Establishing multispecies thresholds for removals in the Chesapeake Bay is particularly challenging due to diverse fishing activity and numerous exploited species; additionally, most targeted species are not year-round Bay residents. To simplify development of the fisheries ecosystem plan (FEP), we identified distinct life history patterns in exploited species that will influence which removals data are used to estimate thresholds. We established three population components that represent Chesapeake Bay fishes (Figure 1)

1) Those residing within the Chesapeake Bay (S_{CB} – the only mandatory component);
2) Those residing in coastal waters outside the Bay (S_{CST}); and
3) Those residing in other estuaries along the mid-Atlantic seaboard (S_{EST}).

Not all species exhibit all three components of population structure. For example, resident species occur only in the Chesapeake Bay component (S_{CB} in Figure 2a). Other species require two components to describe their population structure (S_{CB} and S_{CST} in Figure 2b), while some Bay species include all three (S_{CB}, S_{CST}, and S_{EST} in Figure 2c). The components can represent different ontogenetic stages of a single population. Species with life stages separated in time include blue crab, Atlantic menhaden *Brevoortia tyrannus*, and striped bass *Morone saxatilis.* Alternatively, the three population components may represent species separated in space, with the population components occurring in all three regions during the same life history stage. Bluefish P*omatomus salatrix* and winter flounder *Paralichthys dentatus* are examples of this category.

Diverse combinations of seven interactive processes govern the abundance level of each population component (S_{CB}, S_{CST}, and S_{EST}). Five of these processes decrease the population abundance; two increase the population abundance. The loss terms represent both mortality and emigration.

Each population component

Technical Interactions*—Spatial, temporal, or both orientations of different species that lead to bycatch (capture of nontarget species) in a fishery; when gears primarily directed at one species also catch other species; when different life stages of one species are caught using different gear types.*

Biological Interactions*—Spatial, temporal, or both co-occurrence of different species related by competition for the same food resources or predator–prey relationships.*

Total Removals*—The aggregate weight and number of fish and shellfish from a specified system that are landed or die as a result of fishing activity. Estimates of “total” removals must take into account the total catch (landings, bycatch, and discard) from all fishing sectors (commercial and recreational).*

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experiences three sources of fishing mortality: reported catch, unreported catch, and discard mortality. The level and impact of the three sources will be species- or community-specific. Each population component also experiences a fourth source—natural mortality. These four loss terms are intrinsic to the species or community of species. Finally, for species occurring in more than one component, emigration loss represents the movement of individuals from one population component to one or more of the other components. This last loss term is extrinsic to the species or multispecies community.

The two gain terms represent both production and immigration. Production, whether due to growth or reproduction, is an intrinsic gain resulting from the dynamics of the population component; immigration is an extrinsic gain.

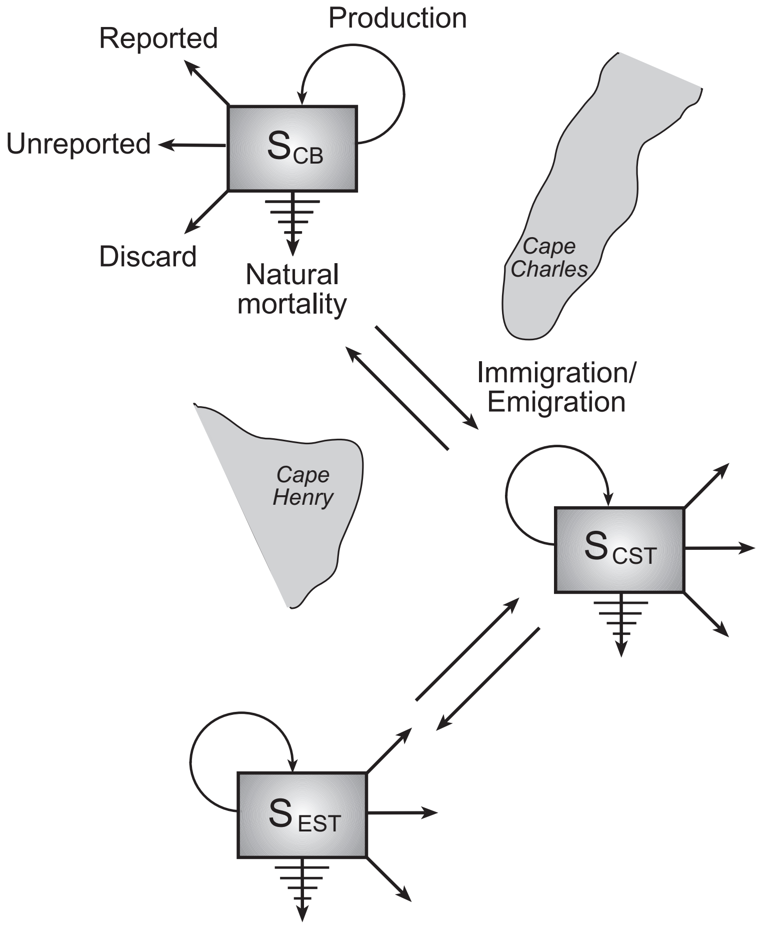

Figure 1. Conceptual figure representing the structure of populations in the Chesapeake Bay. Three component stocks are identified as Chesapeake Bay (S_{CB}), coastal (S_{CST}), and other estuarine (S_{EST}). Up to seven processes that either increase or decrease the spawning stocks are indicated for each stock.

The distinct structure of the populations defined above has profound consequences on the estimation of removals. To consider an entire fishery ecosystem, estimates of growth and mortality rates in all components of all populations are needed to approximate the threshold for total removals. Moreover, management jurisdiction or control over all three potential components of the population is necessary to regulate fishing mortality and removals within identified thresholds. For the immediate future, fishery managers are unlikely to meet such goals. However, this situation should not prevent progress on estimation of the thresholds for total removals in the Chesapeake Bay (S_{CB} in Figure 1), a region for which some coordination between management jurisdictions does exist. Two analyses are required to achieve this kind of progress: identification of all species important to fisheries management with categorization of these species into the three population components (Figure 1) to determine potential management control; and determination of patterns of total removals within the Bay to assess the potential limits on removals.

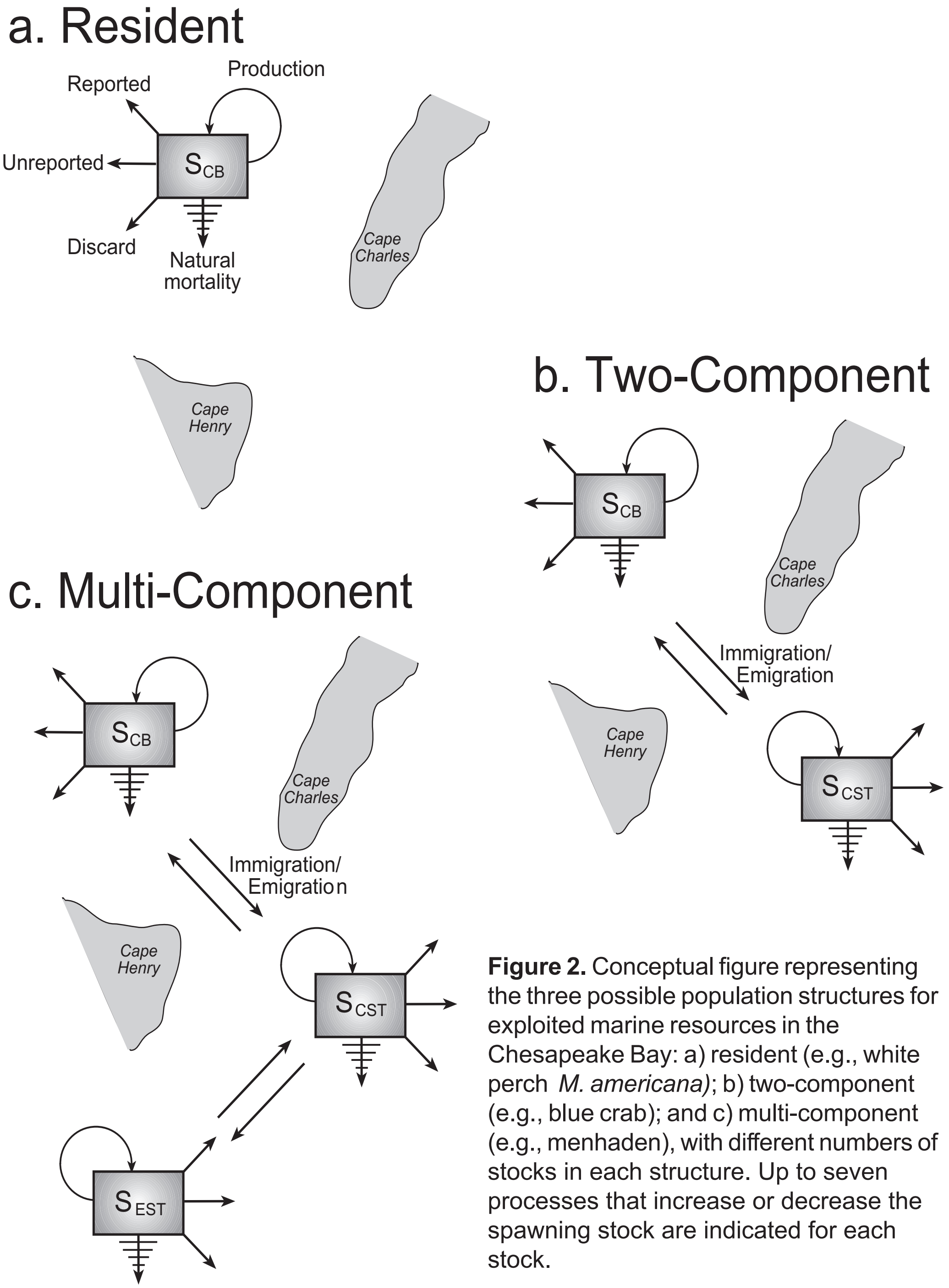

Figure 2. Conceptual figure representing the three possible population structures for exploited marine resources in the Chesapeake Bay: a) resident (e.g., white perch *M. americana*); b) two-component (e.g., blue crab); and c) multi-component (e.g., menhaden), with different numbers of stocks in each structure. Up to seven processes that increase or decrease the spawning stock are indicated for each stock.

Quantifying Total Removals

Utility of Estimating Total Removals

Many industrialized countries estimate the level of removals from their fishery ecosystems as a routine part of stock assessment of individual species. The uses of these estimates, however, vary considerably. The most common use of estimates is to determine catch allocations among competing user groups. Typically, this objective is achieved by estimating abundance levels (numbers at age) for each fished species to determine how much is available during the upcoming fishing season—often termed total allowable catch (TAC). For example, the European Union (EU) relies on scientific advice from the International Council for the Exploration of the Sea (ICES) and individual member states to estimate TACs for the principal fisheries under its jurisdiction. Each TAC is then allocated to member states to ensure the conservation of the EU's increasingly fragile fish stocks while promoting fishing activities enshrined in the EU's Common Fishery Policy. Canada, Australia, and New Zealand follow a similar policy, with the governments of these nations estimating annual TACs for their principal fisheries. Each nation's allocation of the combined TAC then forms the basis for allocation among indigenous, recreational, and commercial fisheries. In these cases, however, no a priori restriction or cap on the magnitude of combined TACs exists that would limit fishing activity. Thus, the overall removals from fisheries are simply the sum of the combined individual fishery TACs for member states with no attempt to set allocations in the individual sectors within member states at levels lower than estimates of TAC for the species.

Use of total removals levels as a principal management tool does take place. From 1949 to 1982, the International Commission for Northwest Atlantic Fisheries (ICNAF) regulated fishing on the northwest Atlantic coast of North America. During the later part of this period, the ICNAF managed the commercial fisheries under a two-tier system. Maximum sustainable yields (MSYs) were calculated for individual fish stocks. Subsequently, a second tier, or combined-stocks multispecies maximum sustainable yield, was established for the ICNAF area that was less than the sum of the individual MSYs. The multispecies MSY restricted fishing on the individual stocks by implicitly recognizing the potential for biological and technical interactions (Fogarty and Murawski 1998). After establishment of the New England Fishery Management Council (NEFMC) in 1982, however, this two-tiered management strategy was abandoned.

The North Pacific Fishery Management Council (NPFMC) established and uses a multispecies TAC approach (Witherell et al. 2000). This council regulates total removals of groundfish stocks through three harvest levels that correspond to the overfishing limit (OFL), the acceptable biological catch (ABC), and the TAC from which actual catches are allocated. The council establishes these three levels such that the OFL is greater than ABC, which is greater than TAC. As a precaution, the council intentionally sets the TAC much lower than the ABC to ensure adequate resilience. Additionally, the sum of all TACs must remain less than 2 million metric tons (MT) per year—below the aggregate acceptable biological catch in the system—thus building a second precautionary buffer into the system.

The southern oceans provide additional examples of two-tiered management. The southeast Australian trawl fishery is managed

Table 1. Reported, unreported, and discard mortality: summary of the state of knowledge of their magnitudes and characteristics. No entry in a cell indicates that the FEP Workshop Workgroup concluded that the particular source of mortality did not apply to that component of the fishery. A ✔ indicates that the source of mortality likely occurs, but its magnitude is unknown. "None" indicates that the source of mortality occurs, but no reporting system is in place. The MRFSS stands for the National Marine Fisheries Recreational Fishery Statistical Survey. The ACCSP is the Atlantic Coastal Cooperative Statistics Program.

Mortality Source	**Finfish**			**Shellfish**		**Crustacean**	
	Commercial	Boat for Hire	Recreational	Commercial	Recreational	Commercial	Recreational
Reported landings (target and bycatch species)							
Level of removals (biomass or numbers)	Trip ticket	Log book	MRFSS	Trip ticket	Reports	Trip ticket	None
Characteristics of removals	Sampled	MRFSS - Insufficient coverage for many non-dominant species - Public vs. private access		Minimum size only	None	Market category, sex	None - Identification of sampling frames - Public vs. private access
Reported discards (target and bycatch species)							
Undersize	ACCSP	MRFSS		MRFSS	None	None	None
Regulatory	ACCSP						
No market	ACCSP						
	- Estimates of the magnitude of the release will be available, but post-release mortality information is poor for all except striped bass. - Information of the magnitude of the release is not available for shellfish or crustaceans.						
Unreported landings (all species)							
Incidental	✔		✔	✔		✔	
Unlicensed	✔		✔	✔		✔	
	- Could be estimated by analysis of arrest rates as a function of number of trips or other effort indicator, but this would not estimate the magnitude or characteristics of the catch.						
Basket trade	✔			✔		✔	
	- Could be estimated by sampling roadside and other non-standard outlets, but would be expensive. - Sampling frames difficult to determine.						
Unclassified	✔						
	- Can be sampled effectively.						
Quasi-recreational			✔		✔		✔
	- Can be sampled with increased reporting requirements for recreational fishers with licenses for "large" gear types (e.g., gill nets, trot lines).						
Live bait	?			?		?	

through a system that accounts for the multispecies nature of many of its fisheries (AFMA 2001). The krill fishery in the Antarctic Ocean is managed on the basis of an acceptable level of total removals through an international agreement. In this case, however, total removals are partitioned into those by capture fisheries and those through natural predation. Thus, the commercial catch of krill is set at levels that ensure the remaining biomass provides an adequate prey base for predator species—principally marine mammals (Nichols and de la Mare 1993; Constable et al. 2000).

The potential use of total removals for management is sparking growing interest in this management tool, despite the relatively small number of examples of its application. The EU has proposed using multi-year, multigear TACs in its revision of the Common Fisheries Policy (Commission of the European Communities 2001). Growing use and recognition of multispecies management (Miller et al. 1996; Hollowed et al., 2000) presupposes that jurisdictions adopting this technique will establish a system-wide limit. Given that the *Chesapeake 2000* agreement identifies such a goal, attention should now be focused on determining the appropriate level or levels of total removals from the Bay ecosystem.

Status of Knowledge in Removals

All major sources of removals must be identified to quantify the level of total removals from Chesapeake Bay. Table 1 identifies three sources of removal. The nature of the estimate for each source can vary among the different fishery sectors. But, data available to characterize different sources of removals remain inconsistent. In cases for which data are not available, we provide examples of how such information could be collected in the future. Additionally, the quality of available data should improve dramatically in the near future following adoption of a coastwide reporting system sponsored by the Atlantic States Marine Fisheries Commission. Once fully implemented, the Atlantic Coastal Cooperative Statistics Program (ACCSP) will provide both landings and catch estimates (including the three sources of removals in Table 1) for all principal fisheries along the mid-Atlantic coast. The ACCSP will characterize both the magnitude and biological attributes of the catch. Even when fully implemented, however, the ACCSP will not report landings and discards of noncommercial species.

The following list details several important contributions to total removals.

1) *Commercial landings of target species.* This category of removal is relatively well assessed and often equated with (or at least reported as) catch in many fisheries. For some species, particularly Atlantic menhaden, concerns remain in identifying the fraction of reported landings caught within the boundaries of the Bay and the fraction caught outside the WtM boundary system but landed in Bay

ports. These concerns bear directly on the ability to partition reported commercial landings among the population components.

2) *Commercial landings of nontarget species (bycatch).* Many types of commercial gear do not catch a single species, but rather a mix of species. Some of these nontargeted species are marketable and may be landed. This fraction of the catch is the bycatch, which is distinguishable from the discard and constitutes another component of fishing mortality and total removals. Importantly for management, bycatch mortality in nontargeted fisheries can be appreciable at the population level. In some cases, bycatch of endangered nontarget species has brought about changes in the regulations of the fishery for the targeted species (e.g., turtle bycatch in shrimp trawl fisheries (Crowder et al. 1994)). Bycatch data in Chesapeake Bay fisheries are not reported consistently, as this catch may not enter the normal markets.

3) *Commercial discards.* In most fisheries, fishermen grade their catch at sea, discarding the portion that is not legal or marketable. Some of the discarded individuals die following release. Even though discards are not recorded as part of the landings, they do contribute to fishing mortality and must be accounted for when estimating total removals (Alverson and Hughes 1996). Commercial discards are poorly assessed in the Chesapeake region. Indeed, no reliable estimates of discarding or the mortality associated with it are available. The level of discard mortality likely varies among the different fisheries, as well as by season, and gear type. Quantifying the extent and pattern of discard mortality in the Chesapeake remains an important topic for future research.

4) *Recreational landings.* Assessment of recreational landings takes place through various fishery-dependent surveys, principally the NMFS-sponsored Marine Recreational Fisheries Statistical Survey (MRFSS). Recreational landings are reported in biweekly “waves” and can be identified by geographic region, including the Bay. Questions about the reliability of MRFSS data to estimate the Bay’s recreational landings still exist because this survey targets marine species; therefore, gaps in the temporal and spatial intensity of the survey coverage, especially in the fresher areas of the Bay, lead to poor coverage and result in missing or questionable estimates for these regions. Estimates of landings of freshwater species taken in the upper Bay and in tributaries are almost completely nonexistent.

   Perhaps the most important deficiency in recreational landings data is the failure to survey the recreational fishery for blue crab. Estimates of the magnitude of the blue crab recreational fishery vary from 6% to 80% in Maryland Bay waters (J. Ashford, Old Dominion University, personal communication; Stagg et al. 1991). Clearly, we lack reliable estimates of recreational landings for the most commercially valuable species caught in Chesapeake waters.

5) *Recreational discards.* As with commercial discards, a significant fraction of released fish will eventually die as a result of capture; these deaths should enter into estimates of total removals. Hook-and-release mortality in the Chesapeake Bay recreational striped bass fishery, for example, averages an estimated 8% of released (discarded) fish (E. Zlokovitz, Maryland Department of Natural Resources, personal communication). This "hooking mortality" estimate is considered in the annual allocation of striped bass to the recreational fishery and must be accounted for in determining fishing mortality and total removals for this species. The MRFSS provides information that could be used to estimate recreational discards. With the exception of striped bass, however, little is known about the mortality rates of released fish. Overall, recreational discards are poorly assessed in the Chesapeake region.

The above five categories form important components of total removals; however, potentially important unreported catch may contribute significantly to total removals from the system (Table 1). Two approaches can account for the uncertainty that this situation introduces into total removal estimates. First, unreported catch could be presumed small compared to total removals and ignored. A second, but better, approach is to invest resources in estimating the magnitude of unreported catch or total removals. Table 1 provides suggestions for achieving such an estimate. These estimates need not be developed annually; rather an average figure could be applied to groups of years for which the fisheries operated similarly.

Patterns in Fisheries Harvests and Abundances

As mentioned previously, two analyses are essential in quantifying the patterns in total removals for Chesapeake Bay. The first classifies the population structure of each species based on the conceptual framework illustrated in Figures 1 and 2 (a, b, and c). The second partitions the reported landings for each species to reflect that population structure. In the following sections, we deal with each suite of analyses, classifying each species ecologically and subsequently estimating the landings for each species from the Bay.

Species Classifications

To determine removals external to the Bay (not considered in further analyses), we characterized species in the Chesapeake catch records by life history category (Figure 1). Individual species fit one of three categories. Resident species form the simplest case. For these species, such as white perch, intrinsic losses and gains describe the population dynamics adequately (Figure 2a). Based on estimates of these variables, traditional single-species management approaches sufficiently characterize the dynamics and can be used to estimate safe levels of removal.

Species that inhabit both the coastal ocean and the Chesapeake Bay have a more complex population structure

Table 2. Classification of common Chesapeake Bay species (either ecologically or commercially important) into taxonomic, trophic, and life history groups identified by population structure: S_{CB}– species that complete their life history entirely within the Bay; S_{CB} and S_{CST} – species that complete their life history within the Bay and coastal ocean; and S_{CB}, S_{CST}, and S_{EST}– species that complete their life history within Atlantic coastal estuaries inclulding the Bay and coastal ocean. Species are also identified by whether they spawned or occupied juvenile habitats within the Bay: resident (res); seasonal (seas); and occasional (occ). Resident species remain in the Bay for the entire year and complete most of their life history within the Bay and included blue crabs even though they spend a brief period as larvae outside the Bay. Seasonal species have an obligate estuarine phase and prolonged periods outside the Bay and included spot and croaker because adults leave the Bay to spawn. Occasional visitors are those caught in Bay waters, but which are not obligate estuarine species. Taxonomic groups were shellfish (S) and finfish (F), based upon taxonomic order. Trophic criteria were **plank**tivore, **benth**ivore, **pisc**ivore, and **detri**tivore, based upon primary diet items.

Common Name	Species	Family	Population Structure	CB Spawn	CB Nursery	Habit	Fish/ shellfish	Trophic Status	Mean Landings (MT)
Bowfin	*Amia calva*	Amiidae	S_{CB}	Y	N	fw	fish	pisc	1.8
Crappie	*Pomoxis* spp.	Centrarchidae	S_{CB}	Y	N	fw	fish	pisc	1.5
Bay anchovy	*Anchoa mitchilli*	Clupeidae	S_{CB}	Y	Y	res	fish	plank	0.0
Gizzard shad	*Dorosoma cepedianum*	Clupeidae	S_{CB}	Y	Y	res	fish	plank/detri	145.0
Common carp	*Cyprinus carpio*	Cyprinidae	S_{CB}	Y	N	fw	fish	pisc/detri	118.9
Soft clam	*Mya arenaria*	Hiatellidae	S_{CB}	Y	Y	res	shell	plank	1064.3
Catfishes	Various	Ictaluridae	S_{CB}	Y	N	fw	fish	pisc	521.2
Gars	*Lepisosteus osseus*	Lepisosteidae	S_{CB}	Y	N	fw	fish	pisc	0.8
White perch	*Morone americana*	Moronidae	S_{CB}	Y	Y	res	fish	pisc	302.2
Eastern oyster	*Crassostrea virginica*	Ostreidae	S_{CB}	Y	Y	res	shell	plank	4380.0
Yellow perch	*Perca flavescens*	Percidae	S_{CB}	Y	Y	res	fish	pisc	21.7
Hogchoker	*Trinectes maculatus*	Solediae	S_{CB}	Y	Y	res	fish	benth	3.3
Hard clam	*Mercenaria mercenaria*	Veneridae	S_{CB}	Y	Y	res	shell	plank	1869.8

Table 2 continued

Sturgeons	*Acipenser* spp.	Acipenseridae	S_{CB} & S_{CST}	Y	Y	seas	fish	benth	3.5
Hickory shad	*Alosa mediocris*	Clupeidae	S_{CB} & S_{CST}	Y	N	seas	fish	pisc	11.9
Alewife	*Alosa pseudoharengus*	Clupeidae	S_{CB} & S_{CST}	Y	Y	seas	fish	plank	3123.3
American shad	*Alosa sapidissima*	Clupeidae	S_{CB} & S_{CST}	Y	N	seas	fish	plank	525.1
Tautog	*Tautoga onitis*	Labridae	S_{CB} & S_{CST}	N	Y	opp	fish	benth	2.9
Blue crab	*Callinectes sapidus*	Portunidae	S_{CB} & S_{CST}	Y	Y	res	fishll	benth	17,167.6
Black sea bass	*Centropristis striata*	Serranidae	S_{CB} & S_{CST}	N	Y	opp	fish	pisc	598.6
Butterfish	*Peprilus triacanthus*	Stromateidae	S_{CB} & S_{CST}	Y	N	seas	fish	pisc	161.9
American eel	*Anguilla rostrata*	Anguillidae	S_{CB}, S_{CST} & S_{EST}	N	Y	seas	fish	pisc	204.2
Atlantic menhaden	*Brevoortia tryannus*	Clupeidae	S_{CB}, S_{CST} & S_{EST}	N	Y	seas	fish	plank	46,803.6
Atlantic herring	*Clupea harengus*	Clupeidae	S_{CB}, S_{CST} & S_{EST}	N	Y	opp	fish	plank	54.6
Horseshoe crab	*Limulus polyphemus*	Limulidae	S_{CB}, S_{CST} & S_{EST}	Y	Y	res	shell	benth	143.8
Striped bass	*Morone saxatilis*	Moronidae	S_{CB}, S_{CST} & S_{EST}	Y	Y	seas	fish	pisc	811.2
Bluefish	*Pomatomus saltatrix*	Pomatomidae	S_{CB}, S_{CST} & S_{EST}	N	Y	opp	fish	pisc	300.8
Spotted seatrout	*Cynoscion nebulosus*	Sciaenidae	S_{CB}, S_{CST} & S_{EST}	N	Y	opp	fish	pisc	15.4
Weakfish	*Cynoscion regalis*	Sciaenidae	S_{CB}, S_{CST} & S_{EST}	N	Y	seas	fish	pisc	575.2
Spot	*Leiostomus xanthurus*	Sciaenidae	S_{CB}, S_{CST} & S_{EST}	N	Y	seas	fish	benth	671.8
Atlantic croaker	*Micropogonias undulatus*	Sciaenidae	S_{CB}, S_{CST} & S_{EST}	N	Y	seas	fish	benth	1019.6
Black drum	*Pogonias cromis*	Sciaenidae	S_{CB}, S_{CST} & S_{EST}	N	Y	opp	fish	benth	28.2
Red drum	*Sciaenops ocellatus*	Sciaenidae	S_{CB}, S_{CST} & S_{EST}	N	Y	opp	fish	benth	5.5
Scups and Porgies	Various	Sparidae	S_{CB}, S_{CST} & S_{EST}	N	N	opp	fish	benth	921.9

(Figure 2b). For example, the blue crab occurs in two components. Thus, the five intrinsic types of losses and gains are not sufficient to describe this population; estimates of extrinsic rates also are required. Extrinsic rates, however, are often quite difficult to estimate. Populations that occur in at least three components form the most complex cases (Figure 2c), with menhaden representing such a situation. Multiple, alternative estuaries along the Atlantic coast may, in fact, represent the S_{EST} component; thus, the dimensionality of the population may even exceed three components. For this most complicated case, complete information of all intrinsic and extrinsic rates (or all stock sizes) is required to understand the population dynamics fully.

In addition to the classification based on population structure, categorizing the species based on several ecological attributes using information in Murdy et al. (1997) proves useful. The following classifications were recognized.

Population structure

1) S_{CB} component only—equivalent to year-round Chesapeake Bay resident
2) S_{CB} and S_{CST}—includes components in the Chesapeake Bay and coastal ocean
3) S_{CB}, S_{CST}, and S_{EST}—incorporates components in the Bay, coastal ocean, and other east coast estuaries

Spawning location

1) Chesapeake Bay
2) Outside Chesapeake Bay

Nursery location

1) Chesapeake Bay
2) Outside Chesapeake Bay

Habit

1) Freshwater (fw)
2) Estuarine resident (res)
3) Seasonal visitor (seas)
4) Opportunist visitor (opp)
5) Occasional visitor (occ)

Trophic status (species can occur in more than one trophic category)

1) Planktivore (plank)
2) Piscivore (pisc)
3) Benthivore (benth)
4) Detritivore (detri)

Taxonomic affiliation

1) Shellfish
2) Finfish

Table 2 details the results of this classification scheme.

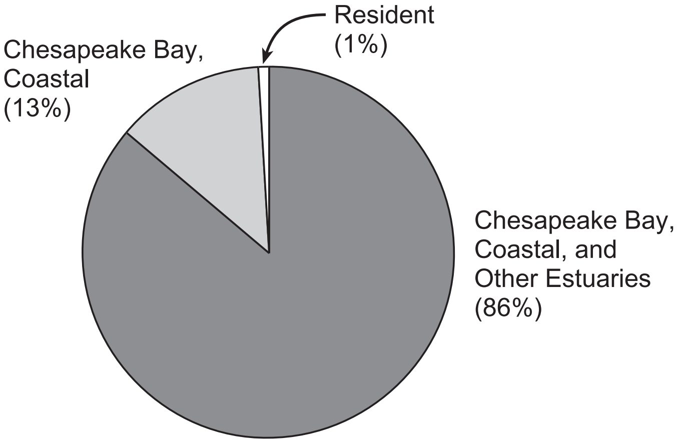

Figure 3. Chesapeake Bay fisheries. Total removals categorized by population structure of commercially caught species.

Data Sources and Preparation

Given the great differences in the extent and reliability of commercial and recreational catch data in Chesapeake Bay, the two data sources were reviewed and analyzed separately. The Virginia Marine Resources Commission and Maryland Department of Natural Resources provided the landings data (1956–1999) to NOAA. Standardizing catch to fishing effort proved impossible since effort data are not systematically collected and recorded for most species. Trends in the data, therefore, may reflect changes in overall population abundance or changes in fishing effort. Data are reported on a species-by-species basis with no information identifying gears used to capture fish. Consequently, the data presented shed do not describe the extent of technical interactions in the fishery.

Records of commercial landings in the Chesapeake region date back to 1880, but remained inconsistent until 1929. Prior to 1952, reported landings from Maryland and Virginia were aggregated into Chesapeake Bay and Atlantic catches landed at ports in both states. After 1952, landings from the Bay and Atlantic were separated, and harvest data are reported specific to Bay waters. Changes in reporting and recording methods complicate the analysis and interpretation of landings trends. In particular, difficulties occurred in determining menhaden catches, the Bay's largest fishery by weight.

Vaughan et al. (2001) provide estimates of menhaden catches in Chesapeake Bay from 1985 to 2000 based

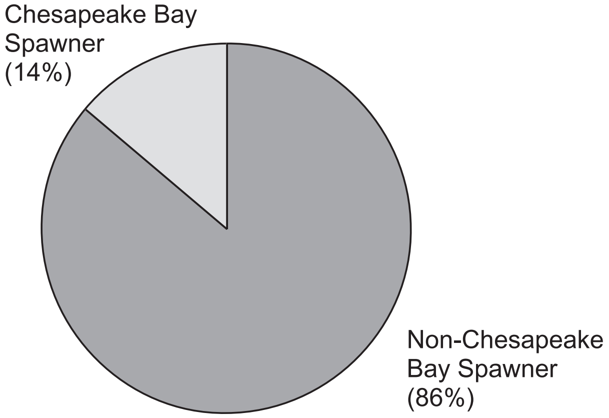

Figure 4. Commercial removals by spawning locations for Chesapeake Bay fisheries.

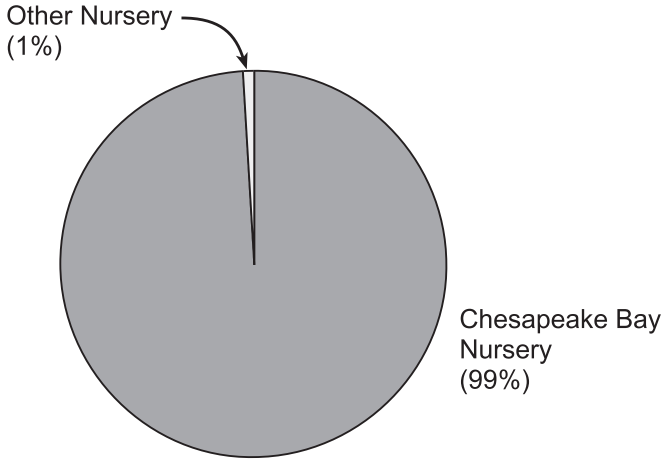

Figure 5. Commercial removals by nursery area for Chesapeake Bay fisheries.

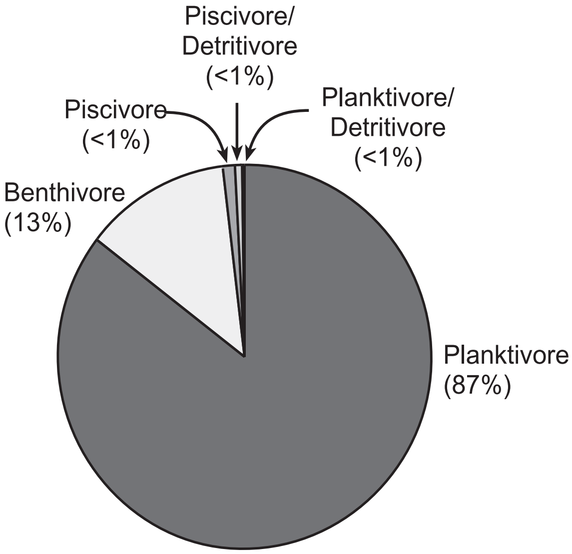

Figure 6. Commercial removals by trophic status for Chesapeake Bay fisheries.

Population Structure

Category	1960 —1969	1970 —1979	1980 —1989	1990 —1999	1955 —1999
S_{CB}	40.58%	38.88%	37.23%	33.74%	30.97%
S_{CB} S_{CST} S_{EST}	15.56%	15.00%	13.96%	12.06%	10.52%
S_{CB} S_{CST} S_{EST}	43.85%	46.11%	48.81%	54.20%	58.51%
	100%	100%	100%	100%	100%

Trophic Structure

Category	1960 —1969	1970 —1979	1980 —1989	1990 —1999	1955 —1999
benth	34.38%	32.42%	30.56%	27.27%	24.78%
pisc	5.94%	5.75%	5.36%	4.80%	4.53%
pisc/detri	0.20%	0.16%	0.14%	0.11%	0.09%
plank	59.46%	61.65%	63.93%	67.81%	70.59%
plank/detri	0.03%	0.02%	0.02%	0.02%	0.02%
	100%	100%	100%	100%	100%

Habit Structure

Category	1960 —1969	1970 —1979	1980 —1989	1990 —1999	1955 —1999
fw	0.98%	0.83%	0.73%	0.63%	0.56%
opp	4.67%	4.01%	3.51%	2.82%	2.33%
res	39.61%	38.05%	36.50%	33.11%	30.42%
seas	54.75%	57.11%	59.26%	63.44%	66.70%
	100%	100%	100%	100%	100%

Table 3. Trends in the composition of the commercial removals from Chesapeake Bay by decade based on ecological category (benth=benthic, pisc=piscivorous, pisc/detri=planktonic/detritivore, fw=fresh water, opp=opportunistic, res=resident, and seassonal.

on logged data from the Captain's Daily Fishing Reports (CDFRs). In addition, these researchers developed estimates of historical landings prior to the CDFRs (1955–1984). Accordingly, commercial menhaden harvests specific to Chesapeake Bay from 1955 to 1999 were available for analysis.

Recreational catches for the Chesapeake Bay were obtained by querying the MRFSS database (http://www.st.nmfs.gov/st1/) and using the following criteria: Years = 1981– 2000; Wave = Annual; Species = All, Geographic Area = mid-Atlantic by state; Fishing Mode =

All; Fishing Area = Inland; and Type of catch = A+B1. Data were then sorted by state, retaining information only for Maryland and Virginia under the assumption that these catches related solely to the Chesapeake Bay.

Life History Categories in Commercial Removals

From 1955 to 1999, total average annual commercial landings from the Bay were 180.89 MT x10^3—lower than comparable figures reported in Miller et al. (1996) and Houde et al. (1998). In both earlier cases, researchers reported considerably higher landings—on the order of 350 x 10^3 MT. The discrepancies occur primarily because the earlier studies used estimates of the Atlantic menhaden landings based on total reported landings, which included catches from the Chesapeake Bay and other regions. Values reported here rest solely on those Atlantic menhaden landings reported to have been taken from the Bay.

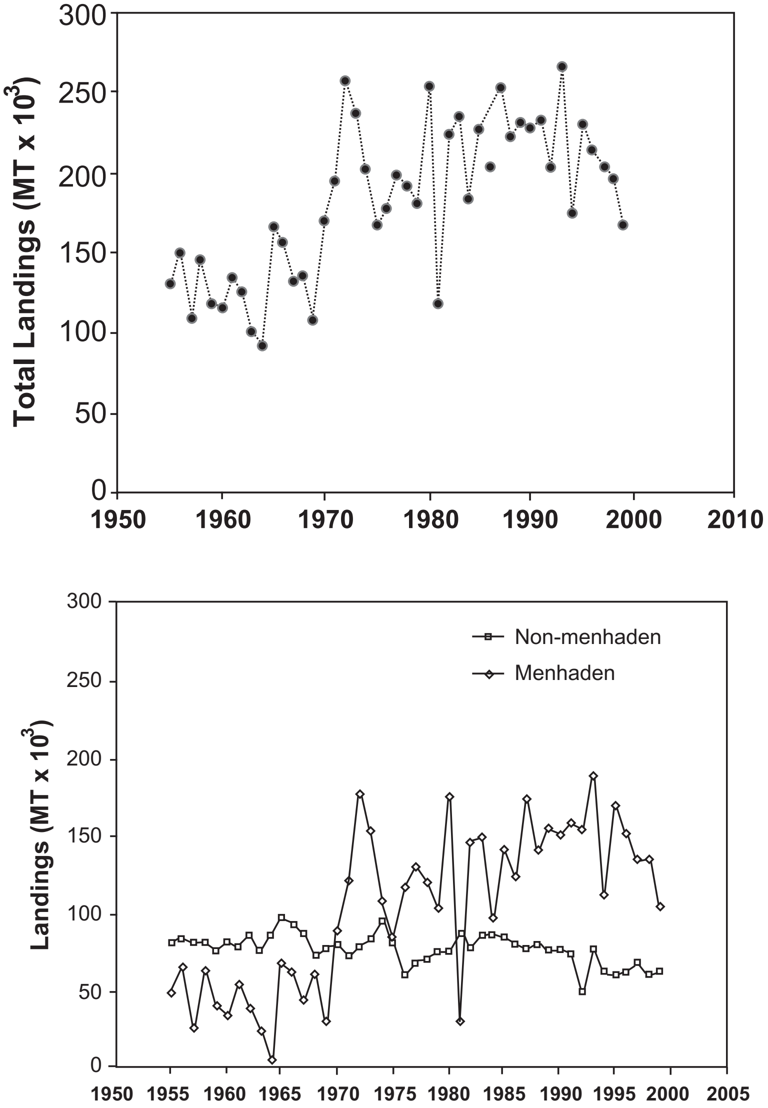

Figure 7. Time series of commercial removals (1955–1999) for total removals (top) and menhaden and non-menhaden removals (bottom) for Chesapeake Bay fisheries.

Based on the ecological classifications above, the contribution of each category to the annual landings from 1955 to 1999 indicated that approximately 58% of the landings come from species with life histories involving the Chesapeake Bay, the coastal ocean, and other estuaries along the eastern seaboard (Figure 3). An additional 11% of the landings come from species with life histories that rely on the coastal ocean, in addition to the Chesapeake. Currently, only 31% of the average annual harvest is comprised of resident species. Species that do not spawn in the Bay constitute 86% of the average annual catch (Figure 4). In contrast, fully 99% of reported landings come from species using the Bay as an important nursery area (Figure 5). The dominant trophic category in the landings is planktivore, making up 87% of the average annual catch (Figure 6). Benthivore forms the

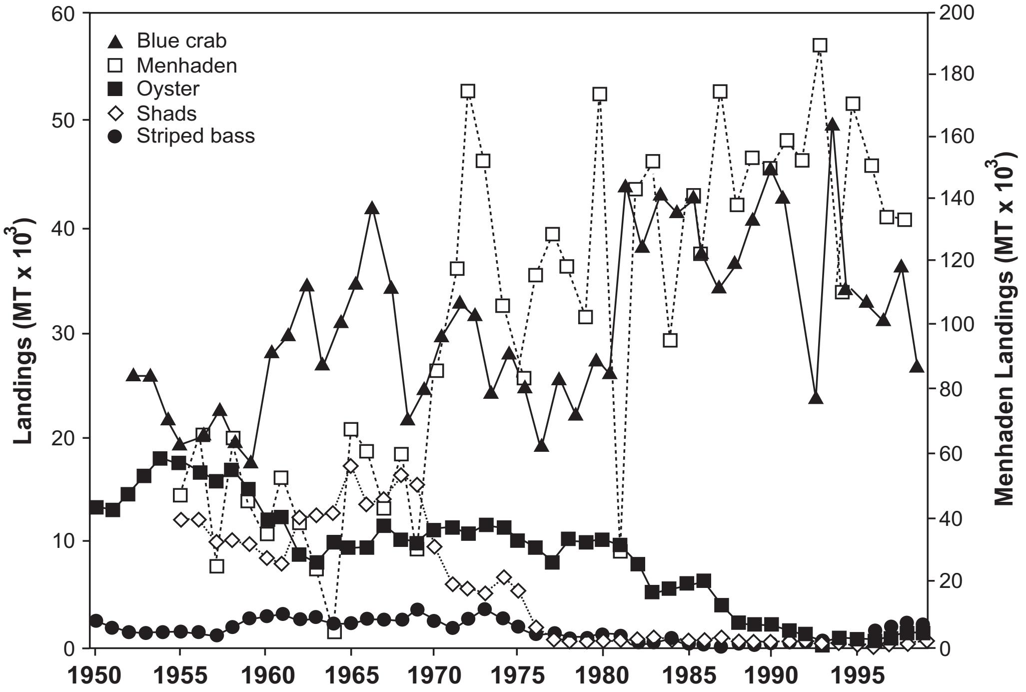

Figure 8. Time series of commercial removals for principal species in commercial catches (1955–1999) for Chesapeake Bay fisheries.

second-most represented category with 13% of the landings. To determine the relative stability of the numbers above, we estimated the contributions in ecological category by decade (Table 3). These estimates show clear trends in the relative contribution of different ecological categories to total removals.

Time Series of Commercial Removals

The total annual reported commercial landings from the Chesapeake Bay vary from 1955 through 1999 (Figure 7). In 1955, total reported landings were 130.67 x 10^3 MT, after which landings increased during the late 1960s. Total commercial landings have remained relatively constant since 1970, with an average level of 270.37 x 10^3 MT. Landings dropped after the mid-1990s with total reported landings of 166.2 x 10^3 MT in 1999. The apparent lack of a landings trend between 1970 and 1999 suggests that the average for this period may provide a preliminary estimate of a sustainable exploitation level. Accordingly, a level of 270 x 10^3 MT may approximate the sustainability target. The trend in total Chesapeake Bay landings is driven largely by changes in estimated landings of menhaden. This species contributed between 68 and 87% of total commercial landings from the Chesapeake Bay during the 1995–1999 time period.

Changes in landings are likely to be driven as much by economic considerations within the menhaden fishery as they are by changes in underlying abundances. Thus, caution is warranted when examining patterns in these data. To clarify this point, Figure 7 (bottom) shows the total removals data partitioned into both menhaden and non-menhaden removals. Clearly, over the period of record, menhaden catches have increased while total non-menhaden removals have remained relatively constant. Accordingly, we recommend a two-tiered sustainability level with a non-menhaden target level of the average non-menhaden removals from 1955 to 1999 (74.34 ± 9.95 x 10^3 MT) and a sustainability target for total commercial removal equal to the average of the total removals during the same time period (207.37 ± 32.18 x 10^3 MT). Recognizing levels of both non-menhaden and total removals protects ecosystem function, as it seems improbable that removals of any species would be equivalent to the substantial level of menhaden removals or the ecological impact of these removals.

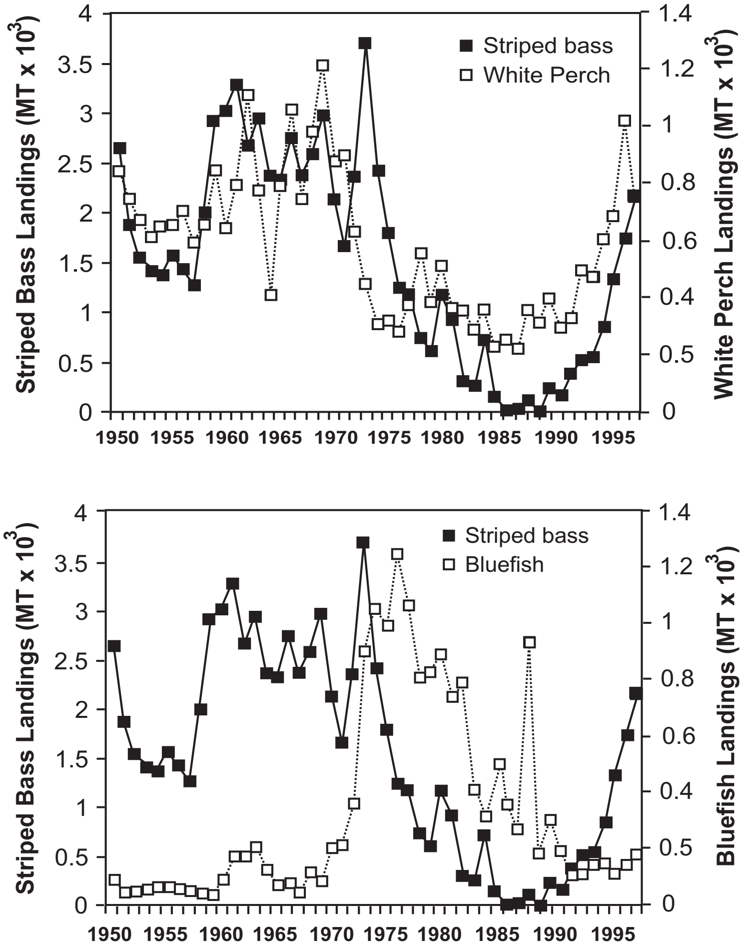

Figure 9. Time series of commercial removals for species pairs that show coherent variation either in-phase (striped bass and white perch in top graph) or out-of-phase (striped bass and bluefish in bottom graph) for Chesapeake Bay fisheries.

Disaggregating the catch and examining the trends of the principal component species allows examination of the data patterns in greater detail (Figure 8). Principal species are those species that contribute substantially to total removals or have a high profile ecologically, sociologically, or because they support an important recreational fishery. From this perspective, several trends in landings since 1950 become apparent. Landings time series for blue crab appear variable but relatively consistent, although the drop in recent years is a concern. In contrast, landing time series for oyster and shads have declined consistently. Figure 9 also shows evidence of both in- and out-of-phase coherent variation for individual species pairs. Thus, some species respond similarly to forcing factors, while others respond differently. Still unclear is whether these responses result from environmental, biological, or technical interactions. Regardless, managers must allow for trends in key species when calculating total removals, especially of species presumed to hold critical roles in trophic webs as top-level predators or as major filter-feeding organisms in the Bay ecosystem.

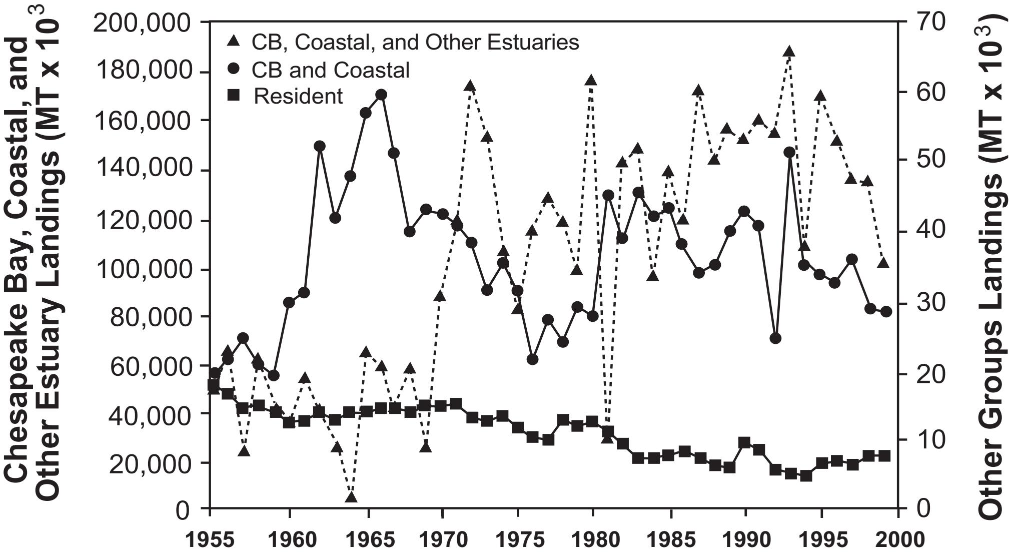

Figure 10. Time series of commercial removals by population structure for Chesapeake Bay fisheries.

We then examined landings by life history form and trophic mode to explore multispecies patterns in the data (Table 2). Landings patterns for species combined during the 1950 to 1999 time series (representing three life-history modes that correspond to the three population components discussed previously and shown in Figure 2 (a, b, and c) were analyzed (Figure 10). Clearly, landings for those species that occur simultaneously in the Chesapeake Bay, surrounding coastal ocean, and other estuaries were dominant due to the magnitude of the Atlantic menhaden fishery. Nevertheless, this pattern points out the importance of the Chesapeake for taxa using the Bay as nursery or breeding grounds, despite this area representing only one of many potential sites along the Atlantic coast. Resident species showed highly variable landings

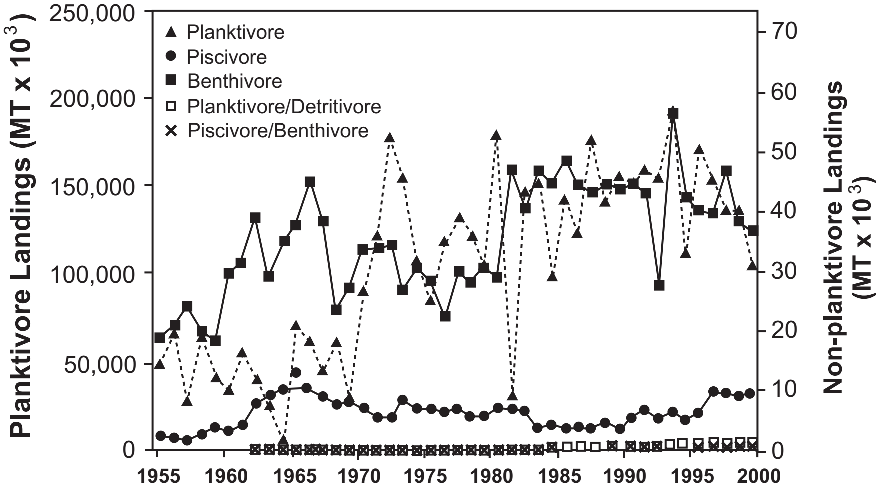

Figure 11. Time series of commercial removals by trophic category for Chesapeake Bay fisheries.

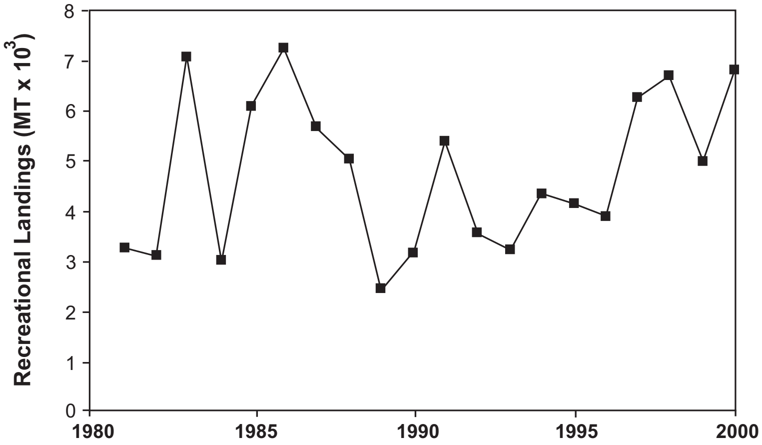

Figure 12. Total recreational landings from the Bay based on 11 species for Chesapeake Bay fisheries.

during the same period, but apparently without trend.

Landings patterns from the 1955 to 2000 time series for all trophic groupings (Figure 11) show that planktivorous fish landings dominate all trophic groupings. As before, menhaden landings form the heart of this finding. With menhaden removed from consideration, landings of planktivorous feeders declined by approximately 80% during this period, corresponding to continued decline of landings and abundances of anadromous shads and river herrings as well as oysters within the Bay.

Landings of piscivorous species declined very slowly during this period. Despite the fishing moratorium imposed on striped bass in Maryland from 1985 to 1989, the overall trend indicates relative stability in total piscivore landings. Yet, the landings time series for individual predator species are highly variable, particularly for bluefish and striped bass (Figure 9). The peak years of striped bass landings (1960s to 1970s) coincided with low bluefish and weakfish *Cynoscion regalis* catches. In addition, commercial landings of bluefish only peaked during the mid to late 1970s, when striped bass catches were declining rapidly and weakfish catches occurred at low levels. A causal relationship does not necessarily explain these patterns; they are not simple replacements, although the same underlying fishing-, trophic-, and environmental-dependent mechanisms may drive the patterns. Shifts in the dominance of piscivorous species in landings almost certainly reflect varying levels of abundance as well as behavior of the fishery, which can transfer its effort based on species availability and market conditions.

In contrast to planktivores and piscivores, probable abundances of benthivorous fishes (as indexed by landings) have fluctuated widely around a long-term mean with no clear long-term trend (Figure 11). The fluctuations represent variation in the catch levels of component species, including spot *Leiostomus xanthurus*,

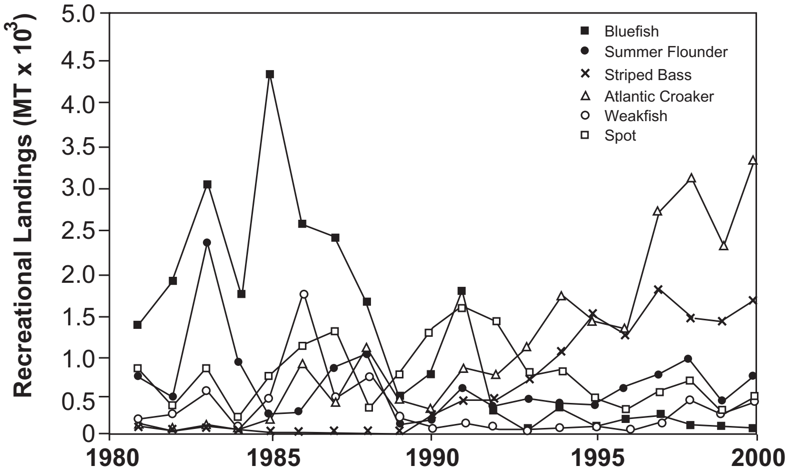

Figure 13. Total recreational landings by species for Chesapeake Bay fisheries.

Atlantic croaker *Micropogonias undulatus*, and blue crab. With the exception of blue crab—a species for which landings have remained relatively steady until recent years—responses by other species of the benthivore group have more similar trends. Catches of these species, primarily Atlantic croaker and spot, peaked in the 1960s and 1980s. Indeed their landings appear somewhat biphasic, with periods of relatively stable and high catches in the 1960s and 1980s (approximately 45–50 x 10^3 MT) and stable but lower landings (approx 30 x 10^3 MT) in the 1970s. Atlantic croaker landings have increased substantially in recent years as its coastal and baywide abundance has grown, likely in response to warm winters and favorable recruitments to the population. Channel catfish *Ictalurus punctatus* landings also have climbed recently, but whether this rise suggests increased abundance remains unclear.

Overall, these summary plots show no clear evidence of dramatic species replacements in the Bay or of complementary patterns in abundance. Ample evidence of complex patterns of covariation (or complex relationships) between the landings time series for groups of species does exist. Resource managers should consider the presence of such covariation, and its potential to affect fisheries landings, when determining and recommending levels of total removals. To further explore the degree of covariation in time series of landings and its implications for setting total removals or amending FMPs, more sophisticated methods and models will be required to explain how covariability affects combined species yields.

Time Series of Recreational Removals

Recreational landings were analyzed for 11 species from 1981 to 2000. Species included: striped bass, bluefish, Atlantic croaker, black drum *Pogonias cromis*, red drum *Sciaenops ocellatus*; summer flounder; black sea bass *Centropristis striata*, spotted seatrout *Cynoscion nebulosus*, spot, and weakfish. The spatial resolution of the data reported is such that it may not be possible to distinguish those fish caught within the boundaries of Chesapeake Bay. No other data were available from MRFSS on a consistent basis.

From 1981 through 2000, the average recreational catch of these species in Chesapeake Bay was $4.73 \pm 1.54 \times 10^3$ MT. Significant variation occurred during the 1980s (Figure 12), with variability generally decreasing during the 1990s, accompanied by a consistent trend of increased recreational catch. The recreational catch of these species in the Chesapeake more than doubled between 1990 and 2000. The principle species contributing to catches were bluefish during the first decade, and striped bass and Atlantic croaker during the second decade (Figure 13).

These preliminary data suggest that the recreational catch does not contribute importantly to the level of overall removals. Such an interpretation should be viewed with caution. First, and most important, the data analyzed do not include the recreational fishery for blue crab although evidence suggests that this fishery might be substantial. The most recent estimates, based on a random telephone survey in Maryland and Virginia counties, indicate that recreational crabbing accounts for perhaps 10% of the commercial harvest. If true, recreational catch could add 10–30 x 10^3 MT to the total removals from Chesapeake Bay.

Major Findings

Fisheries ecosystems have limits to their production capacity. Despite difficulty in defining abundance thresholds, fisheries management policies must identify and remain within rational exploitation thresholds to ensure sustainability. Total removals consist not only of targeted and allocated landings, but also of discard and bycatch—mortality caused by technical interactions in fisheries. Unfortunately, we do not collect the appropriate data to estimate bycatch and discards for all fisheries in Chesapeake Bay. In an ecosystem-based approach to fisheries management, knowing all sources of removals is critical to assess fully the impact of fishery removals on trophic food webs.

Two types of analysis are necessary to achieve progress. Fishery biologists should

1) Identify stock structure and population components (S_{CB}, S_{CST}, or S_{EST}) that categorize life history patterns relative to Bay usage (anadromous, catadromous, spawning or nursery grounds, etc.) for species deemed important in maintaining ecosystem integrity. These definitions will assist in estimation of limits to removals.
2) Determine patterns of total removals within the Chesapeake to estimate the potential limit on removals. A preliminary empirical estimate for a sustainable level of removals based on past Chesapeake Bay landings data is approximately 300 x 10^3 MT for all species combined. Categorizing total removals by trophic status also remains important, and researchers should establish the abundance and yields of piscivores, benthivores, and planktivores.

Panel Recommendations

Management

At present, information remains insufficient to permit immediate development of thresholds for total removals. Recommendations below encourage the estimation and development of thresholds.

1) Establish thresholds for total removals from the Chesapeake Bay.

Regional management agencies have the authority to establish such thresholds. They should do so in a coordinated manner, in consultation with stakeholders and based upon the best scientific advice.

These thresholds should identify the upper limit for the rate of exploitation and the lower limit for stock biomass. In addition, managers should establish a target exploitation rate and associated biomass of fish and shellfish for the Bay, allocating the biomass to the various fisheries based upon historical patterns of exploitation. Yields in the 300,000-ton range had been sustained for decades prior to the 1990s. This level of total removals should be evaluated as a baseline sustainable with managed effort and improved water quality.

2) All mid-Atlantic management agencies should develop, maintain, and improve estimates of removals by species, gear, time, and location.

Agencies should implement sampling programs at appropriate spatial and temporal scales and initiate (or greatly expand) efforts to estimate unreported landings (bycatch and discard).

3) Maintain and post a quality assured and quality controlled database of removals by species for the Bay on the NOAA Chesapeake Bay Office (NCBO) web site.

This database should include time series estimates of commercial landings and discard, recreational landings, discard, and bycatch.

4) Publish a report annually through the NCBO that summarizes levels and patterns in total removals from the Chesapeake Bay.

With establishment of thresholds for total removals, tracking ecosystem response to management measures becomes important to enforce limits and to document the effectiveness of these actions.

5) In each single-species FMP, include explicit estimates of time series of commercial landings, discard mortality, bycatch, recreational landings, recreational discards, fishing mortality, and natural mortality.

In cases for which no information is available, acknowledge this deficiency with a required plan to obtain the data.

6) Consider explicitly in each single-species FMP the consequences of any proposed management actions on total removals from Chesapeake Bay.

Significant changes in the catch of one species can affect present and future total yields of Bay fisheries. With an ecosystem-based management approach, estimating the impact of a proposed change for a particular fishery on the yields for other fisheries and the whole Bay becomes important.

Needed Research and Development

7) Develop and implement fishery-independent surveys of fishery resources to quantify species abundance, distribution, population structure, and trophic interactions (see Monitoring Element).

Existing surveys do not fully cover all life stages for all species. Given the magnitude of such an undertaking, we recommend detailed discussions, analysis, and planning to initiate a full complement of surveys to collect data efficiently and effectively, providing the required estimates.

8) Initiate development of multispecies models to examine patterns and potential

consequences of removals in multispecies fisheries.

Multispecies biomass dynamic models are most likely to be successful in the short term although researchers should also develop and test other models. For example, NCBO's recent emphasis on developing the Ecopath with Ecosim models is responsive to this need (see Food Web Element).

9) Identify and quantify patterns in removals relative to trophic levels, life histories, and habitat associations at appropriate spatial scales to further understanding of biological interactions.

Comprehending how different trophic groups, life history types, and habitat dependencies are linked to total removals will help managers predict patterns of sustainability. For example, knowing total removals of piscivorous fish from the Chesapeake ecosystem and their stability over time is important information. Similarly, knowledge of habitat dependencies in total removal patterns may identify habitats of particular importance that should be conserved to maintain the level of total removals. Some patterns may arise from modeling studies.

10) Identify and quantify technical interactions in commercial and recreational removals at appropriate spatial and temporal scales.

Evaluate the nature of technical interactions (i.e., bycatch and discards) and the levels of removal and mortality attributable to such interactions. Technical interactions arise from the mix of species caught in single gears or in single-species fisheries, occurring in many Bay fisheries including pound net, gill net, and recreational.

11) Expand the intensity of sampling of the MRFSS to ensure that the survey also adequately covers species *not* of primary recreational interest.

Assure acceptably accurate and precise estimates of recreational catch in Chesapeake Bay for all species, including biological characterization of the catch. The multispecies nature of recreational fishing should be adequately documented as some species not targeted extensively by commercial fishing do contribute significantly to the recreational fishery. Current statistical programs remain inadequate to document such species.

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Characterization and Incorporation of Uncertainty in Fisheries Management

Introduction

In its report to Congress, the Ecosystems Principles Advisory Panel recommended an action to "assess how uncertainty is characterized and what kinds of buffers against uncertainty are included in conservation and management actions" (NMFS 1999). Specifically, ". . . decision makers should account for uncertainty with the development of flexible, adaptive, and risk-averse management strategies . . . FEPs (fisheries ecosystem plans) should identify those factors or issues which are likely to bear the greatest degree of uncertainty within the ecosystem. Stock assessment reports, prepared for each new or continuing FMP, should characterize uncertainty and indicate how that uncertainty is incorporated into the assessment." This panel was addressing needs for managed fisheries in the exclusive economic zone (EEZ) under Regional Management Council jurisdiction, but the advice is equally important and applicable for Chesapeake fisheries.

Others have argued for incorporating uncertainty into the decision-making process. Arguments include the need to provide insurance given imperfect information and inherent variability in the ecosystem (Watchman et al. 2001), enhance stock assessments and the information they provide (NRC 1998a), and improve management of the stock and the ecosystem for current and future needs (Yodzis 2001; MD DNR 1993; Weeks and Berkeley 2000). The reasons for incorporating uncertainty or providing insurance against imperfect knowledge are many, but include imperfect estimation of the number, biomass, productivity, and age structure of fish populations, incomplete knowledge of population dynamics, and poorly understood mechanisms such as environmental and ecosystem effects, interactions among multiple species, and effects of humans through harvesting, pollution, habitat disruption, and other factors (NRC 1998a, NRC 1999).

Uncertainty is simply inherent in any understanding of ecosystems regardless of the amount of research devoted to development of a system model. As the Ecosystems Principles Advisory Panel pointed out, however, "While ecosystems are neither totally predicable nor totally unpredictable, they can be managed within the limits of their predictability" (NMFS 1999). Hence, effective management of any fishery, whether from a single-species perspective or under an ecosystem-based approach, requires that uncertainty be characterized and that mechanisms mitigating the effects of this lack of complete knowledge of the fishery and ecosystem be incorporated in the decision-making process.

We take these statements to mean that fisheries management strategies that account explicitly for uncertainty and incorporate risk reduction must be devised to strengthen an ecosystem-based approach. To do so, we must have a clear representation of the uncertainties encountered in developing these strategies. In addition, specifying goals for implementing new approaches is critically important. Only then can a discussion of the means to incorporate uncertainty begin. Managers, scientists, and representatives from the fishing industry must work jointly in developing management regimes that account for uncertainty and reduce the risk of stock depletion and collapse.

Uncertainty is simply inherent in any understanding of ecosystems regardless of the amount of research devoted to development of a system model.

This chapter reviews the sources of uncertainty encountered during the decision-making process for fisheries management plans (FMPs) from both single-species and ecosystem perspectives, describes briefly current methods for characterizing and incorporating uncertainty in single-species fisheries management, discusses how the characterization of uncertainty might be applied in an ecosystem-based FMP, and proposes a set of recommendations for further research. The following sections address each of these subject areas.

Sources of Uncertainty in Ecosystem-Based Fisheries Management

We live in an uncertain world. Every decision has an associated degree of risk. As a result, we weigh the evidence and the risks associated with each possible decision and draw a conclusion based on the best available data. When we cannot assign a weight to the evidence (i.e., we are unable to determine the accuracy of information), decisions are made in a vacuum. Conversely, if we treat information as perfect knowledge, we run the risk of being wrong in our choice. Such is the case in fisheries management as well as in our personal lives. Without some indication of the precision and accuracy of the information used in decision making, we may make the wrong choices for optimal management of the fishery for current and future exploitation. Decisions that rely on an evaluation of information dependability are more likely to yield sustainable exploitation rates and prosperous fisheries.

Several sources of potential error or uncertainty exist in the data and information used in decision making. Some measures are quantifiable (e.g., sampling variability), but others are not (e.g., implementation error). Further, some are already estimated and included in current analyses, while others will need to be addressed in fisheries management.

Several types of data are relevant to fisheries management. These data sets and sources of information also must be addressed when accounting for and incorporating uncertainty into the management plan. Types of data critical to effective fishery management include information about landings by area, time period, species, size and age, and sex; data on the stock such as abundance, size and age structure, growth parameters, longevity, and natural mortality; and knowledge of how stocks interact.

Measurement Error

Measurement error basically fits into one of two error types. The first type results from noise introduced during data collection. Examples, such as miscoding of data values during transcription of a measurement, and misrecording levels of catch, bycatch, or discard, can be mitigated with good planning and data review. The National Research Council (NRC) refers to deliberate changes in the spatial and temporal extent of fishing, catch, bycatch, or other factors in reporting fishery-dependent data as "data fouling" (NRC 2000). These types of errors—deliberate or otherwise—cause variability and bias in the data that often cannot be quantified.

Measurement error can influence both the precision and accuracy of estimates of the parameters of interest to fisheries management. For example, chronic underreporting of discards or bycatch leads to underestimation of the true fishing mortality, and likely the estimate of sampling variability. Predicting the effect of

The Many Sources of Uncertainty in Fisheries Management

Measurement Error: Error in the actual data collection effort (e.g., due to gear efficiency)

Sampling Error: Variability due to sampling a subset of the population of interest (e.g., sampling fish from only ten commercial boats rather than from all commercial boats)

Model Specification: Error in the analysis or estimation due to incomplete understanding of the processes generating the fisheries (e.g., using an incorrect natural mortality rate)

Process Uncertainty: Variability inherent in the ecosystem due to influences outside management control (e.g., inherent stochastic nature of the process or anthropogenic influences)

Implementation Error: Variability due to implementation of a plan (e.g., plan implementation may not follow exactly as recommended, influencing future outcomes)

Every management decision has a degree of risk associated with it. We must weigh the evidence and the risks associated with decisions before reaching conclusions based on the best available data.

mistakes in recording data values may not be possible (e.g., daily landings for an individual boat). If the mistake is near the true value of the estimate, the effect is likely minimal. If the discrepancy is large, however, it could bias the estimate of total landings and change the standard error estimate associated with the estimate of total landings. This type of measurement error is considered unquantifiable, although evaluating biases and measurement errors retrospectively might prove possible if a specific study addresses this issue.

The natural microscale variability of the population (as well as the ability of the gear to sample the population of interest perfectly) presents an additional source of measurement error. This type of variability can occur between two trawl tows taken at the same location and time using the same gear; it is quantifiable. In the trawl tow example, taking multiple tows allows quantification of the variability of data collected at a given site and time. This source of variability is not the same as the measurement error described previously in which the recording equipment induces error. In this case, the data collection effort itself generates the error.

Sampling Error

Sampling error describes variability caused by the collected data that represent only a sample from the population of interest and differs from the measurement error discussed above. Typically, a sample constitutes the set of observations taken at several locations (and possibly times), and represents the entire population of interest. For example, the set of data collected from a winter dredge survey for blue crabs *Callinectes sapidus* conducted by the Virginia Institute of Marine Sciences (VIMS) and the Maryland Department of Natural Resources (MD DNR) makes up a sample. Since a sample is only a subset of the population, estimates vary from sample to sample, causing sampling variability.

When samples are taken using a probability-based method, such as simple random or stratified random sampling, quantifying the sampling variability is possible. Variance may be estimated from an equation (cf. Cochran 1977). If the probability-based sampling design is complex—involving clustering of elements, for example—then the variance can be estimated approximately using the delta method (Wolter 1985; Kendall et al. 1987) or through resampling techniques such as bootstrapping and jackknifing (Efron and Tibshirani 1993). Conversely, measurements based on a sample with no randomization—such as a convenience sample—could be biased and sampling variability cannot be estimated. Equations to calculate an unbiased sampling statistic (e.g., a mean or total) and its associated sampling variance use selection probabilities of the samples to assign weights to each observation. When samples are taken without randomization, then calculating these probabilities is not possible and sampling variability cannot be estimated.

Ad hoc sampling methodologies lead to biased estimates of population parameters whose precision cannot be quantified. For example, some research studies of population abundance choose sampling locations because the species of interest is known to occur at those locations. As a result, any assessment of total species abundance overestimates true abundance (since sites at which the abundances might be low or zero are deliberately excluded). Further, if these stations are chosen by design, no sampling variability occurs since the stations were chosen with certainty. Consequently, one cannot logically estimate a sampling variability for the biased abundance estimate.

Another problem often encountered is misuse of the correct method to estimate sampling variability even when taking a statistically sound sample. In a fishery-independent survey, for example, data may be collected according to a systematic sample with tows completed in a regular pattern over the study region. A common mistake, however, is treating that sample as a true random sample (in which the researcher selects sites completely at random within the study region) and calculating sampling variability using the equations for a random sample. This approach is valid only if the true spatial distribution of the species is random over the study region, without any clear trend or pattern—a situation unlikely to occur in practice. As a result, the estimate of sampling variability can be much larger or smaller, than the true sampling variability due to a systematic sample (Wolter 1985; Christman 2000). Technically, this source is not sampling error but more rightly belongs under model specification error.

Model Specification Error

In this type of error, "model" can take on several meanings. It can mean a statistical model, such as a linear regression model, or a deterministic model, such as virtual population analysis (VPA). It can represent a conceptual model, characterizing the relationships between socioeconomic factors and fishing outcomes generally acknowledged in fisheries management. In other words, "model" connotes any description relating inputs to outputs and outputs to decisions.

Errors can arise from many aspects of the models used to derive estimates. If the model has fixed parameters, such as a fixed value for natural mortality (e.g., M=0.2), but the true values are different from those given, then misspecification has taken place. Model misspecification also occurs when the true parameters that describe the resource vary in time or space. The effects of misspecification are difficult to predict since they depend on the manner in which the model uses the information. In some cases, model outputs may be quite robust to misspecification (Slooten et al. 2000); at other times, they might be quite sensitive to small changes in model parameters (Reilly et al. 2001).

Incorrectly stated relationships among the model variables (which could happen if, for example, the recruitment scenario is wrong) can also cause model misspecification. Accurate depiction of the variables' interrelationships is especially critical for ecosystem-based management in which the need exists to relate other factors that have not conventionally been incorporated. For example, management of the striped bass *Morone saxatilis* fishery in the Bay has not traditionally included prey biomass estimates (which can influence natural mortality and recruitment); neither has it included the interaction between striped bass and blue crab fisheries.

Another example of model misspecification occurs in multispecies models due to the complexity introduced by the use of ecosystem-level (rather than single-species) information. For example, if the linkages between the managed species and its ecosystem are unknown, as might happen when the food web of the managed species is not well understood, then the model is misspecified. A major limitation in developing multispecies models is the lack of knowledge of the linkages between the fishery resource and the nontarget species or between habitat and fishing gear. At present, such linkages tend to be qualitative at best (Murawski 2000).

Errors due to misspecification introduce additional uncertainty in the final decision-making process. The problem is that uncertainty is not simply or easily quantified. For models in which the parameters can be varied, researchers can address sensitivity and specificity. In addition, if misspecification occurs in the shape of a relationship (e.g., linear versus quadratic in a regression model), then appropriate model selection techniques or Bayesian model averaging approaches can identify the best model for the problem.

Process Error

Process error (NRC 1998a) represents any variability resulting from influences outside human control. The two major sources of this error type are natural and anthropogenic.

Natural Variability of the Ecosystem

In single-species or multispecies fisheries, the system under analysis will almost always have unpredictable inherent natural variability. Some of this variability may be due to our lack of complete knowledge of the system but can also result from natural fluctuations. Chaotic behavior may explain some of this latter variability and scientists have drawn on such behavior to explain why weather patterns cannot be predicted beyond 7 to 8 d (Reilly et al. 2001). Alternatively, the variability may stem from the inherent stochastic nature of the ecosystem likely caused by uncontrollable environmental factors. If such fluctuations are extreme, forecasting future landings for a given level of effort with any high degree of certainty is not possible. As a consequence, a degree of uncertainty exists that remains uncontrolled.

Anthropogenic Variability

Human activities cause additional variability that is traditionally considered beyond the control of the fisheries manager, adding to the uncertainty of managing a species or ecosystem (for example, see Rothschild et al. 1994). These sources of variability include fishing pressure on the species population when fishing ventures outside the jurisdiction under management, excess nutrient loading due to land use changes, introduction of exotic species, and other factors. These sources add uncertainty that cannot be quantified but which must be accounted for when setting the standards for future fishing activity.

Implementation Error

Implementation error results from the incorrect application of the management strategies put forward in the plan. Management actions may not always be implemented as directed. For example, marine protected areas (MPAs) might be fished in spite of their closure to commercial or recreational fisheries. If the fishermen view the MPA as a refuge, or sink, for fish recruited to the fishery rather than a nursery or other source of recruits for future fishing, it is unlikely that they will comply with the implementation plan. This type of uncertainty has been referred to as institutional uncertainty and it arises from "the interaction of the individuals and groups (scientists, economists, fishermen, etc.) that composes the management process" (O'Boyle 1993). As a result, the management plan itself introduces some uncertainty in future projections related to the fishery.

A final type of implementation error is any unforeseen consequence of implementation. Here we refer to such events as permanent changes to habitat or ecosystems (new equilibria) due to overfishing based on incorrect management advice, or the failure to recognize overfishing due to model misspecification.

A stock assessment is a model (hence, modeling error) of an inherently stochastic resource (process error) that relies on data (measurement error) and knowledge from observations (sampling error). Management decisions are then likely to be implemented (hence, implementation error). Thus, every management decision has a degree of risk associated with it.

Approaches for Incorporating Uncertainty

Model Improvement and Development

Many sources of uncertainty arise in the development and use of stock assessments. An assessment is a model (hence, modeling error) of an inherently stochastic resource (process error) that relies on data (measurement error) and knowledge obtained from observations (sampling error). Management decisions are then likely to be implemented (hence, implementation error). Unless accounted for properly, errors propagated throughout the process lead to a flawed final management plan. In the past, these errors have not been explicitly factored into the modeling.

In fact, the NRC (1998b) states "one reason why uncertainty is ignored in stock assessment models is that it is difficult to distinguish among the different types of uncertainty entering a model." These problems become exacerbated when fisheries management moves toward an ecosystem-based approach. If the assessment is multispecies or involves both species and their habitats, then the potential for error could be inflated.

In principle, a basic stock assessment proceeds as follows. Data are collected from either fishery-independent surveys or commercial landings, recreational landings, or both to obtain data for the model. The model is sometimes deterministic in which fixed inputs (data assumed to be without error) are entered into equation(s) with "known" values for the model parameters (such as natural mortality, bycatch size, and recreational fishing mortality), and the outputs are treated as exact values. This approach does not account for the various sources of variability or error in the inputs, model parameters, or model specifications.

More sophisticated models evaluate possible consequences of alternative management decisions (NRC 1998b). These models simulate future stock projections under different management options and assess the gains and risks for each. In general, the ability to predict is very limited; this fact should be represented in the simulations. These simulations provide some measure of uncertainty in the entire assessment process but do not address the various sources of uncertainty directly, either quantifiably or otherwise.

Several sources present recommendations for improving stock assessments (Walters and Ludwig 1994; NRC 1998b; NRC 2000; Fu et al. 2000; Weeks and Berkeley 2000; Wade 2000; Regan et al. 2001a; Regan et al. 2001b). A report from the National Research Council specifically addresses the means to improve fish stock assessments (NRC 1998a). In addition to upgrading the models, the NRC recommends that assessment models and related scientific work should undergo external peer review to maintain scientific integrity and credibility. The council has performed such analyses itself (c.f. NRC 1998a, 1988b). We briefly summarize some of their recommendations in the following four subsections, but urge the reader to review details in the NRC reports and its cited literature.

Improving Data

Researchers widely recommend that the quality of the input data for stock assessment models be improved, at a minimum, to help reduce uncertainty. Weeks and Berkeley (2000), for example, advise comprehensive data collection through more frequent and extensive surveys. They indicate a need for improving landings information as well as fishery-independent surveys. Others echo these same two needs (cf. NRC 2000, NRC 1998a). Implementation recommendations fall into two categories: increase the precision and value of the data collected; and collect data with uncertainty that can be quantified. The recommendations include

1) Review fishery-independent surveys to ensure that they provide the best precision for the cost, are statistically rigorous and defensible, and have sufficient statistical power to detect temporal changes in abundance.
2) Improve fishery-dependent data and vessel monitoring data through improvements to gear, vessels, sampling designs, and data collection protocols.
3) Implement formal reviews of sampling protocols to estimate commercial fishery statistics and to identify possible systematic biases due to misreporting.
4) Minimize data fouling (e.g., improve cooperation and communication with commercial and recreational fishermen).
5) Improve data management (quality control and quality assurance).
6) Conduct sampling and perform subsequent analyses with consideration of systematic biases that emerge due to misreporting.
7) Standardize catch-per-unit effort (CPUE) or recreational data across gear types and other collection methods.
8) Create reliable abundance indices (e.g., use results from well-designed fishery-independent surveys).
9) Ensure that changes to the methodology or equipment (gear, boats, etc.) do not reduce the usefulness of future data.

Effects due to input data quality can be explored using simulations while varying the input data. In a study of northeast groundfish stock assessments, NMFS (NRC 1998b) generated simulations of future stock abundance with stock assessment models in which the researchers varied current stock status to evaluate the effect of input value uncertainty on resulting outputs. One difficulty lies in identifying the way in which the data should be varied in the simulations. The intent is to mimic natural, sampling, or measurement variability in the inputs. Lack of information about these sources of variability increases the difficulty of accurately representing the impact of the unknown uncertainty.

Yet some information can indicate the size of the likely impact. The simulations could be based on distributional assumptions for the input variables, such as presuming that the estimate is an observation from a normal distribution with a variance equal to the variance estimate of the raw data (see above—e.g., bootstrapping, statistical formulae, etc). One advantage of simulations (or bootstrapping) is that results come in the form of profiles that express the cumulative probabilities for stock abundance or fishing mortality rate. At a minimum, the NRC (1998a) recommends constructing a decision table that lists the results of simulations of stock recruitment and assessment models under different rates of fishing mortality and alternative stock recruitment scenarios. The researchers caution, however, that the results cannot be used as calculated but must be modified given that the uncertainty is underestimated. Socioeconomic factors must also be considered.

Improving Parameter Values

The quality and accuracy of parameter values used in various models form another important characterization of uncertainty. At a minimum, the modeler should set values with some foundation in observation of the fishery and not base them purely on knowledge of other fisheries. Fu et al. (2000), for example, used independent estimates of stock biomass and retrospective virtual population analysis (VPA) to assess the natural mortality in a population rather than assuming a value. Values can be used in future assessments to fine tune the estimates. The NRC (1998a) recommends that independent estimates of the parameters and their variability be used in the models rather than fixing values based on other management plans. Specifically, they recommend that auxiliary information, such as indices or survey estimates of abundance, population structure, and other population parameters (including natural or fishing mortality, growth, or catchability) be obtained from fishery-independent data to improve the accuracy of assessment models.

Although both recommendations focus on obtaining more realistic values of model parameters, they do not address two other aspects related to the parameters. Specifically, the models might not reflect that the parameters could be temporally or spatially dependent and even if a better parameter value(s) is estimated, it will still have associated uncertainty not yet incorporated into the model.

For the first concern, model development should incorporate parameters that are not constant in time or space, but vary according to some rule or process (NRC 1998a). This suggestion implies that more complex models are needed even for single-species fishery management, but these more complex models should not add uncertainty from model misspecification. If the increasing complexity is not well understood or correctly described in the model, additional uncertainty could result.

For the second concern, three methods have been proposed. One method relies on Bayesian approaches, in which each model parameter is assumed to be a random variable with its own "prior" frequency distribution. The estimates from data collection are assumed to be observations from that distribution (NRC 1998a; Slooten et al. 2000; Walters and Ludwig 1994; Wade 2000). A second method to determine the distribution uses meta-analysis of similar fisheries and available statistics (NRC 1998a). A meta-analysis is a statistical method to synthesize results from disparate studies using different methods and experimental designs. The resulting frequency distribution formally describes the variability of each parameter and allows implicit accounting for this variability in the modeling. Consequently, uncertainty is automatically incorporated in the output. A third proposal uses error propagation techniques in the models (NRC 1998a; Ferson 1993). Examples of these methods include Monte Carlo simulations using interval analysis (Moore and Ferson, unpublished manuscript) or fuzzy arithmetic (Ferson 1993) to specify a range of reasonable values for the parameter. The software package EcoPath with EcoSim and EcoRanger (Christensen et al. 2000) uses a form of this method in which the likely values are listed as a range with simulations run over that range.

When carrying out such simulations, researchers should also check the sensitivity of the models to the chosen parameter values (Slooten et al. 2000; Regan et al. 2001a), verifying that the model itself is not sensitive to the value. If the model shows sensitivity, the results lack credibility since the error in misspecification of the parameter value propagates through the model and into the output. Furthermore, the error lacks quantification. These approaches can only be used to incorporate quantifiable uncertainty. If the model itself is misspecified, placing a Bayesian prior distribution on a parameter to quantify something unknown and not inherently quantifiable (NRC 1998a) leads to a false sense of accuracy.

Improving Model Specification

Questions on model accuracy lead to a related issue, namely whether the model specification itself is correct. For example, a sensitivity analysis of the effect of a parameter value on output uncertainty can address the effect of the parameter value only if the underlying model is correct. If the model is incorrect or incomplete, then the uncertainty of the process has not been addressed and will not be quantified by modifying parameter values. Model accuracy is especially critical in ecosystem-based management since the model(s) now must incorporate information about community structure and habitat for a particular fishery. The NRC (2000) recommends considering a wide range of possible stock responses in modeling instead of a single “best-fit” stock-recruitment model; this step would provide some measure of the uncertainty of the model itself. In cases for which several competing models exist, an alternative approach could be taken by running each of the competing models to determine if management conclusions are robust to the variability among the models (Rosenberg and Restrepo 1994).

If evidence exists that the model form has a measurable effect on the conclusions, then improved data collection and incorporation of additional information can perfect the models. For example, the NRC (2000) recommends that data on essential fish habitat (EFH) be collected and used in the broader scientific context of fisheries science, assessment, and management. These data can lead to better understanding of the spatial and temporal distribution of fish. Additionally, the EFH information can modify sampling designs for fishery-independent studies to increase precision.

Another recommendation is that environmental and ecosystem data be collected and monitored to support needed studies of fishing effects on ecosystems and to assess how confounding factors affect estimates of fish biomass and abundances (Rosenberg and Restrepo 1994). Additional information describing population age structure, abundance levels, and other population parameters—natural or fishing mortality, growth, and catchability—will improve the accuracy of assessment models (NRC 1998a). These findings should prove useful in developing more complex models that reflect the natural ecosystem more accurately. An important caveat, however, is that mathematically sophisticated models do not mitigate poor data quality (NRC 1998a). New model development, therefore, must go hand-in-hand with data quality improvement.

The Precautionary Approach

The precautionary approach is a type of fishery management that exercises prudent forethought to avoid undesirable outcomes with respect to stock status, yield potential, or profitability. This approach accounts for changes in fisheries systems that are only slowly reversible, difficult to control, not well understood, and subject to changing environment and human values.

When developing more sophisticated models, management needs should not constrain biological models (Yodzis 2001). Biological models enhance the study of the biological processes driving the fishery and can be used to explore which data are needed, and where and when they should be collected. Such models tend to be complex with many interactions among elements of the ecosystem. Weeks and Berkeley (2000) argue the need for "portfolio diversity"—that is, information collection should incorporate different operation uses, gear, locations, target fisheries, and other industries. In this way, ecosystem complexities along with social and economic complexities can be included in an ecosystem-based approach to management. Management plans must incorporate such reasonably well-understood models. This incorporation must allow the manager to act (i.e., the models should rest on parameters that can be readily estimated, explicitly account for uncertainty, and are simple to understand and implement). Good management models use the ecosystem-based biological models but have two important features: incorporation of uncertainty through simulations of management actions and quantitative management criteria that translate objectives into levels of acceptable risk (Taylor et al. 2000).

If a model is fully deterministic, running simulations to test its sensitivity and specificity to variability in either input data or model parameters represents only a beginning. The model itself should be modified to include random components; it should allow for variability in the outputs since they are functions of random inputs. An example of a simple deterministic relationship is $Y = mX + b$. In this model, for each value of X we get one and only one value for Y. A statistical relationship between Y and X incorporates random noise to allow for the fact that even if X is known with certainty we cannot perfectly predict a value of Y given X. This new model is written as $Y = mX + b + e$, where e represents a small deviation of Y from the value $mX+b$. The deviation term e can represent unknown effects that influence the value of Y, measurement error, or even a simplistic form of natural stochastic variation in Y's value.

In the modeling of any process, a stochastic component occurs that cannot be explained through the input variables or model parameters. For example, recruitment to a fishery varies from year to year due to naturally stochastic processes, such as weather or abundance shifts of prey or predator species. Consequently, some inherent variability is not captured and incorporated in model outputs. Adding random variability provides a more realistic model of the process under study; therefore, fishery projections should include this inherent system variability (Rosenberg and Restrepo 1994). The model correctly makes projections that become less and less accurate as the projections move into the future since the analysis accounts for this loss in accuracy.

Improving the Decision-Making Process

This section examines how management plans incorporate uncertainty. Specifically, we describe techniques that have been used or are recommended. In some cases, the techniques are quantitative (e.g., probabilistic risk analysis methods used to simulate various scenarios that determine the likelihood of certain events). In other cases, the techniques rest on risk-averse strategies to ensure that overfishing is unlikely to take place (e.g., use of target yields (F_{target}) versus maximum yields (F_{max})).

The first, and perhaps most recommended, method is the precautionary approach (FAO 1996; Restrepo et al. 1998; Butterworth and Punt 2001; Vaughan et al. 2001; NRC 2001) that "specifically requires a more comprehensive treatment of uncertainty than has been the norm in fishery assessment. This requires recognition of gaps in knowledge, and the explicit identification of the range of interpretations that is reasonable given the present information" (FAO 1996). The FAO states that "because uncertainty affects all elements of the fishery system in varying degrees, some degree of precaution is required at all levels of the system: in development planning, management, research, technology development and transfer, legal and institutional frameworks, fish capture and processing, fisheries enhancement and aquaculture" (FAO 1996). The precautionary approach recognizes potentially unacceptable outcomes and provides the means to mitigate or avoid these outcomes. Examples of undesirable outcomes include overexploitation of resources, overdevelopment of harvesting capacity, loss of biodiversity, major physical disturbances of sensitive biotopes, and social or economic dislocations. In addition, the FAO recognized that many future approaches in fisheries are ecosystem-based, stating that "where there are multiple fisheries, plans will also be required to implement precautionary approaches to their aggregate impact on the marine environment."

The precautionary approach is based on the concepts of burden of proof and standard of proof, recognizing that the environmental impacts of fishing cannot be assumed negligible until proven otherwise. In addition, the standard of proof in decisions for fishing activity authorization should be commensurate with the potential risk to the resource, while accounting for the expected benefits of the activities. The approach, therefore, includes the following actions:

1) Avoid changes that are not potentially reversible;
2) Identify undesirable outcomes and measures prior to management action so that they may be avoided altogether or promptly corrected;
3) Initiate corrective measures that can remedy the situation without delay;
4) Prioritize conservation of the resource's productive capacity when the likely impact of an action is uncertain; and
5) Make harvesting and processing capacity commensurate with estimated sustainable levels of the resource and contain any increases in capacity when resource productivity is highly uncertain.

The FAO's (1996) recommendations for implementing the precautionary approach include methods that incorporate uncertainty into the modeling stage of fishery management. Other recommendations focus on data collection or implementation planning. The recommendations include

1) Specify management plans that include decision rules in case of adverse changes in the stock, ecosystem, or environment.
2) Identify operational targets and constraints.
3) Monitor the fishery for changes as well as ancillary impacts (e.g., environmental changes, fish habitat degradation, effects on nonresource species such as birds and mammals). Monitoring should be adaptable and targeted at problem areas that arise during the implementation phase.
4) Include explicit effort-reduction measures—contingency rules that revise targets and constraints for major adverse events with low probability—that would apply in response to unpredicted and marked declines in recruitment.
5) Evaluate management options through simulation modeling.
6) Appraise data and information requirements for effective management under the precautionary approach and evaluate whether they can be met under the status quo.
7) Consider the use of marine protected areas (MPA) for small or artisanal fisheries for which quantitative approaches are not feasible (NRC 2001; Roberts et al.

2001; Seitz et al. 2001).

The FAO document on the precautionary approach also offers guidance for its use in other areas including fisheries research and technology.

Thompson et al. (2000) compared the consequences of traditional management activities with those of the precautionary approach in the management of coastal cetaceans (or marine mammals with teeth). The researchers performed power analyses and other methods to explore the consequences of alternative management actions. Their simulations indicated that the precautionary approach detected declines before traditional approaches. One reason that the precautionary approach detects declines more quickly than the traditional one is the low statistical power of many monitoring programs. The problem is most serious for populations that demonstrate faster rates of decline (Thompson et al. 2000) when lag time is too long for the traditional approaches to capture the onset of a decline. Thompson found that the level of precaution necessary depends on the magnitude of the risk of not reacting. As a result, implementing the precautionary approach requires an understanding of population size, the rate of population decline under present practices, and the social and economic costs of inaction.

In a report providing technical guidance on use of the precautionary approach, Restrepo et al. (1998) state that the "approach is characterized by three features:

1) Target reference points, such as optimum yield (OY), should be set safely below limit reference points such as the catch level associated with the fishing mortality rate or the level defined by the status determination criteria. Because it is a target reference point, OY does not constitute an absolute ceiling, but rather a desired result. An FMP must contain conservation and management measures to achieve OY, and provisions for information collection that are designed to determine the degree to which OY is achieved on a continuing basis—that is, to result in a long-term average catch that is equal to the long-term average OY while meeting the status determination criteria.
2) A stock or stock complex that is below the size that would produce maximum sustainable yield (MSY) should be harvested at a lower rate or level of fishing mortality than if the stock or stock complex were above the size that would produce MSY.
3) Criteria used to set target catch levels should be explicitly risk-averse, so that greater uncertainty regarding the status or productive capacity of a stock or stock complex corresponds to greater caution in setting target catch levels. Part of the OY may be held as a reserve to allow for factors such as uncertainties in estimates of stock size and daily allowable harvest (DAH). If an OY reserve is established, an adequate mechanism should be included in the FMP to permit timely release of the reserve to . . . fishermen, if necessary."

This same document provides technical guidance for implementing the precautionary approach (Restrepo et al. 1998), including detailed discussion of limit control rules; status determination criteria; target specification and use of a default target control rule; changes to the selectivity of fishing gear; approach in a mixed-stock situation; shifts in productivity due to environmental changes; and appropriateness of various proxies for MSY-related parameters. The report contains additional detail.

The precautionary approach is critical when applied to ecosystem-based management (Murawski 2000) since this type of fishery management differs significantly from single-species management in the level of uncertainty. The definition of overfishing has to be extended to the ecosystem level and must include

1) Effects of a fishery on the biomass of other species;
2) Ecosystem diversity;
3) Changes in species compositions;
4) Effect on prey species either directly (bycatch harvest) or indirectly;
5) Cumulative net economic or social benefits over all relevant species, habitats, ecosystems, or environments; and
6) Effects on ecologically important nonresource species.

Murawski (2000) argues that we need more conservative management of fishing capacity along with greater attention to habitat and species interactions effects under alternative management plans.

Related to the ecosystem aspect is the need to coordinate management plans as well to ensure that the interrelationships among different managed species are accounted for in the planning process (MD DNR 1993). Hinman (2000) recommends that precautionary reference points be developed for related species such as predators and prey of the managed species. These reference points create buffers to overfishing and trigger proactive measures to prevent overfishing of prey species. Such reference points should be created for both managed and unmanaged species.

Risk-averse decision making is another approach very similar to the precautionary one. In this case, the burden of proof to show that the proposed change will not harm the ecosystem or fishery under management rests with the decision maker. This approach represents a radical change from previous approaches in which the assumption was that any change would not have a deleterious effect until proven otherwise. In the risk-averse method, the assumption is that a change has the potential for negative effect until demonstrated that it does not.

The FAO report gives an example of a risk management strategy (FAO 1996). When insufficient observations exist to assign probabilities to the different possible outcomes of a management decision, decision tables would be based on maximin and minimax criteria to derive different degrees of management caution. Alternatives include performing risk analyses in which risk to the fishery is quantified in a way that balances biological risk with economic risk. Examples include Monte Carlo simulations, event tree approaches, and theoretical population studies (Mendelssohn 1979; Swartzman et al. 1987; Linder et al. 1987; Hall et al. 1988; Francis 1992; Rosenberg and Brault 1993).

Related to risk-averse strategies is the concept of insurance against model uncertainty and inherent system variability. For example, Watchman et al. (2001) recommends planning for buffer zones and MPAs as well as targeting essential fish habitat (EFH). In such cases, any area targeted as a buffer against uncertainty must be the appropriate choice or the result will become an additional source of error (implementation error). An example of the implementation of protected areas occurred in the Virginia portion of the Chesapeake Bay. The state recently enacted an expansion of a no-collection zone for blue crabs that the state estimates will reduce overall fishing pressure by approximately 6 percent (Lipcius et al. 2003).

Although not an approach that explicitly accounts for uncertainty, implementation error can be reduced by engaging stakeholders early on in the process. Any methods used to account for uncertainty should be carefully documented (Reilly et al. 2001), especially if they include expert opinion solicitation to characterize uncertainty. This documentation clarifies for stakeholders the exact approaches taken to draw conclusions and make decisions about future management actions. In addition, assessment models and management plans need to account for the effect of regulations on how fishing operations are conducted, how regulations could change the size and species composition of the catch, as well as on data collection (NRC 2000). In other words, management councils should consider the effect that proposed regulations have on data quality.

Major Findings

Aquatic ecosystems are highly variable. As a consequence, predicting the state of an ecosystem as complex as the Chesapeake Bay and its living resources will always involve some degree of uncertainty. Many sources of uncertainty exist in the development and use of fish stock assessments. An assessment is a model (hence, modeling error) of an inherently stochastic resource (process error) that relies on data (measurement error) and knowledge obtained from observations (sampling error). Management decisions are made based on assessment results, and then implemented (implementation error). Thus, every management decision has a degree of risk associated with it. We must weigh the evidence and the risks associated with various decisions before drawing conclusions that are based on the best available data. In the absence of understanding mechanisms and processes, assessing the degree of variability in the ecosystem's structure and function (and in its constituent populations) can help to make risk-averse decisions. Estimating the precision and accuracy of information used in the decision-making process can reduce risk.

In single-species or multispecies fisheries, the system under analysis will have inherent natural variability that cannot be predicted. One example is our imperfect understanding of climate effects on the ecosystem. Better understanding of this critical factor will improve in the future, but predictability is likely to remain uncertain far into the future (NRC 1998). Natural fluctuations in populations and communities could result from chaotic behavior, or it could simply represent the inherent stochastic nature of the ecosystem. Environmental factors that cannot be controlled are the likely causes. Fluctuations are so large in most fisheries ecosystems that it may always be difficult to forecast future landings with a high degree of certainty, and we should accept that constraint in managing Chesapeake Bay's fisheries.

The inherent uncertainty in ecosystem and fish population behavior requires a precautionary approach characterized by risk-averse management decisions. This approach is especially critical when applied to ecosystem-based management (Murawski 2000) in which the definition of overfishing must be extended to the ecosystem level.

Panel Recommendations

Management

1) Explicitly include estimates or statements that characterize uncertainty in each Chesapeake Bay FMP.

Whenever possible, the precision of estimates in stock assessments and in simulations derived from models should be explicitly provided in FMPs.

2) Adopt precautionary measures for Chesapeake Bay FMPs to ensure the sustainability of the fishery relative to its supporting ecosystem.

Much is still unknown about the ecosystems to be managed using FEPs; therefore, use of a precautionary approach is critical. For example, a precautionary approach would include designating fish habitat as "essential" when faced with scientific uncertainty, shifting the burden of proof from a need to establish the importance of a particular habitat to the need to provide strong evidence that a particular habitat is unimportant.

3) Follow the advice and recommendations of the National Research Council for improving stock assessments (NRC 1998a) when possible in development and revision of Chesapeake Bay FMPs.

In addition to upgrading models on a regular basis, the NRC recommends that multiple assessment models be applied whenever possible, and that the level of uncertainty be carefully evaluated. The NRC study also recommended that stock assessments undergo external peer review to maintain scientific integrity and credibility. NRC recommendations reduce the risk associated with making fisheries management decisions by improving the data used in the models.

The quality of the data used as inputs to stock assessment models should be improved as one means of reducing uncertainty. Improvement can be accomplished through comprehensive data collection with more frequent and extensive surveys. Collection of landings information should be improved as well as the fishery-independent surveys. The precision and value of the data collected should be enhanced and the uncertainty should be quantifiable for the data collected. The recommendations include

- Review fishery-independent surveys to ensure that they provide the best precision available for the cost, are statistically rigorous and defensible, and have the statistical power to detect temporal changes in abundance;
- Improve fishery-dependent data and vessel monitoring data through improved vessel monitoring systems, sampling designs, and protocols for collecting the data;
- Implement formal reviews of sampling protocols for data to estimate commercial fishery statistics and identify possible systematic biases that emerge due to misreporting;
- Minimize data fouling (e.g., improve cooperation and communication with commercial and recreational fishermen);
- Improve data management (quality control and quality assurance);
- Conduct sampling and perform subsequent analyses with consideration of systematic biases that emerge due to misreporting;
- Standardize CPUE or recreational data across gear types and across other collection methods;
- Create reliable abundance indices (e.g., use results from well-designed fishery-independent surveys); and
- Ensure that any changes to the methodology or equipment (e.g., gear, boats) do not reduce the usefulness of future data.

Improving Parameter Values used in the Models

The values set by the modeler should have some basis in actual observation of the fishery and not just be gleaned from knowledge of other fisheries. Independent estimates of the parameters and their variability should be used in the models rather than fixing values based on other management plans. Auxiliary information in the form of indices or survey estimates of abundance, population structure information, and other population parameters such as natural or fishing mortality, growth, or catchability should be obtained from fishery-independent data to improve the accuracy of assessment models.

Improving the Models Themselves

If the underlying model is incorrect or incomplete, then the uncertainty related to understanding the process has not been addressed and will not be quantified by modifying parameter values. This situation is especially critical in ecosystem-based management since the model(s) now must incorporate information about community structure and habitat for the fishery of interest. A wide range of possible stock responses should be considered in modeling instead of using a single "best-fit" stock-recruitment model; this would provide some measure of the uncertainty of the model itself. In cases where several competing models exist, an alternative approach could be taken by running each competing model to determine if the management conclusions are robust to the variability among the models.

Improving the Decision-Making Process

A precautionary approach includes the recognition of potentially unacceptable outcomes and provides the means to mitigate or avoid these outcomes. The environmental impacts of fishing activities cannot be assumed negligible until proven otherwise. The standard of proof used in decisions regarding fishing activity authorization should be commensurate with the potential risk to the resource, while also accounting for the expected benefits of the activities. The precautionary approach includes the following actions

- Avoidance of changes that are not potentially reversible,
- Prior identification of undesirable outcomes and measures to either avoid or correct them promptly,
- Corrective measures initiated without delay that achieve their purpose promptly,
- Priority given to conserving the productive capacity of the resource when the likely impact of an action is uncertain, and
- Harvesting and processing capacity commensurate with estimated sustainable levels of the resource with any increases in capacity contained when resource productivity is highly uncertain.

Needed Research and Development

4) Develop new techniques to better accommodate incomplete and variable data in stock assessments so the assessments include the effects of environmental fluctuations on Bay fisheries.

The stock assessments should include a stochastic component that allows the scientist to incorporate such fluctuations into the model to estimate the effect of variable environmental and climactic conditions on stocks and in forecasting. The new techniques should allow specification of uncertainty in key model parameters, be robust to measurement error, and include the ability to show risks associated with the estimated uncertainty.

5) Develop methods to determine the propagation of errors in assessment models for Bay species.

Much progress has been made in recognizing the effect of uncertainty in model results. More progress is needed, however, to assess the effect of multiple sources of errors in the models and to address error interactions on model output.

6) Develop models that include the ability to show the risks of various management options associated with the uncertainties inherent in the models.

Assessments should include a decision-theoretic approach to determine the risks of various management decisions on the future of Chesapeake Bay stocks. This recommendation reaches beyond the limited forecasting done now and should include estimates of the probabilities of different outcomes, allowing calculation of gains or losses.

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Indicators of Ecosystem Health and Biological Reference Points

element 6

Introduction

Under conventional single-species management, scientists and managers use biological reference points (BRPs)—metrics of spawning stock biomass and fishing mortality rates (Restrepo et al. 1998)—to set the targets and thresholds that determine the rules adopted to manage a stock. While useful as a rough gauge of the fisheries complex status, the pool of BRPs for individual stocks is insufficient for ecosystem-based fisheries management. Individual stock BRPs are derived from population models that do not consider broader characteristics of the ecosystem. Such wide-ranging features, including habitat and species interactions, affect the stock productivities and the overall productivity potential of the ecosystem.

In ecosystem-based fisheries management, the need for appropriate indicators becomes more complex. Here, the goal is to define sets of indicators that not only characterize the condition of individual stocks but also to identify targets and thresholds at higher levels of organization (e.g., aggregates of species, biological communities, and the ecosystem itself). For example, measures of habitat state and the status of predators and prey of a target species may be included in the metrics that define fisheries health and the supporting ecosystem. Broad measures of aggregate or emergent ecosystem properties—sometimes referred to as ecosystem health—can serve as indicators in ecosystem-based fisheries management. Some aggregated metrics (e.g., biomass or catch estimates of species from similar feeding guilds or from similar habitats) can be developed from data already available in Chesapeake Bay monitoring programs and fisheries statistics. Such metrics may function as effective indicators in multispecies and ecosystem-based management (Link et al. 2002).

Scientists and managers must consider a broad suite of issues, including the social and economic human dimensions of fisheries, in developing indicators that address ecosystem-level concerns in Chesapeake Bay fisheries management. Link (2002a) lists several:

- Geography of the ecosystem,
- Key species,
- Abiotic factors,
- Species interactions,
- Aggregate properties of the ecosystem,
- System-level properties, and
- Fisheries context.

Link (2002b) provides examples of what he terms “ecosystem emergent properties” and associated metrics that could serve as “proxies for decision criteria” in fisheries management. Table 1 (from Link 2002b) lists properties and metrics serving as potential indicators for ecosystem-based fishery management or which could be incorporated into development of such indicators. In addressing the needs for these performance measures, Brodziak and Link (2002) recognized the need to consider societal goals, implying that social and economic indicators are both relevant and necessary in ecosystem approaches to fisheries management.

They noted that effective ecosystem-level performance measures must be directional, sensitive, general, and feasible. Directional metrics must identify both positive and negative changes in ecosystems; sensitive metrics must detect important changes in system attributes; and general metrics should remain broadly applicable over time and space and among systems. Development of any of these metrics must be feasible given available resources. Brodziak and Link (2002) provide numerous examples of such metrics applied to the Georges Bank ecosystem and its fisheries. A similar approach could be initiated for Chesapeake Bay fisheries.

Many approaches exist to categorize potentially useful environmental and fisheries indicators that describe the state of a fisheries ecosystem. Sainsbury and Sumaila (2003) discussed approaches to develop indicators and reference points for ecosystem-based fisheries management. Not surprisingly, such indicators fall into categories that range from suites of single-species reference points (targets and limits) to indicators of emergent properties of ecosystems (e.g., food web dynamics). Sainsbury and Sumaila expect that

Table 1. Examples of measurable ecosystem emergent properties that could serve as proxies for decision criteria in fisheries management. From Link (2002b)

Systems analysis (cybernetic) metrics	Exergy, emergy, total production, total biomass, energy flux, resilience, persistence, resistance, stability, free energy, information content
Aggregate metrics	Mass flux, ascendancy, redundancy, developmental capacity, guild composition, trophic transfer efficiency, production, and biomass in a trophic level or group
Food web metrics	Connectivity, trophic links, modal chain length, percent omnivory, percent cannibalism, linkage density, allocation of species across trophic levels, interaction strength, cycles, predator–prey ratio
Community metrics	Diversity indices, size spectra, species richness, evenness, dominance, overlap indices, interaction indices
Single-species metrics	MSY, F_{MAX}, F_{MSY}, $F_{0.1}$, $F_{20\%MSP}$, SSB, MEY, YPR, F=M, Z, etc.

"best practice" reference points will evolve with the implementation of ecosystem-based management.

In a critical overview of approaches that designate indicators for ecosystem-based fisheries management, Rice (2000) noted the development or adoption of four main classes of community and ecosystem metrics: diversity and similarity indices; ordination methods; metrics of aggregate community properties; and metrics derived from ecosystem models. While all may prove useful, Rice believed that both aggregate and associated metrics that describe abundance and size classes of taxa in a fisheries ecosystem (e.g., dominance or ABC curves, and so-called *k*-dominance curves) can identify and categorize perturbed communities. The ordination methods, which depend on multivariate statistical models (e.g., principal components analysis, correspondence analysis, canonical regression), prove useful in evaluating community and ecosystem structure. Assumptions used in applying the methods, however, are difficult to satisfy and available data often are insufficient to develop reliable indicators (Rice 2000). Nevertheless, Link et al. (2002) demonstrated the application of several metrics using multivariate approaches, providing indicators of ecosystem structure in the northwest Atlantic and showing trajectories in ecosystem state over time. While no single metric sufficiently characterizes the state of a fisheries ecosystem, the authors were reasonably optimistic in concluding that combinations of biotic, abiotic, and human metrics are useful and could be adopted in ecosystem-based fisheries management.

Ecosystem services constitute important considerations in developing indicators of fisheries and ecosystem state or performance. Conserving the service function of ecosystems, while allowing yields to fisheries, is a vital aspect of ecosystem-based fisheries management, but requires appropriate indicators of services (quality and quantity). Ecosystems provide two types of services: fundamental services that maintain ecosystem resilience and function (e.g., nutrient cycling, food web dynamics) and demand-derived services (e.g., fish catches) based on human values (Holmlund and Hammer 1999). When indicators of the quality and quantity of ecosystem services are derived, their values then can be incorporated into broader indicators that categorize the overall state of a fishery ecosystem.

Conserving the service function of ecosystems, while allowing yields to fisheries, is a vital aspect of ecosystem-based fisheries management.

Environmental agencies often apply indicators that categorize environmental state or health independent of fishery management considerations. Such is the case in the Chesapeake Bay. According to the U.S. Environmental Protection Agency (EPA) Ecological Research Strategy, "Ecological indicators are any expression of the environment that quantitatively estimates the condition of the ecological resource, the magnitude of the stress, the exposure of the biological components to stress, or the amount of change in the condition" (EPA 1998). This definition encompasses a broad swath of possible indicators, ranging from concentrations of specific substances in the environment to comprehensive, integrated measures of trends in large ecosystems. Links from the EPA's web site provide many examples at various levels of complexity and integration.

In addressing indicators of ecosystem health for Chesapeake Bay, how could one or more indicators inform and contribute to ecosystem-based fisheries management? Jordan and Vaas (2000) introduced the problem in these terms: "An overarching question frequently posed by citizens and policymakers involved in restoring large ecosystems such as Chesapeake Bay is, 'Is the Bay (or other system) getting better?' That is, 'are our investments of time and money paying off in cleaner water and healthier and more abundant biological resources?'" The need is clear for indicators that provide comprehensive answers to this question at appropriate intervals. Less clear is how such indicators can contribute directly to achieving the goals of ecosystem-based fisheries management either functionally (by directly affecting management decisions) or descriptively (by evaluating the effects of fisheries management on the ecosystem).

Indicators should be simple in presentation and interpretation, robust (not sensitive to small perturbations or irrelevant factors), and predictive, but also grounded in the complexity and variability that compose essential properties of the ecosystem. Such indicators link simple descriptive statistics and complex, process-oriented mathematical models.

"Is the Bay getting better?"

"An overarching question frequently posed by citizens and policymakers involved in restoring large ecosystems such as Chesapeake Bay is, 'Is the Bay (or other system) getting better?' That is, are our investments of time and money paying off in cleaner water and healthier and more abundant biological resources?"

Biological Reference Points

Biological reference points for single-species fisheries typically form limits (thresholds) or targets for fisheries management based on the population ecology of the harvested stock (Caddy and McGarvey 1996; Overholtz 1999). Generally, these reference points are adopted to prevent collapse or long-term decline of stocks and may be derived to maximize production or economic benefits. They typically are expressed as levels of spawning stock biomass and fishing mortality rates that maintain desirable levels of spawning stock biomass, recruitment, or yield. Limits, or thresholds, constitute reference points that may cause significant risk to the stock if exceeded. Targets, on the other hand, represent desirable levels of the indicators; these are usually, but not necessarily, conservative regarding the long-term integrity of the stock. For example, the fishing mortality rate that maintains the spawning stock (SSB) at 10% of its unexploited biomass ($F_{10\%}$) could be a threshold, or a limit not to be exceeded. Alternately, a more conservative $F_{20\%}$ (SSB maintained at 20% of unexploited biomass) could be a target rate for fishing mortality that maintains reasonably high yields with minimum risk of overfishing or stock collapse.

In an ecosystem context, BRPs should extend beyond a single stock to include multiple fished populations, predator–prey interactions, and total system removals. Conceptually, a fished species that also serves as prey for predators might produce high yield to a fishery at a relatively low spawning stock biomass. High fishery yields of the prey species, however, might limit production or sustainable biomass of its predators. Suites of single-species BRPs can function as indicators of the status of stocks in ecosystem-based management, even if they prove insufficient as stand-alone indicators (Sainsbury and Sumaila 2001).

The particular BRPs most effective in multispecies fisheries are not intuitively clear. For example, Collie and Gislason (2001) found that BRPs for prey and predator stocks in the Baltic Sea shift with changes in community structure and environmental regime. They concluded that stock stability for prey species is quite sensitive to predation mortality rates and that biomass-based BRPs from stock-recruitment and production models performed better than those predicting appropriate fishing mortality rates from yield-per-recruit models. In contrast, BRPs that set appropriate fishing mortality rates to prevent growth overfishing can protect predator stock levels. This contrast for prey and predator stocks could be a function of inaccurate estimates of natural mortality rates used in yield-per-recruit (YPR) models. More likely, however, differing life histories are causing the difference. Prey species are typically small, fast-growing, variably recruiting species, while predators have opposing characteristics.

It is axiomatic that all species cannot be harvested at their maximum sustainable yields in a multispecies fishery. For example, Roell and Orth (1998) determined that predators (smallmouth bass) and prey (crayfish) in a river could not both be harvested at maximum sustainable yield; increasing the biomass of one predator in the system could lead to lower biomasses of competing predators. In Chesapeake Bay, some assert that conservative management (i.e., low fishing mortality rates) of striped bass for high spawning stock biomass, in combination with non-conservative harvest of a principal prey species (Atlantic menhaden), has led to food limitation and slower growth rates in the predator (striped bass) population (Jacobs et al. 2002). Setting appropriate BRPs (biomass and fishing mortality rate indicators) for these interacting species is important for effective management of their fisheries, but also fits within the broader context of ecosystem-based fisheries management in the Bay.

Existing Fishery and Ecosystem Indicators

Traditionally, the only indicators routinely available for most Chesapeake Bay fish and shellfish species were annual commercial landings and recruitment indices. Many publications, for example, used historical landings to gauge trends in the Chesapeake Bay oyster resource; in some cases these same data were extrapolated to estimate the ecological impacts of declining stocks (e.g., Newell 1988). Although fishery-dependent data can reflect long-term trends in the relative abundance of individual populations and are essential to fisheries management, they suffer from various biases and sources of variability unrelated to the actual status of fished populations and the ecosystem. Quantitative, fishery-independent assessments as well as estimates of biomass and BRPs have been developed in recent years, but only for a few species (notably blue crab *Callinectes sapidus* and striped bass *Morone saxatilis*). Fishery-independent indices of juvenile abundance for several fished and non-fished species in Chesapeake Bay and its tributaries do exist, however. Decades-long time series are established using consistent methodology and can, therefore, readily support multispecies analysis and interpretation in an ecosystem context (Vaas and Jordan 1990).

Several indicators now exist for components of the Chesapeake Bay ecosystem: phytoplankton, zooplankton, benthic infauna, submerged aquatic vegetation, contaminant burdens in fish and shellfish tissues, and elements of water quality and physical habitat. Each has value for information integration of that particular component and is evaluated relative to specific goals or criteria. Using multivariate statistical analysis, Jordan and Vaas (2000) combined several of these indicators—along with others—into an “index of ecosystem integrity.”

The Chesapeake Bay Program (CBP) produces a large set of “environmental indicators” to illuminate trends in water quality, living resources, and management measures (CBP 2002). These well-documented indicators are available online for public use. In concert, they offer a fairly comprehensive view of Bay trends and restoration efforts and satisfy some of the criteria for ecosystem indicators described in Table 2 and Table 3. Many of these indicators relate to specific fishery stocks in Chesapeake Bay. From a fishery-ecosystem perspective, however, the CBP indicators do not include the multispecies and species–habitat interactions that satisfy the need for more integrative indicators. Presently, interpreting such a large suite of individual indicators in an integrated ecosystem context is difficult or impossible.

Table 2. Examples of existing fisheries ecosystem indicators for Chesapeake Bay.

Indicator (reference)	Data Requirement	Temporal Resolution	Spatial Resolution	Interpretation
Seine assemblage (Vaas and Jordan, 1990)	Juvenile fish surveys	3-year average	Estuarine tributaries	Long-term changes in multispecies recruitments and forage base; ecosystem integrity
Bottom trawl species richness (Carmichael et al., 1992)	Trawl samples, basic water quality	Monthly to annual	Small to medium-sized tributaries	Links fish assemblages to hypoxia and urban land use
Index of ecosystem integrity (Jordan and Vaas, 2000)	Seines, trawls, water quality, SAV, plankton	Annual	Tidal tributary segments	Integrated measure of ecosystem health; sensitive to land use patterns
Chesapeake Bay report card (Chesapeake Bay Foundation)	Various, historical baselines	Annual	Whole Bay	Living resources status and management achievements
Public health advisories for contaminant risks of consuming fish and shellfish (state environmental and public health agencies)	Contaminant concentrations in edible tissues	Annual	Sub-tributary	Safety of consuming fishery products; temporal and spatial trends in toxic contaminants
Chesapeake Bay Program Environmental Indicators	Water quality, living resources, environmental management	Annual	Bay and watershed	Status and trends for a large variety of indicators

Sometimes, the phrase "indicators of ecosystem health" is interpreted more narrowly and literally than intended here, specifically referring to risk of disease or toxic contaminants for human, plant, or animal health. Plant and animal diseases can be associated with degraded environments, but also frequently occur in the absence of obvious human influences. For example, the parasitic diseases MSX and Dermo that have decimated oyster populations in Chesapeake Bay appear to be just as virulent in clean environments as degraded ones, with disease intensity and related oyster mortality closely associated with salinity levels (Jordan 1995; MD DNR 2001). Although human activities have provided vectors for these diseases at times through the transplantation of infected stocks, the parasites also thrive and spread in the absence of human intervention or apparent pollution.

Fish and shellfish consumption advisories (Table 2) reflect the human health risks of consuming tissues contaminated with various toxicants, including heavy metals, metalloids, and various organic compounds. In some cases, the contaminants can be linked to specific sources or localities (effluents, harbors, industrial facilities), but often reflect widespread

Table 3. Examples of potential fisheries ecosystem indicators for Chesapeake Bay.

Indicator	Data requirements	Temporal resolution	Spatial resolution	Interpretation
Multispecies habitat suitability indices	Water quality, food, physical habitat characteristics, and extent	Seasonal to annual	Baywide by segments	Habitat suitability for selected guilds; may be sensitive to water quality and physical habitat alterations
Multispecies fishery economic indicator	Optimum and realized yields for fisheries of interest	Annual	Baywide by state or NOAA code fishery zone	Overcapitalization, overfishing, underutilized species, ecosystem health from a fisheries perspective.
Multispecies biological indicator	Abundance, age, size, distribution of selected species	Seasonal or annual	Baywide by state or NOAA code fishery zone	Ecological and biological integrity of fishery species complex; multispecies reference points

contamination of the environment from diffuse nonpoint sources. The recently publicized stricter fish consumption advisories for Chesapeake Bay, for example, apply mainly to ubiquitous contaminants including methylmercury and polychlorinated biphenyls (MDE 2003). Toxic algal blooms and bacterial contamination that cause advisories and shellfish bed closures can be associated with eutrophication or contaminated discharges, but also can result from natural causes. Indicators of risks to human and animal health contribute to a broader understanding of ecosystem integrity, but more comprehensive indicators are needed to gauge the status of the Chesapeake Bay ecosystem and its fisheries.

One type of indicator that may prove useful to fishery managers links harvested species to habitat conditions (Table 3). For example, if fished populations were limited by water quality, forage, or physical habitat, managers could theoretically take action to correct the limiting conditions. A simple index, based on species richness in samples obtained using a small bottom trawl, gave an accurate indication of habitat quality for smaller estuarine tributaries of the Bay (Carmichael et al. 1992; Jordan and Vaas 2000). Another type of indicator could gauge more broadly the “health” of the ecosystem from a fisheries perspective by incorporating the abundance and size or age distributions of multiple species. Departures from a desirable balance, defined in terms of human values or theoretical considerations, could trigger management actions (e.g., reducing or increasing fishing mortality on specific populations to restore predator–prey ratios). Indicators of this type would be equivalent in principle to multispecies biological reference points.

A composite index of juvenile fish and forage species has been used to compare multispecies recruitment patterns to a baseline, forecast future patterns, and correlate with measures of climatic and environmental change. With enhancements, such as added color, to represent different functional or tolerance groups, graphic snapshots can effectively communicate multispecies trends to a wide audience (Figure 1).

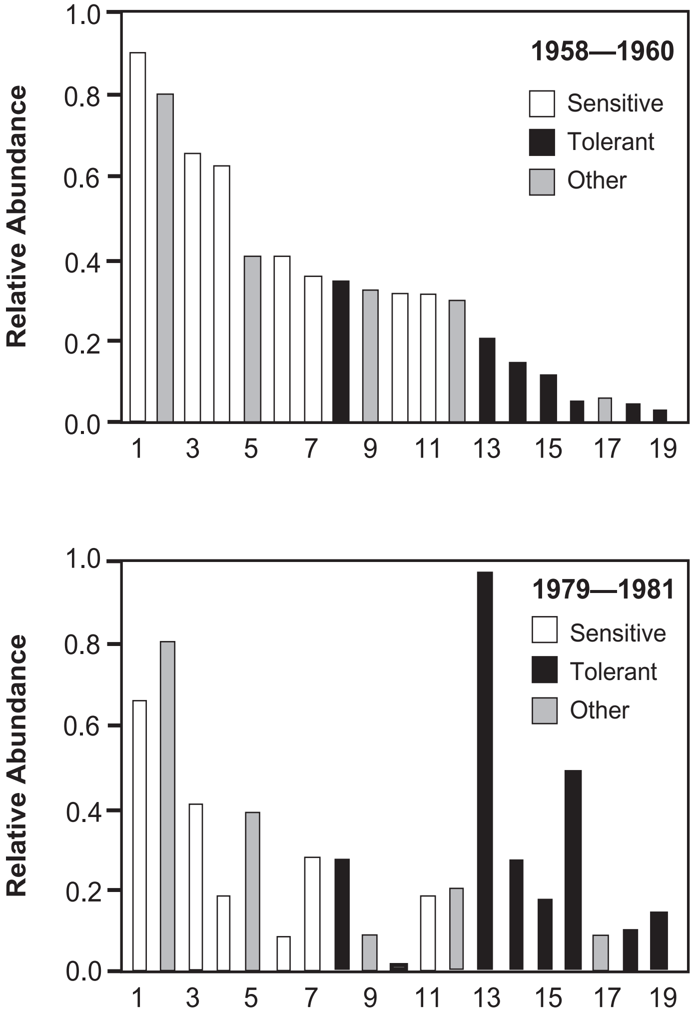

Figure 1. Relative abundance of 19 species of fish from Maryland Chesapeake Bay seine surveys (3-year averages). Species occur in the same order on both charts. Species were classified into “habitat sensitive,” “habitat tolerant,” and “other” based on analyses by Jordan and Vaas (1990). Changes over decades were interpreted as symptomatic of ecosystem degradation.

A multispecies economic indicator may also prove useful. For instance, the combined economic yield of several important species could be indexed to an integrated estimate of optimum yield for those fisheries (Table 3). A predominance of overcapitalized fisheries or overfished species would result in low indicator values; values would rise only under more successful management regimes. Target values for such an indicator could guide management toward both economic and ecological goals. De Leo and Levin (1997) asserted that ecological integrity is too complex for accurate expression by a single indicator. Link et al. (2002), as well as Brodziak and Link (2002), reached the same conclusion for ecosystem-based fisheries management. Any single indicator will most likely not satisfy the needs identified by this fisheries ecosystem plan (FEP). Conceptually, however, a small suite of indicators could

1) Link the integrity of fish populations and communities to habitat conditions,
2) Assess the role of fisheries in modifying the structure and function of the Chesapeake ecosystem, and
3) Measure the long-term productivity and economic performance of the Bay’s fisheries.

Objectives for Indicator Development

In ecosystem-based fisheries management, determining the primary goals and objectives constitutes a primary concern. Is the emphasis on the fishery or the ecosystem? Are we mainly concerned about the impacts of fisheries on the ecosystem, or of ecosystem variability on fisheries? Clearly, both concerns demand attention, but may require different perspectives and approaches for development and implementation of indicators. Objectives that could be addressed by development of fishery-

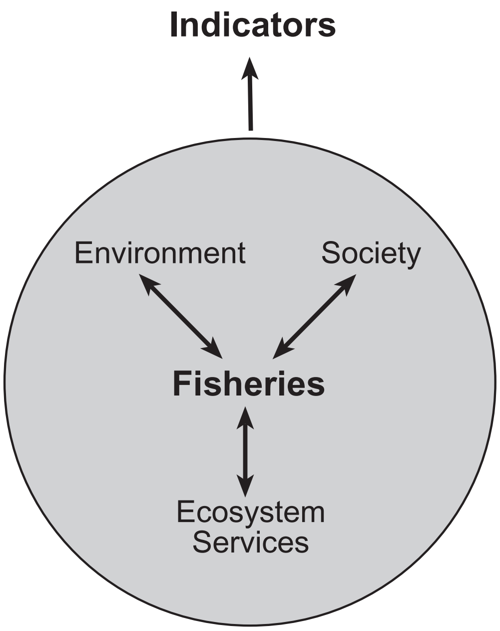

Figure 2. Ideally, indicators integrate information from ecological, environmental, and social dimensions. Here, the focus remains on fisheries—both their role in the ecosystem and how the ecosystem affects them. All of the components, including the indicators, vary over time and space.

oriented ecosystem indicators include:

1) Evaluate and predict the impacts of fisheries management on ecosystem health.
2) Evaluate and predict the impacts of ecosystem integrity on the performance of fisheries and fished populations.
3) Identify changes in fisheries management to improve ecosystem health.
4) Identify changes in fisheries management to improve the abundance, diversity, and yield of fished populations and prey species.
5) Identify changes in environmental management to improve the abundance and diversity of fished populations and prey species.
6) Account for unpredictable or uncontrollable impacts on the ecosystem (e.g., major storms, climatic variations, and other events or trends external to the ecosystem).

Development of Indicators

One plan that proposes an approach for developing essential elements of indicators of ecosystem health uses Boyle (1998) as a foundation.

1) Incorporate relevant societal goals (as established by the CBP and state or interstate fishery management plans).
2) Use as a foundation, a time-dependent conceptual model of the Bay ecosystem that predicts how the system (and, therefore, the indicators) is expected to respond to management. This conceptual model should not be based on equilibrium assumptions, as are most food web or network models. It must include a prediction of long-term change in the ecosystem that explains the need for parallel changes in the indicators.
3) Include multiple dimensions that encompass several species, habitat variables, and ecosystem complexity as well as structural and functional attributes.
4) Incorporate variability (both spatial and temporal) and ensure application over large spatial and temporal scales. The Index of Biotic Integrity (IBI) approach to indicators (e.g., Karr 1981) generally does not encompass temporal variability, which some view as a deficiency.
5) Use data from existing long-term monitoring programs.

Synthesis of this information provides a clear and compelling presentation to managers and the public. Schiller et al. (2001) offer sound advice on the necessity of presenting environmental indicators in an easily understandable form to stakeholders and suggest approaches to achieve this goal. Figure 2 portrays a conceptual overview for developing comprehensive indicators.

Process of Indicator Development

1) Evaluate whether existing indicators can be adapted to meet the requirements of an ecosystem-based approach to fisheries management. Such an adaptation is likely to be at least partially possible as Link et al. (2002) discovered in an evaluation of potential for ecosystem-based fisheries management in the northwest Atlantic marine ecosystem.
2) Make appropriate modifications to existing indicators or establish a framework for new indicators. The link between indicator development and monitoring programs (see Monitoring Element) in the Bay is clear. Suitable monitoring programs will contribute importantly to the development of environmental and fishery-ecosystem indicators.
3) Secure the resources to develop a detailed work plan for the development and implementation of indicators that prove useful in ecosystem-based fisheries management.

Application of Indicators

Clearly, fisheries managers, policymakers, commercial and recreational fishermen, and the concerned public constitute the audience for indicators. Each group, however, will have different reasons for requiring such information. Managers need figures that translate into immediate action; policymakers require indicators that provide long-range predictions and the ability to evaluate the effects of policy decisions. Fishermen may concern themselves with the implications of indicators for short-range economic or recreational horizons. The general public's needs likely orient more toward the status of fisheries, ecosystem health, and the long-term performance of conservation efforts. A carefully selected indicator or set of indicators should meet all of these needs.

Murawski (2000), discussing effective ecosystem indicators in a fisheries context, recommended ". . . the development of simple, robust indices of ecosystem state that gauge . . . production, diversity, and variability," further emphasizing that indicators should have the capacity to predict the results and effectiveness of management. Success in reaching objectives and satisfying all stakeholder groups in Chesapeake Bay will depend primarily on the accessibility, clarity, and edifying value of the indicators.

Major Findings

A primary question looms over the restoration of the Chesapeake: "Is the Bay getting better?" In other words, "Are our investments of time and money paying off in cleaner water and healthier and more abundant biological resources?" The need is clear for indicators that can answer this question comprehensively as restoration proceeds. Less clear is how such indicators might contribute to ecosystem-based fisheries management, either functionally (by directly affecting management decisions) or descriptively (by evaluating the effects of fisheries management on the ecosystem).

Indicators must be simple in presentation and interpretation, robust (i.e., not sensitive to small perturbations or irrelevant factors), and predictive. At the same time, they must accommodate the complexity and variability that constitute essential properties of the ecosystem. Such indicators can form an intermediate step—in terms of time and effort, data organization, and realism in representing the system—between simple descriptive statistics and complex, process-oriented mathematical models. The FEP offers a few examples of real and hypothetical indicators of the Chesapeake ecosystem and outlines key principles and a process for indicator development and application.

Development of integrated, comprehensive indicators of ecosystem health that catalog and project the state of the ecosystem and its fisheries will assist in applying ecosystem approaches to fisheries management. Such biological reference points (BRPs), targets, and thresholds can become triggers for fisheries management actions. These indicators will be applied to individual managed species; they will, however, be based on and can respond to multispecies and ecosystem-level concerns. At present, many simple indicators and biological reference points are available, with some integrated indicators under development (Jordan and Vaas 2000). A shift towards multispecies and ecosystem-based fisheries management, however, will require additional effort to develop indices of Bay health.

Conclusions

1) Several indicators have been proposed or developed and published that are relevant to the Chesapeake Bay FEP, although more are needed. None of the existing indicators appears to satisfy fully the need to link fisheries with the supporting ecosystem.
2) Existing long-term monitoring programs on fisheries and ecosystem attributes may satisfy data needs for future indicator development (including BRPs, targets, and thresholds) without requiring major new monitoring.

Panel Recommendations

Management

1) Identify the audience.

A carefully selected indicator, or set of indicators, could meet the needs of most user groups. Fisheries managers, policymakers, participants in commercial and recreational fisheries, and concerned citizens form the obvious audience. Each of these groups, however, has different reasons for needing the information. Success in reaching these groups depends primarily on the accessibility, clarity, and informative value of the indicators.

2) Illustrate how fisheries managers, environmental managers, or policymakers can use one or more indicator.

Detailing the usefulness of the indicators is a key step in implementing the FEP. Proposed indicators should be presented to target audiences with full explanation of data requirements, calculations, interpretations, and reporting methods.

3) Establish and implement a process for formal adoption of indicators.

No matter how well crafted, indicators will prove ineffective unless accepted and promoted at the highest institutional level with wide publicity among stakeholders. Chesapeake Bay Program adoption of a set of fisheries ecosystem indicators should form an important goal as the adoption process provides opportunities for thorough review and consensus at technical, management, and policy levels.

4) Apply integrated indicators of ecosystem health that explicitly include information on fish stocks, their habitats, and interacting species.

In many cases, existing long-term monitoring programs in Chesapeake Bay should satisfy data needs for indicator development without major new monitoring efforts. Development of appropriate indicators, nevertheless, remains a major task along with identification of the particular indicators most likely to support ecosystem-based fisheries management under an FEP.

5) Establish a process for routine updating and reporting of indicators.

Indicators of fishery ecosystem status have inherently low frequencies, taking months or years to collect, assemble, and process relevant data. Detectable changes can take five to ten years or more before showing significant trends. Fishery ecosystem indicators should be reported annually, but year-to-year variations usually are not indicative of management success or failure.

Needed Research and Development

6) Initiate a process to develop indicators of ecosystem health for Chesapeake Bay.

The research required to develop indicators of fisheries ecosystem health generally is synthetic rather than primary. One key question is, "How can data from existing monitoring programs be used or combined with other information to develop indicators?" Both a strategy and a plan to undertake the synthesis effort are needed.

7) Apply the criteria, objectives, and process outlined above to develop suitable candidate indicators.

A successful effort will result in

- Greater understanding of relationships among fisheries, the ecosystem, society, and the environment;

- Robust, consistent, public reporting of fisheries and ecosystem condition; and
- More responsive management and policy development regarding ecosystem integrity and the multispecies nature of fisheries.

8) Develop and apply integrated indicators of ecosystem health that explicitly include information on fish stocks, their habitats, and interacting species.

When possible, use existing long-term monitoring programs in Chesapeake Bay to satisfy data needs for indicator development. Development of appropriate indicators, nevertheless, is a major task. The kinds of indicators most likely to support ecosystem-based fisheries management under an FEP must be identified.

9) Develop or modify biological reference points (BRPs) within a multispecies context for ecosystem-based management of Chesapeake Bay fisheries.

These reference points include stock abundance (biomass), fishing mortality rate targets, and thresholds that indicate stock status. In an FEP, they should reflect interactions among species (e.g., predator–prey and competitive interactions) and essential ecosystem services provided by exploited species (e.g., the roles of filter feeders in controlling standing stocks of plankton, increasing water clarity, and modifying nutrient cycles).

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element 7

Monitoring in Support of Ecosystem-Based Fisheries Management

Introduction

Monitoring is an essential component of a fisheries management system. Effective monitoring is not only a tool for management plan evaluation, but also provides data for stock assessments. In addition, an ecosystem-based approach to fisheries management should include long-term monitoring that assesses the changing state of the ecosystem along with the effects of fishing on it (NMFS 1999). Monitoring programs should also evaluate whether management actions are protecting fished stocks as well as the communities, habitats, and water quality upon which these stocks depend. The Chesapeake Bay Program (CBP) recognized the need for living resources monitoring from its outset (CBP 1988) although calls for improvements and coordination have also been made (STAC 1996, 1997).

Cronin (1983) defined monitoring as follows, "Monitoring is the systematic sampling and measurement over time of variables which describe the abundance and distribution of biological resources. . ." He added, "Monitoring programs should be designed to accomplish one or more of the following:

1) Determine the time and/or space scales of natural variability which characterize the properties or processes of the system,
2) Describe significant changes over time and space in components and processes,
3) Detect and measure changes in properties and processes that may be caused by human activities,
4) Determine when such changes are in violation of environmental laws and regulations."

Since Cronin wrote these words, fisheries management has become a much less descriptive process and more closely analogous to human actuarial science. This shift has required better and more comprehensive monitoring and modeling of fish stocks. The stock assessment practice of establishing the basic biological characteristics of a species (longevity, growth, age at maturity, fecundity) allows parameter estimates of an unfished population and comparison of present conditions to those of the virgin stock. From the various mathematical models used, several important "biological reference points" (e.g., maximum sustainable yield or percent spawning stock biomass compared to the virgin stock) can be chosen as targets, thresholds, or both for the stock. These reference points, derived from stock monitoring, are themselves indicators of stock status (see Indicators Element). Current stock assessment analyses are much more data intensive than previous assessments for fisheries management. Consequently, historic goals of monitoring require amendment, especially within the context of ecosystem-based management. We suggest the following additions to Cronin's list

5) Fisheries monitoring programs should provide data to estimate input parameters for specific single-species and multispecies stock assessment models.
6) The scope of monitoring programs must be sufficiently broad—in geography and time—to provide reliable data that characterize the species of interest.
7) Fishery monitoring programs should embrace a wide range of collected information. Surveys should include data on habitat, water quality, and associated species, while assuring that other measurements do not compromise the survey goals.

Monitoring in the Ecosystem Context

Since the fisheries ecosystem plan (FEP) is for fisheries, we limit our concept of monitoring to issues dealing directly with fish and fisheries management. A broader ecosystem view would cover the monitoring of many elements—shorebirds, submerged aquatic vegetation, water quality, benthos, phytoplankton and zooplankton, flow, habitat, and toxicants. The CBP (CBP 1988) and associated support groups have overseen one such comprehensive monitoring program since 1984 (see Appendix 1 at the end of this element). The Chesapeake Bay monitoring program collects comprehensive data on 19 physical, chemical, and biological characteristics to afford an ongoing environmental description of the Bay.

The Chesapeake Information Management System (CIMS), an organized, distributed library of information and software tools that strengthens basinwide, public internet access to Chesapeake Bay information (http://www.chesapeakebay.net/cims/) provides access to these and other monitoring data.

Many fish species important to the Bay ecosystem are broadly distributed along the coast and into the exclusive economic zone. Here, we limit the geographic scope of fisheries monitoring to the confines of the Chesapeake watershed and those areas outside the Bay under the jurisdiction of the state management agencies. The FEP cannot impose monitoring or management plans on other jurisdictions. To effectively monitor and manage species that depend on the Bay ecosystem during critical life stages, however, both monitoring and management must be coordinated and comprehensive throughout the species' ranges. Managers of Chesapeake fisheries must incorporate fisheries and ecosystem monitoring information from regions beyond the boundaries

Table 1. Summary of biological, fishery-dependent, and fishery-independent data requirements for single-species analytical stock assessment models (see Removals Element).

Data Category	Assessment Type	Data Description
Biological/Life History	Partial	Growth (length/weight)
		Maturity schedule
		Fecundity
		Stock boundaries
		Migration patterns and schedules
		Partial recruitment schedules
		Longevity/Natural mortality rates
		Life history strategies (reproductive and behavioral)
Fishery-Dependent Data	Analytical	Catch, landings, and effort: commercial and recreational
		Biological characterization of the harvest (size, sex, age)
		Gear selectivity
		Discards/Bycatch
Fishery-Independent Data	Analytical	Biological characterization of the population (size, sex, age)
		Fishing mortality rates
		Estimates of annual juvenile recruitment

of the Bay and its watershed into their fishery management plans (FMPs) when such survey information appears relevant.

Data Needs for Ecosystem-Based Management

Single-Species Context

A suite of standard and accepted analytical frameworks (e.g., virtual population analysis [VPA]), biomass dynamic production modeling) are useful in assessing stocks, projecting future stock size, evaluating recovery schedules, developing rebuilding strategies for overfished stocks, setting allowable catches, and estimating exploitation rates. Various methods also integrate the biological and fisheries resource systems to allow evaluation of alternative management strategies on stock status and fishery performance. These well-established and tested approaches have specific data requirements for biological (life history), fishery-dependent, and fishery-independent information (Table 1). The approaches yield two classes of stock assessment models used in fisheries science: partial assessment (based solely on understanding a species' biology) and full analytical assessment (based on both biology and fishery data).

Multispecies or Ecosystem Context

Traditional stock assessment and management approaches are based on a single species. When the fishery exploits a set of related or dependent species, or the harvest of one community member affects the health of the entire system, single-species assessment and management can lead to erroneous or ineffective conclusions and management strategies. Single-species management does not consider the linked and interactive population dynamic processes that occur in complex ecosystems. Current single-species management attempts, with some success, to manage the populations of several predator species (e.g., striped bass *Morone saxatilis*, weakfish *Cynoscion regalis*, bluefish *Pomatomus saltatrix*) simultaneously in the Bay. Estimating the effect that such an approach may have on unmanaged species is not currently possible.

Multispecies fisheries—trawl or pound net fisheries for example—land a mix of species. Single-species assessment and management cannot achieve optimal production from the ecosystem or insure the sustainability of any individual member species. Furthermore, aggregate regulations based on single-species assessment and management strategies are often impractical or overly burdensome for a multispecies fishery.

Moving management of Chesapeake Bay fisheries toward ecosystem-based, multispecies management models has generated strong interest in the Bay management community (Houde et al. 1998; CBP 2000). Such models require many of the same input parameters as traditional single-species models but may demand additional understanding of species interactions (Daan and Sissenwine 1991). At the multispecies or ecosystem level, the data needed to understand linked population dynamic processes (trophic dynamics, bioenergetics, and biomass flow through the food web) are generally not available. Multispecies management also requires understanding of "technical interactions," including bycatch of nontarget species, discard losses of undersized or oversized individuals of target species, and gear selectivity (Miller et al. 1996).

Species of Interest

In an ecosystem context, the entire complex of species is of interest; each species has a role as predator, prey, or competitor, even if that role is not well understood. From a fisheries management or modeling viewpoint, however, the number of species to consider is finite, although large. The list should include those species managed by any of the management entities covering the Chesapeake region, plus other species of particular economic or ecological importance (see Managed Fisheries Chapter).

Fishery-Independent Surveys

For each of the managed species (along with key interacting species that are predators or prey of these species), fishery-independent surveys must collect data necessary for single-species and multispecies analytical assessments. Some species are year-round residents and their life histories expose them to capture by several types of gear. Some use Bay waters only to spawn or as a nursery for the juveniles. Others are summertime residents, using the Bay as a feeding ground. Because of this variety, surveys must be designed with care. No single capture gear can provide reliable abundance and size data for stock assessment models for all species. Even with a well-designed and well-executed suite of monitoring surveys, we can provide estimates for only those life stages and time periods during which a species resides in the Bay. Involvement of Chesapeake Bay agencies in the Northeast Area Monitoring and Assessment Program (NEAMAP) will enhance cooperation and data collection efforts among Atlantic coastal states in the Northeast region (NEAMAP 2003).

In any case, a suite of integrated, wide-scale fishery-independent monitoring surveys conducted with appropriate gears is needed. Such a suite of surveys must be well planned, well executed, and well funded. Each survey element must estimate one or more of the assessment model parameters, or at least the estimable portion of those parameters, given the limited use that some species make of Chesapeake waters.

By knowing the explicit management goal for a particular species or group of species in advance, the number of fishery-independent monitoring surveys required becomes smaller. For example, a manager could say, "We want to manage the striped bass, Atlantic menhaden B*revoortia tyrannus*, bluefish, weakfish complex based on a multispecies virtual population analysis (MSVPA) to maximize the catch of striped bass while maintaining the menhaden spawning stock biomass at 30% of its virgin condition." In response, an assessment scientist could then

1) Consider the questions implicit in such a scenario,
2) Identify the necessary model parameters to conduct an appropriate analysis,
3) Design a set of surveys to collect the data for parameter estimation, and
4) Define the data elements to be collected in each survey.

Managers seldom pose such specific questions, however, so the set of required monitoring surveys must remain sufficiently broad to answer anticipated management questions. Although broadening the surveys can incur additional expenditures, collecting supplementary data will enable managers to answer unanticipated questions in the future.

Fishery-Dependent Surveys

Fishery-dependent monitoring is simple in concept, yet implementation of such surveys often proves difficult. Catch statistics essential for estimating total removals (levels of landings, bycatch, and discard); effort expended to achieve the catch; and biological characterization of the catch (length, weight, age, sex, and possibly diet composition of harvested fish) must be estimated reliably for both the commercial and recreational sectors of the fisheries.

Several fishery-dependent approaches have been used; each has problems with accuracy, precision, reliability, or data resolution. For commercial fisheries, in theory, a trip ticket system in which both the fisherman and the purchaser report daily catches should provide reliable data, and computer technology allows immediate updates. Problems can arise, however, in the accuracy of catch and effort reporting, catch allocation to specific gears, area identification of reported catch, with difficulties for other elements cropping up as well. Nonetheless, the Atlantic Coastal Cooperative Statistics Program (ACCSP, http://www.accsp.org/)—a partnership program of the 23 Atlantic coast state and federal fisheries management agencies—envisions trip ticket systems in place for each East Coast state.

A complete fishery-dependent assessment also requires reliable estimates of bycatch, discards, gear selectivity, and possibly gear efficiency. Obtaining such estimates requires placing observers on fishing boats and conducting detailed studies of commercial gears and their efficiencies. Recreational catch can be monitored using a combination of creel and telephone surveys to estimate catch rates and effort, respectively. The NMFS Marine Recreational Fisheries Statistics Survey (MRFSS, http://www.st.nmfs.gov/st1/recreational/) has existed for over 20 years and provides useful broad-scale estimates. Improvements in spatial and temporal resolution are desirable, but expensive.

Trophic/Diet Composition Surveys and Monitoring

A missing element in traditional single-species assessment techniques is the understanding of trophic interactions among species. Multispecies and ecosystem management analyses or modeling requires incorporation of these interactions both qualitatively and quantitatively. In a multispecies virtual population analysis, for example, analysis of predator food habits provides required natural mortality rates of young fish (Magnusson 1995). Diet composition monitoring is essential in the development of such models. The fishery-independent and fishery-dependent programs described above can provide fish samples to monitor diets. In an FEP, adequate diet data for species supporting important Chesapeake Bay fisheries must be obtained and monitored (see Food Web Element).

For many species important in Bay fisheries, diet composition studies have already been conducted. To understand the trophic dynamics and the temporal and spatial variability of our system fully, however, such studies must become a fixture of the monitoring program. In different parts of the Bay, or at different times of year, a species may eat different foods. Diet habits may also change over the long term, with such changes signaling important regime shifts that affect prey abundances in the ecosystem on decadal time scales.

Not every species requires complete food-habits monitoring as frequently as determinations of its overall abundance and age distributions. Periodic monitoring of food habits may suffice. A systematic, rotating schedule could ensure that the food habits of any particular species would be monitored every few years.

Scope, Frequency, and Longevity

For any monitoring survey, the data become most valuable only when the survey remains stable and long term. Indeed the term “monitoring” is meaningless unless the program is long term. The most widely valuable monitoring surveys are those broad in geographic scope and frequent in time. Widely valuable, in this context, means that the surveys have the potential to provide various model inputs for several species. Examples in our region include the Virginia Institute of Marine Science (VIMS) Juvenile Fish and Blue Crab Trawl Survey (statewide, monthly); the Maryland and Virginia Beach Seine Surveys (each statewide, conducted several times during the summer and fall); the CHESFIMS/TIES survey (baywide, three times yearly); and the ChesMMAP Trawl Survey (baywide, five times yearly). Such surveys provide the greatest “bang for the buck” as they capture a variety of species over a broad scale, have the potential to obtain many different kinds of data, and provide frameworks upon which to base other studies.

A comprehensive, routine, and continuous monitoring program is essential to any ecosystem management effort. Well-designed monitoring programs yield new information each time they are examined from a fresh perspective.

Important in other ways, however, are surveys with less species coverage, geographic coverage, or frequency. Such surveys often provide assessment model inputs that cannot be gathered otherwise. Regional examples include the Blue Crab Winter Dredge Survey (baywide, winter months only, targeting blue crabs), and various pound and gill net surveys from the spring spawning season for anadromous species.

Supplementary Surveys and Special Needs

A comprehensive, routine, and continuous monitoring program is essential to any ecosystem management effort. In addition, short-term studies and research projects can help meet special data needs to answer. specific questions. Sampling protocol within a comprehensive monitoring program will provide a framework that allows scientists to conduct many short-term studies efficiently. Further, reexamination of historical monitoring data can, at least partially, answer many research questions. Well-designed monitoring programs yield new information with each examination from a fresh perspective. Although some data from monitoring programs may not prove useful in the short term, archived data may allow detection of important trends in abundances. Such data are essential for retrospective analyses or modeling to support both assessments and management decisions. Excellent examples include the recent stock assessments and annual updates for blue crabs (Rugolo et al. 1997; Miller and Houde 1998; and CBSAC 2001).

Data Availability and Management

Data are worthless unless they are made available for analysis. Fortunately, current technology allows nearly instantaneous data management and distribution. A coordinated data management system must form an integral element of a coordinated monitoring program. Despite the various sampling gears, stratification systems, vessel configurations, and measurements, the basic data elements collected tend to remain similar from survey to survey. Scientists must record the location of sample collection, times and dates of sampling, and prevailing physical/chemical/hydrographic/atmospheric conditions. Counts and measurements of sampled organisms, along with related measurements (e.g., meristic and morphometric), or other specific data (tag numbers, gonad stage, age, parasite load, etc.), often constitute important elements of a monitoring program.

Similarity among surveys can lead to a standardized data management system. Experience shows that a relational data model that accommodates the various data elements described above, and then customized for each survey, works well. The ACCSP has developed a data warehouse for all fishery-dependent data collected on the Atlantic coast and may function as a model for fishery-independent data management activities. Because the management of coastal species dependent upon the Chesapeake will benefit from a coordinated data management system, Bay surveys could serve as both catalyst and model for development of an Atlantic coast fishery-independent data management system.

An Example: Striped Bass Monitoring

Although extensive fisheries monitoring programs exist throughout the Chesapeake Bay, only one species—striped bass—is monitored with sufficient intensity for thorough stock assessment. Programs to understand the

Baywide Surveys

Blue Crab Winter Dredge Survey (WDS)

Target species:	Blue crabs
Temporal coverage:	Annual winter hibernation
Spatial coverage:	Entire Chesapeake Bay and tributaries
Gear used:	Crab dredge
First year:	1989
Conducted by:	MD DNR and VIMS
Other species:	None
Primary data elements:	Enumeration and size measurements
Ancillary data elements:	Age determination using lipofuscin (1999–2002)
Primary information provided:	Estimates of overwintering blue crab abundance, size distribution, recruitment potential
Approximate yearly cost:	$300,000

TIES/ChesFIMS

Target species:	Pelagic and bentho-pelagic fish, especially age 0+ and forage fish (also blue crabs, squid)
Temporal coverage:	Three cruises yearly (April, July, October)
Spatial coverage:	Entire Chesapeake Bay mainstem
Gear used:	18 m^2 mid-water trawl, towed obliquely
First year:	1995
Conducted by:	CBL
Other species:	All species are enumerated and measured.
Primary data elements:	Enumeration and size measurements, baywide, and regional distributions
Ancillary data elements:	Diet composition, hydrographic, and weather data
Primary information provided:	Estimates of abundance, size distribution
Approximate yearly cost:	$350,000

ChesMMAP

Target species:	Multiple

Baywide Surveys continued

Temporal coverage:	Five cruises yearly (March, May, July, Sept., Nov.)
Spatial coverage:	Entire Chesapeake Bay mainstem
Gear used:	High-rise, large-mesh 45’ bottom trawl
First year:	2002
Conducted by:	VIMS
Other species:	All species enumerated and measured
Primary data elements:	Enumeration and size measurements, age distribution, gut contents.
Ancillary data elements:	Acoustic estimates of fish abundance, basic water quality, sea state, and weather data.
Primary information provided:	Estimates of abundance, size distribution, age structure, food habits of adult fish.
Approximate yearly cost:	$400,000

State Surveys

Striped Bass Beach Seine Surveys

Target species:	Striped bass
Temporal coverage:	Summer and early fall
Spatial coverage:	Fixed sites in major rivers and Chesapeake Bay
Gear used:	Beach seine, 4’ deep, 1/4"-mesh
First year:	1955 (MD), 1967 (VA)
Conducted by:	MD DNR and VIMS
Other species:	All species enumerated and measured
Primary data elements:	Enumeration and size measurements
Ancillary data elements:	Basic water quality, sea state, and weather data.
Primary information provided:	Indices of relative abundance for juvenile fish, recruitment potential
Approximate yearly cost:	$100,000

Bluefish Beach Seine

Target species:	Bluefish
Temporal coverage:	Summer and early fall

State Surveys continued

Spatial coverage:	Fixed sites on seaside and bayside Eastern Shore
Gear used:	Beach seine, 6' deep, 1/4"-mesh
First year:	1994
Conducted by:	VIMS
Other species:	All species enumerated and measured
Primary data elements:	Enumeration and size measurements
Ancillary data elements:	Basic water quality, sea state, weather data.
Primary information provided:	Relative indices of abundance for juvenile fish
Approximate yearly cost:	$30,000

Pushnet Survey

Target species:	Shad and river herring
Temporal coverage:	Spring and early summer
Spatial coverage:	Fixed sites Mattaponi, Pamunkey, and York rivers
Gear used:	Rigid frame push-net
First year:	1990
Conducted by:	VIMS
Other species:	All species enumerated and measured
Primary data elements:	Enumeration and size measurements
Ancillary data elements:	Basic water quality, sea state, weather data.
Primary information provided:	Indices of relative abundance for juvenile fish, recruitment potentials
Approximate yearly cost:	$130,000

Juvenile Eel Surveys

Target species:	American eel
Temporal coverage:	Spring and early summer
Spatial coverage:	Fixed sites, York and Potomac rivers
Gear used:	Eel ramp
First year:	1999
Conducted by:	MD DNR and VIMS
Other species:	None
Primary data elements:	Enumeration and size measurements
Ancillary data elements:	Basic water quality, sea state, weather data

Multifish Surveys

Spring – General

Target species:	American and hickory shad, alewife, blueback herring, white and yellow perch, channel and white catfish
Temporal coverage:	February – May
Spatial coverage:	Nanticoke River, Choptank River, Severn River, Upper Bay
Gear used:	Commercial pound and fyke nets, bottom trawl
First year:	Not available
Conducted by:	MD DNR
Other species:	Not applicable
Primary data elements:	CPUE, length-at-age, age-at-maturity, spawning history, mortality
Ancillary data elements:	Not applicable
Primary information provided:	See data elements
Approximate yearly cost:	Not available

Spring American Shad

Target species:	American shad
Temporal coverage:	March – May
Spatial coverage:	Upper Bay, Conowingo Tailrace
Gear used:	Commercial pound nets, hook and line
First year:	Not available
Conducted by:	MD DNR
Other species:	Not applicable
Primary data elements:	Abundance, CPUE, length-at-age, age-at-maturity, spawning history, mortality, stock composition (hatchery vs. wild)
Ancillary data elements:	Not applicable

Multifish Surveys continued

Primary information provided:	Indices of relative abundance for juvenile eels
Approximate yearly cost:	$30,000

Juvenile Fish and Blue Crab Trawl Survey

Target species:	Multiple
Temporal coverage:	Monthly, 12 months per year
Spatial coverage:	Entire Virginia Bay mainstem and major tributaries
Gear used:	Bottom trawl, 30 ft., 1/4" cod end mesh
First year:	1955
Conducted by:	VIMS
Other species:	All species enumerated and measured
Primary data elements:	Enumeration and size measurements
Ancillary data elements:	Basic water quality, sea state, weather data
Primary information provided:	Indices of relative abundance, size distribution, recruitment potentials
Approximate yearly cost:	$400,000

Blue Crab Trawl Survey

Target species:	Blue crab
Temporal coverage:	Monthly, May – November
Spatial coverage:	Fixed sites in limited number of Maryland tributaries
Gear used:	Bottom trawl, 16 ft., 1/4" cod end mesh
First year:	1977
Conducted by:	MD DNR
Other species:	All species enumerated and measured
Primary data elements:	Enumeration and size measurements
Ancillary data elements:	Basic water quality, sea state, weather data
Primary information provided:	Indices of relative abundance indices, size distribution
Approximate yearly cost:	Cost included in Maryland portion of Winter Dredge Survey

Multifish Surveys continued

Primary information provided:	Population estimates; see data elements
Approximate yearly cost:	Not available

Summer/Fall

Target species:	Weakfish, bluefish, summer flounder, spot, Atlantic croaker, menhaden
Temporal coverage:	June – September
Spatial coverage:	Honga River, lower Potomac River
Gear used:	Commercial pound nets
First year:	Not available
Conducted by:	MD DNR
Other species:	Not applicable
Primary data elements:	CPUE, length-at-age, age-at-maturity, spawning history, mortality
Ancillary data elements:	Not applicable
Primary information provided:	See data elements
Approximate yearly cost:	Not available

Multifish includes other surveys that do not fall under the term “monitoring” as used here. The total annual budget for Multifish is approximately $870,000.

processes affecting other species remain critically important. The fact that scientists can thoroughly evaluate the stock of only one species, however, demonstrates how broad a scope—birth-to-death, multigear, geographically and temporally diverse surveys—is necessary to monitor many of the Bay’s species adequately.

Each year, about 100 days after striped bass eggs hatch, monitoring begins with beach seine surveys in Maryland and Virginia in most of the main Chesapeake tributaries, with each state using nearly identical methods. These surveys result in the well-known, young-of-year index data *(*www.dnr.state.md.us/fisheries/juvindex/index.html and www.fisheries.vims.edu/trawlseine/sbmain.htm*)* and produce similar indices for many other species as a byproduct (with varying degrees of reliability, depending on a species’ life history). These juvenile (i.e., prerecruit) indices for striped bass usually correspond well to the relative abundance estimates of year-class strength from VIMS Trawl Survey data *(*www.fisheries.vims. edu/trawlseine/mainpage.htm*)* gathered the following winter.

Pre-adults that remain under minimum regulated landing size are monitored through pound net and fyke net catches and through close characterization of commercial and recreational bycatch. Commercial landings of legal-sized striped bass are strictly monitored by a system that requires each landed fish to be tagged. The commercial catch is characterized by size, age, and gender. For migratory striped bass that leave the Chesapeake Bay, other Atlantic coastal states monitor the species with equal intensity. When adults finally return to the Chesapeake to spawn, scientists use gill and pound net surveys to monitor spawning stock abundance, age structure, size, and sex ratio.

Eventually, applying a similar monitoring strategy to each species of interest in our region will become a desirable goal. Some species, such as oysters, blue crabs, shad and herring, are also extensively monitored now. Monitoring strategies for striped bass and blue crab, however, support the needs of specific stock assessment models and management goals.

Current Monitoring

The following section describes the major fishery monitoring programs currently conducted by Chesapeake Bay management jurisdictions. This synopsis does not include historical surveys that no longer take place.

Major Findings

Specific questions asked by managers or scientists have initiated several ongoing surveys to monitor fisheries in the Chesapeake Bay. More monitoring is conducted every year due to both interstate management mandates and increased interest in and concern for the Bay's resources. Some fisheries surveys date back to the 1950s and have demonstrated repeatedly the value of investing in monitoring. Other existing monitoring programs provide environmental data that complement fisheries surveys. Such information, however, has not been used extensively in FMP development or to support management decisions. As interest in regional fishery resources increases, the status of fish populations becomes a yardstick of success in Bay restoration efforts. Current surveys, however, are insufficient to address the needs of the increasingly complex and data-hungry mathematical models required for ecosystem-based multispecies fisheries management.

Monitoring programs are essential for stock assessments and to understand how fish populations interact with the ecosystem; more effective programs will evolve as information needs and models to support ecosystem-based approaches to management become better defined. With more money allocated to support fish monitoring and restoration, it is incumbent upon us to spend these dollars efficiently in support of the best possible science. Optimum management is adaptive; monitoring programs to support such management must also become adaptive.

To assure that monitoring supports management goals, we must develop a plan that considers the data needed to parameterize appropriate models for each species or species group. Undoubtedly, many of the surveys now conducted would be retained, but additional fishery-independent surveys may prove necessary. Existing surveys should be made more representative both temporally and spatially expansive to promote fishery management in its broadest sense within the Chesapeake Bay.

Panel Recommendations

Management

1) Ensure that fishery ecosystem monitoring in the Chesapeake region is based on a comprehensive suite of integrated, broad-scale, fishery-independent and fishery-dependent surveys.

Goals and objectives should be established to meet this goal since current surveys do not provide adequate data to parameterize the appropriate single-species and multispecies assessment models. Given the magnitude of this task, the panel recommends careful analysis and planning prior to the initiation of new surveys to ensure that required data are obtained efficiently and economically. The Fisheries Steering Committee should establish guidelines for the data and information needs of this suite of comprehensive surveys, which must be well planned, well executed, and well funded.

2) Place traditional single-species monitoring into a multispecies context. Ensure that food habits data are obtained for constituent species since such information forms the heart of multispecies fisheries modeling.

Detailed food habits data need not be collected annually for key fished and interacting species, but such data must be collected periodically since changes in diet can signal shifts in the overall food web.

3) Design surveys to collect data to estimate parameters for specific fishery assessment models.

An ecosystem-based approach to fisheries management requires a suite of well-planned, well-designed, well-executed, and well-funded, fishery-independent and fishery-dependent monitoring surveys. Surveys should estimate one or more parameters for a specific fishery assessment model; each model, in turn, should respond to a fishery- or ecosystem-based management goal. To place traditional single-species monitoring into an ecosystem or multispecies context, food habits (diet composition) measurements must form an integral part of monitoring surveys.

4) Implement a trip-ticket system for commercial catch estimation, in compliance with the Atlantic Coastal Cooperative Statistics Program (ACCSP), including biological monitoring (size, age, sex composition) of the commercial catch.

Improved fishery-dependent monitoring must support the move toward multispecies management.

Data collections should expand to include bycatch, discards, gear selectivity, and recreational catch and effort, by instituting an onboard observer program as part of the overall fisheries monitoring strategy**.**

5) Assure acceptably accurate estimates of recreational catch for each important species, including biological characterization of the catch.

For most species, the annual MRFSS survey provides reasonably accurate regional estimates of catch, effort, and size frequency. States can add their own resources to increase accuracy of the information at the state level. Better geographic and temporal resolution in MRFSS data is desirable, though ultimately expensive. For some species (e.g., blue crabs), the MRFSS sampling frame does not sample the fishing population adequately and species-specific surveys are required.

Needed Research and Development

6) Design and implement an onboard fisheries observer program.

A move from single-species to multispecies management in the Chesapeake Bay will require estimation of parameters such as bycatch and gear selectivity. Such information is generally obtained through placement of observers on some fishing vessels.

7) Develop and implement a truly integrated online fisheries data management system.

A coordinated monitoring program for Chesapeake fisheries must have a coordinated data management system as one of its essential elements with data readily available to managers, scientists, and stakeholders. Online data systems (e.g., Chesapeake Information Management System (CIMS), the Atlantic Coastal Cooperative Statistics Program (ACCSP), and the Northeast Area Monitoring and Assessment Program (NEAMAP) are under development. Integration of these data management systems to the fullest extent possible will facilitate coastwide stock assessment and management of mutually important species in the Northeast U.S. Continental Shelf Large Marine Ecosystem that depend upon the Bay.

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Appendix 1

Data sources available (monitoring and other) through the Chesapeake Bay Program (www.chesapeakebay.net/data).

Water Quality Databases

- CBP Water Quality Database (1984–present)
- CBI Water Quality Database (1949–1982)
- CBP Toxics Database
- Alliance Citizen Monitoring Database
- USGS River Input Monitoring Database
- USGS Daily Stream Flow Data
- USGS Potomac NAWQA Datasets
- SRBC Nutrient Assessment Program
- National Estuarine Research Reserve System (NERRS)

Living Resources Databases

- Baywide Benthic Database
- Baywide CBP Plankton Database
- Baywide Fluorescence Database
- Virginia Trawl Survey Database
- Virginia Beach Seine Survey Database
- Baywide CBP Aerial SAV Survey
- Maryland Biological Stream Survey
- NOAA Fishery-Independent Surveys in Chesapeake Bay
- NOAA Fisheries Statistics and Economics Database

Point Source Databases

- CBP Nutrient Point Source Database

Modeling Databases

- CBP Watershed Model Scenario

Output Database, Phase 4.3

Cross-cutting Databases

- CBP GIS Datasets
- CBP Historical Data Sets
- Environmental Monitoring and Assessment Program (EMAP) Data
- Multi-Resolution Land Characteristics (MRLC) Land Cover
- USGS Chesapeake Bay Region Data
- Chesapeake Bay Chlorophyll Remote Sensing Project
- Chesapeake Bay Land Margin Ecosystem Research/Trophic Interaction in Estuary Systems
- National Wetlands Inventory Data
- NASA LANDSAT Imagery
- Atmospheric Deposition Measurement and Analysis Information Resource
- USGS Impacts of Climatic Variability on Chesapeake Bay

Living Resources Monitoring Programs Currently in Place According to the CBP (www.chesapeakebay.net/lrmon.htm).

Partners of the CBP are monitoring biological communities—from algae to birds and mammals. Results are used to measure the Bay's "health" and identify far-reaching responses to management actions such as nutrient and toxic reductions and fisheries management.

Phytoplankton and Zooplankton Monitoring Programs

Maryland Chesapeake Bay Program Plankton Monitoring Programs

The State of Maryland, in cooperation with the U.S. Environmental Protection Agency (EPA) CBP, has monitored phytoplankton, mesozooplankton, microzooplankton, and primary production in the Maryland Chesapeake Bay mainstem and tributaries since August 1984. The series of monitoring programs is designed to give comprehensive spatial and temporal information on the Maryland mainstem's plankton community. The sampling parameters include detailed taxonomic identifications and abundance measurements of target trophic groups.

Virginia Chesapeake Bay Program Plankton Monitoring Programs

The Commonwealth of Virginia, in cooperation with the U.S. EPA CBP, has monitored phytoplankton, picoplankton (0.2-2.0 microns in size), mesozooplanton (animal plankton over 202 microns in size), microzooplankton (animal plankton under 202 microns in size) and primary production in the Virginia Chesapeake Bay mainstem and tributaries since August 1984. The series of monitoring programs is designed to provide comprehensive spatial and temporal information on the Virginia mainstem's plankton community. The sampling parameters include detailed taxonomic identifications and abundance measurements of target trophic groups.

Benthos Monitoring Programs

Maryland Chesapeake Bay Program Long-Term Benthic Monitoring Program

The State of Maryland, in cooperation with the EPA CBP, has monitored benthic species abundance in the Maryland Bay mainstem and tributaries since July 1984. This effort began as an extension of the ongoing Power Plant monitoring studies in the state. The current program provides comprehensive spatial and temporal data on benthic conditions in the Bay. Sampling parameters include water quality measurements, benthic fauna identification and counts, benthic fauna biomass determination, and sediment analysis. Sample collection is performed independently from the Maryland plankton and water quality monitoring programs. Data collected include detailed taxonomic identifications and counts of benthic species, determination of sample biomass, sediment analysis, and hydrographic profiles.

Virginia Chesapeake Bay Benthic Monitoring Program

The Commonwealth of Virginia, in cooperation with the EPA CBP, has monitored benthic species abundances in the Virginia mainstem and tributaries since March 1985. The program provides comprehensive spatial and temporal data on benthic biota. Sampling parameters include water quality measures, benthic fauna identification, benthic fauna biomass determination, and sediment analysis. Sample collection is performed on a quarterly basis independent from the Virginia plankton and water quality monitoring programs. Additionally, in 1996, a benthic sediment profile images (SPI) and image analysis component was added to this program. The SPI data are composed of photographic images and image analysis of the vertical bottom sediment profiles.

Fisheries Monitoring Programs

Virginia Fishery Independent Seine and Trawl Surveys

The Virginia Institute of Marine Science (VIMS) has conducted annual trawl and seine surveys since 1955. The primary objective of the surveys is to monitor trends in abundance of juveniles in approximately 20 recreationally, commercially, and ecologically important finfish and invertebrates. Since 1955, the trawl survey has sampled waters extending from the mouth of the Chesapeake Bay north to the freshwater interfaces of the James, York, and Rappahannock rivers. Samples from about 60 stations are collected monthly with a 30-foot-wide shrimp trawl towed for 5 minutes at each station.

A seine survey for juvenile striped bass was initiated in 1967, but was suspended between 1973 and 1980 due to lack of funding. An index of abundance has been calculated every year since 1980. This effort represents the second longest continuous striped bass index in the United States. The website for the VIMS Fisheries Juvenile Abundance Monitoring Surveys is: www.fisheries.vims.edu/trawl seine/vimspage.htm.

NOAA Chesapeake Bay Program Fisheries Data

The NOAA–National Marine Fisheries Service maintains a division office in Annapolis, Maryland to better serve the Chesapeake Bay region. As part of its services to the Bay area, the office maintains a website that provides a variety of Bay-specific summaries of recreational and commercial fishery trends, stock assessment information, as well as a long-term database of commercial and recreational fisheries landings for the Chesapeake. The web site for the NOAA Chesapeake Bay Program fisheries statistics page is: noaa. chesapeakebay.net/ fisheries.htm.

National Marine Fisheries Statistics & Economics Division Data

The Statistics and Economics Division of National Marine Fisheries Service (NMFS) maintains a home page that provides a wide range of fisheries-related data collected by NMFS from the entire country. Through these online databases, information on commercial fisheries landings, fisheries trade information, recreational fisheries landings, fishery market news, and other fisheries economic information pertaining to the Chesapeake Bay and the rest of the United States is available. The website for the NMFS Statistics and Economics Division home page is: www.st.nmfs.gov/.

Submerged Aquatic Vegetation

Chesapeake Bay Submerged Aquatic Vegetation Aerial Surveys.

The Chesapeake Bay submerged aquatic vegetation (SAV) data were compiled by the Virginia Institute of Marine Science (VIMS) from 1:24,000-scale aerial photography. Data exist for 1971, 1974, 1978, 1979 (Maryland only), 1980, and 1981 (Virginia only), 1984 through 1987, and 1989 through 1998. Submerged aquatic vegetation data for 1999 will soon be available. Also available from VIMS is the Tier I data layer—a compilation of the historical SAV data listed above from 1971 through 1990. The SAV data files are in Arc/Info (ESRI, Redlands, CA) export format. Data files are served as both PKZIP compressed files for use on IBM-compatible personal computers and tar.Z compressed files for use on UNIX platforms. Each file contains both the .e00 Arc/Info export file and also a .txt metadata file. The web site for the VIMS SAV home page is: www.vims.edu/bio/sav/index.html.

Remote Sensing Programs

Chesapeake Bay ODAS Monitoring Program

In Chesapeake Bay, a remote sensing program began in 1989 with the goal of recovering concentrations of chlorophyll using measurements of ocean color from aircraft. These data have been enumerated using the Ocean Data Acquisition System (ODAS), a relatively simple ocean color instrument developed in the mid-1980s by NASA's Goddard Space Flight Center with funding from NASA and NOAA. Since 1997, the remote sensing SEAWIFS aircraft simulator (SASII) instrument has been implemented for improved measurements. The web site for the ODAS home page is http://noaa.chesapeakebay. net/odas_sas. html.

One of the objectives of this program is to improve the monitoring of changes in phytoplankton biomass in response to nutrient reductions in the Chesapeake. The distribution of phytoplankton in estuaries and coastal waters is characterized by high spatial and temporal variability, making it difficult to quantify phytoplankton in these regions using measurements from ships alone. This situation has made remote sensing an attractive tool for sampling in coastal areas.

Environmental Monitoring and Assessment Program (EMAP) Data

The EPA's Environmental Monitoring and Assessment Program (EMAP) is a research program dedicated to developing the tools necessary to monitor and assess the status and trends of national ecological resources. EMAP's goal is to achieve the scientific understanding needed for translating environmental monitoring data from multiple spatial and temporal scales into assessments of ecological conditions and forecasts of the future risks to the sustainability of our natural resources. EMAP's research supports the National Environmental Monitoring Initiative of the Committee on Environment and Natural Resources (CENR). The EMAP program provides both point data sets and GIS databases for its study areas. EMAP data for the Chesapeake Bay Region (the Virginian Province) and the rest of North America are available at: www.epa. gov/emap/.

Multi-Resolution Land Characteristics (MRLC) Land Cover

The EPA publishes Multi-Resolution Land Characteristics (MRLC) land cover data. MRLC data were derived from the classification of Landsat Thematic Mapper satellite imagery acquired between 1991 and 1993. The data are in grid-cell format with a resolution of 30 m. The MRLC data are separated into 15 classes: water, low-intensity developed, high-intensity residential, high-intensity commercial and industrial, hay and pasture, row crops, other grass, evergreen forest, mixed forest, deciduous forest, woody wetland, emergent herbaceous wetland, and three classes of unvegetated land. A land cover map of the Chesapeake Bay watershed based on the MRLC data is available at www. chesapeakebay. net. Metadata can be viewed on the MRLC website at www.epa.gov/mrlc/.

NASA LANDSAT Imagery

The missions of the LANDSAT series are part of NASA's Earth Science Enterprise (ESE), which is being built to continue the flow of global change information to users worldwide. Scientists use LANDSAT satellites to gather remotely sensed images of the land surface and surrounding coastal regions for global change research, regional environmental change studies, and other civil and commercial purposes. LANDSAT 7, the current mission, will provide repetitive, synoptic coverage of continental surfaces; spectral bands in the visible, near-infrared, short-wave and thermal infrared regions of the electromagnetic spectrum; spatial resolution of 30 m (98 ft); and absolute radiometric calibration. No other current or planned remote sensing system matches this combination of capabilities. The data from LANDSAT 7 are being distributed under a cooperative arrangement with the U.S. Geological Survey and can be obtained at http://landsat7.usgs.gov/.

National Wetlands Inventory Data

The U.S. Fish and Wildlife Service publishes National Wetlands Inventory (NWI) data. Each data layer comprises the areal equivalent of one 7.5' quad (1:24,000 scale) map. The wetlands are classified according to the Cowardin et al. (1979) wetland classification scheme. The wetlands are delineated from photointerpretation of aerial photography, mapped on stable-base copies of 7.5' quad sheet overlays and either manually digitized or scanned. The dates of photography used vary widely and range from the early 1970s through the early 1990s. Of the 1,336 7.5' quads that are wholly or partially contained within the Chesapeake Bay watershed, all have had delineation of their wetlands. The NWI data can be downloaded in ARC Export or DLG formats via anonymous FTP. The data are organized by USGS 250K map names, so it is advisable to have a USGS index book for the state in which desired quads are located in order to find which 250K directory to access. Metadata are available on the NWI web site at www.nwi. fws.gov.

Externalities

Introduction

The Chesapeake Bay remains central in the debate on the relative importance of fisheries versus environment in affecting an ecosystem's capacity to sustain fisheries. Recently, Jackson et al. (2001) proposed that fishery effects provoked a regime shift in the Chesapeake Bay ecosystem through the vast removal of oysters during the 19th century. They and others have argued that mass removal of oysters, along with associated ecological losses of habitat and community, drove the ecosystem to a different state—one less productive for fishery resources.

Alternatively, other researchers have argued that bottom-up influences from anthropogenic changes in water quality, nutrients, and related habitat degradation are the forces driving the sustainability of Chesapeake Bay fisheries (Boesch et al. 2001a, 2001b). Early agriculture brought heavy sediment loads to the Bay. Later, the use of industrial fertilizers led to widespread degradation of benthic environments and eutrophication. Related degradation of bottom habitat and increased incidence of hypoxia may have shifted the community structure and led to production losses and the extirpation of some important species. Due to such drastic and widespread changes, understanding the historical perspective of fisheries and anthropogenic changes to the Chesapeake ecosystem is critical.

Historical patterns and trends play a central role in ecosystems and the individual ecologies of their living resources. For instance, a small or moderate alteration in the environment or community structure could initiate a shift that ultimately results in much larger effects. Large-scale changes, such as glaciations or massive deforestation, could provoke irreversible changes in the ecosystem.

Consequently, in this element we examine whether any historical factors precondition the Chesapeake Bay ecosystem to future climatologic or anthropogenic changes—either gradual and subtle or pulsed and cataclysmic. Will recent trends in physicochemical and ecological processes in the Chesapeake Bay undergo gradual or rapid change in the future or remain in steady state? Might trends be reversible so that we can restore elements of the Chesapeake Bay ecosystem to some historical reference point?

Reference points for evaluating effects of fisheries on ecosystems include loss

Externalities—*Those forces (ecological, human, and institutional) external to the traditional domain of fisheries management that structure and constrain living resource production dynamics within an ecosystem.*

of habitat and habitat productivity, reduced biomass of important species assemblages or keystone species, loss of biodiversity, and effects on food webs (Murawski 2000). Further, some species, such as bivalves, may play such essential roles in an ecosystem that their removal can engender regime shift (Jackson et al. 2001).

Externalities are ecological, human, and institutional forces on the ecosystem that shape, structure, and constrain fisheries and over which fishery managers have no direct control (Figure 1). Consideration of externalities and fishery effects on ecosystems mandates an expanded view in time and space—an understanding of forcing events that occur over longer time scales than one generation of a long-lived fish and at larger spatial scales than the most far-reaching migrations. Because other elements emphasize the spatial domain (see Boundaries Element), this element develops a history of the Chesapeake Bay ecosystem, describing past environments and trajectories of environmental change. Such a history gives perspective on fishery issues versus other anthropogenic effects, regime shifts, and ecosystem reversibility.

This chapter includes geological, climatological, ecological, and human changes that have shaped and continue to influence the Chesapeake Bay (Figure 2). Principal historical pathways are presented as branching limbs, emphasizing events that triggered a series of related effects and changed ecosystem structure. Four primary departure points occur (see Figure 2 for the time sequence): Chesapeake Bay formation; glacial retreat and human colonization; development of climax floral and faunal communities; and European colonization and industrialization. This last phase in the Bay's history is afforded the greatest emphasis as the most influential period in the ecology of today's living resources.

Chesapeake Bay Formation

The Chesapeake Bay is among the largest temperate estuaries worldwide—one of several large and relatively shallow estuaries in the Mid-Atlantic Bight and South Atlantic Bight (Paul 2001). The Appalachian Mountain chain forms the western boundary of all these estuaries. Thrown up by continental collision 250 million years ago, the Appalachians once stood as high as the Himalayas (Fisher and Schubel 2001). Early on, streams and rivers that flowed predominantly west towards an inland sea eroded the mountain chain. About 200 million years ago, mantle convection reversed and created a large rift valley with eventual formation of the Atlantic Ocean. Waterways started cutting deeply into the eastern face of the

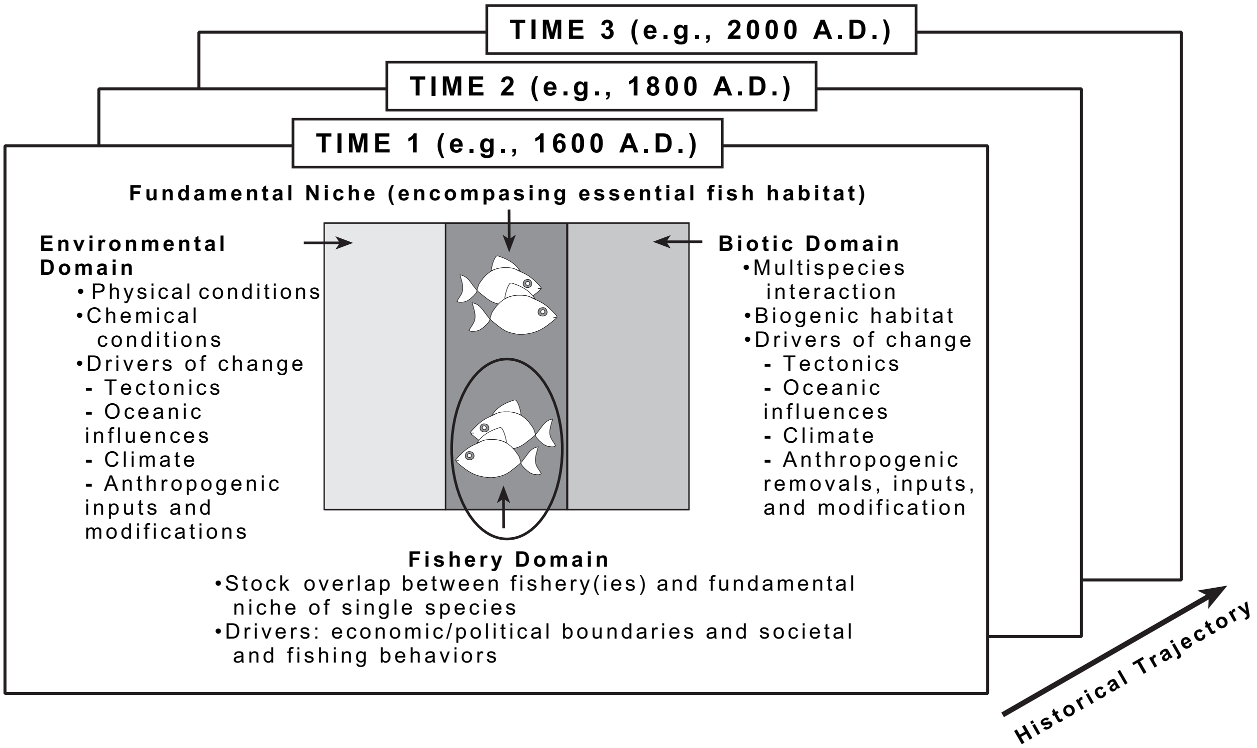

Figure 1. Externalities are those forces (ecological, human, and institutional) external to the traditional domain of fisheries management that structure and constrain living resource production dynamics within an ecosystem. Most immediate to fisheries management is the fundamental niche of a living resource, its habitat, and secondary forces driving changes in habitat and multispecies interactions within the present ecosystem. The current ecosystem, represented as Time 3 (2000 A.D.), is necessarily shaped by historical conditions and regimes, exemplified in this figure as Time 1 and Time 2**.**

Appalachians and adjacent Piedmont province (Fisher and Schubel 2001). An extensive period of weathering began, later accelerated by Pleistocene glaciation, eventually producing one of the world's most extensive coastal plains (Paul 2001).

The ancient estuaries in the drainage now occupied by the Chesapeake Bay waxed and waned with glacial retreats and advances during the past million years (Oertel and Foyle 1995; Kutzbach and Webb 2001). During glaciation and periods of lower sea level (up to 100 m lower than today), tidal estuaries retreated to the Atlantic continental shelf or were virtually eliminated (Kutzbach and Webb 2001). Most of the current Chesapeake estuary existed as nontidal rivers, draining boreal and tundra-like landscapes and slicing deep channels into the shelf. For 90% of the Pleistocene Epoch, glaciers remained pervasive.

During intervening periods of glacial regression and rising sea level, ocean waters inundated the deep river valleys, forming estuaries. Sediment filled the deep channels allowing new estuarine channels, saltwater marshes, and other estuarine littoral habitats to form (Oertel and Foyle, 1995; Fisher and Schubel 2001). The interglacial periods were quite dynamic. Retreat of massive glaciers—

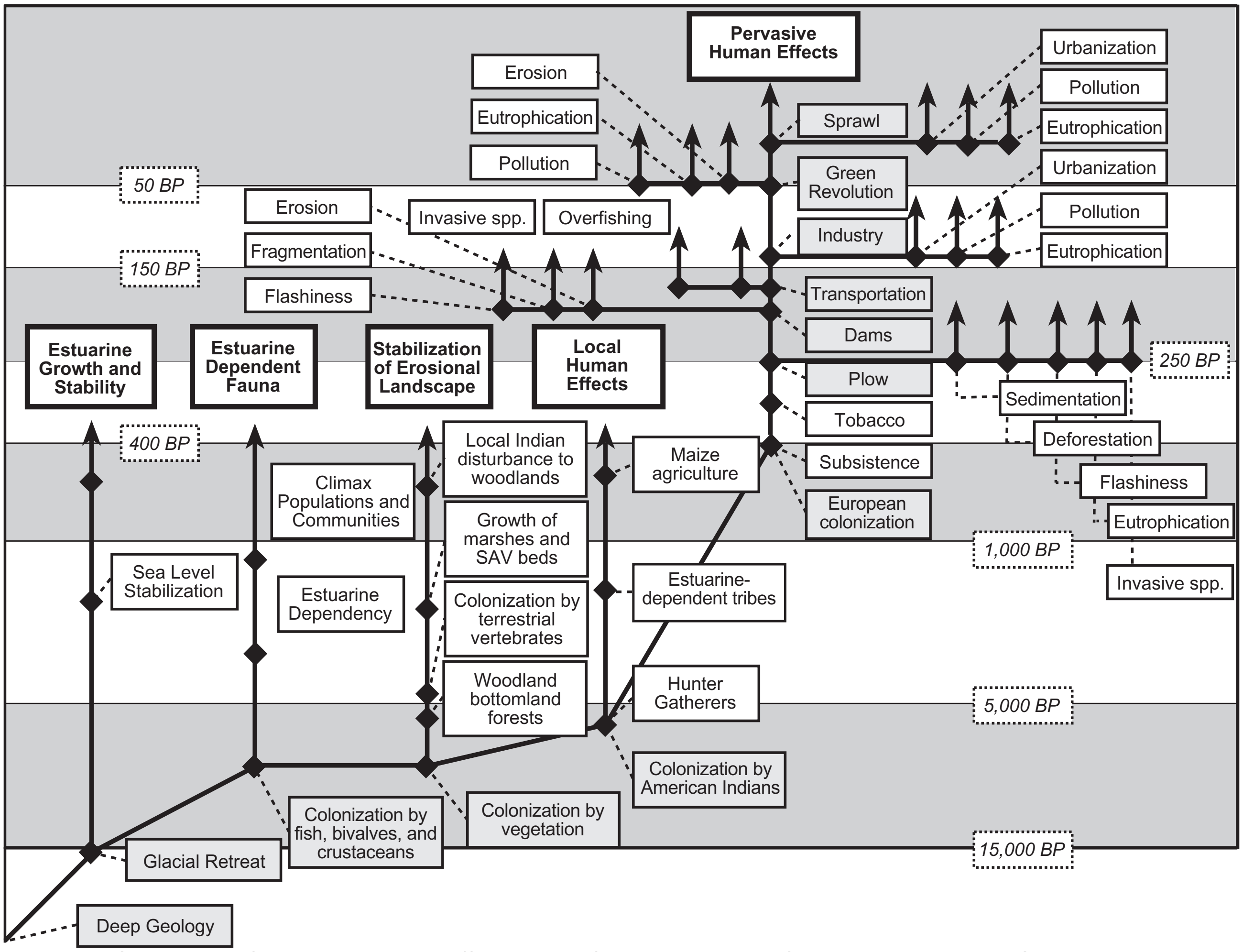

Figure 2. Sequence of historical events affecting the Chesapeake Bay fisheries ecosystem. Several proposed regimes in the current ecosystem are the result of historical sequences of related events: estuarine growth and stability; estuarine-dependent fauna; stabilization of an erosional landscape; local human effects; and pervasive human effects.

up to 2 km thick in northern Pennsylvania and the northeast—resulted in the delivery of millions of tons of sediment from the Appalachian and Piedmont provinces to the Coastal Plain (Kutzbach and Webb 2001). Although glaciers never advanced as far as the Chesapeake Bay, the region was influenced greatly by related climatic, hydraulic, and landscape changes.

The history of the Delmarva Peninsula also relates to the formation of the Chesapeake Bay. Two million years ago, the Chesapeake Bay and the Delmarva Peninsula did not exist; six independent watersheds—the Susquehanna, Patuxent, Potomac, Rappahannock, York, and James—emptied directly into the Atlantic Ocean. The southerly growth of the Delmarva Peninsula, associated with coastal longshore transport of sediments, progressively shifted fluvial channels until they merged with the central channel of the dominant Susquehanna River (Oertel and Foyle 1995). Coastal transport in the lower Chesapeake Bay and Eastern Shore still represents a major source of sediment. Geological analysis of ancient river channels indicates that capture of all major rivers by the Susquehanna channel occurred as recently as 125,000 before present (BP). Thus, the Bay, as a complex estuary, is a fairly recent geological feature.

Glacial Retreat and Human Colonization

The Chesapeake Bay—its current shape, size, and constituent watersheds—is a Holocene invention, beginning with glacial retreat about 15,000 years BP. The regression of the most recent Wisconsin glaciers caused large disturbances in the Chesapeake region due to increased freshwater flows, flooding, erosion, and delivery of glacial sediment loads to the Coastal Plain. Intermittent cooling resulted in cycles of glacial advance and retreat with related effects on downstream watersheds and landscapes. Inundation by ocean waters, in concert with glacial outwash, prevented stable, long-term, hydrographic conditions (e.g., salinity, temperature, turbidity, and nutrients) from developing in the nascent Chesapeake estuary.

About 9,000 BP, continental glaciers had regressed to the St. Lawrence River and the sea began advancing onto the continental shelf and into the deeper channel valleys of the Chesapeake watershed (Kutzbach and Webb 2001). Temperatures oscillated as the glaciers retreated. Evidence of historical fires (charcoal) and forest composition (pollen) for this era indicate that the climate in the Chesapeake Bay may have been warmer and drier than at present. These fluxes in climate and hydrology, along with related changes to the relatively flat Bay watershed, have led some archeologists to speculate that estuarine-dependent fauna did not colonize the Chesapeake substantially until hydrographic conditions stabilized some 2,000 to 3,000 years BP (Custer 1986; Miller 2001). Even now, large meteorological events can greatly disrupt the system. Tropical Storm Agnes of June 1972 represents an example of the potential for unusual weather to destabilize estuarine communities; this storm resulted in an 89% loss of eelgrass, a 90% loss of softshells (also known as softshell clams) *Mya arenaria*, and major losses of oysters throughout the Bay (CRC 1976).

As early as 11,000 BP, paleoIndians moved into the Chesapeake Bay region, perhaps in pursuit of now extinct Pleistocene megafauna such as mammoths and ground sloths (Steadman 2001). More likely, they tracked smaller game (Custer 1986; Miller 2001). Greater dependence by paleoIndians upon Chesapeake Bay resources did not occur until much later. Mollusk shell deposits (oysters, softshell clams, ribbed mussels, and periwinkles) near Indian camps date back to 4,000 years BP (Miller 2001). This timeframe corresponded with a decrease in the rate of sea level rise and presumably more stable hydrographic and hydraulic conditions, which favor nearshore mollusks (Custer 1986; Kearney 1996). The earliest evidence of directed living resource exploitation occurred about 3500 BP with satellite camps in the upper estuary's tidal reaches centered on the harvest of anadromous fish. Archeologists have suggested that large spawning runs of anadromous fishes did not occur until this time (Custer 1986; Miller 1986).

The Chesapeake Bay, or "the Great Shellfish Bay" as the Algonquin Indians named it, did not provide a primary source of sustenance for American Indians until about 1,000 BP (Custer 1986). Oysters then became an essential element in the diet and settlement patterns of Chesapeake Bay coastal tribes. American Indian villages produced large oyster middens during this time. The villages, often located at the confluence of streams with sub-estuaries, depended upon satellite oystering and fishing sites along with inland hunting camps (Custer 1986; Miller 2001).

Oysters and clams were particularly important during winter months when other sources of food proved scarce. Anadromous fish harvested during springtime spawning runs also formed an important dietary component, when terrestrial sources of food were inadequate (Miller 2001). Custer (1986) suggested that movement by American Indians to estuarine sites resulted from increased stability of the estuarine environment and the productivity of estuarine resources. Settlement in these areas favored population growth and brought about fundamental changes to the cultures of coastal province American Indians, beginning an historical trajectory that soon led to agriculture as a principal means of supporting tribal diets.

Climax Floral and Faunal Communities

Written records from early European explorers and settlers contain anecdotes describing the limitless forests of the mid-Atlantic's Coastal, Piedmont, and Appalachian provinces. These forests formed part of a vast deciduous woodland that extended throughout the eastern half of the United States. Oak and hickory dominated much of the forest in the Chesapeake watershed although bottomland forests contained bald cypress, red maple, and white cedar. At higher altitudes, chestnut became an important member of the forest assemblage (Silver 2001). Bay watershed forests were not homogenous climax communities. Although the weather 400 years ago was moderate in comparison to previous periods of the Holocene, hurricanes, other storms, droughts, and fires still occurred. The browsers (e.g., beavers, elk, deer, and bison), seed disseminators (e.g., passenger pigeons), and other "ecosystem engineers" (Jones et al. 1994) caused the forest-dominated landscape to contain a patchwork of vegetated habitats including understory vegetation, meadows, swamps, and marshes (Grumet 2000; Mitchell et al. 2001).

By the time Europeans started exploring the Bay, Native Americans had already become proficient in modifying terrestrial habitats through maize agriculture (Miller 2001). The practice of girdling and killing trees in a plot, burning these trees and understory, then planting seeds in the newly fertilized land, dates back to nearly 1,000 BP. Maize grew among the roots and stumps of burned trees, with plots remaining fertile for several years. The natives then abandoned the plots to forest succession and began developing new ones (Custer 1986). Although removing trees and understory in this manner resulted in local erosion, developed plot sizes were small in proportion to the arable land available. Regeneration of soil fertility in fallow plots required 2 to 3 decades, which further limited the spatial extent of agricultural development by Native Americans. Colonists in the region adopted these same practices for the cash crop of tobacco (Miller 1986). In addition to clearing maize plots, the natives used fire to remove underbrush growing below the forest canopies, which permitted more effective hunting. Still, in comparison to later 18th-century plow-based agriculture, the changes to landscapes rendered by Native Americans and early European colonists to the watershed likely remained local given the “seas of forests” that surrounded them (Grumet 2000). The relatively low rates of sedimentation estimated for the pre-colonial period of human settlement support this contention (Brush 2001).

In estuarine waters from 400 to 1,000 BP, oysters provided the foundation for a climax community that influenced nutrient cycles, food webs, flow, and water quality (Wharton 1957; McCormick-Ray 1998; Paul 2001). Emergent (intertidal) oyster reefs flourished in regions up to 10 m deep, presenting navigation hazards to early European explorers and colonists. Pritchard and Schubel (2001) speculate that these beds were so pervasive that they caused substantial mixing both above and below the pycnocline, reducing the intensity of hydrographic stratification in some areas. Oysters reefs, similar to coral reefs and trees, grow and sequester material over long periods of time. As a reef grows, it promotes greater settlement through increased fertilization rates and large areas of settlement substrate; decreased predation occurs given the large numbers of interstitial refuges (Mann and Evans 1998; Southworth and Mann 1998; Breitburg et al. 2000).

Presumably, centuries of incremental growth under relatively stable estuarine conditions in the late Holocene contributed to wide coverage of the Bay by oyster reefs. Oysters filter phytoplankton from the water (Newell 1988; Ulanowicz and Tuttle 1992; Coen and Luckenbach 2000); historically this filtration occurred not only at the benthic interface but also throughout much of the water column. Sequestration of water column production by oysters not only contributed to reef growth, but also transferred production to the benthos. Ecosystem modeling indicates that historical Chesapeake Bay food webs were based primarily on benthic food chains, in contrast to the pelagic food chain that predominates in modern times (Newell 1988; Ulanowicz and Tuttle 1992). Oyster reefs also provided important structural habitat for crustaceans, fish, and other mollusks (see Habitat Requirements Element).

Fish communities during precolonial times showed strong representation by demersal (bottom) species. Refuse heaps of the earliest European settlers in Maryland show a preponderance of sheepshead *Archosargus probatocephalus* and black drum *Pogonias cromis*. These demersal fishes typically occur at salinities over 20 ppt. Their occurrence at sites that are now oligohaline suggest that the Bay may have been saltier around 300 to 400 BP, perhaps due to lower freshwater discharges from the forested landscape (Wharton 1957; Miller 1986; Kennedy and Mountford 2001). Early written accounts highlight these and other demersal fish, including sturgeon, with frequent comments on the tremendous springtime abundance of anadromous shads, herrings, striped bass *Morone saxatilis*, and sturgeon. Oyster and other shellfish, crab, and sturgeon received particular emphasis in early written records regarding their abundance, ease of capture, and importance in subsistence diets at Jamestown, Virginia and St. Mary's City, Maryland (Wharton 1957).

Until the late 18th century, the human footprint on the Chesapeake Bay was largely local and reversible.

European Colonization and Industrialization

Agrarian Revolution I: The Plow

Until the late 18th century, the human footprint on the Chesapeake Bay was largely local and reversible. After several years of agricultural (primarily tobacco) productivity, the land was left fallow to restore soil fertility. Earle and Hoffman (2001) conclude that the early planters, through the use of small-plot rotation systems, were quite deliberate in ensuring that reforestation and soil restoration balanced local and regional demands on soil productivity. Other practices that retained the dominant role of forests in the watershed during the first 150 years of colonial settlement included use of limited hillside acreage, small hand tools for planting and weeding, and orchard planting in the final years of plot use.

Early efforts by colonists to use aquatic resources as a cash crop were confounded by strong seasonality in most resource species and the lack of a reliable and efficient means to preserve and distribute landed fish. The abundance of anadromous fish from spring to early summer, and their absence during other parts of the year, particularly vexed early settlers who had few ways to harvest these fishes efficiently, nor the means to preserve them. Indeed, this lack of know-how contributed to the "starving time" by early Jamestown settlers (Tilp 1979). Sturgeon was abundant and easily harvested by early settlers. Endeavors to establish a cash crop of caviar (sturgeon roe) and pickled sturgeon heads failed, however, due to lack of good quality salts and vinegar (Wharton 1957; Saffron 2002). Oysters were vital to the early sustenance of Europeans, but a shortage of boats and the means to harvest oysters from deeper waters caused local shoreside depletion (Miller 1986; Kent 1988; Apps 1989).

A major anthropogenic change affected the Chesapeake Bay in the mid-18th century with the advent of a more intensive, European-style, agricultural system. Indentured Europeans and enslaved Africans cleared lands while landowners introduced a more regimented system of agriculture that rotated crops of tobacco with corn, beans, peas, and small grains. Increased demand in Europe for wheat—a crop that requires larger and better-cleared fields—encouraged development of plow-based tillage in the colonies (Silver 2001). Whereas the plot rotation system left large trees, trunks, roots, and much herbaceous ground cover intact during years of production, the new system removed all vegetation from agricultural fields. Mined gypsum, animal manure, and imported guano were the primary substances used to regain soil fertility (Grumet 2000; Kennedy and Mountford 2001). Landowners began to farm hillsides. This period also witnessed substantial human population growth that accelerated the spread of agriculture, particularly in the Piedmont Province. In 1775, the colonial population in the Chesapeake region reached 700,000, one-third of which comprised enslaved African Americans (Grumet 2000). The increased population and development of cash crops (tobacco and wheat) led to the transformation of Baltimore, Alexandria, Richmond, and Norfolk into important trade centers (Silver 2001; Walsh 2001). Livestock and timber became increasingly valuable resources supporting these emerging cities, with the livestock representing early invasive species as they roamed outside fenced agricultural fields, browsed on forest understory, meadows, and riverbanks, and contributed to further erosion. Home building, urban trade centers, European lumber markets, and iron smelting all brought increased demand for regional timber. Intensive agriculture, livestock rearing, and timber extraction rapidly transformed a Chesapeake landscape dominated by forests into one dominated by herbaceous plants (Brush 2001).

A landscape prone to erosion displaced the forested landscape in the course of a mere two to three generations, resulting in fundamental and irreversible changes to the Bay ecosystem. Between 1780 and 1840, 40–50% of the Chesapeake watershed was converted to agricultural fields (Brush 1986, 2001). The advent of plow-based agriculture initiated a cascade of related effects (Figure 2), each contributing to increased soil erosion and subsequent sedimentation. The cleared and plowed fields were far more susceptible to soil loss and gullying. Increased sediment deposition in streams and rivers resulted in channel infilling, bank overwash, and creation of extensive channel levees and backswamps (Earle and Hoffman 2001). Ditch construction and maintenance became necessary to drain fields properly, further exacerbating the erosion-sedimentation cycle. Inhabitants of the late 18th century remarked that during freshets, streams and rivers carried huge loads of Piedmont sediment, with rivers turning blood red (Miller 1986). Sediment settled in tidal waters and important harbors. Meters of new sediment inundated Jug Bay, Port Tobacco, and Joppa Town in Maryland making these ports unusable (Cooper 1995; Grumet 2000; Kennedy and Mountford 2001). Deforested watersheds became more vulnerable to flash floods. Biggs (1970) estimated peak river flows in the Susquehanna River at 25–30% higher in this modified landscape. An especially disastrous flood in 1771 caused rivers to swell 13 m above mean tide; resultant sediment loads made many rivers unnavigable (Silver 2001). Increased overland flow in deforested landscapes translates into a lower water table and reduced base flow conditions during low-flow seasons (Kennedy and Mountford 2001).

Sediment buried hard-bottom fish habitats, including critical spawning areas for sturgeon and other species that require hard, clean bottom for egg attachment. Sediment flooded the oyster beds. Pollen analysis in sediment cores shows that annual erosion rates doubled or as much as quadrupled after 1760 (Brush 2001). Diatom assemblage analysis also indicates that the mid-19th century Chesapeake Bay was substantially more eutrophic and more heavily influenced by freshwater flows than the previous 2,000 years (Cooper 1995). A climate shift during this period brought increased precipitation, compounding the effects of land clearing and lowering salinity levels throughout the Bay (Cronin et al. 2000). Effects of increased sediment loads to seagrass beds remain unknown. Based upon mid-19th century recorded observations, however, the water column in the Patuxent River was probably not occluded. Early landclearing, therefore, may not have substantially affected submerged aquatic vegetation (SAV) (W. Boynton, Chesapeake Biological Lab, personal communication).

Early development of fisheries occurred in concert with the 18th-century agrarian revolution, largely to support slave labor. President George Washington and other plantation owners deployed large haul seines (up to 1500 m in length and 3 m deep) during spring to intercept anadromous herring and shads. Herring and shad (*Alosa* spp.) species were cured with salts imported from Europe and supplied as food to enslaved African Americans throughout the year. Any surplus fish entered the fish, rum, and slave trade circuit of Europe (rum), New England (fish), and the West Indies (slaves) (Wharton 1957). Due to difficulties in the salt supply and the labor force required to operate haul seines and cure fish, however, this first herring and shad fishery was probably only significant in its support of the regional plantation system. Indeed, England's control of the salt supply required for preserving fish and meat was one of many factors that incited the War of Independence (Wharton 1957).

Industrial Revolution

During the early 19th century, lumber mill, iron smelting, and grain mill development brought about deforestation along with the construction of canals and mill dams. Not until after the Civil War did nascent industrial technologies—particularly steam power and iron production—effect a profoundly different set of changes (i.e., habitat loss, pollution, and overexploitation). Coal fueled the early industrial revolution, which could not otherwise have occurred if wood had remained the dominant source of energy. Production of 1,000 metric tons (mt) of iron consumed 20,000 to 30,000 acres of forest (Grumet 2000). Clearly, timber resources could not have supported the industrial development of the late 19th century. Regional coal mines and iron works fueled and built the railways that catalyzed urbanization, industrialization, watershed engineering, and exploitation of aquatic resources. Coal extraction contributed further to erosion in the Piedmont and Appalachian provinces, while mining wastes acidified stream waters. Residences and industries emitted coal smoke; factories released raw waste directly to the watershed (Grumet 2000). Thus, began the course of water and airborne pollution into Bay waters.

In the latter industrial period, gasoline and diesel engines, along with electric motors, replaced coal-powered steam boilers. These changes accelerated industrial and residential development based upon petrochemicals, electricity, steel, and concrete. Steel and concrete made possible the construction of much larger residential and urban buildings and factories in cities. Between 1910 and 1940, turnpikes, roads, airfields, and urban areas developed into impervious expanses of concrete and asphalt. Suburban development followed quickly on the heels of improved automobiles and better roads (Grumet 2000).

Population growth from 1850 to 1930 in the Chesapeake region grew from 1.8 to 5 million, with cities experiencing the highest growth rates (Grumet 2000). Bay-area cities became great manufacturing centers; wheat, sugar cane, corn, cattle, and petroleum were shipped in for processing. Agricultural and livestock demands grew through improved access to national and international markets via trains and ships. Farm mechanization (e.g., tractors) and greater use of imported fertilizers and high-yield genetic strains of grains and livestock generated larger agricultural yields. By 1900, less than 20 percent of the region's original forest remained (Brush 1995). In pursuit of new supplies of timber, swamps were targeted for timber exploitation and wetlands were used either as receptacles for municipal waste or "reclaimed" as agricultural fields (Grumet 2000). Continued influx of eroded soils, in concert with human and animal wastes, resulted in intensive and often noxious pollution to Bay waters, continuing unabated in some urban areas until the 1970s and passage of the Clean Water Act.

Canals and Dams

Construction of major canals occurred prior to this industrial period. The Chesapeake and Delaware (C&D) Canal (connecting upper Chesapeake Bay to middle Delaware Bay) and Chesapeake and Ohio (C&O) Canal (the navigation corridor between Washington, D.C and Cumberland, Maryland) were completed in 1829 and 1850, respectively (Grumet 2000). These canals opened the Chesapeake Bay to industrial centers in the northeast. The C&O Canal, the more ambitious of the two projects, never was developed as a deep navigation channel. Its effect on Chesapeake Bay resources, particularly those in tidal reaches, was likely small. On the other hand, the C&D Canal may have affected populations of anadromous fishes in the upper Chesapeake Bay and mid-Delaware Bay by providing a migration corridor between the two systems. Particularly since 1927, when impoundments were removed and the canal deepened to sea level, migrations have become more likely. Pre-spawning aggregations of striped bass and shortnose sturgeon *Acipenser brevirostrum* occur adjacent to the C&D Canal on the Chesapeake and Delaware sides, respectively. Telemetry studies show that both species

Table 1. Decadal trends in Chesapeake Bay landings (metric tons) for important fisheries. Peak annual landings are shown for each time interval because large data gaps occur in the earlier record and peaks are representative of maximum annual removal rates over the past 170 years. For comparison with actual annual landings, see the Removals Element. With the exception of sturgeon landings, data are rounded to the nearest 1,000 tons. Zeros indicate <500 tons.

Year interval	Oyster	Blue crab	River herring	American shad	Atlantic menhaden	Atlantic sturgeon	Striped bass	Atlantic croaker
1831 —1850	2,000	No data	170,000	41,000	No data	No data	No data	No data
1851 —1870	20,000	No data	No data	No data	No data	No data	No data	No data
1871 —1890	49,000	3,000	14,000	7,000	60,000	252	No data	No data
1891 —1910	46,000	16,000	30,000	8,000	120,000	451	1,000	2,000
1911 —1930	22,000	25,000	21,000	4,000	160,000	30	1,000	11,000
1931 —1950	17,000	29,000	12,000	4,000	90,000	15	2,000	26,000
1951 —1970	19,000	37,000	18,000	3,000	204,000	18	4,000	7,000
1971 —1990	12,000	45,000	7,000	1,000	252,000	12	4,000	4,000
1991 —2000	1,000	50,000	0	0	233,000	0	2,000	7,000

Data from Hildebrand and Schroeder (1927); Tilp (1979); Kennedy and Mountford (2001); Murawski and Pacheco (1977); and NMFS annual landings database.

use the canal (Koo and Wilson 1972; Welsh et al. 2002). The recent occurrence of shortnose sturgeon in the Chesapeake Bay (Welsh et al. 2002) was unexpected after its long absence, but genetic data indicate that these fish are emigrants from the Delaware Bay population (Wirgin et al. 2005). Should these emigrants not return to the Delaware Bay, the C&D Canal could represent a significant source of loss to the endangered Delaware population, affecting its viability. Similarly, some scientists have hypothesized that net flows may convey striped bass eggs and larvae through the C&D Canal into unfavorable Delaware Bay environments (Johnson and Koo 1975).

Throughout the colonial period, mill dams (e.g., sawmills, gristmills, irrigation systems) were periodically constructed and breached in Chesapeake Bay streams; these no doubt contributed to blocked spawning migrations and fragmented habitats, particularly for anadromous shad and herring. During the industrial 19th and 20th centuries, however, steel and concrete and better technology allowed the construction of larger dams in downstream reaches adjacent to the fall lines of major tributaries. By 1940, thousands of dams and small impoundments in the Chesapeake Bay watershed eliminated access to thousands of miles of rivers and streams previously used as migration corridors by anadromous and resident freshwater species. Large dams, such as Conowingo Dam located at the fall line of the Susquehanna River, become traps, storing huge loads of sediment, nutrients, and contaminants. Quick snow melts or large storms can cause flooding with the sudden release of millions of mts of material, as occurred during Tropical Storm Agnes in 1972 (Gross et al. 1978).

Industrial Fisheries

The problems that vexed early fisheries in the Chesapeake Bay—distribution, preservation, and market demand—were largely overcome during the 19th century, resulting in exponential growth in fisheries and overexploitation of important species by 1900. By the 1830s, dependable supplies of vinegar and salt, as well as the means to cure, smoke, and can oysters and herrings allowed rapid expansion of these fisheries. Improved fishing technology (e.g., working and merchant vessels, boat motors and engines, oyster tongs and dredges, pound and gill nets) supported such expansions. With the advent of rail and shipping, improved corridors of commerce also contributed substantially to fisheries development.

After the Civil War, fishing industries attracted the labor of veterans, recent immigrants, and emancipated African Americans. Oyster houses and fish packing operations helped fishing towns and shipping yards throughout the Chesapeake to grow by providing an important new source of revenue for rural regions. A postwar economic boom stimulated the growth of fishery markets in the Bay and elsewhere. Unfortunately, increased demand for oysters and other living resources outpaced the recognition and infrastructure needed to regulate exploitation. By the end of the century, most important fisheries—oysters, river herrings, and American shad *A. sapidissima*—had become severely depleted.

Herring and shad supported the first important fisheries in the Chesapeake Bay. Tilp (1979) calculated that over 6,000 fishermen landed 750 million herrings at 158 sites in the Potomac River in 1832. Assuming a weight of 0.22 kg/fish, the harvested level (about 171,000 mt) would rival recent record yields for Chesapeake Bay Atlantic menhaden *Brevoortia tyrannus* (250,000 mt). American shad *Alosa sapidissima*, albeit less abundant, was also an important early industrial fishery of the 19th century (Table 1). Capturing anadromous herring and shad required large crews and huge haul seines of 400 to 600 m in length and 3 to 4 m in depth deployed in tributaries where the fish spawned. By the end of the century, herring and shad fisheries had moved into the lower sections of these tributaries and the Chesapeake Bay mainstem. In such areas, haul seines that extended nearly 2 km were common (Tilp 1979); pound and gill nets became increasingly common to intercept spawning runs of anadromous fish effectively (Reid 1955; Kennedy and Mountford 2001). By 1898, harvests had dropped by several-fold in Chesapeake Bay since the extremely high harvest of 1832, but the herring/shad fishery still employed about 900 fishermen.

Development of the Chesapeake oyster industry started with the invasion of a fleet of Connecticut dredging schooners in the early 1800s, after the overfishing of New England beds (Kennedy and Breisch 1983). Soon after, both Maryland and Virginia enacted legislation against outside operators dredging within the Chesapeake, stimulating local watermen to supply the oyster market. As shallow beds in the Chesapeake became exhausted, watermen moved to deeper beds using both dredges and deepwater (patent) tongs. Improved transportation in the 1830s opened up regional oyster markets for spiced, fresh, and pickled oysters. In 1839, watermen brought in 700,000 bushels of oysters. Oyster canneries that preserved steamed oysters started in the region in the 1840s (Grumet 2000). Between 1840 and 1890, more than 390 million bushels may have been extracted from the Chesapeake (Kennedy and Mountford 2001). Oysters became a staple around the nation and world, supporting hundreds of oyster canning houses throughout the Bay. Oyster shell was used for lime fertilizer, fill, and road construction. Watermen used dredges and tongs to dig into oyster reefs with vigor for most of the 19th century, with little sense that such abundant stocks could ever become exhausted.

By the 1870s, refrigerated boxcars permitted delivery of fresh fish and crabs from the Chesapeake Bay to points throughout the nation. This advance prompted rapid development of the blue crab *Callinectes sapidus* fishery, which used trotline gear primarily at the time (Cronin 1998;

Grumet 2000). Coincident development of pound nets increased fishing efficiency for several finfish (e.g., summer flounder *Paralichthys dentatus*, bluefish *Pomatomus saltatrix*, striped bass, spot *Leiostomus xanthurus*, croakers, kingfish, weakfish *Cynoscion regalis*, and Spanish mackerel *Scomberomorus maculatus*) that were shipped fresh to distant markets (Hildebrand and Schroeder 1927). Gill nets were also effective gear that emerged in the mid-19th century and supported important fisheries on resident and anadromous fishes. Atlantic sturgeon proved a noteworthy fishery that emerged rapidly due to technology transfer from Europe on how to harvest and produce caviar (Saffron 2002; Secor 2002). The fishery lasted from about 1870 to 1890. Extreme exploitation may have eventually contributed to sturgeon extirpation (Maryland) or endangerment (Virginia) in modern times (Secor 2002).

Industrial exploitation of living resources had long-term, irreversible effects on biotic communities in the Chesapeake Bay. Wholesale removal of oyster beds has continued until modern times, leading to more than 95% destruction of historical (18th-century) oyster grounds (Rothschild et al. 1994). This loss has led to fundamentally altered food webs and an ecosystem less capable of absorbing surfeits of sediment and nutrients. Newell (1988) and Ulanowicz and Tuttle (1992) have suggested that higher abundances of phytoplankton and sea nettles in the modern Bay result from reduced oyster abundance. Anecdotal evidence also supports the idea that sea nettles were not as abundant during the 17th and 18th centuries (Kennedy and Mountford 2001). Dredging and tonging both hard and soft bottom for oysters and clams was temporally frequent and spatially pervasive. These techniques significantly disturbed bottom habitat from the mid-19th century to modern times, impacting bottom structure, biogeochemistry, and infaunal communities (Watling and Norse 1998).

Although the ecological consequence of much-reduced spawning runs of anadromous herrings and shad remains uncertain, some researchers have suggested that these runs were important in delivering marine nutrients to oligotrophic upstream spawning habitats (MacAvoy et al. 2001). Juvenile herring and shad also represent important forage to piscivorous fishes (bluefish, weakfish, and striped bass). The large seine, pound, and gill nets of the late 19th century also intercepted a diverse assemblage of estuarine organisms, and may have depressed abundances in a systemic way throughout the Bay. Tilp (1979) writes of the industrial period,

“. . . the immense exhausting sweeps of the great 1600 fathom seines covering 1200 acres of bottom twice a day; the continual drifting of gill-nets, almost invisible to the fishes in the roily water, yet reaching across the channels often three-quarters of a mile and from surface to the bed of the river; and hundreds of pound-nets, fencing off long sections of the runways of the fishes, until it is

scarcely an exaggeration to say that not a gallon of the water of the river flowed into the Chesapeake Bay without being strained through the meshes of some net."

In particular, the once common Atlantic sturgeon and sheepshead became quite rare during the early 20th century (Hildebrand and Schroeder 1927; Miller 1986). Over-harvesting may have driven these species, with populations already stressed from habitat change, to lower and irreversible production levels. The population structure and biodiversity of other Chesapeake Bay fishes may have also been substantially altered.

Agrarian Revolution II: The Green Revolution

After World War II, industrial fertilizers represented a new and fundamental stress to the Chesapeake Bay. During the 20th century, the means to fix nitrogen from the atmosphere into industrial fertilizers was invented and made viable, yielding a nearly limitless supply of fertilizer and exponential increases in agricultural yields (i.e., the Green Revolution; Horton and Dewar 2000). This process requires substantial energy, fueled by an international supply of oil and gas. Crops actually retain less than 25% of nitrogen fertilizer; the remainder enters the watershed through runoff and the airshed through volatilization (airshed inventories show substantial dry or wet deposition into the watershed).

Much lower costs and high rates of

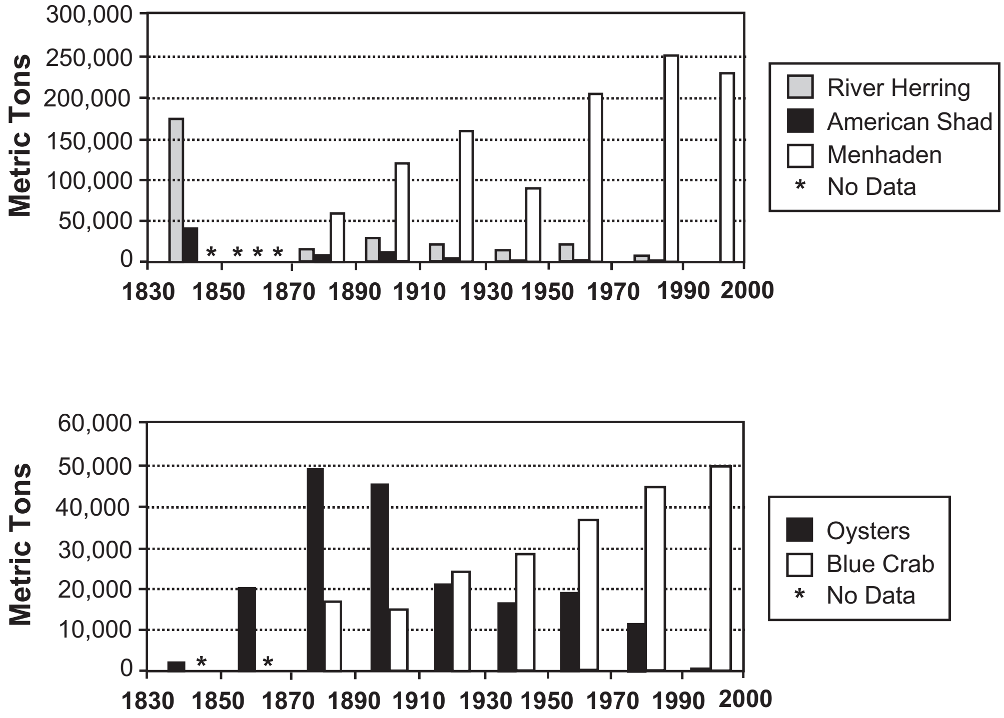

Figure 3. Important Chesapeake Bay fisheries over the past 170 years with peak landings given for each 20-year period. See Table 1 for the rationale in considering peak landings, data sources, and data reporting convention.

industrial fertilizer application translated into an exponential rise of eutrophication during the past 50 years. This trend has been observed in historical records and analysis of pollen and diatom assemblages in sediment cores (Cooper and Brush 1991; Hagy et al. 2004). With increased fertilizer use and reduced costs of grains in animal feeds, manure loading from pastured animals has also increased. In recent models of nitrogen sources to the Chesapeake watershed, the most important source of nitrogen was industrial fertilizers applied to croplands, followed by animal manure, urban sources, and atmospheric deposition (Linker et al. 1999). Corollary evidence for this fundamental change in nutrient enrichment is the rapid increase in spatial and temporal frequencies of summertime hypoxia in bottom waters of depth-stratified portions of the Bay (Officer et al. 1984; Zimmerman and Canuel 2000; Hagy et al. 2004). Industrial fertilizers have also accelerated the loss of seagrass beds (Orth and Moore 1983), increased algal blooms (Harding 1994; Malone et al. 1988), and caused the extirpation or loss of fishes intolerant of low oxygen such as sturgeon (Niklitschek and Secor 2005).

Increased agricultural yields also required greater pesticide application. Regional pesticide use grew from 3,500 mt in 1954 to 13,000 mt in 1987 (Horton and Eichman 1991). Pesticides such as DDT, banned in 1972, had long-term effects on bald eagles and blue herons, greatly reducing their natality rates and abundances. Currently, pesticide use within the Bay's watershed is concentrated in Delmarva, the northern neck of Virginia, and the Piedmont province of Pennsylvania. DDT and industrial products such as PCBs are persistent; once deposited in sediment, the chemicals may be buried for many years but due to infrequent scouring may remain bioavailable to living resources for decades (Boesch et al. 2001c).

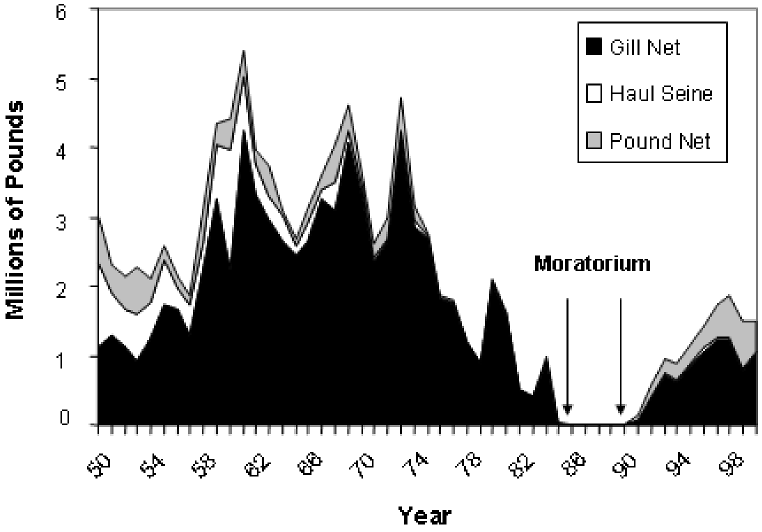

Figure 4. Maryland striped bass landings by gear type. Gill net category includes all gill net gear types (anchor, drift, stake). Fyke net and hook-and-line categories were minor (<9% total landings throughout the series). Data from Zlokovitz (MD DNR).

Modern Industry

The post-World War II Green Revolution and economic boom increased maritime industry, stimulating further development of cities and suburbs in the Chesapeake watershed where the human population increased from 5 million in 1930 to 15 million in 2002 (Grumet, 2000). Until the 1970s and 1980s, entire municipalities released human sewage and detergent phosphates directly into the

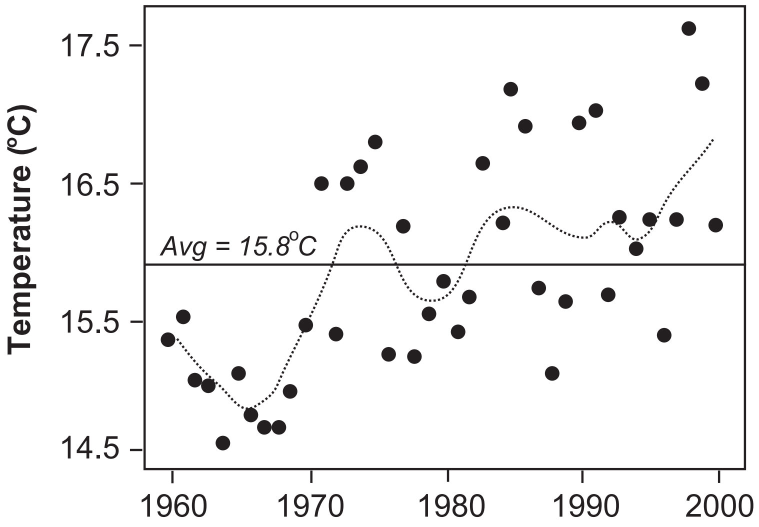

Figure 5. Average annual water temperatures (VIMS pier).

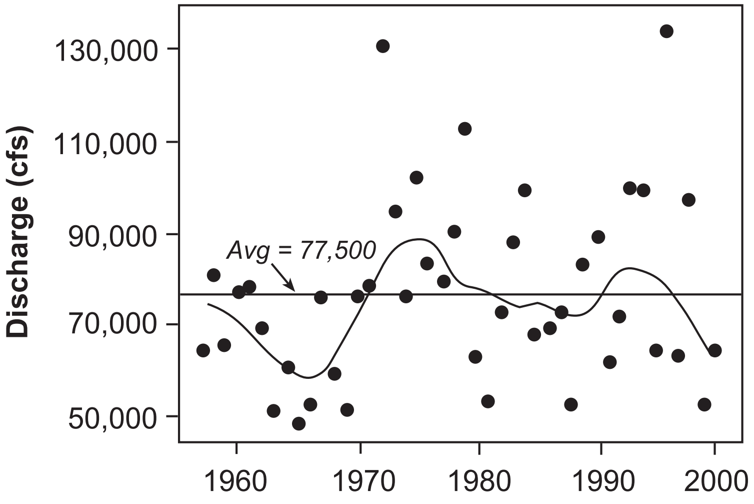

Figure 6. Average annual Chesapeake Bay discharge.

watershed. Highways improved and expanded, which concentrated commerce, industry, and residential development along these corridors. The Chesapeake Bay Bridge (1952) and Chesapeake Bay Bridge-Tunnel (1964) stimulated development in the Eastern Shore region of Maryland and Virginia. Despite gains in forested lands in the watershed (about a 50% increase in forested lands during the past 100 years), impervious surfaces continue as a dominant feature of the landscape, contributing to increased sediment, nutrient, and contaminant loads.

Baltimore and Norfolk kept growing as major maritime centers. In recent years, approximately one hundred million tons of cargo arrived annually in Baltimore (Grumet 2000). Waterborne commerce accounts for about 20% of all jobs in Maryland; in Virginia, Newport News shipyard is the state's single largest employer. The U.S. Navy, with a large base in Norfolk, has also contributed significantly to maritime industry development in the lower Bay. Maritime traffic of larger and deeper-draft merchant vessels required deeper and more frequently maintained navigation channels and harbors. Dredging and the displacement of dredge spoil to other parts of the Bay can affect fish and shellfish by removing or inundating slow-moving or sessile species and their prey (IAN 1999). Dredge spoil can also reintroduce sedimentary inventories of nutrients and contaminants into the water. Observations of non-indigenous invasive species carried in ballast water from distant shipping ports increased during the latter part of the 20th century (Ruiz et al. 2000).

Modern Fisheries

During the past 60 years, blue crab *Callinectes sapidus* and Atlantic menhaden have dominated Chesapeake Bay commercial fisheries (Figure 3). In the 1930s, crab pots were introduced as an effective means to harvest crabs (Cronin 1998; Van

Engel 1999); this gear dominates the fishery that now exceeds $50 million. Atlantic menhaden supported a boom fishery in the early 20th century using large purse seines and factory ships and has remained important throughout the last 100 years. Given the large-scale removals of both species, their historic ecological functions may have diminished. Juvenile menhaden constitute important forage for piscivorous species (Hartman and Brandt 1995). As adults, menhaden consume substantial amounts of phytoplankton (Luo et al. 2001), although the significance of this removal on an ecosystem level is likely limited (~3 to 9% of ecosystem carbon is assimilated and stored as menhaden; Deegan, 1993; Boynton et al. 1995; Durbin and Durbin 1998). As abundant and ubiquitous predators, blue crabs can structure benthic communities through their predation (Micheli 1997; Seitz et al. 2001).

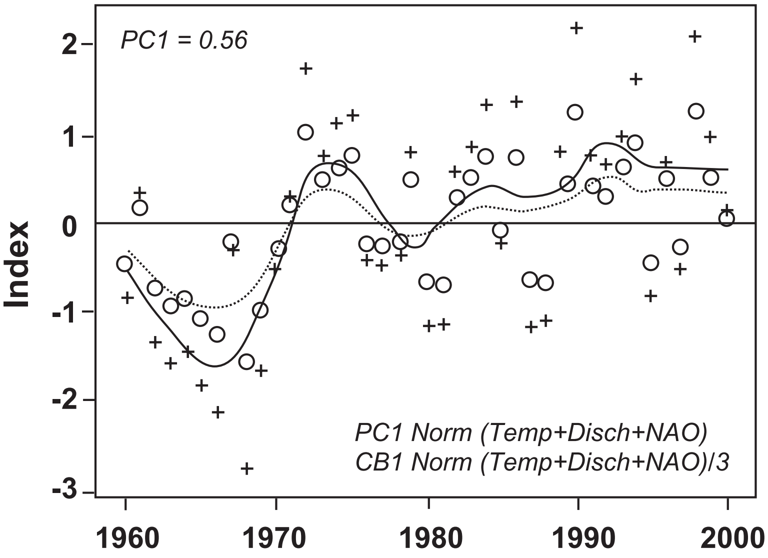

Figure 7. Chesapeake Bay Environmental Index from normalized VIMS pier temperatures, Chesapeake Bay discharge, and the North Atlantic oscillation, along with the index created from a principal components analysis of the same three components.

Due to additional regulations, decreased markets, diminished stocks, and increased recreational allocations, traditional Chesapeake Bay fisheries for finfish have diminished over the past 20 years. Revenues based on recreational angling of Bay fish and crustaceans now dwarf revenues from traditional capture fisheries. The total commercial yield in 2000 was 128 million dollars, 65% of which was attributable to Atlantic menhaden ($28 million) and blue crab ($55 million). Recreational fisheries in 2000 reached $523 million in Maryland alone (MD Sea Grant 2001). The fishery and market for rendered menhaden, while still important, has diminished in recent years due to closure of purse seine fisheries in Maryland and other coastal states as well as competitive markets in soy protein (ASMFC 2004). Virginia maintains an active purse seine fishery and rendering industry. The trend of increased consolidation and reduction in menhaden purse seine fisheries is also related to conflicts with other user groups, such as those who wish to conserve menhaden as forage fish or property owners who do not wish to yield their nearshore water usage and shoreline vistas to purse-seining operations (ASMFC 2004). For other traditional fisheries, such as striped bass, very few haul seine fisheries continue operation in Maryland and gill-net fisheries have diminished nearly fivefold since 1970 (Figure 4). The reasons for diminished commercial finfish fisheries are complex, but socioeconomic factors unrelated to species abundance have had influence in recent decades (see Economic and Social Dimensions Element). In 2000, recreational harvests accounted for a significant fraction of total landings for many living resources, including striped bass (45%), Atlantic croaker *Micropogonias undulatus* (34%), summer flounder (43%), white perch *M. americana* (22%), weakfish (42%), bluefish (50%), Spanish mackerel (34%), and scups (85%). Finfish species other than menhaden that still support important commercial fisheries include striped bass, Atlantic croaker, summer flounder, spot, black sea bass *Centropristis striata*, weakfish, white perch, and catfish. Ex-vessel prices for these fisheries in 2000 each ranged from 1 to 8 million dollars.

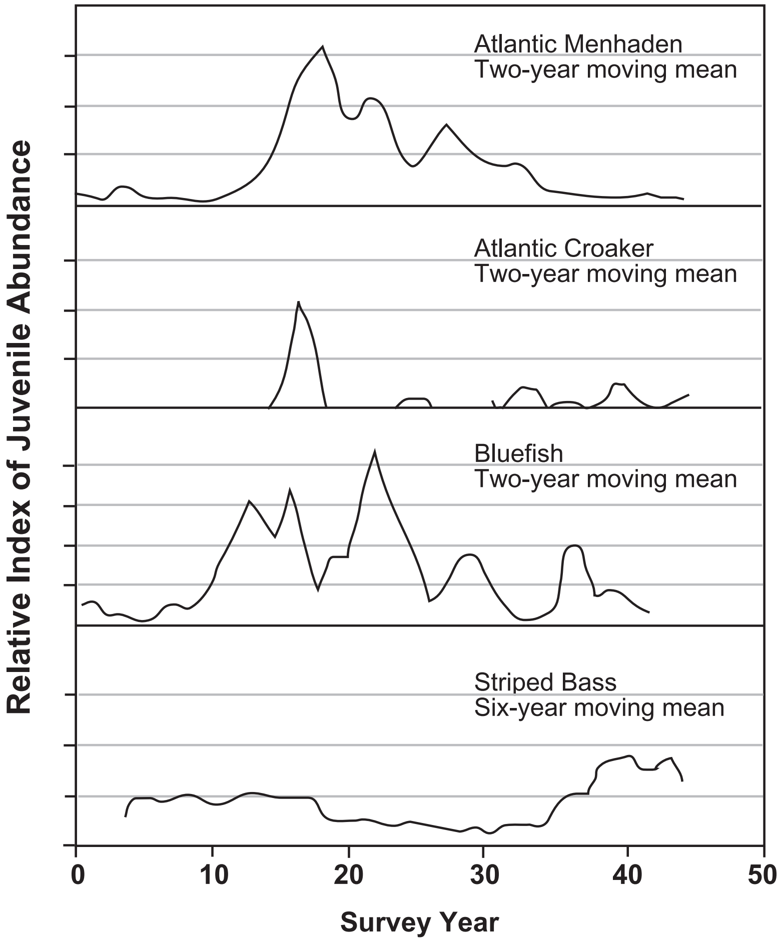

Figure 8. Time series of juvenile (young-of-the-year) abundances of four important living resource species (data from MD DNR littoral seine index, which surveys major tributaries in the Maryland portion of the Bay).

Climate Regimes in Modern Times

Climate represents a chief externality driving fisheries production in addition to ecosystem and societal changes. This element has already reviewed the impact of climate on the formation of the relatively stable hydrological conditions that favor the productivity of the Bay's living resources, such as oysters and anadromous fishes. Understanding modern climate changes over decades and centuries, along with their impact on aquatic species, is also paramount in ecosystem management.

Ecosystems, in spite of substantial interannual variability, tend to fit into multi-year, low-frequency patterns of similar conditions called regimes. Hare and Mantua (2000) define a regime, which ". . . implies a characteristic behavior of a natural phenomenon (sea level pressure, recruitment, etc.) over time, generally a decade or longer." The previous discussion on historical change has focused on regimes that persist over decades. Regime shifts can occur as a smooth transition from regime to regime or as abrupt regime shifts. In the Pacific Northwest, the climate regimes that are frequently cited are characterized as “Cold–Wet” and “Warm–Dry” (Ebbesmeyer et al. 1995).

The success of salmon management in the Pacific Northwest, the virulence of paralytic shellfish poisoning, and oyster condition indices all relate to the climatic regime dominating at the time. Management plans that proved successful 10 years ago can become ineffective if the decadal regime has shifted. Alternating strategies, linked to the corresponding climate regime, appear warranted. Managers should amend their plans to account for regimes if only as a way to raise the level of awareness, and to better understand why one plan succeeds and another fails or why a plan proved successful for a decade and then failed. Clearly, the impact of the controlling climatic regime should be taken into account in managing fisheries.

Can the Chesapeake Bay estuarine climate be characterized by regimes? Just as Ebbesmeyer et al. (1995) used the Pacific Northeast Index (PNI) to characterize that region as “Cold–Wet” and “Warm–Dry,” characterizing the Chesapeake Bay by the predominant decadal regime may also be possible. The annual average surface water temperature in southern Chesapeake Bay (Figure 5) and the annual average discharge (Figure 6) indicate a cool dry period during the 1960s with a warmer wetter decade in the 1970s. The 1980s were intermediate and the 1990s were again warm and wet until 1999. Austin (2002) created a Chesapeake Bay Index using the method of Ebbesmeyer et al. (1995), in which normalized south Bay temperatures (Figure 5), freshwater inflows, and the North Atlantic Oscillation (NAO, a proxy for zonal winds) were combined (Figure 7). From this analysis, decadal periods of “cold and dry” (1960s) or “warm and wet” (1970s and 1990s) became apparent. The 1980s departed from this pattern, showing intermediate characteristics. An independent multivariate statistical approach confirmed this same pattern (Figure 7). Thus, the Chesapeake can be characterized by low-frequency (decadal-scale) climatic regimes.

Do Bay climatic regimes oscillate smoothly between the two extremes or do they sometimes reverse with dramatic suddenness? If such dramatic shifts occur, they could have a profound impact on living resources and resource management. Mosca (1997) conducted a multivariate analysis of Bay temperatures and lower Bay finfish recruitment patterns. He noted a striking shift in the fish assemblage as this area experienced the two warmest winters (1974–1975) followed by the two coldest winters (1977–1978) during the recorded period. A significant winter warming trend has taken place since 1978. Was this a regime shift? Apparently so. Thus, Tropical Storm Agnes, which caused such a drastic decline in the softshell clam population, may have been preceded by thermal stress to the clam stock due to rising temperatures (Shaw and Hamons 1974; Southworth and Mann 1998).

Managers and scientists must manage Bay fisheries against this dynamic background, while also considering changes in water quality, fish stock abundance, contraction or expansion of seagrass beds, and oyster restoration. If CBP management measures or mitigation occur in synchrony with the background climate, such an approach may enhance gains in living resources. Measures occurring out of synchrony may dampen success (Anderson 2000; Hare and Mantua 2000). For example, efforts in restoring Bay water clarity were frustrated during the 1990s by increased freshwater discharge and resultant increased turbidity. Conversely, the success of the Atlantic States Marine Fisheries Commission (ASMFC) striped bass management plan may have been enhanced during the 1990s by strong year classes produced during cool-wet springs (Wood 2000) superimposed on the long-frequency, warmer-wetter decadal regime.

Similar to decadal patterns in climate, time series of recruitments (year-class strengths) of important Chesapeake Bay fishes also indicate multi-year low frequency patterns (Figure 8). For four species with contrasting life histories, time series of year-class strengths from the Maryland Department of Natural Resources' (MD DNR) littoral zone recruitment index survey show two patterns

1) Time series of juvenile production show strong autocorrelation, particularly over one- to three-year intervals. Thus, factors that contribute to high recruitment in one year are likely to favor recruitment in the next; conditions that lead to poor recruitment will likely persist for several years.
2) Multi-year oscillations in juvenile production, although of varying duration, are common among living resources in the Chesapeake. Figure 8 shows the time series for the four species smoothed to reflect age at female maturity across species, with the expectation that this is reflective of population trends. Intervals between periods of relatively high juvenile production ranged 20 years for Atlantic menhaden and striped bass and about five to ten years for Atlantic croaker and bluefish. Longevities for all species exceed 10 years; all species are likely adapted to exploit decadal oscillations in environments salubrious to strong year-class formation. For instance, striped bass, with longevities over 30 years, can persist during a decade of poor juvenile production. Commercial fishes with this life history type—periodic strategists—are typical of most temperate marine and estuarine environments (Winemiller and Rose 1992; Secor 2000a).

Because climate oscillations likely drive decadal cycles in juvenile production (Wood 2000), a precautionary approach should consider both short- and long-term thresholds. First, recent observations of juvenile production should frame short-term expectations for fisheries yields. During a period of depressed abundance, the next year's production is likely to continue at a low level. Thus, we should not set a year's targets and thresholds independent of the recent past. With the absence of information or perspective about recent production trends, taking a fixed fraction of harvested fish from the spawning stock (used historically for Pacific salmon and Caspian Sea sturgeon fisheries—escapement-based fisheries) has been suggested as a precautionary approach (Walters and Parma 1996; Secor et al. 2000).

Second, multi-annual low frequency oscillations require consideration, since the long-term viability and resiliency of living resources depend upon these longer patterns in climate. Should striped bass undergo exploitation that reduces the number of age classes (cohorts of the same age) of mature fish and spawning stock biomass, then a decadal period of poor juvenile production could endanger the population. Not only is it important to implement the more commonly applied spawning stock biomass thresholds used in single-species management, therefore, but also to move toward development and implementation of age structure reference points (Secor 2000a; Marshall et al. 2003).

Fisheries Management, Restoration, Conservation, and the Chesapeake Bay Program

Several pieces of federal legislation have significantly affected the Chesapeake Bay ecosystem during the past 30 years. The Clean Air Act of 1963 reduced industrial emissions into the Bay's airshed. The Clean Water Act followed in 1972, establishing water quality standards and requiring construction of new sewage lines and treatment plants. State and district signatories of the Chesapeake Bay agreement (Washington, D.C, Pennsylvania, Maryland, and Virginia) banned phosphate in detergents, improved stormwater drainage and farming practices, and reduced point sources of nutrients (Boesch et al. 2001a). The Chesapeake Bay Program and states also implemented ambitious programs of SAV recovery, dam removals, and other forms of habitat restoration. The Atlantic Striped Bass Conservation Act (1984) and its successor, the Atlantic Coastal Fisheries Cooperative Management Act (1993), provided a mechanism to develop rational fisheries management guided by scientific assessments and input from stakeholders (watermen and anglers, conservation groups, and state, federal, and academic scientists). These acts also required states to coordinate management and enforce fishing restrictions on important migratory Bay species such as striped bass, bluefish, weakfish, American shad and herrings, sturgeons, and American eels *Anguilla rostrata*. These and other actions taken by Chesapeake states have resulted in recoveries (Richards and Rago 1999; Secor 2000b) and demonstrated that some recent changes to the Bay ecosystem and its stressed species are to some extent reversible. Noteworthy accomplishments include

1) Restoration of bald eagle, osprey, and heron populations;
2) A 67% decrease in the industrial release of chemical contaminants;

3) Approximately 50% reduction of phosphate inputs;
4) A 60% increase in SAV acreage since 1984 (although since 1992 trends in SAV acreage have remained relatively flat);
5) Increase in forest buffers by about 800 km since 1996; and
6) Greater abundance of striped bass and American shad (CBP 2002).

The Prognosis: Two Case Studies

Human population growth and attendant economic development continue unabated in the Chesapeake region, which will undoubtedly bring new ecological, economic, and social changes to the ecosystem. Indeed, climatic events, catastrophic disease, continued accumulation of nutrients and contaminants, and various restoration scenarios conjure numerous and varied scenarios of future change. This section presents two possible trajectories that exemplify the challenges that human industry will bring to Chesapeake fishery ecosystems during the next decade.

Case Study 1: Invasive Disease Species (Anguillicola crassus)

We typically think of invasive species as free-living organisms (e.g., zebra mussels *Dreissena bugensis*, *Phragmites*, Northern snakehead *Channa argus*, channel catfish *Ictalurus punctatus*, nutria), yet such organisms may harbor diseases or parasites that become introduced as well. Typically, indigenous species are more susceptible to these invasive parasites and disease organisms than host species, presumably because they lack the adaptations for resistance acquired only after long periods of parasite-host coevolution. Indeed, the two principal oyster disease microbes—MSX *Haplosporidium nelsoni* and Dermo *Perkinsus marinus*—were probably invasive. The rapid infestation of oysters since the 1950s suggests recent introduction (Andrews 1996; Ford and Ashton-Alcox 1998; Ruiz et al. 1999). Mechanisms of introduction of these and other invasive species are diverse: intentional introductions and transfers (e.g., the transplant of many oysters from the Gulf of Mexico, where the two pathogens occur), aquaculture, aquarium trade, canals, boat movement across watersheds, and maritime traffic. Ballast water may be a particularly important vector of transmission in estuarine and coastal systems (Ruiz et al. 2000).

Anguillicola crassus, an invasive nematode parasite of eels, represents an increasingly typical invasive species in the Chesapeake Bay. Originally associated with Japanese eels and subsequently introduced to European eels, the nematode parasite may have originally become prevalent in the Chesapeake only several years ago (Barse and Secor 1999). The parasite infects the swim bladder and can affect swimming ability. In European eels cultured at high densities, elevated infection rates are associated with secondary infections and mass mortalities. *A. crassus* is one of several factors that may have contributed to recent declines in both European and American eel fisheries

(ICES 2000). Because European and Japanese eels are cultured in the United States, researchers thought that aquaculture was the original mechanism of transmission (Fries et al. 1996), but the parasite has rapidly transmitted to systems where no eel aquaculture occurs (Barse et al. 2001; Morrison and Secor 2003). Significantly, copepod species form the necessary intermediate hosts for the parasite. Thus, ballast water seems the most likely mechanism of the parasite's very rapid introduction to several systems in North America and Europe. Further, a secondary juvenile form of the parasite is nonspecific in the hosts it will infect, ranging from snails to fish to amphibians (Szekely 1994). In a European system, every species of fish investigated carried the juvenile phase of the parasite. This parasite may be affecting Chesapeake eels directly, but also influencing a variety of Bay fauna in subtle and unknown ways. Ruiz et al. (1999) and others have suggested that ecosystem disturbance or stress can promote invasive species colonization. Indicators such as rapid eutrophication, other forms of pollution, and biotic communities during the past 50 years suggest that cryptic invasive species such as *A. crassus* may already be more common than we suspect, and are likely to increase in the near future.

Case Study 2: Industrial Fish Production – Aquaculture

World production of cultured aquatic species has grown substantially in recent decades, now accounting for nearly 25% (29 million mt in 1987) of global fish and shellfish yields (ESA 2001). In the Chesapeake, aquaculture growth has been more limited. Oysters, clams, and catfish constitute the most important species, but commercial activity in this sector remains small compared to commercial and recreational fisheries. Still, given the rapid emergence of salmon, shrimp, clam and even sturgeon aquaculture, aquaculture could grow rapidly in this region.

Most forms of marine aquaculture, as presently practiced, may not be sustainable and are not environmentally benign enterprises in practice (Rosenthal 1985; Naylor et al. 2000). Many of the more lucrative cultured species are carnivorous and require large quantities of wild-captured fishes to make up their formulated feeds. Marine fish and eels convert feed at a ratio of 5 kg of fishmeal per 1 kg of flesh, with increasing demand on fishmeal markets as aquaculture expands (Chesapeake menhaden is used for fishmeal). On a global basis, the Ecological Society of America (ESA 2001) developed the following mass balance equation for the global catch

> *Total Supply (115 million mt) =*
> *Wild landings (96 million mt) +*
> *Aquaculture (29 million mt) –*
> *Fish food (10 million mt)*

Wild fisheries supply fishmeal markets for livestock and fish (30 million mt), a third of which supports aquaculture. Aquaculture, therefore, is not an enterprise functioning independent of wild stocks of fish and fisheries management. It also engenders environmental risk through disease introduction, genetic or ecological impacts caused by cultured fish escaping into the wild, and eutrophication and pollution from excess feed, feces, and antibiotics (Rosenthal 1985; McKinnell and Tomson 1997). Although the Food and Agriculture Organization of the United Nations (FAO) states that the future may bring concepts and practices of sustainability similar to those that guide fisheries management (FAO 1996), aquaculture is considered an extractive industry (ESA 2001).

Aquaculture has and will likely provide substantial benefits to restoration efforts in the Chesapeake Bay. Benefits include planting of oysters, which can crop phytoplankton, increase water clarity, provide habitat, and yield commercial product. Further, oyster aquaculture relies on natural forage and does not require the injection of supplementary feeds into natural systems. Oyster aquaculture has historically occurred in Virginia through leased bottom. Most stakeholders (conservation groups, watermen, scientists, and managers) concur that aquaculture-based tactics should receive priority in oyster restoration, but disease, lack of good locations, and enforcement and legal issues pertaining to leased bottom have hindered oyster planting expansion. Restoration of SAV will also likely depend upon better aquaculture technology.

Hatcheries are by no means new to the Bay, but their role has changed. Originally scientists and managers thought of hatcheries as a way to make up for natural production lost through exploitation or habitat loss, or to introduce commercially valuable fishes. More recently, hatcheries have catalyzed the recovery of species such as striped bass and American shad. While the role of hatcheries in striped bass recovery was minor (Richards and Rago 1999), hatchery released and tagged individuals provided critical information on striped bass growth, migration, and recruitment. Hatchery-released American shad stimulated recovery in the Susquehanna drainage (Hendricks 1994). As state and federal scientists have initiated aquaculture efforts that strengthen restoration, they have moved away from hatcheries that support put-and-take fisheries. Even in conservation efforts, however, significant ecological, genetic, and economic risks associated with large hatchery programs exist. Managers and scientists must weigh these risks against the potential benefits (Lichatowich 1999; Secor et al. 2000; Secor et al. 2002).

Themes of Chesapeake Bay Fishery Ecosystem Change

Historically, the impact of fisheries on the Bay ecosystem was substantial: removal of key species, changes in age and size structure within fished stocks, decreased biodiversity, habitat destruction, community changes, and introduction of exotic strains and species. Pitcher (2001) summarizes fisheries effects on ecosystems as a generalized historical sequence that applies well to the Chesapeake. First, overfishing may alter life history characteristics of exploited species, potentially causing longer-term genetic effects. Next, the habitat degradation associated with some types of fishing redirects carbon flow and stocks from the benthic to the pelagic compartment. Preferential removal of large fish diminishes piscivory and leads to increased numbers of small pelagic fish. Fishermen then work progressively down the food chain, causing trophic cascade effects (e.g., Pauly et al. 2000), resulting in increased system variability (booms and crashes). Similar effects are thought to occur in the Chesapeake Bay, including loss of benthic species (sturgeons and sheepshead) and function (oyster filtration), increased harvest of planktivores (20th-century menhaden fishery), and more variability in recruitment patterns of resource species such as striped bass.

Still, compelling evidence indicates that a profound shift in the watershed from a forested to herbaceous landscape preceded these fisheries effects. This shift resulted in larger sediment loads, bottom habitat degradation, and a "flashier" ecosystem influenced more strongly by freshwater inflow, seasonal weather, and decadal climate oscillations. These initial changes occurred principally in the late 18th and early 19th centuries, long before industrial fisheries on oysters and other species emerged. In more recent times, a further shift in the ecosystem resulted from accelerated eutrophication due to post-World War II use of industrial fertilizers along with urban and residential development. Forces of change not directly related to fisheries but stemming from shifting agricultural practices and other anthropogenic transformations, therefore, had perhaps the greatest impact. These changes preconditioned the Bay ecosystem to amplify the effects imposed by 19th- and 20th-century industrial fisheries.

The current Chesapeake Bay ecosystem functions as a nutrient sink. Nutrients and contaminants are eventually sequestered in sediment where they may be unavailable to biota (Boynton et al. 1995). This more recent role of the benthos as a chemical sink for nutrients and contaminants represents a significant departure from its historical role as a biogenic structure that supported a diverse assemblage of demersal fish and other long-lived species. Biogenic habitat may remain critical to the nursery function of the Chesapeake Bay, yet remnants of such habitats remain highly susceptible to further environmental and anthropogenic stress.

Stresses of the recent past—such as Tropical Storm Agnes, which washed away entire SAV beds (CRC 1976)—and the diseases that devastated oysters are all indications of the potential for future problems. Shortnose sturgeon, perhaps "a canary in a coal mine" given the low tolerance of this species to hypoxia (Niklitschek and Secor 2005), is locally extirpated in Chesapeake subestuaries. Other demersal fishes, such as Atlantic sturgeon, black drum, and sheepshead, remain rare compared to historical abundances. The potential to reverse the pervasive changes wrought by humans in the short term remains an open and debated issue (Ulanowicz and Tuttle 1992; Boesch et al. 2001a).

Recently, study of fisheries effects on ecosystems has focused on ecosystem engineers—critical organisms that play key roles in the ecosystem such that their exploitation leads to ecosystem change (Jones et al. 1994). Oysters and other bivalves in the Chesapeake Bay undoubtedly continue to modify their local environment through filtration and with their structured habitat, but at much reduced levels. Ironically, the introduced bivalve Asian clam *Corbicula fluminea* (Phelps 1994), was associated with remarkable changes in water transparency and increased SAV in up-estuary regions of the Potomac River.

Why then not go "back to the future," as Pitcher (2001) suggests, and recreate a bivalve-dominated ecosystem? The constraint is historical sequence: 18th-century siltation and hydrological regime shift led to 19th-century overexploitation and loss of benthic habitat which led to 20th-century eutrophication and hypoxia regime shift. The Bay's sediment cores provide ample evidence of these changes (Cooper 1995; Cornwell et al. 1996; Brush 2001)—changes that fundamentally altered the ecosystem. Thus, hydrological changes, nutrient and sediment loads, disease, and lack of suitable habitat overwhelm the filtering role that the oyster could provide in the modern Chesapeake. While researchers have proposed other ecosystem engineers (e.g., menhaden), they are unlikely to prove as effective as techniques that control anthropogenic nutrients (e.g., improved tillage and residential development practices, decreased manure loadings) and provide vegetative nutrient sinks (e.g., forest and marsh watershed buffers, SAV) (Boesch et al. 2001a).

Since fisheries are much diminished and will likely continue to decline in the future, caution is warranted in using additional fisheries regulations as a means to effect ecosystem change. In some cases, we may need to reduce removals severely to realize an ecosystem benefit, with substantial risk to traditional livelihoods. Some scientific rationale, however, does indicate that reducing exploitation rates on oysters could stimulate recovery where other strategies have failed (Rothschild et al. 1994; S. Jordan, unpublished). Further, changing regulations to harvest larger menhaden could potentially benefit the commercial yield as well as increase the stock's removal of phytoplankton. Recreational removals will likely continue to increase, making it important to investigate the role that removal of piscivores (e.g., striped bass and weakfish) and benthivores (e.g., summer flounder, spot, and croaker) has on pelagic and demersal communities.

Major Findings

The Chesapeake Bay is a relatively stable and shallow estuary, particularly susceptible to hydrological and anthropogenic influences. Even perfect control over fishing effort and understanding of fish population dynamics is not sufficient to ensure successful stewardship of living resources when so many forces outside of fishing (externalities) affect ecosystem structure and function and fisheries production. In some cases, external forces are regular and periodic events, such as annual spring freshets. Major events, such as Tropical Storm Agnes in 1972, are less predictable and more devastating. Other largely human-induced externalities that represent major forcing factors include nutrient and sediment loads, disease, dams and canals, harmful algal blooms, and contaminants.

Historical events have set the course to some extent for fisheries management in the present Chesapeake Bay. The anthropogenic influences of the past play an important role in expectations for fisheries management now and in the future. Beginning in the late 18th century, clear-cutting agricultural practices contributed large loads of sediment and transformed bottom habitats in Bay tributaries. Until the mid-19th century, fisheries remained small and were unlikely to have had ecosystem-level effects.

Industrial-scale fisheries in the late 19th century, however, coupled with dam construction and degraded habitats, caused large-scale and lasting changes in the Bay ecosystem. Historical removal of oyster beds through dredging irreversibly damaged the Bay's structure and contributed to its present state. Habitat degradation, dams, and overharvesting contributed to population crashes of shads, river herrings, and sturgeons in the early 20th century. Over the past 100 years, some species of shad and river herring have shown limited population recovery. But, shortnose sturgeon is extirpated and Atlantic sturgeon is now rare. The extensive use of industrial fertilizers since the late 1950s triggered a pervasive ecosystem change that resulted in further degradation of bottom habitats along with loss of oysters and other living resources.

Strong recent indications of global climate change and increasing evidence of decadal climate shifts at a regional scale that affect productivity and recruitment levels of Chesapeake Bay fisheries now represent a major externality. Fisheries managers can do little to control such external forcing. Awareness and understanding of the probable impacts, however, must be factored into fisheries management actions. Changing climate will bring decadal shifts in productivity that will have important implications for single-species management, but even more impact on ecosystem-based management with its empahsis on species interactions and overall ecosystem productivity.

The future Chesapeake Bay is likely to see increased prevalence of introduced species, including disease-causing organisms that may lower the carrying capacity for living resources. Contaminants, particularly those from atmospheric deposition, will increasingly compromise the health of living resources. The potential for introducing ecosystem engineers to improve ecosystem structure and function—and possibly provide additional fishing opportunities—also is an externality that must be considered. For example, introduction of filtering organisms, such as the Suminoe oyster *Crassostrea ariakensis* now debated by resource managers, might provide local benefits to water quality in the Bay, but potentially with presently unevaluated risks.

Panel Recommendations

Management

1) Develop management strategies that promote resilience in living resources.

The recent history of the Chesapeake Bay is one of increased anthropogenic influence, in which climatic events more rapidly affect water quality and fish habitats. Species are adapted to such events, but precautionary management is needed to ensure that estuarine-dependent species maintain their resilience to ecosystem change.

2) Look backwards before undertaking programs of restoration or recovery.

Historical perspectives on the Bay show previous patterns of reversible and recalcitrant ecosystem change. Retrospective analyses can prove valuable before initiating restoration programs.

3) Use fishing controls for oysters more effectively to stimulate some local recovery.

The eastern oyster *Crassostrea virginica* represented an important ecosystem engineer in past Chesapeake Bay regimes. Its ecological function as a water filterer and its ability to support a fishery have all but collapsed. Increased fishing controls could stimulate some recovery and improve the likelihood that natural disease resistant strains will occur. Oysters will likely never fully occupy their historical ecosystem niche, but moderate levels of restoration could have local beneficial ecological impacts and sustain livelihoods for watermen.

4) Gain better understanding of the historical role of keystone species in Chesapeake Bay before emphasizing their use as ecosystem engineers.

While the importance of oysters as ecosystem engineers in the historical Chesapeake Bay is well known, the spatial extent of reefs in the historical Chesapeake Bay and their aggregate effect in structuring linkages between benthic and pelagic realms of the Chesapeake ecosystem remains uncertain. Because restoration of native or introduction of exotic oysters will likely be pursued in the future due to their believed roles as ecosystem engineers, a better understanding of the oyster's historical role is critical.

5) Critically evaluate ecosystem engineers before recommending

them as an efficient means for improving habitats for living resources.

Even if restoring the eastern oyster to abundances of 100 years ago was possible, the species' filtering and reef-building capabilities in the Bay would likely be overwhelmed by nutrient inputs, disease, and sedimentation. While additional ecosystem engineers have been proposed, benefits to water quality and the ecosystem will likely remain local. The most productive immediate approach for ecosystem change is bottom-up control of nutrients.

6) Recognize that fishing is an essential component of fisheries ecosystems. Develop ecosystem-compatible regulations, which do not endanger traditional livelihoods.

Pollution, disease, increased international seafood supply, aquaculture, increased regulations, and slow decay of traditional coastal communities are factors that contribute to declining commercial fisheries in the Bay. Reducing the risk that traditional coastal communities will collapse remains essential.

7) Be adaptive. Acknowledge that some restoration efforts will not succeed due to imperfect knowledge and the difficulty in reversing environmental or living resource trajectories. Apply adaptive and multiple approaches for reaching desired outcomes in ecosystem management.

Despite the difficulty in returning an ecosystem to past regimes, some important anthropogenic changes are reversible.

8) Use benthic community and living resources metrics as the most relevant reference points in ecosystem-based management.

Anthropogenic habitat change and removals of living resources have had the greatest effect on demersal living resources.

9) Build safeguards into fisheries management thresholds on multi-annual time scales to ensure that living resources are resilient to climate change.

Such precautionary measures include: using recent information (past one to three years) on stock productivity levels to forecast near-term stock sizes; and developing and implementing management thresholds that guarantee sufficient biomass and age structure to span expected decades of poor juvenile production.

Needed Research and Development

10) Analyze historical fisheries databases to understand Bay regime shifts.

Models and anecdotal data point to the possibility of a regime shift from an ecosystem dominated by demersal species to one dominated by pelagic species. Further analyses of historical fisheries databases should help determine whether this shift is detectable during the past 100 years.

11) Determine the linkages between fish production and climate.

Global climate change—and associated rises in temperature, sea level, and storm frequency—are likely to have dramatic effects in the Chesapeake Bay ecosystem. These changes, in addition to decadal climate shifts, can affect seasonal occurrences and levels of production and recruitment for important Bay fishery species. The ecologies and life histories of Bay living resources have adjusted to decadal-scale variations in climate, yet the understanding of how climate affects fish production is incomplete. Researchers should use historical databases, archeological information, and empirical analyses (e.g., sedimentary and fossil shell tracer studies) more fully to understand the link between fish production and climate.

12) Understand the impacts of invasive species on Bay fisheries production.

A wide spectrum of invasive species may affect the Bay's fisheries production. Invasives may be microbiotic (viral, bacterial, protozoan, plankton,) in addition to the macrofaunal invasives currently emphasized (e.g., nutria, mute swans, zebra mussels). Further research can clarify the infections and stress that invasive organisms impart to resource species in the Bay, and the risk of future invasions or outbreaks of exotic pathogenic organisms.

13) Conduct analyses of historical ecosystem changes, particularly for the past century, to evaluate the feasibility of ecosystem management.

Additional quantitative modeling, more climate and retrospective studies (e.g., Cooper and Brush 1991; Wood 2000), and historical data retrieval (e.g., Hagy et al. 2004) can more rigorously justify ecosystem-based management. A large store of environmental data collected during the past 50 years by state agencies and academic institutions can be brought to bear in evaluating recent ecosystem trajectories.

14) Conduct research to provide a scientifically based rationale for fishery ecosystem management goals related to nutrient abatement.

Despite the CBP's compelling assertion that nutrient reduction benefits living resources, science establishing a link between the Bay's recent regime shift (green revolution) and fisheries losses is minimal (sturgeon remain a notable exception).

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element 9

Economic and Social Dimensions of the Fisheries Ecosystem

> *"It is evident that even if we fully understand the nature and dynamics of marine ecosystems, we still would not be able to manage them successfully without full consideration of the social, political and economic drivers of the fishing industry."*
>
> *– Professor Harold Mooney, Stanford University*

Introduction

An ecosystem-based approach to fisheries management allows managers to minimize anthropogenic changes to the Bay fisheries ecosystem caused by excess fisheries exploitation and activities that degrade fish habitat. Acknowledging the validity of Harold Mooney's quote, we have incorporated economic and social dimensions of the Chesapeake Bay fisheries ecosystem as vital components of an effective ecosystem-based approach. We consider both economic and social dimensions in a single element because both address human dimensions of fishing and related activities in the Bay fisheries ecosystem.

Such an approach must also recognize the potential costs and social benefits of all activities that may affect the health of the Chesapeake's natural resources. Inadequate attention to any single component can easily lead to a regulatory strategy that fails to maximize net benefits to society. Consequently, determining the value of the natural and environmental resources of the Bay (as well as the potential costs and benefits to society of utilizing these resources in alternative ways) constitutes an important concern. Numerous approaches are capable of valuing natural resources, a given state of the environment, or an ecosystem; the discussion on economic dimensions highlights such approaches. In addition, the discussion provides an overview of the economic values of the commercial and recreational fishing industries within the Chesapeake Bay. The economic dimensions section also covers economic issues important for commercial fisheries, concluding with potential economic research necessary to support ecosystem-based fisheries management in the Bay.

Management and regulation of any natural resource is largely governed by society's preferences for the resource. Society desires commercial and recreational products and services from the Bay but also wants the ecosystem to maintain an acceptable level of health. Society also desires that the abundance and availability of many fish and shellfish remain at certain minimum levels, or higher. At the same time, citizens want to participate in activities or acquire goods that may prove detrimental to the “health” of the Bay and its resources. For example, many individuals wish to live in waterfront homes—often causing the loss of valuable wetlands or sending pollution to the Bay. In another example, consumers may demand more blue crabs *Callinectes sapidus* than can be safely removed from the Bay’s population, leading to resource depletion.

An ecosystem-based approach must consider competing uses and values for society to receive the maximum net benefits from Bay resources. Thus, any regulatory strategy will need to be partly based on the economic value or benefits of a wide variety of potential use patterns (e.g., intense vs. minimal coastal development; recreational activities vs. commercial fishing activities; shipping and water-based commerce other than fisheries vs. recreational activities). Particular attention must be given to assessing the economic consequences of trading one activity for another.

The social dimensions portion of this element describes major stakeholders of the Chesapeake Bay ecosystem with presentation of comanagement and its application to fisheries management in an ecosystem context. An introduction to the concept of a “damage schedule” approach follows (Chuenpagdee et al. 2001a, 2001b). This approach integrates stakeholders’ preferences and scientific knowledge in marine ecosystem management and encourages stakeholder involvement in the formulation of policy to support an FEP. Bay researchers are applying this approach to the Chesapeake through funding from the Chesapeake Bay Fisheries Research Program.

Economic Dimensions and Associated Issues

Even after decades of biological and economic overfishing and habitat degradation, the Chesapeake Bay remains an important recreational and economic resource. The Bay supports numerous commercial and recreational fisheries, as well as businesses dependent upon commercial landings and recreational expenditures. Annually, the Bay provides nearly $160 million in ex-vessel value and more than 500 million lbs in ex-vessel landings to the regional economy (Kirkley 1997; Kirkley and Kerstetter 1997).

Blue crab has the highest landed value with finfish (including menhaden) second in importance to the Bay economy. Eastern oyster *Crassostrea virginica*, even after years of declining landings and disease, contributes more than $8.1 million to the total landed ex-vessel value. The commercial fisheries of Virginia supply approximately $500 million and 11,000 full-time employment opportunities to the state economy. Every one million dollars of ex-vessel landings in Virginia creates approximately 92 full-time jobs. About 88% of the total employment generated by Virginia's commercial fisheries does not take place through the fishing process but through restaurants and food service businesses. The contribution of fisheries to Maryland's economy is also substantial. The landed value of blue crabs and oysters in Maryland totaled over $56 million between 1990 and 2000 on an annual average basis. Softshells (also known as softshell clams) *Mya arenaria* contributed another $3.4 million to the landed value.

Residents and visitors alike derive economic benefits or personal satisfaction from the Bay's many recreational opportunities, including several valuable recreational fisheries. In 2000, approximately 1.6 million individuals engaged in recreational saltwater fishing in Maryland and Virginia. In 1996, recreational fishermen in Virginia spent slightly more than $303 million on saltwater activities. With the deduction of offshore expenditures, they spent approximately $250 million in the Virginia portion of the Bay. Saltwater sport fishing in Virginia contributed $477.2 million to the economy and generated full-time employment for 10,944 individuals. The striped bass pulls in the greatest amount of recreational fishing dollars in Virginia, with $63.7 million spent fishing for this species in Virginia during 1996. Comparable data are not available for the Maryland Bay recreational fishery. The state's recreational fishery, however, is quite important to local economies in the state. In 1998, for example, 759,000 individuals participated in saltwater sport fishing in Maryland, representing 2.8 million fishing trips.

The complex multijurisdictional management structure of Chesapeake Bay complicates an ecosystem-based approach. For example, striped bass *Morone saxatilis* are caught in both Maryland and Virginia portions of the Bay, as well as in the waters of other coastal states from Maine to North Carolina. Striped bass are also caught in inland areas, such as the Susquehanna River, and even offshore in the exclusive economic zone (EEZ). Achieving the goals of an economy dependent upon Bay resources may fail if fishing mortality or specific problems affecting the ecosystem remain unaddressed. Activities influencing fish habitat in one geographic area may affect resource conditions in another area. Coordination of management actions between various state and federal agencies in such cases is particularly essential.

An ecosystem-based approach to fisheries management must recognize the potential social benefits and costs of all activities that may affect the well-being of the Bay. Determining the value of the Bay's natural resources, along with the potential costs and benefits of using these resources in alternative ways, allows direct assessments of the “cost of doing business” in the Chesapeake. Several approaches exist for valuing natural resources, a given state of the environment, or an ecosystem. The following section summarizes the approaches appraising natural resources and the economic values of the commercial and recreational fishing industries within the Bay.

Valuing Natural Resources

Noneconomic-Based Approaches

Noneconomic approaches to the valuation of natural resources may be categorized into at least four types:

1) Anthropocentric;
2) Biocentric;
3) “Deep ecology” (also a biocentric perspective); and
4) Energy theory of value.

To a great extent, only the anthropocentric approach has been used to make policy decisions in recent years.

Two basic biocentric approaches address resource valuation: the approach based on Native American ethic and the nonnative biocentric approach of Aldo Leopold (Flader and Callicott 1991). The Native American approach recognizes that although human actions affect the natural world, our role is not to dominate or control nature. Native Americans view the land and all living species as intrinsically valuable, without defining value in terms of human needs. Leopold’s approach rests on a land ethic that presumes all components of nature are linked through balance of the ecosystem. In this concept, the value of each component is based on its ecological role, independent of other value sources.

The “deep ecology” approach of Ness (Devall and Sessions 1985) has a more recent biocentric perspective, rejecting any management approach that alters the environment. In this approach, natural resources do not exist for human benefit and using these resources to satisfy human needs other than vital ones is unethical or inappropriate (Kahn 1998).

In more recent years, Costanza et al. (1991) offered an entirely new approach—ecological economics—as a framework for formulating ecosystem policies that adopt conventional and economic aspects, but integrate ecology with social and economic systems and treat humans as part of the ecosystem. This approach also recognizes that humans have a special place in the system, making them responsible for understanding their role and managing for sustainability. A primary goal of ecological economics is sustainability of the combined ecological economic system. Its major difference from other approaches is its doctrine: the economic value of ecosystems must connect to the ecosystem’s physical, chemical, and biological components within the broader and long-term global system. This value applies regardless of whether the present generation fully recognizes the importance of this role.

This doctrine is consistent with the “minimum safe yield” or “use and time rate of preference” in determining the economic value of an ecosystem. That is, some threshold level of use (i.e., minimum safe yield) exists and society places a different value on the current versus future use of an ecosystem. It may be that society's time rate of preference (i.e., the rate at which they value the future returns or benefits within the current period) for the resource exists at such a low level that the ecosystem is damaged or the resource is harvested at an unsustainable level. With the ecological economic approach, ecosystem utilization must not occur at an ecologically unsustainable level.

Considerable debate exists concerning the suitability of the various valuation approaches. On one hand, Barnett and Morse (1969) demonstrate that biocentric approaches actually indicate economic valuation. These approaches posit that current and future generations value the conservation or protection of a species; the potential benefits to current and future generations of a preserved ecosystem far outweigh any potential benefits generated through its short-term use. On the other hand, Luna Leopold (1991) suggests not placing dollar values on natural resources. While recognizing that society receives value from natural resources, he argues that conservation should not be based on economic valuation because assessing the dollar value of nonmarketable goods and services (e.g., the values of aesthetics, protecting dolphins, or a healthy ecosystem) can prove difficult.

In some respects, the apparent noneconomic valuation approaches are actually economic valuation methods that simply deal with the economic aspects from a different perspective. For example, the Aldo Leopold approach is similar to the "sole owner" approach in which the personal preferences of one owner may define the rate of use or conservation for all society. Even the "deep ecology" approach follows economic valuation. In this case, Arne Næss states a clear preference that natural resource use should be restricted to the vital needs of a society (Devall and Sessions 1985). The feature that distinguishes noneconomic approaches from the economic one is the measure of valuation. With the economic approach, some monetary value is associated with a natural resource's rate of use. This judgment, however, is simply to have a numeric valuation, or measure, to evaluate different use levels of ecosystem components.

Anthropocentric and Economic-Based Approaches

The anthropocentric approach assesses the world in terms of human values and experiences. Since Aldo Leopold's death in 1948, an explosion of research has taken place to determine the values of market and nonmarket goods and services (Freeman 1979; Kahn 1998; Russell 2001). Researchers have conducted extensive studies on the economic value of protecting natural resources. For example, Gupta and Foster (1975) estimated that the economic value of waterfowl habitat equaled $167 per acre per year (in 1975 dollars) and that the wetland function of flood conveyance equaled $191 per acre per year. Farber (1987) assessed the economic value of the wetland function of erosion, wind, and wave barriers at $0.44 per acre per year. Lynne et al. (1981) estimated that the economic contribution of salt marshes to blue crabs with respect to the commercial blue crab fishery equaled $0.92 per acre per year.

An alternative to assessing the economic benefits or net value of components of the ecosystem is to consider the potential economic damages that would occur if the ecosystem failed to provide its basic services . . . To state that society will receive $50 million in net benefits from reducing pollution simply does not have the same impact as stating that failure to reduce pollution will cost society $50 million.

The criticism of using economic valuation to formulate policies that govern natural resources, however, remains strong. The criticism generally focuses not on the methods or concepts, but rather on the accuracy of estimates; no markets for trading ecosystem components exist, after all. Another criticism of economic valuation is the tendency to think only in terms of the direct use utility (e.g., the benefit obtained from sport fishing or from consuming fish).

Alternatively, valuation often considers only the contribution of an industry or business to the general economy (e.g., employment, sales, income, and tax revenues). In actuality, determining the value of natural resources accounts for much more than direct utilization. Besides the direct value or benefit that individuals receive from using a natural resource (these values are typically referred to as direct use values), individuals may receive benefits through option demand, existence value, or bequest motivation. These latter values represent nonuser or nonconsumptive values. Option value is the value a potential user places on the resource to reserve the choice to use it at a future date. Bequest value is the value that an individual holds to preserve a resource for use by future generations. Existence value is the value an individual holds by simply knowing that a resource exists.

Proper valuation of an ecosystem requires an assessment of the benefits to society of all ecosystem components (e.g., the benefits of enhancing submerged aquatic vegetation (SAV), reducing the input of contaminants, increasing the oyster population 10-fold). In actuality, it is doubtful that economic value or benefits of all components of the Bay ecosystem could be empirically estimated with any reasonable degree of accuracy or precision. Perhaps this realization prompted Luna Leopold to suggest that economists should refrain from assessing the value of non-market goods and services.

An alternative to assessing the economic benefits or net value of components of the ecosystem is considering the potential economic damages that would occur if the ecosystem failed to provide its basic services. Consider a failure that caused the population of menhaden to decline drastically in the Bay along with the potential consequences for water quality and the growth and recruitment of several valuable commercial and recreational species (e.g., striped bass and bluefish *Pomatomus saltatrix*). Damages can be fairly viewed as the inverse of benefits. That is, many natural resource policies promote the maximum benefits of a stated goal (e.g., reduction of pollution discharge). One could consider minimization of damages, however, to determine the optimal level of a stated goal (e.g., the optimal level of pollution discharged). When individuals consider damages, rather than purely net benefits, the importance of a fisheries ecosystem management strategy becomes clear. To state that society will receive $50 million in net benefits from reducing pollution simply does not have the same impact as stating that failure to reduce pollution will cost society $50 million.

In developing fishery management plans (FMPs) for fisheries overseen by federal authority, regulatory policies require determination of the economic impacts, in addition to the economic value, of any management or regulatory actions. Section 303 (a)(9) of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) requires preparation of a Fishery Impact Statement (FIS) for any management or regulatory action. The FIS must provide a comprehensive assessment of the net economic benefits, social costs, and economic impacts of proposed regulations. Recent federal requirements for an FMP also require an examination of the economic benefits and costs of protecting or restoring essential fish habitat (EFH).

For the Chesapeake Bay, however, no federal statutory requirements for economic analysis or impacts and value exist. Since Maryland, Virginia, the Potomac River Fisheries Commission, the District of Columbia, and the ASMFC, generally oversee the Bay's fisheries, economic analyses are not required. Nonetheless, keeping federal guidelines in mind may prove important in ensuring proper assessment of impacts and valuation of resources. Management and regulation of fisheries under federal purview (i.e., Magnuson-Stevens Act) require an economic impact statement and an economic valuation of the net benefits to society—mandated requirements of the MSFCMA, Executive Order 12866, the National Environmental Policy Act, the Regulatory Flexibility Act, and the Endangered Species Act.

Legislation not only requires that the potential economic benefits and costs of regulation be examined, it also requires that economic impacts be considered. Economic impacts are not equivalent to economic benefits and costs. Economic impacts are normally changes in the levels of sales or output, income (wages, salaries, bonuses, and profits), and employment. Impact information is important to policymakers wishing to know how management actions may affect both local and higher-level economics.

In a commercial fishery, economic impacts occur through direct, indirect and induced effects. *Direct effects* represent changes in sales, income, and employment in the sector directly affected by the regulation (e.g., regulatory changes in the commercial fishing sector will affect changes in sales, income, and employment in the harvesting sector). *Indirect effects* are changes in sales, income, and employment in the support sectors (e.g., fuel dealers, ice distributors, and marine insurance brokers). *Induced effects* are generated when individuals work for businesses that sell goods and services to the harvesting sector and then spend their income—generating more sales, income, and employment in the local, state, or regional economies (e.g., watermen and fuel dealers spend their income on household and other items). In a fishery, all three types of effects will occur for all sectors from the harvesting to final sales (e.g., restaurants and fish markets).

Presently, no Chesapeake Bay impact model is in place. Kirkley (1997) did develop an input and output or impact model for the commercial fisheries of Virginia. This model, however, is not likely to be very useful for Maryland's Bay fisheries. To estimate economic impacts, therefore, modelers must develop a baywide model or a Maryland input and output impact assessment framework.

Economic impacts, while important, should not be used to assess the appropriateness of individual management actions, particularly if federal guidelines must be followed. Economic impacts measure nothing more than economic activity; they do not provide measures of what a natural resource is worth to society. Also, economic impacts, unless based on highly sophisticated statistical impact models, do not indicate substitution possibilities. For example, if a regulation shuts down a fishery, the traditional impact framework would only be capable of predicting the worst-case outcome; it would not provide a framework for predicting the potential for employment in other fisheries or industries. The impact framework also would not provide measures of how society might benefit or lose from the regulatory action. To understand more fully why economic impacts are inappropriate for evaluating a regulatory option, consider the case of an oil spill (e.g., the Exxon Valdez). The spill resulted in increased amounts of economic activity in the form of expenditures on oil spill cleanup, construction, and sales of other goods and services (Lipton et al. 1995). It is highly unlikely, however, that anyone would view the impacts of an oil spill as beneficial to society.

Federal guidelines and economic theory indicate that the desirability of changes in the levels of natural resources should be partly based on economic value or the value that society places on them. Economic value is quite different from economic impacts. A clear distinction also exists between the way economics and other sciences, such as ecology, use the term "value." The economic emphasis is on human preferences; this does not mean, however, that it is restricted to utilitarian or human consumptive uses. As stated earlier, nonuses of natural resources may also generate value to society.

Consider a coastal area that is degraded and now supports a low level of species abundance. For example, the Chesapeake Bay may not support a desired level of menhaden. In this case, the ecologist might characterize this state of the Bay as less valuable because it supports fewer organisms (Lipton et al. 1995). The economist, however, would declare this state of the Bay as less valuable only if society indicated it was less valuable. If no individual cared about menhaden abundance being low, the economic value of the current state of the Bay could equal the economic value of the original state of the Bay.

Within a broad-based framework, the economic value equals the sum of consumer surplus (value to the consumer in excess of the actual cost to acquire the good or service) and producer surplus (value in excess of what it cost to provide the good or service). Even then, other considerations remain. Consumer surplus represents the amount of money an individual is willing to pay to acquire some good or service or natural resource, minus what they have to actually pay. Producer surplus, narrowly defined, represents the amount of money a producer receives in excess of what it costs to produce a good. Consider the commercial fishery for striped bass. The harvester or fisher receives money from the sale of striped bass. If the producer or harvester receives more than the cost to produce or land the fish, the producer receives producer surplus. Similarly, if consumers are able to pay less than what they were willing to pay for striped bass, they receive a consumer surplus or benefit.

An alternative approach for determining how society values natural resources is conjoint analysis. Conjoint analysis is a technique for determining individual preference across different levels of characteristics of a multi-attribute choice (Kahn 1998). With this approach, individuals articulate their preferences for different states of the environment or different resource levels. Conjoint analysis could be used to determine the preferred mix of commercial and recreational fisheries, state of the environment and ecosystem, and other uses of the Bay.

Economic Valuation within an Ecosystem Context

If ecosystem-based management is to become an effective tool for sustaining fishery resources, it must also consider the economic or social value of all the human uses and their respective costs. It should also attempt to promote maximum net benefits or economic value (economic value is a measure of how society values a good or service; it is not a measure of economic activity such as sales or employment) to society.

The determination of the economic value or benefits of ecosystem-based management requires linking the ecological system and its services to the preferences of society. For example, SAV is important for juvenile fish and the population of blue crabs. Society derives economic value from the direct consumption of finfish and blue crabs. We expect that as the quantity of SAV increases, society should receive benefits from greater numbers of blue crabs and finfish.

What if society desires more waterfront homes and the construction of these waterfront homes damages wetlands, subsequently causing the loss of SAV? With the loss of SAV, finfish and crab numbers decline; commercial and recreational catches and opportunities also decline. The loss of SAV also may cause overall water quality to deteriorate. The economic valuation then requires consideration of the benefits and costs of all the direct use goods and services as well as the nondirect or indirect-use goods and services (i.e., market vs. nonmarket goods and services). Moreover, in a rigorous evaluation of FEP benefits, resource managers would have to consider the potential tradeoffs between the various activities (i.e., which activity or mix of activities generates the highest possible net benefits to society). This hypothetical situation is typical of the kinds of problems associated with determining the economic value of an ecosystem. Chesapeake Bay is a complex ecosystem with highly related, strongly interacting components that must be accounted for in an ecosystem-based approach.

Using a simple illustration, consider the basic problems of determining the economic value or net benefits of the Chesapeake Bay ecosystem. The Bay and Atlantic coastal area supports commercial and recreational fishing, water sports, other recreational activities (such as bird watching), pulp and paper production, oil refinery operations, agriculture, aquaculture, and commercial shipping. Now add existing and new waterfront developments for homes, business establishments, and transportation. Then, consider the ecosystem and its potential linkages to the user groups.

Two primary levels of interactions must be taken into account. First, possible interactions between the user activities and the ecosystem components can occur. Second, interactions between the activities of each group are also possible. For example, more recreational fishing in the Bay might lead to a reduction in commercial landings or an expansion of coastal agriculture might cause nearshore pollution of areas with coastal aquaculture (e.g., the Eastern Shore of Virginia). Several interactions between the economic values of the user groups can also occur. Boating and other water sports may compete with shipping or beach and bathing recreation may compete for space with potential coastal development sites. The ecosystem itself is a major driver of many human uses and of the benefits society receives from nondirect ecosystem services.

An ecosystem-based approach ultimately should consider the economic value to society of major goods and services nurtured or affected by humans. These values should be assessed in development or amendment of Chesapeake Bay FMPs. Inadequate attention to one component of the ecosystem, or one user group, could result in a loss of benefits to society. At the same time, identifying appropriate threshold levels for components of the ecosystem and assessing the economic benefits relative to the threshold levels may become necessary.

The Commercial Fisheries

Commercial fisheries of the Chesapeake region are numerous and complex with several small-scale fisheries that use several types of gear. Watermen seldom depend exclusively on a single species or a single fishery for their income. Unlike many coastal and high seas fisheries, most of the Bay's commercial fisheries tend to be small businesses. Fishing activities and gear types used are highly seasonal, changing with species abundance and availability as well as expected earnings.

In the Chesapeake region, more than 41 fisheries exist (Table 1). The menhaden purse seine fishery has the highest total landed ex-vessel value and represents an exception as an industrial-scale fishery conducted from large vessels based in Virginia. Pot and trap fisheries for blue crab equal the value of menhaden and follow in total landings. The sea scallop *Placopecten magellanicus* dredge fishery is not a Chesapeake Bay fishery as it takes place offshore, but it represents a fishery of substantial economic value to the region. Primarily a Maryland fishery, the soft clam dredge fishery ranks fifth in average annual ex-vessel value. The sink/anchor gill-net fishery, which ranks eighth in value, is primarily a Virginia fishery.

Estimates of landings and ex-vessel revenues show major differences between Maryland and Virginia fisheries (Tables 2 and 3). For both states, the blue crab pot and trap fishery has traditionally generated the highest annual ex-vessel revenues. In Virginia, however, the purse seine fishery for menhaden has the highest average annual ex-vessel revenue from 1990 to 2000. Maryland prohibits purse seining for menhaden within the Bay. Among the uniquely identifiable fisheries of Maryland, the soft clam dredge fishery has yielded the second highest average annual ex-vessel revenues. The Maryland clam fishery focuses on the softshells whereas the Virginia clam fishery is for the hard clam or quahog. Between 1990 and 2000, no soft clam landings were reported in Virginia; during the same period, Maryland reported hard clam or quahog landings only in 1999 and 2000. In Maryland, the trotline fishery ranks third in ex-vessel revenue among all (inshore, coastal, and offshore) identifiable fisheries of Maryland with an average annual value of $7.2 million between 1990 and 2000. In contrast, the trotline fishery in Virginia ranks 31st in value relative to all (inshore, coastal, and offshore) fisheries of Virginia with the average annual value between 1990 and 2000 totaling only $6,900.

More than 170 fish and shellfish species or product forms are landed in Maryland and Virginia. Table 4

Table 1. Average annual landings by gear type and value (2001 constant dollar value) of Chesapeake Bay region fisheries (1990–2000).

Gear	Value (2001 Dollars)	Landings (lbs)
Purse seines (menhaden)*	37,871,374	537,524,835
Pots and traps (blue crab)	37,275,331	50,005,061
Not coded*	21,513,155	19,174,066
Clam dredge	9,119,212	10,673,150
Trot lines with baits	7,223,994	9,151,452
Gill nets (sink/anchor)*	5,379,556	11,219,595
Patent tongs (clam)	4,688,698	812,011
Pound nets (fish)	4,640,955	18,749,343
Tongs and grabs (oyster)	3,818,800	1,014,032
Crab dredge	3,112,377	5,158,962
Gill nets (drift)*	1,905,496	3,095,621
Long lines set with hooks*	1,370,391	579,246
Scrapes	1,332,736	517,346
Pots and traps (fish)	1,261,505	1,944,285
Pots and traps (eel)	1,013,838	658,341
Haul seines (beach)*	927,570	3,181,591
Pound nets (crab)	848,175	421,614
Hand lines (other)	812,958	464,914
Pots and traps (conch)*	734,960	499,015
Patent tongs (oyster)	722,535	180,379
Diving outfits (other)	695,110	169,998
Pots and traps (crab)	623,409	263,157
Fyke and hoop nets (fish)	456,787	685,574
By hand (oyster)	331,685	75,147
By hand (other)	325,098	118,679
Dredge conch	265,093	450,101
Gill nets (other)	115,742	57,949
Gill nets (stake)	96,175	156,715
Pots and traps (box trap)	92,750	78,156

***Table 1** continued*

Gear	Value (2001 Dollars)	Landings (lbs)
Dip nets (common)	14,654	15,341
Pots and traps (other)	13,934	6,166
Rakes (oyster)	3,610	978
Tongs and grabs (other)	2,068	616
Gill nets (drift, shad)	1,716	3,825
Lift net	79	71

* *Includes landings from coastal ocean and/or offshore EEZ fisheries.*

Table 2. Average annual landings by gear type and ex-vessel revenues (2001 constant dollar value) of the Maryland fisheries (1990–2000).

Gear	Value (2001 Dollars)	Landings (lbs)
Not coded*	21,333,973	18,890,739
Pots and traps (blue crab)	15,493,192	18,600,234
Clam dredge*	8,530,485	9,906,647
Trot lines with baits	7,217,056	9,128,538
Tongs and grabs (oyster)	2,473,880	648,271
Pound nets (fish)	1,153,981	3,883,585
Gill nets (sink/anchor)	1,096,078	2,817,710
Long lines set with hooks*	1,063,734	375,868
Gill nets (drift)	863,784	950,428
Scrapes	856,202	336,586
Pots and traps (fish)	830,349	1,028,875
Diving outfits (other)	695,110	169,998
Tongs patent (oyster)	692,154	173,619
Pots and traps (eel)	443,169	285,634
Fyke and hoop nets (fish)	421,105	592,373
Pound nets (crab)	355,616	147,564
Hand lines (other)	336,415	239,789
Dredge oyster (common)	298,182	76,283

Table 2 *continued*

Gear	Value (2001 Dollars)	Landings (lbs)
Pots and traps (conch)	163,187	109,740
Gill nets (other)	115,468	57,778
Pots and traps (box trap)	92,750	78,156
Haul seines (beach)*	85,090	206,430
Dip nets (common)	13,494	12,557
Pots and traps (other)	12,010	5,068
By hand (other)	1,704	2,948
Gill nets (drift, shad)	1,227	3,020
Rakes (oyster)	507	135
Lift net	79	71
Dredge conch	40	39

* *Includes landings from coastal ocean and/or offshore EEZ fisheries.*

Table 3. Average annual landings by gear type and ex-vessel revenues (2001 constant dollar value) of the Virginia fisheries (1990–2000).

Gear	Value (2001 Dollars)	Landings (lbs)
Purse seines (menhaden)*	37,871,374	537,524,835
Pots and traps (blue crab)	21,782,139	31,404,827
Tongs patent (clam, other)	4,688,698	812,011
Gill nets (sink/anchor)*	4,283,477	8,401,885
Pound nets (fish)	3,486,973	14,865,759
Dredge crab	3,112,377	5,158,962
Pots and traps (crab)	2,285,833	964,908
Tongs and grabs (oyster)	1,344,921	365,761
Gill nets (drift)*	1,041,711	2,145,194
Haul seines (beach)*	842,480	2,975,161
Dredge clam	588,727	766,503
Pots and traps (eel)	570,670	372,708
Pound nets (crab)	492,559	274,051

***Table 3** continued*

Gear	Value (2001 Dollars)	Landings (lbs)
Hand lines (other)	476,543	225,125
Scrapes	476,534	180,760
Pots and traps (fish)	431,156	915,410
By hand (oyster)	331,685	75,147
Dredge oyster (common)	329,926	110,479
By hand (other)	323,394	115,730
Lines long set with hooks*	306,657	203,378
Dredge conch	265,053	450,062
Gill nets (stake)	96,175	156,715
Tongs patent (oyster)	41,775	9,295
Fyke and hoop nets (fish)	35,682	93,200
Tongs and grabs (other)	22,751	6,775
Lines trot with baits	6,938	22,914
Gill nets (drift, shad)	5,378	8,857
Gill nets (other)	752	470

* *Includes landings from coastal ocean and/or offshore EEZ fisheries.*

Table 4. Average annual landings by species and ex-vessel revenues (2001 constant dollar value) of Chesapeake region species (1990–2000).

Gear	Value (2001 Dollars)	Landings (lbs)
Blue crab	66,494,648	78,955,744
Unclassified general fisheries*	20,214,848	292,722,309
Atlantic menhaden*	13,169,856	165,606,439
Blue crab (soft)	8,526,915	1,721,026
Eastern oyster	8,119,805	2,196,275
Finfishes, Unclassified bait and animal food*	7,304,337	104,020,009
Quahog clam	5,311,227	964,906
Summer flounder*	4,806,004	3,055,525
Striped bass	4,137,053	2,477,336

***Table 4** continued*

Gear	Value (2001 Dollars)	Landings (lbs)
Blue crab (soft and peeler)	3,977,810	1,021,856
Blue crab (peeler)	3,529,158	1,528,154
Softshell clam	3,440,402	623,371
Atlantic croaker*	3,005,643	7,944,201
Spot	1,629,343	3,398,950
Black sea bass*	1,555,403	1,026,017
Catfishes and bullheads	1,212,796	2,905,648
Snails (conchs)	1,165,189	1,218,680
Weakfish*	1,158,531	1,590,952
American eel	1,148,029	745,667
White perch	1,010,243	1,357,868
Spiny dogfish shark*	712,694	3,882,636

* *Includes landings from coastal ocean and/or offshore EEZ fisheries.*

Table 5. Average annual landings by species and ex-vessel revenues (2001 constant dollar value) of Maryland species (1990–2000).

Gear	Value (2001 Dollars)	Landings (lbs)
Blue crab	40,155,186	41,848,224
Blue crab (soft)	7,842,786	1,556,738
Eastern oyster	6,005,577	1,617,796
Blue crab (soft and peeler)	3,928,864	981,521
Softshell clam	3,440,402	623,371
Striped bass	2,473,248	1,458,459
Catfishes and bullheads	945,686	1,845,230
White perch	918,371	1,233,072
American eel	560,412	359,053
Spiny dogfish shark*	540,830	2,853,401
Black sea bass*	520,735	390,456
Atlantic menhaden*	419,803	3,183,859

Table 5 *continued*

Gear	Value (2001 Dollars)	Landings (lbs)
Finfishes (unclassified general)*	321,153	1,257,745
Shellfish*	301,252	371,759
Atlantic croaker*	278,365	697,712
Gizzard shad	242,676	750,224
Summer flounder*	233,351	120,094
Flatfish*	214,591	105,713
Weakfish*	195,745	251,808
Horseshoe crab	155,646	430,103

* *Includes landings from coastal ocean and/or offshore EEZ fisheries.*

Table 6. Average annual landings by species and ex-vessel revenues (2001 constant dollar value) of Virginia species (1990–2000).

Gear	Value (2001 Dollars)	Landings (lbs)
Blue crab	26,339,462	37,107,519
Finfishes (unclassified general)*	19,893,695	291,464,563
Atlantic menhaden*	12,750,052	162,422,580
Finfishes (unclassified bait and animal food)*	7,303,730	104,013,965
Quahog clam	5,185,891	944,198
Summer flounder*	4,572,653	2,935,431
Blue crab (peeler)	3,468,271	1,498,658
Atlantic croaker*	2,727,279	7,246,490
Eastern oyster	2,114,227	578,479
Striped bass	1,663,805	1,018,876
Spot	1,520,765	3,214,624
Snails (conchs)*	1,094,523	1,149,624
Black sea bass*	1,034,668	635,561
Weakfish*	962,786	1,339,143
Blue crab (soft)	684,129	164,288
American eel	587,618	386,614

Table 6 continued

Gear	Value (2001 Dollars)	Landings (lbs)
Catfishes and bullheads	267,110	1,060,419
American shad	265,230	345,878
Squids*	231,205	812,683
Horseshoe crab*	223,202	465,612
Bluefish	214,823	680,975
Spiny dogfish shark*	171,864	1,029,235

* *Includes landings from coastal ocean and/or offshore EEZ fisheries.*

More than 170 fish and shellfish species or product forms are landed in Maryland and Virginia.

consolidates and summarizes the major species and products. Not all of these species and derived products are caught exclusively in the Bay. Some species, such as sea scallops, are harvested only offshore; other species are harvested from inshore, coastal, and offshore areas (e.g., summer flounder *Paralichthys dentatus*). Blue crab is the most valuable fished species; between 1990 and 2000, the average annual landings and ex-vessel value equaled 78.9 million lbs and $66.5 million, respectively. The average annual landings and value for the menhaden fishery equaled 165.6 million lbs and $13.2 million, respectively. The menhaden fishery takes place in the Bay and inshore areas, extending to offshore areas beyond the territorial sea limit. The eastern oyster—a Bay species—represented the sixth highest average annual ex-vessel revenue with $8.1 million.

Considering only the first four product or species categories for Maryland (Table 5), ex-vessel value and landings by species indicate that blue crab and eastern oyster account for nearly 75.0 % of the total average annual ex-vessel value in Maryland. Landings of hard blue crabs alone accounted for 52.7% of the average ex-vessel revenue of all species landed in Virginia and Maryland between 1990 and 2000. Oysters, once a mainstay of the Bay commercial fisheries, accounted for 7.7% of the ex-vessel revenue of all species landed in Maryland between 1990 and 2000.

In contrast to Maryland's numbers, landings in Virginia's offshore commercial fisheries generate considerably higher total ex-vessel revenue (Table 6). In Virginia, the sea scallop fishery alone accounted for 25.0% of the total ex-vessel revenue; fisheries for sea scallops, however, are prosecuted only in offshore areas. Combined revenues from Virginia's fisheries for blue crab, menhaden, hard clam (or quahog), and peeler crab accounted for only 37.0% of the total average annual ex-vessel revenues of all species landed in the state. The eastern oyster, which once constituted the major commercial fishery in Virginia, accounted for only 2.0% of the average annual total ex-vessel revenue between 1990 and 2000. Menhaden, a major species landed in Virginia, ranked fourth in average annual ex-vessel revenues. Reported menhaden landings are not exclusively from the Chesapeake Bay, however; a fraction of the catch comes from the Atlantic coast and is processed in Virginia.

The Recreational Fisheries

Recreational fishing is highly valued in Chesapeake Bay with recreational fishermen making large catches of finfish and shellfish species. Without a thorough analysis by fishing area, a detailed summary of recreational fishing activity within Bay waters is not possible. Here, we summarize statistics on saltwater fishing activity in the Bay and coastal ocean in the states of Maryland and Virginia to indicate the magnitude of the Chesapeake's sport fishery.

In 2001, the five most popular estuarine and marine species caught in Maryland (indicated by number of fish caught) were striped bass, Atlantic croaker *Micropogonias undulatus*, white perch *M. americana*, black sea bass *Centropristis striata*, and spot *Leiostomus xanthurus* (Figure 1). All five species are caught within the Bay (NMFS 2001). In Maryland, approximately 93% of all saltwater trips are in Bay waters. Nearly 66% of all trips were made aboard a private or chartered fishing boat. In 2001, slightly more than 1.04 million fishermen participated in Maryland's marine recreational fishery, which includes fisheries in federal, state, and Bay waters; more than 3.7 million saltwater fishing trips were made. Approximately 26 species are landed regularly in the Maryland Chesapeake Bay recreational fishery.

In the 2001 Virginia marine recreational fishery, the five most popular species caught were Atlantic croaker, summer flounder, black

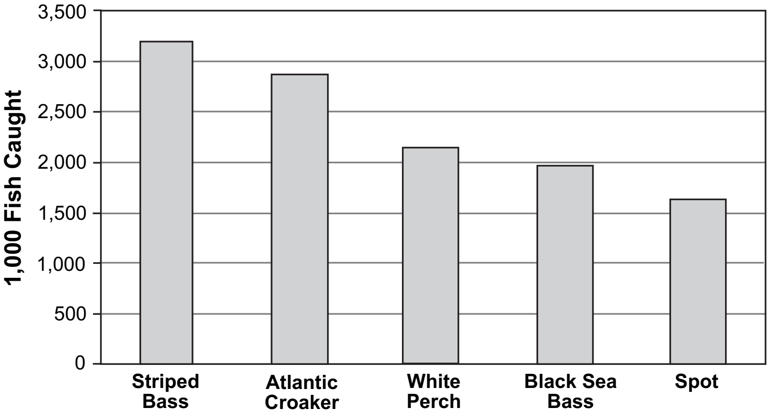
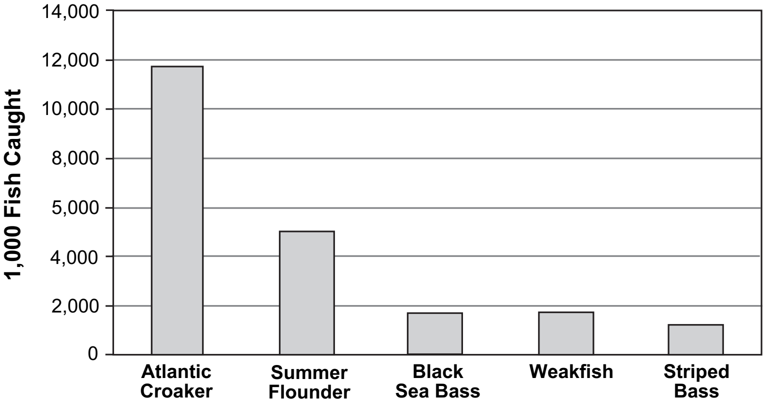


Figure 1. Five species most frequently caught in the 2001 Maryland recreational fishery.



Source: Chesapeake Bay Program (www.chesapeakebay.net/baypartners.htm)

Figure 2. Five most popular fish species caught (Virginia 1998). Source: NMFS 2001; MRFSS Facts and Figures MD 1998.

sea bass, weakfish *Cynoscion regalis*, and striped bass (Figure 2). Approximately 80% of all saltwater fishing trips were taken in Bay waters in 2001—slightly more than 4.1 million trips. Almost 64% of all trips were aboard private or charter boats. Approximately 1.03 million fishermen participated in the Virginia marine recreational fishery in 2001, regularly catching more than 45 species.

Incorporating economic aspects of recreational fisheries requires an evaluation of the societal benefits of this type of fishing and an assessment of associated economic activity (e.g., sales of tackle and fuel). Ecosystem-based management must also account for the technical, biological, natural, economic, and social interactions between commercial and recreational fishermen. The economic value of recreational fisheries also depends on net benefits, given different allocations of the resource to various user groups. Ultimately, any assessment of recreational fishing economics requires expenditure, and fishery data are not currently available in sufficient detail to assess the impact on Maryland and Virginia economies. Development of complex input/output or economic impact models must also take place to understand fully this important economic input.

Technical and Economic Interactions

Bay fisheries use multiple gears, multiple species, and multiple product forms (e.g., although the blue crab fishery is primarily single-species, the product comes in different forms, such as small, medium, and large, or male and female). Any management or regulatory strategy that affects a certain species or gear type may substantially influence other species; it may also have significant social and economic ramifications. Understanding the biological, technical, social, natural, and economic interactions that could occur in targeting a particular species or using a particular gear type, therefore, is critical.

In this section, we focus attention on potential technical and economic interactions for multispecies, multiple-product, and multiple-gear fisheries. No attempt is made to describe the natural or biological interactions critical to effective multispecies management. Various technical and economic interactions may be classified according to the underlying technology or production relationships between landings and inputs used to catch and land fish. In a fishery, inputs include the vessel, gear, days at sea, labor, and fuel; all are lumped together and referred to as fishing effort. The landings of the various species are outputs. The way in which inputs are combined to land fish is the production technology.

For simplicity, assume that watermen can land several species of fish (*S* different species) using various inputs or factors of production (*N* different inputs). For example, a gill net in the Bay may catch spot, Atlantic croaker, striped bass, and bluefish. Inputs (e.g., boat, gear, fuel, and labor or fishing effort) are applied to *S* resources (one resource for each species). Not all watermen, however, want to land all *S* species; some may wish to land only one (e.g., target striped bass) or subgroup of species (e.g., target bluefish and striped bass or spot and Atlantic croaker). Other watermen may not care about the possible levels of each species landed and prefer to catch several species. The various possible species combinations caught by watermen describe or characterize the technical interactions.

Little research has been conducted on the technical interactions of the various Bay fisheries. For example, do watermen substitute bluefish or croaker for striped bass when the abundance or market price of striped bass declines? Alternatively, which fisheries of the Bay are truly single-species fisheries? For example, the blue crab and soft and hard clam fisheries of the Bay are likely to be single-species fisheries; they are not, however, single-product fisheries. During some seasons, the striped bass represents a single-species fishery for some watermen, but not necessarily for all watermen or over all seasons. The menhaden fishery is primarily a single-species fishery, but does experience incidental landings of other species. To some extent, classification of a fishery as either a single- or multispecies fishery may depend on the type of gear used. For example, nets are generally not highly selective; they tend to capture several species. Careful placement or location of nets, however, can allow watermen to target a given species. Other gear types, such as the crab pot or clam dredge, tend to be more selective and are typically deployed to capture only one species.

Economics offers a classification scheme for multiple product technologies, which also applies to multispecies fisheries. General classifications offer the following scheme: joint-in inputs; nonjoint-in inputs; nonjoint-in outputs; and input-output separable. A joint-in inputs fishery is one that captures multiple species and has unique technical interactions among the species. A nonjoint-in inputs fishery is one that involves only single species; a hypothetical example is a single-species fishery for spot and Atlantic croaker in which both species are caught, but only one species at a time. A nonjoint-in outputs fishery uses different gear to capture a complex of species; for example, hook and line and gill nets might be used to land spot and croaker. An input–output separable fishery is one with multiple species and multiple inputs, but treatable as a single-output, single-input fishery since all species can be aggregated to form a composite output (e.g., spot and Atlantic croaker considered panfish), and all inputs can be combined to form a single composite input (e.g., boat services, gear services, labor, and fuel combined into fishing effort).

Although economics affords a formal classification scheme for multiple product or multispecies fisheries, no analyses of the technical and economic interactions of the various Bay fisheries have taken place. Development of a fishery management plan

(FMP) requires information on the technical and economic interactions. An ecosystem-based approach, however, requires knowledge not only of the technical and economic interactions of various species to be managed, but also an understanding of the technical interactions of the ecosystem components (e.g., the impacts of a particular gear type on essential fish habitat).

Technical and economic interactions among Bay fisheries may also exhibit seasonal variation. At certain times during the year, some outputs or inputs may have substitutes; during other periods, they may form complements or the output or input substitution possibilities may become extremely limited or nonexistent. For example, in early fall, striped bass and bluefish may be caught together and classified as complements (two outputs or two inputs are characterized as such if more of one implies more of the other). In late fall or very early winter, however, bluefish is no longer available; at that time striped bass is neither a substitute nor a complement to bluefish.

Thus far, the discussion of technical interactions has been limited to species caught in commercial or recreational fisheries. For an ecosystem-based approach to fisheries management, we must consider the entire food web and its associated interactions. In formulating the technical interactions, knowing how the fishing affects other species—including those not fished—is both desirable and potentially important. Equally desirable is appreciating how other species contribute to the sustainability of commercial and recreational fisheries.

Each of the technology characterizations has implications for management. For all cases with technical interactions, management must consider these interactions when formulating FMPs and regulations. In the case of nonjoint-in inputs, however, managers can treat each species or fishery as a single-species fishery (Kirkley and Strand 1988). No formal evaluation of the technology for Chesapeake Bay fisheries has taken place. Moreover, data for determining the interactions are largely unavailable so that quantitative verification of the various types of fisheries is not currently possible (e.g., Kirkley and Strand 1988). An ecosystem-based approach will require additional knowledge of technical interactions as well as consideration of how the various fisheries depend upon and affect the ecosystem and its components.

Building ecosystem-based management into FMPs for Bay fisheries will require substantial information on technical interactions and substitution possibilities. Managing multispecies fisheries under an FEP umbrella requires the following measures:

1) Identifying targeted species or species complexes;
2) Determining the ability of fishermen or watermen to switch gears, areas, seasons, and market categories;
3) Identifying ports or fishing communities; and

4) Determining the behavioral objectives of fishermen.

Economics of Commercial and Recreational Fishing

The Commercial Fishery

Proper specification of the economic dimensions that motivate commercial fishing in the Chesapeake Bay will prove difficult. Researchers have conducted few extensive studies on the behavioral objectives of Bay watermen (e.g., "Why do individuals fish for a living?" and "What influences their decisions about which species to fish?"). Limited information exists on minimum income levels or the timeframe over which watermen make fishing decisions. One common specification is "constrained profit maximization." That is, an owner or operator maximizes profits over some timeframe (e.g., a day, a trip, a month, a season, or a year) subject to various technical, economic, social or family, and legal constraints. In general, we expect watermen to make decisions based on expectations about prices, catches, landings, and costs (e.g., "What does a watermen expect the price level to be when targeting a species?"). Other important factors include weather, social commitments, and obligations.

In a simple world, a waterman makes decisions about what and how much to produce and the levels of inputs to use based on a desire to maximize profits; he will not allow costs to exceed revenue or ex-vessel value. A fishing operation will not supply more fish, if supplying fewer fish will maximize profits. Development of ecosystem-based FMPs for Bay fisheries will account for the underlying economics and behavioral objectives of watermen.

Unfortunately, little is known about the decision-making behavior of watermen, including whether their decisions are consistent with a desire to maximize profits, maximize revenues, minimize costs, or some other underlying behavioral objective. Most Chesapeake Bay watermen become involved in several fisheries and are, therefore, likely to base decisions on the expected outcomes for multiple fisheries.

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Moving beyond the harvesting sector to the upper market levels, the economic dimensions become even more complicated and vulnerable to the limited state of knowledge. Consumer demand and the willingness to purchase seafood eventually send signals to the watermen. In response, retailers and restaurants provide seafood to consumers based on these signals and expectations about retail sales or profits. The retailers, however, typically purchase seafood from distributors or wholesalers. Again, an exchange of signals occurs, with the buyer and seller making decisions about expected profits or earnings. Finally, the processors and wholesalers offer a signal to watermen in the form of prices offered and quantities desired.

An important issue related to economic dimensions of the fishing industry is the institutional setting. Are any institutions in place that permit the control of prices or purchases? What about cost and availability of docking and offloading facilities? Do limits on the supporting infrastructure exist which might affect decisions by watermen? Where are the markets geographically located relative to the offloading areas? The institutional setting of the Chesapeake Bay fishing industry has largely not been characterized.

The Recreational Fishery

Unlike commercial watermen, who make decisions according to some underlying economic objective, recreational fishermen make choices to optimize their expected level of satisfaction or utility (i.e., a subjective or ordinal measure of the benefit a consumer receives from the commodity or activity). Watermen may also maximize expected utility by maximizing the expected profit. Recreational activity, however, is not a production activity; as such, it does not generate a profit. Moreover, the output of recreational fishing incorporates the quality of the fishing experience and not simply the pounds or number of fish caught.

The drivers behind recreational fishing involve a sequence of decisions in which recreational fishermen maximize their fishing enjoyment based on their level of income. The initial choice is one between work and recreation. A person must then settle on the type of recreation and decide on the allocation of time and income for the chosen activity. If the individual selects saltwater fishing, he or she must decide whether to take a fishing trip, which species to catch, and where to go. Many decisions will hinge on the costs involved and the expected catch. With such information, estimating the economic value or benefits of recreational fishing, along with the economic impacts, is possible but extremely complicated and requires extensive data collection. Determining the distances traveled for fishing trips, specific areas fished, target species, number and size of each species caught, various regulations, and expenses associated with recreational fishing all constitute important parameters.

Similar to appreciating the drivers behind commercial fishing, understanding the existing infrastructure that supports recreational fishing is also important; this is done in part by determining the various fishing areas and associated facilities. The large number of charter boats at Chesapeake Beach, Maryland, for example, allows many recreational fishermen to take charter trips from this site. Alternatively, the marina facilities at Deale, Maryland and the various public and private launch sites near the Bay Bridge permit angler access to areas near the Bay Bridge. Information on tackle sales, boat fuel, and other expenditures by recreational fishermen will also need to be obtained.

An ecosystem-based approach that considers the Bay's recreational sector will require extensive review of available data, along with collection of more data. It also will necessitate development of several input and output models to estimate the economic importance of recreational fishing activity to sales, income, employment, and tax revenues. Economic valuation models will need to be constructed to assess the potential benefits of ecosystem-based fishery management and regulatory strategies. Also necessary is calculating the potential gains or losses in benefits that might occur due to possible changes in the ecosystem or regulations that enhance or protect the ecosystem (e.g., a regulation to prevent mortality or harm to seabirds might result in restrictions on recreational anglers).

Undesirable Inputs and Outputs to Commercial and Recreational Fisheries

Declines in environmental quality can diminish the value of fisheries in the Bay. For example, toxicants have the potential to lessen finfish and shellfish populations, reduce commercial landings and recreational opportunities in the Bay, and shrink the regional demand for seafood regardless of where it was caught. Negative health effects for humans who directly handled seafood contaminated with toxic dinoflagellates in Bay tributaries have been reported. In many cases, the economic cost of such cases far exceeds the realistic or direct effects of the problem. This "halo effect" results when fearful or poorly informed consumers avoid seafood that is perfectly safe.

In their article, Helz and Hugget (1987) explained how contaminants contribute to declines in the Bay's water quality, reducing its potential as a recreational resource and its desirability as a human food source. They discussed six symptoms of illness in the Bay:

1) Declines in harvest levels of anadromous fish;
2) Reductions in acreage of SAV;
3) Declines in oyster landings and reproduction potential;
4) Blooms of blue-green algae and dinoflagellates;
5) Increases of nutrient levels; and
6) Expansion of the extent and duration of summer anoxia in bottom waters.

These factors may be considered undesirable outputs, but they are also undesirable inputs for fishery resources and recreational opportunities. Similarly, events such as red tide or harmful algal blooms, along with *Pfiesteria* (which affects resource levels, commercial and recreational fishing industries, and tourism) form both undesirable inputs and outputs.

The case of *Pfiesteria* or *Pfiesteria*-like dinoflagellates in Chesapeake Bay is illustrative. During the fall of 1996, and again in the spring and summer of 1997, Pocomoke River watermen reported lesions on a high percentage of menhaden, striped bass, and other fish species caught in the lower Pocomoke River. Subsequently, large fish kills occurred with *Pfiesteria* purported as the likely causal agent. During these kills, watermen, the seafood industry of the two states, and Chesapeake Bay or seafood-related businesses dependent on recreational and consumer expenditures experienced dramatic declines in sales. Maryland and Virginia state agencies attempted to mitigate the public's concern by educating the public on issues related to *Pfiesteria*. Despite these outreach efforts, negative public perception of the outbreak caused a decline in seafood sales and reduced aquatic recreational activity, resulting in millions of dollars of lost revenue (Hughes et al. 1997).

The effects of contaminants discharged into the Bay are far-reaching . . . their potential negative social and economic consequences are daunting. A framework for action to resolve problems caused by toxic contaminants and other pollutants should include an ecosystem-based approach for management, mitigation, and control.

The effects of contaminants discharged to the Bay are far-reaching (i.e., the potential recurrence of *Pfiesteria*, harmful algal blooms, and human health advisories for consumption of Bay seafoods) and their potential negative social and economic consequences are daunting. A framework for action to resolve problems caused by toxic contaminants and other pollutants should include an ecosystem-based approach for management, mitigation, and control. Developing this framework will require scientific documentation of the extent of the contaminants and their likely impacts on fish populations and human health. The potential economic impacts and costs to society of toxic contaminants and toxic dinoflagellates need to be ascertained. Programs that mitigate negative consequences and seek cost-effective solutions to the problems need to be developed as do effective baywide public information systems that detail the extent and consequences of toxic contaminants, while minimizing negative social and economic impact.

Social Dimensions

Human involvement in the Bay fisheries ecosystem extends beyond the most obvious groups of commercial and recreational fishermen and their related industries. Other businesses, industries, and activities (e.g., transportation, boating, swimming, sewage disposal, and agriculture) have direct or indirect effects on this ecosystem.

Numerous players, or stakeholders, interact in complicated ways that either promote or diminish the ecosystem's general health and the sustainability of its fisheries. Characterizing these stakeholders enhances our understanding of human behavior relative to the ecosystem in developing an appropriate ecosystem-based plan for managing fisheries (see section on historical stakeholder involvement in the Externalities Element).

Table 7. Land characteristics of the Chesapeake Bay watersheds.

Watershed	Area		Land Cover (percent)					
	Sq. Miles	Percent	Devel.	Agric.	Forest	Water	Wetland	Barren
Susquehanna	27,486	41.4	2.2	29.3	66.2	1.2	0.5	0.7
MD Western Shore	1,670	2.5	17.4	34.4	36.6	8.1	2.4	1.1
Patuxent River	957	1.4	10.7	34.2	42.3	6.4	5.5	1.1
Potomac River	14,679	22.1	4.8	31.8	57.6	3.9	1.1	0.8
Rappahannock	2,845	4.3	1.8	30.9	56.9	6.8	2.5	1.1
York	3,270	4.9	2.2	20.8	60.9	7.6	6.8	1.6
James	10,432	15.7	4.5	17.0	70.8	3.7	2.6	1.3
Eastern Shore	5,048	7.6	2.1	38.7	24.9	18.7	15.0	0.6
Total	**66,388**	**100**	**3.6**	**28.5**	**60.1**	**4.3**	**2.6**	**0.9**

Source: 1991–1993 Landsat Imagery Multi-Resolution Land Characteristic Consortium (MRLC).

Inclusion of stakeholder groups is critical in applying a holistic and integrative approach to fisheries management. A comanagement approach may prove effective in involving the citizenry in Bay management. Involvement of multiple stakeholder groups within a comanagement framework should support a shift towards ecosystem-sensitive fisheries management.

Comanagement in the Chesapeake Bay

Comanagement is broadly defined as “a situation in which two or more social actors negotiate, define and guarantee amongst themselves a fair sharing of the management functions, entitlements and responsibilities for a given territory, area or set of natural resources” (Borrini-Feyerabend et al. 2000). For the Chesapeake Bay, this situation plays out through a partnership in which governments, commercial and recreational fishermen, other stakeholders (e.g., boat owners, fish processors, tourism traders, industries), nongovernmental organizations (NGOs), and academic and research institutions share the responsibility and authority for making decisions about ecosystem resource management.

> *Numerous players, or stakeholders, interact in complicated ways that either promote or diminish the ecosystem’s general health and the sustainability of its fisheries.*

A comanagement approach, in which citizens play a strong role in the management process, involves a shift from the traditional top-down tactic of governmental command and control to a bottom-up method that incorporates community-based

Table 8. Population and housing in Chesapeake watersheds.

Watershed	Population	Housing Unit		
		Urban	Farm	Rural (non-farm)
Susquehanna	3,968,635	795,125	23,623	736,106
MD Western Shore	2,188,148	754,845	1,611	69,814
Patuxent River	590,769	146,942	1,157	31,651
Potomac River	5,243,322	1,513,597	13,063	348,691
Rappahannock	240,754	25,771	2,265	55,451
York	372,488	69,752	1,869	60,743
James	2,522,583	760,118	5,005	137,297
Eastern Shore	467,542	35,399	5,522	125,963
Total	**15,594,241**	**4,101,549**	**54,115**	**1,565,716**

Source: 1990 U.S. Bureau of Census (aggregated to the watershed level by the Chesapeake Bay Program office).

management. The initial challenge lies in determining what type of management should be undertaken to achieve stronger public participation. According to Berkes (1994), the level of user participation and community involvement may range from the minimum exchange of information between government and users (as in the “informative” type of comanagement in which government makes decisions and then informs the community) to the “community control” type in which the reverse occurs.

Several fisheries and fishing communities around the world illustrate successful application of the comanagement strategy. Jentoft and McCay (1995) list 11 countries in Europe and North America as examples with various levels of user participation in fisheries management. Sen and Nielsen (1996) added reviews of 22 case studies of fisheries comanagement to the above study, including developing countries in Africa, Asia, the Caribbean, and the Pacific. Both studies, however, cited difficulties of including user groups in the management process—from finding a management mechanism appropriate to the user group capabilities to the willingness of government officials to relinquish their authority.

Fisheries comanagement initiatives in Canada have long been established; the Bay of Fundy herring fisheries represents one of the earliest cases (1970s) (Kearney 1984). The Canadian Department of Fisheries and Oceans recently developed a “Framework and Guidelines for Implementing the Co-Management Approach” to provide principles and examples of various comanagement arrangements (DFO 1999).

In the United States, the regional fishery management councils may be considered a type of comanagement, with industry and the public as members of the councils together with government scientists. The extent to which power is shared between government and industry, however, depends ultimately on the government’s willingness to share power (Parravano and Spain 2000). The Maine lobster fishery represents one of the U.S. success stories for fisheries comanagement in which lobster councils established for different zones act as a link between government and fishermen, in addition to providing scientific training to fishermen and advice to the state government. Another example is the comanagement agreements between the U.S. Fish and Wildlife Service and Alaska Native organizations to conserve marine mammals. Several projects have been conducted under these agreements, resulting in increased awareness of marine mammal conservation in Alaska and increased awareness of Native ecological traditions. In addition to accounting for ecosystem resources more fully, comanagement creates a more open and transparent management process, ultimately resulting in lower administration and enforcement costs.

The process can also be adaptive, allowing for adjustments in regulations and activities as lessons are learned (Berkes et al. 2001). One criticism of this approach focuses on its seemingly limited application to small and homogenous communities. How will it ever work for the Chesapeake Bay? As a start, an ecosystem management council (EMC) with representatives from all stakeholder groups would be appropriate. The aim of the EMC will be an integrated approach to management of natural resources within the Chesapeake Bay ecosystem, understanding the ecological, social, cultural, political, and economic importance of the Bay and its resources to local communities. Such a coordinated approach to resource management would help ensure that the vigor of the Bay is first improved and then maintained for current and future generations.

Chesapeake Bay Stakeholders

The potential for comanagement depends on the participation of key stakeholder groups. Identifying the groups and their interactions with or impacts on the Bay fisheries ecosystem is a necessary step to develop a successful comanagement approach. In addition to the commercial and recreational fishing communities and people in fisheries-related business, other stakeholders need to be identified. One way to characterize key stakeholder groups is by dividing the Bay into subwatersheds, using summaries of land cover, population size and composition, and urban and rural development characteristics (Tables 7 and 8) (CBP 2001). Accordingly, six subwatersheds make up the Chesapeake Bay watershed: Susquehanna; Maryland Western Shore; Patuxent River; Potomac River; Rappahannock, York, and James rivers; and Eastern Shore.

The Susquehanna subwatershed, the largest of the six, covers about 27,486 mi^2 or approximately 41% of the total watershed area. The agricultural area in this region is also the largest at about 8,000 mi^2, with more farm housing units than the other subwatersheds. Much of the Susquehanna watershed and its human population lies in Pennsylvania, isolated geographically from the Bay proper but nevertheless a partner in efforts to restore and rehabilitate the Chesapeake ecosystem.

The ratio of farm-to-urban housing units, however, is greatest in the Eastern Shore subwatershed where 39% of the land area (about 1,950 mi^2) is agricultural. The highest

Table 9. Number of organizations involved in the Chesapeake Bay watershed.

Type of Organization	# Involved Units
Signatories to Bay Agreement	
• Chesapeake Bay Commission	1
• Commonwealth of Pennsylvania	7
• Commonwealth of Virginia	10
• District of Columbia	2
• State of Maryland	8
• U.S. Env. Protection Agency	7
Non-signatory State Partners	
• State of Delaware	1
• New York State	1
• State of West Virginia	1
Federal Agency Partners	
• U.S. Dept. of Agriculture	5
• U.S. Dept. of Commerce	5
• U.S. Dept. of Defense	7
• U.S. Dept. of Education	1
• U.S. Dept. of Interior	4
• U.S. Dept. of Transportation	2
• U.S. Postal Service	1
• U.S. General Services Admin.	1
• NASA	1
• Natl. Capital Planning Comm.	1
Academic Institutions	12
Env./NGOs in Restoration	14
Other Organizations in Bay	286
Total	**378**

Source: Chesapeake Bay Program (http://www.chesapeakebay.net/baypartners.htm)

percentage of developed land lies on Maryland's western shore and the Patuxent River. Nonetheless, the watershed as a whole has about 60% forest cover; almost 30% is agricultural with only 4% developed (Table 7).

Given that about 29% of the watershed's land area is agricultural, farmers constitute one of the most important stakeholder groups in the Chesapeake ecosystem. Covering an area of about 16 million acres, 83,815 farms exist throughout the watershed, (U.S. Department of Agriculture 1997). Cropland comprises about 90% of these farms, 82% of which is planted with crops such as corn, wheat, soybean, and tobacco. In addition, about 46,600 livestock and poultry farms remain in the watershed, with Pennsylvania leading the number of cattle farms (almost 20,000 farms or 42% of the total cattle farms in the watershed), followed by Virginia with 15,000. Other livestock includes hogs and pigs, sheep, and poultry (U.S. Department of Agriculture 1997). Using the same ratio (the number of farms in the watershed to the total number in all five states), the total number of farm and farm-related jobs in the Bay watershed is estimated at about 1.99 million or 8% of total employment (U.S. Department of Agriculture 2001a).

About 4 million housing units in the watershed are urban with 12% of the population living in five major cities: Baltimore, Maryland; Washington, D.C.; Norfolk, Virginia; Richmond, Virginia; and Arlington, Virginia. Thus, urban dwellers form another stakeholder group important within the context of ecosystem-based management. Transportation constitutes one potentially harmful activity to the ecosystem conducted on a daily basis by this group. About 70% of the watershed's population 16 years or older (about 5 million people) drive to work alone each day. Their average travel time runs between 15 and 30 min each way (U.S. Census Bureau 1990, aggregated to the watershed level by the Chesapeake Bay Program [CBP] office). In addition to transportation pollution, other impacts caused by urban dwellers include sewage, urban runoff, industrial pollution and contamination, and vegetation removal in riparian zones.

The forest industry represents another important economic activity in the Bay. Overall, total timberland in the Chesapeake region forms about 22.2 million acres, of which private individuals own 12.6 million acres. About 49% of the total lies in Pennsylvania; 52% of this forested land in Pennsylvania is privately owned, with farmers and ranchers owning 8% and the forest industry owning 4% (U.S. Department of Agriculture 2001b). Similarly, private individuals own the majority of timberland in Virginia. Forest industry-owned timberland in Virginia, however, exceeds that owned by other states, with an estimated total of 619,000 acres. The total value of harvested forestland in the Chesapeake Bay counties of Virginia during 1999 was $124.7 million, which was about 40% of the total state harvest (Virginia Department of Forestry 1999).

The mining industry contributes about 1% to employment in Maryland counties of the Bay, with at least the same amount in Pennsylvania counties. For counties within the five Bay states, the mining sector employs a minimum of 16,126 people (about 0.06% of total employment in the five states). Sixty-three percent of employment within the mining industry in Bay watersheds occurs in Pennsylvania (U.S. DOC 2001).

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The final stakeholder group consists of governmental and nongovernmental organizations interested in or responsible for managing, protecting, and improving the health of the Bay—referred to here as the environmental group. A total of 35 state and federal agencies have signed the Chesapeake Bay Agreement; Delaware, New York, and West Virginia are non-signatory state partners (Table 9). In addition, 28 other federal agencies and 12 academic institutions are CBP partners. As many as 300 other environmental, nongovernmental, and not-for-profit organizations exist around the Bay, with 14 having taken part in the watershed restoration effort. The large number of organizations and the thousands of individuals in nongovernmental organizations who care about the Chesapeake Bay ecosystem indicates how important it is to maintain or restore the Bay's vital elements, including fisheries and the habitats that support them.

The above characterization of stakeholder groups in the Chesapeake ecosystem is not comprehensive. In addition to the groups listed above, other Bay stakeholders (such as beachgoers, waterfowl hunters, recreational boaters and sailors, commercial transportation, shipping, and others) should be considered in the ecosystem management plan for the Bay.

Assessing the Relative Impact of Bay Activities

Once various stakeholder groups have been properly identified, determining the impacts that their activities may have on the overall health of the Bay ecosystem is key. Given the complexity of this issue and insufficient information to provide a quantitative and comprehensive assessment of these impacts, an alternative approach for impact assessment—the damage schedule (Chuenpagdee et al., 2001a, b)—can prove effective. The damage schedule is a nonmonetary valuation technique that helps decision makers formulate policies sensitive to the relative importance of coastal resources, as determined by the stakeholder groups.

The damage schedule uses paired comparisons to present complex issues in a simple, comprehensible, and comparable way. For example, although quantifying damage to an ecosystem's health caused by various activities remains difficult, evaluating the perception of damage from one activity to that from another is much less problematic. In this process, the questioner presents the stakeholders with paired types of damage. Each stakeholder selects the more severe of the pair; this information is then compiled into a damage scale that indicates the internal ranking of severity based on stakeholder perception.

The schedule gives distribution patterns for these activities on a linear scale; policy responses can be mapped according to the level of severity. Stringent regulations might be imposed on activities considered high impact; those with less impact might receive less rigorous regulation. This scale can then form the basis for policy responses (such as management actions, regulations, sanctions, rules) to activities perceived to cause damage.

One major advantage of using the paired comparison method and the damage schedule is the ability to obtain input directly from diverse stakeholder groups—resource users, general public, environmental organizations, government officials, scientists and researchers—using a single tool. Importantly, rankings from different stakeholder groups can then be compared to determine similarities and differences in value judgments. This type of information can prove key in promoting the collaboration, trust, and respect needed to move forward with comanagement of fisheries in an ecosystem context. Considering the dependency of each stakeholder group on the ecosystem, geographical distribution of their activities, and proximity of their activities to the watershed also remain important. These issues often are difficult to quantify;

relative measures might suggest appropriate weighting after development of a scale.

After individual responses are obtained and a preliminary damage schedule developed, a workshop with resource users, interest groups, scientists, and policymakers can be organized to present and discuss the information. This approach represents yet another step to encourage stakeholder participation, providing a venue for resource users and interest groups to work collaboratively with policymakers in reaching a consensus; it is particularly important in developing and implementing new management approaches.

The Ecopath with Ecosim (EwE) ecosystem modeling exercise (www.ecopath.org) will play a role in applying the damage schedule to the Chesapeake Bay. This model provides a means to develop various health scenarios due to different management measures. The paired comparison survey using these scenarios will then be conducted to obtain preferences for the ecosystem from diverse stakeholder groups. The rankings obtained will be verified during a community workshop. This process will encourage greater participation of the Chesapeake Bay community in ecosystem-based management.

Summary

The economic and social dimensions of Chesapeake fisheries illustrate the significance of the human component in the Bay's fisheries ecosystem. The economic dimensions of the fishing industry highlight the importance of both recreational and commercial fisheries as vital contributors to the regional economy. This FEP element recognizes that the value of Bay living resources depends on many user communities within the watershed with interests that interact with those of the fishing industry. It identifies economic issues that must be considered for an ecosystem-based approach for management of the Bay's natural resources, and outlines an approach that accounts for competing uses and values for society to receive maximum net benefits from Bay resources. The element presents both economic and noneconomic-based approaches for valuing natural and environmental resources. It also points to the need for a regulatory strategy based on the economic value (or benefits) of various use patterns and the need to assess the economic consequences of trading one use pattern for another.

The major stakeholder groups have been identified and characterized. To assist decision makers in formulating policies consistent with the importance of coastal resources, we suggest development of the damage schedule concept—a nonmonetary valuation technique that elicits stakeholder judgment—to determine the impact that activities of different stakeholder groups have on overall ecosystem health. Such a technique emphasizes the importance of stakeholder involvement in the formulation of management policies, especially in a comanagement context. Accordingly, the element also presents a brief overview of comanagement, along with a discussion of its potential application to ecosystem-based management of Chesapeake Bay fisheries.

Major Findings

Economic

The magnitude of the fishing industry's contribution to the Bay's economy is substantial. On an annual basis, the Bay's commercial fisheries provide nearly $160 million in ex-vessel value, and more than 226 thousand metric tons of ex-vessel landings. Industry-related employment is generated not just through the actual fishing process, but through restaurants, food services, tourism-related businesses. Expenditures on recreational fisheries in the Bay are even more substantial, averaging over $300 million annually in recent years.

With ecosystem-based fisheries management, the challenge is to address the equitable distributions of benefits and costs, while also accounting for the resource and environmental issues related to the Bay. Meeting this challenge will require information on societal preferences for the state of the Bay's natural resources; economic benefits or values society receives from alternative uses of Bay resources; and potential economic impacts of multiple economic activities related to the Bay.

Successful implementation of the FEP will be complicated by the number of diverse user groups who benefit from Chesapeake resources while the linkages between ecosystem components and human values are not known. Well-established procedures exist for determining the economic values or benefits of either market or nonmarket goods and services, but data for doing so in the Bay are not presently available. Thus, society's preferred uses of Bay resources have not been determined (e.g., Would society prefer to have better commercial and recreational fishing with less waterfront development, or more waterfront development with fewer beaches?).

Social

Humans and their institutions are important elements of the Chesapeake ecosystem. Many players, or stakeholders, interact in complicated ways to either promote or diminish the general health of the ecosystem and the sustainability of its fisheries. Obtaining information about these stakeholders to enhance our understanding of human behavior relative to the Bay fisheries ecosystem is key. Mangers must consider such information in developing an appropriate ecosystem-based approach in the management of Bay fisheries.

Human involvement in the Bay ecosystem extends beyond the most obvious groups of commercial and recreational fishermen and their related industries. Other businesses, industries, and activities (e.g., transportation, boating, swimming, sewage disposal, and agriculture) have direct or indirect effects on the ecosystem. Inclusion of these stakeholder groups is critical to apply a holistic and integrative approach to fisheries management. A comanagement approach, in which citizens play a strong role in the management process, involves a shift from the top-down approach of governmental command and control to a bottom-up approach that incorporates community-based management. The involvement of multiple stakeholder groups in a comanagement framework supports the shift towards ecosystem-sensitive fisheries management.

Panel Recommendations

Management: Economic Dimensions

1) Identify management issues, goals, and objectives relative to socioeconomic elements of the Chesapeake Bay fisheries ecosystem.

Goals and objectives should be clearly defined and practical; they should reflect the concerns of all stakeholders. Major economic concerns include identification and assessment of the distribution of economic benefits, costs, and impacts among Bay stakeholders.

2) Implement management strategies that recognize and address the multispecies nature of the commercial and recreational fisheries that simultaneously promote the optimum use of Bay resources.

Many commercial and recreational fisheries involve multispecies production; even fisheries for single species can involve multiple products (e.g., hard shell blue crab, softshell blue crab, peelers). When fisheries involve multiple species or multiple products, single-species or single product regulatory regimes may fail to generate maximum economic benefits to society.

3) Consider all user groups to determine patterns that promote optimum use of Bay resources.

The Bay provides benefits to many diverse user groups; attempts to maximize benefits to each group may not generate the maximum benefit to the ecosystem. Allocated mixed uses of the Bay resources may, in fact, promote higher economic benefits. Optimum use should be defined relative to economic value, competing user groups, present and future uses, and social priorities.

4) Promote fisheries management that enhances economic benefit by taking advantage of technical interactions in commercial and recreational multispecies fisheries.

Effective fisheries management hinges on an understanding of both technical and economic interactions. Regulation of one species may redirect fishing effort onto a different species causing unintended changes to the community of species. Such redirection of fishing effort may be a function of technical interactions. The decision to redirect effort is, however, largely based on economic realities (e.g., prices and costs). Understanding such effects will require development of multispecies models of technical and economic interactions.

5) Promote management strategies that enhance the flexibility of fishermen to make changes in fishing strategy that are consistent with their values, while upholding management objectives.

Considering whether a regulation is sufficiently flexible to realize desired management objectives and bring economic benefits to all user groups remains important. Management actions that do not permit sufficient flexibility (e.g., gear restrictions that apply to only one group) may jeopardize the economic viability of other fishermen who don't support the regulation and adopt alternative methods that may reduce the regulation's effectiveness.

Management: Social Dimensions

6) Move toward increasing public participation in the management process and perhaps toward comanagement of Chesapeake Bay resources.

Public participation in the resource management process must be encouraged and incorporated at an early stage in development of management policies. Understanding the roles of various stakeholders and the relative impacts of their activities on the ecosystem is a key element in gaining acceptance of ecosystem-based approaches to fisheries management. Using the damage schedule described in the FEP can provide a starting point to understand impacts of industries and societal needs. The damage schedule framework can encourage greater public participation in contributing to development of comanagement policies for Chesapeake Bay fisheries.

Needed Research and Development: Economic Dimensions

7) Collect socioeconomic data on commercial fisheries.

These data are foremost among economic research needs. Types of data necessary for the commercial fisheries include

- Costs and earnings for fisheries,
- Behavioral objectives of watermen,
- Product distribution and sales,
- Input and output information by gear type or fishery, and
- Demographics of watermen and their communities.

Similar information must be obtained for processors, wholesalers, distributors, and retailers.

8) Collect social and economic data on recreational fisheries.

The types of data that must be collected to consider recreational angling adequately include

- Expenditures,
- Distances traveled to engage in recreational angling,
- Species targeted,
- Number of trips per year,
- Number and size of fish caught on a per-trip basis,
- Areas fished, and
- Mode of fishing (e.g., private boat, beach, pier, or charter boat).

9) Develop a baywide input/output (I/O) economic model for all Bay-dependent economic sectors that includes commercial and recreational fisheries, coastal businesses, agriculture, aquaculture, and other users.

Presently, such a model for any of the Bay-dependent industries does not exist. Input/output models will provide a framework for assessing changes in economic activity (i.e., sales, income, and employment). Its development will require “off-the-shelf” I/O models and the conversion of state and local coefficients to regional coefficients. Surveys will need to be conducted to obtain the necessary information.

10) Develop a research agenda for economic analyses needed for Chesapeake fisheries, especially as the emphasis shifts towards multispecies and ecosystem approaches.

Only through a broad-based collaborative effort will it be possible to develop an appropriate research agenda for determining the economic value or benefits of the Bay and its associated resources. A series of meetings or workshops to develop a comprehensive research agenda and a prioritized list of economics issues is needed.

11) Investigate ways of achieving multiple benefits—living resource restoration *and* improved fisheries quality—to lessen the impact on the livelihoods of traditional commercial fishermen.

Well-defined trajectories in loss of livelihood exist within this group.

Needed Research and Development: Social Dimensions

12)Gather information on other comanagement systems in the United States and abroad to begin formulating an appropriate structure for Chesapeake Bay.

Fisheries comanagement is practiced widely and successfully in many parts of the world, including North America. In Canada, the Atlantic Coast Action Program (ACAP) is well established and constitutes the driving force for several successful resource management initiatives. Several not-for-profit foundations in the United States and some government agencies (such as EPA) are currently promoting community-based management in watersheds of the Chesapeake Bay, although better coordination and a broadened scope are needed to foster ecosystem-based management.

12) Conduct a comprehensive review to determine social and economic impacts of all existing regulations affecting commercial and recreational fisheries in the Bay.

In many instances, changes in behavior of fishermen are constrained or driven by extrinsic factors (e.g., regulations or inadequate infrastructure). Research is necessary to evaluate the efficacy of the existing infrastructure and whether it is adequate to serve the needs of fisheries in the Bay, especially in an ecosystem-based context.

14) Undertake a comprehensive review to determine and understand legal issues, which are critical in developing an appropriate stakeholder-involved management structure for the Chesapeake Bay.

Several governmental agencies have various degrees of control and responsibility for resource management in the Bay region and, in some cases, have overlapping jurisdiction. In addition, numerous nongovernmental environmental organizations and industrial associations with strong interests in the health of the Bay exist. To avoid litigation associated with ecosystem-based approaches to fisheries management and social impacts that may ensue, a comprehensive review of the issues is recommended.

15) Expand environmental education programs to inform the public about the ecosystem-level effects and benefits of fisheries management under an FEP.

Environmental education, already a major component of the CBP and many other institutions and agencies in the Bay region, should be broadened to make the public more aware of resource issues and potential solutions to protect and restore the Chesapeake ecosystem. The effects of ecosystem approaches in fisheries management on the people who use and appreciate the Bay must be emphasized.

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CHAPTER 4

Developing Ecosystem-Based Fishery Management Plans

Introduction

The recommendations of this fisheries ecosystem plan (FEP) rely heavily on ecosystem-based principles and practices. Development of new, or revision of existing, fishery management plans (FMPs) to incorporate these principles and practices has become essential to the implementation of ecosystem-based management in the Chesapeake Bay. The following guidance complements and builds upon the Chesapeake Bay Program (CBP) Fisheries Management Planning and Coordination (FMPC) Workgroup statements of its mission and objectives (below) as well as its guidelines for FMP development. Admittedly, the infrastructure (data and analytical methods) to carry out many of the following actions simply does not exist at present; some actions may require several years to accomplish. Certain steps, however, can be taken immediately to promote implementation and adherence to the Chesapeake Bay FEP. Other steps look down the road toward meeting the *Chesapeake 2000* commitment to implement multispecies approaches to fishery management by 2007. The FEP offers guidance for the kind of strategic planning needed to accomplish the following statements of mission, objectives, and guidelines.

The FEP addresses the FMPC Workgroup mission to

> "Ensure that fishery considerations are integrated into all appropriate Chesapeake Bay Program activities, improve fishery management coordination among Chesapeake Bay jurisdictions, develop an ecosystem approach to fishery management and decision making, and coordinate efforts towards accomplishing the fisheries objectives of the new *Chesapeake 2000* agreement."

The FEP document recognizes and supports the stated workgroup objectives listed below.

1) Develop the pathway for including fisheries management in all appropriate Living Resources Subcommittee (LRSc) activities within the Chesapeake Bay.
2) Coordinate interests of the Chesapeake Bay Program partners to influence coastal management decisions (the Atlantic States Marine Fisheries Commission (ASMFC) and the Mid-Atlantic Fishery Management Council (MAFMC)).
3) Identify emerging fishery issues and bring them to the attention of the LRSc.
4) Improve the efficiency and

effectiveness of fisheries management in the Chesapeake Bay and along the Atlantic coast.

5) Continue the development, implementation, and review of FMPs and address the *Chesapeake 2000* commitments.
6) Expand the scope of fisheries management planning to incorporate ecosystem considerations and multispecies interactions.
7) Support other LRSc work groups in completing the *Chesapeake 2000* commitments.

Steps That Can Be Taken Now

The following actions, in combination with many steps recommended in the Pathways to FEP Implementation chapter, can facilitate the CBP's approach to ecosystem-based fisheries management. To incorporate ecosystem considerations into the management process, all new or revised FMPs should include the following building blocks.

Define the population components of managed (target) species and the geographical boundaries of all life stages.

Three population (stock) components could potentially be represented in managed Chesapeake Bay species (see Total Removals Element, Figure 1):

1) A component representing the population residing within the Chesapeake Bay (S_{CB}—the only mandatory component);
2) A component representing the population residing in Atlantic coastal waters outside the Bay (S_{CST}); and
3) A component representing the population residing in other estuaries along the mid-Atlantic seaboard (S_{EST}).

Not all species will exhibit all three components of population structure. For example, resident species occur only in the Chesapeake Bay component (S_{CB}). Other species require two components to describe their population structure (S_{CB} and S_{CST}), while some Bay species include all three (S_{CB}, S_{CST}, and S_{EST}). In many cases, only certain life stages will define the particular stock structure of a target species.

Appropriate Actions

1) Define for managed species which life history stages occur in the Chesapeake Bay, and which occur in coastal or other estuarine waters (population components can represent different ontogenetic stages of a single population) (see Total Removals Element, Figure 1).

Quantify removals by fishing sector including target and bycatch fisheries for all relevant jurisdictions when possible.

All major sources of removals or other identifiable mortalities from anthropogenic sources must be identified to quantify the level of total removals from Chesapeake Bay; this step is essential to determine patterns in fisheries harvest and abundance.

Appropriate Actions

1) Include explicit estimates of commercial landings for target species,

commercial discards, commercial landings of nontarget species (bycatch), recreational landings, and recreational discards. In cases for which no information is available, this deficiency should be acknowledged with the requirement that a plan be instituted to obtain the data.

2) For managed species, quantify the total removals (by state, region, or water body) inside and outside the Chesapeake Bay. This action requires information exchanges with other relevant jurisdictions (ASMFC, South Atlantic Fishery Management Council [SAFMC], and the mid-Atlantic Fishery Management Council [MAFMC]).
3) Characterize and quantify the uncertainty related to removals estimates. Standardize sampling and analytical methods used by the states to estimate total catch (landings, bycatch, and discard).
4) Identify and quantify technical interactions (i.e., bycatch and discard) in commercial and recreational fisheries at appropriate spatial and temporal scales.
5) Evaluate, or (at minimum) describe, the nature of technical interactions (i.e., bycatch) and the levels of removals and mortality attributable to such interactions.

Identify the general distribution and location of important habitats (e.g., feeding, spawning, nursery) for different life stages of managed species inside and outside the Chesapeake Bay.

Fisheries managers, together with habitat managers, must consider the importance of habitat diversity, complexity, extent, and spatial organization that could affect habitat value. They must also examine and evaluate the importance and consequences of temporal variability and dynamics in formulating management practices and policy. Managers must couple evaluations of habitat areas of particular concern with habitat management strategies and habitat restoration activities.

Ultimately, newly developed and revised FMPs should include descriptions, evaluations, and recommendations for actions that address protection and restoration of the essential habitat for all life stages of managed species, their important predators and prey, and the biogenic structures (e.g., oyster reefs) to which they are linked.

Appropriate Actions

Individual species' FMPs should

1) Identify, and when possible, quantify habitat requirements and habitat use by all life stages of managed species and members of their significant food web;
2) Identify critical habitat areas and issues of concern (including, and in addition to, those discussed below) that may affect fished species and their significant food web;
3) Consider potential effects of issues related to habitat areas of particular concern on sustainable harvest levels due to direct and indirect effects of habitat on fished species; and
4) Determine explicitly whether current habitat criteria and

restoration targets are adequate to protect and sustain exploited stocks.

Identify all relevant jurisdictions and user groups for managed species.

Without close cooperation between Bay and coastal management jurisdictions, the Chesapeake Bay FEP cannot ensure sustainable fisheries for resident species or for estuarine-dependent coastal species that use the Bay during critical life stages. The complex boundary issues related to population (stock) components and the many stakeholders and jurisdictional entities that share interest in management of Chesapeake fish stocks mandate such close cooperation.

Appropriate Actions

1) Identify and establish information exchanges with all jurisdictions and agencies responsible for the management of fisheries for each species.
2) Identify important stakeholders and user groups (types of fishermen, businesses, and social groups) with an interest in fisheries for each species.
3) Indicate for relevant jurisdictions the benefits, differences, or inconsistencies between prescribed actions for managed species (or species groups).

Define key predator and prey relationships for target species and characterize trends in the abundance of predator and prey species.

Understanding how different trophic groups, life history types, and habitat dependencies relate to target species abundance will help managers understand and recommend fishing strategies that support sustainability. For example, knowing total removals of piscivorous fish and forage fish (prey species) from the Bay ecosystem and establishing trends over time is important information for fisheries managers.

Appropriate Actions

1) Identify important interacting predators and prey in the FMP of each target species. Quantify the extent of interactions when possible.
2) Identify and quantify patterns in removals with respect to trophic levels, life histories, and habitat associations at appropriate spatial scales to improve understanding of biological interactions.
3) Apply appropriate trophic modeling approaches and other analytical tools to determine potential implications of predator and prey species removals on fishery yields and the Chesapeake Bay ecosystem.

Describe and quantify (when possible) the consequence of any proposed management action for a species on total removals from Chesapeake Bay.

Significant changes in catch levels of one species can affect present and future total yields of Bay fisheries as well as the overall structure of the ecosystem. Under an ecosystem-based management approach, managers should assess the impact on yields for other fisheries and the entire Bay for any proposed change in a particular fishery.

Appropriate Actions

1) Consider how changes in fishery regulations for the managed target species will impact species related to the target species through predator and prey interactions.
2) Consider how significant changes in the catch of a managed species may affect the overall structure and function of the Bay ecosystem.

Guidelines for Developing or Revising CBP FMPs

The CBP has long held ecosystem-based management as its goal. The Program's existing "Guidelines for Developing and Revising Fishery Management Plans Adoption Statement" rest on important principles of ecosystem-based management. Given the inherent value of these guidelines, they are summarized below together with appropriate recommended actions from the FEP Panel that jointly should promote successful implementation of an FEP management strategy.

Chesapeake Bay Program FMPs should

Be risk averse (i.e., prevent a crisis rather than react to one).

Considering and estimating, when possible, the precision and accuracy of information used in the decision-making process can reduce risk. Follow the precautionary approach.

Appropriate Actions

1) Include explicit estimates, or statements, that characterize uncertainty in each Chesapeake Bay FMP. Allow the specification of uncertainty in key parameters. When possible, explicitly provide the precision of estimates in stock assessments and in simulations from the models. Alternatively, indicate why uncertainty cannot be incorporated into the FMP along with a proposed remedy.
2) Include assessment models that can elucidate the risks of various management options associated with the inherent uncertainties in the models.
3) Adopt precautionary measures for Chesapeake Bay FMPs to ensure the sustainability of the fishery relative to its supporting ecosystem. For example, a precautionary approach designates fish habitat as "essential" when faced with scientific uncertainty. Adopting precautionary, ecosystem-based biological reference points can reduce the risk of uncertain management actions to stocks and the ecosystem.

Use the best scientific information available.

The advice offered here is appropriate for conventional single-species management as well as for the ecosystem-based management emphasized in the FEP. While basing management actions on solid science remains important, foregoing implementation of many management actions until achieving absolute understanding of species dynamics or ecosystem function is neither necessary nor advisable.

Appropriate Actions

1) Develop comprehensive monitoring programs to characterize the status of predator

and prey species, evaluate habitat quality, and demonstrate the effect (or lack thereof) of instituted management actions.

2) Incorporate survey data and analytical results from new multispecies monitoring (CHESMMAP, CHESFIMS) initiatives into stock assessments supporting Bay management decisions.
3) Follow the advice and recommendations of the National Research Council for improving stock assessments (NRC 1998), when possible, in development and revision of Chesapeake Bay FMPs. For example,
    - Upgrade models on a regular basis,
    - Apply multiple assessment models when possible,
    - Evaluate carefully the level of uncertainty, and
    - Undergo external peer review of stock assessments to maintain scientific integrity and credibility.

Establish sustainable, precautionary, and risk-averse limits and targets for managed species to assure resilience of the stock.

Technical guidelines for the 10 national standards that are consistent with the MSFCMA require that managers identify sustainable limits of abundance and exploitation in setting appropriate targets for all managed species (www.nmfs.noaa.gov/sfa/NSGtkgd.pdf). These targets should be precautionary and based on recent trends in abundance, but with consideration of historical baseline levels that could prove sustainable with managed effort, improved water quality, protected and restored habitat, and reasonably stable environmental conditions.

Appropriate Actions

1) Develop limits and targets in consultation with regional management agencies, based on the best scientific advice.

Identify, protect, and restore critical fish and shellfish habitats for all life stages and individual stocks of managed species.

Fisheries management agencies within the Chesapeake region cannot implement measures to improve, protect, and restore habitats on their own. State and CBP environmental agencies must also afford agreement, cooperation, and goodwill to meet these objectives. Instituting such measures will not be easy, but collaboration and cooperation are essential for effective overall implementation of the FEP.

Appropriate Actions

1) Identify and characterize habitat issues and deficiencies that limit productivity of managed fisheries and their sustainability.
2) Improve habitat quality and quantity for the benefit of managed fisheries and important interacting species.
3) Expand use of the CBP watershed approach to restore water quality to provide the vital fish habitat necessary to address *Chesapeake 2000* commitments.
4) Develop plans and coordinate

management actions with environmental agencies to ensure protection and restoration of critical habitats.

Identify, coordinate, and advocate necessary management actions among the jurisdictions, including regulations and legislative actions.

Appropriate Actions

1) Facilitate improvement in the coordination and information exchange between agencies responsible for fisheries and habitat management.
    - The Fisheries Steering Committee, in cooperation with the Water Quality Steering Committee and the Living Resources Subcommittee, should function as a coordinating body for agencies responsible for managing fishery resources and those responsible for the quality of fish habitat within the Chesapeake Bay fisheries ecosystem (Maryland Department of the Environment, Virginia Department of Environmental Quality, ASMFC, MAFMC, SAFMC, Maryland and Virginia watermen's associations).

Manage a fishery or species by maintaining essential food web relationships through multispecies management.

Included in the FEP are diagrammed food webs of managed species, indicating strong and weak interactions between predator and prey (see Food Web Element). These webs summarize fundamental knowledge about the Bay food web structure and relationships. Managers can use them in a precautionary manner to guide development of ecosystem-based regulations that allow sustainable fishery yields while conserving prey resources and important predator-prey relationships. Major research must be conducted, however, before multispecies fisheries management in the Bay can be confidently implemented.

Appropriate Actions

1) Use the Food Web Element and its updates to explore existing and potential models that inform managers of critical food web relationships for managed Bay species.
2) Consider explicitly strong linkages between predators and prey in allocating fishery resources. Be precautionary by determining the needs of predators before allocating forage species to fisheries.
3) Identity gaps in information that limit understanding of the Bay's food web and recommend needed additional research and development.

Consider the long-term socioeconomic health of a fishery.

Humans form an integral part of the Chesapeake Bay ecosystem. The fishing industry's contribution to the Bay's social and economic well-being is substantial. For ecosystem-based fisheries management, being able to avoid potential inequitable distribution of benefits and costs, while effectively addressing resource and environmental concerns, poses one of the greatest challenges. The Bay provides benefits to diverse user groups; maximizing benefits to each group will not maximize benefits to the ecosystem.

Appropriate Actions

1) Identify and quantify user group participation in fisheries for each managed species and identify stakeholders in the resources other than fishermen. This information should appear in respective FMPs and inform management decisions.
2) Consider all user groups (fishermen and others) to determine patterns that promote optimum use of Bay resources; patterns should be defined relative to economic value (net benefits), competing user groups, present and future uses, and social preferences.
3) Identify and promote management strategies to enhance the flexibility of fishermen to change fishing behavior when consistent with their values, while upholding management objectives. Consider whether proposed regulations are sufficiently flexible to realize desired management objectives and bring economic benefits to all user groups. Management actions that do not permit sufficient flexibility (e.g., gear restrictions that apply to only one group) may jeopardize the economic viability of fishermen, while reducing effectiveness of the regulation.

Adopt more conservative approaches than ASMFC and MAFMC when all signatories of the CBP agree such action proves necessary.

When research indicates that more rigorous management or conservative allocation of fisheries resources appears necessary in the Bay (as opposed to the East Coast), the FMPC Workgroup should propose the more conservative approach. Such rigor remains consistent with the need to protect the Bay as the productive engine of the ecosystem. For effective FEP implementation managing and protecting local fisheries, while generating coastwide benefits as a product of good Bay stewardship, should become a primary goal.

Appropriate Actions

1) Follow the precautionary approach in management of Bay fisheries (see Guideline 1). This approach is desirable given existing uncertainties.
2) Promote research investigating the linkages between abundance of coastal stocks and estuarine water quality (fish habitat) in Chesapeake Bay. When possible, document the dependency of coastal stocks on Bay health and productivity.

Minimize bycatch and discards.

Bycatch and discards represent direct losses to the abundance and biomass of target and nontarget species. The magnitude of these losses remains a critical concern for effective fishery management and overall management of the ecosystem. Productivity of fish stocks and sustainability may be overestimated significantly if bycatch or discard mortality is high and unaccounted for in assessment models.

Appropriate Actions

1) Include explicit estimates of bycatch and discards in each FMP

for commercial and recreational fisheries. In cases for which no information is available, this deficiency should be acknowledged along with recommended actions to obtain the required data.

2) Promote fishery regulations that ensure species- and size-selective gear types to reduce the catch of nontarget species and prerecruits of target species.

3) Recommend other management actions that reduce bycatch and discard mortality (e.g., temporal and spatial management actions that reduce the interactions between fisheries and nontargeted species or prerecruits of targeted species.

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CHAPTER 5

Pathways to Fisheries Ecosystem Plan Implementation

Introduction

Implementing the Chesapeake Bay fisheries ecosystem plan (FEP) is an incremental process that requires the cooperation of organizations within relevant jurisdictions. The first step in its implementation has also taken place, with the formal adoption of the FEP by the Chesapeake Bay program. Also important is the endoresement by appropriate Chesapeake Bay and regional agencies charged with fisheries and environmental management. Although endorsement will initially take place in principle, it must ultimately be followed by concrete actions to implement FEP recommendations.

The FEP has built on the capabilities and successes of present institutions and policies for implementation. Clear need exists, however, for new actions that conserve the productive capacity and services of the ecosystem to support sustainable fisheries in the Bay. After FEP endorsement and adoption, a plan to prioritize and enact policies for implementation is a logical next step—a step that will require joint input from the Chesapeake Bay Fisheries Steering Committee, the Chesapeake Bay Program (CBP) Living Resources Subcommitte Fisheries Management Planning and Coordination (FMPC) Workgroup, the FEP Technical Advisory Panel, state agencies responsible for fisheries and habitat management, as well as stakeholders throughout the Chesapeake Bay.

Desired FEP Outcomes

The FEP is a strategic rather than a tactical plan; its design and intent are to guide fishery management planning. Desirable outcomes from its development and adoption include

1) More effective, holistic, and better overall management decisions leading to productive and sustainable fisheries.
2) Improved coordination between fishery management agencies and other management or regulatory agencies that control or influence decisions affecting water quality and fish habitat.

The FEP will serve as

1) A guide for fisheries managers and those responsible for developing and amending fishery management plans (FMPs).
2) A “living” document—revised or amended on a regular basis—and used by the Living Resources Subcommittee (LRSC) and FMPC Workgroup in FMP development, amendment, and revision.

3) A guide, reference, and information source for the CBP on concepts, issues, and principles of ecosystem-based approaches for fisheries management.

Accordingly, the FEP will support coordination of ecosystem-based management actions by relevant institutions to sustain mutually important regional and coastal fisheries. Success will require development of an effective action plan by key institutions to promote incremental FEP implementation with emphasis on short-term actions and achievement of long-term objectives. Gaining consensus among the diverse agencies and stakeholders is necessary for this document to be fully effective.

The Pathway to Implementation

The CBP has a long history of commitment to improve water quality (fish habitat) and adopt ecosystem-based management. Accordingly, many important steps have already been taken to embrace or apply ecosystem-based principles in the Bay.

1) The CBP uses a set of "environmental indicators" to elucidate trends in water quality, living resources, and several management measures. Many of these indicators provide a framework for reference point development and "best practice" management criteria in ecosystem-based fisheries management (www.chesapeakebay.net/indicators. htm).
2) Models of the Chesapeake watershed and estuary have been operational for nearly two decades. Currently, three linked models exist: an airshed model, a watershed model, and a hydrodynamic model of the Chesapeake estuary. These models can help researchers and managers gain broad-scale, long-term understanding of how perturbations to the ecosystem may affect fisheries production *(*www.chesapeakebay.net/model.htm*).*
3) Several initiatives are underway to develop ecosystem-level models in support of fisheries management. One such effort is the development of a dynamic mass-balance model (Ecopath with Ecosim) to quantify trophic relationships at all levels of the aquatic ecosystem, but emphasizing exploited groups *(*http://noaa.chesapeakebay.net/ecosystem.htm*).*
4) Progress in multispecies monitoring and assessment is being made through ongoing baywide fishery-independent surveys (ChesMMAP and CHESFIMS). These surveys quantify geographical and seasonal distribution of key fish species, food web interactions, and fish community structure in relation to environmental variability *(*http://hjort.cbl.umces.edu/chesfims.html and http://www.fisheries.vims.edu/chesmmap/*).*
5) The Chesapeake Information Management System (CIMS) is an organized, distributed library of regional data, information, and software tools that increase basinwide public access. The CIMS partners have enacted memoranda of agreement (MOAs) to follow guidelines in assembling and

publishing Chesapeake Bay-related information and maintain the internet sites within CIMS (www.chesapeakebay.net/cims/index.htm).

6) Designation of marine-protected areas and plans to expand this approach in Chesapeake Bay are being initiated by CBP partners. Prominent examples include oyster reefs (www.chesapeakebay.net/reefrest.htm and www.oysterrecovery.org) and blue crab migration corridors (www.serc.si.edu/education/resources/bluecrab.htm).

Implementing the FEP

Not all FEP recommendations can be implemented immediately; the process must remain incremental and viewed with a long-term perspective. The FEP Panel identified the critical next steps and key actions to promote the gradual implementation of ecosystem-based fisheries management in the Chesapeake Bay.

Steps at the Baywide Level

1) Obtain formal adoption of the FEP by the Chesapeake Bay Program to address the mandate for multispecies management in the CBP's Chesapeake 2000 agreement (http://www.chesapeakebay.net/agreement.htm) and support ecosystem approaches that will become more prominent in management of Chesapeake fisheries.

- At the 2005 Annual Meeting (11/29/05) of the Chesapeake Bay Program Executive Council (EC), the FEP document "Fisheries Ecosystem Planning for Chesapeake Bay" was formally adopted as the framework for the CBP's gradual transition from single-species fisheries management to an ecosystem-based multispecies approach for the Bay and coastal region. In the FEP Adoption Statement (http://www.chesapeakebay.net/info/pressreleases/ec2005/doc-fisheries_ecosystem_adoption_statement.pdf), the EC agreed that ecosystem-based principles, goals, and policies (as included within the FEP) should be incorporated into CBP fishery management plans and practices.

2) Develop an FMP or revise an existing FMP as an ecosystem-based FMP providing "proof-of-concept," with input and guidance from the FEP Panel on ways to incorporate FEP recommendations; discussions with the FSC suggest that Atlantic menhaden *Brevoortia tyrannus* may be an appropriate candidate.

3) Emphasize fisheries as an important driver for Bay restoration efforts.

- Increase the visibility of key fisheries and reference points of their status and health as indicators of Bay ecosystem health, thus promoting the need for effective management of water quality, habitat, and predator–prey interactions.
- Encourage statements in the goals and objectives of each CBP subcommittee that emphasize the subcommittee's role in conserving and restoring viable

fish habitat.

4) Consider a mechanism to establish continued contributions by the FEP Technical Advisory Panel, or its successor, to the Bay fisheries management process. Appropriate actions would
    - Continue the FEP Panel with a renewed charter and a process to appoint and select new panelists.
    - Consider the FEP a “living document,” with ongoing revisions as knowledge of the Bay fisheries ecosystem increases and management needs change.
    - Consider an FEP Panel presence on the FMPC Workgroup.

5) Consider the structure and potential for development of a Chesapeake Bay institution vested with baywide fisheries management authority, a task possibly to be undertaken by the Chesapeake Bay Fisheries Steering Committee. Such a baywide institution will greatly facilitate adoption of ecosystem approaches in fisheries management.
    - The guiding principles and many elements of the FEP can be implemented without a baywide institution. However, because the ecosystem is the focus of the FEP and ecosystem-based fisheries management, coordinated baywide management actions can facilitate full implementation.

Steps at the Regional Level

1) Seek regional endorsement and adoption of both the Chesapeake Bay FEP concept and its management recommendations.
    - Present the Chesapeake Bay FEP to regional fisheries management institutions (Atlantic States Marine Fisheries Commission (ASMFC), Mid-Atlantic Fishery Management Council (MAFMC), and South Atlantic Fishery Management Council (SAFMC)) requesting their endorsement or acceptance of FEP recommendations to support the CBP’s gradual approach to ecosystem- based management at least in principle.
    - Build a formal cooperative framework between regional fisheries and water quality-habitat management bodies (CBP, ASMFC, MAFMC, SAFMC, Maryland Department of the Environment, and Virginia Department of Environmental Quality) with jurisdiction over coastal and estuarine areas where fishing activities and environmental conditions affect organisms and habitats that support Chesapeake Bay fisheries.

List of Acronyms

ABC	Acceptable Biological Catch
ACCSP	Atlantic Coastal Cooperative Statistics Program
ACFCMA	Atlantic Coastal Fisheries Cooperative Management Act
ASMFC	Atlantic States Marine Fisheries Commission
BBCAC	Bi-state Blue Crab Advisory Committee
BMPs	Best Management Practices
BRDs	Bycatch Reduction Devices
C2K	Chesapeake Bay Agreement 2000
CBA	Chesapeake Bay Agreement
CBC	Chesapeake Bay Commission
CBP	Chesapeake Bay Program
CBSAC	Chesapeake Bay Stock Assessment Committee
CDFRs	Captain's Daily Fishing Reports
CHESFIMS	Chesapeake Bay Fishery-Independent Multispecies Survey
CHESMMAP	Chesapeake Bay Multispecies Monitoring and Assessment Program
CIMS	Chesapeake Information Management System
COMP	Comprehensive Oyster Management Plan
CPR	Coastal Pelagic Resources
CPUE	Catch Per Unit Effort
CWA	Clean Water Act
DAH	Daily Allowable Harvest
DCEHA	D.C. Environmental Health Administration
DEA	Data Envelopment Analysis
DEQ	Department of Environmental Quality
DCFM	D.C. Fisheries Management
DCFWD	D.C. Fisheries and Wildlife Division
DNR	Department of Natural Resources (also MD DNR)
DO	Dissolved Oxygen
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement

ESA	Endangered Species Act
EU	European Union
EwE	Ecopath with Ecosim
FAO	Food and Agriculture Organization
FCZ	Fishery Conservation Zone
FCMA	Fishery Conservation and Management
FEP	Fisheries Ecosystem Plan
FSC	Fisheries Steering Committee
FMPs	Fishery Management Plans
GMFMC	Gulf of Mexico Fisheries Management Council
HAPC	Habitat Areas of Particular Concern
HIS	Habitat Suitability Index
IBI	Index of Biotic Integrity
ICES	International Council for the Exploration of the Sea
ICPRB	Interstate Commission on the Potomac River Basin
INCNAF	International Commission for Northwest Atlantic Fisheries
IPCC	Intergovernmental Panel on Climate Change
ITQ	Individual Transferable Quota
LRSC	Living Resources Subcommittee
LME	Large Marine Ecosystem
M	Natural Mortality
MAFMC	Mid-Atlantic Fishery Management Council
MD DNR	Maryland Department of Natural Resources (also DNR)
MDE	Maryland Department of the Environment
MESY	Maximum Expected Stationary Yield
MEY	Maximum Economic Yield
MPA	Marine Protected Area
MRFSS	Marine Recreational Fisheries Statistical Survey
MSFCMA	Magnuson-Stevens Fishery Conservation and Management Act
MSP	Maximum Spawning Potential
MSST	Minimum Stock Size Threshold
MSVPA	Multispecies Virtual Population Analysis
MSY	Maximum Sustainable Yield or Minimum Safe Yield
MSYPR	Multispecies Yield Per Recruit
MT	Metric Tons
NCBO	NOAA Chesapeake Bay Office
NEAMAP	Northeast Area Monitoring and Assessment Program
NEFMC	New England Fishery Management Council

NEFSC	Northeast Fisheries Science Center
NERR	National Estuarine Research Reserves
NESDIS	National Environmental, Satellite, Data, and Information System
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPFMC	North Pacific Fisheries Management Council
NRC	National Research Council
NSGs	National Standard Guidelines
OFL	Overfishing Limit
OY	Optimum Yield
PBT	Persistent Bioaccumulative Toxic
PFBC	Pennsylvania Fish and Boat Commission
PRFC	Potomac River Fisheries Commission
S_{CB}	Chesapeake Bay Stock
S_{CSTt}	Coastal Stock
S_{EST}	Estuary Stock
SAFMC	South Atlantic Fisheries Management Council
SAV	Submerged Aquatic Vegetation
SEAMAP	Southeast Area Monitoring and Assessment Program
SDSS	Spatial Decision Support System
SFA	Sustainable Fisheries Act
SPR	Spawning Potential Ration
SSB	Spawning Stock Biomass
SSBR	Spawning Stock Biomass Per Recruit
STAC	Scientific and Technical Advisory Committee
TAC	Total Allowable Catch
TIES	Trophic Interactions in Estuarine Systems
TMDL	Total Maximum Daily Load
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VA DEQ	Virginia Department of Environmental Quality
VIMS	Virginia Institute of Marine Science
VMRC	Virginia Marine Resources Commission
VPA	Virtual Population Analysis
WtM	Watershed-to-mouth of the Bay
WTOA	World Trade Organization Agreement
YPR	Yield-Per-Recruit

Fisheries Ecosystem Plan Glossary

Abundance index – Information obtained from samples or observations and used as a measure of the weight or number of fish that make up a stock.

Algal bloom – A natural phenomenon resulting in the proliferation of either phytoplankton or seaweed. Nutrient pollution, however, has resulted in a substantial increase in algal blooms along many coastal regions over the past two decades. Phytoplankton blooms can produce toxic effects on humans and other organisms, cause physical impairment of fish and shellfish, or result in severe oxygen depletion of bottom habitats. Blooms involving phytoplankton are sometimes called “red tides” though, in reality, they can be of various colors, or not visible at all. Even miniscule doses of some algal toxins, such as domoic acid or saxitoxin, can cause severe illness or death in humans. Most algal species, however, pose no threat to human health.

Allocation – Distribution of the opportunity to fish among user groups or individuals. The share that a user group receives is sometimes based on historic harvests.

Allowable biological catch – The catch that can be taken in a specific year that achieves the biological objectives or avoids the biological constraints of fishery management. Such objectives and constraints are usually set in terms of stock sizes that must be maintained, fishing mortality rates that shall not be exceeded, or both. Estimates of allowable biological catch should be based on the best scientific advice available.

Anadromous – Fish that spend most of their life in salt water but migrate into freshwater tributaries to spawn.

Angler – A person catching fish or shellfish with no intent to sell, including those who release the catch.

Anoxic – Literally without oxygen, a condition hostile to almost all life forms. Operationally, the monitoring program defines anoxic as less than 0.2 mg oxygen per liter. Much of the anoxic zone is anaerobic, with absolutely no oxygen, a condition in which toxic hydrogen sulfide gas is emitted during decomposition.

Anthropogenic – Of human origin.

Apron – The hard flap on the bottom side of a crab that protects the abdomen.

Atmospheric deposition – The process in which air pollution comes in contact with the earth surface. Air pollution washed out of the sky by rain or snow is “wet deposition.” The deposition of air pollution without rain is “dry deposition.”

Aquaculture – The raising of fish or shellfish using some controls. Ponds, pens, tanks, or other containers may be used and feed is often provided. A hatchery is also aquaculture, but the fish are released before reaching harvest size.

Availability – Refers to the distribution of fish of different ages or sizes relative to that of the fishery.

B_{MSY} – Long-term average biomass that would be achieved if fishing at a constant fishing mortality.

Bathymetric – Pertaining to depth measurement.

Bathymetry – The physical characteristics—including depth, contour, and shape of the bottom—of a water body.

Bayesian models – Classical frequentist statistical models assume that model parameters are constant (fixed in value) but unknown. Frequentist statistical methods estimate these unknown fixed quantities. In Bayesian models, the parameters are assumed unknown but variable. Bayesian statistical methods assume a probability distribution for unknown parameters. This distribution also has parameters that are usually assumed to be fixed and must be estimated. These parameters are referred to as hyperparameters and are often considered the best estimates of the original model parameters. Bayesian statistical methods estimate the hyperparameters and then use these estimates to calculate quantities of interest.

Beach – A sloping landform on the shore of large water bodies, generated by waves and currents and extending from the water to a distinct break in landform or substrate.

Benthic – Describes organisms living on or in the bottom of the sea; associated with live bottoms, hard-bottom banks, patch reefs, and reef complexes.

Benthic macrointertebrates - Large, generally soft-bodied organisms that lack backbones living in or on the bottom sediment in aquatic environments.

Benthos – The community of marine life inhabiting the sea floor.

Best management practices (BMPs) – A practice or combination of practices that provides the most effective and practicable means of controlling point and nonpoint pollutants at levels compatible with environmental quality goals.

Bioavailable – The degree to which a contaminant or nutrient in the environment can be absorbed, transported, and utilized physiologically.

Biological Interactions – Spatial co-occurrence of different species related by competition for the same food resources or predator–prey relationships.

Biological reference point (BRP) – A particular value of stock size, catch, fishing effort, and fishing mortality, which may be used as a goal in fisheries. Such values can be categorized as limits or targets, depending on their intended use. Socioeconomic reference points also exist.

Biomass (B) – The quantity of living matter, expressed as a concentration or weight per unit area. The total weight of several organisms or the population of a species. A fish population can have a high biomass and still be overfished.

Biota – Animal and plant life in a region.

Bioturbation – Reworking or disruption of sediments by animals burrowing or feeding.

Bivalve – Mollusk with two shells connected by a hinge (e.g., clams, oysters).

Bootstrapping – When sampling variability cannot be easily calculated, bootstrapping is one method for estimating or approximating the sampling error. The method requires that the original sample be treated as a "pseudo-population" and that samples be repeatedly taken from this pseudo-population. Sampling is with replacement (if a unit is selected, it is measured and then returned to the pseudo-population so that it could be sampled again) and simulates the original sampling design. This pseudosampling is repeated resamplings; the variability of the estimator is approximated using the sampling variability in the pseudosamples taken from the pseudopopulation.

Bottom-up control – Refers to direct or indirect dependence of community structure on factors producing variation at lower trophic levels or in their resources.

Brackish – Water with a salt concentration between that of fresh water and sea water.

Buckrams – Crabs that have recently shed, but have not yet grown into their new shell. Buckrams are lightweight and yield less meat than fully developed hard crabs.

Burden of proof – The responsibility to demonstrate that a fishing activity will or will not lead to overfishing or negative effects on the ecosystem

Bycatch – Unintentional catch; catch that occurs incidentally in a fishery that intends to catch other fish (e.g., different size, species); mortality caused by technical interactions in fisheries.

- **Economic discards –** Species with little or no current economic value, such as certain sponges, corals, skates, or targeted species in poor condition;
- **Regulatory discards –** Individuals of commercially valuable species discarded for not meeting regulatory requirements (a prohibited species, an illegal size, or because the quota for the species has already been filled and the fishery is closed).
- **Collateral mortality –** Individual species killed through encounters with active or discarded fishing gear (Alverson, 1998).

Calcareous – Formed of calcium carbonate or magnesium carbonate by biological deposition.

Cap load – The maximum pollutant loads of nutrients and sediments that can be allowed and still meet Chesapeake Bay water quality criteria.

Carrying capacity – The number or biomass of resources that can be supported by an ecosystem.

Catadromous – Fish that live in fresh water and migrate to salt water to spawn. The opposite of anadromous species, catadromous species spawn in the sea; their young then migrate to fresh or brackish water to grow and mature.

Catch – The total number or weight of fish captured from an area over a period of time, including fish that are caught but are released or discarded. The catch may take place in an area different from where the fish are landed. Note: catch, harvest, and landings have different definitions.

Catchability coefficient (q) – The average portion of a fish stock that a unit of gear (e.g., one crab pot) is capable of catching. Catchability is a measure of the catch efficiency of the gear.

Catch per unit effort (CPUE) – An indicator of stock abundance or stock density. The number or weight (biomass) of fish caught by a given amount of effort. Effort is a combination of gear type, gear size, and length of time a gear is used. The CPUE may be influenced by changes in abundance.

Charter boat – A boat available for hire, normally by a group of people (usually anglers) for a short time.

Coastal plain – The level land with generally finer and fertile soils downstream of the piedmont and fall line, where tidal influence is felt in the rivers.

Coastal waters – Inshore waters within the geographical areas defined by each state's coastal zone management program.

Coastal wetlands – Forested and non-forested habitats, mangroves, and all marsh islands exposed to tidal activity. These areas directly contribute to the high biological productivity of coastal waters through input of detritus and nutrients, by furnishing nursery and feeding areas for shellfish and finfish and by providing habitat for many birds and other animals.

Cohort – A group of fish spawned during a given period, usually within a year.

Comanagement (cooperative management) – Either informal or legal arrangements among government representatives, community groups, and other user groups to take responsibility for, and manage, a fishery resource and/or its environment on a cooperative basis.

Commensal – A relationship that benefits one member of a two-species association but has neither positive nor negative effect on the other.

Commercial fishery – A term related to the process of catching and marketing fish and shellfish for sale, including fisheries resources, fishermen, and related businesses.

Common property resource – A resource owned by the public, such as fish in public waters, trees on public land, or the air. The government regulates the use of a common property resource to ensure future benefits.

Community – A group of plants and animals living in a specific region under relatively similar conditions.

Confidence interval – The estimated range of values of the parameter of interest that has a high probability of covering the true value of the parameter.

Conservation and management – The rules, regulations, conditions, methods, and other measures required and useful to rebuild, restore, or maintain any fishery resource and the marine environment and which ensure that: 1) a supply of food and other products may be taken, and that recreational benefits can be obtained on a continuing basis; 2) irreversible or long-term adverse effects on fishery resources and the marine environment are avoided; and 3) many options will remain available with respect to future use of these resources (adapted from NMFS, 1996).

Continental shelf – That portion of the ocean floor that lies between the shoreline and the abrupt change in slope (the shelf edge), which generally occurs at a water depth of 200 meters. The shelf is characterized by a gentle slope and the region is home to diverse fish and shellfish species.

Control rule – Describes a plan for pre-agreed management actions as a function of variables related to the status of the stock. For example, a control rule can specify how F or yield should vary with biomass. In the National Standard Guidelines, the "MSY (maximum sustainable yield) control rule" is used to determine the limit fishing mortality, MFMT. Control rules are also known as "decision rules" or "harvest control laws" in some scientific literature.

Convenience sample – A sample for which the site or location was selected for convenience rather than according to sound statistical principles. For example, ten fish taken from the top of the holding container represent a convenience sample. It differs from a statistical sample in which methods ensure that every fish in the container has some known probability (greater than zero) of being selected. In a convenience sample, not every fish has a chance to be sampled, potentially introducing bias into the analysis. In the commonly used method of simple random sampling, every fish has an equal chance of being selected.

Council – A regional fishery management group. The Fishery Conservation and Management Act of 1976, as amended, created the regional councils.

Coriolis force – This apparent force, named after Gustave Gaspard Coriolis (1792–1843) is not a force at all but describes a phenomenon due to the movement of an independent body over a rotating curved surface. In the northern hemisphere, wind and water traveling over the earth's surface appear to be deflected to the right, relative to their original direction of movement. The apparent deflection seen by an earthbound observer results from the earth's rotational movement under the wind.

Cradle – When a male crab carries a female peeler crab just prior to maturity so that mating can occur immediately after the hard shell is molted.

Crustacean – The class of aquatic arthropods including copepods, isopods, amphipods, barnacles, shrimp, and crabs, characterized by jointed appendages and gills. Crustaceans are the aquatic analogs of insects; both are members of the phylum Arthropoda. Found in both fresh and salt water, crustaceans are invertebrates and characteristically have a segmented body and exoskeleton, with paired and jointed limbs. Examples include lobsters, crabs, shrimp, and barnacles.

Cull rings – Plastic rings worked into the mesh of a crab pot and sufficiently large in diameter to allow small, sub-legal crabs to escape.

Decision rule – A rule for deciding whether to reject or not reject a hypothesis. Specification of the responses to estimated or perceived changes to the states of nature.

Demersal – Living at or near the bottom of the sea.

Depensation – A reduction in per capita productivity of a fish population.

Deterministic model – A model in which fixed inputs (data assumed to be without error) are entered into equation(s) with "known" values for the model parameters (such as natural mortality, size of the bycatch, and recreational fishing mortality), with the outputs treated as exact values. It does not incorporate any means of accounting for the various sources of variability or error in the inputs, model parameters, or model specifications.

Detritus – Particulate organic matter originating primarily from the physical breakdown of dead animal and plant tissue.

Diatoms – Microscopic algae with plate-like structures composed of silica. Diatoms are a good food source for zooplankton.

Directed fishery – Fishing focused on a certain species or group of species in both sport and commercial fishing.

Discards – A portion of what is caught and returned to the sea unused. Discards may be either alive or dead. Many types of discards exist: economic discards (when a portion of the catch that is not economically rational to land is discarded); regulatory discards (discarding due to a prohibition on retaining some of the catch); and highgrade discards (discarding the portion of the catch with a lower value than the portion retained to comply with regulations that limit how much catch can be retained). Highgrading is a form of regulatory discarding.

Discharge – The spilling, leaking, releasing, pumping, pouring, emitting, emptying, or dumping of any pollutant or hazardous substance, including discharge from storm sewers.

Dissolved inorganic nitrogen (DIN) – An important nutrient for the growth of plants; a form of nitrogen readily usable by plants.

Dissolved oxygen – Microscopic bubbles of oxygen that are mixed in the water and occur between water molecules. Dissolved oxygen is necessary for healthy lakes, rivers, and estuaries. Most aquatic plants and animals need oxygen to survive.

Diurnal – Having a daily cycle.

Diversity – An ecological measure of the variety of organisms in a habitat.

Ecology – The study of the interrelationships between living things and their environment.

Ecological economics – A framework for formulating ecosystem policies that adopts conventional and economic aspects for integrating ecological with social and economic systems. It treats humans as one species in an ecosystem, recognizing their special place in the system since humans are responsible for understanding their role and managing sustainability.

Economics – The study of how scarce resources are allocated among competing uses.

Economic overfishing – A level of fish harvesting that is higher than that of economic efficiency; harvesting more fish than necessary to yield maximum profits for a fishery. Occurs whenever the effort exceeds that needed to maintain maximum economic yield (MEY).

Ecopath with Ecosim (EwE) – Ecological modeling software that provides a consistent description of the system investigated, emphasizing certain aspects to understand their function. Ecopath: a static, mass-balanced snapshot of the system. Ecosim: a time-dynamic simulation module for policy exploration. Ecopath software can address ecological questions, evaluate ecosystem effects of fishing, explore management policy options, evaluate the impact and placement of marine-protected areas, and evaluate effects of environmental change.

Ecospace – A spatial and temporal dynamic module of the Ecopath modeling package primarily designed to explore the impact and placement of protected areas.

Ecosystem – A complex, interactive community of organisms and the environment functioning as an ecological unit.

Ecosystem-based fishery management – Fishery management actions to conserve the structure and function of marine ecosystems, in addition to conserving the fishery resource.

Ecosystem engineers – Organisms that directly or indirectly modulate the availability of resources to other species by causing physical state changes in biotic or abiotic materials, thus modifying, maintaining, and creating habitats. **Autogenic engineers** (e.g,. corals, trees) change the environment through their own physical structures (i.e., living and dead tissues). **Allogenic engineers** (e.g., woodpeckers, beavers) change the environment by transforming living or non-living materials from one physical state to another through mechanical or other means.

Ecosystem overfishing – Fishing-induced ecosystem impacts, including reductions in species diversity and changes in community composition; large variations in abundance, biomass, and production in some of the species; declines in mean trophic levels within ecological systems; and significant habitat modifications or destruction. Catch levels considered sustainable under traditional single-species management may adversely affect other living marine resources, creating ecosystem overfishing.

Ecosystem services – Those critical ongoing streams of services (e.g., water purification, maintenance of biodiversity, and climate stabilization) spontaneously generated by a thriving ecosystem.

Effluent – The liquid waste of sewage and industrial processing.

Effort – The amount of time and fishing power used to harvest fish. Fishing power includes gear size, boat size, and horsepower.

Elver – Small eels that have only recently entered the Bay from the ocean.

Emissions – Pollution released or discharged to the air from natural or manmade sources. Pollutants may be released directly from a structure (e.g., smokestack, chimney, exhaust pipe) or indirectly via volatilization or dispersal (e.g., aerosol spraying).

Endemic species – A species restricted in its distribution to a particular locality or region.

Entrainment – When the intake of surface waters through condenser cooling systems at nuclear power plants draws in aquatic organisms sufficiently small to pass through the debris screens. These organisms may travel through the entire condenser cooling system and be exposed to heat, mechanical and pressure stresses, and possibly biocidal chemicals, before being discharged to the water body.

Environment – Place in which an organism lives and the circumstances under which it lives. Environment includes moisture and temperature, as much as the actual physical place where an organism is found.

Environmental impact statement (EIS) – An analysis of the expected impacts of a fishery management plan (or some other proposed action) on the environment.

Epibenthic – Located *on* the bottom as opposed to *in* the bottom.

Epibiota – Animal or plant life living on the surface of other plants or animals.

Epifauna – Animals living on the surface of a substrate.

Epifaunal – Plants, animals, and bacteria attached to the hard bottom or substrate are capable of movement or those that live on the sediment surface.

Epipelagic – The upper sunlit zone of oceanic water extending to a depth of approximately 200 meters.

Epiphyte – A plant that grows upon another plant, using it for structural support or as a way to get off the ground and into the canopy.

Epiphytic – Refers to organisms that live on the surface of a plant.

Erosion – The wearing away of the land by water, wind, ice, or other geologic agents.

Escapement – The percentage of fish in a particular fishery that escape from an inshore habitat and move offshore, where they eventually spawn.

Essential fish habitat (EFH) – Those waters and substrate necessary for fish to spawn, breed, feed, and grow to maturity (NMFS, 1996).

Estuarine – Of or relating to an estuary.

Estuarine species - A permanent resident of an estuary. Also called a resident species.

Estuary – Coastal semi-enclosed body of water that has a free connection with the open sea and where fresh water meets and mixes with sea water.

Euryhaline – Fish that live in a wide range of salinities.

Eutrophic – Describes an aquatic system with high nutrient concentrations. These nutrient concentrations fuel algal growth. The algae eventually dies and decomposes, which reduces the amount of dissolved oxygen in the water.

Eutrophication – Enrichment of a water body with nutrients introduced by natural or artificial means and accompanied by an increase of respiration, which may create an oxygen deficiency.

Exclusive Economic Zone (EEZ) – The maritime region adjacent to the territorial sea, extending 200 nautical miles from the territorial sea baseline, in which the United States has exclusive rights and jurisdiction over living and non---living natural resources except for the tuna fishery.

Exotic species – Any non-native species that does not have a natural range covering the geographic region of interest. For example, the mute swan is an exotic species since it is a native European species not found in North America except in areas where it has been introduced.

Exploitation (u) – The fraction of a population at a given time that is removed by fishing over the course of a year (also accounts for any concurrent natural mortality). May also be expressed as a percentage of the population.

Extant species – A species currently in existence (the opposite of extinct).

Externalities – Those forces (ecological, human, and institutional) external to the traditional domain of fisheries management that structure and constrain living resource production dynamics within an ecosystem.

Extirpated – A species that has been totally destroyed.

Extinct species – A species that has disappeared from existence due to either natural or human-induced means (opposite of extant).

Ex-vessel – Activities that occur when a commercial fishing boat lands or unloads a catch. For example, the price received by a captain for the catch is an ex-vessel price.

$F_{\%-}$ ($F_{extinction}$, F_{crash}) – Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the survival ratio at the origin of the stock-recruitment relationship. A stock fished at or above this level for a prolonged period is expected to collapse.

F_{high} – Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the 10th percentile observed survival ration.

F_{low} – Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the 90th percentile observed survival ration.

F_{max} – The level of fishing mortality (F) that maximizes the yield per recruit. F_{max} is one of the biological reference points used to define overfishing.

F_{med} – Fishing mortality rate corresponding to an equilibrium SPR equal to the inverse of the median observed survival ration.

F_{MSY} – Fishing mortality rate which, if applied constantly, would result in MSY.

f_{MSY} – Effective fishing effort corresponding to $F_{MSY.}$

$F_{X\%}$ – Fishing mortality rate that results in x% equilibrium spawning potential ratio (e.g., $F_{30\%}$ is the mortality rate that will result in a spawning potential ratio of 30 percent).

$F_{0.1}$ – A reference point based on the value of fishing mortality, F, at which the slope of the yield per recruit curve is 0.1 (10 percent) of its initial value; regarded as a conservative level of exploitation which allows for economic viability and a buffer against recruitment overfishing.

$F_{10\%}$ – The level of fishing mortality rate that allows at least 10 percent of the spawning stock to escape the fishery to reproduce. $F_{10\%}$ is measured at 10 percent of the estimated spawning stick under unfinished conditions.

$F_{10\%\ epr}$ – The level of fishing mortality, F, at which an average female in the population will produce 10 percent of the eggs that would be produced by a female left to live her natural life span (i.e., unfished).

Fall line – An imaginary line joining the waterfalls on several rivers marking the point where each river descends from the upland to the lowland and also denoting the limit of navigability on each river.

Fauna – A group of animals representative of a particular region.

Fecundity – The number of eggs produced per female per unit time (often per spawning season).

Filter feeder – An organism that filters food from the environment using a straining mechanism, such as gills.

Fish – Finfish, mollusks, crustaceans, and all other forms of marine animal and plant life other than marine mammals and birds (NMFS 1996).

Fisheries ecosystem – The complex interactive community of organisms, including humans and their institutions, and its shared environment (habitats and ecological processes) that contributes to, influences, or determines the fishing industry.

Fishery – 1) The industry or occupation devoted to the catching, processing, or selling of fish, shellfish, or other aquatic animals. 2) A place where fish or other aquatic animals are caught. 3) A fishing business. 4) A hatchery for fish. 5) The legal right to fish in specified waters or areas. (American Heritage Dictionary)

Fishery – 1) One or more stock of fish treated as a unit for purposes of conservation and management, which are identified on the basis of geographical, scientific, technical, recreational, and economic characteristics; and 2) any fishing for such stocks (NMFS 1996).

Fishery Conservation and Management Act – The federal law that created the regional councils and is the federal government's basis for fisheries management in the exclusive economic zone. Also known as the Magnuson Act after its chief sponsor, Warren Magnuson.

Fishery conservation zone (FCZ) – The area from the seaward limit of state waters out to 200 miles. The term is used less often now than exclusive economic zone.

Fishery-dependent data – Data obtained from commercial or recreational harvest. Fishery-dependent data consist of catch reports, sea sampling, and other data concerning the resource and the fishery that are obtained from the fishery.

Fishery-independent data – Data collected through independent research surveys rather than from commercial or recreational harvest, typically including abundance and recruitment information.

Fishery Management Council – The Fishery Conservation and Management Act of 1976, as amended, created the eight regional councils responsible for developing fishery management plans (FMPs) in the federal waters of the regions. Each council consists of representatives from each state in the region and up to 19 members from various stakeholder groups. The eight regions are New England, Mid-Atlantic, South Atlantic, Gulf of Mexico, Caribbean, Pacific, North Pacific, and Western Pacific. (NRDC)

Fishery management plan (FMP) – A plan to achieve specified management goals for a fishery. It includes date, analysis, and management measures for a fishery.

Fishing – Any activity that can reasonably be expected to result in the catching, taking, or harvesting of fish or any operations at sea in support of, or in preparation for, such activities.

Fishing down the food web – Refers to systematic removal of the largest and usually most valuable fish species in a system (explicitly top-level predators), resulting in the capture of smaller, less-valuable species (typically prey or forage species).

Fishing mortality rate (F) – That part of the total mortality rate applying to a fish population that is caused by fishing. Fishing mortality is usually expressed as an instantaneous rate and can range to values exceeding unity, such as 2.0 or higher.

Fish stock – A species, subspecies, geographical grouping, or other grouping of fish managed as a unit (NMFS 1996).

Flocculent – Pertaining to a material that is cloudlike and noncrystalline.

Flora – Plant life characteristic of a region.

Food chain/food web – The network of feeding relationships in a community as a series of links of trophic levels, such as primary producers, herbivores, and primary carnivores. Includes all interactions of predator and prey, along with the exchange of nutrients into and out of the soil. These interactions connect the various members of an ecosystem and describe how energy passes from one organism to another.

Fouling – Occurs when large numbers of marine plants and animals attach and grow on various submerged structures, often interfering with their use.

Fresh – Term applied to water with salinity less than 0.5 ppt.

Freshet – A sudden rise in water flow often during the late winter or spring, owing to increased precipitation and snow melt in the watershed.

Fully exploited – When a fishery is fully utilized and additional harvest is discouraged to avoid overfishing. In an underutilized fishery, additional harvest does not threaten the population.

Fuzzy arithmetic – A hybrid between simple interval arithmetic and probability density functions. In interval arithmetic, a quantity is assigned a range of possible values rather than a single constant with the assumption that any value in the interval is the true value. No statement is made concerning the validity of the interval. Probability density functions assign a range of values to a quantity as well but the assignment is accompanied by a probability that the value falls within some given range. Fuzzy numbers are a set of intervals, each with a specified level of associated possibility. Rules for arithmetic operations (such as addition, subtraction) have been constructed to handle fuzzy numbers. Hence, the set of rules is called fuzzy arithmetic.

Generation time – In the context of the National Standard Guidelines, generation time is a measure of the time required for a female to produce reproductively active female offspring for use in setting maximum allowable rebuilding time periods.

Ghost fishing – Mortality of fish caused by lost or discarded fishing gear.

Ghost pots – Crab pots lost to storms or abandoned at the end of the fishing season.

Groundfish – Fish species that live on or near the bottom.

Groundwater – Underground water, excluding water in pipes, tanks, and other manmade containers.

Growth – A fish's increase in length or weight with time. Also may refer to the increase in numbers of fish in a population over time.

Growth overfishing – When total mortality on the stock causes many fish to be caught at a relatively small size (discarded or landed) such that the potential production of the stock due to individual fish growth (yield-per-recruit) is not realized.

Gyre – A closed circulatory system.

Habitat – A specific type of environment occupied by an organism, a population, or a community.

Harvest – The total number or pounds of fish caught and kept from an area over a period of time. Landings, catch, and harvest are different.

Hazardous substance – Toxic pollutants referenced in, designated in, or pursuant to the Federal Water Pollution Control Act; any substance designated pursuant to the Federal Water Pollution Control Act; or any hazardous waste having the characteristics of those identified within the act or listed.

Hermatypic coral – Reef-building corals that produce hard, calcium carbonate skeletons and possess symbiotic, unicellular algae within their tissues.

Hydroclimatic conditions – Meteorological and hydrological conditions, such as temperature, rainfall, and river flow.

Hydrologic – Of or relating to the properties, distribution, and circulation of water.

Hypersaline – Waters with salinity greater than 40 ppt due to land-derived salts.

Hypoxia – Depressed levels of dissolved oxygen in water. A state of low dissolved oxygen concentration relative to the level required by oxygen-breathing species. Anoxia is the complete absence of oxygen in the water. Organisms that cannot flee oxygen-depleted zones may die if levels drop too low.

Ichthyology – The study of fishes, including their biology, life history, habitat, diversity, and classification.

Impaired Waters List – The list of waters that do not meet state water quality standards. Under the Clean Water Act, Section 303(d), states, territories and authorized tribes are required to develop lists of impaired waters. The law requires that these jurisdictions establish priority rankings of waters on the list and develop TMDLs for these waters.

Impingement – Aquatic organisms too large to pass through the mesh of intake debris screens (usually 1 cm/0.4 in), but unable move away from the intake flow and may be caught against the screens at nuclear power plant condenser cooling systems. If the organisms are trapped for long periods, they will suffocate; if they receive severe abrasions, they will die.

Impoundment – The denial of normal water exchange with the surrounding area in a water body or wetland due to manmade impediments (e.g., dikes, dams, weirs, and other water control structures).

Indigenous species – A species that evolved and occurs naturally in a given geographic area.

Individual transferable quote (ITQ) – A form of limited entry that gives private property rights to fisherman by assigning a fixed share of the catch to each fisherman. Sometimes referred to as an individual fishing quota (IFQ).

Industrial fishery – A fishery for a species not directly used for human food. An example is menhaden.

Industrial wastewater – Water that has been used and contains pollutants but does not contain significant amounts of human waste and disease-causing bacteria and viruses.

Inland water body – Inshore saltwater and brackish water bodies such as bays, estuaries, and sounds, not including inland freshwater areas.

Inner shelf – The continental shelf from the mean low tide to a depth of 20 meters.

Input controls – Limitations on the amount of fishing effort; restrictions on the number, type, and size of fishing vessels of fishing gear or fishing areas; or restrictions on the allowable times for fishing.

Inquiline – An animal that lives in close association with another animal without harming it (e.g., living shells that provide habitat or shelter for other animals).

Interannual climate variability – Variability of meteorological conditions between years.

Intraseasonal climate variability – Variability of meteorological conditions within a season.

Insemination rate – Proportion of females in the blue crab population that mated successfully during their terminal molt.

Instar – Instar is the hard-shell stage between molts when a crab is not increasing in size. Crabs increase shell size when old shells are molted (shed) and new shells are soft and expandable.

Introduced species – Species that have been intentionally or inadvertently brought into a region or area. Also called exotic species.

Invertebrate – Animals without a backbone (jellyfish, octopus, and sponges are examples of marine invertebrates). In fishery management terms, invertebrate generally refers to shellfish (e.g., lobsters, shrimp, oysters, and clams) for which significant fisheries exist.

Isobath – A contour mapping line that indicates a specified constant depth.

Jackknifing – A parameter estimation procedure. The most common jackknife method for sample surveys is to delete one primary sampling unit (PSU) at a time (a PSU can contain a cluster for correlated data) from the original sample of size *n*, and then calculate the statistic (e.g., the mean) for all subsamples of size *n*-1. The values from these subsamples are then pooled (by calculating the mean, for example) to obtain a final estimate; they are used to quantify the variance.

Juvenile – Strictly, a juvenile is any member of a species that is not yet sexually mature. In the context of many surveys, however, it is most often used interchangeably with young-of-year (YOY).

Keystone species – A predator at the top of a food web (or a discrete subweb) capable of consuming organisms of more than one trophic level below.

Land subsidence – A local mass movement that involves principally the gradual downward settling or sinking of the earth's surface with little or no horizontal movement (American Geological Institute, 1974).

Landings – The number or poundage of fish unloaded at a dock by commercial fishermen or brought to shore by recreational fishermen for personal use. Landings are reported at the places where fish are brought to shore. Landings, catch, and harvest define different things.

Length frequency – A breakdown of the different lengths of a kind of fish in a population or sample.

Length-weight relationship – Mathematical formula for the weight of a fish in terms of its length. When only one parameter is known, the scientist can use this formula to determine the other.

Limit reference points – Benchmarks used to indicate when harvests should be constrained substantially so that the stock remains within safe biological limits. The probability of exceeding limits should be low. In much of the National Standards Guidelines, limits are referred to as thresholds. In much of the international literature (e.g., Food and Agriculture Organization documents), "thresholds" are used as buffer points that signal when a limit is being approached.

Limited entry – A program that changes a common property resource, such as fish, into private property for individual fishermen. License limitation and the individual transferable quota (ITQ) are two forms of limited entry.

Linear regression model – A model relating a random variable (Y) to one or more independent variables (X_1, X_2. . . X_p) so that the relationship is "linear in the parameters." For example, a simple model would be Y = mX + b + e where m is the slope of the straight-line relationship between Y and X, b is the intercept term, and e is the random noise term. The two coefficients, m and b, are model parameters.

Littoral – Pertaining to the ocean benthic environment or depth zone between high water and low water

(American Geological Institute, 1974).

Macroalgae – Algal plants sufficiently large (either as individuals or communities) to be readily visible without optical magnification.

Mariculture – The raising of marine finfish or shellfish with some controls. Ponds, pens, tanks, or other containers may be used; feed is often used. A hatchery is also mariculture but the fish are released prior to reaching harvest size.

Marine – Of, pertaining to, living in, or related to the seas or ocean.

Marine Protected Areas (MPAs) – According to Executive Order 13158: any area of the marine environment reserved by federal, state, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein (see marine reserves).

Marine Recreational Fisheries Statistics Survey (MRFSS) – An annual survey by the National Marine Fisheries Service to estimate the number, catch, and effort of recreational fishermen, serving as a basis for parts of fishery management plans.

Marine reserves – Geographically defined space in the marine environment where special restrictions protect some aspect of the marine ecosystem including plants, animals, and natural habitats (see marine protected areas).

Mark-recapture – The tagging and release of fish for later recapture. These studies investigate fish movement, migration, mortality, and growth, and estimate population size.

Marshes – Persistent, emergent, non-forested wetlands characterized by vegetation consisting predominantly of cordgrasses, rushes, and cattails.

Maximum economic yield (MEY) – The total amount of profit that could be earned from a fishery if owned by an individual.

Maximum sustainable yield (MSY) – A management goal specifying the largest long-term average catch or yield (in terms of the weight of fish) that can be taken continuously (sustainably) from a stock or stock complex under prevailing ecological and environmental conditions, without reducing the size of the population.

Megalopae – A post-larval blue crab.

MELSY (Maximum expected log stationary yield) – Maximum statistical expectation of the logarithm of long-term yield, considering uncertainties in parameter values and natural (process) variability.

Mercury – A naturally occurring element that is released into the environment by human activities, including waste incineration, coal burning, and mining. Mercury constitutes an ongoing public health concern due to its high toxicity. Exposure to high levels can permanently damage the brain and kidneys as well as a developing fetus. Fish consumption constutes one of the most important exposure routes for humans. Mercury bioaccumulates, meaning that top predators, such as sharks and swordfish, have higher levels in their tissues than fish feeding at lower trophic levels.

Meristics – A series of measurements on a fish, such as scale counts, spine counts, or fin ray counts that is used to separate different populations or races of fish.

Mesohaline – Pertaining to moderately brackish water with low salinities (from 5 to 18 ppt).

Mesopelagic – Of or relating to oceanic depths from about 200 to 1000 meters.

Mesotrophic – Describes an aquatic system characterized by moderate nutrient levels, which is intermediate to eutrophic (nutrient-enriched) systems and oligotrophic (nutrient-poor) systems.

MESY (Maximum expected stationary yield) – Maximum statistical expectation of long-term yield, considering uncertainties in parameter values and natural (process) variability.

Meta-Analysis – A statistical approach to combine information from several experiments or research studies that used different methods, tested different (but related) hypotheses, and utilized different experimental designs. The intent is to develop an overall consensus or conclusion from experiments that might have yielded conflicting results individually.

Metric ton – The unit of measurement often used for commercial and recreational landings, equal to 1000 kilograms, 0.984 long tons, 1.1023 short tons, or 2204.6 pounds.

Microorganism – An organism requiring magnification to see or study (microscopic).

Midden – An accumulation of refuse about a dwelling place; especially, an accumulation of shells or of cinders, bones, and other refuse on the supposed dwelling sites of prehistoric tribes.

Migratory – Groups of organisms that move from one habitat to another on a regular or seasonal basis.

Minimax/maximin criteria – A means of examining uncertainty and making decisions by including explicit statements of the probabilities of alternative outcomes. Relative values (and losses or "regrets") are assigned to each possible outcome under each possible decision. The maximin values criterion selects the decision with the largest minimum value of the outcome. The minimax criterion selects the smallest maximum "regret" due to the outcome of a decision.

Model – In fisheries science, a description of relationships or a condition that cannot be directly observed. Often, a set of equations and data used to make estimates.

Mollusk – The invertebrate phylum that contains bivalves (e.g., oysters), gastropods (e.g., snails), and squids.

Molt – To shed the exoskeleton (outer covering) prior to new growth.

National Marine Fisheries Service (NMFS) A federal agency with scientists, research vessels, and a data collection division responsible for managing the nation's saltwater fish.

It oversees the actions of the councils under the Fishery Conservation and Management Act.

National standards – The Fishery Conservation and Management Act requires that a fishery management plan and its regulations meet ten national standards that identify the nation's interest in fish management.

Native species – Species that occur naturally in a particular region or area.

Natural mortality (M) – The rate of removal of an organism from a population due to natural causes (disease, predation, old age). The fish dying during the year expressed as the fraction of the fish alive at the beginning of the year.

Nepheloid layer – A layer of water near the bottom that contains significant amounts of suspended sediments.

Neritic – Ocean zone extending from the mean low tide to the edge of the continental shelf.

Niche – The specific ecological role of an organism in the life of the community and its position in the ecosystem.

Nitrification – The process by which bacterial populations under aerobic conditions gradually oxidize ammonium to nitrate with the intermediate formation of nitrite. Biological nitrification is a key step in nitrogen removal during wastewater treatment.

Nitrogen (N) – A nonmetallic element used primarily by plants and animals to synthesize protein. Nitrogen enters the ecosystem in several chemical forms and also occurs in other dissolved or particulate forms, such as in the tissues of living and dead organisms.

Nominal fishing effort (f) – Fishing effort measured in time (days fished) and number of gear units (e.g., number of pots).

No Net Loss – Federal policy to protect wetlands regulated under the Clean Water Act. Wetland losses must be offset by wetland gains.

Nonpoint source – A diffuse source of pollution that cannot be attributed to a clearly identifiable, specific physical location or a defined discharge channel. This type of pollution includes nutrient runoff from any land use—croplands, feedlots, lawns, parking lots, streets, forests as well as nutrients that enter the water through air pollution, from groundwater, or through septic systems.

Non-resource species – Species that are not part of fisheries management but which are impacted by changes in management. For example, birds relying on a managed species as a food resource are affected by changes in the stock status as well as by specific decisions to manage the stock.

Nursery – That part of a fish's or animal's habitat where the young grow up.

Nutrients – Compounds of nitrogen and phosphorus dissolved in water that are essential to both plants and animals. Too much nitrogen and phosphorus, however, leads to unwanted consequences—primarily algae blooms that cloud the water and rob it of oxygen critical to most forms of aquatic life. Wastewater treatment plants, industries, vehicle exhaust, acid rain, and runoff from agricultural, residential, and urban areas are sources of nutrients entering the Bay.

Ocean – In fisheries management, a combination of the State Territorial Sea and the Federal Exclusive Economic Zone (EEZ).

Oligohaline – Water with salinity of 0.5 to 5 ppt due to ocean-derived salts.

Oligotrophic – Water bodies or habitats with low concentrations of nutrients.

Omnivore – Organisms that eats both plants and animals.

Open access – A state of affairs occurring when no property rights systems constrain access to a resource or withdrawals of resource units (typically for a natural resource).

Open access fishery – A fishery in which any person can participate at any time.

Optimum yield – The optimum biomass that a fisheries stock is theoretically capable of yielding without collapse.

Organic – Of, relating to, or containing carbon compounds.

Output controls – Limitations on the weight of the catch (a quota), or the allowable size, sex, or reproductive condition of individuals in the catch.

Overcapitalization – When harvesters invest in and deploy more fishing gear than what is necessary to harvest a given amount of crabs (for example, when a harvester enters the fishery using 100 pots to catch 20 bushels of crabs, later increasing his investment to 200 pots but still catching only 20 bushels of crabs).

Overfished – An overfished stock or stock complex is one “whose size is sufficiently small that a change in management practices is required in order to achieve an appropriate level and rate of rebuilding.” A stock or stock complex is overfished when its size falls below the minimum stock size threshold (MSST). Overfished stocks require a rebuilding plan.

Overfishing – Harvesting at a rate or level that jeopardizes the capacity of a stock or stock complex to produce maximum sustainable yield on a continuing basis (NMFS 1996).

Palustrine – Being, living, or thriving in a marsh.

Pangea – Postulated former supercontinent composed of the entire continental crust of the earth that later fragmented into Laurasia and Gondwana through continental movement.

Parameters – Numerical characteristics of populations. Parameters are values, usually unknown (and which, therefore, have to be estimated), used to represent certain population characteristics. Within a population, a parameter is a fixed value.

Parasite – A plant or animal living on or in an organism of another species from which it derives nutrition and/or protection, often with harmful effects to the host.

Partial recruitment – Patterns of relative vulnerability of fish of different sizes or ages due to the combined effects of selectivity and availability.

Passive gear – Gear that requires the animal to enter voluntarily (as opposed to active gears such as trawls and dredges which move to trap animals and prevent them from escaping).

Pelagic – The open ocean, excluding the ocean bottom and shore.

pH – The negative logarithm of the effective hydrogen ion concentration or hydrogen ion activity in gram equivalents per liter used in expressing both acidity and alkalinity on a scale with values running from 0 to 14 (7 represents neutrality; numbers under 7 represent increasing acidity; numbers over 7 represent increasing alkalinity).

Phosphorus (P) – A key nutrient in the Bay's ecosystem, phosphorus occurs in dissolved organic and inorganic forms, often attached to particles of sediment. It is a vital component in the process of converting sunlight into usable energy forms for production of food and fiber. Inorganic phosphates are preferred, but organisms will use other forms of phosphorus when phosphates are unavailable.

Photic zone – The layer in a water body that receives ample sunlight for photosynthesis.

Photosynthesis – The process by which plants convert carbon dioxide and water into carbohydrates and oxygen. The carbohydrates are then available for use as energy by the plant or other consuming organisms. ($CO_2 + H_2O + \text{Sunlight} = C_6H_{12}O_6 + O_2$). Also known as primary production.

Phytoplankton – Tiny, free-floating, photosynthetic organisms in aquatic systems usually suspended in the water column, including diatoms, desmids, and dinoflagellates.

Piedmont – Uplands or hill country above the fall line of coastal rivers where rapids or cataracts descend to the level topography where tidal influence begins. In the United States, the Piedmont is the physiographic province east of the Appalachians.

Plankton – Small or microscopic algae and organisms associated with surface water and the water column.

Point source – A distinct and identifiable source, such as a sewer or industrial outfall pipe, from which a pollutant is discharged.

Pollutant – Any substance that may alter or interfere with the restoration or maintenance of the chemical, physical, radiological, and biological integrity of an area, including dredge spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemicals, chemical wastes, hazardous wastes, biological and radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, oil, gasoline and related petroleum products, and industrial, municipal, and agricultural wastes.

Polyhaline – Pertaining to waters with salinities from 18 to 30 ppt.

Population – All individuals of the same species occupying a defined area during a given time.

Population dynamics – The study of fish populations and how fishing mortality, growth, recruitment, and natural mortality affect them.

Population structure – Composition of a population in terms of size, stock (genetic or regional), age class, sex, or other variable.

Possession limit – The number and/ or size of a species that a person can legally have at any one time. Refers to commercial and recreational fishermen. Possession limits generally do not apply to the wholesale market level and beyond.

ppt – Parts per thousand

Precautionary approach – An approach to fishery management that exercises prudent forethought to avoid undesirable outcomes with respect to stock status, yield potential, or profitability. The precautionary approach recognizes that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to changing environment and human values.

Predator – Organism that hunts and eats other organisms, including both carnivores and herbivores.

Predator-prey relationship – The interaction between one species (the predator) and the species it consumes (the prey).

Prey – Organism hunted and eaten by a predator.

Primary producers – Organisms, such as algae, that convert solar energy to organic substances through chlorophyll. Primary producers serve as food sources for higher organisms.

Primary production – Creation of organic matter by plants through photosynthesis (using inorganic carbon, nutrients, and an external energy source) to form the base of the food chain.

Probabilistic risk analysis – An analysis in which various scenarios are simulated and the results observed. Used to determine the likelihood of different outcomes under different management schemes.

Pulse fishing – Harvesting a stock of fish, then moving on to other stocks or waiting until the original stock recovers.

Put-and-take fishery – The placing of hatchery-raised fish in waters for angling by fishermen. Few marine fisheries fit this description; most cases occur in inland streams and lakes.

Pycnocline – A layer in a water body characterized by a rapid change of density with depth.

Quota – The maximum number of fish that can be legally landed during a time period. It can apply to the total fishery or an individual fisherman's share under an Individual Transferable Quote (ITQ) system. Can also refer to fish size.

Radiatively active gases – While often referred to as "greenhouse" gases, this analogy is not technically correct. Gases such as carbon dioxide and methane are "radiatively active" since they are transparent to earthbound short-wave radiation produced by the sun, but not to long-wave radiation re-radiated skyward from a sun-warmed earth. As radiatively active gases accumulate, the atmosphere becomes less transparent to outgoing radiation with resultant heat buildup. This phenomenon is inconsistent with the greenhouse analogy because the relative warmth that builds within a greenhouse depends primarily on the glass walls preventing evaporative cooling and the advection of heat stored in warm air and water vapor.

Range – The entire geographic area where a species is known to occur or to have occurred.

Rebuilding plan – A plan designed to recover stocks to the B_{MSY} level within ten years when they are overfished (i.e., when B < MSST). Normally, the ten years would refer to an expected time of rebuilding in a probabilistic sense.

Recent catch – In the context of the FEP, refers to the average catch during a time period for which evidence of stable abundance exists. As this type of information is unlikely to be available in many data-poor cases, scientist could carefully consider defining recent catch as the median catch during the last five, ten, or 15 years.

Recreational fishery – Harvesting fish for personal use, fun, and challenge; does not include sale of a catch. The term includes the fishery resources, fishermen, and businesses providing needed goods and services.

Recruit – An individual fish that has moved into a certain class, such as the spawning class or fishing-size class.

Recruitment – A measure of the weight or number of fish that enter a defined portion of the stock such as fishable stock (those fish above the minimum legal size) or spawning stock (those fish which are sexually mature).

Recruitment overfishing – When fishing mortality reaches a level at which removals from a stock are so high and its spawning capacity so diminished that fewer and fewer juveniles are produced.

Red tide – A dense outburst of phytoplankton (usually dinoflagellates) often coloring the water red-brown.

Reef fish complex – Used by the Gulf of Mexico Fishery Management Council to describe the many species of fish found around natural reefs, artificial reefs, ledges, and mud lumps.

Reference points – Values of parameters (e.g., B_{MSY}, F_{MSY}, $F_{0.1}$) that are useful benchmarks for guiding management decisions. Biological reference points are typically limits that should not be exceeded with significant probability (e.g., MSST) or targets for management. (e.g., optimum yield (OY)).

Regime shift – Major changes in the levels of productivity and reorganization of ecological relationships over vast oceanic regions potentially caused by various factors including climate variability or overfishing.

Relative abundance – An index of fish population abundance used to compare fish populations from year to year without measuring the actual number of fish, but showing changes in the population over time.

Relict – A persistent relief feature of an otherwise extant flora or fauna or kind of organism.

Relief – The difference in elevation between the high and low points of a surface.

Resident – Species that are permanent living members of a particular area.

Resilience – The ability of a population or ecosystem to withstand change and recover from stress (natural or anthropogenic).

Riparian – Relating to, living, or located on the bank of a natural waterway.

Riparian forest buffers – An area of trees, usually accompanied by shrubs and other vegetation adjacent to a water body and managed to: maintain the integrity of stream channels and shorelines; reduce the impact of upland sources of pollution by trapping, filtering, and converting sediments, nutrients, and other chemicals; and supply food, cover, and thermal protection to fish and other wildlife.

Risk – The probability of something undesirable happening.

Robust – A model is robust to changes if results obtained from a model do not vary with changes to the model. These changes could be either the input data or parameters.

Roe – Fish eggs, especially while still massed in the ovarian membrane; caviar.

Salinity – The total amount of solid material in grams contained in 1 kg of water when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all the organic matter completely oxidized.

Salt marsh – A coastal habitat consisting of salt-resistant plants residing in an organic-rich sediment accreting toward sea level. (American Geological Institute, 1974).

Saltwater intrusion – Phenomenon occurring when salt water invades fresh water because of its greater density; occurs in either surface or groundwater sources.

Sampling variability – A sample taken from a population is only a subset of that population. If taken according to sound statistical principles, it represents the population. Since samples are only subsets, different samples lead to different values for the quantities being estimated with the variability among estimates known as sampling variability.

Scute – Large, dermal, keratinous plates (e.g., the bony armor of a sturgeon).

Sediment – Material transported and deposited by water, wind, glacier, precipitation, or gravity; a mass of deposited material.

Sedimentation – Accumulation of sediment, often occurring in aquatic environments as the velocity of flowing water carrying sediment slows. Can also occur when plant matter accumulates in quiet waters, on marsh surfaces, or on land.

Selectivity – The ability of a type of gear to catch a certain size or kind of fish, compared with its ability to catch other sizes or kinds.

Sessile – Permanently attached or established; not free to move about.

Shellfish – General term for crustaceans and mollusks.

Shell plant – Shell placed on the bottom as substrate for oyster habitat.

Significant food web – Predator/prey interactions important to either the predator or prey population.

Siltation – The deposition of silt suspended in a body of water.

Simulation – An analysis that shows the production and harvest of fish using a group of equations to represent the fisherman and can predict events in the fishery if certain factors are changed.

Size class – Crabs within close size of each other and presumably close in age.

Size distribution – A breakdown of the number of fish of various sizes in a sample or catch. The sizes can be in length or weight and are most often displayed on a chart.

Sludge – The solid or semi-solid material removed from wastewater during treatment, including but not limited to grit, screenings, grease, oil, settleable solids, and chemicals added to the treatment processes.

Social impacts – The changes in people, families, and communities resulting from a fishery management decision.

Socioeconomics – Identifies the importance of factors other than biology in fishery management decisions, such as how an income surplus is distributed between small and large boats or part-time and full-time fishermen.

Softshell phase – The time immediately after a crab molts when the new shell is soft and expandable.

Source-sink population dynamics – The demographic (i.e., births, deaths, immigration, emigration) differences between sub-populations residing in habitats differing in quality. For a given species, habitats of good quality yield a demographic surplus (births + emigrants > deaths + immigrants) and are classified as “source” habitats. Habitats of poor quality yield a demographic deficit, are classified as sinks,” and may not persist without immigration from “source” habitats.

Spat – Juvenile, newly attached oysters.

Spawn – To release eggs and/or sperm into the water.

Spawner-recruitment relationship – The concept that the number of young fish (recruits) entering a population is related to the number of parent fish (spawners).

Spawning potential ratio (SPR) – The number of eggs that could be produced by an average recruit in a fished stock divided by the number of eggs that could be produced by an average recruit in an unfished stock. Can also be expressed as the spawning stock biomass per recruit (SSBR) of a fished stock divided by the SSBR of the stock before it was fished.

Spawning stock – All females that survive natural and fishing mortality to reproduce.

Spawning stock biomass (SSB) – Total weight of fish in a stock that are old enough to spawn.

Spawning stock biomass per recruit (SSBR) The spawning stock biomass divided by the number of recruits to the stock or how much spawning biomass an average recruit would be expected to produce.

Species – A population or group of populations that are in reproductive contact but are reproductively isolated from all other populations.

Spermatheca – A receptacle on the underside of female crabs for receiving and holding sperm for later use in fertilizing eggs.

Sport fishery – See recreational fishery.

Sprawl – A form of land development that moves outward from urban areas in a manner that creates large areas of relatively low density.

Standard error of the estimate – When a data set is obtained from sampling, it is used to calculate estimates of the quantities of interest. The estimators are themselves random, since they are based on a sample rather than complete knowledge of the population. As a result, the estimates will vary from sample to sample as well as with the measure of that variability known as sampling error. This type of error can be calculated when the sample has been collected according to accepted statistical sampling methods.

Standardized data – Generally refers to the transformation of data from different sources to a common scale. In this context, it refers to standardizing data collected by different gear or methods to a common scale. For example, if one gear collects on average 80 percent of the biomass collected by different gear, then multiplying the raw estimates obtained from the first gear by 1.25 would standardize biomass estimates to a common scale.

Standardization factors – Factors used to standardize estimates of biomass, abundance, or other characteristics of the population based on different gear or collection methods.

Standing stock – The total weight of several organisms, or population of a species, in the geographic unit of interest.

State territorial seas – The zone extending three nautical miles from shore for all states except Puerto Rico and the gulf coast of Florida where the seaward boundary is three marine leagues (approximately ten statute miles).

State waters – The combination of inland and state territorial seas.

States of nature – A description of the condition and dynamics of the resource and the fishery including parameters such as stock abundance, age structure, fishing mortality, economic condition of the industry, and the state of the environment.

Statistical uncertainty – Stochastic error or variability from one or more sources that can be described by statistical methodology.

Status determination criteria (SDC) – Objective and measurable criteria to determine if a stock is being overfished or is in an overfished state according to national standard guidelines.

Stressed area – An area of special concern regarding harvest, perhaps because the fish are small or because harvesters are in conflict.

Stochastic – Involving or containing a random variable or variables; involving chance or probability.

Stock – An interbreeding sub-population of a species, reproductively isolated to some extent from other populations. Used as a unit for fishery management, however, "stock" refers to a specific population or group of populations of one or more species.

Stock assessment – An evaluation of a stock in terms of abundance and fishing mortality levels and trends, and relative to fishery management objectives and constraints if specified.

Stormflow – Rainfall runoff that reaches a stream channel during, or soon after, a precipitation event that causes high rates of discharge.

Submerged aquatic vegetation (SAV) – Rooted vegetation that grows underwater in shallow zones where light penetrates. Also known as bay grasses.

Substrate – The base upon which an organism lives.

Subtidal – Submerged; not exposed at the lowest tide.

Surplus production – Total weight of fish that can be removed by fishing without changing the size of the population. Calculated as the sum of the growth (in weight of individuals) in a population, plus the biomass from new recruits, minus the biomass of animals lost to natural mortality during a defined period (usually one year).

Surplus production model – A model that estimates the catch in a given year and the change in stock size. The stock size could increase or decrease depending on new recruits and natural mortality. A surplus production model estimates the natural increase in fish weight or the sustainable yield.

Survival Ratios – Ratios of recruits to spawners (or spawning biomass) in a stock-recruitment analysis.

Sustainability – A community's control and prudent use of natural, human, manmade, social, and cultural capital to foster economic security and vitality, social and political democracy, and ecological integrity for present and future generations. Ecological sustainability more narrowly focuses on maintaining and enhancing ecological integrity and biodiversity, and generally on protecting the life-support and waste-sink functions of the earth.

Sustainable Fisheries Act (also the Magnuson-Stevens Act) – The 1996

Sustainable Fisheries Act amended the habitat provisions of the Magnuson Act. The re-named Magnuson-Stevens Act calls for direct action to stop or reverse the continued loss of fish habitats. Toward this end, Congress mandated the identification of habitats essential to managed species and measures to conserve and enhance these habitats. The act requires cooperation among NOAA fisheries, regional fishery management councils, fishing participants, and federal and state agencies to protect, conserve, and enhance essential fish habitat.

Swamp – A wetland dominated by woody vegetation.

Swim bladder – An organ regulating the buoyancy in most teleost (bony) fish.

Target (biological reference point) – Benchmarks to guide management objectives for achieving a desirable outcome (e.g., OY). Provide a precautionary safeguard to prevent exceeding the threshold. Provide desired levels of harvest of stock size that afford the greatest potential benefit to harvesters. Target reference points should not be exceeded on average.

Target species – Those fish explicitly sought by fishermen to meet social and economic needs. Their catch is the direct consequences of targeted fishing effort.

Technical interactions – Spatial orientations of different species that lead to bycatch (capture of non-target species) in a fishery; when gears directed primarily at one species also catch other species; when different life stages of one species are caught using different gear types.

Terminal molt – Last molt in female blue crabs that precedes maturity.

Terrestrial – Living on land.

Terrigenous – Derived from or originating on land (usually referring to sediments) as opposed to material produced in the ocean (marine) or from biological activity (biogenous).

Territorial sea – The area from the average low-water mark on the shore extending to three miles for the states of Louisiana, Alabama, and Mississippi and to nine miles for Texas and the west coast of Florida. The shore is not always the baseline from which the three miles are measured. In such cases, the outer limit can extend further than three miles from the shore.

Thermally stratified – The condition when warmer surface waters overlay cooler bottom waters, generally occuring in warm, low-wind conditions that typically prevail during summer.

Threshold (biological reference point) – In fishery science, represents a theoretical limit above which the basic sustainability of the species becomes threatened. On the safe side of this threshold, stocks or harvests can reasonably be expected to maintain a healthy, reproductive fishery; on the other side, lies the risk of stock collapse.

Tides – Periodic movement of water resulting from gravitational attraction among the earth, sun, and moon.

Top-down control – Refers to situations in which the structure (abundance, distribution, and/or diversity) of lower trophic levels depends directly or indirectly on trophic activities of higher trophic levels.

Topography – The configuration of a surface including its relief and the position of its natural and manmade features.

Topological analysis – An instrument to determine the structure of particular trophic groups in the food web that illustrates the degree of connectivity between a particular species or trophic group and its predators and prey.

Total allowable catch – The annual catch from a stock allowed under fishery management regulations.

Total length – The length of a fish measured from the tip of the snout to the tip of the tail.

Total maximum daily load (TMDL) – The amount of a contaminant from all sources (natural and man-induced) that may occur in a water body without causing impairment of the designated uses of the water body.

Total mortality (Z) – A measurement of the rate of removal of fish from a population by both fishing and natural causes (either annual or instantaneous).

Total removals – The aggregate weight and number of fish and shellfish from a specified system that are landed or die from fishing. Estimates of total removals must account for the total catch (landings, bycatch, and discard) from all fishing sectors (commercial and recreational).

Toxicant – A poisonous or toxic agent that is harmful to plants or animals.

Trend analysis – A formal statistical process for determining the presence or absence of changes in the measures of water quality over time or over a geographic area.

Tributary – A stream that joins or flows into a larger stream or lake.

Trophic level – Layer in the food chain in which one group of organisms comprises the nutrition source for another group.

Trophic web – The network that represents the predator/prey interactions of an ecosystem.

Turbidity – Reduced clarity due to suspended matter in the water.

Uncertainty – Results from a lack of perfect knowledge of many factors that affect stock assessments, estimation of reference points, and management. Five types of uncertainty exist: measurement error, process error, model error, estimation error, and implementation error.

Underutilized species – A species of fish with the potential for additional harvest.

Unit stock – A population of fish grouped for assessment purposes, which may or may not include all fish in a stock.

Upland – Any land area other than wetland.

Vertebrate – Animals with a backbone including fish, amphibians, reptiles, birds, and mammals.

Yield per recruit (YPR) – Amount of per capita yield obtained at a given value of F, conditional on values of partial recruitment, growth, and natural mortality.

Virgin stock biomass (B_0) – A stock of fish with no commercial or recreational harvest. A virgin stock changes only in relation to environmental factors and its own growth, recruitment, and natural mortality.

Virtual population analysis (VPA) – An age-based assessment model that uses fisheries-dependent and fisheries-independent data to estimate fishing mortality rates and stock size. The analysis uses the number of fish caught at various ages or lengths and an estimate of natural mortality to estimate fishing mortality in a cohort. It also provides an estimate of the number of fish in a cohort at various ages.

Wastewater – Waters removed from their normal course or place and used in a manner such that pollutants have been added or increased during their use or altered so that discharge into a body of water may result in pollution.

Watershed – A region bounded at the periphery by physical barriers that cause water to part and ultimately drain to a particular body of water.

Wet deposition – Atmospheric deposition that occurs when precipitation (rain or snow) carries gases and particles to the earth's surface.

Wetlands – Areas that contain much soil moisture or are inundated by surface or groundwater with a frequency sufficient to support a prevalence of vegetative or aquatic life requiring saturated or seasonally saturated soil conditions for growth and reproduction.

Year class – All of the fish of any species hatched during an annual spawning period constitute a year class. For mathematical purposes, fishery analysts often treat members of the year class as if all fish hatched on one day.

Yield – The production from a fishery in terms of numbers or weight.

Yield per recruit (Y/R) – Analysis of how growth and natural mortality interact to determine the best size of animals to harvest; the expected lifetime yield-per-fish of a specific age. For a given exploitation pattern, fishing regime, rate of growth, and natural mortality, an expected equilibrium value of Y/R can be calculated for each level of fishing mortality (F).

Young-of-the-year – All of the fish of a species younger than one year of age. Usually scientists assign an arbitrary "birth date" to all fish of a species hatched over a two- or three-month period in one year. The fish are then assigned to age 1 status on that birth date. By convention, this date is usually January 1.

Zoea – Blue crab larvae

Zooplankton – A community of floating, often microscopic animals that inhabit aquatic environments. Unlike phytoplankton, zooplankton cannot produce their own food and are consumers.

Biographical Sketches of FEP Panel

Dr. Herbert M. Austin is a professor of marine science at the Virginia Institute of Marine Science College of William and Mary in Gloucester Point. Austin has been with VIMS for over 25 years, having come to the Fisheries Department of VIMS from the National Marine Fisheries Service in Washington, D.C. He has served on the Management and Science Committee of the Atlantic States Marine Fisheries Commission, the Scientific and Statistic Committee of the Mid-Atlantic Fisheries Management Council, and various advisory panels for the Potomac River Fisheries Commission and the Virginia Marine Resources Commission. His research interests include the Virginia juvenile finfish surveys (the "trawl survey" and young-of-year striped bass and bluefish surveys) and assessing how climate variation affects fishery recruitment patterns.

Christopher F. Bonzek is a member of the professional faculty in the Department of Fisheries Science at the Virginia Institute of Marine Science, serving as a fisheries data analyst. He received a B.S. in biology from the University of Massachusetts at Dartmouth (1977) and an M.S. in zoology from North Carolina State University (1983). From 1981 until 1989, he worked in the Fisheries Division (now the Fisheries Service) at the Maryland Department of Natural Resources; he has worked at VIMS since that time. Bonzek specializes in the methodology, data handling, and analytical aspects of fishery monitoring surveys. His current work assures that monitoring surveys are designed and prosecuted such that they directly support analytical fish stock assessments. He serves as chair of the Atlantic States Marine Fisheries Commission's (ASMFC) Management and Science Committee and as chair of the Operations Committee of the ASMFC's Northeast Area Monitoring and Assessment Program. This group coordinates existing monitoring programs in the northeast region and develops new surveys to fill data gaps in existing assessments. He is also a long-standing member of the Chesapeake Bay Stock Assessment Committee (CBSAC). Recently, he initiated the Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) Trawl Survey to provide data for development of multispecies management models in the Chesapeake region.

Dr. Denise Breitburg is a senior scientist at the Smithsonian Environmental Research Center, an adjunct professor at the University of Maryland, and a participating faculty member in the Marine Estuarine Environmental Sciences graduate program. Her research integrates aspects of ecology and behavior in studies of the organization, functioning, and human influence on estuarine ecosystems. Breitburg's current research includes experiments on the effects of multiple stressors and food web complexity on estuarine assemblages; field and laboratory studies studying the effects of low dissolved oxygen on food webs, fish, and gelatinous zooplankton; data analyses examining the effects of eutrophication, habitat restoration, and fishing pressure on estuarine fish assemblages; and field and laboratory studies assessing the importance of the spatial arrangement of habitats to population dynamics of gelatinous zooplankton. Dr. Breitburg has served on the governing boards of the American Society of Limnology and Oceanography and Estuarine Research Federation and is a member of the Ecological Society of America. In addition to her participation in developing the Fisheries Ecosystem Planning document, she serves as vice chair of the Scientific and Technical Advisory Committee and has participated in Chesapeake Bay Program subcommittees as well as working and advisory groups. She received a B.S. in biology from Arizona State University and an M.A. and Ph.D. in biology from the University of California, Santa Barbara.

Dr. Mary Christman is a biometrician with experience and interest in statistical modeling of environmental and biological processes—incorporating uncertainty into prediction and forecasting, developing methods to analyze animal movement and use of space, and statistical methods to assess biodiversity. A related area of interest is developing sampling designs that are optimal for accurate estimation. She has worked in several research areas, including modeling of spatial cluster processes and estimation of abundance using classical survey sampling methodology, as well as model-based approaches and applying spatial and mixed models to ecological and environmental research. Examples of some of the models include time series analyses for studying short-term behavior of chlorophyll a in river systems, prediction models for estimating the timing and size of the first brood of economically important insect pests using weather data, spatial models describing the biodiversity of juvenile finfish in the Chesapeake Bay, spatial models for the distribution of cave species in karst areas of the United States, and models for predicting earthquake-induced landslides in southern California using geological information.

Dr. Ratana Chuenpagdee is senior research fellow at the International Ocean Institute—Canada, at Dalhousie University in Halifax, Nova Scotia. She is also a codirector of the Coastal Development Centre Thailand and an adjunct professor at the Fisheries Centre of the University of British Columbia. She was formerly an assistant professor at the Department of

Coastal and Ocean Policy, Virginia Institute of Marine Science and College of William and Mary in Gloucester Point, Virginia. She received a B.S. in marine science from Chulalongkorn University in Bangkok, Thailand; an M.S in fisheries management and economics from Michigan State University; a second M.S. in fisheries biology from the University of North Wales, UK; and a Ph.D. in resource management and environmental studies from University of British Columbia, Vancouver, Canada. Her current research projects include integrated multiple demands in coastal zones, global analysis of small-scale fisheries, community participation in natural resource management, fisheries and coastal governance, and social impact assessment of natural resource policies.

Dr. Edward D. Houde serves as co-chair of the Fisheries Ecosystem Plan Technical Advisory Panel. He earned his Ph.D. in fishery science from Cornell University in 1968 and is currently a professor in the University of Maryland's Center for Environmental Science. His research interests include fisheries science and management, larval fish ecology, and fisheries oceanography. Houde has served previously as director of the National Science Foundation's Biological Oceanography Program. He is the recipient of the Beverton (Fisheries Society of the British Isles) and Sette (American Fisheries Society) awards for career achievement and is a fellow of the American Association for the Advancement of Science and an elected national associate of the National Academy of Sciences. He has served on numerous committees and panels, including the National Research Council's Ocean Studies Board, International Council for the Exploration of the Sea, the Living Resources Committee, the National Marine Fisheries Service Ecosystem Principles Advisory Panel, and as chair of the Ocean Studies Board Committee on marine protected areas.

Dr. Stephen J. Jordan is a supervisory ecologist and chief of the Ecosystem Assessment Branch at the Gulf Ecology Division of the U.S Environmental Protection Agency's Office of Research and Development in Gulf Breeze, Florida. Jordan received a Ph.D. in Marine, Estuarine, and Environmental Science at the University of Maryland in 1987. From 1985 to 2002, he was employed by the Maryland Department of Natural Resources, most recently as director of the Sarbanes Cooperative Oxford Laboratory. His principal research interests are the ecology of large coastal ecosystems and the application of ecological information in management. He has been author, co-author, or editor of numerous publications and technical reports. He chaired the Chesapeake Bay Living Resources Monitoring and Ecologically Valuable Species workgroups, the Maryland Oyster Roundtable Scientific Committee, and was a member of several other Bay committees, workgroups, and task forces. He served as president of the Estuaries Section of the American Fisheries Society (2003–2005). Jordan is a long-time member of the National Shellfisheries Association and the Estuarine Research Federation. He has received awards and citations from the Chesapeake Bay Program, Maryland Department of Natural Resources, Governor of Maryland, U.S. Senate, and Sigma Xi.

Dr. James E. Kirkley is a professor and chair of the Department of Coastal and Ocean Policy at the College of William and Mary. Kirkley holds a Ph.D. in agricultural and resource economics from the University of Maryland. His background and experience include analysis of technical and economic efficiency in fisheries, economic analysis in support of state and federal fisheries management throughout the mid-Atlantic and northeastern United States, economic impact analysis of fisheries management and regulation and coastal economic development, and community impact assessment of fisheries management and regulation. Recently completed projects include an assessment of the economic impacts of new quotas and essential fish habitat protections for the surf clam and ocean quahog fishery and estimation and analysis of over-capacity in five federally managed fisheries. Ongoing work includes the assessment of community and economic impacts associated with highly migratory species management, design and development of a buyback program for the northwest Atlantic sea scallop fishery, development of an economic impact model to assess the economic importance of U.S. commercial fisheries to the country, and development of a framework to assess the economic contributions of commercial fisheries to the mid-Atlantic region.

Dr. Lisa Kline (now Lisa Desfosse) received her B.S. in marine science from Millersville University of Pennsylvania in 1983 and her Ph.D. from the Virginia Institute of Marine Science, College of William and Mary in 1990. She accepted a position as a research statistician with the Maryland Department of Natural Resources in 1990. Research conducted at the department included serving as co-principal investigator on a project to evaluate the early life history, growth, and mortality of striped bass, assisting with the Maryland striped bass recreational statistics survey and conducting studies to evaluate the growth and mortality of adult striped bass and American eel. In 1993, Kline became the recreational fisheries statistics coordinator with the Atlantic States Marine Fisheries Commission (ASMFC) and was promoted to director of research and statistics with the ASMFC in 1995. At present, major projects through the ASMFC Research and Statistics Program include multispecies assessments to evaluate interactions between Atlantic menhaden and key predator species (striped bass, bluefish, weakfish), coastwide assessment of the cumulative impacts of power plant impingement and entrainment on Atlantic menhaden, oversight of the ASMFC stock assessment peer review process; assessment of and technical support for the ASMFC's Interstate Fisheries Management Program, coordination of coastwide fisheries-independent data collection activities, integration of social and economic information into the ASMFC's Interstate Fisheries Management Program; coordination of Atlantic coast scientific and angler-based tagging programs, and development of scientific standards and protocols (e.g., state aquaculture guidance, fish aging methods). In 2004, she became the national cooperative research coordinator with the National Marine Fisheries Service and in 2005 she accepted the position of team leader of the NMFS National Observer Program.

Dr. Robert J. Latour is an assistant professor at the Virginia Institute of Marine Science (VIMS) in Gloucester Point, Virginia. He received a B.A. in mathematics in 1994 from Western New England College in Springfield, Massachusetts and an M.BMA (1996, Biomathematics) and Ph.D (2000, Biomathematics) from North Carolina State University in Raleigh, North Carolina. From 2000 to 2001, he was a postdoctoral research associate in the Anadromous Fishes Program at VIMS. Latour's research interests are diverse, but typically involve the use of modeling techniques (both mechanistic and descriptive) to understand fish population dynamics and develop management strategies for exploited marine resources. Current research projects include development of a multispecies trophodynamic model to support sustainable fisheries management in Chesapeake Bay; design and implementation of Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP); and stock assessment and population monitoring of American shad and striped bass in the Bay. Latour currently serves as a member of several Atlantic States Marine Fisheries Committees and teaches in the School of Marine Science at VIMS.

Dr. Romuald N. Lipcius is professor of marine science at the Virginia Institute of Marine Science of the College of William and Mary. He received a B.S. in zoology from the University of Rhode Island (1976), and a Ph.D. in biological science from Florida State University (1984). From 1984 to 1985, he was a postdoctoral fellow at the Smithsonian Environmental Research Center (SERC), where he investigated predator–prey interactions of the blue crab in Chesapeake Bay under Dr. Anson H. Hines. In 1985 and 1986, he was a National Research Council postdoctoral fellow at the Oregon State University Marine Science Center, where he investigated trophic interactions among flatfish, the Dungeness crab, and benthic invertebrate prey. More recently, he was a senior postdoctoral fellow at SERC, where he conducted experimental field studies on source-sink dynamics of estuarine bivalves. Research interests focus on marine conservation biology with particular emphasis on the blue crab, Caribbean spiny lobster, queen conch, and estuarine bivalves. Investigations include the effectiveness of marine reserves in conservation and restoration, predator-prey dynamics, catastrophic disturbance and ecosystem alteration, food web dynamics and multispecies management, population viability analysis, recruitment processes, and marine stock enhancement. Lipcius advises or serves on various national and regional committees concerned with the management and conservation of marine and estuarine species, particularly exploited invertebrates and fish.

Margaret M. McBride serves as co-chair of the FEP Technical Advisory Panel and coordinated Plan development. She is a research fisheries biologist at the NOAA Chesapeake Bay Office. McBride holds a B.S. from Brandeis University and an M.S. in fish and wildlife science from Oregon State University (1989). She also studied invertebrate zoology and marine ecology at the Marine Biological Laboratory in Woods Hole. During her 17 years at the Woods Hole Laboratory of the NMFS Northeast Fisheries Science Center, she was a member of the Population Dynamics Branch and conducted stock assessments on yellowtail flounder and silver hake. McBride spent one year (1990–1991) as a visiting scientist at the Institute of Marine Research in Bergen, Norway where she developed a method to estimate total catch including discard in Norway's trawl fishery for Atlantic cod. She worked three years (1993–1996) on striped bass, Atlantic sturgeon, and American shad restoration programs at the Maryland Fisheries Resources Office of the U.S. Fish and Wildlife Service. McBride also worked from 1996 to 1999 at "institution building" as part of a Norwegian foreign aid project at the Institute of Fisheries Research in Maputo, Mozambique. The project's aim was to enable Mozambique to research and manage its own fisheries more effectively.

Dr. Thomas Miller is a fisheries ecologist on the faculty of the University of Maryland's Center for Environmental Science Chesapeake Biological Laboratory. His research interests include fish early life history, recruitment, and population dynamics of fish and aquatic invertebrates. In 2005, he led a team to assess and recommend targets and thresholds for the Chesapeake Bay blue crab fishery. Most recently, his research has involved multispecies interactions in the Chesapeake Bay. He leads a NOAA-funded project to develop a fishery-independent survey of Chesapeake Bay fishes and a Maryland Sea Grant-funded project to develop new methodologies for predicting the abundance of animals in estuaries. He was a co-convener of two STAC-funded projects that reviewed the potential for multispecies management of Chesapeake Bay resources and drew together national and international experts to make recommendations about the implementation of such approaches to the region. He serves on scientific advisory panels to the Mid-Atlantic Fishery Management Council, the BiState Blue Crab Committee, and the Chesapeake Bay Stock Assessment Committee. In 2002, he was elected co-chair of the ICES Recruitment Processes Workgroup. He has published over 40 peer-reviewed scientific articles on both freshwater and marine organisms and has received several awards for service and education.

Derek Orner is a research fisheries biologist with the National Marine Fisheries Service working in the NOAA Chesapeake Bay Office (NCBO). Orner has been with the NCBO since 1995 working on fisheries research and management issues. He is the current chair of the Chesapeake Bay Fisheries Steering Committee that oversees and guides numerous fisheries research and management activities in the Bay, including development of the fisheries ecosystem plan (FEP) and Chesapeake Bay Program multispecies management plans. He is also chair of the Multispecies Subcommittee with the Atlantic States Marine Fisheries Commission that develops advice for incorporating multispecies and ecosystem-based assessments into the management process. In addition to his participation in developing the FEP, he serves on the technical advisory panel to the Bistate Blue Crab Committee and the Chesapeake Bay Stock Assessment Committee and participates in various CBP subcommittees, working groups, and steering committees. Orner also coordinates the Chesapeake Bay Fisheries Research Program that awarded over $1.4 million in competitive fisheries research awards in 2002. Examples of projects funded and coordinated under this program include stock assessments for blue crab, hard clam, oyster, and soft clam; tagging studies for blue crab; ecosystem-based fisheries modeling, including development of the Chesapeake Bay Ecopath with Ecosim model; and development and implementation of Baywide, cooperative multiple species monitoring surveys.

Dr. David H. Secor is a professor at the Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science. He received a B.A. from Macalester College (1983) and a Ph.D. in biology from the University of South Carolina (1990). During 1986 and 1987, he was a research fellow at Kagoshima University, training in aquaculture and studying Japan's Sea Ranching Program. Secor's research interests focus on "connectivity" in the life cycles of estuarine and coastal fishes—how migration and habitat use (as behaviors) control and regulate population dynamics and cause individuals to be differentially vulnerable to exploitation and pollution. Current research projects are ocean ecology of juvenile bluefish, Atlantic bluefin tuna stock structure, sturgeon conservation, blue crab demographics, spatial ecology of estuarine-dependent fishes, assemblage analysis of Maryland's Coastal Bays fishes, and estuarine ecology of eels. Secor serves on several national and regional committees concerned with marine fisheries conservation and estuarine environmental issues. He serves as co-chair and also teaches in the fisheries area of specialization of the Marine, Estuarine, and Environmental Studies Graduate Program at the University of Maryland in College Park.

Dr. Alexei F. Sharov is a research statistician at the Maryland Department of Natural Resources. He received an M.S. in 1983 and a Ph.D. in 1987 from the Department of

Ichthyology at the Moscow State University, Russia. From 1987 to 1993, he worked as a stock assessment scientist at the Institute of Marine Fisheries and Oceanography, where he conducted assessments on several species in the northeast Atlantic and north Pacific regions. Sharov has been a member of several stock assessment working groups of the International Council for the Exploration of the Sea. From 1993 to 1997 he worked as a research associate at the University of Maryland and University of Massachusetts. His interests are primarily in the field of population dynamics and stock assessment. He is involved in studies of population dynamics of blue crab in Chesapeake Bay, striped bass, and menhaden on the Atlantic coast as well as multispecies interactions modeling. Alexei served as a panel member of several regional stock assessment workshops and is also a member of the Chesapeake Bay Stock Assessment Committee and several technical committees of the Atlantic States Marine Fisheries Commission.

Dr. Robert J. Wood is a research scientist at the NOAA Chesapeake Bay Office where he is identifying and characterizing the effects of climatological variability and food web dynamics on coastal and estuarine fisheries and ecosystem conditions. He received his Ph.D. in Fisheries Science from the School of Marine Science of the College of William and Mary in 2000 and previously worked as an assistant research scientist at the University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory. In addition to his involvement with the Fisheries Ecosystem Plan, Wood is an advisory panelist for the Chesapeake Bay Community Ecosystem Model, sits on the steering committee for the Chesapeake Research Consortium's Chesapeake Bay Community Modeling Steering Committee, and actively participates in regional workshops, workgroups, and meetings focused on Chesapeake Bay management issues.

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