A dynamic model of the Chesapeake Bay ecosystem: Final Report

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Report prepared for the NOAA Chesapeake Bay Office (NCBO)

by

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Executive summary

There is widespread agreement of the need to move toward an ecosystem approach to management of marine and estuarine resources, and the Chesapeake Bay has been at the forefront of the development through the Chesapeake Bay Program's *Chesapeake 2000* agreement, and by being the first area to develop a Fisheries Ecosystem Plan (NOAA CBFEAP, 2006). This document summarises work done in support of the Fisheries Ecosystem Plan by an ecosystem modeling advisory team from the University of British Columbia, Fisheries Centre (UBCFC) in cooperation with scientists in the Chesapeake Bay region, notably from the NOAA Chesapeake Bay Office (CBO). Emphasis has been on construction and application of an Ecopath with Ecosim (EwE) model of the bay ecosystem, and it has been of major concern to facilitate and support ecosystem modeling in the Chesapeake Bay area through extensive cooperation with researchers from an array of local institutions. The work has been funded through the NOAA CBO's Fisheries Research Program, NOAA Award No. NA17FU1654. The project has during its existence arranged xx workshops and training courses in the area, which have had participation of xx persons; it has developed and documented a trophic ecosystem model of the Chesapeake Bay to the level where it can be of use for ecosystem-based management in support of the Chesapeake Bay Fisheries Ecosystem Plan. The model is fully documented in a comprehensive technical report, which currently is undergoing review before submission.

Introduction

This report describes a project targeted at developing an ecosystem model of the Chesapeake Bay (CB), the Fisheries Ecosystem Model (FEM), based on the Ecopath with Ecosim approach and software. The FEM was created in response to a management need in the CB Region for a quantified model describing trophic pathways and exploitation of ecosystem resources in the Bay. This information can be used to understand how stocks affect each other within the food web, and how the many Bay fisheries impact both target and non-target species. Through its linkages to environmental drivers it also opens for evaluating how fisheries and the environment interact. Because the life histories and population dynamics of the thousands of organisms that live within the Bay are complicated, a model is necessary to provide data-driven analysis of how the system may react to human impact. Currently, the model includes 45 functional groups of organisms, some of which represent life history stanza of individual species, and representing all trophic levels. The input data primarily includes assessment results from the Chesapeake Bay (including biomasses, mortality rates, catches, and effort) supplemented with research vessel survey data (fisheries and biological oceanography studies); ecological studies (as available from researchers and institutions in the region); and parameter estimates obtained from literature where necessary to supplement local data.

Project goals

Project objectives

- To provide spatial and temporal resolution to an ecosystem model centered on the exploited parts of the Chesapeake Bay, but including all trophic levels, and of which an initial version has been developed;
- To assemble time series data related to the abundance and exploitation of the ecosystem resources of the Chesapeake Bay, and to fit the time-dynamic ecosystem model to these data;
- To explore policy options for exploitation of the Chesapeake Bay based on the fitted ecosystem model;
- To promote a strong participation of Chesapeake Bay scientists in the development of the ecosystem model through conduction of two workshops, as well as inter-workshop consultation.

Project overview

The model development has been tedious, partly because of a strong commitment to developing the model in cooperation with the Chesapeake Bay research community. This was done through a series of workshops over the first three years of the activity. During the third project year the local coordinator resigned abruptly in the spring 2004, and the UBC group had to take over the model documentation and development process. This was carried out successfully through the completion of a 200-page Technical Report by early 2005, which, however, still is under review due to an extensive review process. A close cooperation and coordination has been established with the new model coordinator, Dr

Howard Townsend, and the project staff working with Dr Townsend, Ms. Maddy Sigrist and Dr Hongguang Ma.

Time line

In response to the need for models to examine ecosystem-wide fisheries issues (Houde *et al.*, 1998) and to facilitate incorporating ecosystem modeling into management in the Chesapeake Bay area, the NOAA Chesapeake Bay Office (NCBO), initiated a series of workshops and training courses through the current project in order to get a broad support and involvement in the CB research community for the planned development of a quantitative ecosystem model for the Chesapeake Bay (see Table 1). The model is based on the Ecopath with Ecosim approach and software, which with the included dynamic and spatial modeling approaches, Ecosim and Ecospace have been widely used to examine numerous fisheries issues ranging from harvest regulations to the effectiveness of protected areas (Pauly *et al.*, 2000).

The first of these modeling workshops was convened during October 22-24, 2001 at the National Fish and Wildlife Service's Patuxent Wildlife Visitor Center, Laurel, Maryland, with the goals of presenting the Ecopath approach to the Chesapeake Bay community. The approximately 70 registered participants received the EwE User's Guide and a CD with the software and models, and were then tasked with developing policy questions for model exploration and developing a balanced draft ecosystem model, (see the list in Appendix 1). The workshop resource persons from the UBCFC included Mr. Alastair Beattie, Dr Villy Christensen, Mr. Dave Preikshot, Dr Carl Walters, and Dr Daniel Pauly.

In support of the modeling, two training courses were arranged in the region. The first of these was held during February 19-20, 2002, and was

hosted by the Chesapeake Research Consortium/Smithsonian Environmental Research Center, Edgewater, Maryland. This initial workshop focused on developing and using the mass-balanced Ecopath model and was led by Dr Christensen.

A follow-up training course was held at the same location during May 8-10, 2002 with a focus on Ecosim, notably how to develop the model and explore policy options. This workshop was led by Drs Walters and Christensen.

Table 1. List of workshops and training courses conducted as part of the project

Dates	Topic	Venue
2001, Oct. 22-24	Ecosystem modeling WS	USFWS, Patuxent
2002, Feb. 19-20	Ecopath training course	CRC/SERC, Edgewater
2002, May 8-10	Ecosim training course	CRC/SERC, Edgewater
2002, May 13-14	Ecosystem modeling WS	VIMS, Gloucester Point
2003, April 28-29	Ecosystem modeling WS	USFWS, Patuxent
2006, Aug 28-31	Ecosystem modeling programming training course	CRC/SERC, Edgewater

The second training course was followed May 13-14, 2002 by a workshop at the Virginia Institute of Marine Science (VIMS), Gloucester Point, VA with the goal of prioritizing the policy objectives that were developed at the

first modeling workshop (Appendix 1), to continue to refine the ecosystem model, and to begin exploration of specific policy questions.

A third modeling workshop was then convened April 28-29, 2003 at the Patuxent Wildlife Visitor Center, Laurel, Maryland with the objective of presenting the complete status of the model, comparing the model's predictions to actual time series abundance data for various species, and examining the model's application to policy questions about management of the Bay's living resources. Break-out groups discussed policy and management questions related to (1) oyster and filter feeders, (2) blue crab, and (3) striped bass and menhaden. The following served as resource persons at the workshop, Dr Villy Christensen, Mr. Dave Preikshot and Dr Carl Walters, UBC; Dr Rob Latour and Dr Ratana Chuenpagdee, Virginia Institute of Marine Science (VIMS); Steve Martell, CBL; Alasdair Beattie, Chesapeake Research Consortium (CRC)/NOAA; and Bob Wood, NOAA.

Some noteworthy results from this workshop include,

- the model could reproduce many (but not all) of the important time series trends well,
- there remained a need to directly incorporate water quality parameters, abiotic processes and lower trophic level dynamics, and
- there will be tradeoffs between many of the stated Chesapeake 2000 objectives. With finite ecosystem productivity, it is unrealistic to believe that all fish species can be returned to their historic peak levels of abundance simultaneously,

Addressing these three conclusions shaped the project continuation, and to address these and to further improve the base model, Dr Rob Latour

from VIMS and Mr. Alasdair Beattie from CRC visited UBC May 29 to June 3, 2003 to work with the UBCFC team.

At the 2004 Chesapeake Bay Fisheries Research Symposium (February 25-26), the need for obtaining long-term environmental data became increasingly clear, and the project initiated development of simple spatial hydrodynamic model for the Chesapeake Bay. The model runs with monthly time steps from 1950, and the EwE software was updated to link to time series of Chesapeake Bay nutrient loading derived from the model.

Mr. Beattie, the local project coordinator, departure abruptly from CRC/NOAA and the Chesapeake Bay ecosystem modeling activity in the spring of 2004 made it necessary to re-evaluate planned activities and project progress. An important element of this was that Dr Christensen took over the responsibility for preparation of the technical report of which a complete draft was ready by January 2005.

The new coordinator, Dr Howard Townsend, NOAA CBO/Oxford Cooperative Laboratory visited UBC from October 4 to 8, 2004. During this time Dr Townsend was provided with detailed instruction on how to construct and analyze ecosystem models using the EwE software.

For many functional groups in the CB FEM only very incomplete time series (typically from early 1980s onwards) were available. The UBCFC team therefore conducted a series of assessments (typically stock reduction analysis) to obtain indicative time series population trends back to 1950. We emphasize the importance of time series information for ecosystem analysis, and recommend that effort is allocated to obtaining especially historic information about the recreational fisheries in the Bay.

Work has continued on the refinement and elaboration of the CB Fisheries Ecosystem Model. Model parameters continue to be improved, and more time series appropriate for analyses of dynamic processes has been added. The species groups that has been paid particular attention too are the multi age stanza groups (striped bass, bluefish, weakfish, white perch, Atlantic menhaden, blue crab, and oyster) and those which are commercially important (American eel, Atlantic croaker, summer flounder, spot, alewife, American shad, black drum, catfish, and bivalves). Specific changes have been made to the parameters for all of these species on the basis of new assessment information available since the inception of the CB FEM model in 2001. The CB FEM is thus continuously being updated as new information becomes available.

In the last year of the project the focus was on fitting the CB FEM developed through the project to time series data and on the consequential updates of the Technical Report describing the model. It has over the years been of major emphasis for the project to expand the group of scientists involved ecosystem modeling in the Chesapeake Bay area. To further support this, the project arranged an ecosystem model programming workshop in cooperation with NOAA Chesapeake Bay Office and the Chesapeake Research Consortium at the Smithsonian Environmental Research Center, Edgewater, Maryland. The purpose of the workshop was to introduce scientists from the Chesapeake Bay area to the inner workings of the new Ecopath with Ecosim version 6 (EwE6), and to teach how to interact with the programming environment, including how to make new modules for it. The programming workshop was well attended and had 20 participants in addition to the 5 lecturers, and was conducted during August 28-31, 2006.

The project activity supporting the development of the CB FEM is being continued through a new four-year award from NOAA.

Management and financial aspects

The project initially received NOAA/CBO support of $85,000 through NOAA Award NA17FU1654, which had the title "A dynamic mass balance model of the Chesapeake Bay ecosystem" and started on October 1, 2001 with one-year duration. Four follow-up proposals have been supported; the first at the level of $75,000 starting October 1, 2002; the second for $80,000 starting October 1, 2003; the third for $70,000 from October 2004; and the last for $49,832 from October 2005. It was expected that the project would be continued beyond September 2006, but the continuation was awarded as a new project, and by the time this was known it was not possible to spend an unused balance, which had been 'saved' to hire a Ph.D. student/GRA to further develop a spatial model of the CB.

Villy Christensen, UBCFC has served as leading Principal Investigator through the project period, while Mr. Alastair Beattie, CRC, served as local model coordinator during the first 2½ years of project activity, and Dr Howard Townsend NOAA CBO/Cooperative Oxford Laboratory, during the last 2 years. An Ecosystem Modeling Advisory Panel and Steering Committee has overseen the modeling work through the project period. Mr. Derek Orner, NOAA CBO has served as NOAA program officer through the project period.

Scientific aspects

The current project is based on application and further development of the Ecopath with Ecosim approach, which is being developed by the UBCFC team, and which currently has some 5000 registered users in 150 countries. The software along with the source code is made freely available (http://www.ecopath.org). It is the most widely-used approach for ecosystem modeling of aquatic ecosystems, and is evaluated as a very capable approach for ecosystem-based management (Plaganyi, 2007), as well as one of the ten biggest scientific breakthroughs in NOAA's 200-year history (http://celebrating200years.noaa.gov/breakthroughs/welcome.html).
The modeling approach has been developed considerably through the project period, and credit should be given to NOAA/CBO for long-term support of the continuous development of the approach.

Model approach description

Ecopath is a static mass-balance model used for parameterization, which requires identifying and quantifying feeding relationships between the various living resource stocks in an aquatic system (Christensen and Walters, 2004). The feeding relationships require estimates of biomass of each living resource and feeding rates of predators on prey items. Mortalities from predation as well as harvest and any other mortality terms are also important to 'predicting' yields of each trophic group; factors that alter the ecosystem populations can be assessed for impacts on any organism or group of the ecosystem. These factors, for example, might be the potential management policies in the system (fishing limits, gear types,

etc.) or natural control through events such as storms, hurricanes, disease, and parasitism.

As a static model, Ecopath provides single point-in-time estimates of energy flow through the food web of a given ecosystem. More important to include management options in the considerations, however, is the inclusion of time and space dynamics. This is accomplished through two other components of the modeling approach, Ecosim (temporal dynamics via dynamic simulations, Walters et al., 1997; Walters et al., 2000) and Ecospace (a spatial dynamic model, Walters et al., 1999). Ecosim incorporates time-series data of known mortality rates, catches, and effort, and fits the model to such reference data through various fitting procedures. The approach can predict changes in biomasses and mortality rates through time, and is increasingly being used for fisheries management (Christensen and Walters, 2005). With this capability, potential management policies can then be explored through model simulations. Spatial simulations are accommodated through Ecospace modeling, in which Ecosim dynamics are applied over a grid of equal-sized cells. The cells are linked by dispersal, fishing effort, movement, and allocation. Ecospace ultimately predicts the spatial distribution of aquatic animal species, and can be used to address stock responses to specific options such as establishing protected areas or changing habitat.

Programming of the hydrodynamic component of the CB FEM model was initiated by Dr Walters, and the first version completed with assistance from Dr Martell, Mr. Korman and Mr. Buszowski. The two-layer hydrodynamic model uses monthly time series data of wind, river flows from major freshwater inputs, nutrient loading, chemistry and bathymetry. From these input data, the model can produce time series of total primary production, nitrogen and phosphorous concentrations, oxygen, and

salinity. These predicted values are compared to historical data to further improve model parameterization. This historical information on nutrient loading and physical mixing is then used to calculate changes in temporal nutrient loading for the Chesapeake Bay. An updated version of the hydrodynamic model with a more complete documentation is currently being developed in cooperation with Drs Townsend and Ma.

Use of the Fisheries Ecosystem Model

The CBFEM has been used by the local NCBO modeling group for providing insight into the CB fisheries ecosystem. The local team has presented the model and scenarios informally to many science and management agencies in the region including. Descriptions of the presentations are listed in the table below.

Agency or Institution	**Presentation Description or Title**
Maryland Department of Natural Resources	Basics of EwE & CBFEM, exploratory simulation scenarios with Menhaden and predators
Virginia Marine Resources Commission	Basics of EwE & CBFEM
Chesapeake Bay Fisheries Steering Committee	Basics of EwE, progress reports on model develop (~5 presentations), "Using Ecopath with Ecosim for Ecosystem-based Fisheries Management"
Virginia Institute of Marine Sciences	Presentation to Introductory Marine Science class - "Applied Food Web

	Modeling: Ecopath with Ecosim and The Chesapeake Bay Fisheries Ecosystem Model"
University of Maryland Centers for Environmental Sciences – Chesapeake Biological Laboratory	Presentation to Marine Science Seminar class - "Applied Food Web Modeling: Ecopath with Ecosim and The Chesapeake Bay Fisheries Ecosystem Model"
Chesapeake Bay Program - Modeling Subcommittee	Basics of EwE & CBFEM, progress reports on model develop, and "CBFEM Analysis of base and Tributary Strategy Conditions" (~5 presentations on effects of water quality changes on fisheries ecosystem),
Chesapeake Bay Program – Living Resources Subcommittee	Basics of EwE & CBFEM
Chesapeake Bay Program – Fish Passage Workgroup	"Ecosystem Modeling & Monitoring"
Chesapeake Bay Program – Toxics Subcommittee	Basics of EwE & CBFEM, Demo Model of Simplified CBFEM for a Mercury Food Web Model
South Atlantic Fisheries Management Council	"The Chesapeake Bay Fisheries Ecosystem Model in support of an Ecosystem-Based Approach to Fisheries Management"
Stakeholders meeting with	"Ecopath with Ecosim and The

Omega Protein – Menhaden Fishing Industry	Chesapeake Bay Fisheries Ecosystem Model", exploratory simulation scenarios with Menhaden and predators
Stakeholders meeting with "Menhaden Matters" – Environmental NGOs coalition in support of regulating Menhaden fishing	"Ecopath with Ecosim and The Chesapeake Bay Fisheries Ecosystem Model", exploratory simulation scenarios with Menhaden and predators

The primary means of doing this has been through presentations at National and International Scientific meetings and through posters and presentations to local and regional management agencies and meetings.

1. Townsend, H. 2006. Exploring the interactions of fisheries and water quality management using a model of the Chesapeake Bay fisheries ecosystem.
2. Christensen, V. and H. Townsend 2006. Using the Chesapeake Bay Fisheries Ecosystem Model to Explore the Effects of Water Quality and Fishing Effort on the Blue Crab Population (NCBO Symposium – poster)
3. Townsend, H. 2005. Modeling the influence of water quality on the Chesapeake Bay fisheries ecosystem. International Council for the Exploration of the Seas. Aberdeen, Scotland 2005.
4. Townsend, H., V. Christensen, and R. Wood. 2005. Exploring management policy options for menhaden and striped bass using

the Chesapeake Bay Fisheries Ecosystem Model based on the Ecopath with Ecosim Software. Estuarine Research Federation. Norfolk, VA.

5. Christensen, V., S. Martell, C. Walter, and H. Townsend. 2005 Towards ecosystem-based management in the Chesapeake Bay: Linking estuarine processes and fisheries trophic interaction through complementary modeling efforts. Estuarine Research Federation. Norfolk, VA.

6. Townsend, H. and V. Christensen Chesapeake Bay Fisheries Ecosystem Model Scenarios for Exploring the Role of Atlantic Menhaden in the Chesapeake Bay Fisheries Ecosystem (white paper for Chesapeake Fisheries Steering Committee – Menhaden Ecosystem-based fisheries management plan)

In addition to the presentations listed above - the model is being used to support other efforts. The primary efforts have been 1) development of a Mercury Food Web model and 2) development of educational tools. A workshop to begin the development of the Mercury Food Web Model is scheduled for October 2007. The databases for the model have been used in development of the Chesapeake Ecosystem explorer – an interactive, web-based visualization tool of the Chesapeake Bay food web. Future educational uses of the model are planned with the new versions of the EwE software, which is designed with a modular approach, and which can accommodate different user interfaces (including visualizations for gaming).

Model 'spin-off'

There have been considerable 'spin-off' from this project, where the model or parts of the model has been used as part of other projects, e.g., to explore blue crab or menhaden dynamics. We have compiled a tentative list of such contributions in Table 2, and note that many related projects have been submitted to NOAA CB for funding but are not listed here.

Table 2. List of publications derived from or related to the project activity

Topic	**Reference**
Technical Report: Fisheries ecosystem model of the Chesapeake Bay: Methodology, parameterization and model exploration	(Christensen *et al.*, *in review*)
BioScience description of 'The Chesapeake Connection' (this project)	(Dybas, 2002)
Chesapeake Environmental Models	(Anon., 2005)
Evaluation of single-species MSY *vs.* ecosystem MSY	(Walters *et al.*, 2005)
Interaction between Atlantic menhaden and Striped bass	(Zhang *et al.*, 2006)
Framework for integrating scientific ecosystem knowledge with stakeholders' preferences	(Chuenpagdee *et al.*, 2006)
EwE methods paper: shared foraging arenas and bout feeding	(Walters and Christensen, 2007)
A summary model of the historical factors	(Christensen, Walters,

influencing the estuarine ecology of the Chesapeake Bay for ecosystem-based management: Chesapeake Bay Regional Estuarine Ecology Model	Ma, and Townsend, in development)

Project evaluation

The model data is being evaluated under the supervision of the Chesapeake Bay Ecosystem Modeling Technical Advisory Panel and the Chesapeake Research Consortium. EMTAP members have been invited to review the Chesapeake Bay Fisheries Ecosystem Model (CBFEM) data, and ensure that we are using the best available data for the model and adequately representing the major trophic relationships in the ecosystem. The primary means of accomplishing this will be through the review of the FEM Technical Documentation. Members and CRC personnel are: reviewing data sections of the technical report, identifying outside data sets/providers/reports that can be used to improve the model's ability to represent the Chesapeake Bay fisheries ecosystem dynamics since 1950, assisting in finding outside experts who can examine the model, specifically the data sets, assumptions, and model dynamics.

In addition a review of the model by the Center for Independent Experts (CIE) will be initiated in FY 2007. The NOAA Alaska Fisheries Science Center has implemented EwE-based models for providing management advice to relevant agencies and councils. They were able to do so after a successful CIE review. The UBC PIs will work closely with Dr. Townsend to support this external review of the CBFEM and supporting modeling efforts.

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Appendices

Appendix 1. Research questions suggested by participants at the October 22-24, 2001 workshop for potential evaluation through the CB Fisheries Ecosystem Model.

1. What are the ecohabitat and fishery impacts of increases or decreases in nutrient loading, dissolved oxygen (DO), and turbidity?
2. What are the consequences of a tenfold increase in the oyster population in the Chesapeake Bay?
3. Should we stop fishing menhaden in the Chesapeake Bay versus outside the Bay?
4. What are the nutrient impacts of increases or decreases in fishing, particularly for filter feeders?
5. Is game fish restoration appropriate given the status of mid-chain forage fish stocks?
6. Can water quality (e.g., DO) be managed by top-down actions such as fishery regulations?
7. Are there too many striped bass in the Chesapeake Bay?
8. What is the optimal configuration of harvest in terms of rent?
9. What would happen to the ecosystem if sea grasses could be restored (specifically addressing turbidity and nutrients)?
10. Would increases in freshwater input reduce oyster disease mortality?
11. What is the relative importance of climate variation on fish populations versus that of harvesting pressure?
12. Can the crab stock be restored through fishery reductions and the use of protected areas?

13. Can the crab stock be increased by the "control" of other mortality agents, particularly predators?

14. Can protected areas for oysters enhance abundance and aid in their restoration?

15. What defines a healthy Chesapeake Bay ecosystem? Is there consensus on what it would mean to successfully manage that ecosystem? What are the trophic limits to the configuration of that system?

16. Have fishery or habitat changes caused changes in the ratio of gelatinous organisms to fish? Does this ratio represent a stable alternate state?

17. Have increases in high-frequency variability in primary productivity (blooms?) contributed to increases in gelatinous organisms?

18. Has the removal of stream barriers to anadromous fish spawning allowed increases in shad, herring, or bass, or are these fish just food for the exotic predators (such as large mouth, small mouth bass, and catfish) upstream of the barriers? Would the same thing happen if additional barriers were removed?

19. What are the effects of water bird predation on their prey, specifically, and Chesapeake Bay fisheries, generally?

20. What is the role of forage fish in Chesapeake Bay ecosystem dynamics?

21. Is there an effect of changes in primary production on fish (planktivore) populations?

22. What are the impacts of wetland restoration?

23. What are the implications of migratory piscivores (e.g., bluefish, croaker) on the Chesapeake Bay environment?

24. What is the effect of land management in the Chesapeake Bay watershed on the estuarine food web?

25. What are the effects of aquaculture, species introductions, and hatcheries on the ecosystem?