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A Pilot Study in the Gulf of Maine

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A Pilot Study in the Gulf of Maine

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Executive Summary

Study Goals and Objectives

- Improve existing nutrient-related eutrophication assessment methods, updating (from early 1990s to early 2000s) the eutrophication assessment for systems included in the study with the improved method.

- Develop a human-use/socioeconomic indicator to complement the assessment indicator. The human-use indicator was developed to evaluate costs of nutrient-related degradation in coastal waters and to put the issue into a broader context relevant to the interested public and legislators as well as to scientists.

- Project objectives included collecting existing water quality data, developing an accessible database appropriate for application to a national study, and applying the assessment methods to 14 coastal systems – nine systems north of Cape Cod and five systems south. The geographical distribution of systems was used to examine potential regional differences in condition.

- The intent is to use the lessons learned in this pilot study on a national scale to guide completion of an update of the 1999 National Estuarine Eutrophication Assessment[1].

Methods and Modifications

- Data collection for water quality variables used in the application of the eutrophication assessment was carried out by mailed data-request surveys combined with personal visits. National Marine Fisheries Recreational Fish Catch data for development of the human-use indicator was acquired from the National Oceanic and Atmospheric Administration National Marine Fisheries Service and entered into a database.

- Three eutrophication assessment methods were evaluated for possible use in the study. The method selected, the National Oceanic and Atmospheric Administration National Estuarine Eutrophication Assessment/Assessment of Estuarine Trophic Status method (NOAA NEEA/ASSETS), offered these advantages: ease of application, its Pressure-State-Response approach is useful for evaluating potential management actions, and, of the three methods, it resulted in condition assessments that most closely reflected the conditions in the systems as understood by regional experts.

- Modifications were made to the ASSETS method and applied to 14 Gulf of Maine systems. Modifications include:

  1. Data were used for assessments rather than the expert knowledge approach used in the original NEEA.

  2. The epiphyte indicator variable was excluded from the original list of ASSETS indicators because of lack of data. The remaining five variables were assessed: Chlorophyll a (Chl a), dissolved oxygen (DO), macroalgae, harmful algal blooms (HABs), and losses of submerged aquatic vegetation (SAV).

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[1] The first update is presently underway and anticipated for release in late 2006 (see details at http://ian.umces.edu/neea or http://www.eutro.us).

3. Data were analyzed for the estuary as a whole. Previously, data had been analyzed in spatial zones determined by salinity.
4. Statistical criteria used for assessing DO and Chl a require annual data but in some systems annual data were not available. Because the program's intent is to make an assessment with the data that is available, mean values for Chl a and DO were used in cases where only index period (i.e., summer months) data were available. This was designed to avoid biasing the data toward a potentially false higher impact expression.
5. Previously, toxic and nuisance algal blooms had been considered a High impact in systems. However, where the blooms begin naturally offshore and are advected into the system, the HABs impact was considered as a Low impact. Applying the ASSETS method with a rating of High for the HAB indicator variable provides a falsely High eutrophication impact assessment. (This may also apply to Pacific Northwest and some Gulf of Mexico systems in a national application)
6. Where previously only losses were recorded for SAV spatial coverage, a new response of Increase was added. Although it gets a value of 0 and therefore does not impact the assessment rating, it is important to note where seagrasses are returning.
7. The level of human influence was determined by applying a simple model that compares natural background nutrient levels to levels caused by human-associated loads.

- National Marine Fisheries Recreational Fish Catch data were used in conjunction with water quality data to develop a human-use impacts indictor. The model links changes in fish catch rate for three species (bluefish, striped bass, winter flounder) to changes in DO, taking into account other influencing factors such as avidity of the angler and water temperature.

Results and Conclusions

- For two systems, Kennebec/Androscoggin River and Saco River, there were inadequate data for applying the assessment method.
- Assessment results suggest slight differences in overall eutrophication impact between Gulf of Maine and Mid-Atlantic systems. Although most assessments resulted in a rating of Moderate, the two systems assessed as Good were in the Gulf of Maine, while the one system assessed as Bad was in the Mid-Atlantic.
- Assessment of the Chl a indicator showed High levels in nine of 12 systems, but no apparent regional patterns. The DO indicator showed striking differences, with ratings of No Problem in the Gulf of Maine and Low to Moderate problems in the Mid-Atlantic systems.
- The modified criteria for HABs resulted in changes in the assessment of overall eutrophic condition from High to Moderate for Casco Bay and from Moderate High to Low for Wells Bay. This led to changes in the overall ASSETS rating from Poor to Moderate in Casco Bay and from Poor to Good in Wells Bay.
- Although it may not be reflected in the categorical assessment ratings (e.g., High, Moderate, Low), results suggest a relationship between nitrogen loading and waterbody response. This approach may lead to development of a predictive capability, however, it is premature to draw any conclusions from this limited data.
- Results of this study compared to results of the 1999 assessment were made only for Chl a and DO. Chl a concentrations are higher now than in the early 1990s in all systems north of Cape Cod. DO conditions in the Mid-Atlantic remained the same, while in the northern systems conditions improved from Low for many systems to No Problem for all systems. Because the data were analyzed for the estuary as a whole, it was not possible to identify the area within the systems that had become worse or better.

- Human-use indicator results suggest that fish catch rates may serve as an indictor of the negative effects of eutrophication in estuaries, with striped bass giving the best results of the three species considered.
- Analysis of the predictive capability of the model in three systems showed smaller differences in expected catch with changes in DO concentrations in Long Island Sound than in Potomac and Patuxent Rivers. While complicated, the probable explanation is that the larger, deeper Sound has greater habitat availability for fish to migrate to as hypoxic conditions develop.
- The approach used for the human-use indicator is transferable and the intent is to develop it for use as a nationally applicable indicator. However, before a full application can be made, research must be done on the appropriate fish species to use in different coastal systems because striped bass will likely not be useful on a national scale.

Recommendations

- A limiting factor for both the eutrophication assessment and the development of the human-use indicator was the availability of data. It is recommended that the most effective data gathering would be through site visits to the actual data holders, because mail and phone requests for data proved unsuccessful and many organizations do not offer data on the internet.
- For the best and most accurate assessment results, annual data should be acquired wherever possible.
- Data collection and analysis on a salinity zone or other spatially-determined basis for the eutrophication assessment would be useful for examining changes that occur within the systems over time. Changes observed in the systems from the early 1990s (the timeframe of the 1999 NEEA report) and the early 2000s (this study) could be described for component variables but not spatially.
- Continued research should be supported to fully explore the relationships between nutrient load and waterbody response that are so critical to the development of successful management measures. This includes efforts to develop accurate load estimates as well as to support more robust data collection and monitoring activities.
- Development of the human-use indicator and conversion to a nationally applicable methodology requires further research on the fish species that are appropriate for use in different regions of the coastal U.S. Only species where the catch rates are shown to be significantly impacted by the environmental variables should be used.
- Conversion of the human-use indicator to a socioeconomic indicator requires research and/or modeling of the multipliers (e.g., costs per fish) that can be applied to the results of the human-use indicator developed here.
- These assessments should be updated every two to five years to monitor success of implemented management measures and trends in condition within coastal waterbodies. Existing State-Federal and Federal-Federal partnerships for monitoring, assessment, and development of appropriate management plans should be encouraged and strengthened for this purpose.

Introduction

The recent National Estuarine Eutrophication Assessment (NEEA, Bricker et al., 1999) has shown that nutrient-related water quality problems are observed in 60% of our nation's estuaries. Problems include low dissolved oxygen, excessive and unsightly algal blooms, and losses of submerged aquatic plants that serve as habitat critical for sustaining coastal fisheries. These nutrient-related impacts cause economic losses to tourism and losses to commercial and recreational fisheries, with potential long-term losses to fish diversity and abundance (Breitburg, 2002). As a result of the NEEA and other studies (CENR, 2003; Boesch et al., 2001; NRC, 2000; CSO, 1999), nutrient pollution has been noted as one of the greatest threats to U.S. estuarine and coastal water quality. These reports recommend watershed and adaptive management approaches for reducing and mitigating nutrient-related eutrophication symptoms. They also argue for further research and assessment efforts to reduce uncertainties in the information that mangers use to make decisions (CENR, 2000; NRC, 2000; Bricker et al., 1999).

Responding to the need for more accurate assessments, this study was designed to develop and improve transferable, accurate, and reproducible methods for assessment of nutrient-related water quality conditions and human-use impacts in estuaries and coastal waters.

Several assessment methods have been used recently in the U.S. and in Europe to evaluate the status of nutrient-related conditions in coastal waterbodies. Much of this is in direct response to mandates of the U.S. Clean Water Act and the European Union Water Framework Directive to periodically evaluate the condition of, in this case, coastal water bodies. Among the methods are:

- Assessment of Estuarine Trophic Status (NEEA/ASSETS, Bricker et al., 2003), which is a modification of NOAA's National Estuarine Eutrophication Assessment (NEEA, Bricker et al., 1999)
- EPA's National Coastal Assessment (US EPA, 2004)
- Oslo Paris Convention for the Protection of the North Sea Comprehensive Procedure (OSPAR COMPP, OSPAR, 2001).

All use a similar suite of biological and chemical indicator variables, and all combine these to produce a single index value representing the eutrophic condition within a waterbody (Table 1).

Table 1
Comparison of indicator variables used by three assessment methods.

Variables	NEEA ASSETS	EPA NCA	OSPAR COMPP
Nutrient (DIN, DIP) Load/ Concentration/Ratio		X	X
Chlorophyll a	X	X	X
Dissolved Oxygen	X	X	X
Water Clarity		X	
HABs/Algal Toxins	X		X
Phytoplankton Indicator SPP			X
Macroalgal abundance	X		X
Submerged Aquatic Vegetation loss	X		X
Zoobenthos/Fish kills			X

There are also differences in the indicators used and in the methods for calculating the index. A sensitivity analysis showed the NEEA/ASSETS assessment method to be more responsive to changes in indicator variable levels. NEEA/ASSETS does not use waterbody nutrient concentrations as an indicator variable. Concentrations are not used because they reflect the net biological, physical and chemical processes such that one can have a severely degraded water body with low concentrations while a relatively healthy water body might have high nutrient concentrations. That method also gives secondary or indirect impacts (dissolved oxygen (DO), submerged aquatic vegetation (SAV) loss, and harmful algal bloom (HAB) occurrences) a higher weight than the primary or direct impacts (Chl a and macroalgae). There is no weighting of variables in the other methods (Table 2).

Based on a sensitivity analysis, this study selected the NEEA/ASSETS method (Bricker et al., 2003) to use as a starting point for the water quality assessment method modification/improvement. This is a Pressure-State-Response (P-S-R) approach where nutrient loads are considered P or influencing factors, the water quality variables (i.e. Chl a, DO) represent the S or water body condition and R is what will happen in the future. The modified method was then applied to the systems selected for study.

The other objective of this study was to develop a human-use indicator to complement the eutrophication indicator. There have been few studies that link the human use or socioeconomic costs of nutrient-impaired coastal water quality. Those that have been done have focused on the costs of toxic algal blooms to fisheries (e.g., Anderson et al., 2000). The intent of the current study was to develop an indicator that could illustrate to non-scientists, as well as scientists, the impacts of nutrient-related water quality degradation on various human uses of a system. Using model-derived costs, the impact of the degradation might then be translated into economic costs.

Most human uses, however, are not well defined by data that can be used in conjunction with water quality data to substantiate a link between losses of a use and water quality. Recent innovative studies by Lipton and Hicks (1999, 2003) suggest that fisheries catch data and water-column DO data exhibit predictable relationships. This study used the work of Lipton and Hicks (1999, 2003) as a starting point for developing a human-use indicator.

The results of this study include:

1. A modified eutrophication assessment method.
2. A human-use indicator.
3. A database of water quality and fish data necessary for application of the eutropication and human-use indicators.
4. Updates to the eutrophication assessment for the systems selected for inclusion in the study.
5. A human-use assessment for the study sites.
6. A regional perspective on eutrophic conditions and human-use impairments for Gulf of Maine and Mid-Atlantic systems.

The methods are transferable and will be used in a national update of the NEEA that will include the human-use assessment.

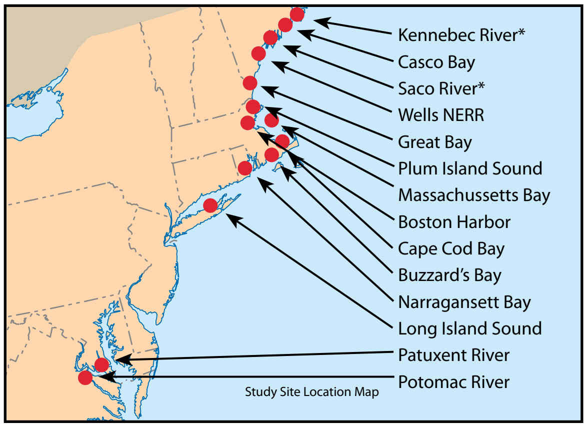
Table 2
Summary comparison of three assessment methods.

		NEEA/ ASSETS	EPA NCA	OSPAR COMPP
Grouping of Variables	Influencing Factors (Pressure)	Nitrogen Load		DIN, DIP, Load of TN,TP
	Direct/ Primary (State)	Chla, Macroalgae, Epiphytes		Chl a, PP indicator spp, macroalgae/ microphytobenthos
	Indirect/ Secondary (State)	HABs, SAV loss, DO		DO, zoobenthos/ fish kills
	Other or No grouping		DIN, DIP, Water Clarity, Chl a, DO	Algal toxins
Temporal focus		annual cycle	summer	growing season, winter for nutrients
Indicator Criteria		thresholds determined from national studies	thresholds determined from national studies	comparison to reference station
Combination Method		Average of Primary and Highest Secondary are combined by matrix	Ratio of indicators: good/fair indicators to poor/missing data	one out all out for each indicator group, ratio of results for 4 indicator groups

Study Site Description

Fourteen estuaries and coastal waterbodies from the Gulf of Maine and Mid-Atlantic were selected for inclusion in this study (Figure 1). They were analyzed by region (those in the Gulf of Maine north of Cape Cod and those south) to see if there are regional differences in response. Systems were selected to represent a diversity of types (e.g., riverine, tidal, oceanic) with varying physical characteristics, including a range of waterbody and watershed areas, tidal ranges, and flushing rates (Table 3). Watershed characteristics differ as well, from systems with low population density within the watershed to those with higher-density population and greater urban influence (Table 4). These differences result in different levels of expression of eutrophic symptoms, both in terms of the variables that become problematic and in the severity of problems observed.

Figure 1
Map of relative location of systems included in this study.



*System was not evaluated due to inadequate data

Another reason for selection of the Gulf of Maine systems in particular is that the original NEEA assessment results showed several systems to be highly eutrophic on the basis of one indictor only: the occurrence of HABs (Bricker et al., 1999). In these systems, as for others in the Pacific Northwest and Gulf of Mexico, annual toxic bloom events are naturally occurring, starting offshore and advecting into the estuary or coastal waterbody. For several systems, there were no other perceivable impacts, and thus this provided a good case study for modifying the indicators and thresholds for more accurate assessment.

These results will be modified for eventual inclusion in the larger National Estuarine Eutrophication Assessment Update Program that seeks to modify the assessment method by type of system (Table 5). This study is a first step toward fulfilling these goals on a national basis. Additional criteria for selection of sites were: data availability, including spatial and temporal coverage, and the perception of the ease with which the data could be acquired from the data holders.

Table 3
General physical and watershed characteristics of estuaries included in the study.

System	Type	Estuarine Area (sq km)	Water-shedArea (sq km)	Depth (m)	Tidal Range (m)	Salinity (avg. ppt)	Tidal FW Flushing (days)	FWinflow (1000sm^3 d-1)	Water-shed Popula-tion (1000s people)	Suscep-tibility
Kennebec/ Androscoggin River	Riverine	76	24601	6.3	1.7	7	4	38968	426	L
Casco Bay	Oceanic	427	2561	12.0	2.8	29	10	3211	229	L
Saco Bay	Riverine	49	4593	10.1	2.7	28	7	7370	133	L
Wells Bay	Tidal (small)	1.7	102	2.0	2.6	30	<1	>49	3	L
Great Bay	Tidal	47	2555	3.8	2.4	21	1	1890	265	M
Plum Island Sound	Tidal	15	597	2.1	2.6	26	?	553	146	M
Boston Harbor	Tidal	186	1623	6.2	2.9	29	2	1131	2127	M
Massachusetts Bay	Oceanic	768	553	29.1	2.7	29	60	179	411	L
Cape Cod Bay	Oceanic	1439	566	22.6	2.8	29	34	147	103	M
Buzzards Bay	Oceanic	639	1257	10.1	1.1	29	42	420	308	M
Narragansett Bay	Riverine/ Tidal	416	4310	8.3	1.2	27	24	4918	4830	M
Long Island Sound	Oceanic	3259	12773	19.5	1.9	28	56	15451	5435	H
Patuxent River	Riverine	142	2504	3.8	0.5	12	26	1169	638	H
Potomac River	Riverine	1260	36804	5.1	0.6	11	36	34095	5350	H

(Data from S.V. Smith, 2003 except for population which is from 2000 US Census, and for Wells Bay which is from Ward, 1993)

Table 4
Land Use in watersheds of estuaries in this study (as percent of total watershed area).
Data for Kennebec/Androscoggin River and Saco Bay was inadequate for full assessment.

System	Urban	Ag	Forest	Wetland	Range	Barren
Kennebec/AndroscogginR.	2	6	88	3	0	0
Casco Bay	17	11	71	1	0	0
Wells	9	7	79	5	0	0
Saco Bay	5	4	88	3	0	0
Great Bay	19	8	70	3	0	0
Plum Island Sound	34	7	50	10	0	0
Massachusetts Bay	77	1	21	1	0	0
Boston Harbor	79	1	20	0	0	0
Cape Cod Bay	27	1	60	9	3	0
Buzzards Bay	23	8	65	4	1	0
Narragansett Bay	41	5	51	2	0	0
Long Island Sound	16	11	71	2	0	0
Patuxent River	33	31	33	2	0	0
Potomac River	12	36	52	0	0	0

(From Coastal Assessment and Data Synthesis System, 1999 adaptation of USGS Land Use and Land Cover data)

Table 5
Modified results from 1999 NEEA results using five indicators for comparison to results from this study.
Using Chl a, macroalgae, DO, SAV, HABs and excluding epiphytes.
Modified HAB method was not used in this re-calculation of the assessment.

System	OHI	OEC						DFO	ASSETS
		Primary		Secondary			Overall		
		Chl a	Macroalgae	Dissolved Oxygen	HABs	SAV Loss			
Kennebec/ Androscoggin River	L	M	NP	L	NP	NP	U	U	U
Casco Bay	ML	M	M	L	H	M	H	IL	Poor
Wells	The 1999 NEEA report did not include an analysis of this system, no results are available								
Saco Bay	L	L	NP	L	H	U	U	U	U
Great Bay	ML	M	M	L	L	I	M	WH	Moderate
Plum Island Sound	MH	M	NP	L	NP	NP	L	WH	Moderate
Boston Harbor	MH	M	M	M	NP	L	M	IL	Moderate
Massachusetts Bay	M	M	H	NP	M	L	MH	WL	Poor
Cape Cod Bay	ML	M	L	L	L	L	L	NC	Good
Buzzards Bay	ML	M	L	L	NP	L	L	NC	Good
Narragansett Bay	MH	M	L	L	M	L	M	NC	Moderate
Long Island Sound	MH	H	H	M	M	L	MH	NC	Poor
Patuxent River	MH	H	NP	M	M	L	H	WL	Bad
Potomac River	MH	H	L	H	M	M	H	WL	Bad

L = Low, M = Moderate, H = High, MH = Moderate High, ML = Moderate Low, U = Unknown, NP=No Problem, I = Increase, IH = Improve High, IL = Improve Low, WH = Worsen High, WL = Worsen Low, NC = No Change

Methods

Data Collection

The NEEA (Bricker et al., 1999) used a questionnaire to collect responses from experts, who summarized their data in order to provide the responses. The strongest criticism of the NEEA report was that the reader could not consult the original data. Therefore, one of the most important modifications this study proposed was to collect and use data for the assessment and then to make the data available to readers. For this study, the data were referenced, built into a database, and the database used for the assessment. The database will be made available on request from the authors.

The project team began the data collection effort by identifying data holders for each system and each indicator variable. Among the factors considered was the ease with which the data could be acquired. The team first sent data holders a letter requesting their data. The letter presented the benefit to the data holder of participating in the project. This effort was largely unsuccessful. Data holders were then contacted by phone. Although most agreed to send data, often it was not provided. In some cases, data were accessible electronically and this was partly successful. However, in many cases it was necessary to contact someone familiar with the database for clarification of metadata and other information. The most successful data collection method was a personal visit, but with limited project resources, this was not possible at an appropriate scale.

Thus, although there was adequate data to make the assessment for most systems, there is very likely uncollected data that could provide additional insight into the conditions in these systems. In cases where recent data were not found for index variables, the assessment results should be interpreted with caution.

Database Development

Two different database packages were considered for this project, Barcawin2000 and SAS. BarcaWin2000 is a relational water quality database, developed at the Geochemical and Ecological Modelling, Faculty of Sciences and Technology, New University of Lisbon, Portugal. It includes the features most used in oceanographic data analysis. However, SAS was chosen, despite the high purchase cost, because the National Marine Fisheries Service (NMFS) Marine Recreational Fisheries Statistical Survey (MRFSS) data were already in that format. Also, the human-use indicator model was more easily applied using statistical programs that are accommodated by SAS but not by Barcawin2000.

NEEA/ASSETS Method and Modifications

This study used the NEEA/ASSETS (Bricker et al., 2003) as a starting point for the water quality assessment method with modifications to make the method more suitable to the estuaries included in this study. The methodology uses a Pressure-State-Response framework to assess eutrophication in three component parts:

- Overall human influence (OHI) on development of conditions (Pressure)
- Overall eutrophic conditions (OEC) within a water body (State)

- Determination of future outlook (DFO) for conditions within the system (Response), note that this is not the traditional "Response" whereby management scenarios in response to condition are determined. Rather this approach determines the probable future response of the system based on expected future changes in nutrient load.

A simple model is used for determining "Pressure". Statistical criteria are used for indicator variables (where possible) to determine "State". The "Response" determination is mostly heuristic, although research models are being developed to improve this component (Bricker et al., 2004). The three components are determined individually and then combined into a single rating. Aspects of each component use a decision-logic approach to combine data and information into single multi-dimensional descriptors, and matrices are used to combine two components into single descriptors for each of the three components. A full description of the original method and details for previous modifications can be found in Bricker et al. (1999, 2003).

Pressure – Overall Human Influence (OHI): ASSETS OHI Model

The Pressure component of the assessment was designed to determine the influence of human-related inputs relative to the natural tendency of a system to either retain or flush nutrients (i.e., susceptibility). This component is determined by combining an estimate of susceptibility of a system and the level of nutrient inputs from the watershed.

The susceptibility of a system is determined from a combination of flushing and dilution values (e.g. High, Medium, Low) for a system. These values take into account stratification and dilution volume, tidal range, and the ratio of freshwater inflow to estuary volume, respectively (see Bricker et al., 1999 for method details).

In the 1999 NEEA study, nitrogen load estimates from the USGS SPARROW model (Smith et al., 1997) were classified into High, Medium, and Low ranges. This study uses a simple model described in Bricker et al. (2003) to estimate nutrient inputs. Briefly, the model compares anthropogenic nutrient loading and natural background concentrations. It also factors in potential nutrient inputs from oceanic sources. Thus, it addresses the question of whether management measures would be successful. For these systems, the background nutrient loads from the watershed are assumed to be negligible, compared to human pressure.

Equation 1 gives the nitrogen concentration in the estuary due to basin loading, making the assumption that natural sources are negligible, and accounting for the dilution effect of tidal exchange, which is reflected in the salinity terms:

$$m_h = \frac{m_{in}\,(S_o - S_e)}{S_o} \qquad (1)$$

where:

m_h = Human derived nitrogen concentration
m_{in} = Nitrogen concentration of the river
S_o = Salinity of ocean (end member)
S_e = Salinity of estuary

Equation 2 gives the nitrogen concentration if only nutrient input from offshore seawater is considered:

$$m_b = \frac{m_{sea}\,S_e}{S_o} \qquad (2)$$

where:

m_b = Background nitrogen concentration
m_{sea} = Nitrogen concentration of the ocean

From Equations 1 and 2, m_c, the expected total concentration of dissolved inorganic nitrogen (DIN), considering only conservative processes, may be obtained as:

$m_c = m_h + m_b$

The overall human influence is defined as m_h/m_c expressed as a percentage, which is essentially the ratio of land- or human-related inputs to oceanic inputs. It is assigned one of five categories: High, Moderate High, Moderate, Moderate Low, or Low. Model results are combined in a matrix with the susceptibility measure in place of the nutrient-load estimates that were used in the original NEEA method. For a full description of model development and use of the matrix to estimate the level of human influence, see Bricker et al. (2003).

Load Estimates

A search was done for loading estimates made for these systems so that load-response relationships could be analyzed. Model estimated loads were available for most of these systems from two separate models, the USGS SPARROW (Smith et al., 1997; Alexander et al., 2001) model and the WATERSN model (Whitall et al.,

Table 6
Load Estimates (10^3 metric tons/yr) for estuaries included in this study.

Source of Estimate, Base Year	SPARROW ~1997	WATERSN ~2000	Other
Kennebec/ Androscoggin R.	11.4		
Casco Bay	1.14	0.98	
Wells Bay			0.67 Langan, personal communication
Saco Bay	1.97		
Great Bay			
Plum Island Sound	6.62		
Boston Harbor			
Massachusetts Bay	0.665		
Mass. Bay + Boston Harbor		7.56	
Cape Cod Bay			
Buzzards Bay		2.18	
Narragansett Bay	4.38	8.44	7.07 Nixon et al. 2005
Long Island Sound	9.88	39.85	56.74 NYSDEC and CTDEP, 2000
Patuxent River	1.39		1.886 MD DNR, 2004
Potomac River	20.6		1.365 MD DNR, 2004

(SPARROW, Smith et al., 1997; WATERSN, Whitall, et al., 2004, Castro et al., 2003, 2002; R. Langan personal communication; NYSDEC and CTDEP, 2000; MD DNR, 2004).

2004; Castro et al., 2003; Castro and Driscoll, 2002). In addition, where budget estimates were made for specific systems, these are included for comparison (Table 6). Information on land use within the watershed is also helpful when examining sources of nutrient loading and influences on water quality (see Table 4).

State – Overall Eutrophic Condition (OEC)

The NEEA/ASSETS method for overall eutrophic condition uses a combination of six variables selected from the original 16 characterized in the NEEA (Bricker et al., 1999). These were divided into two groups. One group consisted of variables that are indicators of primary or early-stage symptoms:

- Chlorophyll a (Chl a)
- Epiphytes
- Macroalgae

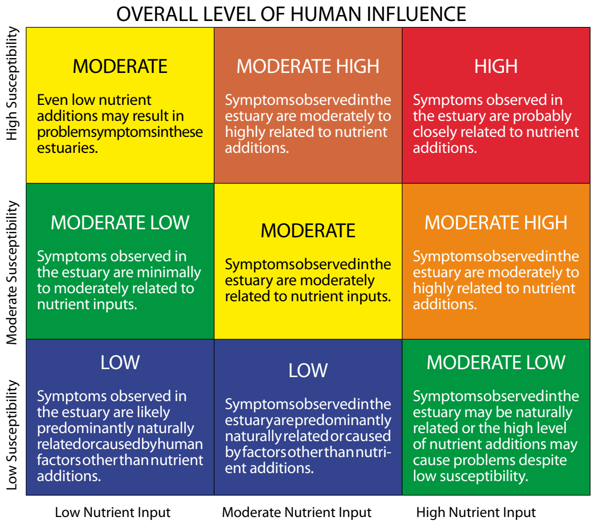
The second group of variables gives indications of secondary or well-developed eutrophication symptoms:

- Dissolved oxygen (DO)
- Submerged aquatic vegetation (SAV) loss
- Harmful algal bloom (HAB) occurrence

A determination is made of the level for each indicator by combining the concentration or condition of the variable (e.g., bloom concentration of Chl a, or lowest concentration of DO), the spatial area over which the extreme conditions occur, and the frequency with which it is observed (e.g., annually, periodically, episodically; Table 7). Separate salinity zone results are combined to give a weighted average value for the estuary. This numerical value is then converted to a categorical rating (High, Moderate, Low).

The overall primary symptom level is determined by averaging the values for Chl a, epiphytes, and macroalgae. The highest of the three secondary symptoms (DO, loss of SAV, HAB occurrences) is selected based on the assumption that these symptoms indicate a well-developed problem. The values are combined by matrix to determine an overall rating of eutrophic conditions for the estuary (Figure 2).

Figure 2
Determination of overall eutrophic condition (OEC) from primary and secondary symptom expression by matrix.



OVERALL LEVEL OF HUMAN INFLUENCE

	Low Nutrient Input	Moderate Nutrient Input	High Nutrient Input
High Susceptibility	MODERATE Even low nutrient additions may result in problem symptoms in these estuaries.	MODERATE HIGH Symptoms observed in the estuary are moderately to highly related to nutrient additions.	HIGH Symptoms observed in the estuary are probably closely related to nutrient additions.
Moderate Susceptibility	MODERATE LOW Symptoms observed in the estuary are minimally to moderately related to nutrient inputs.	MODERATE Symptoms observed in the estuary are moderately related to nutrient inputs.	MODERATE HIGH Symptoms observed in the estuary are moderately to highly related to nutrient additions.
Low Susceptibility	LOW Symptoms observed in the estuary are likely predominantly naturally related or caused by human factors other than nutrient additions.	LOW Symptoms observed in the estuary are predominantly naturally related or caused by factors other than nutrient additions.	MODERATE LOW Symptoms observed in the estuary may be naturally related or the high level of nutrient additions may cause problems despite low susceptibility.

(From Bricker et al., 2003).

Extreme values for Chl a and DO, which are measured in a standard manner, are determined from annual data, in contrast to the NEEA, which relied on expert judgment for the determination. Statistical criteria are used for the assessment: the 90th percentile concentration during the annual cycle for Chl a and the 10th percentile for DO (Bricker et al., 2003). These are then con-

Table 7
Method of Assessment for indicator variables used in NEEA/ASSETS methodology.

Indicator Variable		Method of Assessment
Primary Symptom Indicators	Chlorophyll a	90th percentile + spatial coverage of highest concentrations + frequency of occurrence of highest concentrations
	Macroalgae Epiphytes*	Problems are heuristically determined as detrimental impacts to any biological resource + frequency of occurrence of problems
Secondary Symptom Indicators	Nuisance and Toxic Blooms	Problems are heuristically determined as detrimental impacts to any biological resource + frequency of occurrence of problems + duration of blooms
	Bottom Water Dissolved Oxygen	10th percentile + spatial coverage of highest concentrations + frequency of occurrence of highest concentrations
	Loss of SAV	Decreases in spatial coverage of submerged grasses

* (Not used in present study)

verted to categorical ratings using the NEEA thresholds. Additional improvements to the original "expert knowledge" methodology have also been proposed for the other variables; presently, however, these are still determined heuristically (Table 7).

OEC Method Modifications

Several changes were made to the eutrophic assessment method described above:

1) The project team determined that of the six variables, the epiphyte indicator would not be useful to this study for several reasons: there is no standard measure; existing data for epiphytes was scarce for the selected systems; and the SAV indicator variable, in large part, reflects the level of epiphyte colonization.

2) The team also evaluated the threshold levels for each indicator to determine whether they would give an accurate assessment of the conditions within these systems. With one exception, the thresholds were evaluated as accurate for these systems. The exception was toxic blooms. In the 1999 report, including toxic blooms had resulted in the assessment of some Gulf of Maine systems (e.g., Narraguagus Bay) as highly eutrophic, despite no other serious symptoms. These blooms occur on an annual basis but they begin naturally in offshore waters and are advected into the Bay. The original report noted these systems as highly eutrophic because it was unclear whether the blooms were grown within the system as a result of land-based nutrient inputs. The project team decided to qualify this indicator and to use a Low assessment rating if the blooms began offshore. There was discussion about whether to exclude HABs completely in these cases, however, it is also believed that nutrients within the estuary can support and maintain the populations that enter, and thus a rating of Low was more justifiable.

3) It was determined that there was an increase in SAV spatial coverage in some systems. The original method has no response category for observed increases – only losses. The project team thought it important to note where grasses are increasing in spatial coverage and added a response of Increase. Although the expression value is 0 and thus does not alter the resultant rating, it notes where increases are occurring.

4) For some systems, only seasonal data were available and requirements for use of the statistical criteria were not met. In these cases, mean values were used for the data that were available because using the percentile method of determination (10th for DO and 90th for Chl a) would bias the results.

5) The spatial coverage for indicator variables was determined for the entire estuary, and not by separate salinity zones as in the original methodology. Spatial coverage for the indicator variables was made by analyzing the data for each station and visually examining the individual station results plotted on an estuary map.

Response – Determination of Future Outlook (DFO)

The Response component – or future outlook – is designed to estimate changes that might occur given predicted changes in nutrient input to a system. Predictions of nutrient loading (increase, decrease, unchanged) are based on predicted population increase, planned management actions, and expected changes in watershed uses. The expected change is combined in a matrix with the susceptibility, which influences the rate at which a system will respond, to give an assessment of expected future condition – Worsen, No Change, or Improve.

ASSETS Synthesis – Grouping Pressure, State and Response Indicators

The last step is to combine the OEC, OHI, and DFO into a single overall score. The scores fall into one of five categories: High, Good, Moderate, Poor, or Bad. These categories are used by the EU Water Framework Directive (EUWFD, 2000/60/EC). Although the Directive does not apply to U.S. systems, the framework provides a useful scale for setting eutrophication-related reference conditions for different types of systems (e.g., Bettencourt et al., 2004) and should be encouraged in the U.S. It is used in this methodology.

Data

The only data that were available for almost all systems were Chl a and DO (See Table 8), which were usually accompanied by salinity, temperature, and depth. It was difficult to find data for SAV, macroalgae and HABs, because there are no standard measures for these variables. For two systems, Kennebec/Androscoggin River and Saco River, there were insufficient data for analysis. For several systems, results should be interpreted with caution because of missing data for SAV, macroalgae, and HABs (Table 8). For some systems, Chl a and DO data were available, although sampling was done only during the summer months (e.g., data for Narragansett Bay and Buzzards Bay are EMAP data which are collected during an index period). For these situations, an assessment was still made but the statistical procedure was not applicable instead. The assessment was based on mean values because the 90th and 10th percentile would bias the results (see Appendix 1: Narragansett Bay and Buzzards Bay).

Human-Use Indicator Method

Another significant goal of this project was to develop a socioeconomic or human-use indicator of coastal eutrophication. The traditional approach to assessing coastal eutrophication and related water quality impacts focuses on how human activities affect water quality. Recently, there has been great interest in looking at the issue from a different perspective: documenting how eutrophication and its related water quality affect human uses of coastal waters and estuaries (U.S. EPA, 2005). This study develops an indicator for one of the many possible impacts to human uses of an estuary, complementing the NEEA/ASSETS method and providing a more complete picture of the system.

Selection of a Human-Use Indicator

Given the complex nature of the process and expression of eutrophication, there are a variety of potential human-use impacts, including impacts to commercial and recreational fishing, fish consumption, swimming, boating, aesthetics, and tourism (Bricker et al., 1999; U.S. EPA, 2005). For this pilot project, an indicator was selected that was likely to be sensitive to eutrophication and for which there was common data among the estuarine systems. Earlier work has shown a relationship between catch rates of recreational species and water quality (Bockstael et al., 1989; Freeman, 1995; Karou et al., 1995). Recent work by Lipton and Hicks (1999; 2004) related striped bass (Morone saxatalis) recreational fish catch rates directly to DO measurements in the vicinity of the fishing activity. Striped bass is a migratory species that is targeted by recreational fishing activity in all the estuaries within the study area. Two other recreational species, bluefish (Pomatomus saltatrix) and winter flounder (Pseudopleuronectes americanus), were also selected for inclusion in the analysis. These species were chosen because they are popular recreational species that migrate throughout the range of the study area.

The Recreational Catch Rate Model

Following Lipton and Hicks (2004), expected recreational fish catch was modeled as a function of angler-specific factors and environmental factors:

$$C_{i,j,k,m} = \alpha + \beta_1 MC_{j,k,m} + \beta_2 HRSF_{i,j,k,m} + \beta_3 FDAY_i + \beta_4 SSALIN_{k,m} + \beta_5 BSALIN_{k,m} + \beta_6 STEMP_{k,m} + \beta_7 BTEMP_{k,m} + \beta_8 BDO_{k,m} + \beta_9 (BDO_{k,m})^2 + \beta_{10} CHLA_{k,m} + \beta_{11} (BDO_{k,m} {*} BTEMP_{k,m})$$

where $C_{i,j,k,m}$ is the catch of recreational angler i, fishing for species j (striped bass, bluefish, or winter flounder) in area k, representing the 10 estuarine systems in the study (there was inadequate data for the other four systems), in month m. HRSF is the number of hours spent fishing on the specific recreational trip being surveyed. $MC_{j,k,m}$ is the mean catch of all anglers fishing for species j in estuary k in month m. By normalizing on mean catch, it is expected that deviations in catch rate from the mean are due either to angler skill or environmental factors. Angler skill is captured by the FDAY variable, which represents the number of days in the previous period the angler took a fishing trip.[1] $SSALIN_{k,m}$ and $BSALIN_{k,m}$ represent surface and bottom salinity, respectively. Similarly, surface and bottom water temperature were represented as $STEMP_{k,m}$ and $BTEMP_{k,m.}$ Bottom dissolved oxygen measurement in the estuary was included as $BDO_{k,m}$ in a quadratic form with the expectation that the squared term would have a negative coefficient so that the impact of increased dissolved oxygen on catch rate would diminish with increasing oxygen levels. Bottom DO and temperature were also included as an interactive term. Finally, Chl a concentration ($CHLA_{k,m}$) was included to determine what impact that might have on fish catch. Parameters to be estimated in the statistical model are represented by α and β_2- $\beta_{11.}$

One of the major differences between this study and Lipton and Hicks (2004) is that this study examined the effects of eutrophication on three different species in 10 different estuarine systems. The previous work looked at only one species (striped bass) in one system (Chesapeake Bay). With multiple species and systems, it is possible to see how results vary by species or if species can be combined. It is also possible to examine whether different classifications of estuarine systems respond differently. Another major difference is that Lipton and Hicks (2004) looked at spatial water quality variations within an estuary within a single year. The present study aggregates the observations up to the estuary level and looks at multiple years of data.

Data

The water quality data used to estimate the model (including the water quality variables for surface and bottom waters such as temperature, salinity, Chl a, and DO) were taken directly from the ASSETS/NEEA database. Recreational fish catch and angler data were taken from the National Marine Fisheries Service's (NMFS) Marine Recreational Fisheries Statistical Survey (MRFSS) database (Gray et al., 1994). The MRFSS database has collected recreational fisheries data since 1979 in all coastal states except Hawaii, Alaska, and U.S. territories. MRFSS data were collected using a telephone survey and interviews at fish landing intercept sites. Only the data from the intercept site interviews were used here to develop the indicator. The intercept data provide information on the primary species sought by the angler during the fishing trip, the total number of fish caught of that species, the length of time spent fishing, and the number of days the angler has gone fishing in the past 12 months. This study only used data from fishing trips where striped bass, winter flounder, or bluefish were the primary species sought by the angler. The monthly mean catch rate for a species in an estuary ($MCR_{j,k,m}$) was calculated from the MRFSS data for the period 1993-2002.

Latitudes and longitudes of each intercept site were plotted on a geographical information system (GIS) program and any intercept site not within the boundary of the estuaries under study was excluded. Wherever possible, estuarine boundaries were taken from the NOAA's Estuarine Eutrophication Surveys (Bricker et al., 1996, 1997a, b, c, and 1998). Of the study sites, only Wells National Estuarine Research Reserve (NERR) is not included in the NOAA Estuarine Eutrophication Surveys. The estuarine boundaries for Wells NERR were drawn heuristically across the mouth and extend up to the head of tide. Figure 3 is an example of how the MRFSS intercept sites within Long Island Sound compare with the locations of the estuary's water quality sites. In this manner a single MRFSS/ASSETS database was developed for each estuary included in the study. The ASSETS/NEEA water quality data were averaged by month and estuary. The angler data were then merged with the water quality data so that each individual fishing trip was assigned the average water quality data for that estuary for the month in which the fishing trip took place (Figure 4).

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[1] Lipton and Hicks (2004) also include the number of years of fishing experience for the angler, but this was subsequently dropped from this model because of data limitations.

Figure 3
GIS depiction of fisheries intercept sites and water quality sampling stations within Long Island Sound.

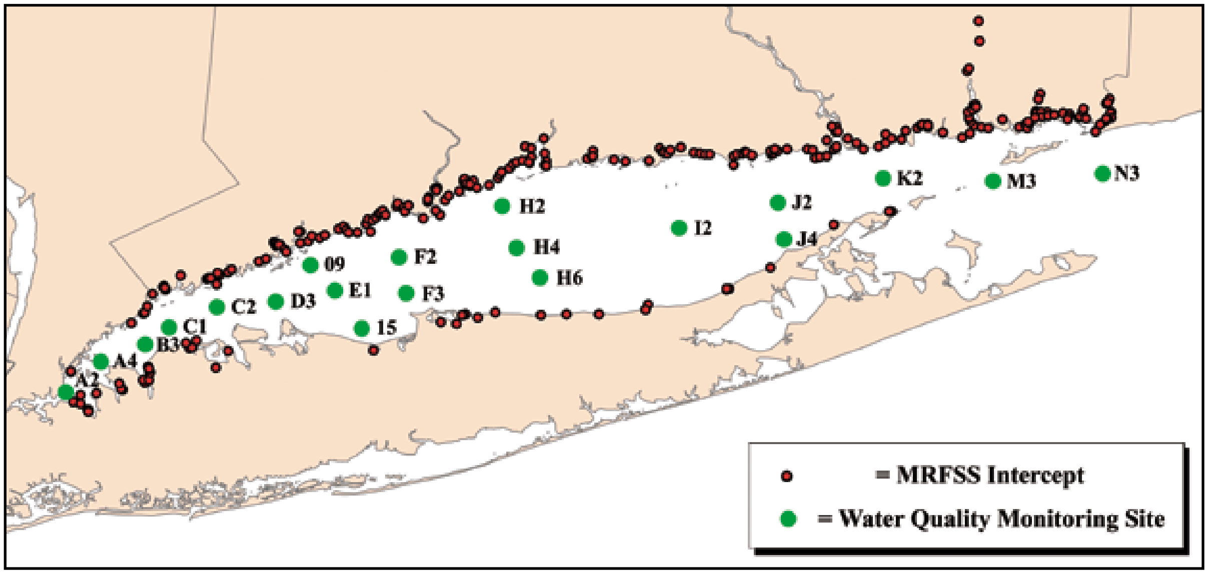


Figure 4
Depiction of combining MRFSS and the ASSETS data.

MRFSS	ASSETS	COMBINED
Fish Survey Data • Type I — angler info • Type II — unavailable catch • Type III — available catch Angler Variables • Hours Fished • Days fish in last 12 months • Historical fish catch	Water Quality Variables • Surface /Bottom Salinity • Surface /Bottom Temperature Eutrophication Variables • Surface Chi a • Bottom DO • Bottom DO squared • Bottom temperature and DO cross product d	Final Database — Water Quality — Fish Survey

Results and Discussion

NEEA/ASSETS Eutrophication Assessment

The NEEA/ASSETS methodology, with the modifications described, was applied to 12 estuarine and coastal systems in the Gulf of Maine and Mid-Atlantic. Although the proposed objective was to update the eutrophic condition assessment, the Pressure-State-Response method could not be applied without nutrient-loading and concentration data, thus these data were collected as well. Because of inadequate data, the application could not be completed for the Kennebec/Androscoggin River and Saco River systems (Table 8). For other systems (e.g., Narragansett Bay, Buzzards Bay), data were available but not on an annual basis. In these cases, data synthesis and heuristic methods were combined to make the strongest and most complete evaluation possible. In cases where data for some indicators, such as macroalgal abundance, could not be acquired, this was noted and the method carried out as completely as possible.

Pressure – Overall Human Influence (OHI)

Results for the evaluation of Pressure, or factors influencing the expression of eutrophic conditions in these systems show a pattern of increasing human influence from north to south. Lower overall human influence was found in the Gulf of Maine systems and higher levels in systems of the Mid-Atlantic region. This is a combined estimate using the susceptibility of a system and the nutrient load (described in the Methods section). This reflects the lower residence times and higher tidal ranges in the northern systems, but also corresponds to lower populations in these systems (Table 3). Watershed population estimates show a general increase from north to south, with the exception of Boston Harbor and Massachusetts Bay, which are high by comparison to other Gulf of Maine systems. There is no apparent regional pattern in either total load or load normalized to the estuarine area.

State – Overall Eutrophic Condition (OEC)

Chlorophyll a (Chl a)

Chlorophyll a (Chl a) was assessed as High in most systems; only Wells and Buzzards Bays received Low assessment ratings (Table 8, Figure 5). There is no apparent regional pattern of Chl a, with High level conditions observed along the entire transect of systems.

Figure 5
Chl a level of expression in estuaries included in this study Level of expression is a combination of the highest concentration observed in an annual cycle (determined as 90th percentile), spatial coverage of the highest concentrations, and frequency of occurrence of the highest concentrations.

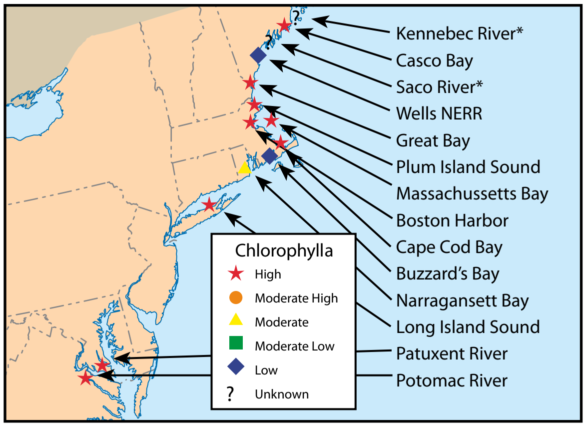


Table 8
Results of the application of NEEA/ASSETS methodology, with specified modifications by project team, to systems included in this study.

System	OHI	OEC						DFO	ASSETS
		Primary		Secondary			Overall		
		Chl a	Macroalgae	Diss. Oxy.	HABs	SAV loss			
Kennebec/AndroscogginRiver									
Casco Bay	L	H	U	NP	L	I	M	IH	Moderate
Saco Bay									
Wells Bay	L	L	U	NP	L	U	L	WL	Good
Great Bay	L	H	U	NP	U	I	M	WH	Moderate
Plum Island Sound	M	H	U	NP	M	U	MH	WH	Poor
Boston Harbor	M	H	U	NP	NP	L	M	IL	Moderate
Massachusetts Bay	L	H	U	NP	L	U	M	WL	Moderate
Cape Cod Bay	ML	H	L	NP	L	U	M	WL	Moderate
Buzzards Bay	ML	L	L	NP	NP	L	L	WL	Good
Narragansett Bay	M	M	H	M	L	L	MH	NC	Poor
Long Island Sound	M	H	U	L	U	L	M	IL	Moderate
Patuxent River	H	H	NP	M	L	I	M	IL	Moderate
Potomac River	H	H	NP	L	H	I	H	IL	Bad

For Casco Bay and Wells Bay when HABs were included, the ASSETS assessment result was Poor for both and OEC was H for Casco and MH for Wells. Given a low assessment for HABs the OEC changed to M and L respectively variable gives a more accurate assessment of these systems. L = Low, M = Moderate, H = High, MH = Moderate High, ML = Moderate Low, U = Unknown, NP=No Problem, I = Increase, IH = Improve High, IL = Improve Low, WH = Worsen High, WL = Worsen Low, NC = No Change, Bold L for HABs indicates use of the modified HAB criteria which would previously have been noted as H.

Macroalgae

Macroalgae data were difficult to find (Table 8, Figure 6). There are only five systems for which this information was available and the level of expression in these systems was designated as Low, High, and No Problem. These data are inadequate to resolve any regional patterns.

Dissolved Oxygen (DO)

Dissolved oxygen (DO) level of expression varies from No Problem to Moderate. Conditions in two systems are shown as Unknown because there were inadequate data with which to make an assessment (Table 8, Figure 7). There is a noticeable trend, with the systems north of Cape Cod showing No Problems with low DO conditions, and those to the south showing Low to Moderate conditions. While this might be interpreted as corresponding to lower temperatures in the more northern systems, it is also concurrent with the generally higher tidal ranges, lower watershed populations, and lower agricultural land use in those systems (Tables 3 and 4).

Harmful Algae Blooms (HABs)

Data for occurrences of nuisance and toxic blooms, together called HABs, were found for most, but not all, systems (Table 8, Figure 8). This indicator is intended to evaluate the occurrence of nuisance and toxic blooms that form inside the system resulting from human-related nutrient sources. HABs are observed in many Gulf of Maine systems and for many of these systems shellfishing is subsequently banned. However, the origin of the blooms is typically offshore where they occur naturally and then advect into these systems.

In the original method, toxic bloom occurrences in the North Atlantic systems usually received a High rating because of the duration and frequency with which they occur. This lead to falsely High eutrophication assessment ratings for these systems, which often had no other indicators of nutrient-related problems. In this study, this indicator was modified for systems that have occurrences of HABs (toxic blooms, in particular) as a result of advection into the system of naturally occurring offshore blooms. They receive an expression value of Low to indicate that although they form offshore, nutrients within these systems may maintain and grow the blooms.

There were two systems for which this modification changed the assessment ratings. For Casco Bay, the overall eutrophic condition (OEC) changed from High to Moderate, and the ASSETS value changed from Poor to Moderate. For Wells Bay, the OEC changed from Moderate High to Low and ASSETS from Poor to Good. It was anticipated that other systems north of Cape Cod would require application of the modified HAB expression value. However, for the other systems where HABs could be evaluated, nuisance or toxic blooms that originate within the system were observed in addition to blooms that advect in from offshore. These systems were rated based on the other blooms observed.

There is no distinct regional pattern of HAB occurrences. For several systems, data were insufficient to make an evaluation (Table 8).

Loss of Submerged Aquatic Vegetation (SAV)

There is no apparent trend in loss of submerged aquatic vegetation among the systems studied (Figure 9). Among those for which an assessment could be made, increases in distribution of SAV have been observed in systems in the Gulf of Maine and in the Mid-Atlantic, and there have been low magnitudes of loss recorded for other Mid-Atlantic systems

Figure 6
Macroalgae level of expression in estuaries included in this study. Level of expression is combination of observation of problem occurrences in an annual cycle and frequency of occurrence of problem abundances.

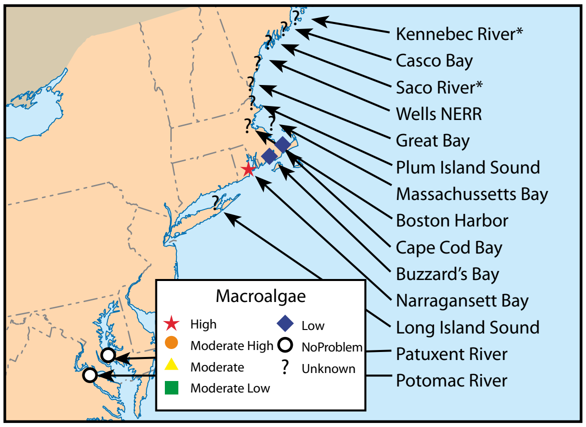


Figure 7
Dissolved oxygen level of expression in estuaries included in this study. Level of expression is combination of the lowest concentration observed in an annual cycle (determined as 10th percentile), spatial coverage of the lowest concentrations, and frequency of occurrence of the lowest concentrations.

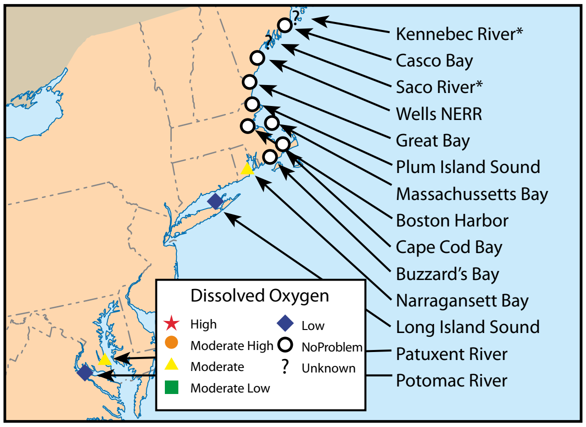


Figure 8
HAB level of expression in estuaries included in this study. Level of expression is combination of the observation of problem occurrences of highest concentration observed in an annual cycle and their frequency of occurrence.

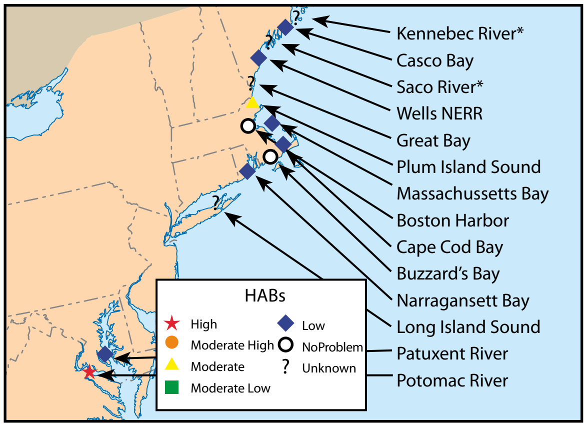
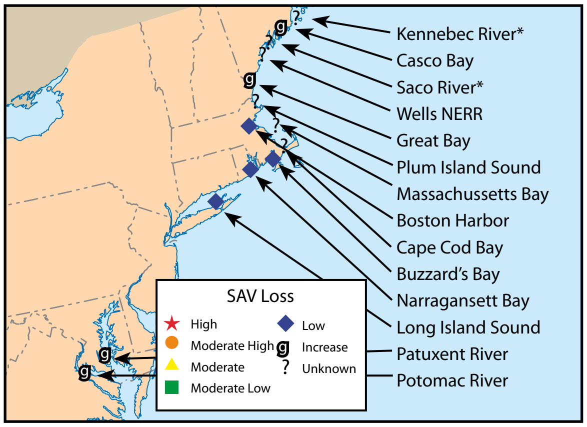


Figure 9
SAV loss level of expression in estuaries included in this study. Level of expression is combination of observation of loss of spatial coverage of submerged grasses and the magnitude of the loss.



Up arrow indicates an increase in spatial coverage of submerged grasses.

Response – Determination of Future Outlook (DFO)

Determination of future conditions is based on known or expected population trends, land use changes, and implemented or planned management measures. For most systems, there is the expectation that management measures either will be implemented or that presently existing measures will take full effect in the future. However for several systems, conditions are expected to worsen because of projected increases in coastal population that will likely counteract management measures (Table 8). The general pattern seen here is that conditions in most systems north of Cape Cod are expected to worsen, while conditions in systems south of the Cape are expected to improve.

ASSETS Synthesis

The three components are synthesized into a single ASSETS assessment expression, shown in Figure 10. There is no apparent pattern. Seven systems were assessed as Moderate, two were assessed as Poor, two were assessed as Good, and one as Bad. Notably, the one system with the Bad assessment, Potomac River, is south of Cape Cod, and the two with the Good assessments are on or north of Cape Cod (Buzzards Bay and Wells Bay).

Comparison of results from this study (Table 8) with the 1999 NEEA results (Table 5) shows some changes. The earlier results were reworked to match the factors used in the current study by, for instance, excluding epiphytes. Nevertheless, there are still differences in the formulations, and thus comparisons should not be made of the overall results. Only comparisons for DO and Chl a were made. The most striking results are for Chl a. All systems north of Cape Cod have higher levels now than they did in the early 1990s, the timeframe represented by the 1999 NEEA report. For DO there is also a regional difference: all Gulf of Maine systems show changes from assessments of Low to No Problem; the Mid-Atlantic system DO conditions remained mostly the same. Results for the other indicators cannot be compared due to missing data. Because this study did not distinguish data by salinity zone, it is not possible to determine where changes have occurred. The level of detail provided by assessing salinity zones separately is important for that type of analysis, and on a larger scale, the data should be collected by salinity zone or some other spatial framework.

Figure 10
ASSETS values for estuaries included in this study.
Combined rating of OHI, OEC and DFO.

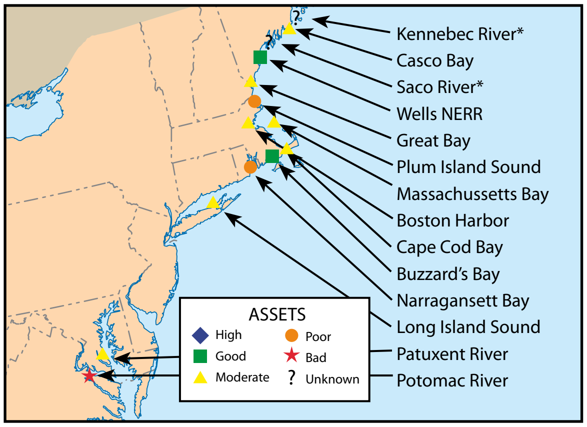
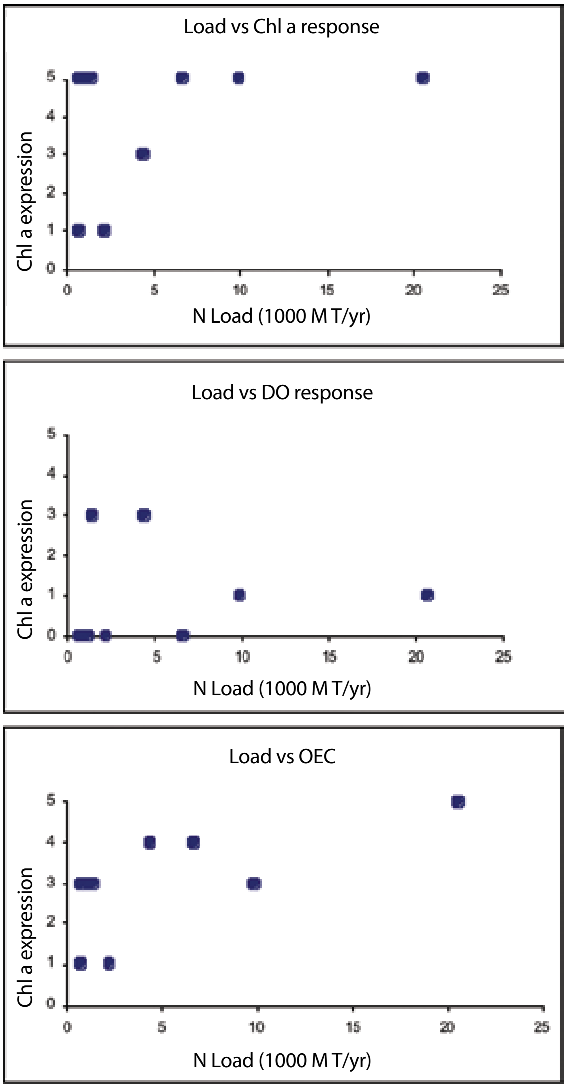


Figure 11
Load-response relationships.
No regressions made due to the noncontinuous nature of the data.



(Loading data from Table 6: SPARROW, Smith et al., 1997; WATERSN, Whitall, et al., 2004, Castro et al., 2003, 2002; Langan personal communication.)

Load Response Relationships

The idea that different types of systems process nutrients differently and express eutrophic symptoms differently, suggests that if a relationship could be developed, predictions could be made to increase the success of management measures. This is being pursued by EPA (Latimer and Kelly, 2003) and is the focus of one of the NEEA Program working groups (Typology, Bricker et al., 2004; Smith et al., 2004). Although the results here are not continuous, the temptation was to attempt to find relationships between nutrient load and waterbody response (Figure 11). There is the suggestion of a relationship between nutrient load and the combined Chl a response expression (top panel Figure 11) and between nitrogen load and the OEC rating (bottom panel Figure 11). Results are not as promising for the load vs. DO response (middle panel Figure 11). While it is tempting to calculate regressions for these relationships, the data are non-continuous, and so not amenable to regression analysis. And while it is premature to draw conclusions based on this limited data, it is encouraging to see that there are the possibilities of relationships, and thus of potential predictive capabilities. However, much more research and analysis is needed before any confidence can be placed in these relationships.

Table 9
Data constraints to estimating recreational fish catch rate model.

	Striped Bass	Bluefish	Winter Flounder
Boston Harbor	None	Fish	Fish
Buzzards Bay	WQ	WQ	WQ
Cape Cod Bay	None	Fish	Fish
Casco Bay	Fish	Fish	Fish
Great Bay	Fish	Fish	Fish
Kennebec/Androscoggin	WQ	WQ	WQ
Long Island Sound	None	None	None
Massachusetts Bay	Fish	Fish	Fish
Narragansett Bay	None	None	None
Patuxent River	None	None	Fish
Plum Island Sound	WQ	WQ	WQ
Potomac River	None	None	Fish
Saco River	WQ	WQ	WQ
Wells NERR	Fish	Fish	Fish

Limiting factors:
WQ=water quality, fish=recreational fishing data, None or Both

Human-Use Assessment

The fish catch rate models were estimated using a Poisson regression. A Poisson distribution has the mean and variance equal, and was employed because of the high number of zero observations acquired when measuring fish catch. The model was estimated at different levels of aggregation (Figure 12). At the highest level, the aggregation was performed across fish species and estuaries, so that the basic question of whether water quality impacts recreational fish catch rates can be examined. At the most disaggregated level, estimates were made of the impacts of water quality on catch rates for each one of the species in each specific estuary. At the more disaggregated level, data limitations prevented estimating the model for all species and estuaries (Table 9). Typically, it was the lack of recreational fish data that prevented this, but in a few cases too few observations of water quality was the limiting factor[1].

Figure 12
Sequence of recreational catch rate model runs.

Test Of Model

1. All estuaries, all fish species
2. All estuaries , individual fish species
3. Regional estuaries, all fish species
4. Regional estuaries, individual fish species
5. Open/Closed estuaries, all fish species
6. Open/Closed estuaries, individual fish species

Figure 13
Summary of results for all estuaries – all fish species.

All Estuaries — All Fish Species

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	NS*
Surface Chi a	B
DO x Temp Cross Product	B

*NS indicates a non-significant relationship

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[1] MRFSS was designed to allow estimates of recreational fish catch and effort on a state-by-state level; therefore, sampling effort in smaller estuaries may be inadequate for a particular level of disaggregation by geographic area.

Because the greatest concern is with the predictive capability of the model as it relates to eutrophic conditions, the focus is on reporting results for the "core variables". The core variables are those that include DO and Chl a. (Results for other model parameter estimates are available from the authors.) Changes in dissolved oxygen correspond to changes in fish catch, except that once oxygen levels reach a certain point, there is no added benefit to further increases (i.e., the fish catch will remain the same even if dissolved oxygen continues to increase in concentration). Using the dissolved oxygen squared term (DO^2) takes that into account. The core model results are summarized in Figure 13.

All fish, all systems

In this model, we looked at angler catch rates regardless of species sought or estuarine system. The angler is still assigned the mean catch rate and water quality depending on the species sought and area fished, but the dependent variable is simply expected fish catch. In this aggregate model, the water quality variables that showed a significant (at the 90% confidence level) relationship to fish catch were bottom water DO, surface Chl a, and the cross-product of bottom water temperature and bottom water DO (Figure 13; a complete table of core variable results can be found in Appendix 2). The relationship for bottom water DO was positive so that one can state that, in the aggregate, improvements in bottom DO lead to higher recreational fish catch rates. The inverse is true for both surface Chl a and the DO-temperature cross-product.

Individual species, all systems

The next iteration tested the model separately for each species, but continued to aggregate across estuaries. The model performed fairly well for all species, but was best for striped bass in all estuaries. For striped bass, all of the core variables were significant at the 90% confidence level (Figure 14). For bluefish, both DO and the DO^2 variables were significant (Figure 15), whereas for winter flounder only bottom water DO was not significant (Figure 16). For striped bass, the results for all estuaries included in the study show an increase in fish catch rate concurrent with an increase in bottom water DO. The opposite is true for DO^2, surface Chl a, and the DO-temperature cross-product. As the value for these variables increase, the fish catch rate decreases. For bluefish, the results for all estuaries included in the study show an increase in fish catch rate concurrent with an increase in both bottom water DO and its squared value. For winter flounder, the results for all estuaries included in the study show that an increase in the fish catch rate is concurrent with a decrease in the DO^2 variable and an increase in both surface Chl a and the DO-temperature cross-product.

Figure 14
Summary of results for all estuaries — striped bass.

All Estuaries — Individual Fish Species

STRIPED BASS

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	B
Surface Chl a	B
DO x Temp Cross Product	B

Figure 15
Summary of results for all estuaries — bluefish.

All Estuaries — Individual Fish Species

BLUEFISH

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	G
Surface Chl a	NS
DO x Temp Cross Product	NS

Figure 16
Summary of results for all estuaries — winter flounder.

All Estuaries — Individual Fish Species

WINTER FLOUNDER

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	B
Surface Chl a	G
DO x Temp Cross Product	G

All species by region

To examine whether there are regional differences among results, we placed the systems into either a Gulf of Maine or Mid-Atlantic region. Estuaries north of and including Cape Cod were considered to be in the Gulf of Maine region and any estuary south of Cape Cod was considered to be in the Mid-Atlantic region (Table 10).

Figure 17
Summary of results for Mid Atlantic estuaries — all fish species.

Mid Atlantic Estuaries — All Fish Species

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	NS
Surface Chl a	B
DO x Temp Cross Product	NS

Figure 18
Summary of results for Gulf of Maine estuaries — all fish species.

Gulf of Maine Estuaries — All Fish Species

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	G

Figure 19
Summary of results for Mid Atlantic estuaries — striped bass.

Mid Atlantic Estuaries — Individual Fish Species

STRIPED BASS

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	B

For the Mid-Atlantic region with all fish species combined, only bottom water DO and surface Chl a were significantly related to fish catch (Figure 17). Model results show that as bottom water DO levels increased, the fish catch rate also increased. For surface Chl a, however, as concentrations increased, fish catch decreased. In contrast, for Gulf of Maine estuaries, bottom water DO, DO^2, and surface Chl a were significantly related to fish catch (Figure 18). The bottom water DO variable and surface Chl a variables were negatively related to fish catch rate; however, the DO^2 and DO-temperature cross-product were positively related to catch rate.

Species by region

Each region was tested using individual fish species. For striped bass in the Mid-Atlantic region, bottom water DO was not significant, but DO^2 was significant and had a positive sign (Figure 19). For Chl a, the cross-product of bottom water DO and bottom water temperature, the coefficient was significant and negative. For striped bass in the Gulf of Maine region, surface water Chl a was the only core variable that was not significant at the 90% confidence level (Figure 20). DO^2 and the cross-product of bottom water DO and bottom water temperature were both significant and positive, whereas DO alone had a significant and negative effect on catch rate.

Table 10
Physical location, open vs. closed, type of system, and region information for systems in study.

Estuary	Percent Open	Open vs Closed	System Type	Region
Buzzards Bay	3.58	Closed	1	Mid Atlantic
Narragansett Bay	4.2	Open	1	Mid Atlantic
Long Island Sound	1.66	Closed	7	Mid Atlantic
Patuxent River	0.41	Closed	1	Mid Atlantic
Potomac River	1.33	Closed	1	Mid Atlantic
Casco Bay	4.75	Open	7	Gulf of Maine
Wells Bay	0.85	Closed	7	Gulf of Maine
Great Bay	1.49	Closed	7	Gulf of Maine
Plum Island Sound	3.24	Closed	7	Gulf of Maine
Boston Harbor	4.49	Open	7	Gulf of Maine
Massachusetts Bay	20.55	Open	5	Gulf of Maine
Cape Cod Bay	10.5	Open	5	Gulf of Maine

Type is based on Bricker et al., in preparation.

In the Mid-Atlantic region, bluefish catch was significant and positively related to bottom water DO^2 (Figure 21). Bluefish catch rate in the Gulf of Maine estuaries is significant and negatively related to bottom water DO and surface Chl a, and positively related to bottom water DO^2 (Figure 22).

For winter flounder in the Mid-Atlantic region, both surface Chl a and the cross-product of bottom water DO and bottom water temperature positively impact the catch rate (Figure 23). Insufficient data prevented an estimate of the model of Gulf of Maine estuaries for winter flounder.

All species by estuarine classification

For further analysis of how recreational fishing in an estuary might be impaired by eutrophic conditions, the estuaries were re-grouped into two categories based on one of the estuary's important physical characteristics: how open or closed the estuary is relative to mixing with the oceanic environment. To determine whether an estuary is open or closed, the amount of the estuary's perimeter that borders open water was examined. The idea is that, in general, in a closed estuary eutrophic conditions may be amplified or enhanced because there is less interaction with open waters, and the relative estuarine fish population may be more influenced by occurrences and responsive to factors and conditions occurring within the estuary. For open systems, the reverse may hold true. To categorize the estuaries, the percent open was estimated by dividing the estuary's perimeter adjoining open water by the total perimeter (Smith, 2003). The resulting value was plotted for all 136 estuaries for which these data were available and the threshold was heuristically determined (i.e., by visual determination of a natural break point from the data; Figure 24) to be 4%. Any estuary with 4% or more of its perimeter adjoining open water is thus considered open, and any estuary with less that 4% of its perimeter adjoining open water is considered closed (Table 10).

This compares reasonably well with groupings made in a preliminary type classification with the systems in this study primarily represented within two of 10 groupings of systems that resulted from a clustering

Figure 20
Summary of results for Gulf of Maine estuaries — striped bass.

Gulf of Maine Estuaries — Individual Fish Species

STRIPED BASS

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	NS
DO x Temp Cross Product	G

Figure 21
Summary of results for Mid Atlantic estuaries — bluefish.

Mid Atlantic Estuaries — Individual Fish Species

BLUEFISH

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	G
Surface Chl a	NS
DO x Temp Cross Product	NS

Figure 22
Summary of results for Gulf of Maine estuaries — bluefish.

Gulf of Maine Estuaries — Individual Fish Species

BLUEFISH

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	NS

Figure 23
Summary of results for Mid Atlantic estuaries — winter flounder.

Mid Atlantic Estuaries — Individual Fish Species

WINTER FLOUNDER

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	B
Surface Chl a	G
DO x Temp Cross Product	G

analysis (Smith et al., 2004). The Mid-Atlantic systems are mostly represented by Type 1, described as medium depth, medium mouth openness, and medium temperature. The Gulf of Maine systems are described as Type 7, characterized by high tidal range, medium mouth openness, and low temperature. Massachusetts Bay and Cape Cod Bay, with significantly larger percent open ratios, are classified as Type 5, with high mouth openness and high depth.

When estimating the model for open estuaries and the aggregate recreational fish catch rate, all of the core variables were significantly related to fish catch (Figure 25). Both the DO^2 and the cross-product of bottom water DO and bottom water temperature were significant, with an increase in these values concurrent with an increase in the fish catch rate. Chl a and bottom water DO were significant, with an increase in these values concurrent with an decrease in the fish catch rate.

For the closed estuaries and all three fish species, only bottom water DO and Chl a were significant (Figure 26). As bottom water DO increases, the fish catch increases in closed estuaries, while as surface Chl a increases, the fish catch decreases.

Estuarine classification by species

The model was run on individual fish species in both closed and open estuaries. Striped bass in closed estuaries had significant results in all of the core variables (Figure 27). As the DO and DO^2 increase, so does the fish catch rate. For surface Chl a and the bottom water DO and temperature cross-product, the results showed that an increase in either corresponds to a decrease in the fish catch rate in closed estuaries. DO^2 and the cross-product were the only two core variables that were significant for bluefish in closed estuaries (Figure 28). As DO^2 increased, the fish catch rate also increased. The cross-product of DO with temperature led to a decrease in the fish catch rate as the cross-product increased. For winter flounder in closed estuaries, only bottom water DO was not significant (Figure 29). As surface Chl a and the cross-product of DO and temperature increased, the fish catch rate also increased. The DO^2 value was significant, with an increase corresponding to a decrease in the fish catch.

In open estuaries, much like Gulf of Maine estuaries, it was not possible to successfully run the model on winter flounder because of inadequate fish catch records. However, for striped bass in open estuaries, only Chl a was not significantly related to fish catch (Figure 30). As both DO^2 and the cross-product term increase, the fish catch rate increases in open estuaries for striped bass.

Figure 24:
Percent open mouth for all estuaries.
4% selected as a natural break point heuristically.
Above 4% open – open mouth system.
Below 4% – closed mouth system

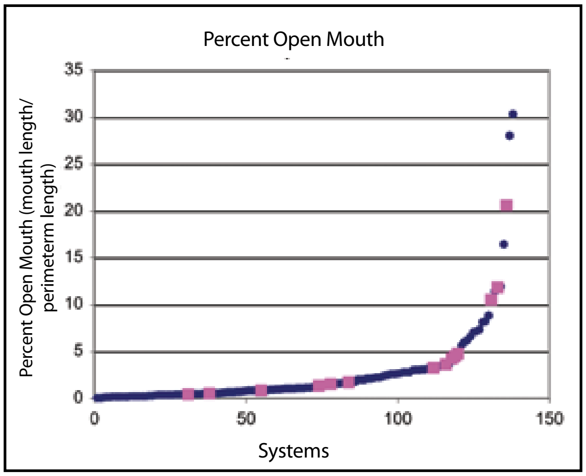

Figure 25
Summary of results for open estuaries — all fish species.

Open Estuaries — All Fish Species

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	G

Figure 26
Summary of results for closed estuaries — all fish species.

Closed Estuaries — All Fish Species

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	NS
Surface Chl a	B
DO x Temp Cross Product	NS

Figure 27
Summary of results for closed estuaries — striped bass.

Closed Estuaries — Individual Fish Species
STRIPED BASS

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	B

Figure 28
Summary of results for closed estuaries — bluefish.

Closed Estuaries — Individual Fish Species
BLUEFISH

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	G
Surface Chl a	NS
DO x Temp Cross Product	B

Figure 29
Summary of results for closed estuaries — winter flounder.

Closed Estuaries — Individual Fish Species
WINTER FLOUNDER

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	B
Surface Chl a	G
DO x Temp Cross Product	G

Figure 30
Summary of results for open estuaries — striped bass.

Open Estuaries — Individual Fish Species
STRIPED BASS

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	NS
DO x Temp Cross Product	G

Bottom water DO is opposite, showing a decrease in the fish catch rate as the variable increases.

For bluefish in open estuaries, only the cross-product was not significant (Figure 31). As both DO and Chl a decrease, the fish catch rate decreases in open estuaries for bluefish. Increases in DO^2 are concurrent with an increase in bluefish catch for open estuaries.

Predictive capabilities: preliminary results

For some systems, the results suggested that water quality, measured at the time of a fishing trip, significantly influences the catch of recreational anglers. When a reasonable model can be estimated, it can also be used to predict changes in catch rates that are predicated with expected changes in water quality. In particular, if modeling efforts produce estimates of changes in DO or Chl a concentrations, these estimates can be used to predict an increase in angler catches. For example, if the bottom water DO at mean conditions for a given estuary was 8 mg/l and corresponded to an expected fish catch of 5.0 fish per trip, it can be determined how much an increase of bottom water DO to 10 mg/l would change the expected fish catch, or inversely, where a target fish catch determines what water quality conditions would be necessary. These answers would vary based on the system or group of systems being studied, as well as on what fish species or group of species were being studied.

To demonstrate the predictive capabilities of this model, three systems were chosen that had relatively good results for striped bass. Striped bass was chosen for this predictive model because of its sensitivity to changes in bottom water DO. The three systems chosen for the predictive model – Long Island Sound, Patuxent River, and Potomac River – were selected based on the

Figure 31
Summary of results for open estuaries — bluefish.

Open Estuaries — Individual Fish Species
BLUEFISH

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	NS

number of striped bass fishing observations that were available. An expected fish catch rate was calculated at mean bottom water DO conditions for each individual estuary (Table 11) using Equation 1. Next, expected fish catches were calculated for each system at both 5 mg/l and 2 mg/l DO; these represent the upper limit of the NEEA-defined biological stress (2 to 5 mg/l) and hypoxia (>0 to 2 mg/l) thresholds, respectively. Finally, the percent increase of the change in expected fish catch was calculated as a reference between systems.

The expected striped bass catch for Long Island Sound at August 2002 mean DO conditions of 7.18 mg/l was 2.75 striped bass per angler per trip. When the DO level is set at 5 mg/l, the corresponding expected striped bass catch 2.77 (Table 11). When the DO level is set at 2 mg/l the corresponding expected striped bass catch drops to 2.71 per angler per trip. That is a difference of only 2.1% when the DO levels change from hypoxic conditions to the upper limit of biological stress.

For the Patuxent River estuary, the expected striped bass catch at August 2002 mean DO conditions of 5.99 mg/l was 7.63 striped bass per angler per trip. When the DO level is set at 5 mg/l, the corresponding expected striped bass catch drops to 6.27 (Table 11). When the DO level is set at 2 mg/l the corresponding expected striped bass catch drops to 2.16 striped bass per angler per trip. This is a difference of 65.5% when the DO levels change from hypoxic conditions to the upper limit of biological stress.

For the Potomac River estuary, the expected striped bass catch at August 2002 mean DO conditions of 4.53 mg/l was 4.07 striped bass per angler per trip. When the DO level is set at 5 mg/l, the corresponding expected striped bass catch drops to 4.55. When the DO level is set at 2 mg/l the corresponding expected striped bass catch drops to 1.45 striped bass per angler per trip. This is a difference of 68.1% when the DO levels change from hypoxic conditions to the upper limit of biological stress.

The difference in expected striped bass catch between these systems depicts well the variability that occurs within individual estuaries. For example, in Long Island Sound the change in catch rate at hypoxic DO concentrations and the upper level of biological stressful concentrations of DO was only 2.1%. This indicates that striped bass catch for Long Island Sound is less sensitive to changes in bottom water DO than the catch for the Patuxent and Potomac River estuaries, which had 65.5% and 68.1% increases respectively over the same range (Table 11).

Although there are multiple factors involved, one possible cause for this difference in sensitivity can be found in the physical differences among the three systems. Long Island Sound is a relatively large, deep estuary with a mean depth of approximately 19.5 m. This compares to the Potomac and Patuxent River estuaries, which are relatively small and have mean depths of 5.1 m and 3.8 m respectively (Table 3). These large differences in both relative size and mean depths correspond to amounts of available habitat for fish to migrate into when hypoxic conditions arise. For example, in Long Island Sound when bottom water hypoxic conditions arise, striped bass can migrate higher up into the water column and to other available areas within the estuary. In the Patuxent and Potomac River estuaries however, striped bass do not have the same available water depth and so cannot migrate higher into the water column as easily as they might in Long Island Sound.

Table 11
Striped bass expected fish catch (per angler per trip) results at mean and predictive conditions.

System	Expected Fish Catch at Aug. 2002 Mean DO	Expected Fish Catch at 5 mg/L	Expected Fish Catch at 2 mg/L DO	Percent Increase from 2 to 5 mg/L
Long Island Sound	(mean = 7.18 mg/L) 2.75	2.77	2.71	2.1
Patuxent River	(mean = 5.99 mg/L) 7.63	6.27	2.16	65.5
Potomac River	(mean = 4.53 mg/L) 4.07	4.55	1.45	68.1

Conclusions

Data were adequate for updated eutrophic condition assessment for 12 of 14 systems. However data for SAV loss, HABs and macroalgae were difficult to find. There are no striking differences in the overall ASSETS rating of eutrophication impact between the Mid-Atlantic and Gulf of Maine systems. Most assessment results were Moderate. The two systems that were assessed as Good (Wells Bay and Buzzard's Bay) are located at or north of Cape Cod. The one system assessed as Bad (Potomac River) is south of Cape Cod. Results show Chl a to be High along the transect of systems, with no apparent regional differences. Depleted DO occurs often enough and over a spatial scale leading to assessments of Low and Medium in the more southern systems in the study. The systems in the north do not have significant problems with low DO.

Although toxic blooms are observed in some systems, for Gulf of Maine systems they are often naturally occurring. The modified methodology to assign a Low expression value to systems with toxic blooms that are advected in from offshore resulted in a lower overall rating for two systems. The modified criteria were applied to Wells Bay and Casco Bay, which suffer annual blooms that are advected into the estuaries. This changed the OEC rating of Casco Bay from High to Moderate, and ASSETS rating from Poor to Moderate. For Wells Bay, the OEC rating of Moderate High was changed to Low, and the ASSETS rating from Poor to Good. Although it was expected that the modified method would apply to more Gulf of Maine systems, other systems that suffer these blooms also suffer from nuisance and/or toxic blooms that begin within the system and the HAB rating reflects those, rather than the advected blooms (e.g., Cape Cod Bay and Massachusetts Bay). It is advisable to promote interdiction of shellfishing during the months that these blooms typically occur, and this is already being done in most of these systems.

For the SAV indicator, it is very encouraging to note that in almost half the systems for which records could be found, there is an increase in spatial coverage of seagrasses, indicating improvements in condition. The modification of the method allows recording where SAV increases have occurred, which is important to note as the success of management measures is evaluated.

While preliminary load/response relationships are suggested by this limited data, no conclusions should be drawn without further investigation. Yet these results are encouraging, given the ongoing efforts of the EPA and States to develop and refine critical nutrient load limits and other water quality regulations for estuarine and coastal waterbodies.

The linkage between changes in DO and recreational fish catch has been successfully shown here and could serve as a complementary indictor to the existing eutrophication indicator. At the broadest scale, it appears that recreational fish catch rates serve as a good human-use indicator of the negative effects of eutrophication in estuaries. [However, bottom water DO^2 is not significant and this is likely due to both the large variation in responses of different recreational species to eutrophication and to the response of the estuarine systems themselves.] This was true in most cases where one of the core variables was not significant. For example, striped bass appeared to be particularly sensitive to low DO conditions, whereas winter flounder and bluefish were not. Similarly, results seem to be as expected for the Mid-Atlantic region and closed estuaries, but not for the Gulf of Maine region or open ones. For example, for both the Mid-Atlantic region and closed estuaries there was an increase in fish catch rate concurrent with an increase in the DO as expected, because DO levels directly affect fish. Also, although not directly associated, for the same two groups there was a decrease in fish catch rate concurrent with an increase in the Chl a. This, too, was expected, because high levels of Chl a can, through estuarine processes, cause low DO. Yet for the Gulf of Maine region and open systems, results were opposite of those for the Mid-Atlantic region and closed estuaries. Examination of DO water quality data from the estuaries that make up both the Gulf of Maine and open systems (see Table 8, Figure 6) revealed that the DO 10th percentile levels rarely, if ever, drop down to the level of biological stress (< 5 mg/l). With this understanding, it is possible to see that further increases in the levels of DO would not greatly affect the fish catch rate. The DO^2 value takes this into account, and as such, results showed that it became significant and positive for both the Gulf of Maine region and open systems.

The human-use indicator performed much better when data for the recreational catch was disaggregated into individual species and examined on a system-by-system basis. These results suggest that when choosing a human-use indicator such as recreational fish catch, a flexible approach involving multiple steps is more appropriate than choosing one indicator and applying it everywhere. The first step would be to select candidate species that are important recreational fisheries within an estuary or group of estuaries and develop and test a model of catch rate related to water quality measures associated with eutrophication. Only species where the catch rates are shown to be significantly impacted by the environmental variables should be used as an indicator.

In this study, neither bluefish nor winter flounder recreational catch rates proved to be good human-use indicators. This may be due in part to a lack of sufficient data regarding these species; but it also may reflect their physiological nature and migratory behavior that results in their catch rates being relatively insensitive to the core variables. It may be appropriate to use a single species or an aggregation of species as the indicator. Once the model is developed, it can be used as a predictive tool to measure the contribution of changes in the core variables to changes in recreational catch rates, as was described using Long Island Sound, Potomac, and Patuxent River estuaries. By using this modeling approach, it is possible to adjust for changes in human-use activity that are not due to changes in eutrophic condition. Thus, if catch rates are higher, the reason may be climatic factors related to water temperatures, and not to an improvement in water quality.

Recommendations

Acquiring data was the most difficult part of this study and inadequate data was a limiting factor. Therefore, it is recommended that site visits to data holders be used to collect the data. Data were found in a number of places and had to be retrieved from a number of investigators; other forms of data collection proved unsatisfactory. Inadequate data was a limiting factor for both the eutrophication assessment and the development of the human-use indicator. Where possible, annual data should be acquired to meet the requirements of the method, because index period samples sometimes miss periods of extreme degradation or overemphasize these conditions, leading to an inaccurate assessment.

For the eutrophication assessment method, the use of data collection and analysis on a salinity zone or other spatial analytical basis would be useful for examining changes that occur within the systems over time. The changes observed in the systems from the early 1990s (the timeframe of the 1999 NEEA report) and the early 2000s (this study) could be identified by variable but not by location within the estuary. A spatial analysis of trends could provide insight to the success of management measures.

Additional and continued research should be supported to fully explore the nutrient load-waterbody response relationships that are so critical to the development of successful management measures. This includes support for the development of accurate load estimates, as well as for annual data collection for waterbody indicator variables.

Further development of the human-use indicator and conversion to a nationally applicable methodology requires further research on the fish species that are appropriate for use in different regions of the coastal U.S., because it is unlikely that there is one species that can be used nationally. Only species where the catch rates are shown to be significantly impacted by the environmental variables should be used as the indicator. For instance, here neither bluefish nor winter flounder recreational catch rates proved to be good human-use indicators. Additionally, conversion to a socioeconomic indicator requires research and/or modeling of the multipliers (e.g., costs per fish) that can be applied to the results of the human-use indicator developed here.

Nutrient-related water quality problems are now considered the number one challenge to the health of U.S. coastal water bodies. Thus, it is recommended that this type of eutrophication and human-use assessment be conducted every two to five years. Only by examining trends over such time scales can management success be evaluated properly and adjusted as necessary. This type of assessment requires data for water quality indicators, fish catch (or other human-use data for indicators that might be developed in the future), as well as physical, hydrologic, and nutrient-load data to compare to the long-term eutrophic conditions within the water bodies. Some Federal and State agencies are already collecting much of this data and, in some cases, are making assessments of eutrophication and tracking trends through time (e.g., EPA, 2001, 2004; Bricker et al., 1999, 2004). There are existing State-Federal and Federal-Federal collaborations on these issues that should be encouraged and strengthened to provide the strongest basis possible for understanding and finding successful management approaches to solve this pervasive problem.

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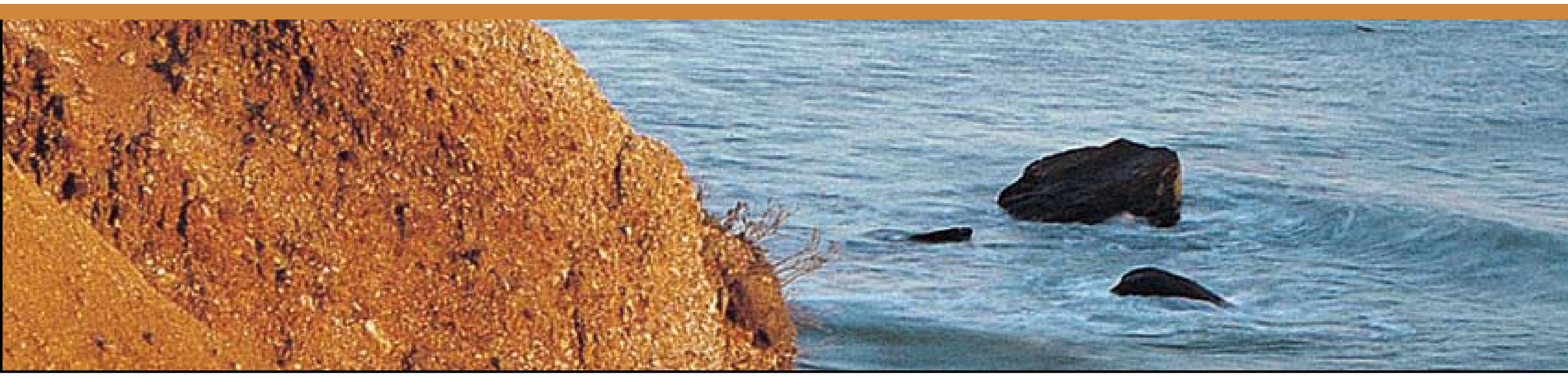

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Appendices

APPENDICES:

APPENDIX 1: INDIVIDUAL SYSTEM RESULTS

Kennebec/Androscoggin River

The Kennebec Androscoggin Bay is made up of a narrow, shallow estuary consisting of the Kennebec River and Androscoggin River. Freshwater inflow from both rivers dominates this estuary and is the largest source of freshwater to Maine estuaries. Circulation is affected by strong tidal and non-tidal currents. Vertical mixing of salinity occurs in this estuary. The tidal range is 1.95 m near the city of Bath (NOAA, 1997).

Data availability

There were not enough available water quality data for the ASSETS application for the Kennebec and Androscoggin Rivers. However, what data were available came from the University of Maine's Department of Oceanography (Mayer, 1996). The data cover an average of eight stations per month for September 1993, February 1994, and May-August 1994. For Chl a there were a total of 168 samples for all months and years of available data. There were no available data for DO for any of the stations.

Pressure – Overall Human Influence

Kennebec Androscoggin Bay is classified as having Low susceptibility to eutrophic conditions because its flushing potential is High and its dilution potential is Moderate.

At the time of this study there was no estimate of land-based nitrogen load available for the Kennebec Androscoggin Bay area, and thus no new OHI calculation was derived. Nitrogen loading to the system was documented as Moderate in the original National Estuarine Eutrophication Assessment (NEEA) (Bricker, 1999).

OHI for the Kennebec Androscoggin Bay was Low in the early 1990s, based on the original NEEA (Bricker, 1999).

State – Overall Eutropic Condition

Insufficient data were available to make OEC calculations. More years of data are required or more samples within a given year.

OEC for the Kennebec Androscoggin Bay was Low in the early 1990s, based on the original NEEA report (Bricker, 1999).

Response – Determination of Future Ooutlook

Future trends for the Kennebec and Androscoggin Rivers are unknown at this time. DFO was not calculated or projected in the original NEEA report.

ASSETS Synthesis

No ASSETS value can be assigned to Kennebec Androscoggin Bay because of lack of data.

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Casco Bay

Casco Bay, located in the northeast U.S., supports industries including shipping, petroleum transport, commercial fish and shellfish harvesting, and tourism. Maine's largest city, Portland, is located on the southeast shore of Casco Bay and is the third largest oil-handling port on the East Coast. The port of Portland supports $314 million in sales, $70 million in wages and $9 million in taxes per year from these industries (Casco Bay Plan).

Data availability

Water quality data used for the ASSETS application for the Casco Bay come from the Friends of Casco Bay (http://www.cascobay.org/) for 10 stations and represents about 1,760 monthly samples for 2001-02 for DO and 1,154 samples for Chl a. Physical and hydrologic data are from CADS (http://cads.nos.noaa.gov). Nutrient-loading estimates are from USGS SPARROW model (Smith et al., 1997). Land use is from Banner and Libby (1995).

Figure 1
Chl a and DO in Casco Bay used for ASSETS and human use assessment (http://www.cascobay.org/).

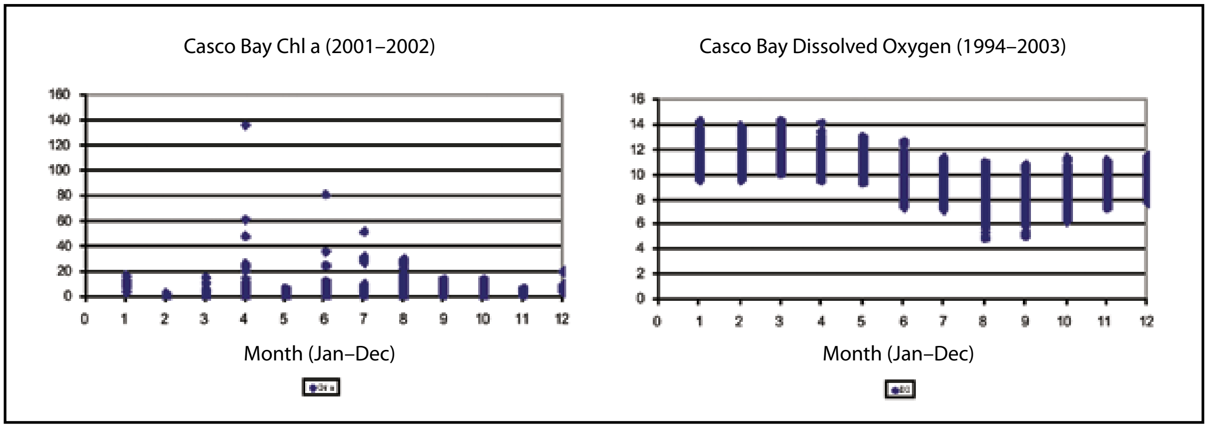
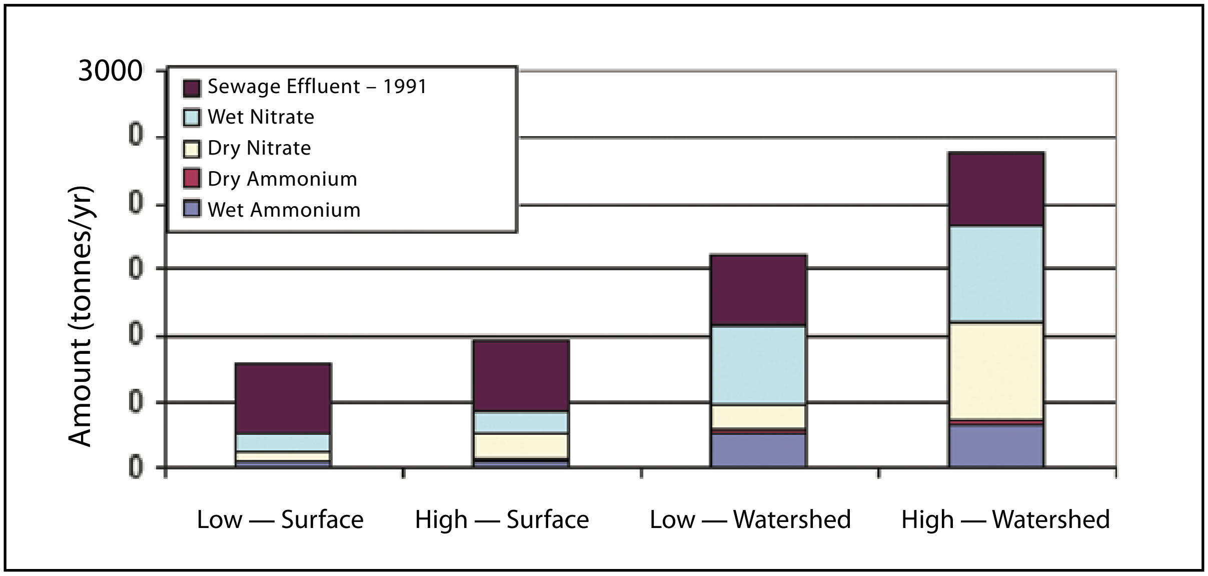


Figure 2
Summary of sewage effluent discharges, estimates of dry deposition, and wet deposition of inorganic nitrogen to Casco Bay from 1998 to 2000. Low and High signify deposition estimate ranges. "Surface" refers to the surface of Casco Bay while "watershed" refers to the entire watershed surface area. (Ryan et al. 2003)



Pressure – Overall Human Influence

Casco Bay estuary consists of Casco Bay and East Bay with several rocky islands interspersed. Freshwater to this system is limited (3.21 x10^6 m^3 d^{-1}, CADS) and enters from the east through the Presumpscot and Royal Rivers. The system is large (427 sq km) and deep (mean depth 12 m) and the mean tide height is 2.7 m (CADS). Circulation is dominated by strong tidal mixing, especially around shoal areas (Bricker et al., 1997). Limited freshwater input combined with High tidal range results in a Moderate residence time (125 days; CADS) in this well-mixed system. Casco Bay is classified as having a Low susceptibility to nutrient inputs because the system has a High capacity to both dilute and to flush nutrients.

The watershed of Casco Bay is mostly forested, with the main center of population in and surrounding the city of Portland. Like many northeast systems, the system includes extensive rocky shores (200 sq km) and boasts 758 rocky islands that provide habitat for a range of inter-tidal plant and animal species.

Total loading (dry plus wet) of inorganic nitrogen deposition to the Casco Bay surface ranged from 255 to 428 metric tons/yr (Figure 2). Over the 2551 square km watershed surface area total (dry plus wet) inorganic nitrogen deposition ranged from 1,097 to 1,842 metric tons/yr. This means atmospheric (dry plus wet) deposition of inorganic nitrogen into Casco Bay is estimated to have ranged from 225 to 1,842 metric tons/yr from 1998 to 2000 (Casco Bay Plan; Table 1). The factor of 8 range in the inorganic nitrogen atmospheric deposition total is primarily the result of uncertainty about the fraction/amount of atmospheric deposition to the watershed that reaches the Bay. Future work should be performed to refine this range by investigating and estimating the role and/or percentage of atmospheric deposition to the watershed that reaches the Bay. Total (dry plus wet) inorganic nitrogen deposition is predominately in the form of nitric acid plus nitrate (70-80%) with the remainder in the form of ammonium (20-30%).

Table 1
Load estimates to Casco Bay.

Source	1000s metric tons/yr	Timeframe
Atmospheric	0.225 to 1.842	1998 - 2000
Sewage	0.540	1991
Total	0.765 – 2.387	

Ryan et. al, 2003

Mosher (2000) reported that point-source discharges in 1991 from sewage treatment effluent introduced roughly 540 metric tons/yr of nitrogen into Casco Bay. The 1991 data were used because more recent data are lacking. Based on this information and atmospheric deposition estimates, results show that a range of 30% to 70% of the total amount of inorganic nitrogen pollution entering Casco Bay comes from atmospheric deposition. For comparison, 21% of the nitrogen pollution entering Chesapeake Bay comes from the air (e.g., U.S. Environmental Protection Agency, 2000a). Thus, atmospheric deposition is estimated to be a greater source of inorganic nitrogen input to Casco Bay (30-70%) than it is to Chesapeake Bay (21%).

The level of nitrogen load is considered Low, based on model calculations (see Bricker et al. 2003 for OHI calculation) giving a value of 0.3 using the highest of the estimates (Table 1). Low loads and Low susceptibility give an overall human influence rating of Low.

State – Overall Eutrophic Condition

Chl a concentrations vary seasonally ranging in 2001-02 from less than 0 to 136.8 micrograms/l with highest concentrations observed in the spring and summer months. The Chl a 90th percentile for Casco Bay is 10 micrograms/l, which gives a rating of Medium. Spatial coverage is High and frequency of occurrence is Periodic. The overall rating for Chl a in this system is High.

No data were found for epiphytes or macroalgae for Casco Bay and these parameters were not included in the index calculation.

The overall primary expression value for the Casco Bay is High.

DO varies seasonally from 4.9 to 14.3 mg/l but rarely goes below 5 mg/l. The 10th percentile is 7.9 mg/l, which gives a rating of No Problem. There are small areas in Maquiot Bay, a part of Casco Bay, (Casco Bay Plan) that are suspected to have low-DO problems; however, there are no data available to support this suspicion. This gives an overall rating of No Problem for DO in Casco Bay.

SAV in Casco Bay at present has a very low spatial coverage, having been lost to wasting diseases in the 1940s. There have been small increases in SAV coverage in recent years (Casco Bay Plan). This variable is given a rating of Increased SAV coverage.

Several species of toxic blooms are known to occur annually in Casco Bay, including Alexandrium sp., Dinophysis sp., Prorocentrum lima, and Pseudonitzchia sp. In addition, Gymnodinium sp., and Prorecentrum micans also occur, and while they are not toxic, can cause low-DO events and smother benthic organisms when they occur in large abundance or form dense algal mats. There is usually a spring bloom and sometimes a fall bloom where Alexandrium (PSP) is involved. PSP events can occur in spring, summer, or fall, lasting for a whole season. Where Pseudonitzschia is concerned, problems always occurred in the colder months (fall and winter) (L. Bean, Maine Department of Marine Resources, personal communication).

The spatial coverage is High and the frequency of occurrence is Periodic for nuisance and toxic blooms and duration is seasonal. However, these typically originate offshore and then are advected into the estuary (L. Bean, Main Department of Marine Resources, personal communication). Thus, the rating for nuisance and toxic blooms for Casco Bay, while High, is recorded here as Low because they are not triggered by in-estuary nutrients.

The overall rating for secondary symptoms for Casco Bay is Low because there is No Problem with DO, SAV is increasing, and nuisance and toxic blooms originate offshore and are considered Low.

The final classification for State (OEC) falls within the Moderate category due to High expression values for primary symptoms and Low/No Problem expression values for secondary symptoms.

Response – Determination of Future Outlook

The expected response of this system was examined by considering future changes in nutrient loading by looking at watershed population growth, potential management measures to be implemented, and other land-use changes that will influence water quality within the Casco Bay. Watershed population growth from 1970 to 1990 was 25% and is expected to increase in the future (Casco Bay Plan Chapter 1: State of the Bay, http://www.cascobay.usm.maine.edu/Chapter1.pdf). While Casco Bay does not appear to have major nutrient-enrichment problems at present, the potential for problems will increase as population and development continue. However, the population increase is balanced by management actions that have already been implemented or proposed. Because Casco Bay was selected for inclusion in the National Estuary Program in 1990, a preliminary management plan for the Bay has been developed, and a final Comprehensive Conservation and Management Plan with recommendations for priority corrective actions to restore and maintain the estuarine resources was produced in 1995. To date, a series of implementation and demonstration projects have been undertaken. (Casco Bay Plan Chapter 1: State of the Bay http://www.cascobay.usm.maine.edu/Chapter1.pdf). These include:

- The Agricultural Stabilization and Conservation Service distributed over $200,000 in cost-share funds in Casco Bay watershed to address agricultural nonpoint source pollution.
- A public education campaign provided information on the need to restore eroding stream banks along the Pleasant River. Volunteers performed the restoration work.
- A training program for municipal officials was developed to provide information on nonpoint source pollution and best management practices.
- Administrative structures to ensure the inspection and maintenance of septic systems are being evaluated.
- A storm water management plan for a town center is under development to demonstrate storm water control planning in areas designated as growth areas under local zoning ordinances (from EPA http://www.epa.gov/ecoplaces/part2/region1/site3.html).

The planned or implemented management measures, in combination with the Low susceptibility of Casco Bay, results in a future outlook forcast of Improve High.

ASSETS Synthesis

Casco Bay is given an overall classification of Moderate, which reflects an OHI of Low, Moderate OEC, and Improve Low for future outlook (Table 2).

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Table 2
ASSETS Synthesis for Casco Bay.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilutionpotential	High	Low Susceptibility	Low	OHI = 5 OEC = 3 DFO = 5 Moderate
		Flushingpotential	High			
	Nutrient inputs	Low				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate	
		Macroalgae	No Data			
	Secondary Symptom Method	Dissolvedoxygen	No Problem	Low		
		Submerged aquaticvegetation	Increase			
		Nuisance and Toxic Blooms	Low			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease			Improve Low	

Saco Bay

Saco Bay is a highly stratified, saltwedge-type of estuary. Freshwater inflow is dominated by the Saco River. Salinity stratification is more pronounced during periods of high freshwater inflow. The estuary begins below the Cataract Dam on the Saco River. Tidal range is 2.62 m near the mouth of the estuary (NOAA, 1997).

Data availability

There were not enough available water quality data for the ASSETS application for the Saco River. However, what data were available came from the Maine Department of Marine Resources. These data cover an average of eight stations per month for July and August 1992, and August-September 1993. For Chl a there was a total of 75 samples for all months and years of available data. For DO there were 1,688 samples for all months and all years of available data. The limiting factor for being unable to produce an ASSETS application was the lack of a significant number of representative months in a given year.

Pressure – Overall Human Influence

Saco River is classified as having a Low susceptibility to eutrophic conditions because its flushing potential is High and its dilution potential is Moderate.

At the time of this study, there was no estimate of land-based nitrogen load available for the Saco River area. As such, no new OHI calculation was derived. Nitrogen loading to the system was documented as Low in the original National Estuarine Eutrophication Assessment (NEEA) (Bricker, 1999).

OHI for the Saco River was Low in the early 1990s, based on the original NEEA (Bricker, 1999).

State – Overall Eutrophic Condition

Insufficient data were available to make OEC calculations. More years of data or more samples within a given year are required.

OEC for the Saco River was Moderate, based on the original NEEA report (Bricker, 1999).

Response – Determination of Future Outlook

Future trends for the Saco River are unknown at this time. DFO was not calculated or projected in the original NEEA report.

ASSETS Synthesis

No ASSETS value can be assigned to Saco River due to lack of data.

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Wells Bay

Wells National Estuarine Research Reserve (NERR), located in Southern Maine, is composed of two barrier-built marsh systems, the Webhannet River Estuary and the Little River Estuary (Ward, 1993). The Webhannet River watershed is approximately 35 sq km (Ward, 2004) and the watershed of Little River is almost twice the size of the Webhannet at 67.3 sq km (WNEER, 2002), for a total watershed area of 102 sq km. The Webhannet River contributes 50% and the Blacksmith Brook about 25% to the daily freshwater inflow (~49 x10^3 m^3/day; Ward, 2004). Although the discharge from Little River is not known, it is predicted to be three to four times the flow from the Webhannet River and Blacksmith Brook (WNEER website http://www.wellsreserve.org).

Wells NERR is a tide-dominated system with a mean semi-diurnal tide range of 2.6 m and spring tidal range of 2.9 m (Ward, 1993). Depth varies throughout the system, but averages about 2.5 m at the head of tide and about 4.5 m near the mouth of the estuary (Ward, 2004).

The land in Wells Bay watershed is primarily forested, with the Webhannet watershed showing the greatest development at about 20% (Table 2).

Data availability

Water quality data for the ASSETS application for Wells NERR come from the NERR system's System-wide Monitoring Program (SWMP) for Chl a, DO, and nutrients. SWMP data is controlled and housed by the NERR system's Centralized Data Management Office (CDMO) and was accessed through the web at CDMO Data Dissemination page (CDMO, 2005). Chl a data for 2002 were not available online and had to be directly requested from the Wells NERR contacts. The data represent samples from four stations in 2002, including 262 samples for Chl a and 12,781 samples for DO. The nutrient data for the calculation of overall human influence are from DIN data, also for 2002.

Pressure – Overall Human Influence

Wells NERR is classified as having a Low susceptibility to development of eutrophic conditions because it has a High capability to both flush and dilute incoming pollutant loads, with a flushing rate of 5 hours (M. Dionne, personal communication – Webhannet Morphometrics.doc).

The estimated land-based nitrogen load for Wells NERR OHI calculation was derived using the 2002 median DIN value of the head-of-tide station located in the Webhannet River and the 2002 median DIN value of the inlet station as the ocean-end member. The results show an OHI ratio of 0.074, which is in the Low category. Combined with the Low susceptibility, the OHI to Wells NERR is estimated to be Low.

State – Overall Eutrophic Condition

Chl a concentration data for all four stations and for all months sampled in 2002 range from 0.26 to 9.11 micrograms/l. The 90th percentile for all data is 4.85 micrograms/l which falls into the Low category. When analyzed by station, the Low values have High spatial coverage seen on an annual basis. As such, the Chl a expression value is 0.25, or Low.

There were no available data for macroalgal abundance.

The primary symptoms in Wells NERR are Low, based on Chl a only, because there are no data for macroalgal abundance.

DO concentration data for the four stations for all months in 2002 ranged from 2.2 to 16.7 mg/l. The 10th percentile value for all data is 5.6 mg/l, which falls into the category of No Problem. No occurrences of hypoxia or anoxia were observed, and the expression value is 0, or No Problem.

There is no SAV information for Wells Bay.

PSP (paralytic shellfish poison toxin) was detected at an average of approximately 50 micrograms of toxin per 100 grams of shellfish tissue from April to June of 2002 (Bean, 2004, unpublished). The duration of the toxic bloom is Months and the frequency is Periodic, giving a rating for nuisance and toxic blooms or HABs as a Problem. However, it is likely that these blooms begin offshore and advect into the system, and therefore they are not included in the assessment formulation.

The secondary-symptom indicators in Wells NERR are Low, despite the occurrence of toxic blooms.

The overall eutrophic condition for Wells NERR is Low, due to the Low primary and Low secondary-symptom expression.

Table 3
Land use in Wellls Bay watershed (as percent; WNERR,2002).

	Webhannet River	Merriland River	Branch Brook	Little River
Wetlands	0.3	2.1	0.2	1.3
Fresh Water	3.4	0.2	0.1	0.3
Tidal Marsh	10.2	0	0.2	0.9
Beach	1.1	0	0	0.1
Total water + wetland	15	2.3	0.5	2.6
Hardwood, mix	22.1	36	42.6	38.1
softwood	40.1	50.1	40.4	45.8
> 30% harvested	1.5	0	0	0
Total woodland	63.7	86.1	83	83.9
Total agriculture (Hay, pasture, mowed)	2.8	5.8	10.6	7.9
Developed, low density	6.2	4.4	2.6	3.5
Developed, high density	10.1	0	0	0
Commercial	2	0.1	2.5	1.1
Sand & Gravel pit	0.1	1.3	0.8	1.1
Dump	0.2	0	0	0
Total developed land	18.6	5.8	5.9	5.7

Table 4
ASSETS Synthesis for Wells Bay.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilutionpotential	High	Low Susceptibility	Low	OHI = 5 OEC = 5 DFO = 2 Good
		Flushingpotential	High			
	Nutrient inputs	Low				
State OEC index	Primary Symptom Method	Chlorophyll a	Low	Low	Low	
		Macroalgae	No Data			
	Secondary Symptom Method	Dissolvedoxygen	No Problem	Low		
		Submerged aquaticvegetation	N Data			
		Nuisance and Toxic Blooms	Low			
Response DFO index	Future nutrient pressures	Increase in nutrient loading in the future			WL	

Response – Determination of Future Outlook

Land use in the Merriland, Branch Brook, and Little Mouth Rivers is mostly undeveloped, with an approximate 83% forest coverage (WNERR, 2002; Table 2). However, the whole region has been experiencing an increase in development pressure over the past few years. In 1991, only about 6% of the watershed was developed, but between 1990 and 2000 the Webhannet River watershed had an increase in new housing growth of about 50% (WNERR, 2003). This trend in development points to increases in land-based nitrogen inputs to the system. Management practices overall for the region are lax, allowing development of the shoreland zone to occur with virtually no enforcement of the laws pertaining to vegetated shoreland buffers. Positive management practices in the region include government ownership of land for preservation purposes, continued monitoring of multiple water quality variables, and identification and remediation of probable problem areas. Management has had some successes, notably the reopening of clam beds in 1996 after a 10-year closure. As such, the determination of future outlook for Wells NERR is Worsen Low, because of an increase in nutrient loading with Low susceptibility.

ASSETS Synthesis

The combination of Low overall human influence, Moderate High overall eutrophic conditions, and Worsen Low for future outlook forecast gives an ASSETS synthesis classification of Moderate (Table 3).

References

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Ward, Larry G. 2005 (in press). Variations in Physical Properties and Water Quality in the Webhannet River Estuary (Wells National Estuarine Research Reserve, Maine). Department of Earth Sciences and Jackson Estuarine Laboratory, University of New Hampshire.

Ward, Larry G. 1993. Precipitation, Streamflow and Water Characteristics (Physical and Chemical) of the Webhannet River Estuary, Wells, Maine. Department of Earth Sciences, Jackson Estuarine Estuary, University of New Hampshire.

Wells National Estuarine Research Reserve (WNERR). 2003. Webhannet River Watershed Conservation Strategy report: summary handout. Maine Department of Environmental Protection. (http://www.wellsreserve.org/cmp/wcs/webhannet.pdf)

Wells National Estuarine Research Reserve (WNERR). 2002. Merriland, Branch, and Little River Watershed Shoreland Survey of Non-point Sources. Maine Department of Environmental Protection.

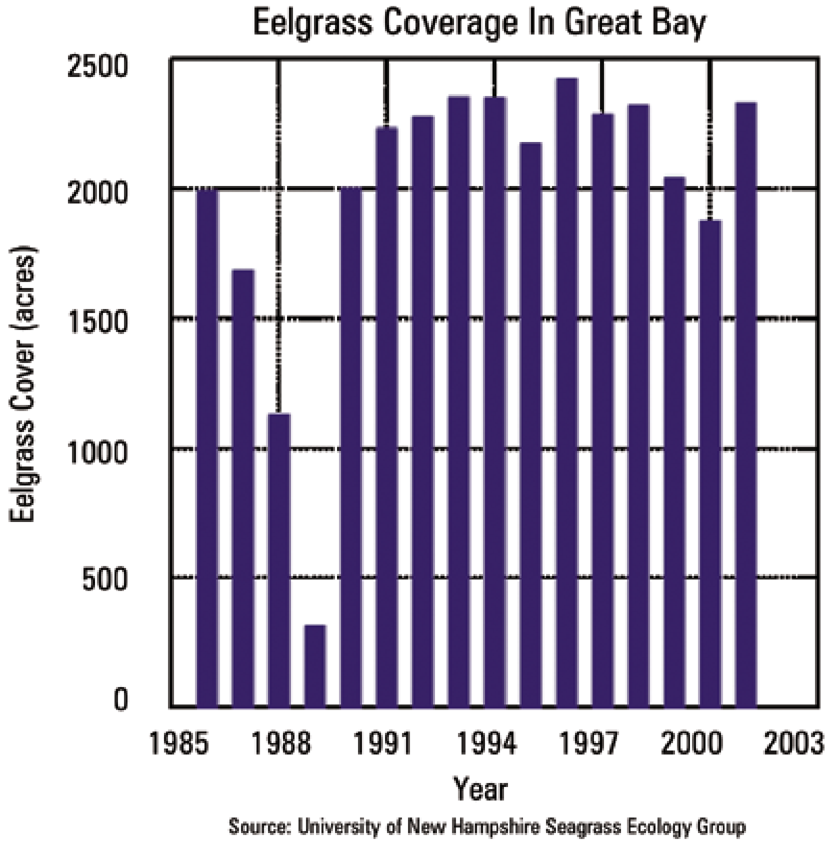
Great Bay

Great Bay is a relatively small estuary of 53.9 sq km, located between New Hampshire and Maine (NOAA, 1997). The estuary itself is tidally dominated and composed of the Piscataqua River, Little Bay and Great Bay areas. Seven major rivers as well as several small creeks and their tributaries also drain into the Bay. Within the Great Bay estuary is the Great Bay National Estuarine Research Reserve (NERR) which is composed of 21.4 sq km of tidal waters and mudflats, as well as about 77.2 km of shoreline (GBNERR, 2005). The Great Bay NERR has five component stations – Adams Point/Crommet Creek, Lubberland Creek, Squamscott River, Wilcox Point, and Sandy Point – as well as stations in the Lamprey and Oyster Rivers. Along with these stations, there is also a coast lab inlet station for which data are collected.

Data availability

Water quality data for the ASSETS application for Great Bay came from the NERR system's System-wide Monitoring Program (SWMP) for Chl a, DO, and nutrients. SWMP data are controlled and housed by the NERR system's Centralized Data Management Office (CDMO) and was accessed through the web at CDMO Data Dissemination page (CDMO, 2005). Data for the additional coast lab inlet station were acquired via direct request to the University of New Hampshire's (UNH) Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET). The data represent samples from three stations in 2002 representing 645 samples for Chl a and samples from five stations in 2002 that include 36,156 samples for DO. The nutrient data for the calculation of overall human influence come from DIN data, also for 2002.

Figure 3
Changes in eelgrass coverage in Great Bay. (NHEP, 2003).



Source: University of New Hampshire Seagrass Ecology Group

Pressure – Overall Human Influence

Great Bay is classified as having a Moderate susceptibility to eutrophic conditions because its flushing potential is High and its dilution potential is Low.

The estimated land-based nitrogen load for the Great Bay OHI calculation was derived using the 2002 median DIN value of the head-of-tide station (a weighted average of the Lamprey and Oyster River stations for 2002) and the 2002 median DIN value of the coast lab inlet station as the ocean-end member. The results show an OHI ratio of 0.131, which is in the Low category. Combined with the Moderate susceptibility, the overall human influence to Great Bay is estimated to be Low.

State – Overall Eutrophic Condition

Chl a concentration for three stations and all months sampled in 2002 ranged from 0.581 to 28.756 micrograms/l. The 90th percentile for all data is 14.138 micrograms/l, which falls into the Medium category. When analyzed by station, the Medium values have High spatial coverage seen on an annual basis. As such, the Chl a expression value is 1, or High.

There were no available data for macroalgal abundance.

The primary symptoms in Great Bay are High, based on Chl a. There are no data for macroalgal abundance.

DO concentration data for five stations for all months in 2002 ranged from 1.2 to 19.6 mg/l. The 10th percentile value for all data is 5.5 mg/l, which falls into the category of No Problem. Fifteen occurrences of hypoxia were recorded, and no anoxia was observed. As such, DO has an expression value of 0, or No Problem.

Eelgrass coverage for Great Bay increased from approximately 1,800 acres in 2000 to approximately 2,300 acres in 2001. In 2001, there was an increase in SAV coverage of approximately 500 acres (NHEP, 2003; Figure 3).

There were no available HAB data for Great Bay.

The secondary symptom indicators in Great Bay are Low because of the DO indicator.

The overall eutrophic condition for Great Bay is Moderate due to the High primary-symptom and Low secondary-symptom expression.

Response – Determination of Future Ooutlook

Land use in the Great Bay drainage area has been changing over the past 10 years. According to Trowbridge (2003), the percent of impervious surfaces for the Great Bay alone increased 46.4% between 1990 and 2000 (Fig. 4). Most of the major river systems draining into Great Bay, such as the Lamprey, Oyster, and Squamscott Rivers, showed percent increases in impervious surfaces in the range of approximately 46-60%. Trowbridge (2003) also discovered a strong linear relationship between population increases and impervious surface increases. Management practices in the region are good, but it has been determined that reducing the amount of impervious surfaces in the watershed is not currently feasible (Trowbridge, 2003). As of 2002, the

Table 5
ASSETS Synthesis for Great Bay.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	Low	Moderate Susceptibility	Low	OHI = 5 OEC = 3 DFO = 1 Moderate
		Flushing potential	High			
	Nutrient inputs	Low				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate	
		Macroalgae	?			
	Secondary Symptom Method	Dissolved oxygen	No Problem	Low		
		Submerged aquatic vegetation	Increase			
		Nuisance and Toxic Blooms	Low			
Response DFO index	Future nutrient pressures	Increase in population and impervious surfaces			Worsen High	

New Hampshire Estuaries Program (NHEP) had acquired 172.3 sq km of land in the coastal watershed for environmental protection, representing 8.4% of the total watershed area (NHEP, 2003). Their goal is to acquire a total of 15% of the total coastal watershed land area. Even with the good management practices in the region, it will be difficult to counteract the increasing population and subsequent increases in impervious surfaces. As such, the DFO for Great Bay is Worsen Low, because of an increase in population and impervious surfaces, with Moderate susceptibility.

ASSETS Synthesis

The combination of Low overall human influence, Moderate overall eutrophic conditions, and a Worsen Low forecast for future outlook gives an ASSETS synthesis classification of Moderate (Table 5).

References

Centralized Data Management Office (CDMO). 2005. National Estuarine Research Reserve (NERR) System-Wide Monitoring Program Data Dissemination website. (http://cdmo.baruch.sc.edu/data_dissemination.html, viewed 05-04-05).

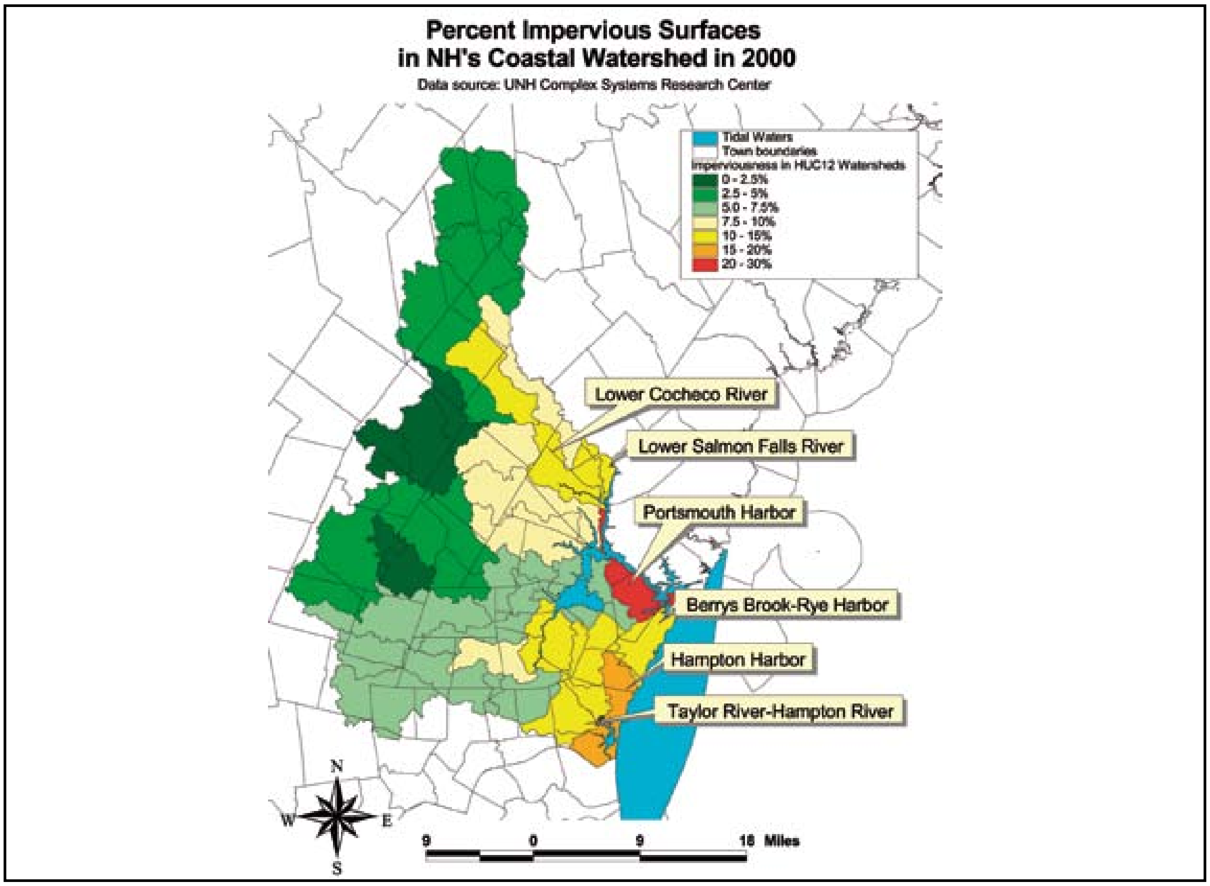
Great Bay National Estuarine Research Reserve (GBNERR). 2005. Great Bay NERR website. Centralized Data Management Office (CDMO). (http://cdmo.baruch.sc.edu/hpages/GRB/index.html, viewed 5-04-05).

New Hampshire Estuaries Project (NHEP). 2003. State of the Estuaries: 2003. U.S. Environmental Protection Agency (EPA), National Estuary Program. 29 p.

National Oceanic and Atmospheric Administration (NOAA). 1997. NOAA's Estuarine Eutrophication Survey. Volume 3: North Atlantic Region. Silver Spring, MD: Office of Ocean Resources Conservation and Assessment. 45 p.

Trowbridge, Phil. 2003. Environmental Indicator Report: Land Use and Development. New Hampshire Estuaries Project, New Hampshire Department of Environmental Services.

Figure 4
Percent Impervious Surface, New Hampshire's Coastal Watershed in 2000. (Trowbridge, 2003).



Plum Island Sound

Plum Island Sound is a relatively small estuary of approximately 60 sq km with three main river drainage basins: the Parker (155 sq km), the Rowely (26 sq km), and the Ipswich (404 sq km) River basins (PIE-LTER, unpublished). Part of the watershed falls in the Greater Boston metropolitan area, and as such development pressures are high. The watershed also contains the largest saltmarsh-dominated estuary in New England (PIE-LTER, unpublished).

Data availability

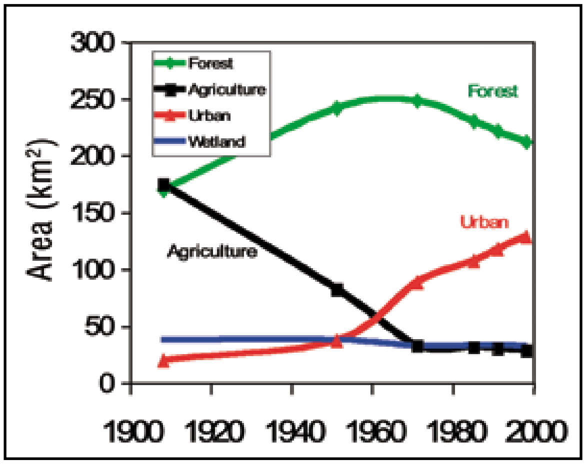
Data for the ASSETS application came from the Plum Island Sound Long-Term Ecological Research website (http://ecosystems.mbl.edu/pie/data.htm). The data cover 23 stations for Chl a and represent 274 samples for nine years of a 10-year span, 1994-2003. There are data for DO for three stations, representing 95,189 samples from 2001-02.

Pressure – Overall Human Influence

Plum Island Sound is classified as having a Moderate susceptibility to eutrophic conditions because its flushing potential is High and its dilution potential is Low.

The estimated land-based nitrogen load for the Plum Island Sound OHI calculation was derived using the 2000-01 median DIN concentration at the head-of-tide station and the 2000-01 median DIN concentration at the Audubon station as the ocean-end member. The results show an OHI ratio of 0.43, which is in the Moderate category. Combined with the Moderate susceptibility, the overall human influence to Plum Island Sound is estimated to be Moderate.

Figure 5
Changes in Land Use of Plum Island Sound from 1900-2000 (from Schneider and Pontius, 2001).



State – Overall Eutrophic Condition

Chl a concentration for 23 stations and all months (sampled in April-October of 2000-02) ranged from 0 to 114.9 micrograms/l. The 90th percentile for all data is 26.1 micrograms/l, which falls into the High category. When analyzed by station, the High values have Moderate spatial coverage when seen on an annual basis. As such, the Chl a expression value is 1, or High.

There were no available data for macroalgal abundance.

The primary symptoms in Plum Island Sound are High, based on Chl a only. There are no data for macroalgal abundance.

DO concentration data for three stations for all available months (June-November) in 2001-02 ranged from 0.24 to 15.8 mg/l. The 10th percentile value for all data is 5.43 mg/l, which falls into the category of No Problem. Multiple occurrences of hypoxia were recorded, and no anoxia was observed. As such, DO has an expression value of 0, or No Problem.

No SAV data were found.

HAB data for Plum Island Sound came from the Plum Island Estuary Long Term Ecological Research Site's (PIE-LTER) unpublished Summary of Research Findings. HABs are observed periodically for one to two weeks where the Parker River enters the estuary. As such, the expression for HABs is Moderate and gets a value of 0.5.

The secondary symptom indicators in Plum Island are Moderate, due to the HAB indicator.

The overall eutrophic condition for Plum Island Sound is Moderate High, due to the High primary and Moderate secondary symptom expression.

Response – Determination of Future Outlook

As of 1991, land use in the Plum Island Sound basin was approximately 32% urban/suburban, 7% agriculture, 15% open water and marsh, and 46% forest (PIE-LTER, unpublished; Figures 5 and 6). Population is expected to continue to increase, and thus the nutrient loads are also expected to increase. The future outlook is rated "Worsen High", based on the combination of increased nutrient loads and Moderate susceptibility.

ASSETS Synthesis

The combination of Moderate overall human influence, Moderate High overall eutrophic conditions and an outlook rating of Worsen Low gives an ASSETS synthesis classification of Poor (Table 6).

References

Plum Island Estuary Long Term Ecological Research Site (PIE-LTER), unpublished. Summary of Research Findings. National Science Foundation's (NSF) Long Term Ecological Research (LTER) Network. The Ecosystems Center at the Marine Biological Laboratory, the University of South Carolina, the Massachusetts Audubon Society, the Wells National Estuarine Research Reserve, the University of New Hampshire and Clark University. (http://ecosystems.mbl.edu/pie/ResSumm.pdf, viewed 05-05-05). Schneider, L. and J. R. G. Pontius. 2001. Modeling land-use change in the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems & Environmental 85(1-3): 83-94

Figure 6
Population growth in the Ipswich River Basin 1870—2000 (C. Hopkinson, personal communication).

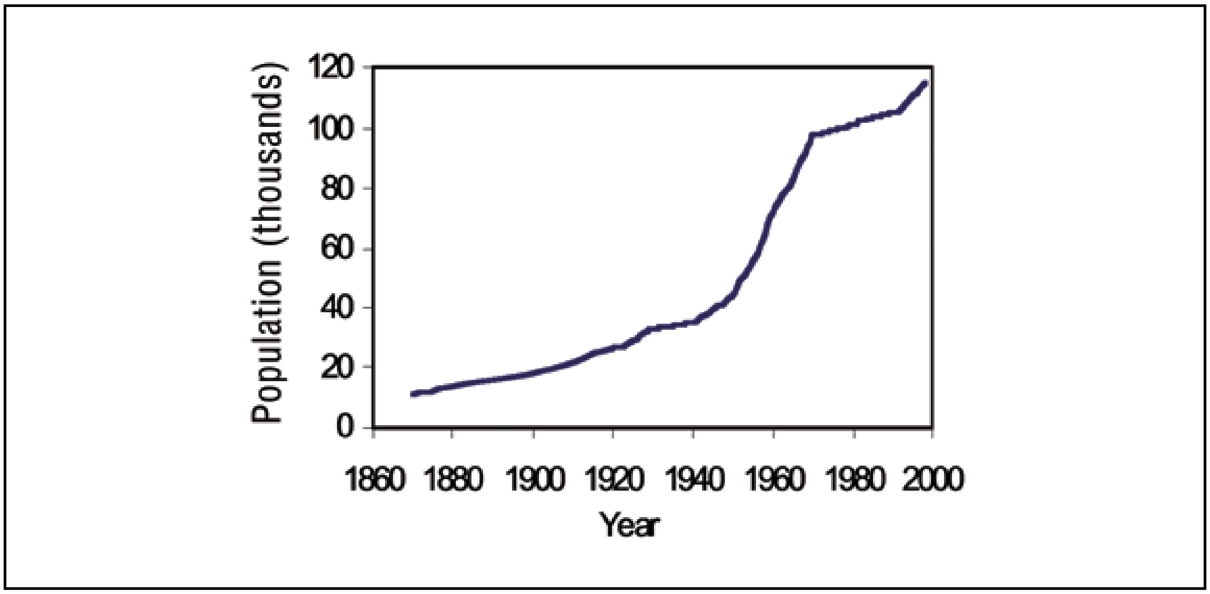


Table 6
ASSETS Synthesis for Plum Island Sound.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilutionpotential	Low	Moderate Susceptibility	Moderate	OHI = 3 OEC = 2 DFO = 1 Poor
		Flushingpotential	High			
	Nutrient inputs	Moderate				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate High	
		Macroalgae	?			
	Secondary Symptom Method	Dissolvedoxygen	No Problem	Moderate		
		Submerged aquaticvegetation	?			
		Nuisance and Toxic Blooms	Moderate			
Response DFO index	Future nutrient pressures	Increase due to population and development			Worsen High	

Boston Harbor

Boston Harbor is an urban system consisting of Boston Harbor and several smaller coastal embayments. Gulf of Maine salinities exist within the main harbor. Freshwater inflow is dominated by the Neponset River, but there are also contributions from two other rivers, the Mystic and the Charles. Salinity is vertically homogeneous throughout the Bay. Circulation is strongly affected by tidal influences and non-tidal surface currents. Tidal range is approximately 2.76 m near the mouth of Boston Harbor (Bricker et al., 1997b). It is a relatively shallow system with an average depth of about 4.6 m and is well-flushed by strong tides. Average residence time in the harbor is short, Massachusetts Bay and river waters replace the harbor water in 5 to 7 days though the channels flush more quickly and inner harbor and shoreline areas flush more slowly (Hornbrook et al., 2002).

The most notable characteristic of Boston Harbor is the recent change in the location of the sewage outfall. Sewage discharges ended in 1991, today it is landfilled.

Before July 1998, poorly treated wastewater was discharged into the harbor. Between 1998 and 2000 several improvements were made: sewage treatment in the two main plants discharging to the harbor was upgraded to secondary treatment and a new outfall was built that now transports cleaner effluent out of the harbor completely and into Massachusetts Bay. The Bay outfall became operational on September 6, 2000. Today, no treatment plants discharge directly to the Bay (Libby et al., 2003).

Noted improvements in Boston Harbor include increases in water clarity, decreases in ammonium concentration in the Harbor, decreases in indicator bacteria, decreases in Chl a, and Harbor beaches are swimmable most of the time (Rex et al., 2002).

Data availability

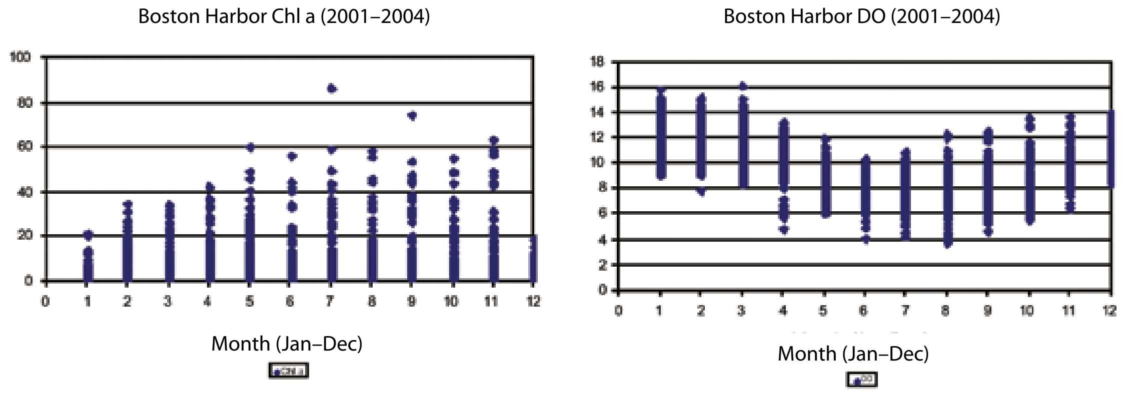
Water quality data for the ASSETS application for Boston Harbor are derived from the Environmental Monitoring and Mapping System (EM&MS), an Oracle database maintained by the Massachusetts Water Resources Authority (MWRA) Environmental Quality Department (ENQUAD) for Chl a, DO, and nutrients. The 2003 data represent samples from 23 stations with 1,142 samples for Chl a and 1,137 samples for DO (Figure 7). The nutrient data for the calculation of overall human influence are for nitrogen concentrations, specifically DIN, and are also for 2003.

Pressure – Overall Human Influence

Boston Harbor is classified as having a Moderate susceptibility to development of eutrophic symptoms because the system has Moderate capacity to both dilute and flush nutrients.

Neither the SPARROW (Smith et al., 1997; Alexander et al., 2001) nor the WATERSN (Whitall et al., 2004; Castro et al., 2003; Castro and Driscoll, 2002) model provide load estimates for Boston Harbor. For the OHI calculation, a flow weighted average of DIN concentration was used to estimate the land-based nutrient sources from the Charles, Neponset, and

Figure 7
Chl a and DO data for Boston Harbor used for ASSSETS and Human Use Assessment (MWRA).


Boston Harbor Chl a (2001–2004)

Boston Harbor DO (2001–2004)

Mystic Rivers. A station in Massachusetts Bay was used to represent the oceanic-end member. The results show an OHI ratio of 0.37, which is in the Moderate Low category. Combined with the Moderate susceptibility, the overall human influence to Boston Harbor is estimated to be Moderate.

State – Overall Eutrophic Condition

Chl a concentration data for all 23 stations and for all months sampled in 2003 range from 0.32 to 60 micrograms/l. The 90th percentile for all data is 9.38 micrograms/l, which falls into the Moderate category. Analyzed by station, the Moderate values show High spatial coverage and these concentrations are seen on an annual basis. The Chl a expression value is 1, or High.

No data or information are available for macroalgal abundance.

The primary symptoms in Boston Harbor are High, based on Chl a only, because there are no data for macroalgal abundance.

DO concentration data for the 23 stations for all months of 2003 ranged from 4.88 to 14.9 mg/l. The 10th percentile value for all data is 7.18 mg/l, which falls into the category of No Problem. No occurrences of hypoxia or anoxia were observed and the expression value is 0, or No Problem.

At present, Boston Harbor has only small areas of submerged aquatic grasses. The grasses had died out almost completely by the late 1980s because of high turbidity, viral diseases, and excessive epiphytic growth due to high nutrient levels (Hornbrook et al., 2002). Since the loss of the grass meadows in the 1980s, turbidity has not decreased to the point of regrowth of the grasses. The expression value for SAV loss is given a value of 0.25, because the losses occurred previously but the water quality is such that regrowth has not occurred.

There were no records of nuisance or toxic bloom occurrences in Boston Harbor during this time and thus this indicator receives a score of No Problem.

The secondary symptom indicators in Boston Harbor are Low due to the SAV indicator.

The overall eutrophic condition for Boston Harbor is Moderate, based on the High primary and Low secondary symptom expression.

Response – Determination of Future Outlook

Loads to Boston Harbor have decreased significantly since September 2000, when the Massachusetts Water Resources Authority transferred the wastewater discharges from the Deer Island treatment facility to Boston Harbor, 16 km offshore, for diffusion in the bottom waters of Massachusetts Bay (Figure 8). This "offshore transfer" ended the bulk of the discharges of wastewater from the City of Boston and surrounding communities to Boston Harbor (Taylor, 2004). This has led to decreases in nutrient concentrations and in summertime Chl a concentrations, as well as to increases in summertime DO concentrations (Figure 8). While the analysis here shows that Chl a is considered High, the trends noted are encouraging and the expectation is that additional improvements will be seen in the

Table 7
ASSETS Synthesis for Boston Harbor.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	Moderate	Moderate Susceptibility	Moderate	OHI = 3 OEC = 3 DFO = 4 Moderate
		Flushing potential	Moderate			
	Nutrient inputs	Moderate Low				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate	
		Macroalgae	No Data			
	Secondary Symptom Method	Dissolved oxygen	No Problem	Low		
		Submerged aquatic vegetation	Low			
		Nuisance and Toxic Blooms	No Problem			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease			Improve Low	

future (Hornbrook et al., 2002). The combination of an expected decrease in nutrient loads to Boston Harbor with Moderate susceptibility leads to a classification for determination of future outlook of Improve Low.

ASSETS Synthesis

The combination of Moderate overall human influence, Moderate overall eutrophic conditions, and Improve Low rating for future outlook gives an ASSETS synthesis classification of Moderate (Table 6).

References

Bricker, S., C. Clement, S. Frew, M. Harmon, M. Harris, and D. Pirhalla. 1997b. NOAA's Estuarine Eutrophication Survey- Volume 3: North Atlantic Region. National Oceanic and Atmospheric Administration, National Ocean Service, Office of Ocean Resources Conservation and Assessment. Silver Spring, MD. 45 p.

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Figure 8
Noted changes in Boston Harbor chemical, biological and physical measures from 2000-2003 (from Taylor, 2004).

Summary of differences in Harbor water-quality between the 36-months and baseline.

VARIABLE	CHANGE DURING 36-MONTHS	
TN (umoll^{-1})	F	-10.0 (-32%)
DIN (umoll^{-1})	F	-7.0 (-59%)
DIN as % TN	F	-14 (-37%)
TP (umoll^{-1})	F	-0.58 (-28%)
DIP (umoll^{-1})	F	-0.4 (-38%)
DIP as % TP	**F**	-7 (-14%)
TN:TP	F	-1.3 (-9%)
DIN:DIP	F	-3.8 (-33%)
TOTAL CHL-A (ugl^{-1}) (summer)	F	-3.4 (-35%)
'ACTIVE' CHL-A (ugl^{-1}) (summer)	F	-2.5 (-36%)
PHAEOPHYTIN (ugl^{-1}) (summer)	F	-1.0 (-36%)
POC (umoll^{-1})	F	-12.1 (-28%)
TSS (mgl^{-1})	**FC**	+0.25 (+7%)
POC as % TSS	F	-6.0 (-42%)
k (m^{-1})	–	-0.01 (-2%)
SECCHI DEPTH (m)	**C**	+0.1 (+4%)
DO CONC (mgl^{-1}) (mid-summer)	C	+0.5 (+7%)
DO % SAT (mid-summer)	C	+5.0 (+6%)
SALINITY (ppt)	g	+4.0 (+1%)

Up-facing arrows indicate increases, down-facing arrows, decreases. Blue arrows indicate changes that might be interpreted as 'improvements'.
Red arrows indicate changes that might not be viewed as improvements. Gray hatched arrows denote differences that cannot at this time be assessed as beneficial or not.

Massachusetts Bay

Massachusetts Bay comprises a large coastal bay with multiple smaller coastal embayments. Gulf of Maine salinities exist within the main Bay. Circulation is strongly influenced by tides and non-tidal surface currents. Tidal range is approximately 2.74 m near Beverly Harbor. (Bricker et al., 1997b). There is a general counterclockwise circulation in the Gulf of Maine, with inflow from the Scotian shelf and flow to the southwest along the coast of Maine towards Massachusetts Bay. Some of the water sweeping past Cape Ann enters Massachusetts Bay and contributes to a counterclockwise circulation (Geyer, 1999). The main Bay is approximately 100 km long from north to south, 50 km wide from east to west, and 35 m deep on average. The Bay is closed in the north, west and south, and is open to the Gulf of Maine in the east at Stellwagen Bank, which is approximately 20 m deep. Freshwater from Boston Harbor tributaries and the Massachusetts Water Resources Authority (MWRA) effluent at the outfall site provide point sources of fresh water and nutrients. Thus, the Massachusetts Bay is a semi-enclosed embayment (Jiang and Zhou, 2003).

Data availability

Water quality data for the ASSETS application for Massachusetts Bay are derived from the Environmental Monitoring and Mapping System (EM&MS), an Oracle database maintained by the MWRA Environmental Quality Department (ENQUAD) for Chl a, DO, and nutrients. The data represent samples from 31 stations during 2001-04; 6,062 samples for Chl a and 5,888 samples for DO. The nutrient data for the calculation of overall human influence are for nitrogen concentrations, specifically DIN, for 2003.

Pressure – Overall Human Influence

Massachusetts Bay is classified as having Low susceptibility to eutrophic conditions because its dilution potential is High and its flushing potential is Moderate.

The estimated land-based nitrogen load for the Massachusetts Bay OHI calculation was derived using the 2003 median DIN concentration of the head-of-tide station, which in this situation was the station closest to land, and the 2003 median DIN concentration of the ocean-end member, or the station farthest from land. The results show an OHI ratio of 0.019, which is in the Low category. Combined with the Low susceptibility, the overall human influence to Massachusetts Bay is estimated to be Low.

State – Overall Eutrophic Condition

Chl a concentration for 31 stations and all months sampled in 2003 ranged from 0.001 to 20.9 micrograms/l. The 90th percentile for all data is 7.53 micrograms/l, which falls into the Medium category. When analyzed by station, the Medium values have High spatial coverage seen on an annual basis. As such, the Chl a expression value is 1, or High.

There were no available data for macroalgal abundance.

The primary symptoms in Massachusetts Bay are rated High, based on Chl a only since there are no data for macroalgal abundance.

DO concentration data for 31 stations for all months in 2003 ranged from 5.67 to 13.1 mg/l. The 10th percentile value for all data is 7.71 mg/l, which falls into the category of No Problem. There were no occurrences of hypoxia recorded, and no anoxia observed. As such, DO has an expression value of 0, or No Problem.

At the time of this publication no SAV data were available.

A minor Phaeocystis pouchetii bloom was observed throughout most of Massachusetts Bay in April 2002. These blooms did not deplete nutrient levels in the surface waters until June, as the waters were weakly stratified until this survey (Libby et al., 2003). There are annual occurrences of the dinoflagellate Alexandrium tamarense in the Gulf of Maine and as a result this region has annually recurrent outbreaks of paralytic shellfish poisoning (PSP) caused by this and other closely-related species (Anderson undated 1, 2; Anderson, 1997; Figure 9). As such, HABs are given an expression of High and a value of 1.

The secondary symptom indicators in Massachusetts Bay are High due to the HAB indicator.

The overall eutrophic condition for Massachusetts Bay is High due to the High primary and High secondary symptom expression.

Response – Determination of Future Outlook

Land-based inputs to the Massachusetts Bay come from a wide variety of sources. The Merrimack River and rivers further north in the Gulf of Maine provide most of the freshwater inflow to Massachusetts Bay (MWRA, 2003). Although they do not empty directly into the Bay, their flow is much greater than the Charles River and other Massachusetts Bay rivers. Another important source of inputs to Massachusetts Bay is the new Boston Harbor outfall pipe, which releases waste treatment plant water directly into the center of the Bay. Increases in population over time, as well as increases in impervious surfaces, will cause small increases in land-based nitrogen inputs to the system. As such, the DFO forecast for Massachusetts Bay is Worsen Low because of an increase in land-based nitrogen loading with Low susceptibility.

ASSETS Synthesis

The combination of Low overall human influence, High overall eutrophic conditions, and a Worsen Low forecast for future outlook gives an ASSETS synthesis classification of Moderate (Table 8).

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Figure 9
Alexandrium bloom 1993. (Modified from Geyer, 1999).

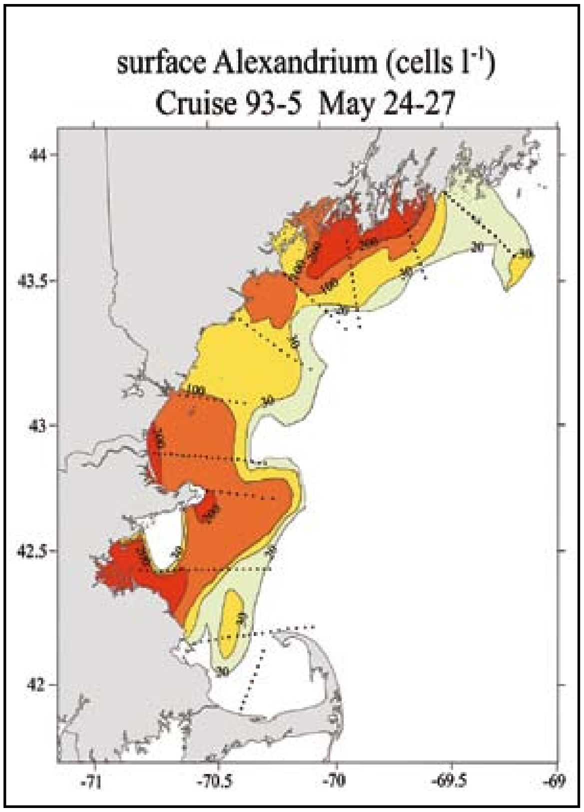


Table 8
ASSETS Synthesis for Massachusetts Bay.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilutionpotential	High	Low Susceptibility	Low	OHI = 5 OEC = 3 DFO = 2 Moderate
		Flushingpotential	Moderate			
	Nutrient inputs	Low				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate	
		Macroalgae	?			
	Secondary Symptom Method	Dissolvedoxygen	No Problem	Low		
		Submerged aquaticvegetation	?			
		Nuisance and Toxic Blooms	Low			
Response DFO index	Future nutrient pressures	Increase in population and impervious surfaces			Worsen Low	

Cape Cod Bay

This system consists of a large coastal bay (the largest in the North Atlantic region) that is partially enclosed by Cape Cod, a ridge on the Coastal Plain consisting of glacial deposits. Four smaller bays and harbors make up the rest of the system. Circulation is strongly affected by tidal influences and non-tidal surface currents. Salinity is vertically homogeneous throughout the Bay. Tidal range is approximately 2.74 m near Wellfleet Harbor (Bricker et al., 1997b).

Data availability

Water quality data for the ASSETS application for Cape Cod are derived from the Environmental Monitoring and Mapping System (EM&MS), an Oracle database maintained by the Massachusetts Water Resources Authority (MWRA) Environmental Quality Department (ENQUAD) for Chl a, DO and nutrients. The data from 2001–2004 represents samples from four stations with 420 samples for Chl a and 397 samples for DO. The nutrient data for the calculation of overall human influence are for nitrogen concentrations, specifically DIN for 2003.

Pressure – Overall Human Influence

Cape Cod Bay is classified as having Moderate susceptibility to eutrophic conditions since its dilution potential is High and its flushing potential is Moderate.

The estimated land-based nitrogen load for the Cape Cod Bay OHI calculation was derived using the 2003 median DIN concentration of the head-of-tide station, which in this situation was the station closest to land, and the 2003 median DIN concentration of the ocean-end member, or the station farthest from land. The results show an OHI ratio of 0.007, which is in the Low category. Combined with the Moderate susceptibility, the overall human influence to Cape Cod Bay is estimated to be Moderate Low.

State – Overall Eutrophic Condition

Chl a concentration for four stations and all months sampled in 2003 ranged from 0.022 to 19.8 micrograms/l. The 90th percentile for all data is 7.68 micrograms/l, which falls into the Medium category. When analyzed by station, the Medium values have High spatial coverage seen on an annual basis. As such, the Chl a expression value is 1, or High.

The Natural Resources Department has long been aware of an enormous and growing quantity of sea lettuce Ulva lactuca in Round Cove. Throughout the Cove, this floating macroalgae, which consume oxygen through respiration, have formed large mats, at present often 0.61 to 0.91 m thick. In addition, the decaying material releases nitrogen back into the water (Office of Harwich Harbormaster, 1998) Macroalgae abundance receives a Low Value since data is spatially limited.

The primary symptoms in Cape Cod are rated High based on Chl a and limited macroalgal abundance data.

DO concentration data for four stations for all months in 2003 ranged from 5.819 to 12.431 mg/l. The 10th percentile value for all data is 7.975 mg/l, which falls into the category of No Problem. There were no occurrences of hypoxia recorded, and no anoxia observed. As such, DO has an expression value of 0, or No Problem.

A minor Phaeocystis pouchetii bloom was observed throughout most of Cape Cod Bay in April 2002. These blooms did not deplete nutrient levels in the surface waters until June, as the waters were weakly stratified until this survey (Libby et al., 2003). There are annual occurrences of the dinoflagellate Alexandrium tamarense in the Gulf of Maine and as a result this region has annually recurrent outbreaks of paralytic shellfish poisoning (PSP) caused by this and other closely related species (Anderson undated 1, 2; Anderson, 1997). As such, HABs are given an expression of High and a value of 1.

The secondary symptom indicators in Cape Cod Bay are High due to the HAB indicator.

The overall eutrophic condition for Cape Cod Bay is High due to the High primary and High secondary symptom expression.

Response – Determination of Future Outlook

Land use in the Cape Cod Bay drainage area has changed dramatically, almost doubling over the last 40 years (Figure 10). Increases in population density as well as increases in impervious surfaces (Figure 11) have been noted in recent decades (WHRC, 2005). These increases, along with the addition of the Boston Harbor/Massachusetts Bay water treatment outfall pipe, have continued to increase nitrogen loading to Cape Cod Bay. As such, the DFO for Cape Cod Bay is Worsen Low, due to an increase in population and impervious surfaces, with Moderate susceptibility.

Figure 10
Population change in Barnstable County, MA,1765 to 2003 (CCC, 2003).

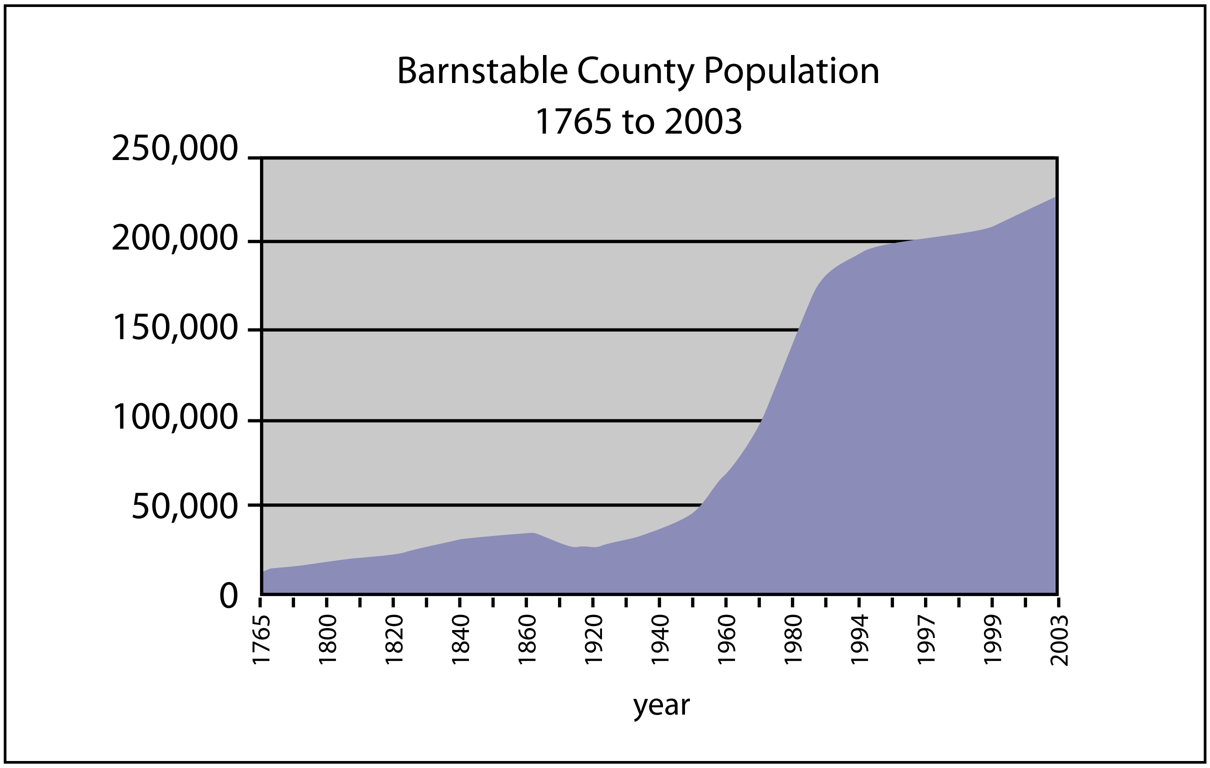
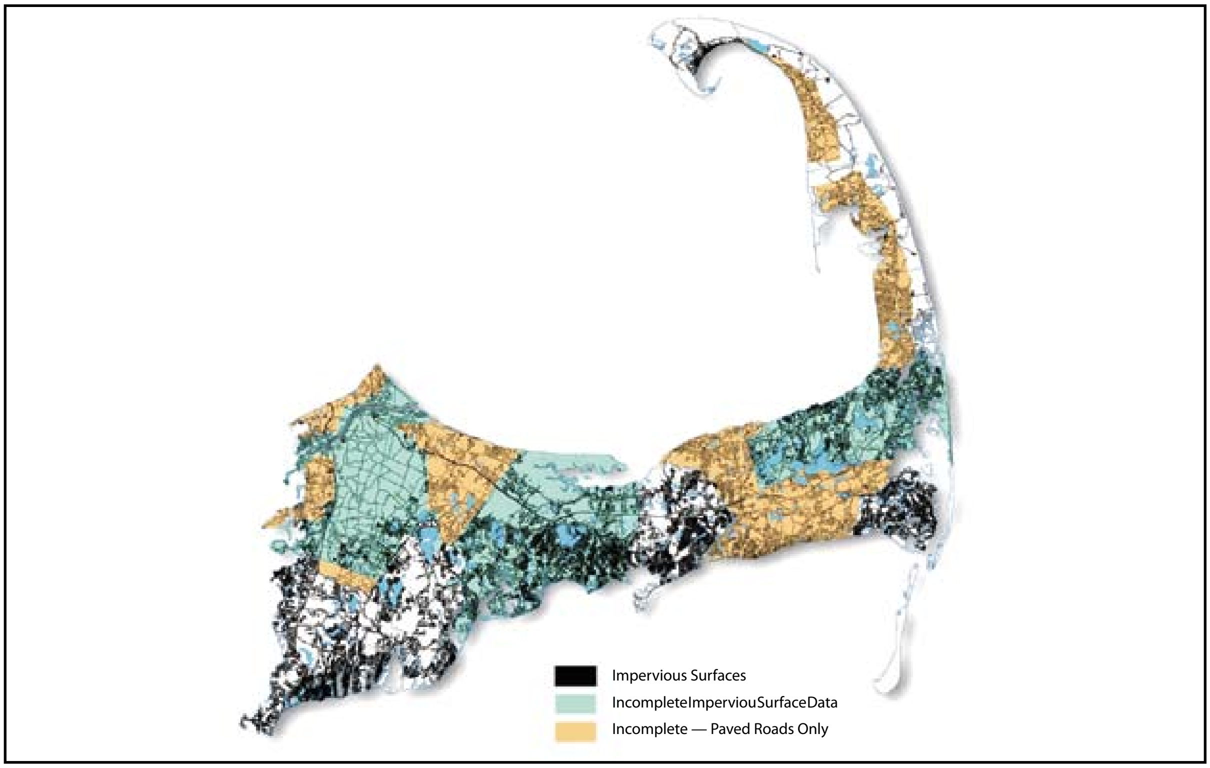


Figure 11
Impervious surfaces on the Cape Cod peninsula (WHRC, 2005).



ASSETS Synthesis

The combination of Moderate Low overall human influence, Moderate overall eutrophic conditions, and a Worsen Low forecast for future outlook gives an ASSETS synthesis classification of Moderate (Table 9).

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Table 9
ASSETS Synthesis for Cape Cod Bay.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	High	Moderate Susceptibility	Moderate Low	OHI = 4 OEC = 3 DFO = 2 Moderate
		Flushing potential	Moderate			
	Nutrient inputs	Low				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate	
		Macroalgae	Low			
	Secondary Symptom Method	Dissolved oxygen	No Problem	Low		
		Submerged aquatic vegetation	?			
		Nuisance and Toxic Blooms	Low			
Response DFO index	Future nutrient pressures	Increase in population and impervious surfaces			Worsen Low	

Buzzards Bay

Buzzards Bay is located on the southwestern end of Cape Cod between the Elizabeth Islands and the Southeast Massachusetts coastline. The Bay has an open water surface area of approximately 590 sq km and drains a total area of approximately 1120 sq km (US EPA, 1991). Tidal range is about 1.2 m throughout the bay (Bricker et al., 1997b). The basin includes all or parts of 17 municipalities in both Massachusetts and Rhode Island. Population increases in the region have been dramatic in recent years; over the past five decades there has been a 50% increase (Howes, 1996). Current estimates place the population at approximately 373,000 people, with 40% of these living in the Greater New Bedford area (http://www.savebuzzardsbay.org/).

There are 11 primary rivers that empty into Buzzards Bay; seven on the western shore and four on the eastern shore. All are tidally influenced, however they differ in their nutrient inputs based on their respective land usage (Howes, 1996). For example, in Buzzards Bay as a whole, sewage treatment facilities account for 45-55% of nitrogen released into the Bay, but in the sub-embayment Buttermilk Bay (a typical embayment as far as land use), private septic tank systems account for about 74% of nitrogen inputs (Costa, 2003).

Data availability

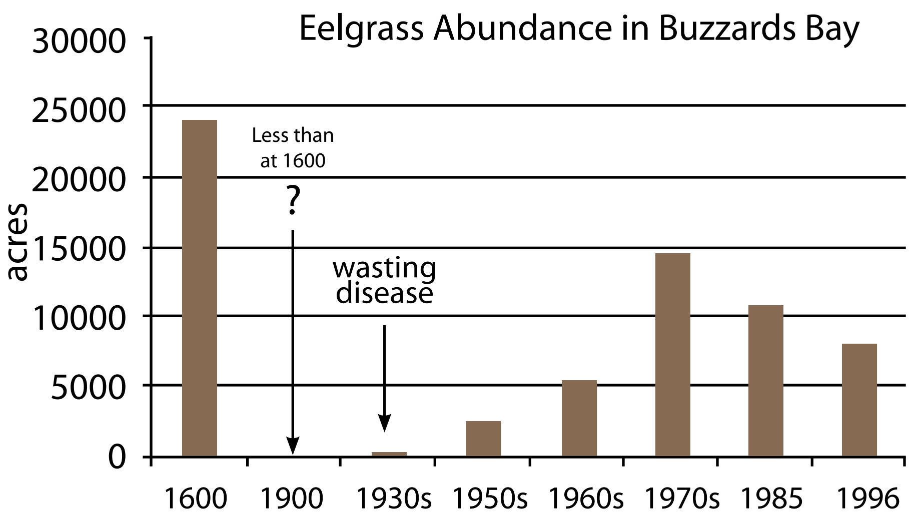
Water quality data for the ASSETS application for Buzzards Bay came from both the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP) database and the Coalition for Buzzards Bay (CBB). The EMAP database includes data for DO, Chl a, salinity, and temperature. The data represent samples from approximately 217 stations (varies depending on water-quality variable) in 1990-93, 2000-01 and 38 samples for Chl a and 86 samples for DO. The part of the CBB database retrieved for this study had data only from 2002-03. The CBB database had a total of 1,326 Chl a samples and 3,773 DO samples.

Pressure – Overall Human Influence

Buzzards Bay is classified as having Moderate susceptibility to eutrophic conditions because its dilution potential is High and its flushing potential is Low.

The Buzzards Bay nitrogen loading estimate of 2.18 x 10^6 kg of nitrogen per year is from estimates of riverine loading WATERSN model (Whitall, 2004; Castro, 2002, 2003). OHI model results show a ratio of 0.176, which is in the Low category. Combined with the Moderate susceptibility, the overall human influence to Buzzards Bay is estimated to be Moderate Low.

Figure 12
Historical Summary of eelgrass in Buzzards Bay (Adapted from Costa 2003 State of Buzzards Bay presentation).



Estimate for 1600 is speculative and based on 2/3 of potential habitat; 1930s - 1970s is extrapolated from trends at selected sites documented with historical aerial photographs, Data for 1985 from Costa (1988), and 1996 data from Mas sGIS, both adjusted.

State – Overall Eutrophic Condition

Chl a concentration data were available only for the months July-August 2002-03. These 1,350 samples range from 0.04 to 100.69 micrograms/l. The data for surface samples were averaged because the 90th percentile calculation would significantly bias the assessment results toward a falsely High value. The average is 5.33 micrograms/l, which falls into the Low range. The assessment for Chl a is Low.

Macroalgae in Buzzards Bay was observed in the middle portion of the Slocums River in 2003. There was High abundance of macroalgae, but because the spatial coverage was Low, macroalgae is categorized as Low.

The primary symptoms in Buzzards Bay are Low, based on the Chl a and macroalgae data.

DO concentration data were available for only the months July-August in 2002-03. These data range from 1.5 to 15.5 mg/l. The data for bottom samples were averaged because the 10th percentile calculation would bias the data toward a falsely Low assessment. The average for July and August 2002-03 is 6.4, or No Problem.

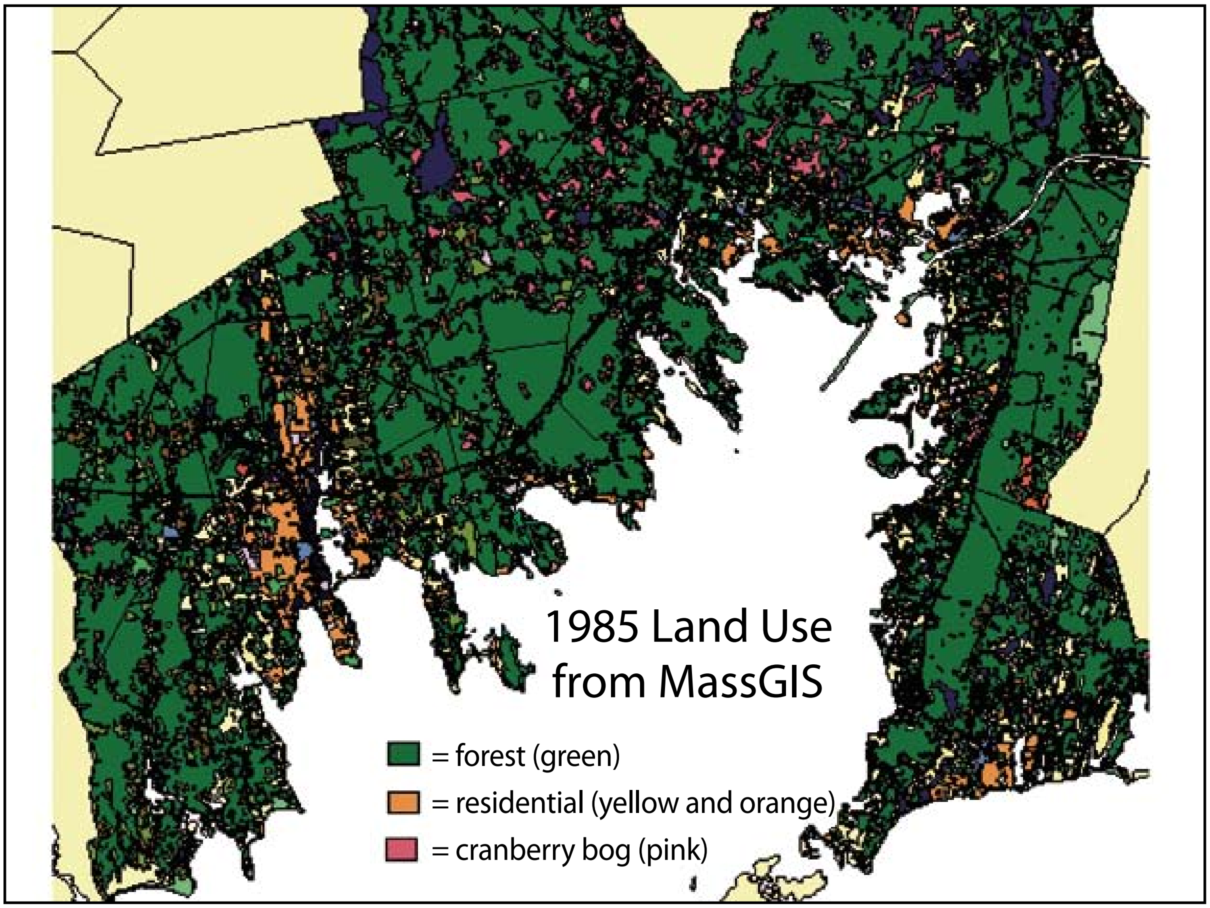
Buzzards Bay experienced an overall loss of SAV between 1985 and 1996 (Costa, 2003; Figure 12). The observed loss is estimated to be Low and receives an ASSETS expression of Low.

HABs were not a problem in Buzzards Bay during the timeframe of our assessment.

The secondary symptoms in Buzzards Bay are Low, as all three of the subcategories are Low or No Problem.

The overall eutrophic condition for Buzzards Bay is Low due to the Low primary and Low secondary symptom expression.

Figure 13
Land use in Buzzards Bay (1985).



Response – Determination of Future Outlook

Land use in Buzzards Bay varies tremendously, from highly developed sub-bays like Clark's Cove (5% forest coverage, 92% developed) to relatively undeveloped sub-bays like Widow's Cove (88% forest coverage, 11% developed) (Costa, 1999; Figure 13). Forest coverage in Buzzards Bay as a whole has been on the decline in the 21st century. This loss of forestation is primarily caused by development along the coastal region. The trend toward increasing development points to increases in land-based nitrogen inputs to the system. Management of the coastal areas of Buzzards Bay is ongoing, but with such a diverse range of potential problem areas spread over such a large area, the DFO for the Bay is Worsen Low because of an increase in nutrient loading with Moderate susceptibility.

ASSETS Synthesis

The combination of Moderate Low overall human influence, Low overall eutrophic conditions, and Worsen Low for future outlook gives an ASSETS synthesis classification of Good (Table 10).

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Table 10
ASSETS Synthesis for Buzzards Bay.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	High	Moderate Susceptibility	Moderate Low	OHI = 4 OEC = 5 DFO = 2 Good
		Flushing potential	Low			
	Nutrient inputs	Low				
State OEC index	Primary Symptom Method	Chlorophyll a	Low	Low	Low	
		Macroalgae	Low			
	Secondary Symptom Method	Dissolved oxygen	No Problem	Low		
		Submerged aquatic vegetation	Low			
		Nuisance and Toxic Blooms	No Problem			
Response DFO index	Future nutrient pressures	Future nutrient pressures increase			Worsen Low	

Narragansett Bay

Narragansett Bay is a medium-sized (370 sq km), relatively well-mixed temperate latitude estuary that includes several smaller embayments such as Greenwich Bay and Mount Hope Bay. The watershed is about 4,714 sq km with three major river basins – the Taunton, Blackstone and Pawtuxet – with 60% of the drainage basin found within the boundaries of Massachusetts (Deacutis, 2004). It has relatively low input of freshwater, receiving the majority of freshwater from the Blackstone and Taunton Rivers. Circulation is affected largely by tidal mixing and wind currents and is generally well mixed, but seasonal stratification occurs in the upper Bay and in some embayments. Ocean water intrudes further up the East Passage than the West Passage. It has an average depth of 9 m with tides ranging from 0.91 m at the mouth of the bay to approximately 1.52 m near Warwick, Rhode Island (Bricker et al., 1997a). Average flushing rate is 26 days (Pilson, 1985).

Data availability

Water quality data used for the ASSETS application for Narragansett Bay are from several sources, although none represent an annual cycle. In this case, means were used instead of 90th and 10th percentiles since that would bias the results, given that the samples were taken only in the summer months. DO data for 1,356 samples from 65 stations for three sampling dates in 2002 and 2003 are from the Insomniacs Nighttime Cruises, a multidisciplinary team including academic, State, and Federal partners (http://www.geo.brown.edu/georesearch/insomniacs/index.html). The data were sorted to include only samples from 4.5 m depth and below, assuming an average depth of 9 m, since there was no identification of the relative depth, only the actual depth measure. Additional DO data for 104 samples and 127 samples for Chl a from 51 stations from July and August came from the EPA EMAP program for 2000-01 (EMAP). National Estuarine Research Reserve (NERR) program automatic sampler results are continuous measures (10th and 90th percentile was determined from these data) from 1995 to1998, including 51,000 samples for DO and 65,500 samples for Chl a from four locations. Other NERR data from 2002 include 104 Chl a samples from three stations from March through December, and 16,009 samples for DO from two locations (T-Wharf and Potter's Cove) from an autosampler (i.e., annual data were collected). Physical and hydrologic data come from CADS (http://cads.nos.noaa.gov). Nutrient-loading estimates are from Nixon et al. (2004).

Pressure – Overall Human Influence

The susceptibility for Narragansett Bay is Moderate because of Low flushing and High dilution potentials.

The 2003-04 estimated land-based nitrogen load to Narragansett Bay is 7.07 x10^3 metric tons/yr (Nixon et al., 2004) which includes atmospheric deposition (0.24 metric tons/yr) but excludes estimated oceanic input (0.21 metric tons/yr). The OHI calculation included an oceanic NO_3 concentration from Smith (CADS improved). The results show an OHI ratio of 0.53, which is in the Moderate category. Combined with the Moderate susceptibility, the overall human influence to Narragansett Bay is estimated to be Moderate.

State – Overall Eutrophic Condition

Chl a concentration for the July and August samples from EMAP 2000-2001 ranged from 0.81 to 95 micrograms/l. Averages were used instead of the 90th percentile due to the limited timeframe of the samples. Because there was no significant difference between surface, mid-depth and bottom concentrations, they were used together to give a summertime mean of 9.23 micrograms/l. This falls within the Moderate category. The NERR data from two sampling stations (Potters Cove and T-Wharf) range from 0.23 to 7.48 micrograms/l. (Nags Creek data were not used because the location in a creek could potentially bias the results.) The 90th percentile of all data is 1.91 micrograms/l, which falls into the Low category. Because the NERR data are limited spatially, the EMAP data were used and produced a result of Moderate for Chl a concentration for Narragansett Bay. The spatial coverage and frequency cannot be determined from this data, and thus the overall value is 0.5, or Moderate for this indicator.

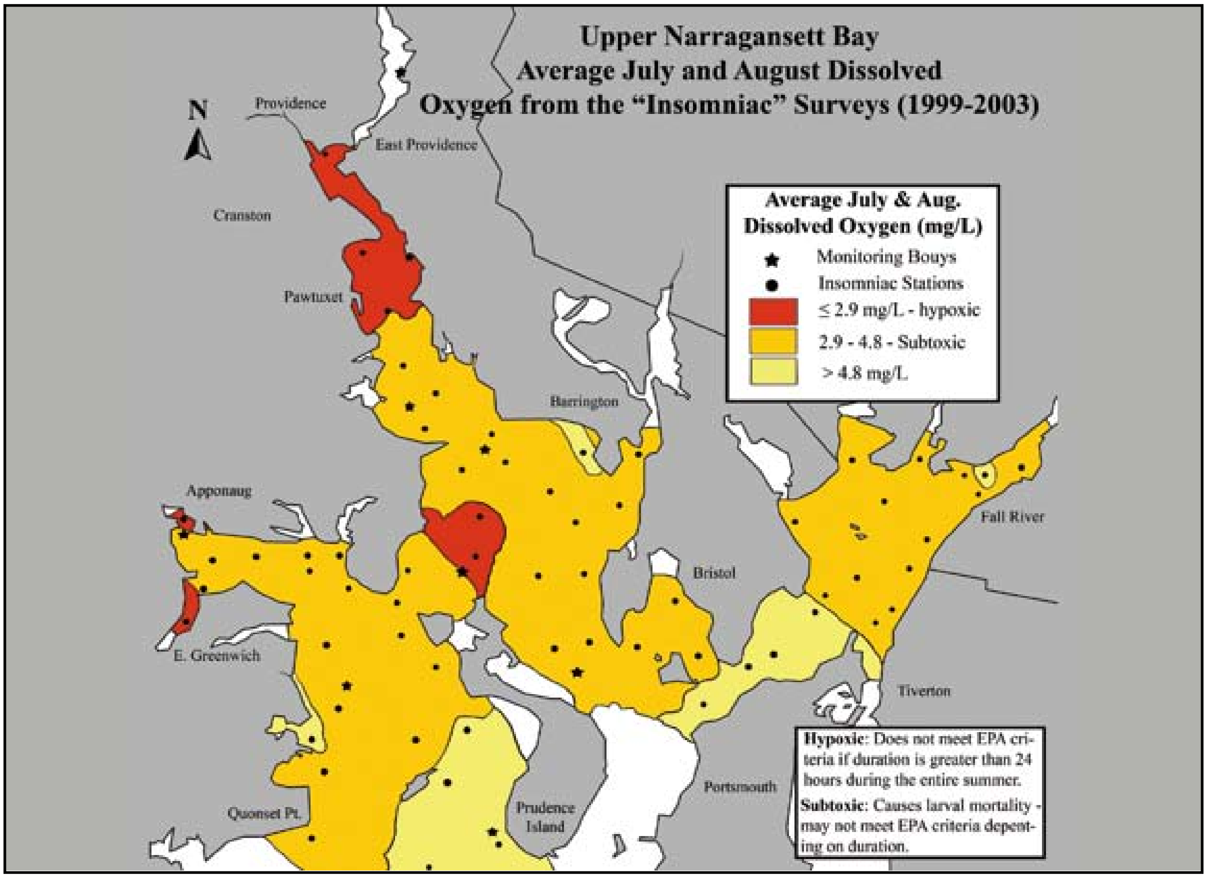
Macroalgae problems have been common for the past 10-15 years in the Providence River, and they appear to be spreading down the Bay and into many shallow coves (RISG, 2005). Macroalgal populations have become so dense and lush in the upper Bay that the Rhode Island Department of Environmental Management can no longer conduct fish survey trawls there because the algae clog the trawls, making sampling impossible. The abundance of macroalgae appears to have increased over time, but the data are limited. In some embayments, such as Greenwich Bay and other shallow embayments in the upper Bay, large Ulva mats have been observed for some time (RISG, 2005). The assessment value for this indicator is 1, or High, due to observed problems with a Periodic frequency.

The overall primary expression value is High, due to the combination of High macroalgal and Moderate Chl a assessment values.

When seasonal stratification occurs, it is stronger in the Providence River relative to the rest of the estuary, making this portion of the system more prone to hypoxia and more likely to maintain hypoxic conditions longer. Water column stratification is set up by river flow to the head of the Bay and strengthened by the depth of the dredged channel, which is difficult to mix vertically during summer conditions. In Bullock Reach, for instance, stratification is a major forcing function in the development of low oxygen concentrations. Because of this, hypoxia is common in the upper Bay, short-term anoxia events have been observed (Figure 14; RISG, 2005), and fish kills have been recorded in 1999 and 2003 (Deacutis, 1999; RIDEM, 2003).

EMAP 2000-01 data for DO ranges from 0.9 to 11.1 mg/l, with an average of 5.72 mg/l for the July and August samples. But one sample (2%) falls within the hypoxic range and 34% fall within the biologically stressful DO range. Data results from the multi-agency Insomniacs team, sampled June-August 2002-03, show a range from 0.08 to 10.83 mg/l, with an overall average of 4.7 mg/l. When averaged per station, there are two of 65 stations (3%) that have means falling within the hypoxic range and 32 stations, or almost 50%, where averages fall within the biologically stressful concentration range. The value for this indicator is Moderate, based on Moderate concentration, Moderate spatial coverage, and Periodic frequency (http://www.geo.brown.edu/georesearch/insomniacs/).

Figure 14
Average Dissolved oxygen concentrations compiled from five summers of nocturnal, neap tide monitoring surveys. (Modified from RISG, 2005; summarized from Saarman, 2005)



Eelgrass is now found only in the lower Bay; it is completely absent in the upper Bay. It is believed that present nutrient-loading levels preclude the return of eelgrass in upper Bay areas. Restoration of eelgrass has been successful only around Prudence Island (RISG, 2005; Deacutis, 1999). The expression value for SAV is Low (0.25), given that losses have already occurred but nutrient conditions prevent recolonization.

Nuisance and toxic blooms (including benthic macroalgae) are observed in the upper Bay (lower Providence River) and in western Greenwich Bay (RISG, 2005). Because of the limited data and information about these blooms, this indicator receives a Low expression value.

The overall secondary expression is Moderate, due to the Moderate values for DO concentrations.

Combined with the High primary symptom expression, the overall eutrophic condition assessment expression for Narragansett Bay is Moderate High.

Table 11
ASSETS Synthesis for Narragansett Bay.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	High	Moderate Susceptibility	Moderate	OHI = 3 OEC = 2 DFO = 3 Poor
		Flushing potential	Low			
	Nutrient inputs	Moderate				
State OEC index	Primary Symptom Method	Chlorophyll a	Moderate	High	Moderate High	
		Macroalgae	High			
	Secondary Symptom Method	Dissolved oxygen	Moderate	Moderate		
		Submerged aquatic vegetation	Low			
		Nuisance and Toxic Blooms	Low			
Response DFO index	Future nutrient pressures	Inputs will remain the same due to STP improvements despite population increase			No Change	

Response – Determination of Future Outlook

Nixon et al. (2005) report that total nitrogen loads have remained fairly constant from the 1980s, and that phosphorus loads have decreased by more than half. In projections to 2010, nitrogen loads are expected to remain the same, based on full realization of reductions of nitrogen from sewage treatment plants. These decreases are expected despite a projection of a population increase of 5-10% by 2008 (Crosset et al., 2004). With the Moderate susceptibility and a No Change in nutrient loading, the determination of future response is No Change.

ASSETS Synthesis

The combination of Moderate overall human influence, Moderate High overall eutrophic conditions, and No Change for future outlook gives an ASSETS synthesis classification of Poor (Table 11).

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Long Island Sound

Long Island Sound is a large (3,400 sq km) estuary with connections to the ocean at its western end via Block Island Sound and via the East River and New York Harbor to the east. The major tributaries, the Housatonic and Connecticut Rivers, enter from the north, with the Connecticut River accounting for about 70% of total freshwater inflow (Wolfe et al., 1991). The East River promotes stratification in the western Sound, particularly during the spring runoff period (Bricker et al., 1997). Average tidal range is about 2 m.

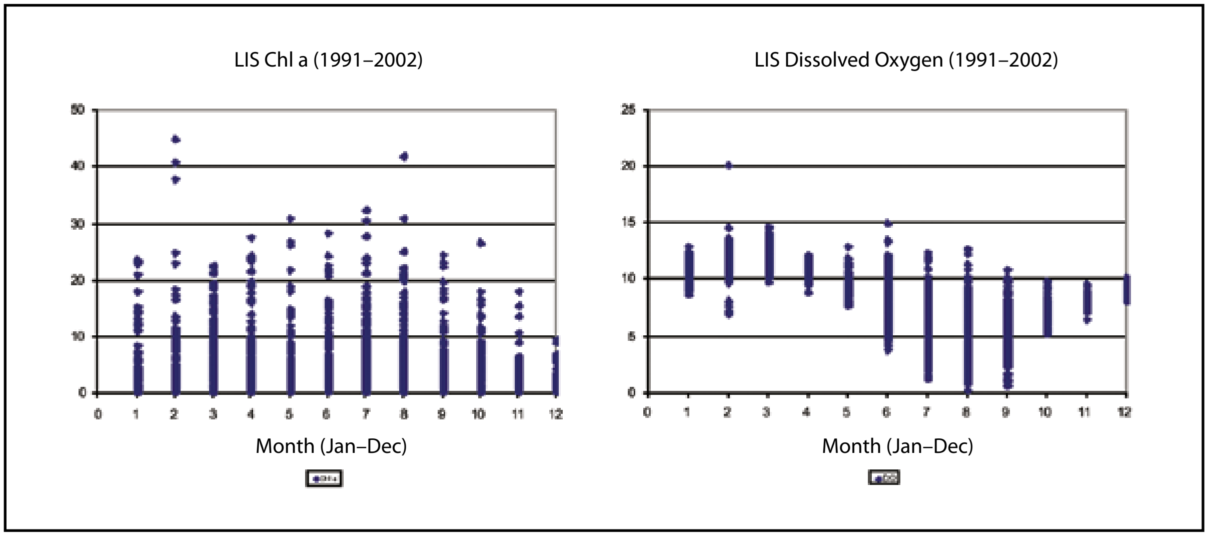
The NEEA/ASSETS method was applied to Long Island Sound to see if there have been noticeable changes between 1991 and 2002, a decade after the implementation of management measures designed to limit nitrogen inputs to the Sound.

Pressure – Overall Human Influence

The most significant feature of this system is its location adjacent to one of the most heavily populated regions of the United States: the New York metropolitan area and Bridgeport and New Haven, two of Connecticut's largest cities. The total population in the basin is greater than 8 million, with the majority residing in New York and Connecticut (U.S. Census Bureau, 2002). Although Long Island Sound receives some input from Massachusetts, Vermont, and New Hampshire, New York and Connecticut account for more than 80% of total inputs. The total nitrogen loading to Long Island Sound is 60.7 X 10^3 ton yr^{-1}, primarily from point sources (NYSDEC and CTDEP, 2000). Since 1990, about 25 of the 105 sewage treatment plants in Connecticut and New York have been upgraded to biological nutrient removal of nitrogen and more are under construction or are being proposed. These upgrades have led to a 30% decrease in nitrogen loading from wastewater treatment plants since 1990 (LISS, 2003) and it is expected that these improvements will continue (NYCDEP, 2000; NYSDEC and CTDEP, 2001).

The combination of High dilution potential and Low flushing potential gives this system a susceptibility rating of Moderate.

Figure 15
Chl a and DO in Long Island Sound used for ASSETS and Human Use assessment (LIS Study).



Data availability

Water quality data used for the ASSETS application to Long Island Sound are from the Long Island Sound Study (undated; Figure 15) and represent more than 111 monthly samples for seven stations in 1991 and 387 monthly samples for 17 stations in 2002. Physical and hydrologic data are from CADS (1999). Nutrient-loading estimates are from NYSDEC and CTDEP (2000).

Application of the loading-susceptibility model using a conservative re-entrainment value of 50% gives a human level of influence of 59% in 1991 and 51% in 2002, both falling within the Moderate category. With Moderate inputs and Moderate susceptibility, the rating for OHI is Moderate for both years.

State – Overall Eutrophic Condition

Chl a data for Long Island Sound show a decrease in the 90th percentile concentration from 18 micrograms/l to 9 micrograms/l, between 1991 and 2002. Additionally, average Chl a concentrations at the winter/spring bloom have decreased from 17 micrograms/l to about 2 micrograms/l in Western Long Island Sound (LISS, 2001). For both years, the frequency of occurrence is Periodic, the spatial coverage is High and the rating for Chl a is High.

Epiphytes were identified as a Moderate problem and macroalgae were identified as a High-level problem in Long Island Sound in the early 1990s (Bricker et al., 1999). However, there are no data for comparison to conditions in 2002. These variables were not used in the assessment.

The primary symptom expression value for Long Island Sound is High for both years.

DO 10th percentile for all stations together shows an increase from 3.9 mg/l in 1991 to 6.4 mg/l in 2002. However, biologically stressful concentrations are seen in both years, with a spatial coverage of High for 1991

Table 12
ASSETS Synthesis for Long Island Sound 1991.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	High	Moderate Susceptibility	Moderate	OHI = 3 OEC = 1 DFO = 4 Bad
		Flushing potential	Low			
	Nutrient inputs	Moderate				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	High	
		Macroalgae	?			
	Secondary Symptom Method	Dissolved oxygen	Moderate	High		
		Submerged aquatic vegetation	High			
		Nuisance and Toxic Blooms	No Data			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease, significant population/ development increases – Improve Low			Improve Low	

Table 13
ASSETS Synthesis for Long Island Sound 2002.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	High	Moderate Susceptibility	Moderate	OHI = 3 OEC = 3 DFO = 4 Moderate
		Flushing potential	Low			
	Nutrient inputs	Moderate				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	Moderate	
		Macroalgae	?			
	Secondary Symptom Method	Dissolved oxygen	Low	Low		
		Submerged aquatic vegetation	Low			
		Nuisance and Toxic Blooms	No data			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease, significant population/ development increases – Improve Low			Improve Low	

and Moderate for 2002. This is concurrent with an observed decrease in hypoxic area from almost 800 sq km in 1987 to about 330 sq km in 2002 (LISS, 2003). Although the duration is highly variable, there is a trend toward a decreasing duration of Low-DO events over the same time period. The rating for DO in 1991 is Moderate and for 2002 is Low.

Nuisance and toxic blooms were identified as a Moderate-level problem in the early 1990s (Bricker et al. 1999) but there are no data for 2002 for comparison. This variable was not used in the assessment.

SAV was lost in the 1970s and 1980s due to High Chl a concentrations in the water column (LISS, 2003). SAV spatial coverage is Very Low for both 1991 and 2002, however, there has been a small increase in SAV from 1991 to 2002. In Mumford Cove, Connecticut eelgrass has increased by 0.2 sq km from 1987 to 2002 (LISS, 2003). The rating for SAV for 1991 is High and the rating for 2002 is Low.

The overall secondary symptom expression for Long Island Sound is High for 1991 and Low for 2002.

The overall eutrophic condition for Long Island Sound 1991 is High, and for 2002 is Moderate.

Response – Determination of Future Outlook

Although the population is expected to increase in the Long Island Sound watershed over the next 20 years, the EPA-approved TMDLs and the agreement to reduce nitrogen by 58.5% by 2014 (LISS, 2003) are likely to result in continued declines in loadings. The expected decrease in inputs, combined with the Moderate susceptibility, gives a response rating of Improve Low for expected eutrophic conditions in Long Island Sound.

ASSETS Synthesis

The combination of Pressure-State-Response results for Long Island Sound for 1991 result in an ASSETS rating of Bad. The improvements in conditions within the system that resulted from the decreases in loadings during 1990s are reflected in the ASSETS score of Moderate for Long Island Sound for 2002 (Table 12, 13).

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Patuxent River

The Patuxent River is a smaller estuary with a surface area of approximately 140 sq km. It is the largest river that falls completely within the state of Maryland and drains a total basin area of around 2,270 sq km. The median salinity of the Patuxent River was 11.3 for 2002. Tidal range is about 0.3 m at the mouth (Bricker et al., 1997a).

Land use in the Patuxent River Basin is varied, with nearly equal areas of urban (30%), agriculture (26%), and forest (44%) (Figure 16).

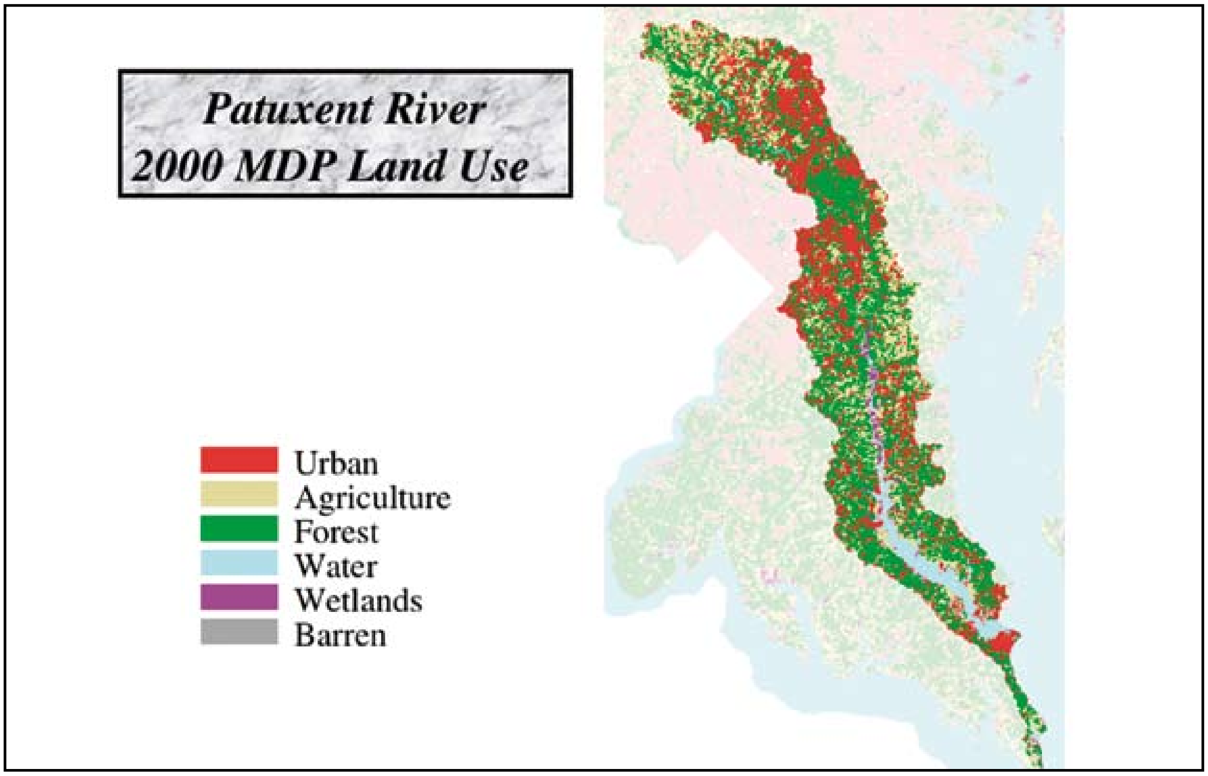
Data availability

The data used for the Patuxent River NEEA/ASSETS assessment is from a number of different sources. The water quality data (Chl a, DO, and salinity) and nutrient data (DIN) comes from the Chesapeake Bay Program's online database (http://www.chesapeakebay.net). Chl a 90th percentile for 2002 was calculated from nine stations and represents 582 individual samples. DO 10th percentile for 2002 was calculated from nine stations and represents 795 individual samples. A median salinity was calculated for the estuary using the Chesapeake Bay Program's data for the years 1997-2002. DIN median for 2002 was also calculated from the Chesapeake Bay Program's database.

The change in SAV coverage in 2002 was calculated using the 2001 and 2002 SAV coverage dataset that was produced at the Virginia Institute of Marine Science from aerial photography taken in 2001 and 2002. Areal SAV coverage (square meters) in 2001 and 2002 was calculated using ArcMAP. The change in SAV coverage was then calculated by subtracting the areal coverage of 2001 from the areal coverage for 2002.

Harmful algal bloom (HAB) data were collected from the Eyes On the Bay website (http://mddnr.chesapeakebay.net/hab/, 2002 HAB report search). Physical, hydrological, and land-use data for the Patuxent River came from both the original NEEA database and from the Patuxent River Basin Summary (MDDNR, 2004).

Figure 16
Land use in the Patuxent River Basin 2000 (Basin Summary Team and Chesapeake Bay Program Tidal Monitoring and Analysis Workgroup, 2004).



Pressure – Overall Human Influence

The Patuxent River drains part of the large agricultural area of Maryland as well as some of the newly developed areas near Columbia, Maryland. Along with these large agricultural and suburban nutrient sources, the Patuxent lies between the two major metropolitan centers of Washington, DC and Baltimore. Land use for the Patuxent watershed is 44% forest/wetlands, 26% agriculture, and 30% urban (MDDNR, 2004). The 2000 population estimate for the Patuxent River basin was 618,000, with significant increases expected in the future. Nitrogen, phosphorus, and sediment inputs to the Patuxent River have all decreased since 1985, however there have been significant increases in population and development over that same period.

The Patuxent River has a Moderate dilution potential but a Low flushing potential. This gives the system an overall susceptibility rating of High. Nitrogen-loading for the system calculated the human influence to be 82.2% for 2002, which corresponds to a value of High. With High inputs and High susceptibility, the OHI value is High for 2002.

State – Overall Eutrophic Condition

Chl a 90th percentile concentrations in the Patuxent River estuary during 2002 ranged from Medium to Hypereutrophic in the following approximate spatial coverage: Medium, 90%; High, 4%; and Hypereutrophic, 5%. The overall 90th percentile value for all 2002 data and all stations was 35.14 micrograms/l, which corresponds to a value of High. The highest spatial coverage above (which is for Medium Chl a) is adopted for the overall Chl a value for the Patuxent River estuary for 2002, and as such the system gets an expression of High.

Macroalgae for the Patuxent River in 2002 was No Problem (Peter Tango, MDDNR, personal communication).

DO levels in the Patuxent River estuary during 2002 ranged from No Problem to Biological Stress in the following approximate spatial percentages: No Problem, 14% and Biological Stress, 85%. The overall combined 10th percentile for all stations in 2002 was 3.8 mg/l, which corresponds to Biological Stress. This spatial coverage and DO level correspond to an overall rating of Moderate, with a value of 0.5.

Table 14
ASSETS Synthesis for Patuxent River.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	Moderate	High Susceptibility	High	OHI = 1 OEC = 3 DFO = 4 Moderate
		Flushing potential	Low			
	Nutrient inputs	High				
State OEC index	Primary Symptom Method	Chlorophyll a	High	Moderate	Moderate	
		Macroalgae	No Prob			
	Secondary Symptom Method	Dissolved oxygen	Moderate	Moderate		
		Submerged aquatic vegetation	Small Increase			
		Nuisance and Toxic Blooms	Problem			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease, significant population/ development increases – Improve Low			Improve Low	

In 2001, SAV in the Patuxent River had a spatial coverage of approximately 1,341,822.21 sq m, whereas in 2002 there was a slight increase to 1,344,817.18 sq m.

HABs had only minor appearances during 2002. On April 15, 2002, there was a single recorded event of low levels of Dynophysis accuminata in the Patuxent River. The low duration gives HABs an overall Low value of 0.25.

Secondary symptoms are Moderate. The overall eutrophic condition is Moderate due to Moderate primary and secondary symptoms.

Response – Determination of Future Outlook

For the Patuxent River basin, nitrogen loading, phosphorus loading, and sediments all decreased between 1985 and 2002 (Patuxent River Basin Summary, 2004). In contrast, however, population growth in Maryland is projected to increase at an approximately 1% every year, and the Patuxent River basin itself includes many new suburban communities that are expected to continue to experience rapid suburban growth.

Therefore, even though nitrogen, phosphorus, and sediment loading are decreasing, significant population increases and development may mask the decreases in loading and cause there to be only small positive changes in future nutrient pressures. Thus, with High susceptibility and only small improvements in future nutrient pressures, the overall calculation for DFO forecast in the Patuxent River is Improve Low for 2002.

ASSETS Synthesis

The pressure to the system (OHI) was High, and the state of the system (OEC) was Moderate. There are only small expected improvements in the future nutrient pressures (DFO). These three values combine for an overall ASSETS rating of Moderate (Table 12).

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Potomac River

The Potomac River is a medium-sized estuary (1,267 sq km) with a low median salinity around 11.3. It drains parts of Maryland and Virginia (7,200 sq km) as well as parts of West-Virginia, Pennsylvania and Washington, D.C. before emptying out into the main stem of the Chesapeake Bay. The river is tidally influenced with the head-of-tide just beyond the upstream limits of Washington, DC. The Potomac River contributes approximately 20% of the total freshwater to the Chesapeake Bay (MDDNR website). Tidal range is about 0.4 m near the mouth (Bricker et al., 1997a).

Data availability

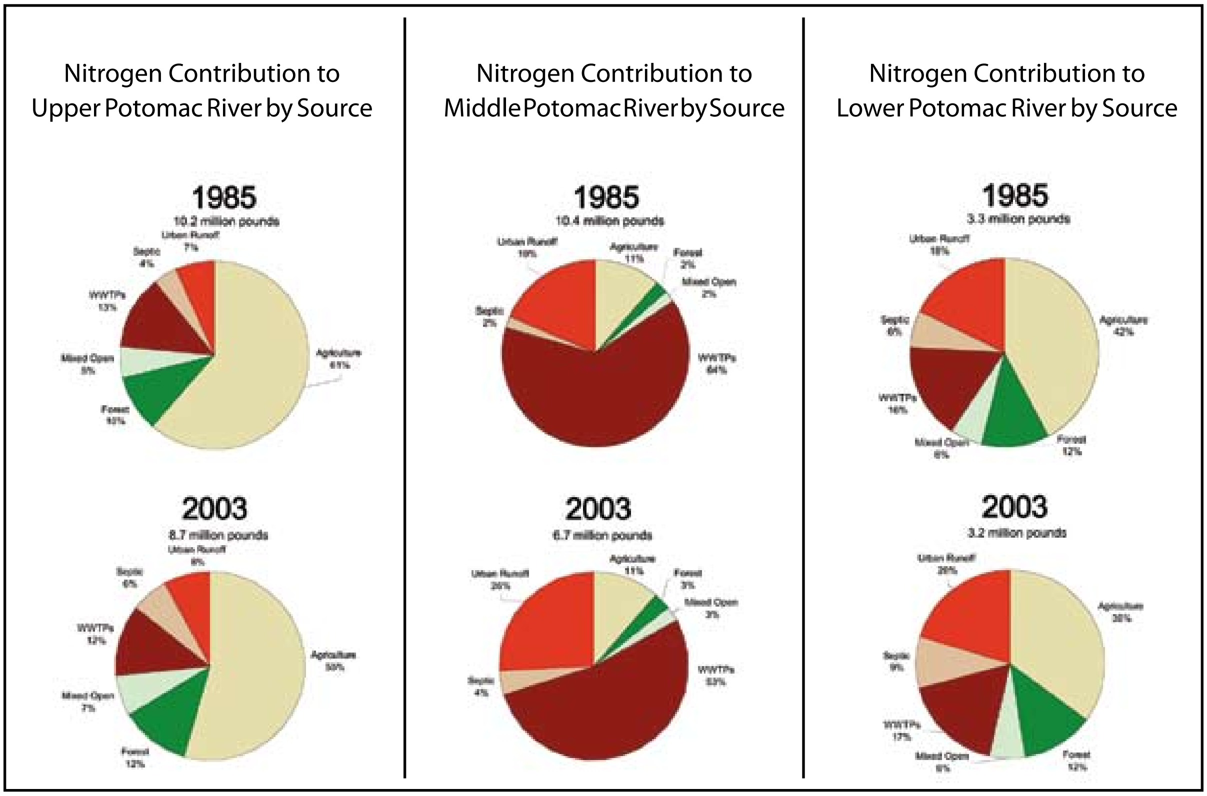
The data used for the Potomac River NEEA/ASSETS assessment are from a number of different sources. The water quality data (Chl a, DO, and salinity) and nutrient data (DIN) come from the Chesapeake Bay Program's online database (www.chesapeakebay.net). Chl a 90th percentile for 2002 was calculated from 12 stations and represents 645 individual samples. DO 10th percentile for 2002 was calculated from 11 stations and represents 1,329 individual samples. A median salinity was calculated for the estuary using the Chesapeake Bay Program's data for the years 1997-2002. DIN median for 2002 was also calculated from the Chesapeake Bay Program's database.

The change in SAV coverage in 2002 was calculated using the 2001 and 2002 SAV coverage dataset, produced at the Virginia Institute of Marine Science from aerial photography taken in 2001 and 2002, using ArcMAP (part of the ArcGIS program). Areal SAV coverage (in square meters) in both 2001 and 2002 was calculated. The change in SAV coverage for the Potomac was then calculated by subtracting the areal coverage of 2001 from the areal coverage for 2002.

HAB data were collected from the Eyes On the Bay website (http://mddnr.chesapeakebay.net/hab/, 2002 HAB report search).

Physical, hydrological, and land-use data for the Potomac River came from both the original NEEA database and the Potomac River Basin Summary (MDDNR, 2004).

Figure 17
Nitrogen Loading to the Upper, Mid and Lower Potomac 1985 and 2003 (Basin Summary Team and Chesapeake Bay Program Tidal Monitoring and Analysis Workgroup, 2004).



Nitrogen Contribution to Upper Potomac River by Source

Nitrogen Contribution to Middle Potomac River by Source

Nitrogen Contribution to Lower Potomac River by Source

Pressure – Overall Human Influence

The Potomac River basin drains large agricultural areas in Maryland, Virginia, Pennsylvania and West Virginia as well as the Washington DC metropolitan area. The estimated total population for the Maryland side of the basin alone (excluding DC) is 643,000 (MDDNR, 2004). The River can be classified into upper and lower segments, with the delineation being the head-of-tide. The upper Potomac River is made up of 48% forest/wetlands, 38% agriculture, and 14% urban. Land use for the lower Potomac River is 60% forest/wetlands, 24% agriculture, and 16% urban (MDDNR, 2004). Nitrogen, phosphorus, and sediment loading to the Potomac River decreased between 1985 and 2003, while the population, along with development, significantly increased (Figure 17). However, there is new evidence that nutrient inputs are now increasing (B. Romano, Personal Communication).

The Potomac River has a High dilution potential but a Low flushing potential, giving the system an overall susceptibility rating of High. Nitrogen loading for the system calculated the human influence to be 94.8% for 2002, which corresponds to a value of High. With High inputs and High susceptibility, the OHI value for 2002 is High.

Table 15
ASSETS Synthesis for Potomac River.

Indices	Methods	Parameters/ Values / EAR			Index category	ASSETS grade
Pressure OHI index	Susceptibility	Dilution potential	High	High Susceptibility	High	OHI = 1 OEC = 1 DFO = 4 Bad
		Flushing potential	Low			
	Nutrient inputs	High				
State OEC index	Primary Symptom Method	Chlorophyll a	High	High	High	
		Macroalgae	No Prob			
	Secondary Symptom Method	Dissolved oxygen	Low	High		
		Submerged aquatic vegetation	Large Increase			
		Nuisance and Toxic Blooms	Problem (1)			
Response DFO index	Future nutrient pressures	Future nutrient pressures decrease, significant population/ development increases – Improve Low			Improve Low	

State – Overall Eutrophic Condition

Chl a 90th percentile concentrations in the Potomac River estuary during 2002 ranged from Low to High in the following approximate spatial coverage: Low, 1%, Medium, 59% and High, 9%. The overall 90th percentile value for all 2002 data and all stations was 16.42 micrograms/l. The highest spatial coverage (which is for Medium Chl a) was adopted for the overall Chl a value for the Potomac River estuary for 2002, and as such the system gets an expression of High.

Macroalgae for the Potomac River in 2002 was No Problem (Peter Tango, MDDNR, personal communication, August 23, 2005)

DO levels in the Potomac River estuary during 2002 ranged from No Problem to Hypoxia in the following approximate spatial percentages: No Problem, 23%; Biological Stress, 28%; Anoxia, 19%. The overall combined 10th percentile for all stations in 2002 was 4.2 mg/l, which corresponds to Biological Stress.

In 2001, SAV in the Potomac River had a spatial coverage of approximately 529,557.04 sq m, whereas in 2002 there was an increase of approximately 34 million sq m, to 34,479,090.57 sq m.

HABs were a large problem during 2002. There were multiple different blooms throughout the year, however the largest and longest bloom was that of Dinophysis accuminata from February until around April of 2002 (Eyes on the Bay website, viewed 6-04). During the three months of the bloom, shellfish beds were closed and no harvesting was allowed. HABs carried the largest NEEA/ASSETS secondary symptoms value and were combined with the overall primary symptom value to calculate the OEC.

The overall eutrophic condition for the Potomac River in 2002 was High and was calculated from a primary symptoms value of High and a secondary symptoms value of High.

Response – Determination of Future Outlook

For the Potomac River basin, nitrogen loading, phosphorus loading, and sediments all decreased between 1985 and 2002 (Potomac River Basin Summary, 2004). In contrast, however, population growth in Maryland alone is projected to increase at an approximate 1% every year, while the Potomac River basin itself includes many new suburban communities that are expected to continue to experience rapid suburban growth.

As a result, even though nitrogen, phosphorus, and sediment loading are decreasing, significant population increases and development may mask the decreases in loading and cause there to be only small positive changes in future nutrient pressures. Thus, with High susceptibility and only small improvements in future nutrient pressures, the overall calculation for DFO in the Potomac River is Improve Low for 2002.

ASSETS Synthesis

The ASSETS synthesis for the Potomac River in 2002 resulted in a value of Bad. Both the pressure to the system (OHI) and the state of the system (OEC) were rated High. There are only small expected improvements in the future nutrient pressures (DFO), giving a rating of Improve Low. These three values combine for an overall ASSETS rating of Bad (Table 15).

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Appendix 2: Figure of Core Variable Results for Human Use Indicator

All Estuaries — All Fish Species

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	NS
Surface Chl a	B
DO x Temp Cross Product	B

All Estuaries — Individual Fish Species

STRIPED BASS

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	B
Surface Chl a	B
DO x Temp Cross Product	B

All Estuaries — Individual Fish Species

BLUEFISH

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	G
Surface Chl a	NS
DO x Temp Cross Product	NS

All Estuaries — Individual Fish Species

WINTER FLOUNDER

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	B
Surface Chl a	G
DO x Temp Cross Product	G

Mid Atlantic Estuaries — All Fish Species

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	NS
Surface Chl a	B
DO x Temp Cross Product	NS

Gulf of Maine Estuaries — All Fish Species

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	G

Mid Atlantic Estuaries — Individual Fish Species

STRIPED BASS

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	B

Gulf of Maine Estuaries — Individual Fish Species

STRIPED BASS

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	NS
DO x Temp Cross Product	G

Mid Atlantic Estuaries — Individual Fish Species

BLUEFISH

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	G
Surface Chl a	NS
DO x Temp Cross Product	NS

Gulf of Maine Estuaries — Individual Fish Species

BLUEFISH

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	NS

NS = Not Significant.

NM = No Model was possible.

Mid Atlantic Estuaries — Individual Fish Species

WINTER FLOUNDER

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	B
Surface Chl a	G
DO x Temp Cross Product	G

Gulf of Maine Estuaries — Individual Fish Species

WINTER FLOUNDER

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NM
Bottom Water DO^2	NM
Surface Chl a	NM
DO x Temp Cross Product	NM

Closed Estuaries — All Fish Species

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	NS
Surface Chl a	B
DO x Temp Cross Product	NS

Closed Estuaries — Individual Fish Species

STRIPED BASS

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	G
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	B

Closed Estuaries — Individual Fish Species

BLUEFISH

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	G
Surface Chl a	NS
DO x Temp Cross Product	B

Closed Estuaries — Individual Fish Species

WHITE FLOUNDER

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NS
Bottom Water DO^2	B
Surface Chl a	G
DO x Temp Cross Product	G

Open Estuaries — All Fish Species

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	G

Open Estuaries — Individual Fish Species

STRIPED BASS

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	NS
DO x Temp Cross Product	G

Open Estuaries — Individual Fish Species

BLUEFISH

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	B
Bottom Water DO^2	G
Surface Chl a	B
DO x Temp Cross Product	NS

Open Estuaries — Individual Fish Species

WINTER FLOUNDER

INCREASE IN CORE VARIABLES	CHANGE IN FISH CATCH RATE
Bottom Water DO	NM
Bottom Water DO^2	NM
Surface Chl a	NM
DO x Temp Cross Product	NM

NS = Not Significant.

NM = No Model was possible.

ASSETS	Assessment of Estuarine Trophic Status
CADS	Coastal Assessment and Data Synthesis
Chl a	Chlorophyll a
DFO	Determination of future outlook
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
EAR	Eutrophication assessment rating
EM&MS	Environmental Monitoring and Mapping System
EMAP	Environmental Monitoring and Assessment Program
EPA NCA	Environmental Protection Agency National Coastal Assessment
EUWFD	European Union Water Framework Directive
GIS	Geographic information system
HAB	Harmful algal bloom
MRFSS	Marine Recreational Fisheries Statistical Survey
NEEA	National Estuarine Eutrophication Assessment
NMFS	National Marine Fisheries Service
OEC	Overall eutrophic condition
OHI	Overall human influence
OSPAR COMPP	Oslo Paris Convention for the Protection of the North Sea Comprehensive Procedure
PSP	Paralytic shellfish poisoning (PSP)
SAV	Submerged aquatic vegetation
SPARROW	Spatially referenced regressions on watershed attributes
TMDL	Total maximum daily load

United States Department of Commerce
Carlos M. Guiterrez, Secretary

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