Assessment of sewage and septic derived N in the Choptank and Patuxent Rivers.

Final Report

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Executive Summary

An assessment of nitrogen sources to the Choptank and Patuxent River (including Island Creek), was conducted during the summer of 2003. A relatively new technique using stable isotope ratios of macroalgae incubated *in situ* was used, along with more traditional measures of water quality to determine the impacts of point sources such as sewage and septic derived nitrogen. Results were compared to reference sites located near the town of Cape Charles just inside the mouth of the Chesapeake Bay.

The Choptank and Patuxent Rivers receive inputs from a number of point sources, including sewage treatment plants (STP) and septic outfalls, in additional to a variety of non-point source inputs such as agricultural and urban runoff. The Choptank River has moderate urban development, an agricultural watershed, and the STPs are distributed throughout the river. In contrast, the Patuxent has extensive urban development, a forested watershed and all its STPs are upstream.

Results demonstrated that both rivers were compromised with sewage derived nutrients, with elevated δ^{15}N isotopic ratios occurring near to, and downstream of wastewater discharges. Additionally, concentrations of water column nitrogen and phosphorus, chlorophyll *a*, and dissolved oxygen, as well as water clarity (measured as secchi depth) varied throughout the rivers.

Four reporting regions were defined for each river (upper, middle, lower and mouth) (Figs. 1 & 2) and an assessment of ecosystem health (Ecosystem Health Index) was made for each region. In both Rivers there was a gradient from poorer to better ecosystem health from upstream to downstream, influenced by the concentration of nutrient inputs, water residence time and flushing with the bay. Overall, the ecosystem health of the Patuxent River was superior to the Choptank River.

Island Creek in the lower reaches of the Patuxent River receives no inputs from sewage treatments plants, only septic outfalls from the residences along the creek. The Ecosystem

Health Index was lower than the mean value for the entire Patuxent River. Small scale variability in the results highlighted sections along the creek with poorer ecosystem health.

The ecosystem health of the Cape Charles region was significantly higher than either the Choptank or Patuxent River, with fewer nutrient inputs and good flushing with oceanic waters. Water quality parameters and stable isotope signatures showed that there was significantly lower impacts from nutrient inputs.

The Ecosystem Health Index for each reporting region was converted to a report card grade from A+ to D- and F for fail (Table 1). This style of ecosystem health report card is a useful monitoring tool which can help focus management and research efforts by providing rapid and effective feedback on the health of Chesapeake Bay.

A spatially explicit index of ecosystem health such as this is a useful monitoring tool which can help focus management and research efforts by providing rapid and effective feedback on the health of Chesapeake Bay. When used over time, a report card also become temporally explicit and responsive to annual changes in the health of Chesapeake Bay.

Table 1. Ecosystem Health Report Card for Patuxent and Choptank Rivers compared with reference sites near Cape Charles.

Patuxent Overall	**D+**	*Choptank Overall*	**D**
Upper Patuxent	**F**	Upper Choptank	**F**
Middle Patuxent	**C-**	Middle Choptank	**D**
Lower Patuxent	**D**	Lower Choptank	**D**
Mouth Patuxent	**C**	Mouth Choptank	**D+**
Island Creek	**D-**	*Cape Charles*	**B+**

Excellent	**Poor**
Acceptable	**Very Degraded**

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Introduction

The Choptank and Patuxent Rivers flow into Chesapeake Bay at 0.74 $\times10^9$ m^3 yr^{-1} and 0.65 $\times10^9$ m^3 yr^{-1}, respectively. Despite the similarity in flow rates, there are considerable differences in surface area (Choptank, 0.36 $\times10^9$ m^2; Patuxent, 0.14 $\times10^9$ m^2) and volume (Choptank, 1.35 $\times10^9$ m^3; Patuxent, 0.65 $\times10^9$ m^3) (Boynton *et al.* 1995).

Both rivers have similar tidal ranges (0.5 m at the mouths, and increase to 0.8-1.0 m in the tidal fresh areas) and similar mean depths (4.0 m and 5.4 m for the Choptank and Patuxent, respectively). However, the depth of the Choptank is relatively constant along its length, compared with the Patuxent which is very shallow in the upper reaches, with a deep channel through the middle which is particularly prominent in the lower reaches (Figs. 1 & 2).

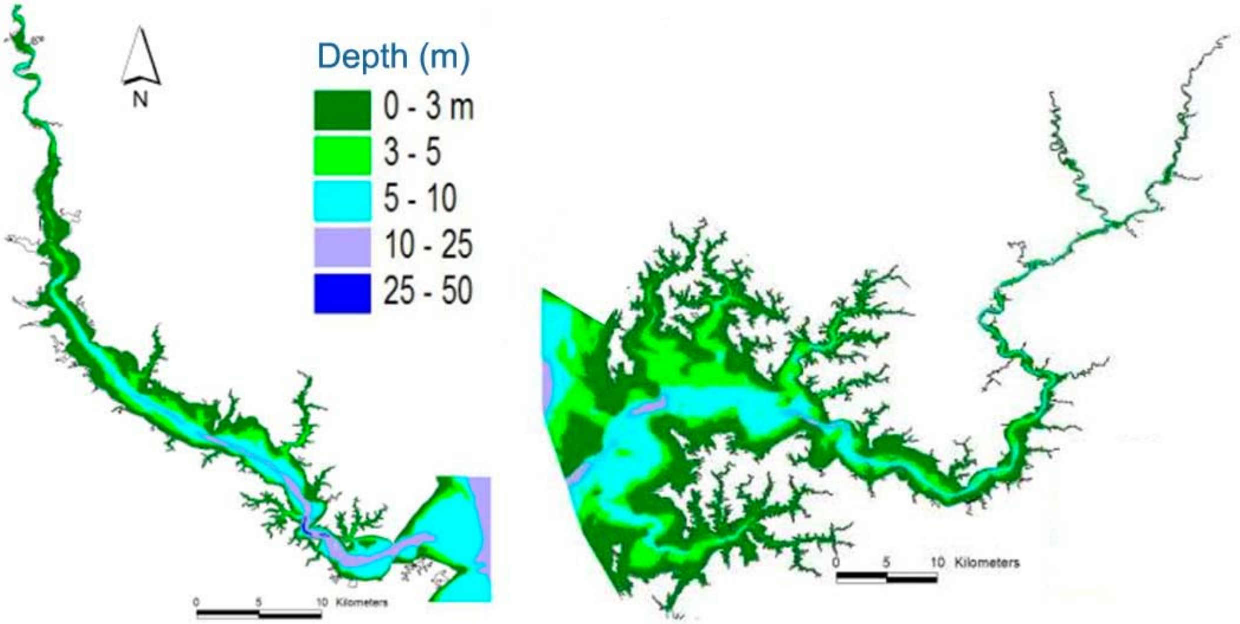

Figure 1. Patuxent River and Choptank River bathymetry

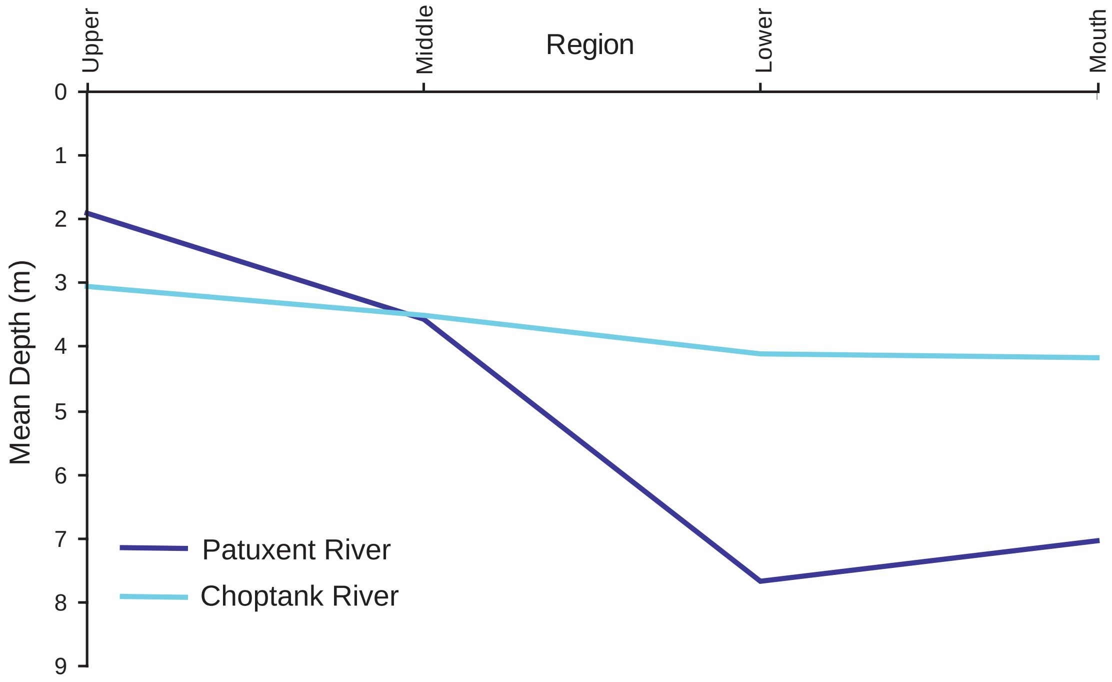

Figure 2. Mean depths of the Patuxent and Choptank Rivers for each of the reporting regions.

The Choptank and Patuxent Rivers receive inputs from a number of sewage treatment plants (STP) and septic outfalls. The Choptank River has moderate urban development, an agricultural watershed (Fig. 3), and the STP's are distributed throughout the river (Fig. 5). In contrast, the Patuxent has extensive urban development, a forested watershed (Fig. 4) and all its STP's are upstream (Fig. 5). The three distributed STP's in the Choptank vary significantly in terms of daily volume, with the Cambridge plant being the biggest with 4.4 MGD, then Easton with 1.4 MGD, and Denton with 0.4 MGD. In contrast, the STP's in the Patuxent River effectively function as one source from the upper reaches to the rest of the river, providing a more consistent source of nutrients to the rest of the river. The three most downstream STPs are located at Laurel (5.5 MGD), Bowie (1.8 MGD) and Upper Marlboro (17.4 MGD) (Chesapeake Bay Foundation, 2003). The volume and nitrogen load from sewage is much greater entering the Patuxent than the Choptank River (Table 2).

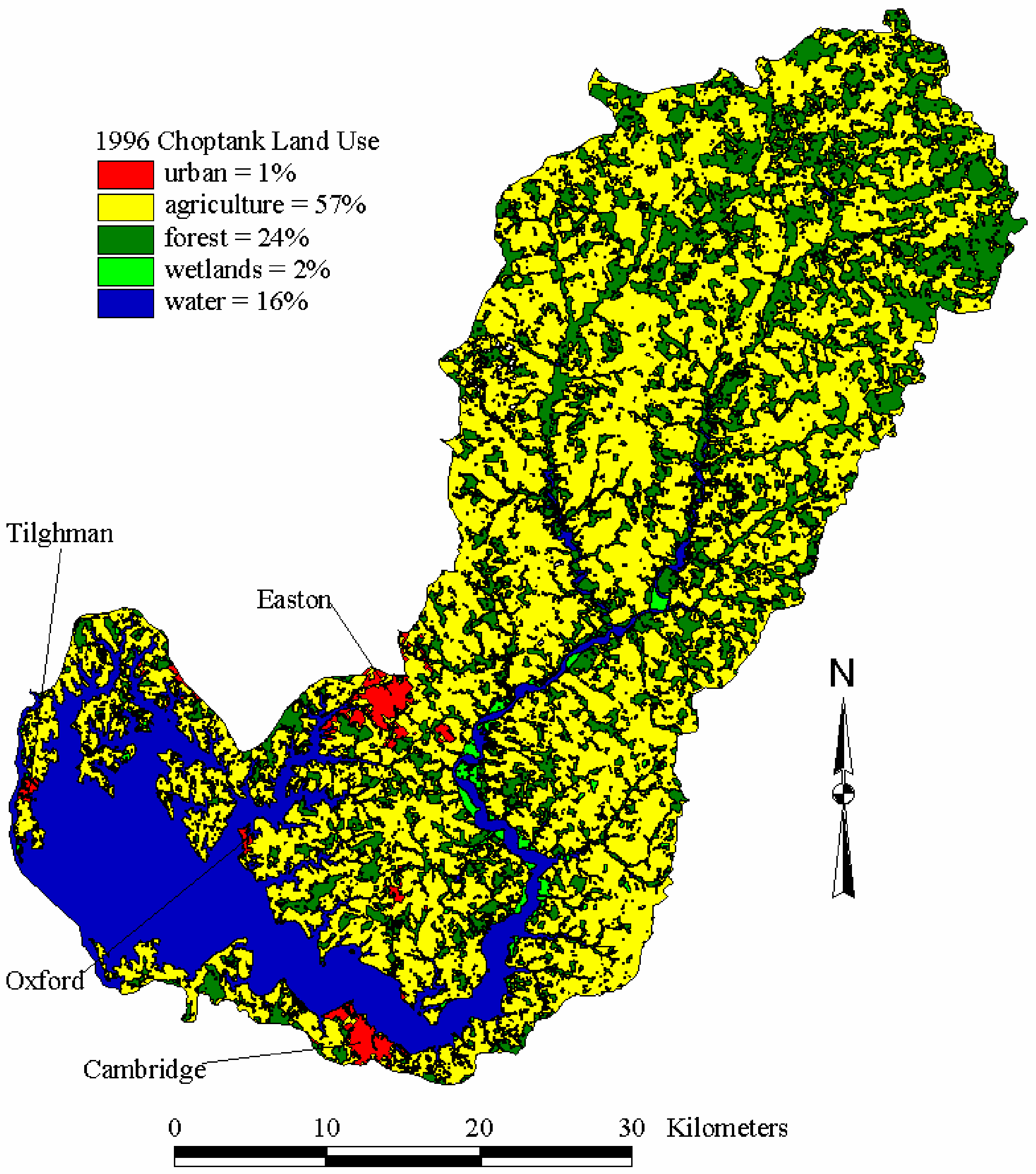

Figure 3. Land use map of the Choptank River showing the high percentage of agricultural area and very small urban regions (Image courtesy Tom Fisher, HPL).

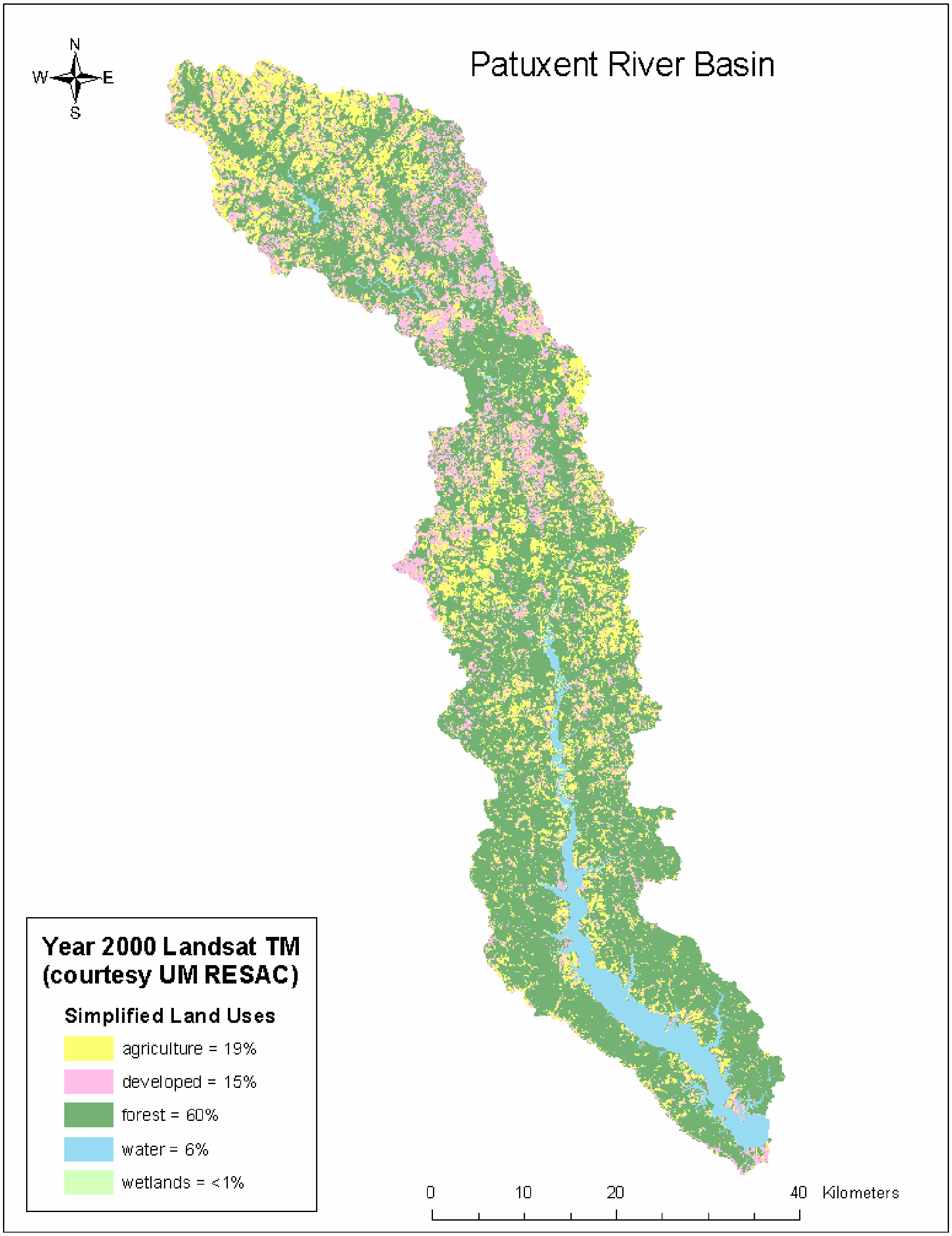

Figure 4. Land use map of the Patuxent River showing the large percentage of developed (urban) and forested areas, and the relatively (c.f. Choptank River) small agricultural area (Image courtesy UM RESAC).

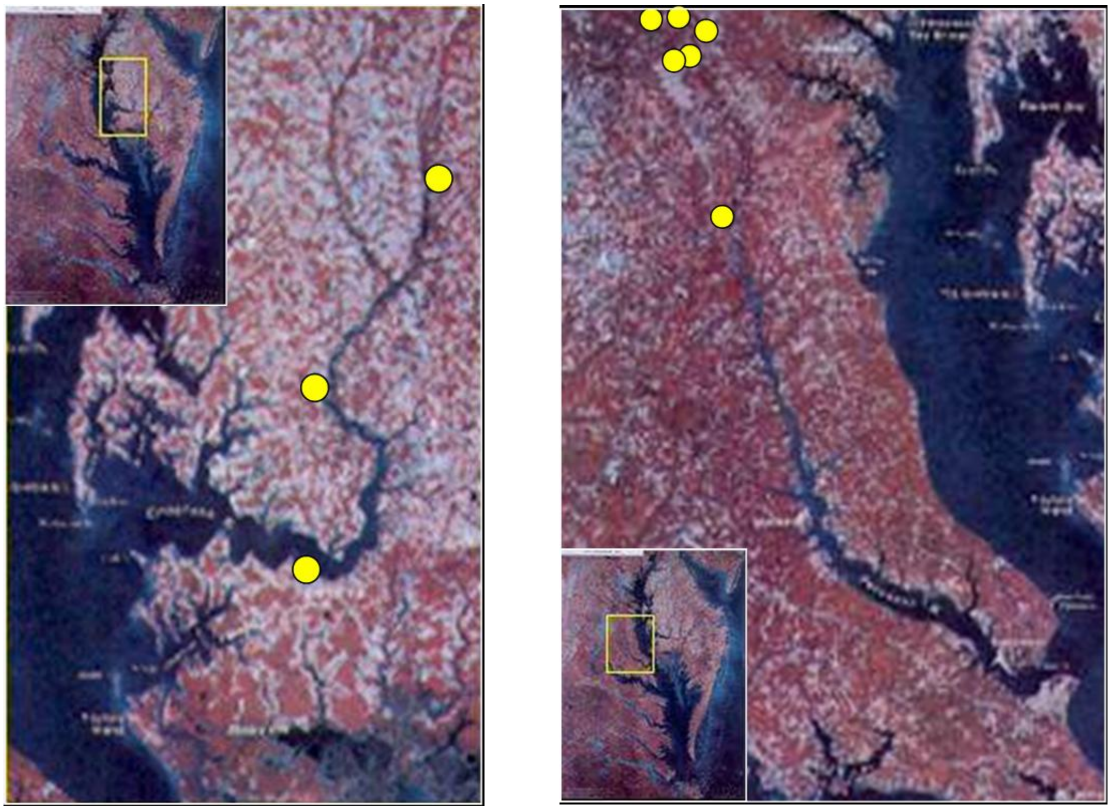

Figure 5. Location of sewage treatment plants in the Choptank and Patuxent Rivers. (Image courtesy USGS)

Table 2. Sewage treatment plants discharging into the Choptank and Patuxent Rivers (adapted from Chesapeake Bay Foundation, 2003)

Sewage Treatment Plant	**Overall Score**	**Flow(mgd)**	**Nitrogen Conc (mg/l)**	**Nitrogen Load**
CHOPTANK RIVER				
Denton	Needs Improvement	0.4	5.1	5,601
Easton	Unacceptable	1.4	10.8	47,061
Cambridge	Unacceptable	4.4	9.2	122,238
PATUXENT RIVER				
Laurel	Good	5.5	4.0	66,601
Bowie	Unacceptable	1.8	10.2	56,901
Upper Marlboro	Needs Improvement	17.4	7.8	410,808
Little Patuxent	Needs Improvement	17.1	6.7	350,198
Patuxent	Good	4.9	3.2	47,862
Fort Meade	Excellent	1.8	2.3	12,222

Determining the impacts and extent of sewage and septic derived nitrogen in marine systems with multiple inputs (both point and non-point source) is typically problematic, and it has been shown that physical and chemical water quality monitoring techniques cannot determine the ecological impact of wastewater discharges. Biological indicators have long been used to determine ecological impacts of point source discharges (Worf, 1980; Kramer, 1994). The key feature of biological indicators is their ability to provide temporally and spatially integrated insights into the biological impacts of changes in anthropogenic activity. Unlike traditional chemical analyses of water column nutrients, these biological indicators reflect the availability of biologically available nutrients (Lyngby, 1990) which provides more ecologically meaningful information. This is in contrast to 'traditional' water quality parameters such as dissolved nutrient concentrations, which simply provide an instantaneous chemical measurement.

Nitrogen (N) occurs in two forms, ^{15}N and ^{14}N, although the ^{14}N form predominates (99.6%). The various sources of nitrogen often have distinguishable ^{15}N to ^{14}N ratios, thereby making it possible to identify the source of the nutrients (Heaton, 1986). Stable isotope ratios of nitrogen ($\delta^{15}N$) have been used widely in marine systems as tracers of discharged nitrogen from point and diffuse sources, including sewage effluent (Rau *et al.*, 1981; Heaton, 1986; Wada *et al.*, 1987; Van Dover *et al.*, 1992; Macko & Ostrom, 1994; Cifuentes *et al.*, 1996; McClelland & Valiela, 1998). Plant $\delta^{15}N$ signatures have been used to identify nitrogen sources available for plant uptake (Heaton, 1986). Elevated $\delta^{15}N$ signatures in seagrass, mangroves and macroalgae have been attributed to plant assimilation of N from treated sewage effluent (Wada *et al.*, 1987; Grice *et al.*, 1996; Udy & Dennison, 1997; Abal *et al.*, 1998). The elevated $\delta^{15}N$ signature subsequent to treatment of the sewage effluent is a result of isotopic fractionation during ammonia volatilization, nitrification and denitrification (McClelland & Valiela, 1998).

The main limitation with all bioindicators sampling techniques has been spatial resolution due to natural occurrence of appropriate indicator organisms. A technique has been developed to detect and integrate the effects of nitrogen inputs by analyzing the isotopic signature of nitrogen ($\delta^{15}N$) in biological indicator organisms actively deployed and incubated *in situ* (Dennison and Abal 1999; Costanzo, *et al.* 2001). The stable isotope analysis ($\delta^{15}N$) of aquatic plants has proven successful in identifying the location and extent of plumes from sewage treatment plants, aquaculture farms, septic outfalls and agriculture (Costanzo *et al.* 2001; Jones *et al.* 2001).

This plume mapping technique utilizes the fact that the relative proportion of the heavy isotope of N is typically higher in animal waste than N from other atmospheric sources, and N in fertilizer applied to agricultural fields is typically lower. Plants in regions subject to sewage derived nitrogen assimilate this ^{15}N enriched nitrogen and the relative content can be analyzed on a stable isotope mass spectrometer to determine the δ^{15}N (the ratio of ^{15}N to ^{14}N compared to an atmospheric standard).

The primary aim of this project was to conduct a comprehensive, spatially intensive survey of the two rivers, analyzing stable nitrogen isotope ratios (δ^{15}N), together with traditional water quality parameters (pH, dissolved oxygen, temperature, salinity, total nitrogen and phosphorus, and chlorophyll *a* concentration) to determine the source and distribution of nutrients. These parameters were spatially correlated to produce a rating of ecosystem health.

Materials and Methods

Study Region

Two tributaries of Chesapeake Bay, the Choptank River (105 sites) and the Patuxent River (67 sites) were sampled along with a region at the mouth of the bay near Cape Charles (8 sites) to provide a reference location with fewer point source inputs and considerable oceanic flushing (Fig. 6). One tributary in the Patuxent River (Island Creek) was sampled more intensively to assess fine scale variability. Site locations were generated randomly using GIS software, producing a spatial grid to facilitate the production of statistically valid interpolated maps.

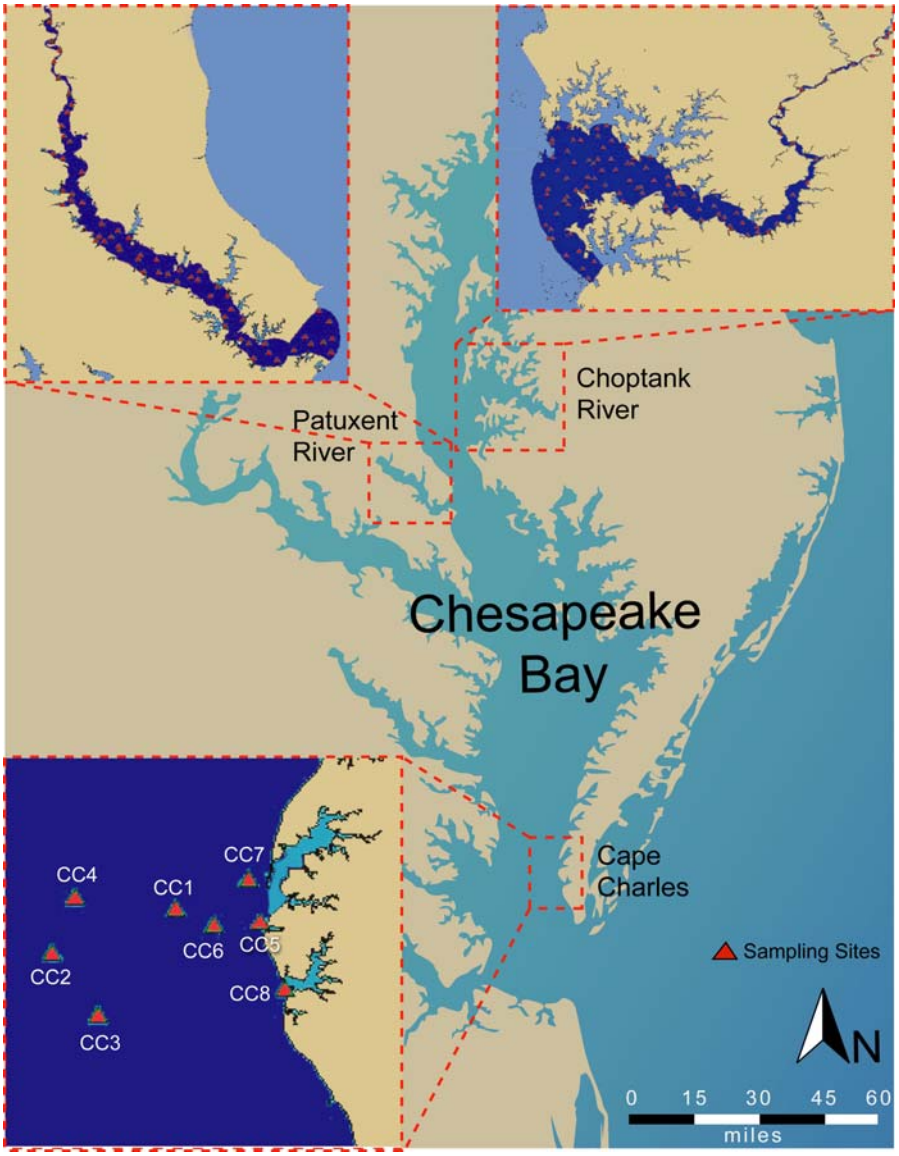

Figure 6. Map of Chesapeake Bay with insets showing sampling sites in the Choptank River (105 sites), Patuxent River (67 sites) including Island Creek (6 sites), and Cape Charles (8 sites).

For the purposes of reporting ecosystem health and for the spatially explicit report card, both rivers were divided into reporting regions; upper, middle, lower, and mouth (Figs. 7 & 8).

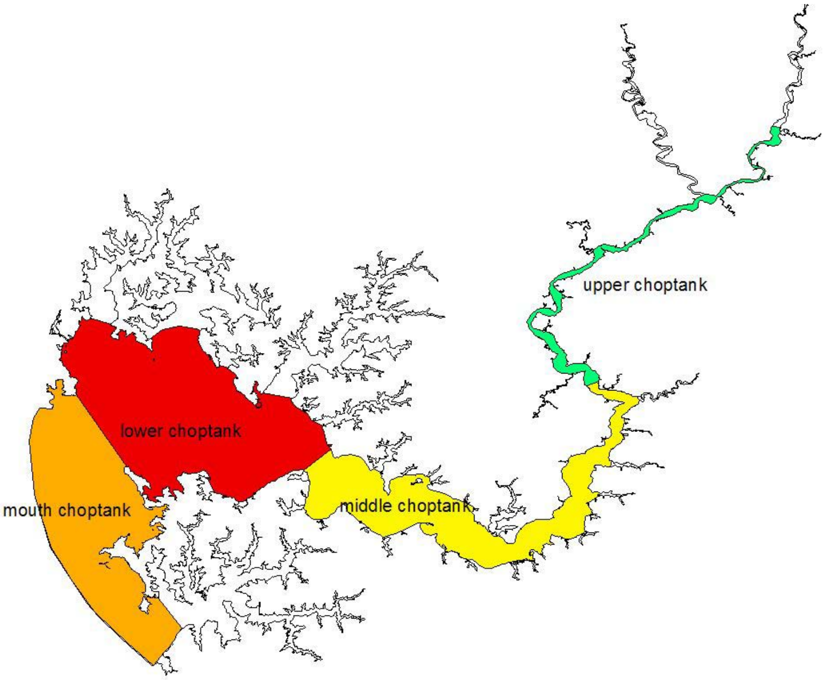

Figure 7. Reporting regions for the Choptank River

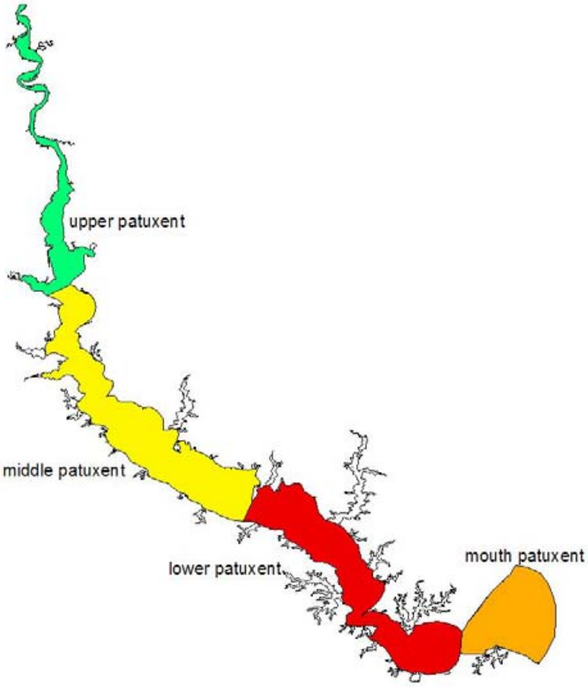

Figure 8. Reporting regions for the Patuxent River

Water Quality Sampling

Salinity (expressed on the Practical Salinity Scale[1]), pH, temperature and dissolved oxygen (DO) were measured with a Hydrolab water quality probe. Secchi depth was determined by lowering a 20 cm diameter secchi disk (black and white alternating quarters) through the water column until it was no longer possible to distinguish between the black and white sections.

Water Column Nutrients

Total nitrogen and total phosphorus were determined by collecting water samples in pre-rinsed containers, placed on ice and returned to the laboratory where they were frozen for subsequent analysis in accordance with the methods of Clesceri *et al.* (1989).

Chlorophyll a

Chlorophyll *a* concentrations were used as an indicator of phytoplankton biomass. At each site, chlorophyll *a* concentration was determined by filtering a known volume of water through a Whatman GF/F filter which was immediately frozen. In the laboratory, the filter was ground in acetone to extract chlorophyll *a*, spectral extinction coefficients were determined on a fluorometer and chlorophyll *a* concentrations calculated according to Parsons *et al.* (1989).

Stable Isotope Technique

An initial scoping study was conducted along the Choptank and Patuxent Rivers, collecting inhabitant flora and fauna (submerged aquatic vegetation, marsh, macroalgae and bivalves) for δ^{15}N analysis. This technique is termed ‘passive’ sampling and provides an indication of the range of δ^{15}N signatures in the system being sampled as well as determining potential differences in the fate of nutrients; water column (macroalgae), sediments (SAV, marsh) or particulates (bivalves) and identifies sensitive bioindicator organisms for ‘active’ sampling. Active sampling involves incubation of a single species at all sites for a known period of time and at a greater spatial intensity than is possible with passive sampling.

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[1] Practical salinity (S) is the ratio of the conductivity of a sample of seawater at 15 ºC compared to that of a defined potassium chloride (KCl) solution. Seawater with a practical salinity of 35 will have the same conductivity as a solution of 32.4356 g of KCL in 1 kg of water.

For active sampling, the red macroalga *Gracilaria* sp. was collected from Chincoteague Bay. Sub-samples were analyzed for their initial $\delta^{15}N$ isotopic signature. At each site, the macroalgae were incubated for 4 days in transparent, perforated chambers (at half secchi depth to ensure uniform light availability) using a combination of buoy, rope and weights. Samples were oven dried to constant weight at 60 °C, ground and oxidized in a CN Biological Sample Converter. The resultant N_2 was analyzed by a continuous flow isotope ratio mass spectrometer (Fig. 9). Total %N was determined, and the ratio of ^{15}N to ^{14}N was expressed as the relative difference between the sample and a standard (N_2 in air) using the following equation (Peterson & Fry, 1987): $\delta^{15}N = (^{15}N/^{14}N \text{ (sample)} / {}^{15}N/^{14}N \text{ (standard)} - 1) \times 1000$ (‰).

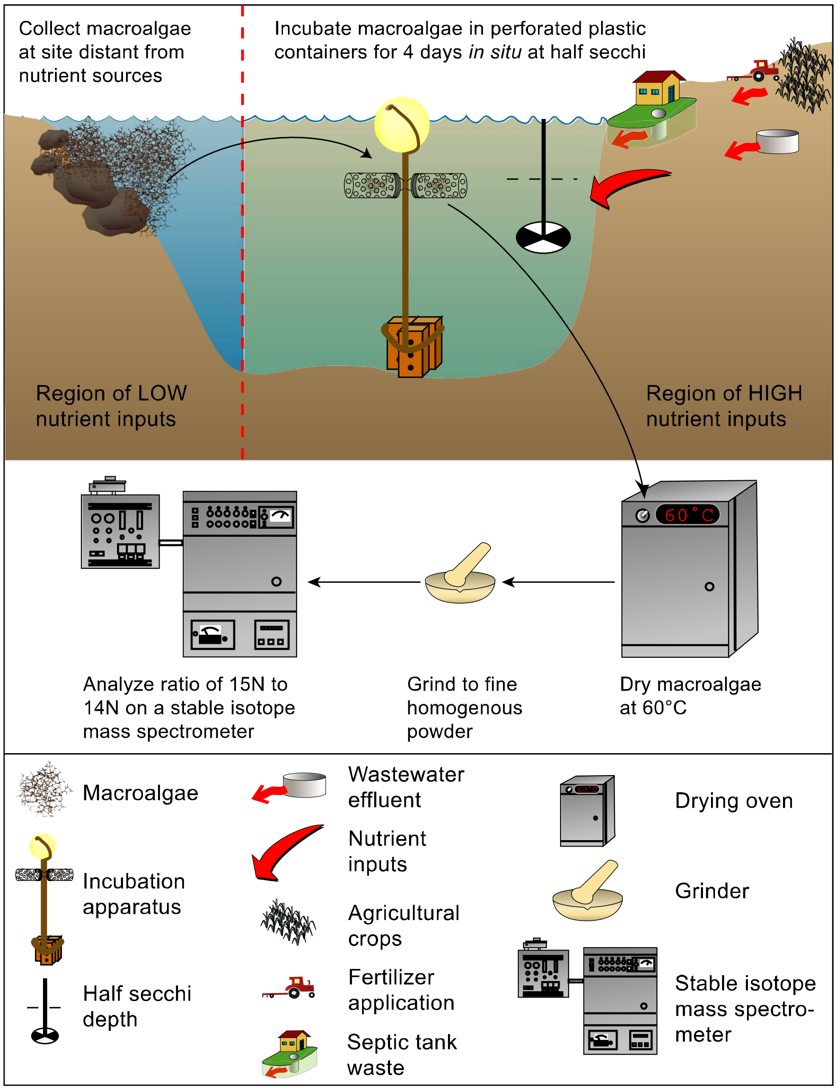

Figure 9. Plume mapping technique showing deployment of macroalgae at half secchi in perforated plastic jar using a system of weight, rope and buoy and subsequent grinding and analysis on a stable isotope mass spectrometer.

Developing the spatial Ecosystem Health Index (EHI)

Ecosystem (or ecological) health has been variably defined, including:

- Ecological health is the maintenance of biodiversity and ecosystem integrity (ANZECC Guidelines), and
- Ecological health is represented by
  a) a lack of distress syndrome,
  b) stability over time, and
  c) resilience to change (Rapport *et al.* 1995)

These definitions are appropriate for describing the ecosystem health concept, but do not define it in terms of measurable quantities. Our definition of ecosystem health is that:

- Key processes operate to maintain stable & sustainable ecosystems
- Zones of human impacts do not expand
- Critical habitats remain intact

Management objectives such as clear water and reduced nutrient inputs can be linked to ecosystem health indicators which can then be quantified, mapped and integrated. A reference value for each of these indicators provides information on whether the management objectives are being met. These indicators should ideally provide information on various aspects of the ecosystem. The Chesapeake 2000 agreement highlighted four interconnected ecosystem elements: **Living Resources**, **Water Quality**, **Land Use** and **Vital Habitat**. A monitoring strategy including indicators from each of these categories would provide integrated ecosystem information about whether the goals of the Agreement are being met. This study monitored indicators of water quality and land use (Fig. 10).

Two important steps in the actual assessment of the ecosystem health status of an area are the choice of indicators to be included in the assessment, and the method of integrating them into an informative measure that is conceptually simple to understand and easy to communicate. It is important that ecosystem health indicators be tied to management objectives to ensure their ability to provide effective feedback on resource management actions. A conceptual diagram of potential ecosystem health indicators for Chesapeake Bay has been created (Fig. 11). In this pilot study for the Choptank and Patuxent Rivers, we utilized 6 of these indicators (Table 3) derived from the management objectives outlined in the Chesapeake 2000 agreement.

An Ecosystem Health Index (EHI) was developed as a quantitative measure of ecosystem status in terms of explicitly defined performance measures (Pantus and Dennison, 2003). The EHI is based on the concept of compliant zones with respect to a performance measure and is that portion of a reporting region where the performance measure does not exceed the reference value, as specified in the management objectives (see Table 1 for the indicator reference values used in the present study). The reference values for this pilot study were based on several sources. The chlorophyll a, Secchi, TN and TP came from the SAV Tech Synthesis II (ref). The DO value is a generally regarded threshold used in the field. The δ15N value is currently the most ambiguous due to the lack of research with this parameter in the Chesapeake region. A value of 14‰ was chosen based on the highest and mean values obtained. Continued research in the region will likely alter this value in the future. The threshold function assigns a value of 1 to each performance measure complying with the reference value and 0 otherwise. The mean value for all parameters is the ecosystem health index for that site.

Various reporting regions (Figs. 7 and 8) were established to enable the creation of an EHI for spatially defined regions within the rivers. The power of an EHI is improved with the number of parameters used in its calculation. The conceptual diagram of Chesapeake ecosystem health indicators (Fig. 10) shows other possible indicators appropriate for the Chesapeake region.

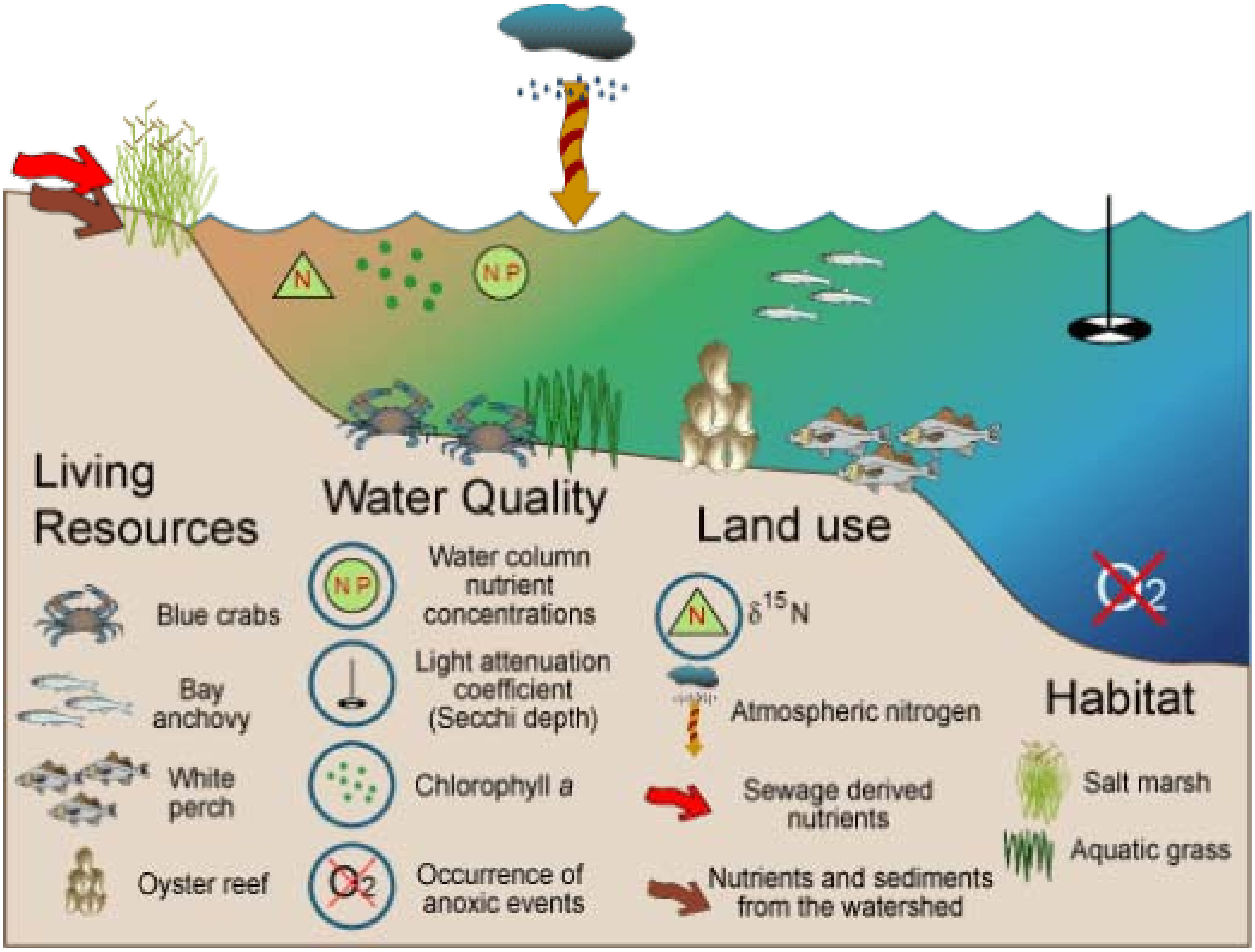

Figure 10. Conceptual diagram of ecosystem health indicators appropriate for use in Chesapeake Bay and its tributaries.

Table 3. Table of management objectives for Chesapeake Bay and its tributaries together with ecosystem health indicators and reference values to determine the status of the objectives.

Management Objective	**Ecosystem Health Indicator**	**Reference Value**	**Source**
Maintain suitable fisheries habitat	Dissolved oxygen	DO > 5 mg L^{-1}	US EPA, 2003
Clear water	Secchi depth	Secchi > 1.0 m	Batiuk *et al*., 2000
Reduce phytoplankton	Chlorophyll *a*	Chl *a* < 15 µg L^{-1}	Batiuk *et al*., 2000
Reduce phosphorus	Total phosphorus	TP < 1.4 µM	Malone *et al*., 2003
Reduce nitrogen	Total nitrogen	TN < 46 µM	Malone *et al*., 2003
Reduce sewage inputs	Delta ^{15}N ($\delta^{15}N$)	$\delta^{15}N$ < 14 ‰	Costanzo *et al*., 2001

Results

Salinity

The range of salinities within the two rivers was comparable, from 0.1 to 10.45 PSU (mean = 7.6) in the Choptank River and from 0.1 to 11.24 PSU (mean = 7.1) in the Patuxent River (Appendix 1). Mean salinity at the Cape Charles sites was 19.3 PSU.

pH

pH was similar in both rivers, ranging from 7.1 to 8.8 (mean = 8.2) in the Choptank River and 7.2 to 8.4 (mean = 7.8) in the Patuxent River (Appendix 2).

Temperature

The Patuxent River had a higher maximum water temperature, ranging from 25.7 °C to 32.7 °C (mean = 27.4) compared with 25.5 °C to 28.7 °C (mean = 26.9 °C) in the Choptank River (Appendix 3).

Dissolved Oxygen

The concentration of dissolved oxygen (DO) in the Choptank River (Fig. 12) ranged from 4.3 to 10.1 mg L^{-1} (mean = 7.1 mg L^{-1}), compared with 3.4 to 9.1 mg L^{-1} (mean = 6.1 mg L^{-1}) in the Patuxent River (Fig. 13).

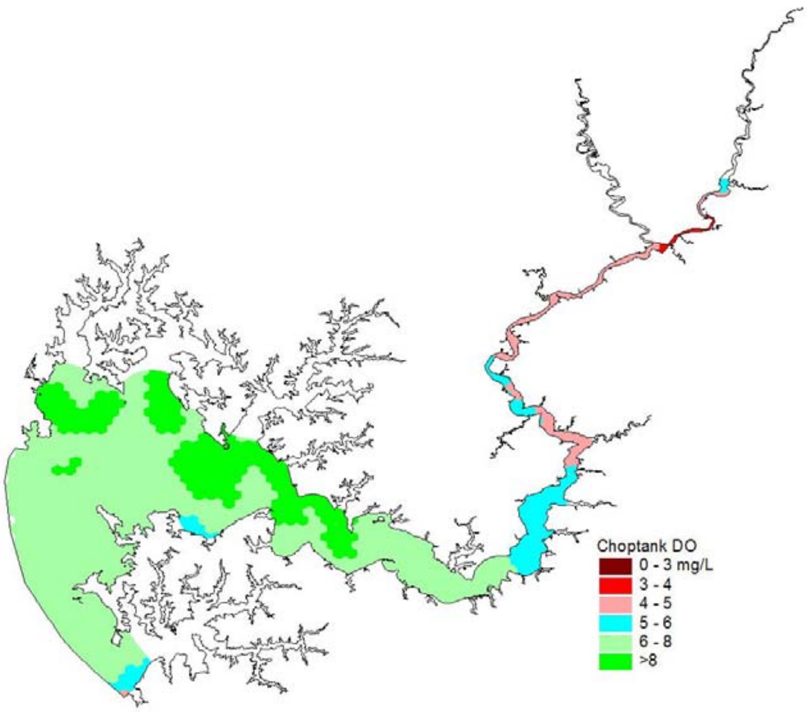

Figure 12. Dissolved oxygen concentrations (mg L^{-1}) within the Choptank River.

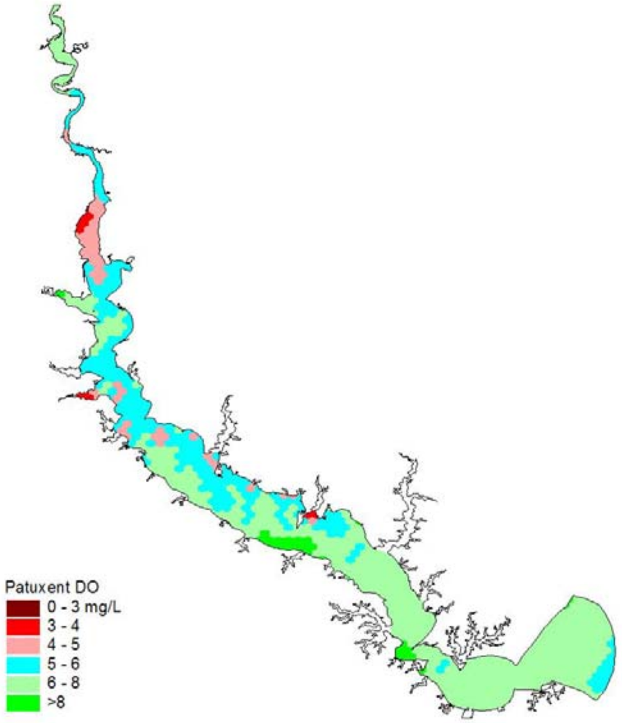

Figure 13. Dissolved oxygen concentrations (mg L^{-1}) within the Patuxent River.

Secchi Depth

Secchi depths within the Choptank (Fig. 14) and Patuxent Rivers (Fig. 15) varied from 0.05 m to 0.9 m. The mean secchi was not significantly different between the rivers (0.46 m for the Patuxent River and 0.43 m for the Choptank River. In contrast, the mean secchi for the sites off Cape Charles at the mouth of Chesapeake Bay was 1.15 m.

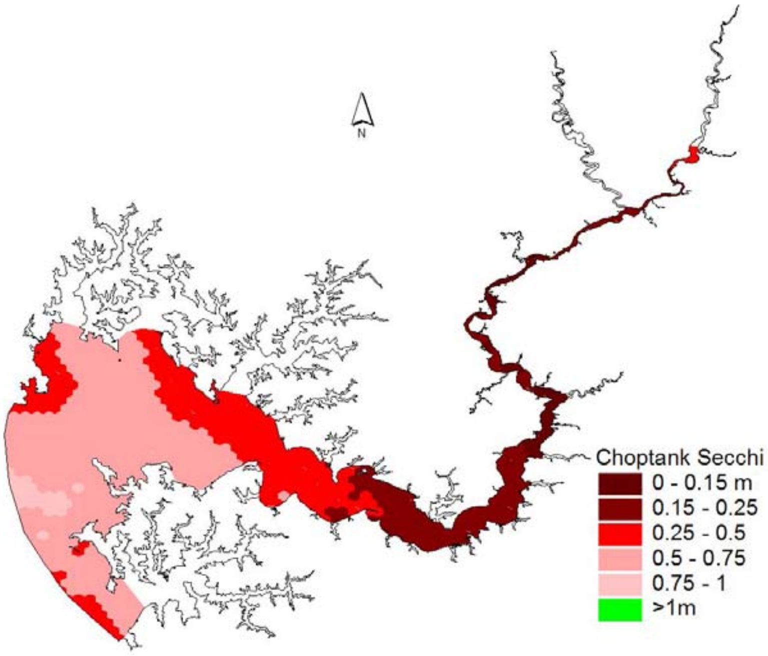

Figure 14. Secchi depth along the Choptank River.

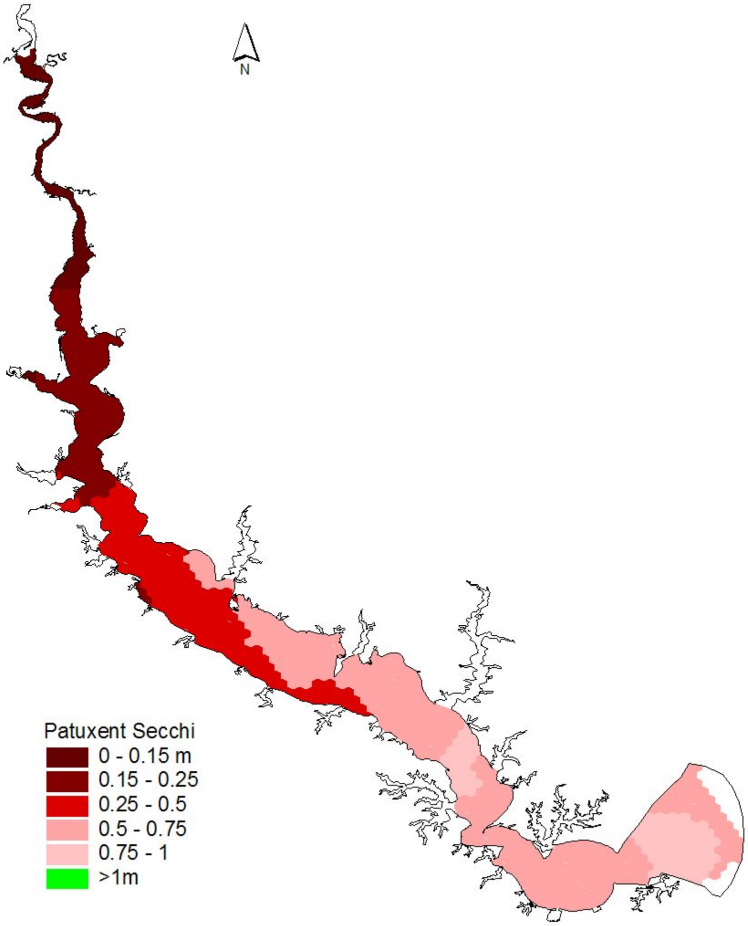

Figure 15. Secchi depth along the Patuxent River.

Water Column Total Nitrogen

The concentration of total nitrogen in the Choptank River (Fig. 16) ranged from 26 to 176 µM (mean = 68 µM), compared to 9.4 to 112 µM (mean = 47 µM) in the Patuxent River (Fig. 17), and 25 to 36 µM (mean = 30 µM) at the Cape Charles sites (Table 4).

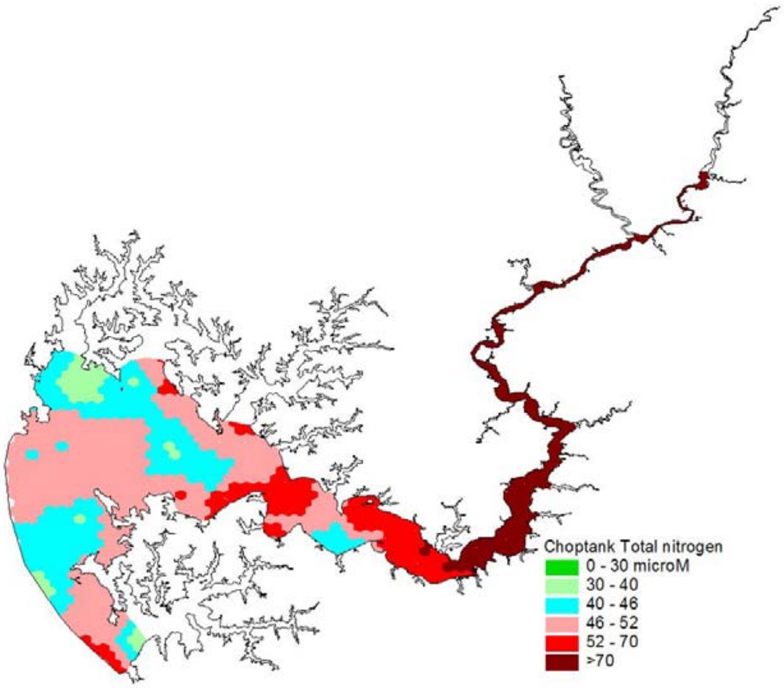

Figure 16. Water column total nitrogen concentration (µM) in the Choptank River

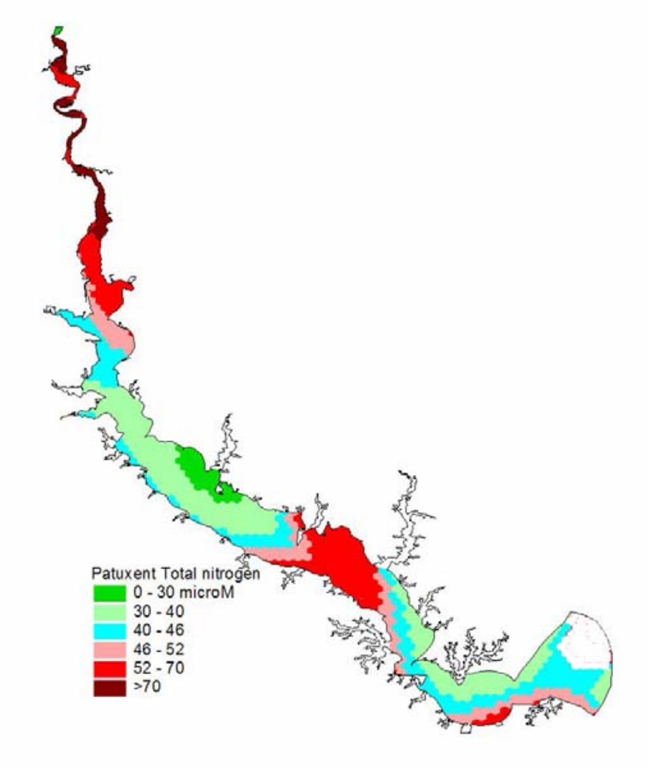

Figure 17. Water column total nitrogen concentration (µM) in the Patuxent River

Water Column Total Phosphorus

The concentration of total phosphorus in the Choptank River (Fig. 18) ranged from 0.9 to 5.2 µM (mean = 2 µM), compared to 1 to 5 µM (mean = 2.9 µM) in the Patuxent River (Fig. 19), and 1.1 to 2.6 µM (mean = 1.5 µM) at the Cape Charles sites (Table 4).

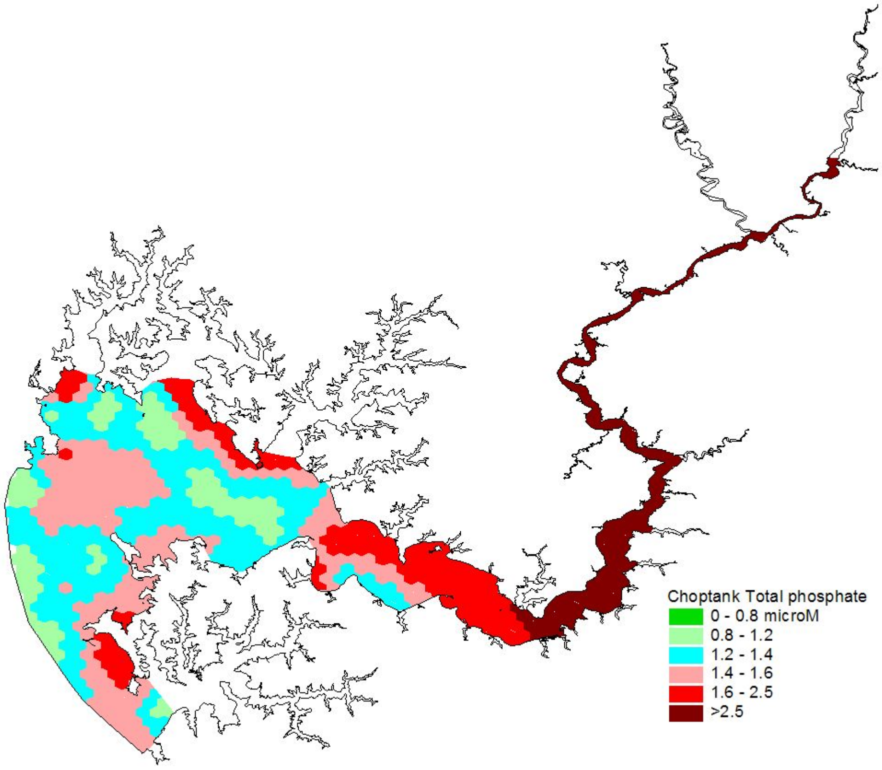

Figure 18. Water column total phosphorus concentration (µM) in the Choptank River

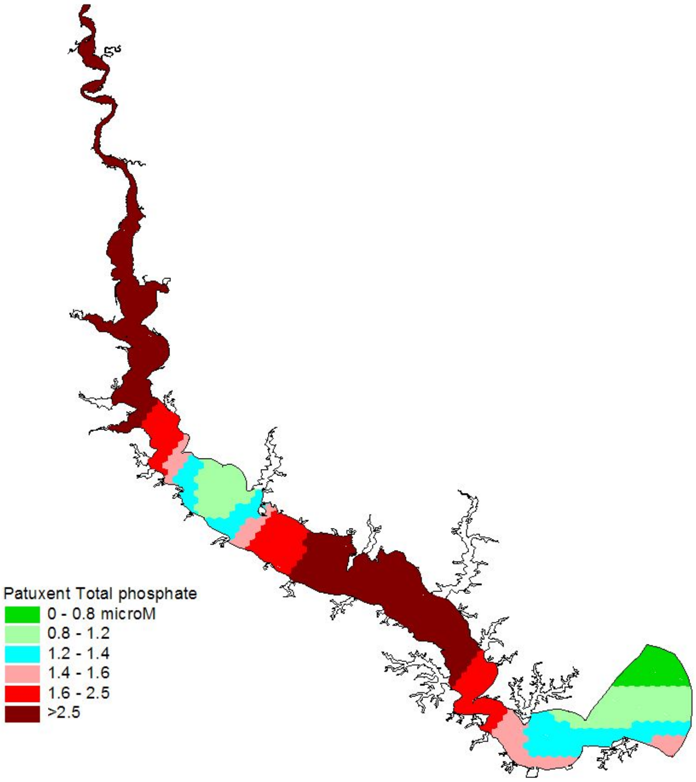

Figure 19. Water column total phosphorus concentration (µM) in the Patuxent River

Chlorophyll a *Concentration*

The concentration of chlorophyll *a* in the Choptank River (Fig. 20) ranged from 4.6 to 91 µg L^{-1} (mean = 24 µg L^{-1}), compared to 1.9 to 103 µg L^{-1} (mean = 23 µg L^{-1}) in the Patuxent River (Fig. 21), and 2.8 to 22.8 µM (mean = 10.8 µM) at the Cape Charles sites (Table 4).

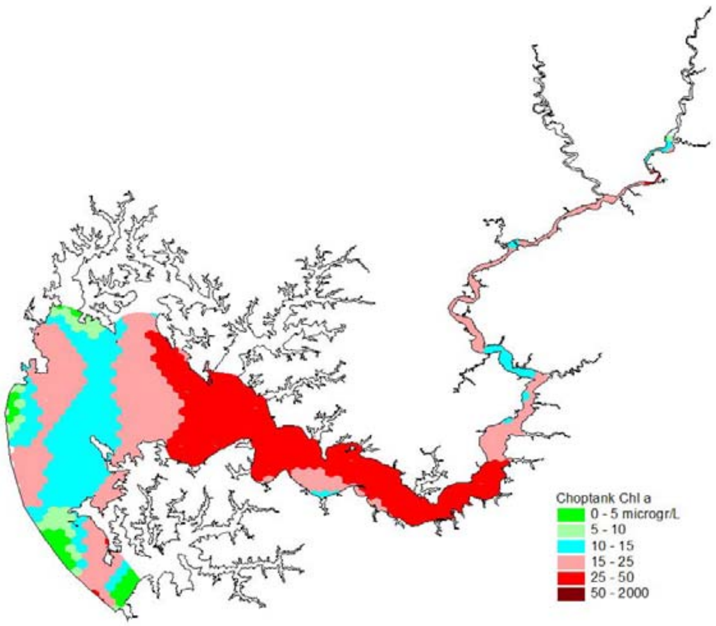

Figure 20. Chlorophyll *a* concentration (µg L^{-1}) in the Choptank River

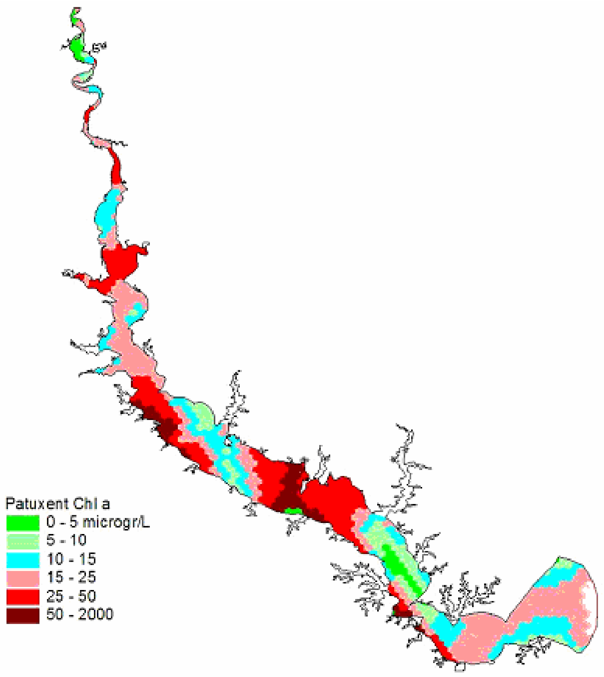

Figure 21. Chlorophyll *a* concentration (µg L^{-1}) in the Patuxent River

δ^{15}N Stable Isotope Ratio of Nitrogen

The range in δ^{15}N of organisms from the passive sampling event was similar between the Choptank (5.6‰ to 22.5‰; mean = 12.9‰) and Patuxent (4.3‰ to 21.7‰; mean = 12.6‰) Rivers. In both rivers, the highest δ^{15}N values were found in the bivalves, then macroalgae, followed by the SAV and the marsh plants, indicating a dominance of water column and particulate nitrogen pools.

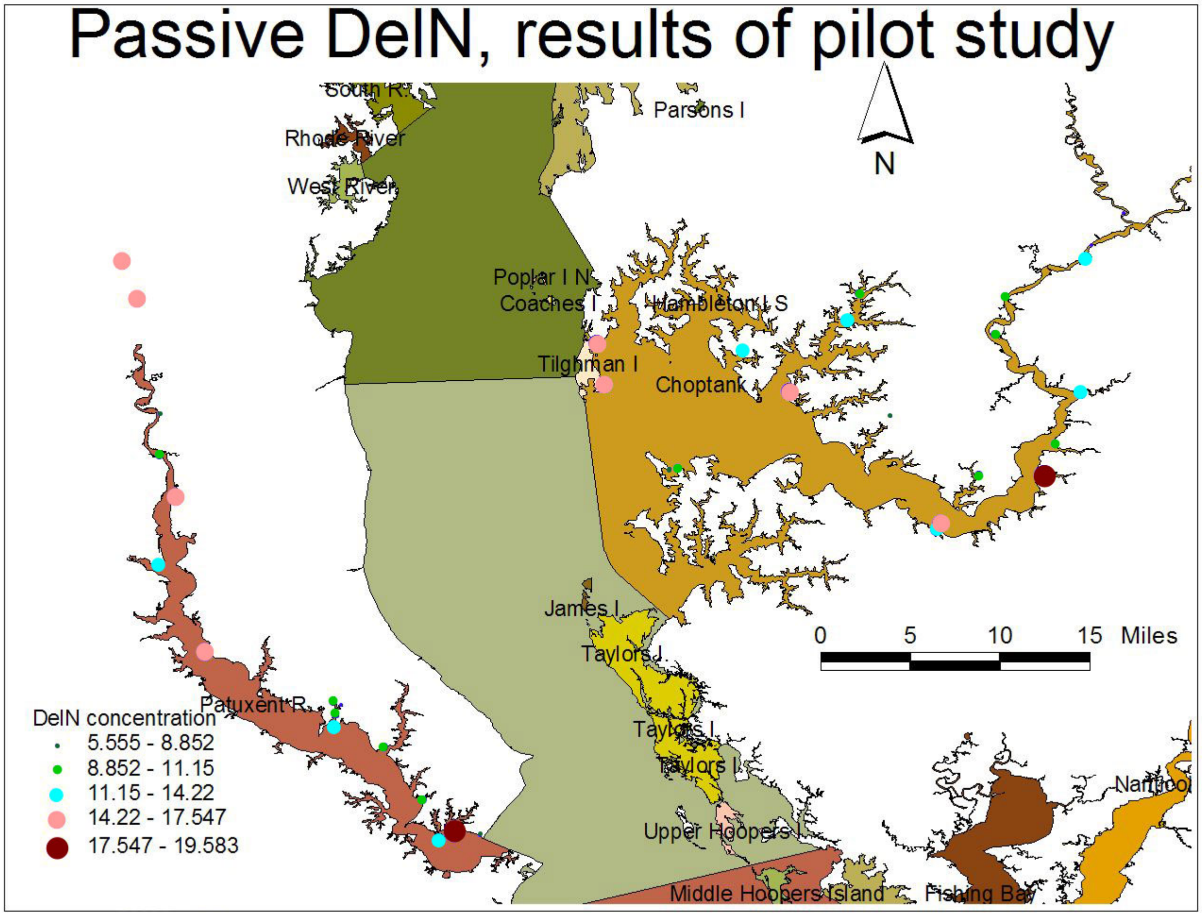

Figure 24. Mean δ^{15}N values of various inhabitant organisms including SAV, macroalgae, marsh and bivalves.

The δ^{15}N of the deployed macroalgae in the Choptank River was 10.8‰ to 21‰ (mean = 14.5‰), in Patuxent River, 11.3‰ to 19.3‰ (mean = 13.9‰) and Cape Charles was 12.8‰ to 15.3‰ (mean = 13.8‰).

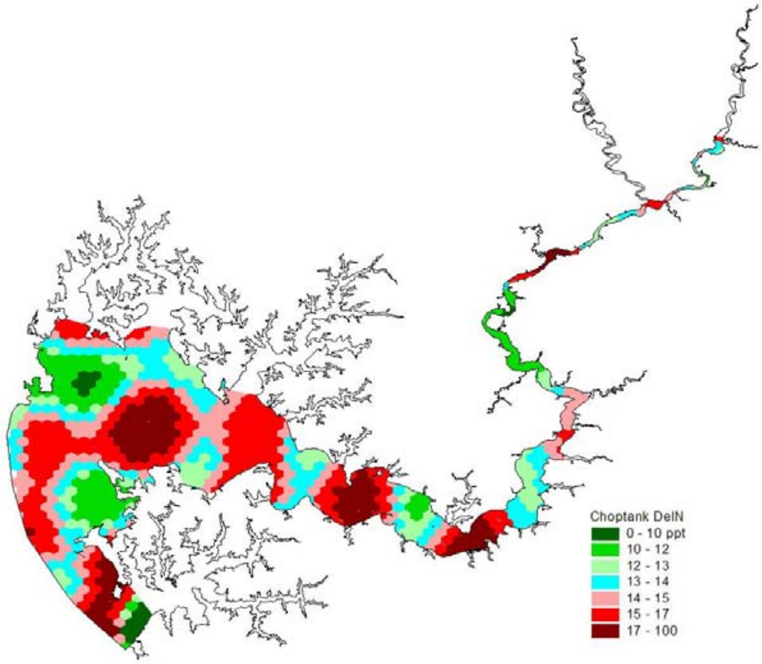

Figure 22. δ^{15}N isotopic signature of deployed macroalgae in the Choptank River

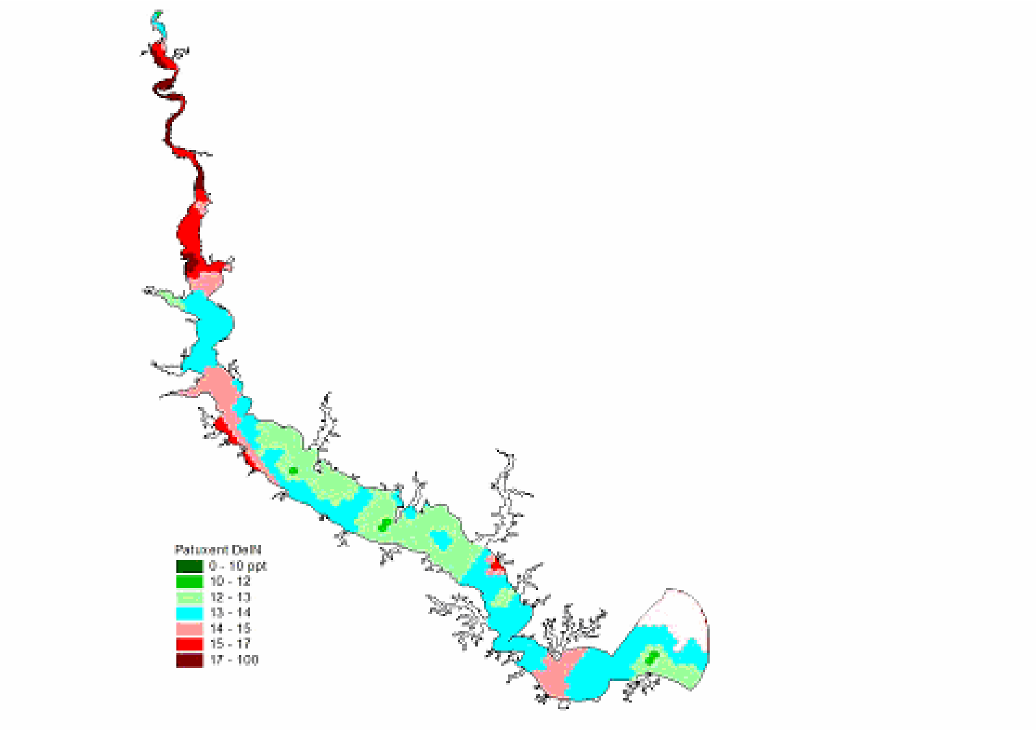

Figure 23. δ^{15}N isotopic signature of deployed macroalgae in the Patuxent River

Ecosystem Health Index (EHI)

The Ecosystem Health Index was determined for each of the reporting regions in the Choptank River, the Patuxent River (incl. a separate Island Creek region) and for the region near Cape Charles at the southern end of Chesapeake Bay. This data is summarized in Tables 4, 5 & 6 and Figures 25 to 29. The Patuxent River had high EHI values in the middle (0.52) and mouth (0.58) regions, with low ecosystem health in the upper (0.21) and lower (0.48) reaches. The Choptank River had generally lower overall EHI values (0.40) than the Patuxent River (0.48), with only some areas around the mouth (0.49) of the river showing higher ecosystem health. Figures 28 & 29 show the variability in the EHI in each region of the rivers. For example, even though the lower and mouth regions of the Choptank score a mean of 0.44 and 0.49 (considered poor ecosystem health), respectively, both contain sites with an EHI of above 0.5 which is considered acceptable ecosystem health. In both rivers there is increased variability in the EHI values, presumably due to influence of mixing with the mainstem of the Chesapeake Bay, compared with the more consistent values in the upper reaches. The variability in the middle reaches of the Patuxent River is much greater than in the Choptank, again most likely due greater flushing in the Patuxent due

The mean EHI for Island Creek was 0.38, with the far downstream region being 0.16. The significant variation in the EHI along the length of Island Creek (0.16 to 0.66) may be due to localized hotspots of septic discharge within the creek. Island Creek flows into the Patuxent in a region with an EHI of ~0.5 and the impact of Island Creek can been seen by the small dark red plume entering the Patuxent from Island Creek (Fig. 26).

The Cape Charles region had a significantly higher EHI (0.75) than any other region in either of the rivers. This result is indicative of the lower nutrient inputs and improved flushing in this region. This was the only region with secchi depths above the reference value of 1.0 m.

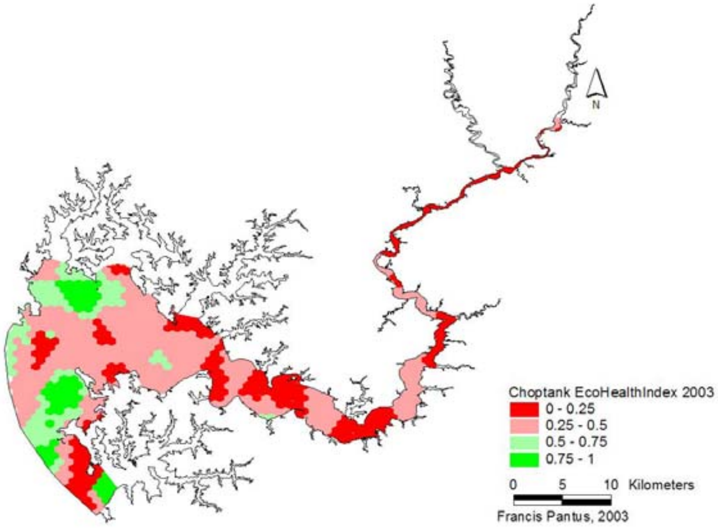

Figure 25. Ecosystem Health Index (EHI) for the Choptank River

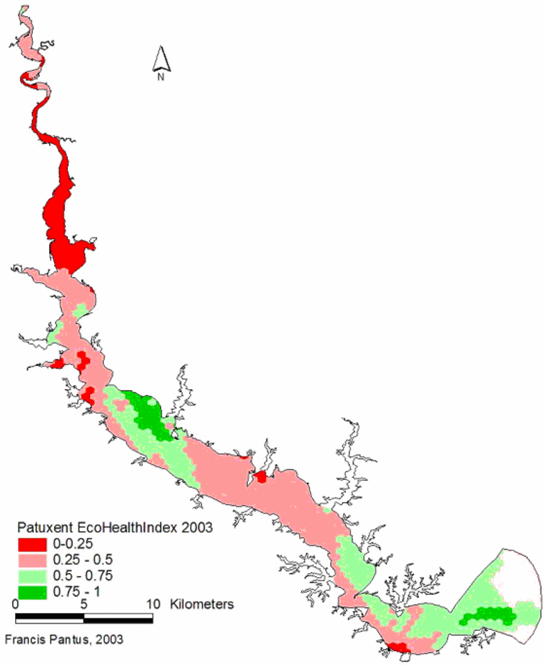

Figure 26. Ecosystem Health Index (EHI) for the Patuxent River

Table 4. Ecosystem health indicator parameters recorded at 8 sites near Cape Charles in the lower Chesapeake Bay

Site	**Secchi depth (m)**	**Chl *a* (µg L^{-1})**	**Total N (µM)**	**Total P (µM)**	**δ^{15}N (‰)**	**EHI**
CC1	1.15	2.79	29.3	2.64	15.27	0.6
CC2	1.2	20.25	36.4	1.37	13.55	0.8
CC3	1.4	10.88	29.8	1.08	14.37	0.8
CC4	1.6	22.75	35	1.53	13.67	0.6
CC5	1.0	6.55	24.9	1.24	13.03	1.0
CC6	1.1	7.89	27.5	1.09	12.79	1.0
CC7	0.9	8.42	30.7	1.54	14.25	0.4
CC8	0.9	6.63	26.5	1.39	13.28	0.8
Mean	*1.16*	*10.77*	*30.01*	*1.49*	*13.78*	*0.75*

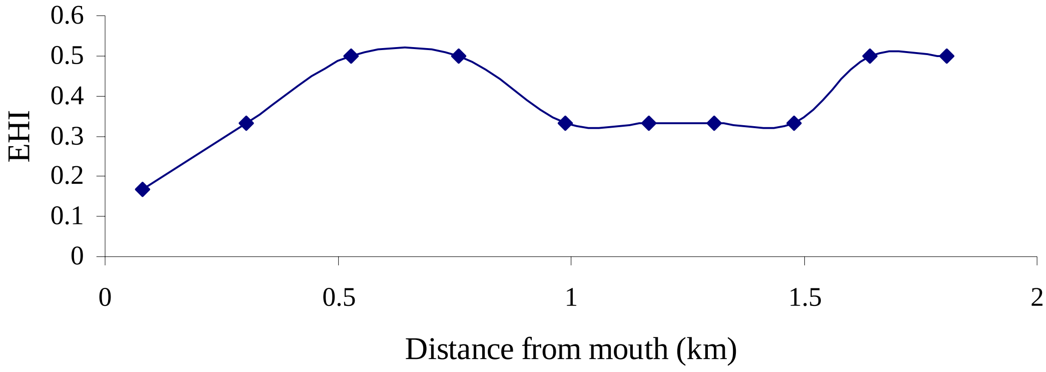

Figure 27. Ecosystem Health Index (EHI) for Island Creek in the Patuxent River

Table 5. Ecosystem health parameters for Island Creek

Site	Secchi depth (m)	DO	Chl *a* (μg L^{-1})	Total N (μM)	Total P (μM)	$\delta^{15}N$ (‰)	EHI
IC1 (upstream)	0.7	4.1	39.6	38.1	3.47	11.76	0.5
IC2	0.5	4.9	7.8	28.2	2.46	13.47	0.66
IC3	0.6	3.8	22.1	32.2	2.45	11.78	0.5
IC4	0.7	5.8	48.5	38.9	2.89	15.43	0.16
IC5	0.4	6.8	12.9	62.7	4.47	13.23	0.33
IC6 (downstream)	0.5	3.4	5.1	49.6	3.23	13.81	0.5
Mean	*0.57*	*4.8*	*22.7*	*41.6*	*3.2*	*13.8*	*0.38*

Table 6. Ecosystem Health Indices (0-1) and report card values for the Choptank River, Patuxent River and Cape Charles regions. EHI is for the entire region with all parameters. The values for the indicators used are the mean compliance value for that indicator.

Region	EHI	Area (km^2)	% Area	DO	Secchi	Chl a	TP	TN	$\delta^{15}N$
Patuxent Overall	0.48	165	100	0.92	0.00	0.33	0.33	0.58	0.70
Upper	0.21	21	13	0.66	0.00	0.34	0.00	0.09	0.15
Middle	0.52	61	37	0.91	0.00	0.26	0.28	0.87	0.80
Lower	0.48	53	32	0.99	0.00	0.37	0.18	0.47	0.85
Mouth	0.58	30	18	1.00	0.00	0.38	0.93	0.53	0.62
Island Creek*	0.38	L=1.8 km	N/A	0.60	0.00	0.56	0.00	0.45	0.77
Choptank Overall	0.40	373	100	0.96	0.00	0.30	0.42	0.30	0.43
Upper	0.20	16	4	0.26	0.00	0.24	0.00	0.00	0.71
Middle	0.26	88	24	0.95	0.00	0.04	0.06	0.06	0.42
Lower	0.44	160	43	1.00	0.00	0.24	0.59	0.39	0.40
Mouth	0.49	109	29	1.00	0.00	0.62	0.53	0.38	0.42
Cape Charles	0.75	N/A	N/A	nd	0.75	0.75	0.63	1.00	0.63

* Island Creek not included in Patuxent Overall Ecosystem Health Index calculations

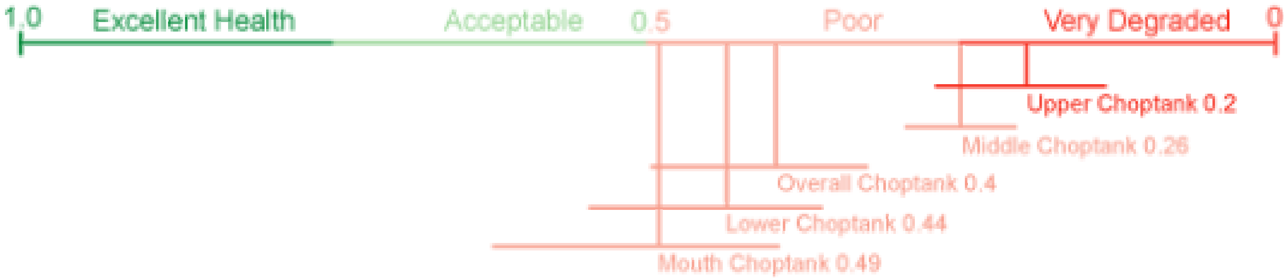

Figure 28. Diagrammatic representation of the variability of the Ecosystem Health Index (EHI) for the various reporting regions in the Choptank River.

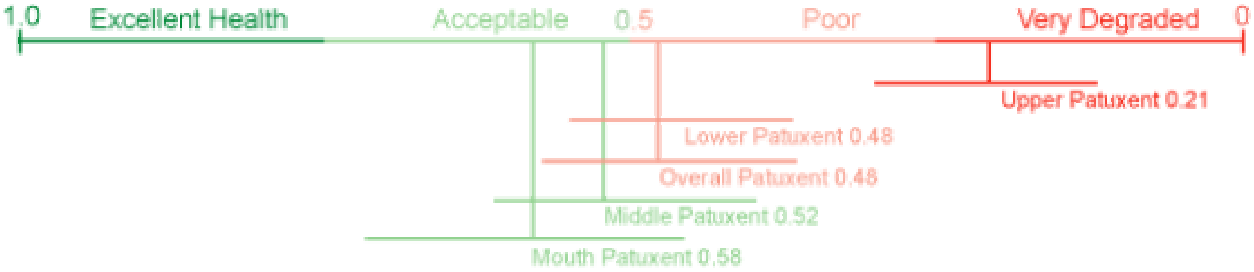

Figure 29. Diagrammatic representation of the variability of the Ecosystem Health Index (EHI) for the various reporting regions in the Patuxent River.

Discussion

Water Quality

High precipitation resulted in greatly reduced salinities, increased nutrients, chlorophyll *a* and reduced secchi depths within the Choptank and Patuxent Rivers during sampling in July 2003. In both rivers there was a general gradient from the upper reaches to the mouth in terms of water clarity (secchi disk depth), dissolved oxygen concentration and to a lesser degree total water column nitrogen and phosphorus concentrations. All areas of both rivers failed to meet the reference Secchi depth value of 1 m, with most areas having a Secchi depth of less than 0.75 m. This level of light penetration is considered inadequate for the survival and growth of aquatic plants like seagrasses. In contrast, 6 of the 8 sites in the Cape Charles region had compliant secchi depths. Figure 30 shows the shallow secchi depths for the two rivers relative to 2002 and the mean for the years 1985-2001.

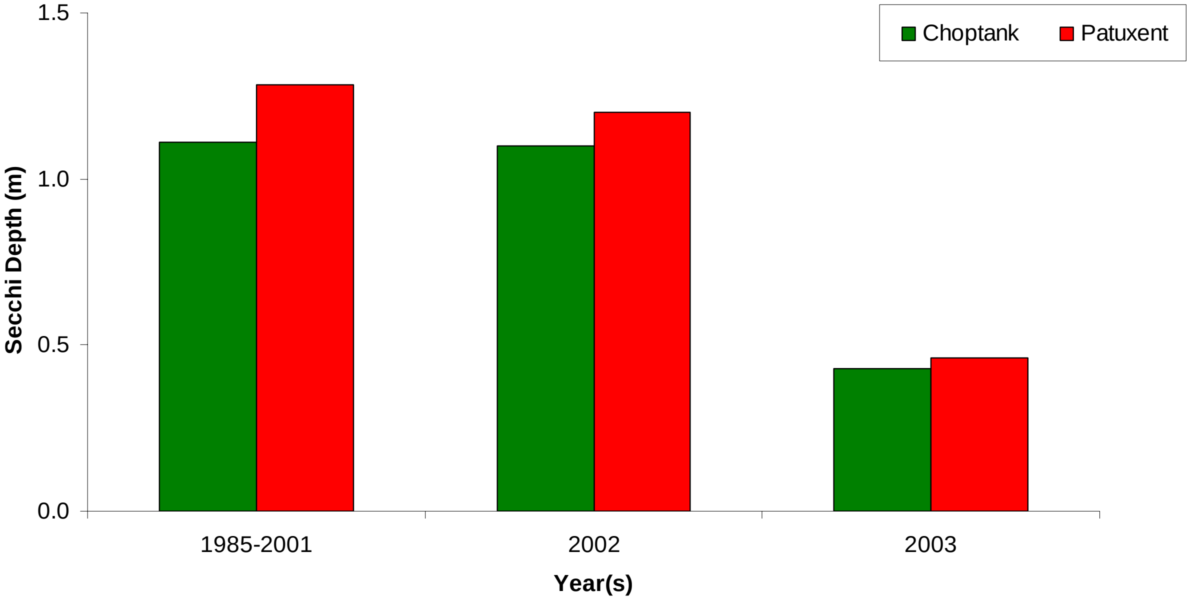

Figure 30. Graph of mean Secchi depth for the Choptank and Patuxent Rivers for 1985-2001 and 2002 (CBP data) and 2003 (data this study).

Chlorophyll *a* concentrations were higher in the mid reaches of both rivers (especially the Choptank) where total nitrogen and phosphorus concentrations were still relatively high, but light availability was improved (measured as deeper secchi depths). Regions with high nutrient concentration and improved water clarity are often subject to excessive phytoplankton in the water column which may result in nighttime sags in oxygen concentration and possible anoxia, especially at depth. Figure 31 shows the relatively high concentrations of chlorophyll *a* in the two rivers compared with 1985-2001 and 2002.

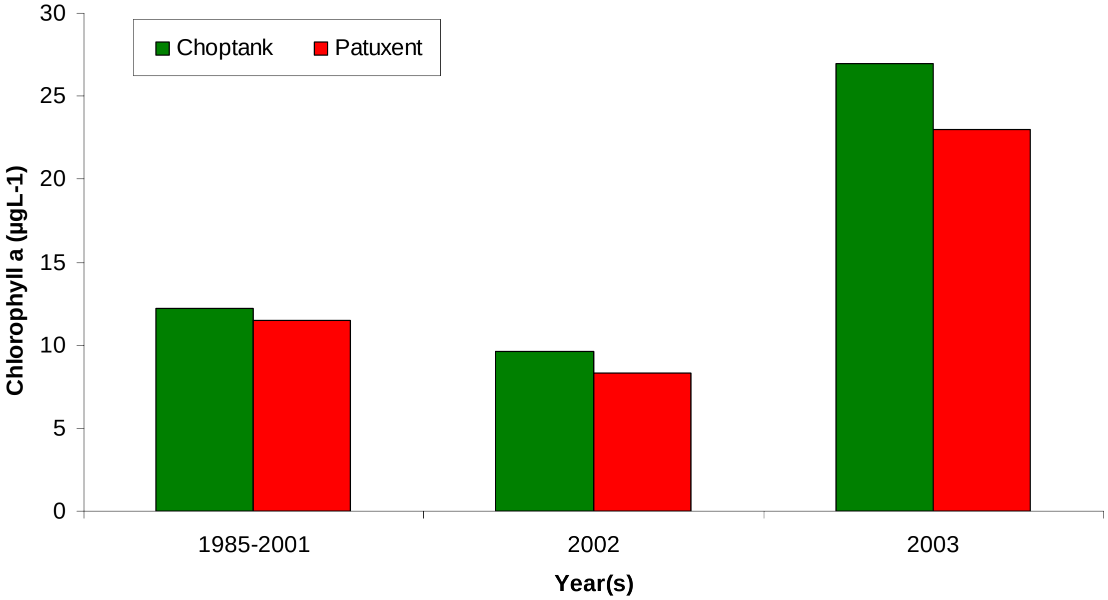

Figure 31. Graph of mean chlorophyll a concentrations for the Choptank and Patuxent Rivers for 1985-2001 and 2002 (CBP data) and 2003 (data this study).

Surface dissolved oxygen (DO) was generally adequate in both rivers, meeting or exceeding the reference value of 5 mg L^{-1} necessary to sustain fisheries. However, DO was not measured in the bottom waters, where hypoxia generally occurs.

Both rivers showed high concentrations of total phosphorus in the upper reaches, improving towards the mouth. There was a region in the middle Patuxent River which met the reference value of 1.4 µM. Total nitrogen showed a similar pattern to total phosphorus concentrations, with the upper portions of both rivers showing high levels of nitrogen, improving downstream.

The Patuxent River again had a region midriver with low concentrations of nitrogen, the same area which had low chlorophyll *a* and total phosphorus levels, suggesting that algal blooms in this area may be limited by nutrients.

N to P ratios varied considerably, with a mean of 34 in the Choptank River, 16 in the Patuxent River and 20 at Cape Charles. A sample of effluent from the Cambridge sewage treatment plant was also analyzed for nutrient concentrations and the N: P ratio was 49. The high ratio in the Choptank may be an anomaly due to the elevated runoff during the wet spring/summer of 2003, as Boynton *et al.* (1995) reported ratios of 17 for the Patuxent (consistent with our results), but only 21 for the Choptank River. Increased rainfall during 2003 may have affected the nitrogen concentrations in the Choptank River more than the Patuxent due to erosion and nutrient runoff from the large areas of agricultural fields in the Choptank.

Tissue %Nitrogen Content

The tissue N content (%N) of marine plants is a potential indicator of biologically available nutrient concentrations (Gerloff & Krombholz, 1966; Duarte, 1990), especially in macroalgae (Horrocks *et al.*, 1995) which have the ability to store large reserves of "luxury" nitrogen for metabolism during times of nutrient stress. In previous isotope studies there has typically been a strong correlation between plant δ^{15}N and %N at sites influenced by sewage / septic waste, but a poor correlation when agricultural fertilizer was the key nitrogen source (Costanzo *et al.*, 2003). The response was observed because although commercial fertilizer is high in nitrogen, it is manufactured from atmospheric nitrogen and as such has a δ^{15}N signature close to zero.

In the present study, the mean total tissue nitrogen content of the incubated macroalgae was 2.41% in the Patuxent River, 2.35% in the Choptank River and 2.14% at Cape Charles. Regression analysis of total N to δ^{15}N signature revealed no correlation, suggesting that there are sources of low δ^{15}N nitrogen in these systems. However, there was also no correlation between %N or δ^{15}N and the water column total nitrogen concentration, which does not support the hypothesis of agricultural fertilizer inputs resulting in low δ^{15}N, high %N results. Another possibility is physiological stress in degraded areas inhibiting storage of luxury N.

δ^{15}N Stable Isotope Ratio of Nitrogen

δ^{15}N analysis effectively detected sewage input in both rivers. The Patuxent River showed generally low levels of δ^{15}N, with the exception of the upper reaches, consistent with the lack of sewage treatment plants in the middle and lower river. However, the Choptank River showed well-defined areas of elevated δ^{15}N adjacent to and downstream from sewage treatment plants in Denton, Easton and Cambridge. Areas of elevated δ^{15}N were evident downstream from Cambridge, suggesting sewage nitrogen may become tidally retained in the Choptank River.

Despite the overall similarities in the mean δ^{15}N in the two rivers, the more scattered distribution of the point source inputs in the Choptank River is evidenced by the patchy nature of the δ^{15}N signature (Fig. 22), compared with the Patuxent River, which had high values in the upper reaches (15‰ to 19.3‰) and low values in the lower reaches (mostly 10‰ to 14‰) (Fig. 23). This is consistent with the location of the STP's in the upper reaches of the Patuxent River. Some of the 'hotspots' in the Choptank River correspond to the STP outfalls, however others (especially those towards the mouth) may be related to water flow patterns within the river.

Nutrient budgets show that of the nitrogen entering the tidal Patuxent, only a relatively small proportion (21-23%) is transported out of the estuary into Chesapeake Bay, with the remainder being stored or processed by the system (Fisher *et al.* 2003). This observation is consistent with the reduction in water column total nitrogen and macroalgal δ^{15}N values from the upper reaches to the mouth of the Patuxent.

Ecosystem Health Index

The Ecosystem Health Index (EHI) ratings (between 0 and 1) for each site were converted into a report card value (A+ to D- and F for fail) based on defined cutoffs for each value (Fig. 7). This 'report card' approach translates the scientifically rigorous data for broader communication and understanding of the results.

Table 7. Ecosystem Health Index (EHI) and Report Card values for the Choptank and Patuxent Rivers, Island Creek and the Cape Charles region.

Region	**EHI**	**Report Card Value**
Patuxent Overall	0.48	D+
Upper	0.21	F
Middle	0.52	C-
Lower	0.48	D
Mouth	0.58	C
Island Creek*	0.38	D-
Choptank Overall	0.40	D
Upper	0.20	F
Middle	0.26	D
Lower	0.44	D
Mouth	0.49	D+
Cape Charles	0.75	B+

The ecosystem health index serves as a device for succinctly reporting upon, and tracing the results of, management actions in terms of the stated objectives, based on a targeted monitoring. In the context of an adaptive management approach, the ecosystem health index is an effective means to close the loop between monitoring and management actions. Tracking ecosystem health indices over time provides a means for measuring the effectiveness of management interventions relative to the stated operational objectives. By being explicit about the reporting requirements, development of an ecosystem health index also guides and constrains the process of design and implementation of monitoring programs, and helps to specify a clear goal for often very costly field programs.

Conclusions

During the summer of 2003 the ecosystem health of the Patuxent River was better than the Choptank River. This may be considered a non-typical year (above normal precipitation), but clearly the Ecosystem Health Index (EHI) approach proved effective at determining the differences between the rivers, as well as highlighting the regions which are more greatly compromised by nutrient inputs. The EHI approach provided a range of ratings from a B+ (excellent) for the well flushed Cape Charles region, down to an F (fail) for the upper reaches of both the Patuxent and Choptank Rivers.

- Ecosystem health indicators, based on management objectives, can be modeled, measured and mapped
- Maps of ecosystem health indicators can be combined into overall ecosystem health map
- Report card values can be assigned for various reporting regions
- Effective communication of report card values and integration into management program can lead to ecosystem health improvements

A rigorous defined and spatially explicit index of ecosystem health and the report card approach (A to F rating) together are a useful monitoring tool which can help focus management and research efforts by providing rapid and effective feedback on the health of Chesapeake Bay.

Recommendations

- Develop a bay wide $\delta^{15}N$ sampling program
- Incorporate fisheries and habitat indicators as well as watershed indicators into ecosystem health assessment
- Use field sampling, remote sensing, autonomous sampling and underway sampling programs to produce ecosystem health indicator maps
- Develop a monitoring framework to produce annual report cards

Science Communication

This project has resulted in a variety of science communication outputs on the techniques that can be used to determine the ecosystem health of Chesapeake Bay, as well as the results from this study.

PowerPoint Presentations

Dennison, Jones and Pantus:
Chesapeake Bay report card: Providing effective feedback for resource management
September 2003 Chesapeake Bay Seminar Series, Annapolis MD
Available online in PDF and Multimedia at www.ian.umces.edu/presentations.htm

Dennison & Pantus:
Assessing ecosystem health in coastal waters
June 2003 Oceanology International 2003, New Orleans
Available online in PDF at www.ian.umces.edu/presentations.htm

Jones & Dennison:
Assessing Nutrient Sources in Tidal Waters
March 2003 Reducing Nitrogen Pollution from Septic Systems' forum. Laurel, MD
March 2003 Watershed Restoration Action Strategy - Lower Patuxent River Steering Committee
March 2003 Tidewater Environmental Health Association (TEHA)
March 2003 Coastal & Watershed Resources Advisory Committee - (CWRAC)
Available online in PDF at www.ian.umces.edu/presentations.htm

Newsletters

Integration and Application Network

Developing a Chesapeake Bay Report Card

November 2003

Available online in PDF at www.ian.umces.edu/newsletters.htm & as an appendix to this report

Integration and Application Network

Assessing Nutrient Sources

Feb 2003

Available online in PDF at www.ian.umces.edu/newsletters.htm & as an appendix to this report

Manuscripts

Jones, A.B., Dennison, W.C. & Pantus, F. (in prep) Developing a Chesapeake Bay report card: A pilot study in the Choptank and Patuxent Rivers. Marine Pollution Bulletin.

Web Pages

The results from the project and detailed information on the techniques used, as well as a copy of this report are available on the IAN website at: www.ian.umces.edu/reportcard.htm

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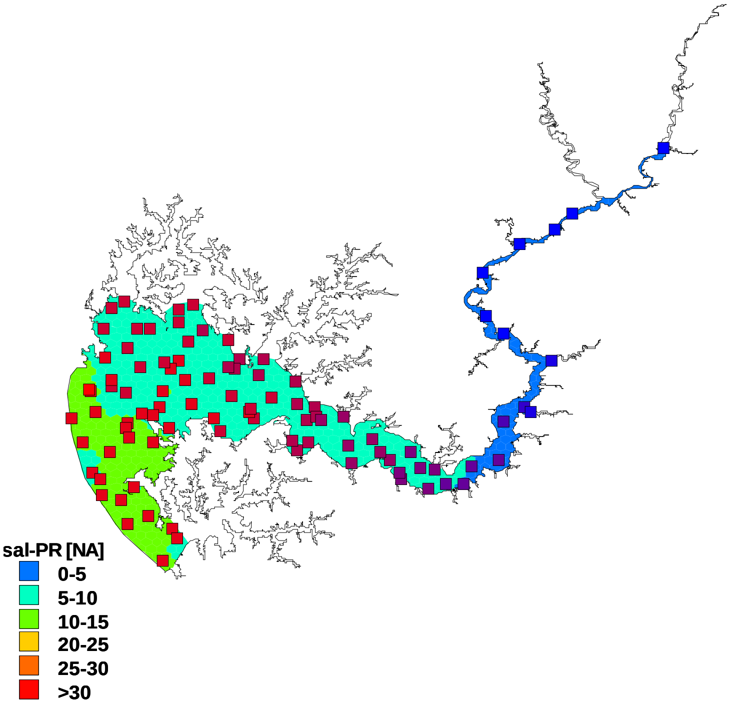
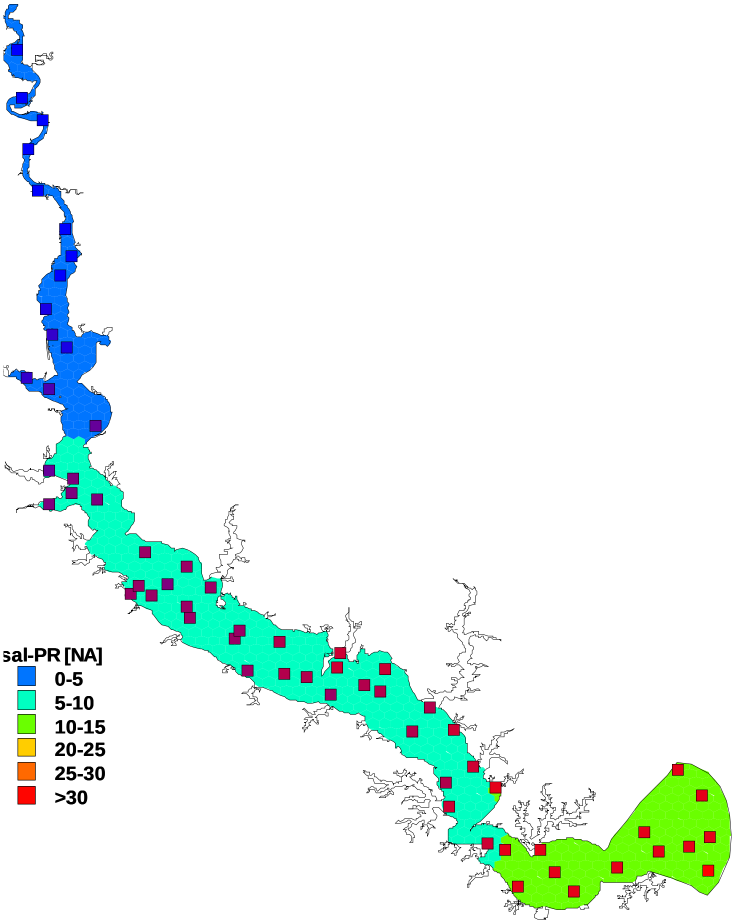
Appendix 1 – Salinity Maps

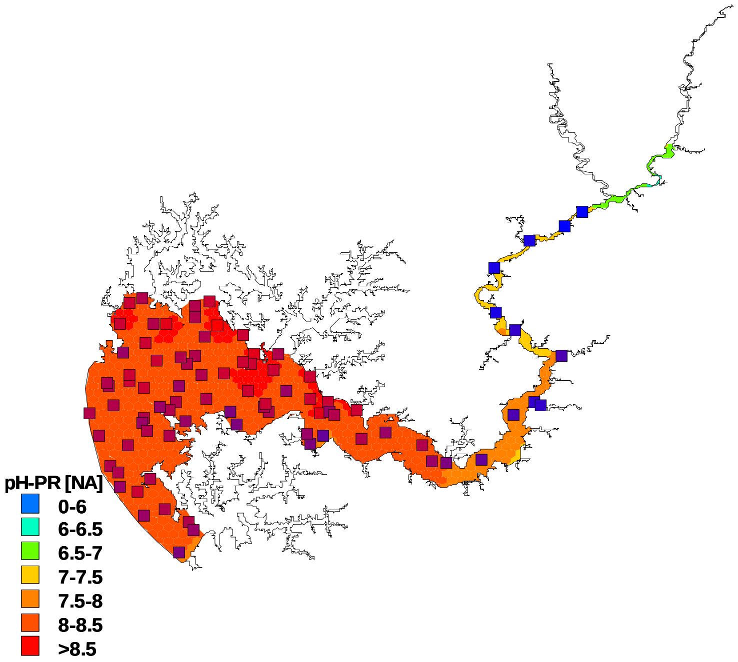


Salinity in the Choptank River

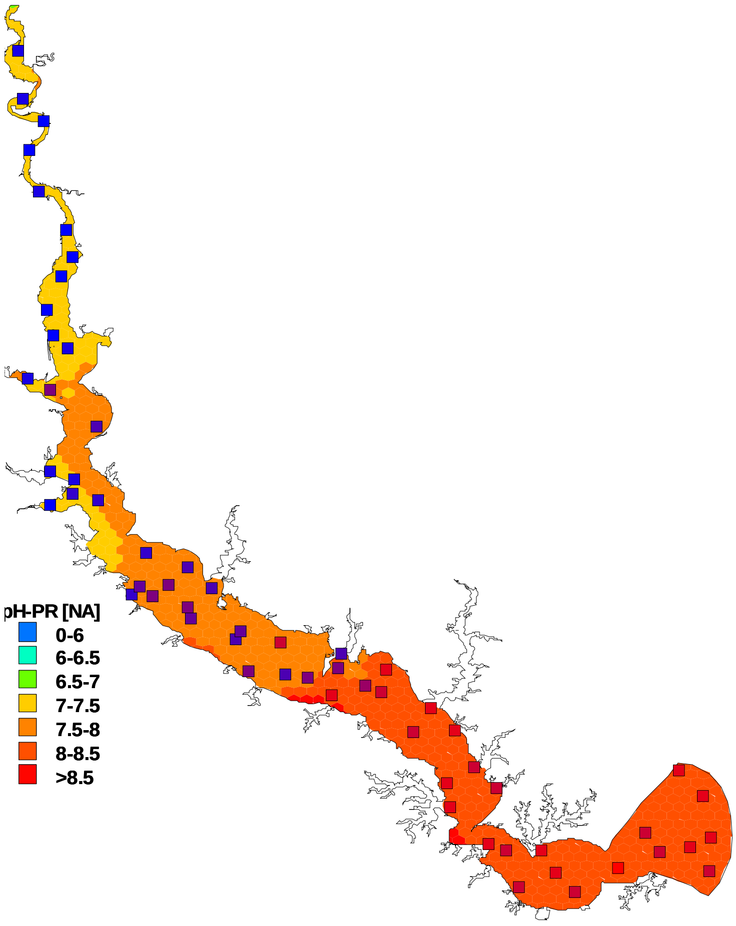


Salinity in the Patuxent River

Appendix 2 – pH Maps

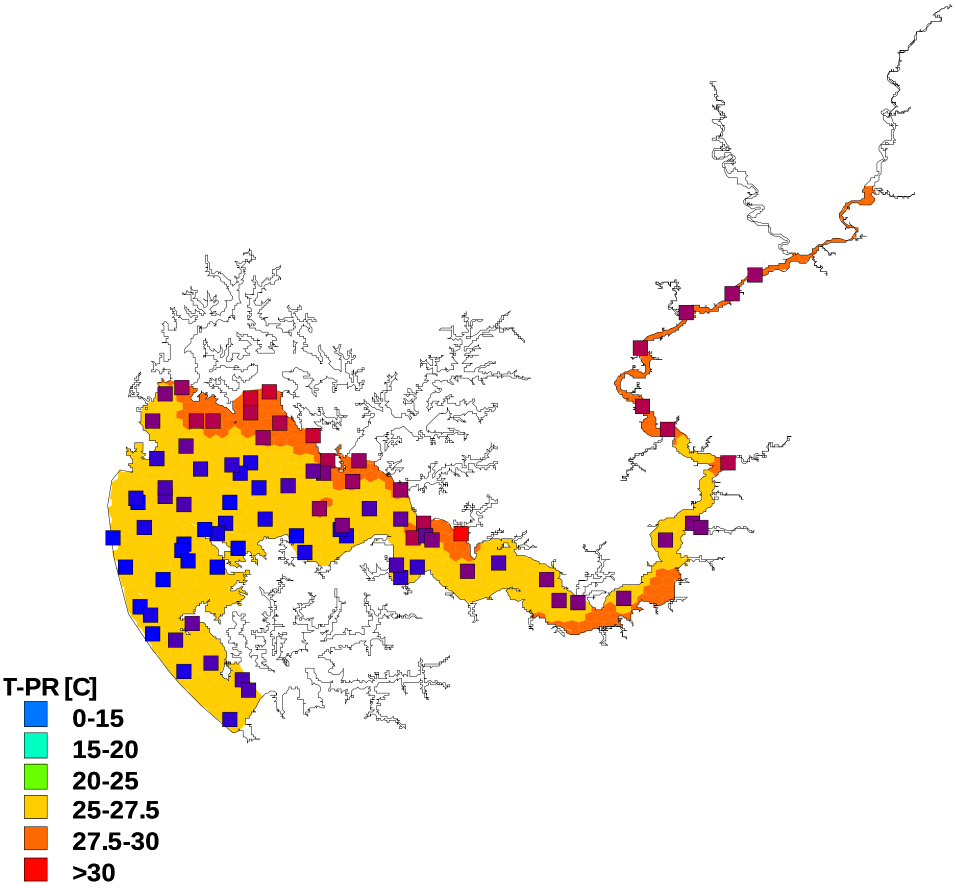


pH along the Choptank River

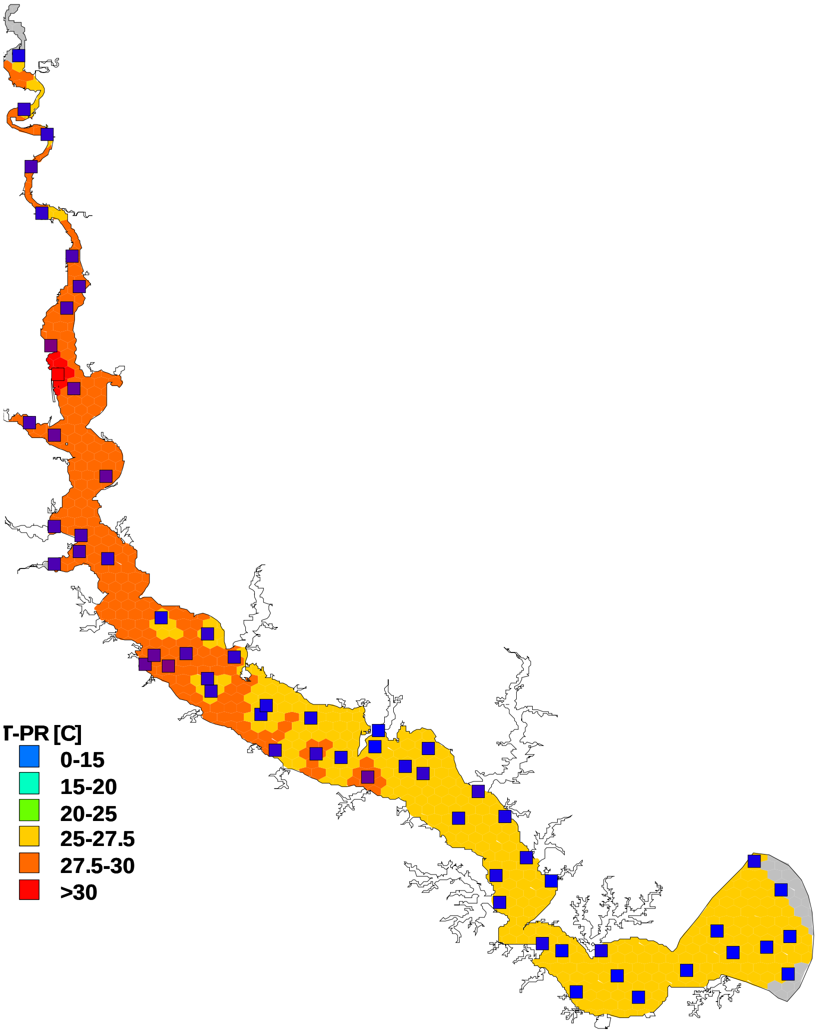


pH along the Patuxent River

Appendix 3 – Temperature



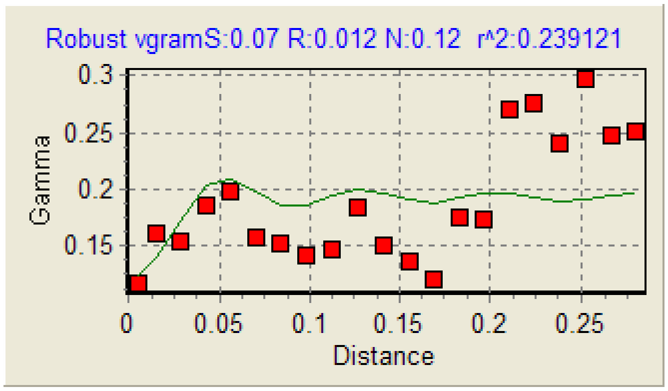
Choptank water temperature (degreed Celsius)



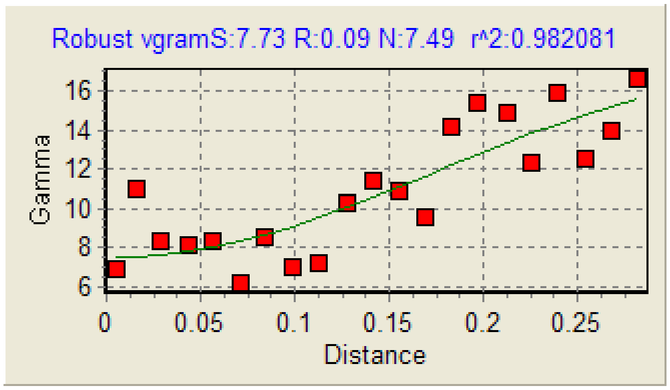
Patuxent water temperature (degreed Celsius)

Appendix 4 – Prediction Variograms

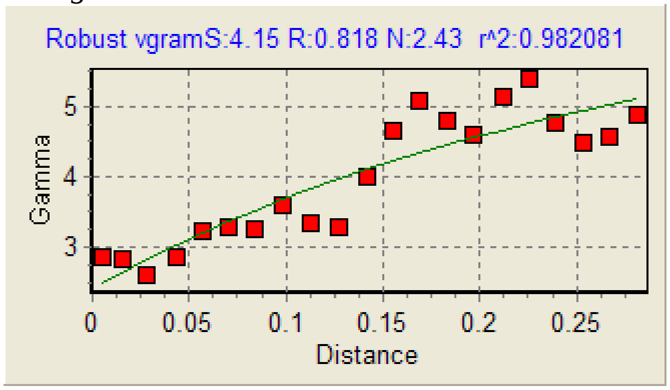
Choptank δ^{15}*N 2D natural spline, negative values->0, sine-based variogram model.*



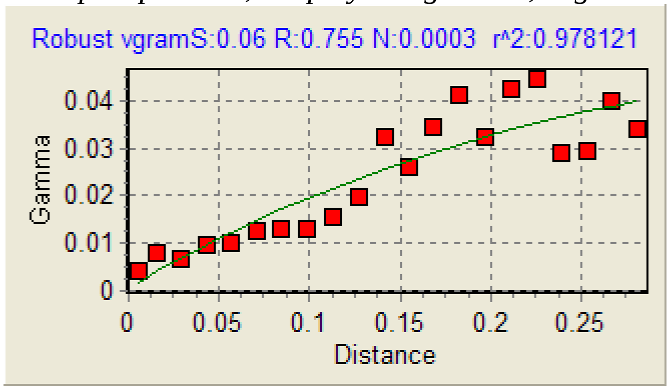
Choptank Chl a, 2D cubic spline large scale, negative values->0, sine-based variogram model.



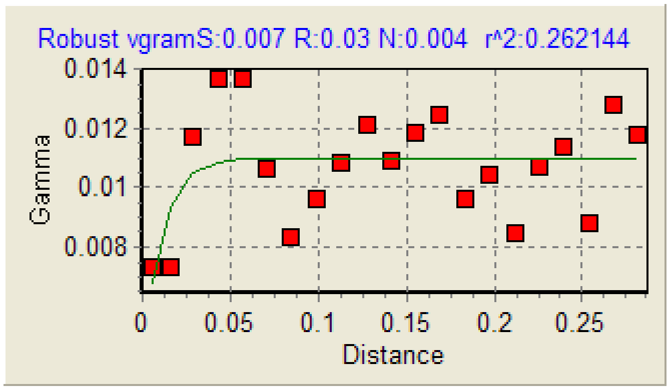
Choptank Total nitrogen, 2D cubic spline/poly2 y large scale, negative values->0, exp variogram model



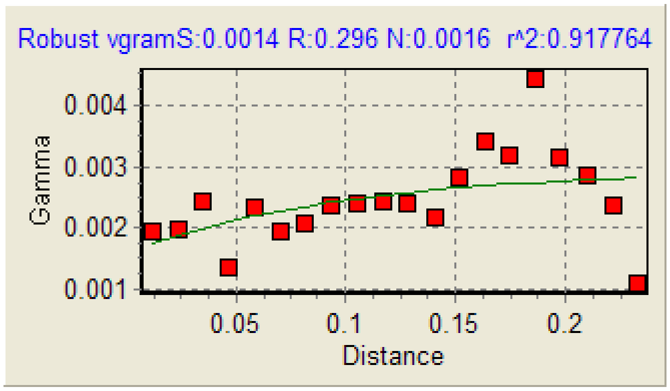
Total phosphorous, 2D poly2 large scale, negative values->0, exp variogram model



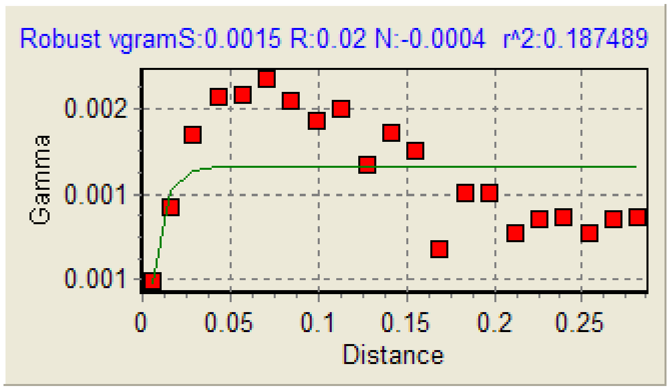
Salinity, 2D cubic spline large scale, negative values->0, exp variogram model



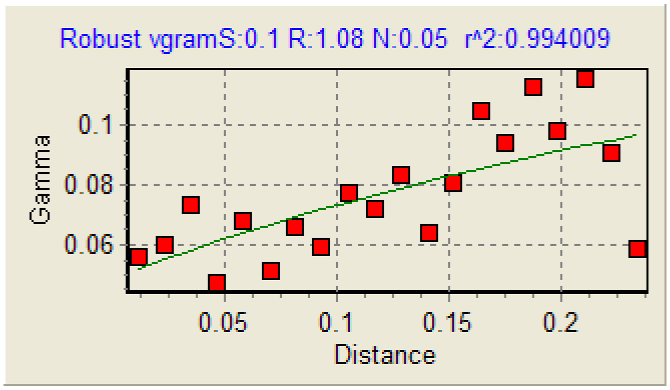
pH, 2D cubic spline large scale, negative values->0, exp variogram model



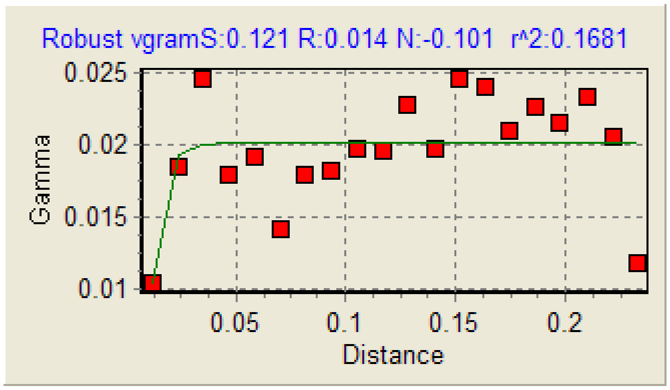
Choptank Secchi, 2D cubic spline large scale, negative values->0, exp variogram model



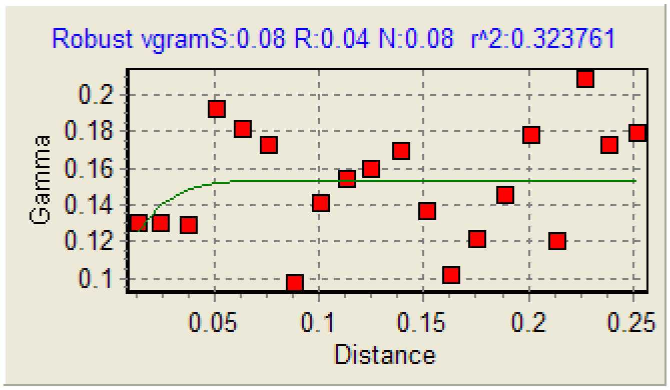
Choptank DO, 2D cubic spline large scale, negative values->0, exp variogram model



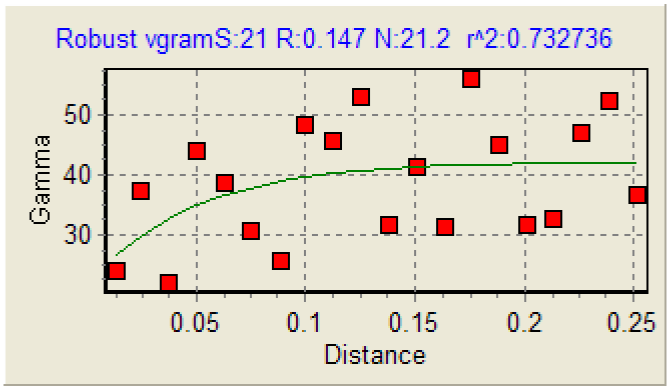
Choptank Temperature, 2D cubic spline large scale, negative values->0, exp variogram model



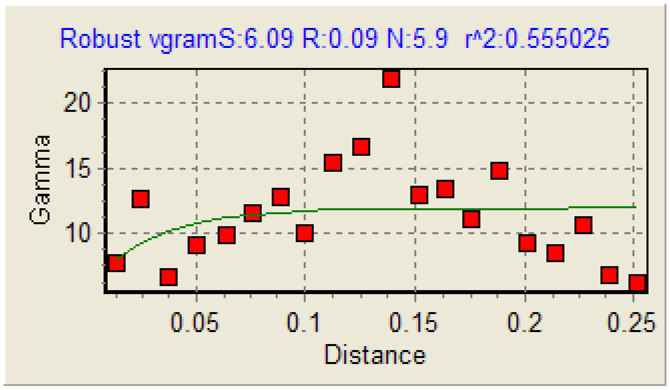
Patuxent δ^{15}N, polynomial x^3,y^2, negative values->0, exponential variogram model.



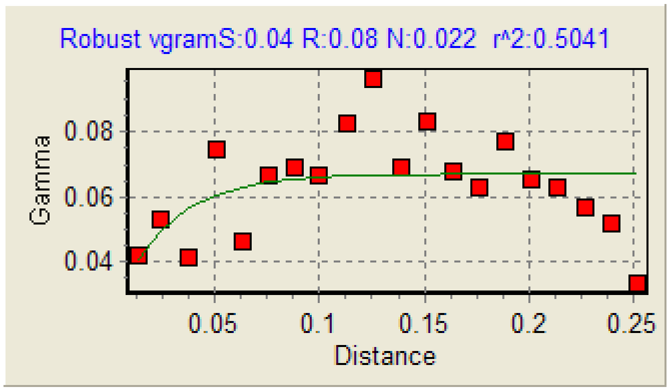
Patuxent Chl a, large scale fit, negative values->0, exp variogram model



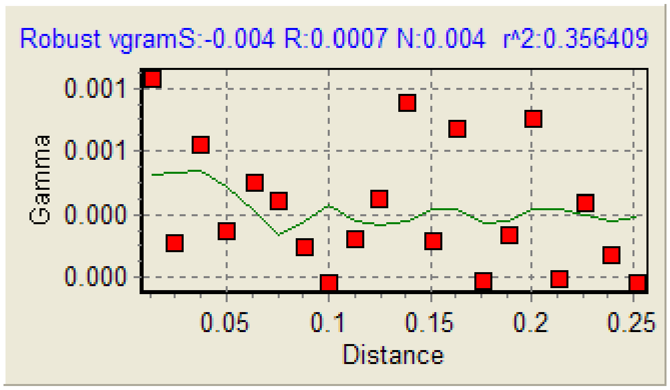
Patuxent Total nitrogen, 2D cubic spline large scale, negative values->0, exp variogram model



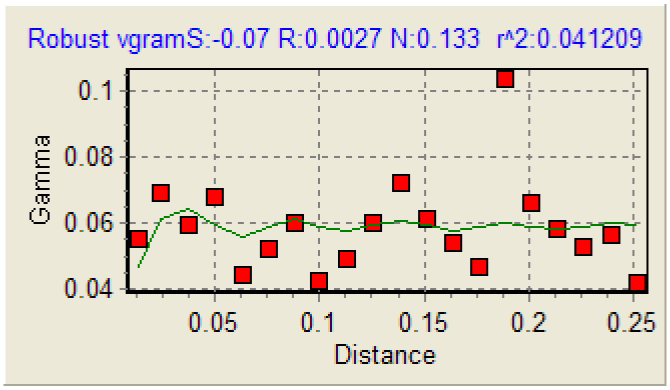
Patuxent Total phosphorous, 2D polynomial large scale, negative values->0, exp variogram model



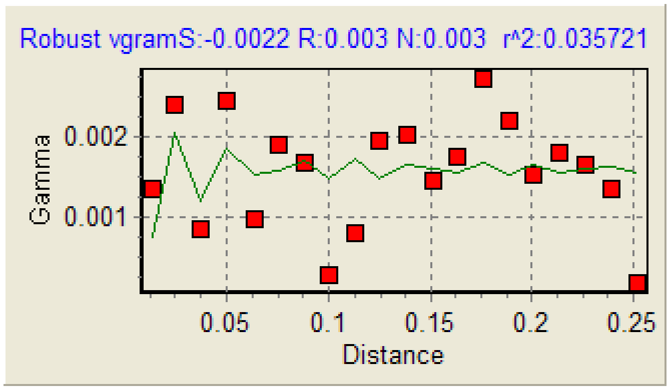
Patuxent Secchi, 2D natural spline large scale fit, sine-based variogram



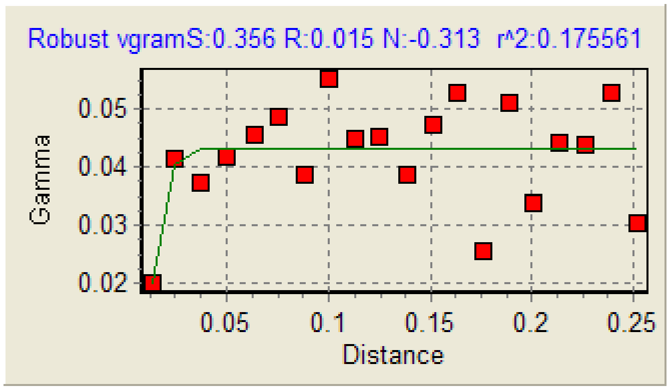
Patuxent DO, 2D natural spline large scale fit, sine-based variogram model



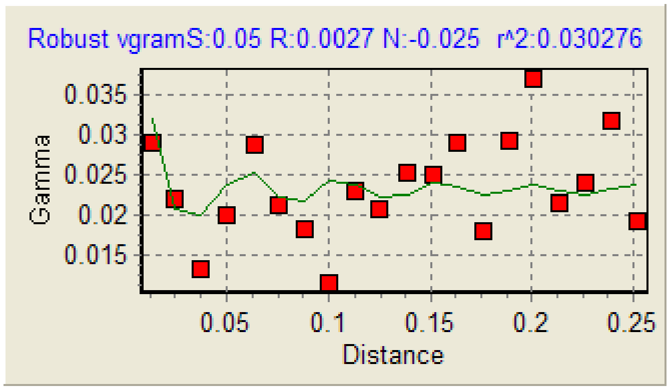
Patuxent pH, 2D cubic spline large scale fit, sine-based variogram model



Patuxent Salinity, 2D polynomial large scale fit, exp variogram model

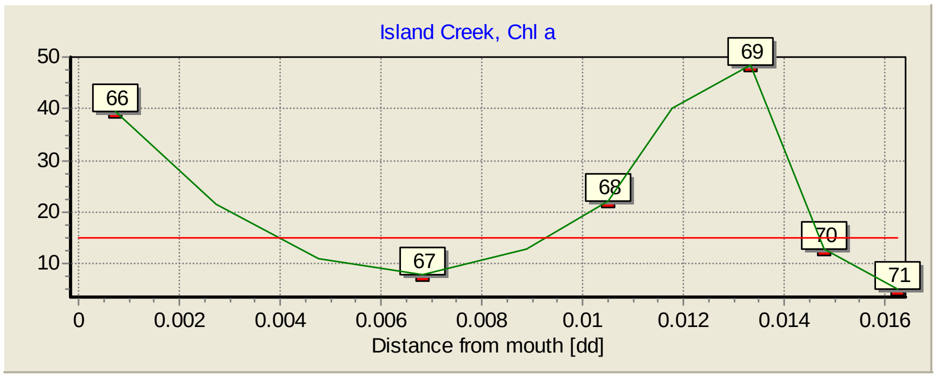


Patuxent Temperature, 2D cubic spline large scale fit, sine-based variogram model

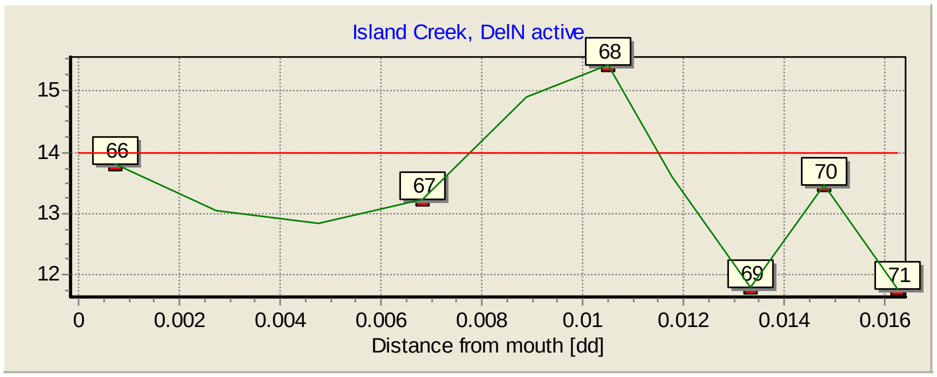


Appendix 5 – Island Creek Linear Predictions

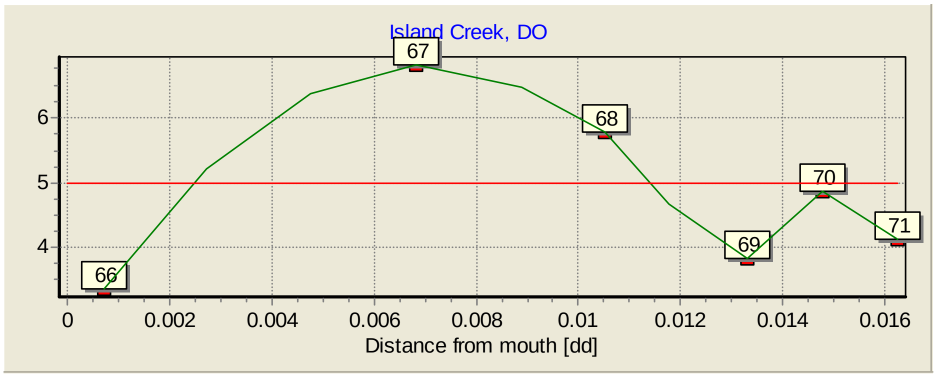
Island Creek Chlorophyll a



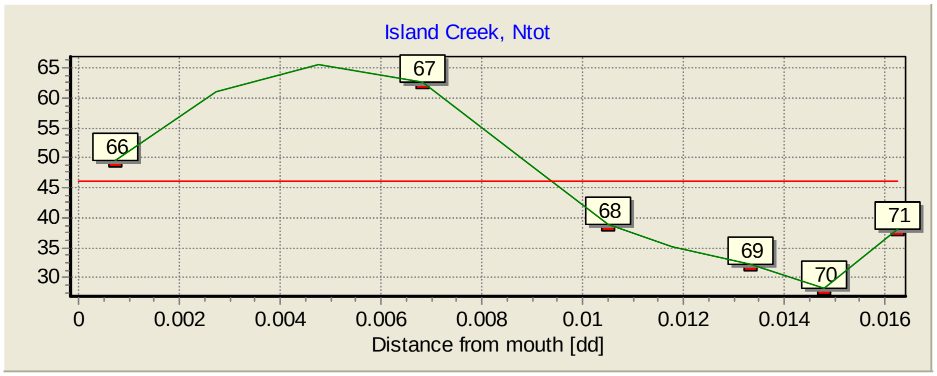
Island Creek $\delta^{15}N$



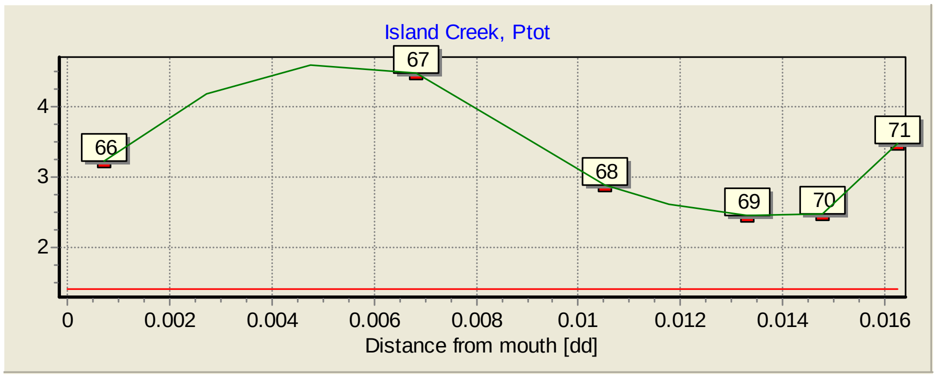
Island Creek DO



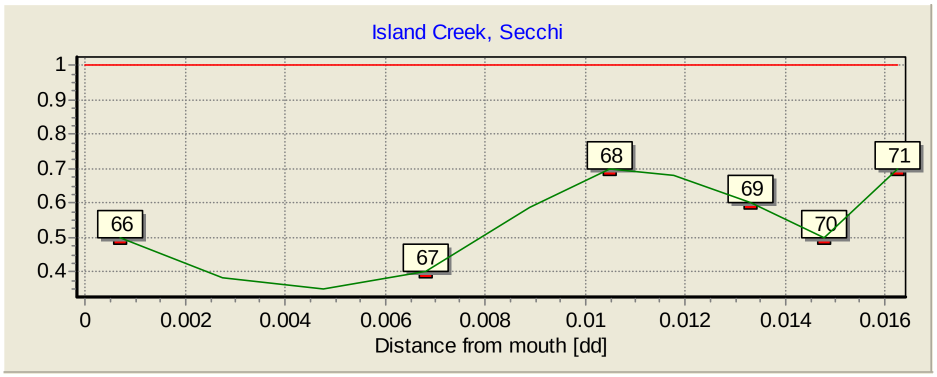
Island Creek Total Nitrogen



Island Creek Total Phosphorus



Island Creek Secchi



Appendix 5 – Choptank Passive $\delta^{15}N$ data

Site	Lat/Long	Species	%N	$\delta^{15}N$
Choptank 1	**38.67918N 76.17442W**	Mussel	10.8	15.98
Choptank 1	38.67918N 76.17442W	*Phragmites*	2.6	8.48
Choptank 2	**38.75716N 76.1187W**	Mussel	6.5	22.01
Choptank 2	38.75716N 76.1187W	*Phragmites*	2.8	9.22
Choptank 2	38.75716N 76.1187W	*Enteromorpha*	0.8	14.07
Choptank 3	**38.73655N 76.12829W**	SAV	2.5	13.28
Choptank 4	**38.71772N 76.32939W**	SAV	2.9	12.76
Choptank 4	38.71772N 76.32939W	Mussel	10.4	17.07
Choptank 4	38.71772N 76.32939W	*Ulva*	1.0	17.87
Choptank 4	38.71772N 76.32939W	*Enteromorpha*	0.3	16.24
Choptank 5	**38.68414N 76.32341W**	*Ulva*	1.3	19.31
Choptank 5	38.68414N 76.32341W	Pippi	9.3	15.82
Choptank 5	38.68414N 76.32341W	*Phragmites*	1.7	10.49
Choptank 5	38.68414N 76.32341W	Brown algae	2.3	14.37
Choptank 5	38.68414N 76.32341W	Mussel	7.4	15.96
Choptank 5	38.68414N 76.32341W	SAV	1.7	11.83
Choptank 6	**38.61654N 76.26469W**	SAV	3.3	10.5
Choptank 7	**38.61631N 76.27137W**	*Spartina*	3.5	8.95
Choptank 7	38.61631N 76.27137W	Grass	1.7	5.56
Choptank 7	38.61631N 76.27137W	*Ulva*	0.7	13.95
Choptank 8	**38.57251N 76.05258W**	*Enteromorpha*	6.3	16.48
Choptank 9	**38.56739N 76.05566W**	*Enteromorpha*	0.1	22.52
Choptank 9	38.56739N 76.05566W	Brown algae	2.4	15.02
Choptank 9	38.56739N 76.05566W	*Spartina*	3.9	13.51
Choptank 10	**38.6108N 75.96881W**	*Spartina*	3.5	11.25
Choptank 10	38.6108N 75.96881W	*Enteromorpha*	0.7	19.58
Choptank 11	**38.63604N 75.96096W**	*Rangia* clam	12.5	17.28
Choptank 11	38.63604N 75.96096W	*Spartina*	3.8	10.29
Choptank 11	38.63604N 75.96096W	*Enteromorpha*	1.2	13.15
Choptank 12	**38.6781N 75.93965W**	*Rangia* clam	8.4	21.05
Choptank 12	38.6781N 75.93965W	*Spartina*	4.1	14.12
Choptank 13	**38.72416N 76.00946W**	*Spartina*	3.0	10.79
Choptank 14	**38.75472N 76.00064W**	*Rangia* clam	9.2	21.74
Choptank 14	38.75472N 76.00064W	*Spartina*	2.7	9.57
Choptank 15	**38.82243N 75.90483W**	*Cladophora*	1.7	12.27
Choptank 15	38.82243N 75.90483W	Grass	2.3	10.14
Choptank 16	**38.86707N 75.84029W**	Grass	2.6	12.37
Choptank 17	**38.79642N 75.93079W**	Reed	4.6	11.25
Choptank 18	**38.78645N 75.93565W**	Reed	3.2	9.49
Choptank 18	38.78645N 75.93565W	*Phragmites*	2.9	12.21
Choptank 19	**38.61127N 76.02257W**	*Ulva*	1.7	12.19
Choptank 19	38.61127N 76.02257W	*Enteromorpha*	1.2	13.61
Choptank 19	38.61127N 76.02257W	*Spartina*	4.2	9.99
Choptank 20	**38.65924N 76.09293W**	*Enteromorpha*	3.6	11.10
Choptank 20	38.65924N 76.09293W	*Spartina*	4.1	8.44
Choptank 20	38.65924N 76.09293W	*Cladophora*	0.5	12.12
Choptank 21	**38.712N 76.21183W**	*Phragmites*	2.5	9.62
Choptank 21	38.712N 76.21183W	Mussels	10.1	12.87

Appendix 6 – Patuxent Passive δ^{15}N data

Site	Lat/Long	Species	%N	δ^{15}N
Patuxent 1	**38.32096N 76.42365W**	*Phragmites*	4.9	8.32
Patuxent 2	**38.32437N 76.4441W**	*Phragmites*	3.0	9.77
Patuxent 2	38.32437N 76.4441W	*Enteromorpha*	0.3	19.33
Patuxent 3	**38.31757N 76.45697W**	Enteromorpha	0.5	13.78
Patuxent 3	38.31757N 76.45697W	SAV	1.4	11.85
Patuxent 3	38.31757N 76.45697W	Cyanobacterial mat	0.1	13.56
Patuxent 4	**38.34918N 76.47021W**	*Phragmites*	3.1	9.79
Patuxent 5	**38.39195N 76.50165W**	*Enteromorpha*	1.4	15.06
Patuxent 5	38.39195N 76.50165W	SAV	1.1	11.15
Patuxent 6	**38.40854N 76.54079W**	*Phragmites*	2.9	7.07
Patuxent 6	38.40854N 76.54079W	Mussel	8.6	14.08
Patuxent 6	38.40854N 76.54079W	SAV	1.0	12.76
Patuxent 7	**38.41683N 76.5387W**	*Enteromorpha*	1.3	11.95
Patuxent 7	38.41683N 76.5387W	*Phragmites*	4.7	7.67
Patuxent 7	38.41683N 76.5387W	SAV	1.0	10.27
Patuxent 8	**38.4189N 76.54128W**	Grass	4.7	9.96
Patuxent 8	38.4189N 76.54128W	*Enteromorpha*	8.1	14.66
Patuxent 9	**38.42657N 76.5357W**	*Phragmites*	2.9	7.64
Patuxent 10	**38.42866N 76.54265W**	*Phragmites*	3.4	10.17
Patuxent 10	38.42866N 76.54265W	*Enteromorpha*	1.5	21.74
Patuxent 11	**38.4685N 76.6452W**	Mussel	9.7	15.48
Patuxent 11	38.4685N 76.6452W	*Phragmites*	3.8	4.25
Patuxent 11	38.4685N 76.6452W	*Enteromorpha*	1.6	17.55
Patuxent 12	**38.53972N 76.68256W**	*Enteromorpha*	4.7	14.22
Patuxent 12	38.53972N 76.68256W	*Phragmites*	4.4	12.78
Patuxent 13	**38.62723N 76.68261W**	*Phragmites*	3.4	10.31
Patuxent 13	38.62723N 76.68261W	*Chaetomorpha*	2.0	15.15
Patuxent 14	**38.66066N 76.68202W**	*Phragmites*	4.3	8.85
Patuxent 15	**38.78381N 76.71203W**	*Phragmites*	4.0	15.23
Patuxent 15	38.78381N 76.71203W	Reed	3.8	12.85
Patuxent 16	38.75378N 76.70043W	Grass	4.0	16.02
Patuxent 17	**38.59327N 76.66903W**	*Enteromorpha*	0.9	16.34
Patuxent 17	38.59327N 76.66903W	*Phragmites*	3.1	11.26

Appendix 6 – Choptank Ecosystem Health Data

Site	Longitude	Latitude	Temp	Salinity	pH	DO	Secchi	Chl *a*	Tot N	Tot P	%N	δ^{15}N
chp001	-76.22919	38.62641	25.78	9.44	8.09	6.04	0.75	26.014	54.4	1.46	2.67	13.61
chp002	-76.23990	38.70203	27.88	8.3	8.76	9.7	0.3	38.293	52.2	1.88	2.61	13.07
chp003	-76.20821	38.67688	27.96	8.24	8.67	9.93	0.4	32.287	48.9	1.79	2.95	14.93
chp004	-75.84832	38.85035	nd	nd	nd	nd	0.25	10.153	156.72	3.32	0.99	15.03
chp005	-75.98687	38.59112	nd	4.6	nd	nd	0.15	40.491	84.1	3.62	2.35	14.31
chp006	-75.93826	38.78791	27.52	0.08	7.18	4.4	0.25	7.269	174.63	4.4	1.88	12.62
chp007	-76.30582	38.72596	27.48	8.65	8.27	6.91	0.6	9.897	40.1	1.42	nd	nd
chp008	-76.04664	38.56592	nd	5.5	nd	nd	0.25	34.539	64.9	2.38	2.81	14.15
chp009	-75.99782	38.71305	27.95	0.64	7.39	4.91	0.1	6.825	153	5.08	1.90	11.38
chp010	-76.07938	38.59115	nd	6.5	nd	nd	0.25	9.783	55.8	1.89	2.22	13.30
chp011	-76.01647	38.57057	nd	4.6	nd	nd	0.15	54.839	72	2.84	2.54	16.71
chp012	-76.06213	38.59748	27.35	6.12	8.27	7.78	0.25	43.299	61.8	2.23	nd	nd
chp013	-76.24737	38.72317	28.29	8.66	8.55	8.44	0.3	31.479	50.6	2.04	2.73	16.11
chp014	-76.16254	38.60708	26.63	7.97	8.22	7.11	0.45	34.152	50.6	1.72	nd	nd
chp015	-76.08737	38.59694	nd	6.6	nd	nd	0.3	55.722	45.7	1.69	2.06	16.26
chp016	-76.31829	38.59699	25.63	10.07	8.28	6.63	0.9	12.051	45	1.41	2.48	14.03
chp017	-76.11510	38.60316	27.2	7.16	8.38	8.86	0.25	22.068	45.7	1.53	2.48	15.55
chp018	-76.20018	38.63151	25.94	9.44	8.36	7.38	0.8	33.538	43.9	1.4	2.43	14.37
chp019	-76.31679	38.72093	27.25	8.8	8.46	7.7	0.5	14.307	44.71	2.08	1.96	15.69
chp020	-76.33650	38.65137	25.88	10.45	8.28	7.12	0.7	6.291	44.5	0.97	3.11	15.39
chp021	-76.32649	38.57451	25.86	10.06	8.41	7.25	0.8	14.788	44.85	1.14	2.98	15.89
chp022	-76.26006	38.71916	28.2	8.69	8.31	7.46	0.5	21.576	44.98	1.37	2.75	14.77
chp023	-76.13854	38.62442	27.32	7.03	8.36	7.82	0.3	4.900	58.89	1.9	2.81	15.49
chp024	-76.18689	38.67638	27.73	8.09	8.42	7.73	0.3	32.883	53.4	1.92	nd	nd
chp025	-76.33374	38.58022	25.52	9.94	8.32	6.73	0.6	11.830	41.21	1.22	2.62	14.89
chp026	-76.25936	38.67540	26	9.7	8.38	7.38	0.6	15.698	49.43	1.32	2.60	14.24
chp027	-76.14256	38.62747	26.88	7.87	8.22	6.71	0.3	50.933	56.96	1.88	2.67	15.48
chp028	-76.24948	38.63818	25.9	9.71	8.33	7.4	0.7	32.319	46.97	1.37	3.22	14.72
chp029	-76.35072	38.62586	25.74	10.35	8.3	6.87	0.7	20.653	45.87	1.21	3.03	12.11
chp030	-76.15873	38.59862	26.21	7.73	8.05	6.5	0.5	39.920	56.18	1.59	0.20	14.30
chp031	-76.25923	38.70883	28.05	8.75	8.35	7.51	0.6	7.344	39.52	1.01	nd	nd
chp032	-76.25181	38.69162	27.68	8.78	8.4	7.87	0.7	15.471	41.22	1.04	2.08	15.22
chp033	-76.24108	38.67521	26.78	8.85	8.47	7.93	0.5	nd	50.32	1.51	3.19	14.33
chp034	-76.26468	38.53139	26.72	10.05	8.34	6.6	0.6	12.558	44.27	1.34	nd	nd
chp035	-76.27397	38.64942	25.7	10.17	8.23	6.45	0.8	16.381	47.74	1.41	2.59	14.26
chp036	-76.07131	38.57908	nd	6	nd	nd	0.2	12.230	58.6	2.29	2.52	15.72
chp037	-76.28620	38.54256	26.64	9.98	8.4	6.95	0.6	11.774	50.21	1.69	1.80	19.81
chp038	-76.30505	38.61736	25.57	10.29	8.25	6.54	0.6	15.698	46.03	1.3	2.56	14.59
chp039	-76.04107	38.58197	27.23	5.51	7.97	6.53	0.2	34.614	67.42	2.63	2.59	15.18
chp040	-76.26606	38.66837	25.87	9.71	8.32	7.09	0.6	16.949	47.46	1.51	2.84	15.32
chp041	-76.33025	38.63193	25.88	10.27	8.32	6.87	0.7	18.461	47.45	1.39	nd	nd
chp042	-76.19826	38.63439	27.13	8.67	8.53	8.72	0.5	28.032	45.46	0.99	2.85	14.88
chp043	-76.33490	38.64894	25.84	10.44	8.28	7.06	0.7	8.825	53.69	1.7	2.48	12.35
chp044	-76.21765	38.67002	27.08	8.24	8.45	8.06	0.2	49.122	48.78	1.4	2.69	14.19
chp045	-76.11267	38.58804	nd	7	nd	nd	0.2	6.830	42.9	1.31	2.31	14.93
chp046	-76.28126	38.62848	25.86	9.72	8.32	6.97	0.6	20.653	47.6	1.4	2.38	12.86

Site	Longitude	Latitude	Temp	Salinity	pH	DO	Secchi	Chl *a*	Tot N	Tot P	%N	δ^{15}N
chp047	-76.17991	38.64465	26.66	8.57	8.2	6.58	0.5	30.660	46.88	1.34	nd	nd
chp048	-76.28139	38.60555	25.83	10.09	8.4	7.02	0.5	16.949	46.85	1.44	2.61	12.33
chp049	-75.98179	38.69798	27.92	1.03	7.47	5.06	0.1	15.807	146.85	4.75	1.49	11.49
chp050	-76.31654	38.65380	26.58	9.29	8.52	8.18	0.5	18.883	49	1.63	2.55	14.34
chp051	-76.06981	38.57439	nd	6.2	nd	nd	0.25	33.229	52.03	2.32	nd	nd
chp052	-76.30411	38.53641	26.14	10.3	8.21	6.62	0.6	12.399	50.08	1.4	2.60	14.48
chp053	-76.01034	38.58466	27.32	5.04	7.84	6.37	0.25	49.056	88.6	3.42	2.75	15.63
chp054	-75.94177	38.67553	27.88	1.35	7.61	4.72	0.1	33.863	139.96	5.13	1.74	14.82
chp055	-76.21750	38.69351	28.17	8.41	8.45	6.5	0.3	17.538	50.35	1.69	2.35	14.15
chp056	-76.27235	38.67363	26.2	9.4	8.4	7.43	0.6	10.238	46.89	1.49	2.50	14.09
chp057	-76.15958	38.65752	27.73	7.82	8.59	8.83	0.3	29.306	48.65	1.35	2.85	14.29
chp058	-76.30174	38.61013	25.62	10.18	8.28	6.64	0.8	12.285	36.65	1.02	3.00	13.31
chp059	-75.99944	38.75124	27.97	0.3	7.32	4.8	0.1	26.306	167.91	5.22	1.20	12.67
chp060	-76.21131	38.66842	27.44	8.24	8.52	8.55	0.4	51.684	52.39	1.57	2.73	14.65
chp061	-76.19119	38.66311	27.76	8.16	8.57	9.15	0.3	26.999	47.54	1.31	2.51	14.42
chp062	-76.32467	38.56086	25.72	10.43	8.25	6.82	0.6	12.627	37.73	1.17	nd	nd
chp063	-76.29316	38.67063	26.25	9.24	8.45	7.63	0.6	26.306	48.28	1.44	3.19	13.78
chp064	-76.30925	38.55716	26.68	9.91	8.49	7.2	0.6	10.124	44.33	1.33	2.24	13.70
chp065	-76.30302	38.68653	26.93	8.88	8.5	8.22	0.5	24.912	46.65	1.5	2.90	13.93
chp066	-76.25390	38.65946	25.94	10.14	8.36	7.34	0.8	31.268	49.12	1.41	1.88	20.25
chp067	-76.28433	38.70261	28.07	8.8	8.64	8.68	0.5	14.192	42.87	1.35	2.38	14.04
chp068	-75.98217	38.62396	27.44	4	7.72	5.41	0.25	20.537	94.46	3.86	2.46	13.59
chp069	-76.03186	38.56995	nd	5.2	nd	nd	0.25	26.537	69.71	2.57	2.08	20.16
chp070	-75.92361	38.80095	27.56	0.07	7.09	4.34	0.2	9.520	176	4.55	1.18	13.98
chp071	-75.96879	38.77582	27.46	0.08	7.35	4.65	0.1	8.873	173	3.62	1.10	21.00
chp072	-76.34227	38.60612	25.75	10.07	8.3	6.82	0.8	15.810	46.37	1.03	2.40	14.93
chp073	-76.11888	38.62825	28.73	7.15	8.58	9.13	0.2	37.253	45.9	1.7	nd	nd
chp074	-75.90433	38.80622	nd	nd	nd	nd	0.25	4.604	170.5	4.43	1.22	12.70
chp075	-76.32455	38.70330	27.38	8.82	8.56	8.64	0.5	19.961	41.42	1.1	0.12	10.82
chp076	-76.05325	38.58362	27.17	5.76	8.19	6.89	0.2	49.306	74.1	2.15	3.07	15.43
chp077	-76.30356	38.62178	25.57	10.28	8.27	6.72	0.8	16.483	44.89	1.11	2.46	14.72
chp078	-76.27567	38.63547	25.85	9.8	8.33	6.91	0.8	16.244	45.42	1.24	2.61	14.92
chp079	-76.14857	38.60564	26.47	7.92	7.83	6.16	0.6	25.253	50.53	1.19	2.40	14.32
chp080	-76.27324	38.50406	26.18	10.44	8.04	5.35	0.5	11.148	54.96	1.59	3.20	12.30
chp081	-76.31652	38.65919	26.54	9.5	8.48	8.08	0.5	20.537	45	1.38	2.91	15.41
chp082	-76.09413	38.60813	26.8	7.11	8.18	6.29	0.2	48.054	60.32	1.96	2.54	16.43
chp083	-76.15878	38.63831	27.1	7.82	8.47	8.39	0.5	42.999	52.29	1.55	2.84	15.29
chp084	-76.32270	38.67765	26.27	9.45	8.21	7.45	0.3	18.691	48.64	1.63	2.53	11.82
chp085	-76.29075	38.63045	25.63	9.91	8.19	6.31	0.5	17.828	49.26	1.5	2.82	15.13
chp086	-76.23436	38.65981	26.49	9.18	8.52	8.13	0.5	21.114	36.3	1.05	2.82	13.78
chp087	-76.26080	38.52408	26.63	10	8.22	6.14	0.7	9.897	34.59	1.11	nd	nd
chp088	-76.22399	38.61513	25.85	9.41	8.03	5.2	0.65	25.383	48.86	1.37	2.20	13.93
chp089	-75.96467	38.63511	27.23	2.46	7.53	5.25	0.15	16.018	112.88	3.7	2.38	15.72
chp090	-76.29824	38.56787	26.94	9.88	8.32	6.4	0.25	11.148	47.12	1.73	2.33	12.08
chp091	-76.14368	38.63538	27.97	7.38	8.58	8.96	0.3	33.671	52.94	1.69	2.86	14.74
chp092	-76.26793	38.61835	25.53	9.88	8.12	6.31	0.5	21.524	49.27	1.52	nd	nd
chp093	-76.21415	38.64479	27.76	8.6	8.56	9.4	0.6	28.037	42.34	1.12	2.69	15.20
chp094	-76.30449	38.64777	26.79	9	8.47	7.96	0.5	18.388	45.91	1.46	nd	nd
chp095	-76.29526	38.70299	27.85	8.78	8.4	7.87	0.6	9.576	26.07	0.87	2.54	13.88

Site	**Longitude**	**Latitude**	**Temp**	**Salinity**	**pH**	**DO**	**Secchi**	**Chl *a***	**Tot N**	**Tot P**	**%N**	**$\delta^{15}N$**
chp096	-75.89604	38.81113	nd	nd	nd	nd	0.25	91.135	162	3.26	1.17	14.87
chp097	-76.15054	38.62531	27.96	7.74	8.64	10.07	0.5	59.854	55.75	1.68	2.69	15.65
chp098	-76.19561	38.62689	26.12	9.18	8.34	7.5	0.7	22.865	63.92	1.16	2.12	16.16
chp099	-75.84561	38.85730	nd	0.1	nd	nd	0.25	11.603	159.62	3.7	1.26	13.36
chp100	-75.86123	38.83337	nd	nd	nd	nd	0.2	9.555	163.76	3.36	1.32	12.42
chp101	-75.86870	38.82423	nd	nd	nd	nd	0.25	8.653	159.62	2.93	nd	nd

Appendix 7 – Patuxent Ecosystem Health Data

Site	**Longitude**	**Latitude**	**Temp**	**Salinity**	**pH**	**DO**	**Secchi**	**Chl *a***	**Tot N**	**Tot P**	**%N**	**Del N**
ptp001	-76.49432	38.33977	26.97	9.16	8.38	7.65	0.7	44.55	34.5	1.74	nd	nd
ptp002	-76.57360	38.41696	27.1	8.53	8.24	7.53	0.7	58.51	31.3	1.66	2.47	13.40
ptp003	-76.61582	38.42842	27.49	7.44	7.75	6	0.4	18.77	38.5	2.2	2.42	13.33
ptp004	-76.68181	38.49742	28.17	5.5	7.43	5.49	0.25	7.68	35.5	3.18	2.68	13.96
ptp005	-76.68007	38.56138	32.71	3.22	7.21	4.91	0.2	13.15	9.43	2.72	1.81	18.86
ptp006	-76.57132	38.40210	27.75	8.21	7.65	7.74	0.6	13.52	40.5	2.95	2.49	12.83
ptp007	-76.47605	38.32265	26.42	9.84	8.3	7.09	0.7	11.42	45.9	2.4	3.36	12.98
ptp008	-76.38149	38.32108	25.74	10.96	8.28	6.58	0.9	12.27	42.9	1.88	2.24	14.33
ptp009	-76.61735	38.43309	27.27	7.45	7.82	6.37	0.4	9.23	40.8	2.98	2.40	11.30
ptp010	-76.44459	38.30889	26.15	10.52	8.29	6.77	0.6	15.03	46.3	2.54	3.08	13.78
ptp011	-76.62628	38.44373	28.38	6.71	7.82	6.53	0.35	8.54	32.88	2.41	2.30	13.39
ptp012	-76.63400	38.43881	29.25	7.01	7.86	6.97	0.35	12.40	53.5	4.04	2.63	13.23
ptp013	-76.58864	38.40347	27.41	7.64	7.9	6.08	0.4	21.27	44	3.06	2.37	13.49
ptp014	-76.48320	38.35862	26.66	9.49	8.26	6.68	0.7	10.01	41.5	3	2.83	12.47
ptp015	-76.45105	38.31937	26.45	10.43	8.37	7	0.7	10.69	30.7	1.86	2.31	14.59
ptp016	-76.38656	38.35712	26.45	10.79	8.38	8.13	0.6	10.50	43.28	1.03	2.75	14.50
ptp017	-76.47250	38.34882	26.2	10.19	8.18	6.15	0.7	16.27	39.85	1.69	2.26	13.93
ptp018	-76.68171	38.53535	28.96	4.23	7.83	8	0.2	34.91	39.3	3.09	2.55	13.00
ptp019	-76.50295	38.38580	27.11	8.95	8.28	6.82	0.6	7.26	28.69	1.21	2.26	12.07
ptp020	-76.59222	38.42243	26.96	7.81	7.73	6.57	0.5	30.34	26.4	1.82	2.68	12.58
ptp021	-76.52633	38.39370	27.16	8.71	8.2	6.71	0.5	44.55	112.21	4.05	2.36	13.40
ptp022	-76.69665	38.69467	26.74	0.1	7.4	6.53	0.1	5.36	76	3.85	1.47	14.78
ptp023	-76.67409	38.61041	28.41	0.27	7.31	5.21	0.1	37.44	70.6	4.74	1.32	18.82
ptp024	-76.67374	38.55493	28.68	1.76	7.44	4.59	0.2	59.32	62.65	3.8	2.67	14.50
ptp025	-76.68698	38.62900	27.63	0.12	7.35	5.45	0.1	14.90	74.9	4.7	1.26	15.70
ptp026	-76.54643	38.40474	26.28	9.2	7.89	5.38	0.7	19.79	43.4	2.46	2.20	12.82
ptp027	-76.41561	38.31141	26.33	10.42	8.39	7.59	0.7	13.76	44.1	2.12	2.88	13.63
ptp028	-76.61713	38.45200	27.14	7.55	7.65	5.15	0.6	7.15	32.4	2.31	2.41	11.98
ptp029	-76.37172	38.32526	25.74	10.89	8.28	6.56	0.7	19.58	41.1	1.38	2.60	13.74
ptp030	-76.69247	38.54052	28	3.03	7.38	7.58	0.15	26.16	36.2	4.17	2.36	12.36
ptp031	-76.64378	38.43978	28.77	6.97	7.48	5.87	0.2	84.41	34.3	2.69	2.38	17.73
ptp032	-76.63661	38.45895	26.89	7.33	7.48	3.85	0.4	11.77	34.14	2.15	2.36	12.60
ptp033	-76.43549	38.29965	26.22	10.16	8.26	6.78	0.7	19.73	46.6	2.28	nd	nd
ptp034	-76.56103	38.40015	27.08	8.22	7.84	5.81	0.5	84.92	66.17	2.11	2.56	11.48
ptp035	-76.37525	38.34462	26.16	10.96	8.38	7.43	0.6	16.85	nd	nd	nd	nd
ptp036	-76.53431	38.39700	26.97	8.45	8.03	6.14	0.6	37.17	52.16	3.43	2.27	12.76
ptp037	-76.68313	38.57315	29.86	1.73	7.28	4.19	0.2	1.89	63.9	3.91	2.48	16.24
ptp038	-76.67162	38.59762	27.96	0.25	7.31	4.99	0.1	10.01	71.1	4.73	1.37	14.01
ptp039	-76.67068	38.49382	27.89	5.78	7.44	5.2	0.15	28.15	34.6	3	2.80	14.00
ptp040	-76.39602	38.31891	25.76	10.89	8.22	6.14	0.8	14.54	39.4	1.5	3.43	11.49
ptp041	-76.40240	38.32735	25.76	11	8.19	5.8	0.8	16.15	44.3	1.57	2.14	13.90
ptp042	-76.46786	38.31923	26.08	10.49	8.17	5.91	0.6	15.47	47.6	2.13	nd	nd
ptp043	-76.49532	38.35071	27.09	8.91	8.29	7.1	0.8	6.37	35.7	3.04	2.61	12.94
ptp044	-76.68493	38.66164	27.44	0.1	7.31	5.94	0.05	11.08	75.6	4.1	1.86	16.39
ptp045	-76.63979	38.44353	28.94	6.81	7.73	6.61	0.3	103.24	41.2	2.42	2.91	13.19
ptp046	-76.37271	38.30953	25.71	11.24	8.18	5.81	0.7	26.66	nd	nd	nd	nd
ptp047	-76.67134	38.48653	28.23	5.97	7.46	5.92	0.2	13.04	36	2.34	3.32	15.06

Site	Longitude	Latitude	Temp	Salinity	pH	DO	Secchi	Chl *a*	Tot N	Tot P	%N	Del N
ptp048	-76.65988	38.51863	28.89	4.66	7.57	6.43	0.15	5.32	40.9	3.69	nd	nd
ptp049	-76.52396	38.40435	26.69	9	8.28	6.85	0.5	53.31	68.2	4.12	2.31	12.00
ptp050	-76.60575	38.44217	27.51	7.62	7.58	4.84	0.5	15.80	30.3	2.33	2.24	12.87
ptp051	-76.37208	38.30899	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
ptp052	-76.59501	38.41804	27	7.63	7.64	5.02	0.5	13.89	30.9	2.21	2.26	12.84
ptp053	-76.49165	38.37547	26.72	9.43	8.28	6.81	0.8	9.44	nd	nd	nd	nd
ptp054	-76.51153	38.37493	26.92	8.75	8.2	6.64	0.7	9.23	nd	nd	nd	nd
ptp055	-76.68168	38.48145	27.98	6.07	7.27	3.6	0.4	12.40	40.41	5.06	2.61	13.96
ptp056	-76.69160	38.64832	28.15	0.1	7.24	5.42	0.1	34.16	74.3	4.4	nd	nd
ptp057	-76.46211	38.30225	25.97	10.5	8.25	6.66	0.6	21.39	50	2.18	2.93	14.34
ptp058	-76.67637	38.58883	28	0.032	7.21	4.54	0.1	13.73	72.4	4.72	nd	nd
ptp059	-76.65911	38.48390	27.45	5.89	7.48	4.8	0.3	26.78	37.5	2.66	3.15	14.79
ptp060	-76.54977	38.39184	28.65	7.79	8.33	9.08	0.35	60.29	60.4	3.79	2.49	12.86
ptp061	-76.69463	38.67203	27.48	0.1	7.39	6.28	0.1	8.87	74.3	3.62	3.99	19.33
ptp062	-76.54100	38.42668	27.18	8.75	7.61	4.14	0.7	5.10	38.1	3.47	2.82	11.76
ptp063	-76.54002	38.42394	27.51	8.56	7.81	4.88	0.5	12.85	28.2	2.46	2.68	13.47
ptp064	-76.53930	38.42257	27.73	8.39	7.7	3.84	0.6	48.49	32.2	2.45	2.87	11.78
ptp065	-76.54015	38.41996	27.47	8.6	8	5.78	0.7	22.07	38.9	2.89	0.13	15.43
ptp066	-76.54132	38.41598	27.57	8.33	8.15	6.82	0.4	7.85	62.7	4.47	2.45	13.23
ptp067	-76.54520	38.41133	26.32	9.33	7.64	3.37	0.5	39.64	49.6	3.23	2.06	13.81

Appendix 8 - Statistical summaries

Choptank, measurements

Choptank	**Chl.a**	**Ntot**	**Ptot**	**secchi**	**DO**	**sal**	**Temp**	**pH**
Min:	4.6	26.07	0.87	0.05	4.34	0.07	25.52	7.09
1st Qu.:	12.29	45.7	1.35	0.25	6.5	6.575	25.94	8.19
Mean:	**26.56**	**67.8**	**2.006**	0.4329	**7.138**	7.568	26.8558	**8.2254**
Median:	20.54	49.27	1.55	0.5	7.075	8.665	26.84	8.32
3rd Qu.:	32.88	63.92	2.29	0.6	7.952	9.74	27.55	8.45
Max:	262.8	176	5.22	0.9	10.07	10.45	28.73	8.76
Total N:	105	105	105	105	105	105	105	105
NA's :	0	0	0	0	15	5	15	15
Std Dev.:	28.01	40.28	1.065	0.2194	1.262	2.978	0.8755	0.3578
SE Mean:	2.73	3.93	0.104	0.0214	0.133	0.298	0.0923	0.0377
LCL Mean:	21.14	**60.01**	**1.8**	0.3904	6.873	6.977	26.6724	8.1505
UCL Mean:	31.98	**75.59**	**2.212**	0.4753	7.402	8.158	27.0391	8.3004

Patuxent, measurements

Patuxent	**Chl.a**	**Ntot**	**Ptot**	**secchi**	**DO**	**sal**	**Temp**	**pH**
Min:	1.89	9.43	1.03	0.05	3.37	0.032	25.71	7.21
1st Qu.:	10.55	35.6	2.165	0.2125	5.252	5.91	26.502	7.48
Mean:	**23.28**	**46.53**	**2.882**	0.4636	**6.077**	7.135	27.359	**7.847**
Median:	14.96	41.1	2.69	0.5	6.145	8.215	27.17	7.825
3rd Qu.:	27.81	52.83	3.74	0.7	6.803	9.405	27.975	8.248
Max:	103.24	112.21	5.06	0.9	9.08	11.24	32.71	8.39
Total N:	66	66	66	66	66	66	66	66
NA's :	0	3	3	0	0	0	0	0
Std Dev.:	20.65	17.04	1.02	0.2351	1.168	3.39	1.17	0.39
SE Mean:	2.54	2.15	0.128	0.0289	0.144	0.417	0.144	0.048
LCL Mean:	**18.2**	**42.24**	**2.626**	0.4058	5.79	6.302	27.072	7.752
UCL Mean:	**28.35**	**50.82**	**3.139**	0.5214	6.365	7.968	27.647	7.943

Choptank, prediction

Choptank	**Chl.a**	**Ntot**	**Ptot**	**secchi**	**DO**	**sal**	**Temp**	**pH**
Min:	8.526	30.49	1.0285	0.08537	3.9021	0	19.5993	6.303
1st Qu.:	16.63	45.84	1.3224	0.24185	6.3228	6.286	26.1032	8.0712
Mean:	23.272	**65.48**	**2.0031**	0.44603	6.8873	7.529	26.8004	8.1413
Median:	23.799	48.58	1.4832	0.48231	6.9389	8.768	26.865	8.2988
3rd Qu.:	30.506	60.32	2.1204	0.61437	7.7575	9.921	27.412	8.404
Max:	33.252	176.76	5.1909	0.89234	9.7804	11.451	30.4512	8.7411
Total N:	820	820	820	820	820	820	820	820
Std Dev.:	7.353	37.91	1.1197	0.19842	1.211	3.166	0.9179	0.4273
SE Mean:	0.257	1.32	0.0391	0.00693	0.0423	0.111	0.0321	0.0149
LCL Mean:	22.768	**62.88**	**1.9264**	0.43243	6.8043	7.312	26.7375	8.112
UCL Mean:	23.776	**68.08**	**2.0799**	0.45963	6.9703	7.746	26.8634	8.1706

Patuxent, prediction

Patuxent	**Chl.a**	**Ntot**	**Ptot**	**secchi**	**DO**	**sal**	**Temp**	**pH**
Min:	0	0	0.8792	0.05247	4.0735	0	25.6569	6.9663
1st Qu.:	12.902	37.09	2.1015	0.24111	5.4994	5.87	26.4054	7.5377
Mean:	22.575	**47.98**	**2.7062**	0.47218	6.049	7.27	27.2977	7.8987
Median:	18.376	43.44	2.5362	0.53051	6.1305	8.26	27.1801	7.95
3rd Qu.:	29.931	56.59	3.4308	0.67392	6.5825	10.21	28.0475	8.2545
Max:	93.316	122.09	4.8324	0.87426	8.0039	11.87	32.3577	9.5694
Total N:	816	816	816	816	816	816	816	816
NA's :	0	0	0	45	45	0	45	0
Std Dev.:	15.502	15.72	0.9085	0.22744	0.6627	3.42	1.0456	0.4021
SE Mean:	0.543	0.55	0.0318	0.00819	0.0239	0.12	0.0377	0.0141
LCL Mean:	21.51	**46.9**	**2.6438**	0.4561	6.0022	7.04	27.2238	7.8711
UCL Mean:	23.64	**49.06**	**2.7687**	0.48826	6.0959	7.51	27.3716	7.9264

Appendix 9 – Photos

Plate 1. Cambridge Wastewater Treatment Plant. Sewage effluent has a high δ^{15}N isotopic signature which can be detected by analyzing organisms inhabitant or incubated in the region.

Plate 2. Fertilized lawns along the rivers provide a source of nutrients

Plate 3. Initial Collection of inhabitant SAV occurred at many sites along the Choptank and Patuxent Rivers

Plate 4. Deploying the incubation rig with buoy, perforated macroalgal chamber, sinker and bricks

Plate 5. Incubation chamber deployed in the upper Choptank River. Note the highly turbid nature (shallow secchi depth) of the water in this region of the river which experiences low flushing

Plate 6. Fish kills were a common occurrence during sampling in July 2003, associated with toxic algal blooms and periods of hypoxia/anoxia

Appendix 9 – About the Integration and Application Network

The Integration and Application Network is an UMCES initiative, established in 2002. Its charter is to provide resources to assist in the communication of science between scientists, managers and eventually the community with the explicit objective of assisting in better management of Chesapeake Bay to produce improvements in ecosystem health. It is a collection of scientists interested in solving, not just studying environmental problems. The intent of IAN is to inspire, manage and produce timely syntheses and assessments on key environmental issues, with a special emphasis on Chesapeake Bay and its watershed. IAN is an initiative of the faculty of the University of Maryland Center for Environmental Science, but will link with other academic institutions, various resource management agencies and non-governmental organizations.

IAN aims to provide opportunities for scientists to build credibility with stakeholders, as well as enhancing credibility with scientific peers. Creative ways of synthesizing data, communicating results and developing solutions are being pioneered at UMCES, using established and emerging technologies. In terms of tenacity, UMCES is in the business of environmental problem solving for the long term. From the creation of Chesapeake Biological Laboratory in 1925, scientists at UMCES have been devoting their professional lives to studying and solving environmental problems. In terms of virtue, the creation of IAN represents the latest in a series of faculty initiatives to stimulate and enhance the effectiveness of their research.

IAN will strive to facilitate the transfer of data into information, into knowledge, and ultimately, into problem solving.

IAN's primary objectives are to:

- Foster problem solving using integration of scientific data and information
- Support the application of scientific understanding to forecast consequences of environmental policy options
- Provide a rich training ground in complex problem solving and science applications
- Facilitate a productive interaction between scientists and the broader community

IAN was inspired by the notion that university scholarship in the 21st century must be multifaceted. The University of Maryland Center for Environmental Science (UMCES) has embraced the four dimensions of scholarship (including integration and application) proposed by The Carnegie Foundation for the Advancement of Teaching. We use the term “network” rather than “center” or “institute” because IAN spans across UMCES’ three laboratories into all corners of our information and knowledge resources and beyond—a virtual nexus.

A major feature of the University of Maryland Center for Environmental Science is the focus on science integration and application. Science integration is an effort that goes beyond the generation and reporting of data—it is the attempt to synthesize and interpret the world in light of new scientific findings. Developing an integrated picture using disparate findings is often the most difficult challenge for scientists. Science integration typically requires input from a variety of disciplines, and a large part of the science conducted at UMCES is multi-disciplinary, often combining physics, chemistry, geology and biology. Science application is an effort that goes beyond the scientific peer group—it is the attempt to conduct research that will have direct applications, particularly in resource management. Scientific results are typically published in journals and books that are targeted for other like-minded scientists. The efforts to communicate findings to a broader audience and to develop ways to implement various policies that stem from research findings are included in science application. The combination of science integration with science application is a powerful approach in dealing with environmental problems—it allows scientists to go beyond just identifying and documenting problems and provides opportunities to actually solve important problems.

Appendix 10 – Developing a Chesapeake Bay Report Card

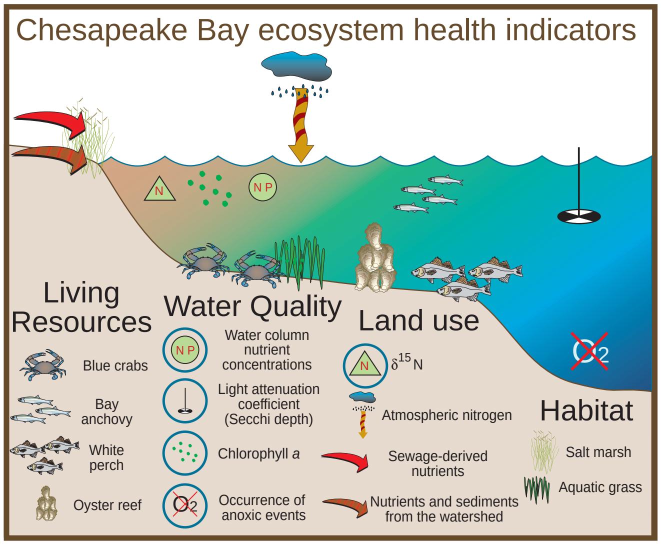
Developing a Chesapeake Bay Report Card

November 2003

This newsletter details the importance of developing a scientifically rigorous, spatially explicit ecosystem health report card on Chesapeake Bay and its watershed to facilitate coordination and feedback between monitoring, management and research. A pilot study was conducted in July 2003 on the Patuxent and Choptank Rivers using a novel stable isotope technique (see "Assessing Nutrient Sources" newsletter below) together with more traditional water quality monitoring techniques. Spatial statistical analysis and mapping was conducted and an Ecosystem Health Index (EHI) developed. From these, report card values (A to F) were determined for various reporting regions within the rivers and compared to a region near the mouth of Chesapeake Bay. A spatially explicit index of ecosystem health such as this is a useful monitoring tool which can help focus management and research efforts by providing rapid, effective and timely feedback on the health of Chesapeake Bay.

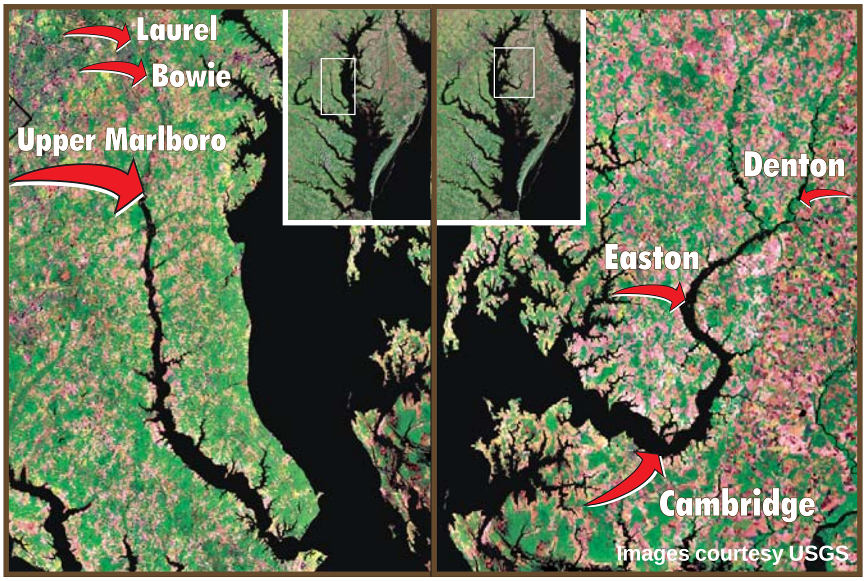
DEVELOPING A CHESAPEAKE BAY REPORT CARD

Coordination and feedback between monitoring, management and research is essential in achieving healthy Chesapeake waterways. There is a need for a scientifically rigorous, spatially explicit ecosystem health report card on Chesapeake Bay and its watershed, and so a pilot study was conducted in July 2003 on the Patuxent and Choptank Rivers. δ^{15}nitrogen signatures in the Choptank River showed elevated sewage nitrogen levels adjacent to and downstream from sewage treatment plants. The Choptank River had generally lower ecosystem health than the Patuxent River, except in the upper reaches where both rivers exhibited low ecosystem health. Incorporating seasonal sampling and a broader range of indicators from different ecosystem elements would produce a complete and more robust report card. This study indicates the potential for a Bay-wide ecosystem health report card to provide rapid, effective, and spatially and temporally explicit monitoring feedback to managers, scientists and the broader community .


Chesapeake Bay ecosystem health indicators

With the aim of maintaining fisheries and improving water quality, management objectives such as clear water and reduced nutrient inputs can be linked to ecosystem health indicators which can then be quantified, mapped and integrated. A reference value for each of these indicators provides information on whether the management objectives are being met. These indicators should ideally provide information on various aspects of the ecosystem. The *Chesapeake 2000* agreement highlighted four interconnected ecosystem elements: **Living Resources**, **Water Quality**, **Land Use** and **Vital Habitat**. A monitoring strategy including indicators from each of these categories would provide integrated ecosystem information about whether the goals of *Chesapeake 2000* are being met. The conceptual diagram (left) depicts potential indicators from each ecosystem element. This study monitored indicators of water quality and land use (circled parameters on the conceptual diagram).

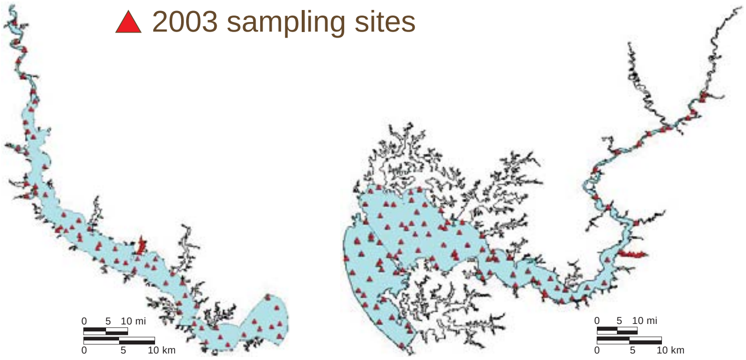
The **Patuxent River** has a largely forested watershed with extensive urban development. There are a number of sewage treatment plants (STPs) although these are all located upstream. The three most downstream STPs are located at Laurel (discharge 30,210 kg nitrogen year^{-1}), Bowie (25,810 kg N yr^{-1}) and Upper Marlboro (186,342 kg N yr^{-1}). [1]



Images courtesy USGS

The **Choptank River** has a largely agricultural watershed with moderate urban development. There are a number of STPs located along the length of the river. The three main STPs on the Choptank River are located at Denton (discharge 2,541 kg N yr^{-1}), Easton (21,347 kg N yr^{-1}) and Cambridge (55,447 kg N yr^{-1}). [1]

WATER QUALITY WAS MEASURED IN PILOT STUDY



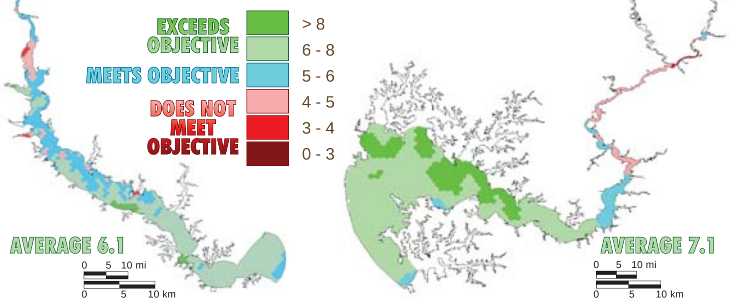
106 sites in the Choptank River and 67 sites in the Patuxent River were sampled over one week in July 2003 for the water quality and nutrient parameters listed below. A non-stratified and spatially randomized experimental design was used to select the sampling sites. Spatial analysis of the data resulted in the following maps.

Additional sampling was conducted at Cape Charles City, which functioned as a 'reference' site.

MANAGEMENT OBJECTIVE →	ECOSYSTEM HEALTH INDICATOR →	REFERENCE VALUE
Maintain suitable fisheries habitat	Dissolved oxygen	DO > 5 mg L^{-1} [2]
Clear water	Secchi depth	Secchi depth > 1.0 m [3]
Reduce phytoplankton	Chlorophyll *a*	Chl *a* < 15 µg L^{-1} [3]
Reduce phosphorus	Total phosphorus	TP < 1.4 µM [4]
Reduce nitrogen	Total nitrogen	TN < 46 µM [4]
Reduce sewage inputs	δ^{15}nitrogen	δ^{15}N < 14 ppt [5]

Surface dissolved oxygen (mg L^{-1})

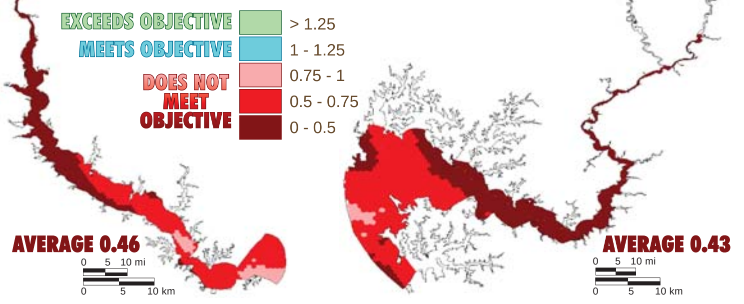
Reference value: 5 mg L^{-1}



Surface dissolved oxygen (DO) was generally adequate in both rivers, meeting or exceeding the reference value of 5 mg L^{-1} necessary to sustain fisheries. However, DO was not measured in the bottom waters, where hypoxia generally occurs.

Secchi depth (m)

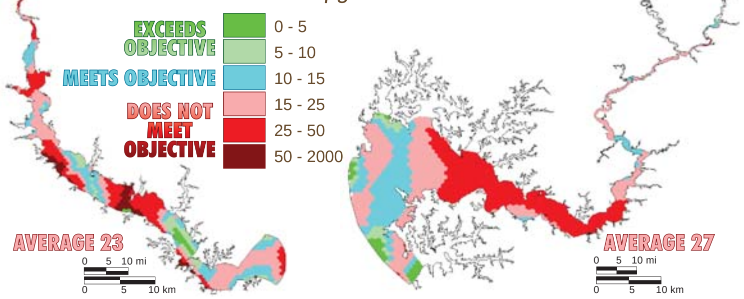
Reference value: 1 m



All areas of both rivers failed to meet the reference Secchi depth value of 1 m, with most areas having a Secchi depth of less than 0.75 m. This level of light penetration is considered inadequate for the survival and growth of aquatic grasses.

Chlorophyll *a* (µg L^{-1})

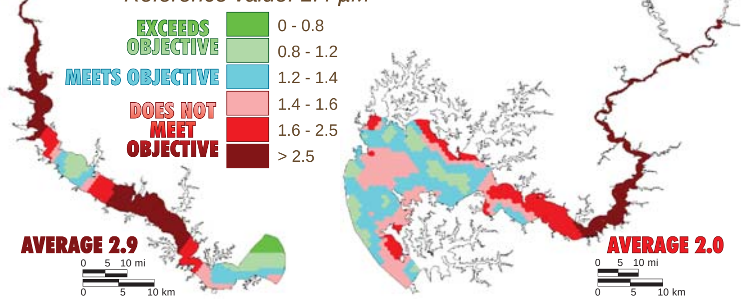
Reference value: 15 µg L^{-1}



Chlorophyll *a* concentrations were higher in the middle reaches of both rivers where total nitrogen and phosphorus concentrations were still relatively high. In the Patuxent River, the high phytoplankton was associated with lower turbidity (increased Secchi depth). Excessive phytoplankton in the water column reduces the amount of light reaching aquatic grasses.

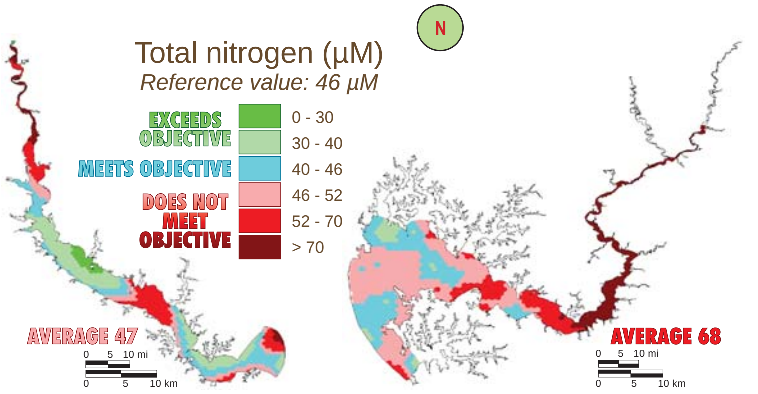
Total phosphorus (µM)

Reference value: 1.4 µM

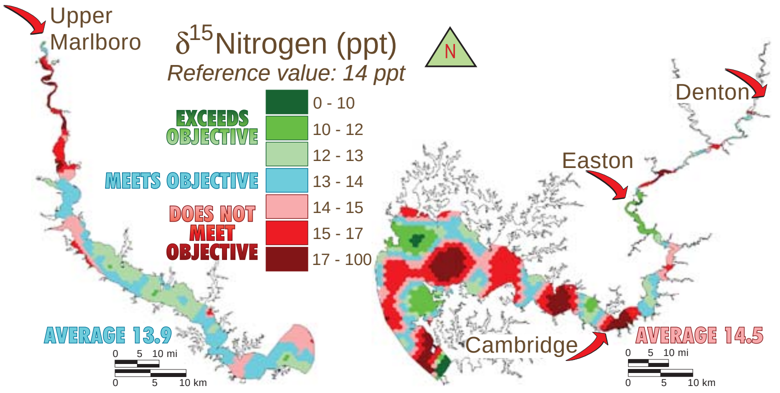


Both rivers showed excessive levels of total phosphorus in the upper reaches, with concentrations reducing towards the mouth. There was a region in the middle Patuxent River which met the reference value of 1.4 µM. Excess nutrients can result in algal blooms in the water column, and in reduced oxygen in the bottom waters from the decaying algal biomass.

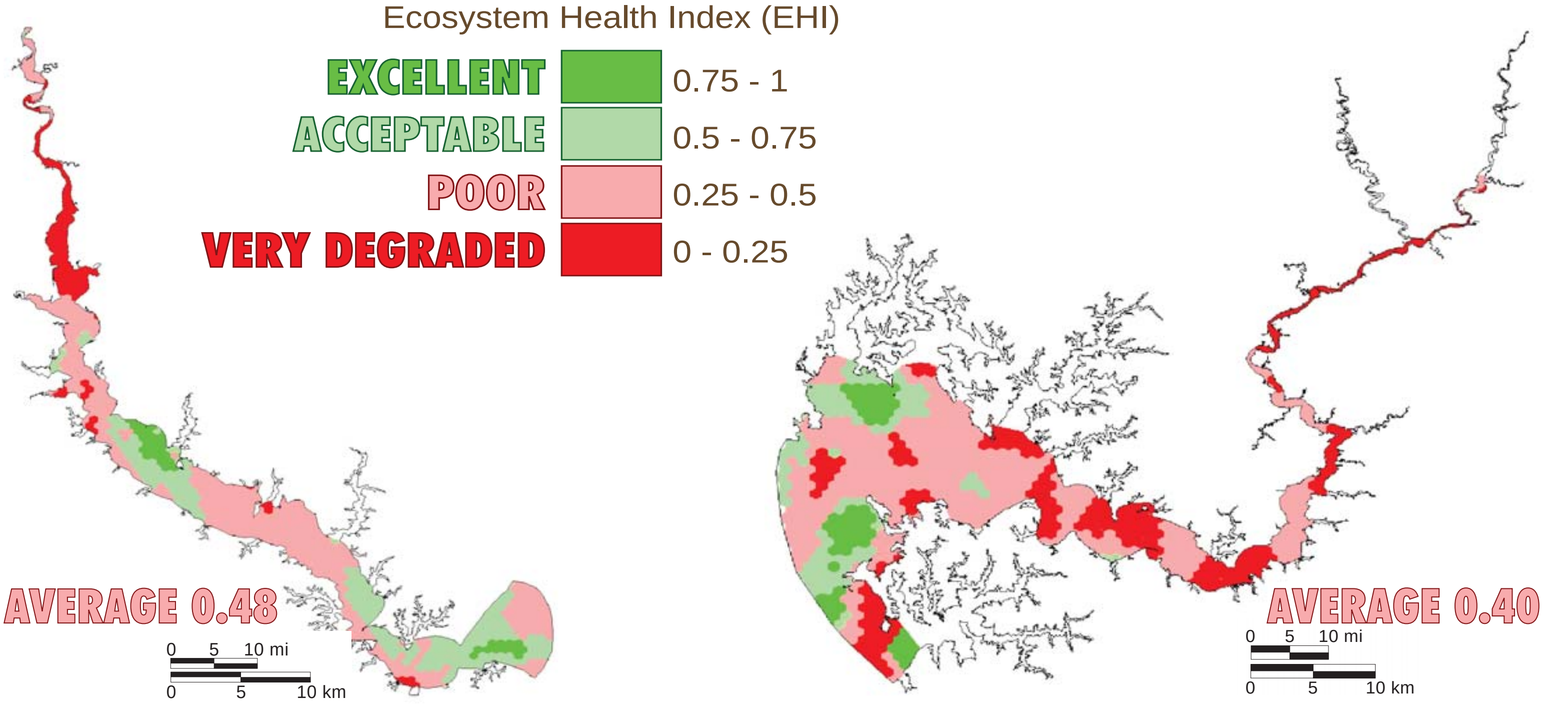
DATA INTEGRATION PROVIDED ECOSYSTEM HEALTH INDEX



Total nitrogen showed a similar pattern to total phosphorus, with the upper portions of both rivers showing high levels of nitrogen, improving downstream. The Patuxent River again had a region mid-river with low levels of nitrogen, the same area which had low chlorophyll *a* and total phosphorus levels, suggesting that phytoplankton in this area may be limited by nutrients.



δ^{15}nitrogen analysis is a technique used to identify the source and distribution of sewage nitrogen.[5] The Patuxent River showed generally low levels of δ^{15}N, with the exception of the upper reaches, consistent with the lack of sewage treatment plants in the middle and lower river. The Choptank River showed well-defined areas of elevated δ^{15}N adjacent to and downstream from sewage treatment plants in Denton, Easton and Cambridge. Areas of elevated δ^{15}N were evident downstream from Cambridge, suggesting sewage nitrogen may become tidally retained in the Choptank River.

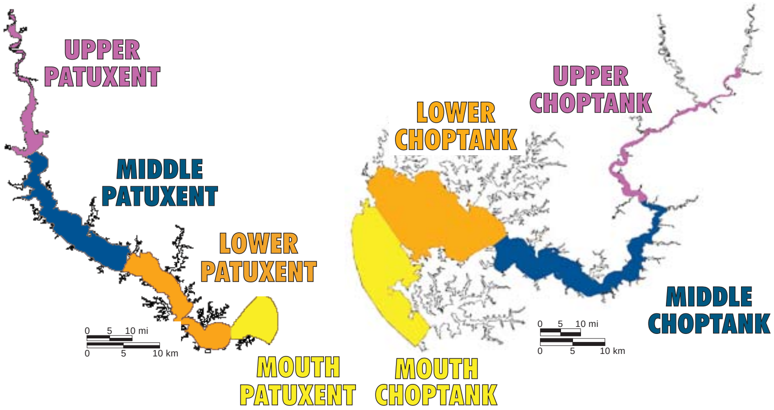


An Ecosystem Health Index (EHI) was produced for each river by averaging the data from the measured variables at each sampling site. Areas of the rivers which met or exceeded the reference value for each of the indicators attained a maximum EHI of 1. A minimum EHI of 0 was attained by areas of the rivers which failed to meet the reference values for all indicators. The average EHI value for both rivers was less than 0.5, indicating poor ecosystem health.

The Patuxent River had areas of high ecosystem health in the middle and mouth regions, with low health in the upper reaches. The Choptank River had generally lower ecosystem health than the Patuxent River, with only some areas around the mouth of the river showing higher ecosystem health. In contrast, the reference sites sampled at Cape Charles attained an EHI of 0.75.

This Ecosystem Health Index approach can summarize the patterns in the data for each river. A spatially explicit index of ecosystem health such as this is a useful monitoring tool which can help focus management and research efforts by providing rapid, effective and timely feedback on the health of Chesapeake Bay.

REPORTING REGIONS WERE IDENTIFIED



Region	EHI	Region	EHI
Upper Patuxent	**0.21**	Upper Choptank	**0.20**
Middle Patuxent	**0.52**	Middle Choptank	**0.26**
Lower Patuxent	**0.48**	Lower Choptank	**0.44**
Mouth Patuxent	**0.58**	Mouth Choptank	**0.49**
Patuxent Overall	**0.48**	Choptank Overall	**0.40**
Cape Charles City	**0.75**		

EHI range	Grade	EHI range	Grade
> 0.81	A	0.26 – 0.50	D
0.66 – 0.80	B	< 0.25	F
0.50 – 0.65	C		

2003 REPORT CARD

Upper Patuxent	F	Upper Choptank	F
Middle Patuxent	C-	Middle Choptank	D-
Lower Patuxent	D+	Lower Choptank	D+
Mouth Patuxent	C	Mouth Choptank	D+
Patuxent Overall	D+	Choptank Overall	D
Cape Charles City	B+		

The spatially explicit Ecosystem Health Index (EHI) can be used to identify reporting regions. Four reporting regions were identified in the Patuxent and Choptank Rivers. An ecosystem health value given to each region can be converted into report card values, A – F. Overall, the Patuxent River received a D+ and the Choptank River a D, with the upper reaches of both rivers receiving an F. The reference sites at Cape Charles City, with an EHI value of 0.75, received a B+.

This 'report card' approach translates scientifically rigorous data for broader communication and understanding of the results. Incorporating seasonal sampling and a broad range of indicators would produce a complete and more robust report card. When used over time, a report card also becomes temporally explicit and responsive to annual changes in the health of Chesapeake Bay.

Acknowledgements:

Funding for this study was provided by the Maryland Department of Natural Resources

References:

[1] Chesapeake Bay Foundation (2003). Sewage Treatment Plants: The Chesapeake Bay watershed's second largest source of nitrogen pollution. Report published 29 October 2003.

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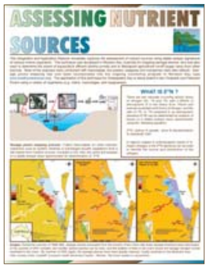
[3] Batiuk RA, *et al*. (2000). *Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-Based Requirements and Restoration Targets: A Second Technical Synthesis*. U.S. EPA and Chesapeake Bay Program.

[4] Malone, TC, Boicourt, WC, Cornwell, JC, Harding, LW, and Stevenson, JC. (2003). *The Choptank River: A mid-Chesapeake Bay Index site for evaluating ecosystem responses to nutrient management*. Final Report to U.S. Environmnetal Protection Agency.

[5] Costanzo SD, O'Donohue MJ, Dennison WC, Loneragan NR & Thomas MT (2001). A new approach for detecting and mapping sewage impacts. *Marine Pollution Bulletin* 42: 149-56.

Further reading:



These IAN newsletters are downloadable from **www.ian.umces.edu**

*The **I**ntegration and **A**pplication **N**etwork (IAN) is a collection of scientists interested in **solving**, not just studying environmental problems. The intent of IAN is to inspire, manage and produce timely syntheses and assessments on key environmental issues, with a special emphasis on Chesapeake Bay and its watershed. IAN is an initiative of the faculty of the University of Maryland Center for Environmental Science, but will link with other academic institutions, various resource management agencies and non-governmental organizations.*

PRIMARY OBJECTIVES FOR IAN

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- **Facilitate** a productive interaction between scientists and the broader community

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SCIENCE COMMUNICATION
Principal investigator: Dr Adrian Jones
Spatial analysis by Francis Pantus
Graphics, design and layout by Jane Thomas

INTEGRATION APPLICATION NETWORK

Appendix 11 – Assessing Nutrient Sources Newsletter

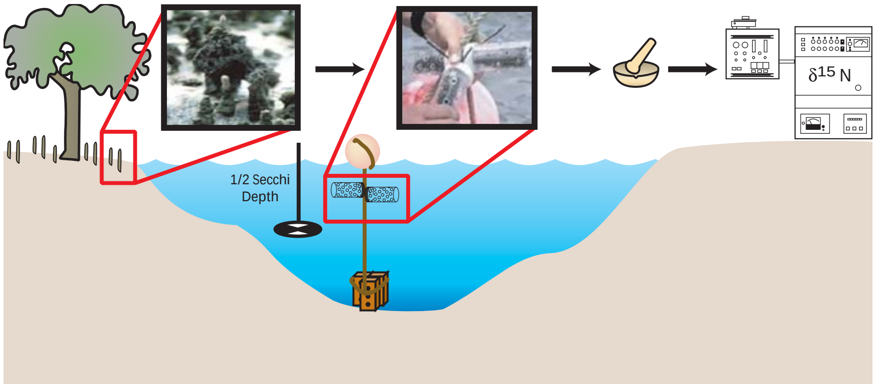
Assessing Nutrient Sources

Feb 2003

This IAN newsletter explores the assessment of nutrient sources using stable isotope signatures of various marine organisms. This technique was developed in Moreton Bay, Australia for mapping sewage plumes, and was also used to determine the extent of aquaculture effluent (shrimp ponds) and to distinguish agricultural runoff (sugar cane) from other sources. The stable isotope ratio of nitrogen in organisms can be used to determine the influence of different nitrogen sources. A high $\delta^{15}N$ signature (the ratio of ^{15}N to ^{14}N) typically indicates influence by sewage, septic or animal waste, whereas a low or negative $\delta^{15}N$ identifies fertilizer inputs. The technique, unlike traditional water quality measurements, detects only bioavailable nutrients and integrates nutrient history over time. This technique will be used in the Choptank and Patuxent Rivers during the Spring and Summer of 2003, with results made available on the IAN website.

ASSESSING NUTRIENT SOURCES

This Integration and Application Network newsletter explores the assessment of nutrient sources using stable isotope signatures of various marine organisms. This technique was developed in Moreton Bay, Australia for mapping sewage plumes, and was also used to determine the extent of aquaculture effluent (shrimp ponds) and to distinguish agricultural runoff (sugar cane) from other sources. Most of the analyses were conducted with macroalgae, but oysters, seagrass and mangroves were also utilized. Sewage plume mapping has now been incorporated into the ongoing monitoring program in Moreton Bay (see www.healthywaterways.org). The application of this technique for Chesapeake Bay is being tested in the Choptank and Patuxent Rivers using a variety of organisms (e.g. clams, macroalgae, and seagrasses).



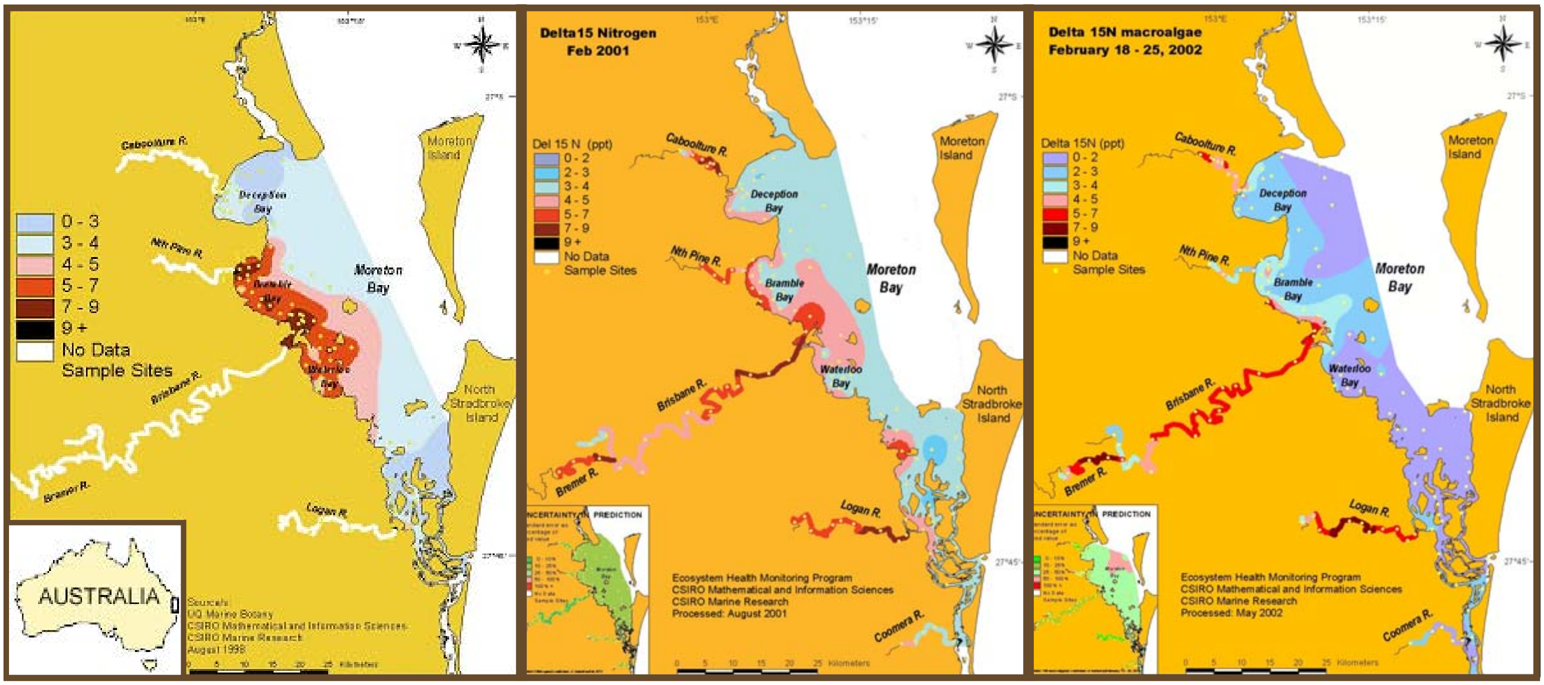
Sewage plume mapping process: *Collect macroalgae (or other indicator organisms such as oysters, bivalves or submerged aquatic vegetation) from a site distant from nutrient sources, incubate in situ, then dry, grind and analyze on a stable isotope mass spectrometer for determination of* $\delta^{15}N$.

WHAT IS $\delta^{15}N$?

There are two naturally occurring atomic forms of nitrogen (N), ^{14}N *and* ^{15}N*, with 0.3663% of atmospheric N in the heavy form. Plants and animals assimilate both forms of nitrogen, and the ratio of* ^{15}N *to* ^{14}N *compared to an atmospheric standard (*$\delta^{15}N$*) can be determined by analysis of tissue on a stable isotope mass spectrometer using the following equation:*

$$\delta^{15}N = [(\text{atom \% sample} - \text{atom \% standard})/\text{atom \% standard}]*1000$$

In regions subject to anthropogenic inputs of nitrogen changes in the $\delta^{15}N$ *signature can be used to identify the source and distribution of the nitrogen.*



Images: *During the summer of 1998 (left), sewage plumes emanated from the mouths of two rivers with large sewage treatment plant discharges. In the summer of 2001 (middle), two smaller, distinct plumes can be seen, and the addition of sites in the rivers shows the sewage nitrogen mostly restricted to the rivers. By summer of 2002 (right), the sewage plumes have been greatly reduced, mostly restricted to the Brisbane river.*

Data courtesy of Ben Longstaff, Ecosystem Health Monitoring Program. Website: http://www.coastal.crc.org.au/ehmp/

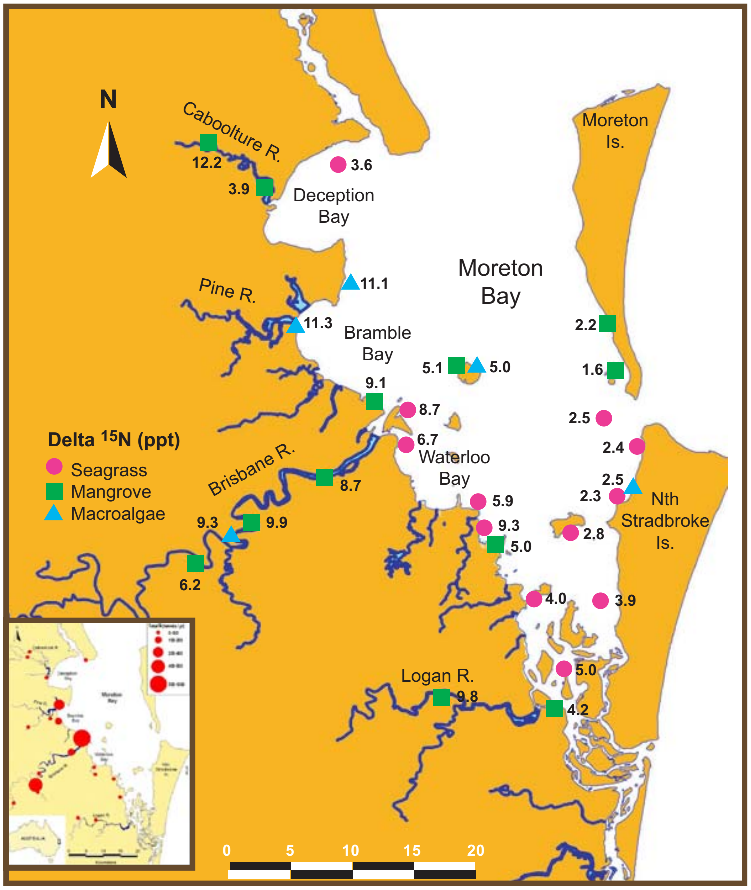
SEAGRASS, MACROALGAE & MANGROVES

δ^{15}N can be measured in different species

Nitrogen (N) discharge from sewage treatment plants was identified from analysis of ambient algae, seagrass, mangrove and macroalgae samples. The elevated signature detected in the sediment identified that sewage N was available in the environment. The presence of the elevated signatures in the plant bioindicators distinguished that the N was incorporated into the vegetation.

δ^{15}N signatures of marine plants were highest when grown in the vicinity of sewage outfalls within the rivers and the estuarine portions of the Moreton Bay. At sites adjacent to sewage treatment plants (STPs) in the rivers, the δ^{15}N signatures of mangrove leaves were greater than 9. In the bay, at sites adjacent to STPs, mangrove leaf values were 9.1 at the Brisbane River mouth and 11.3 (for macroalgae) at the Pine River mouth, while in the eastern bay, the mangrove leaf δ^{15}N signature was as low as 1.6. These values demonstrate the strong influence of sewage in the rivers and western bay near to sewage discharges.

This map, resulting from a variety of bioindicators, provides support for interpretation of nutrient sources, but demonstrates the relative differences between the species used. Standardizing the bioindicator species used is an important component of an assessment program.



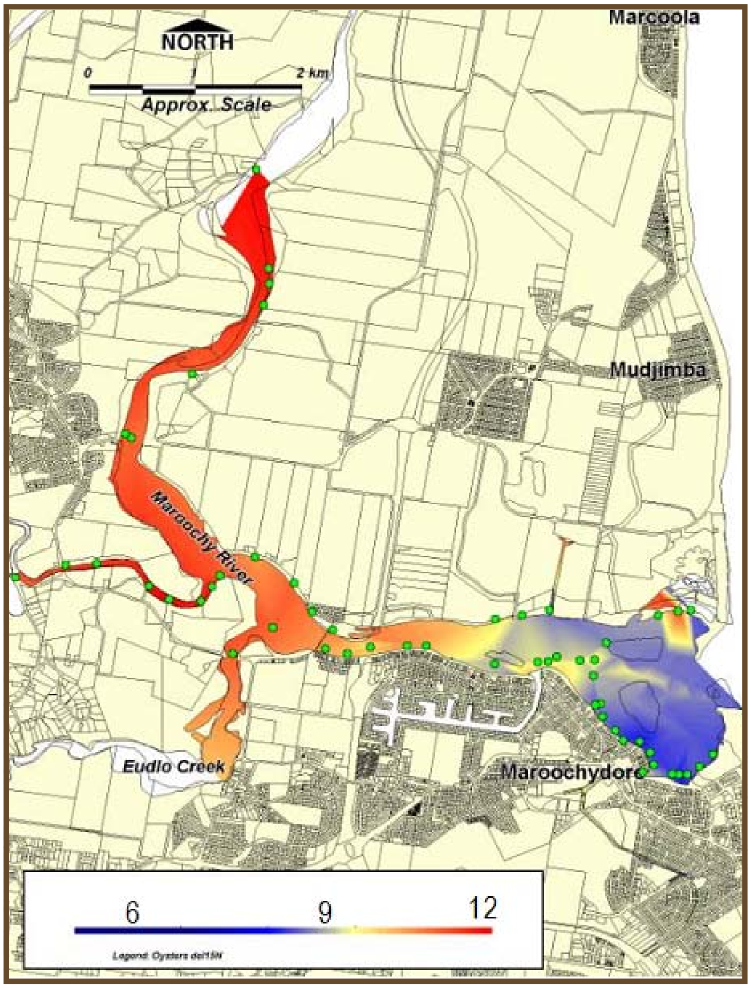
Passive bioindicator: *Ambient δ^{15}N signatures of marine plants in Moreton Bay. High δ^{115}N signatures were found near sewage discharges, while at sites distant to sources, signatures were low.*

Inset: *Location and size of sewage treatment plants in Moreton Bay. The relative size of the red dots represents the total N*

ACTIVE VS PASSIVE BIOINDICATORS

The collection of macrobiota (including algae, mangroves and seagrasses) allows detection of the δ^{15}N signature from plants which over time have integrated the signature of their environment. These are passive indicators as they incorporate the signature in their natural environment throughout their growth cycle. However, there are many sites in which these biological indicators are not available for collection such as in the open water and in degraded areas. Here, biological plant indicators may be actively deployed to incorporate the signature over smaller time periods (days). These are therefore active indicators which provide a view of the δ^{15}N of the environment at the time in which the indicator was deployed. The results of active sampling varies at different sampling times and therefore provides insight into temporal variation (such as seasonal) of the extent of sewage nitrogen.

OYSTERS: Most δ^{15}N measurements are of plants that directly absorb nutrients. However, the uptake of nutrients by phytoplankton which are then filtered by oysters, provides a δ^{15}N signature within oysters that reflects nutrient sources in the ecosystem.



Passive bioindicator: *Observed δ^{15}N of oysters reflects sewage and septic inputs in the Maroochy River, Australia.*

POINT & NON-POINT SOURCES

δ^{15}N signatures may identify different nutrient sources

DETECTING DIFFERENT NUTRIENT SOURCES

The various sources of nitrogen pollution to coastal ecosystems often have distinguishable ^{15}N/^{14}N ratios (Heaton 1986).

Nitrogen fertilizer, produced by industrial fixation of atmospheric nitrogen results in low to negative δ^{15}N signatures.

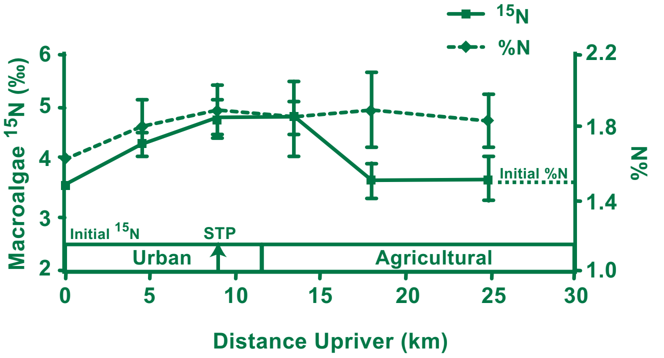
In animal or sewage waste, nitrogen is excreted mainly in the form of urea, which favours conversion to ammonia and enables volatilization to the atmosphere. Resultant fractionation during this process leaves the remaining ammonium enriched in ^{15}N.

Further biological fractionation results in sewage nitrogen having a δ^{15}N signature of ~10‰. Septic undergoes less biological treatment and is likely to have a signature closer to that of raw waste (~6‰).

The approach of using biological indicators (bioindicators) has several advantages:

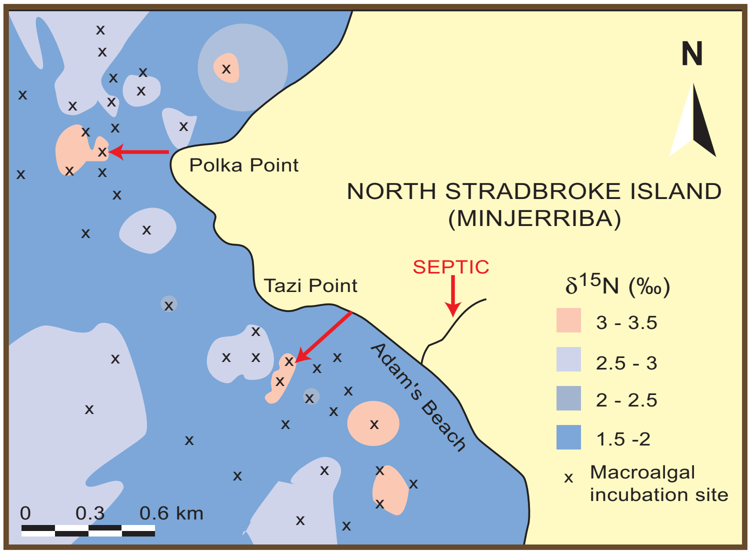
- **Integration over time:** marine organisms assimilate nutrients for use in metabolism and growth which are manifested as measurable changes over the life span of the organism, from days to years.
- **Bioavailable nutrients:** only those forms of nutrients that are available for uptake and assimilation by organisms are measured.
- **Sensitive:** bioindicators can detect very low nutrient concentrations and non-steady state conditions (eg. pulsed) that would go undetected by traditional sampling.
- **Interpretive power:** nutrient bioindicators can be used to infer source of nutrients and ecosystem impacts of nutrient enrichment.

Data courtesy of Simon Costanzo



Tweed River transect in which δ ^{15}N signatures of agricultural inputs (sugar cane) can be distinguished from urban inputs.

Data courtesy of Simon Costanzo



δ ^{15}N is sensitive at small spatial scales and effective at detecting small sewage sources (see red arrows) as well as septic discharges.

Adrian Jones

Agricultural inputs (δ^{15}N ~ 0-1)

Nigel Preston

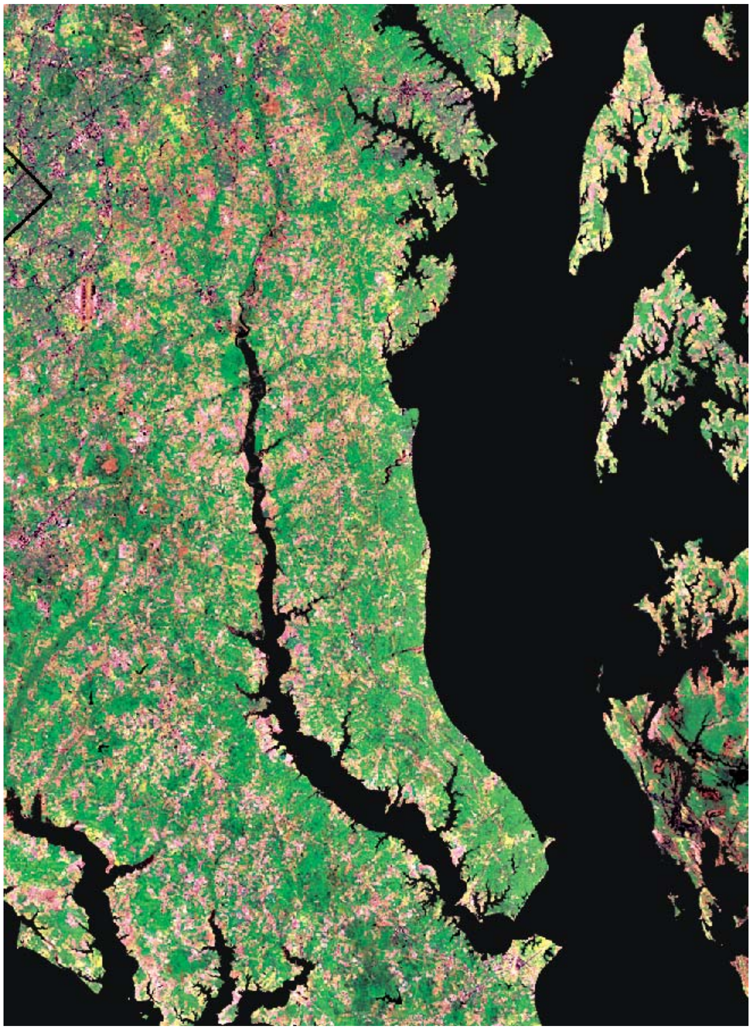
Aquaculture discharge (δ^{15}N ~ 5+)

Adrian Jones

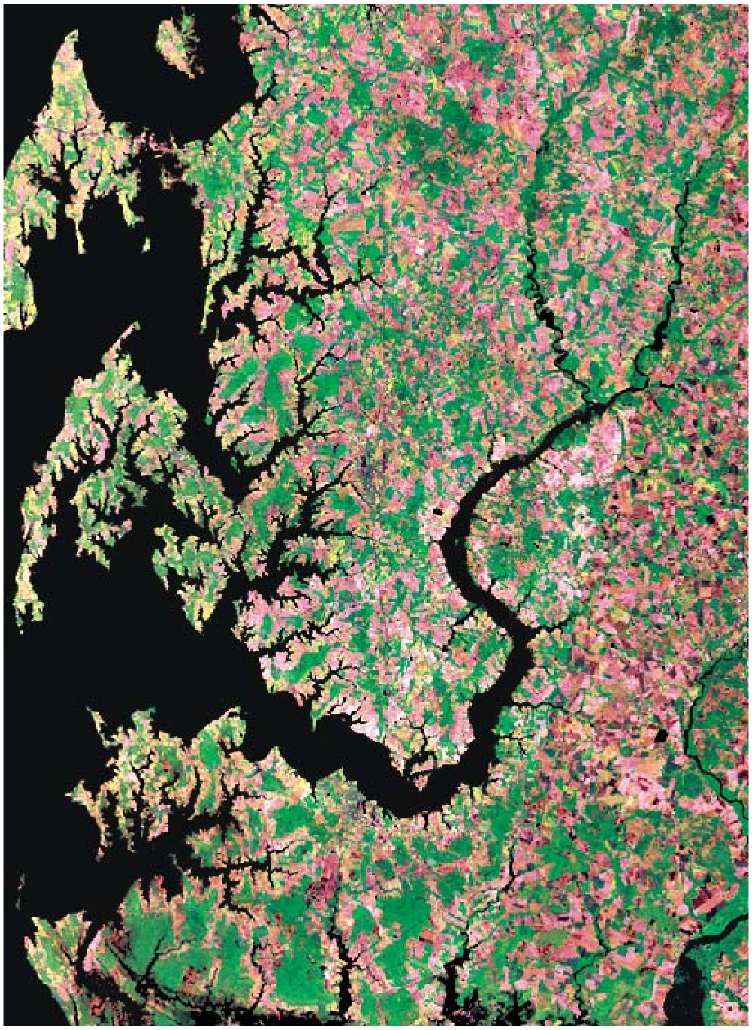
Sewage treatment plant (δ^{15}N ~ 9)

CHESAPEAKE BAY SEWAGE PLUME MAPPING

Patuxent and Choptank Rivers



Patuxent River (sewage and septic dominated)



Choptank River (agricultural dominated)

Images courtesy of USGS http://chesapeake.usgs.gov/images/cbimag2.jpg

The Choptank River on the Eastern Shore of Chesapeake Bay is largely surrounded by agricultural land, with several sewage treatment plants discharging into the river. In contrast, the Patuxent River on the Western Shore of Chesapeake Bay is largely surrounded by forested lands with suburban development, with most of the sewage discharged upstream. Nutrient sources for these two river systems also include atmospheric inputs. The stable isotope analysis approach will attempt to distinguish the various sources throughout each of the river systems.

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*The **I**ntegration and **A**pplication **N**etwork (IAN) is a collection of scientists interested in **solving**, not just studying environmental problems. The intent of IAN is to inspire, manage and produce timely syntheses and assessments on key environmental issues, with a special emphasis on Chesapeake Bay and its watershed. IAN is an initiative of the faculty of the University of Maryland Center for Environmental Science, but will link with other academic institutions, various resource management agencies and non-governmental organizations.*

PRIMARY OBJECTIVES FOR IAN

- **Foster** problem-solving using integration of scientific data and information
- **Support** the application of scientific understanding to forecast consequences of environmental policy options
- **Provide** a rich training ground in complex problem solving and science application
- **Facilitate** a productive interaction between scientists and the broader community

Further Reading:

Abal EG, Dennison WC & Greenfield PF (2001) Managing the Brisbane River and Moreton Bay: An integrated research/management program to reduce impacts on an Australian estuary. *Water Science and Technology* 43: 57-70.

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Heaton THE (1986) Isotopic studies of nitrogen pollution in the hydrosphere and atmosphere: a review. *Chemical Geology* 59: 87-102.

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Udy JW, Dennison WC (1997) Physiological responses of seagrasses used to identify anthropogenic nutrient inputs. *Marine and Freshwater Research* 48: 605-14.

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SCIENCE COMMUNICATION Prepared by Dr. Adrian Jones & Tracey Saxby
February 2003

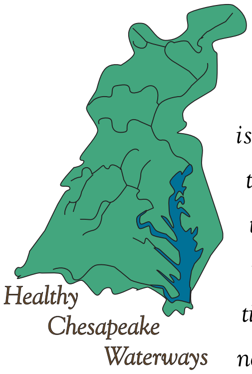
Appendix 12 – Healthy Chesapeake Waterways Newsletter

Healthy Chesapeake Waterways

May 2002

This science newsletter focuses on the role of the Integration and Application Network (IAN) in achieving healthy Chesapeake waterways. This is the first in a series of IAN newsletters on topical issues and is directed towards the scientific and technical audience. This newsletter identifies IAN's vision for *Healthy Chesapeake Waterways* and includes an overview of environmental problem solving, through transfer of data into information into knowledge and ultimately into problem solving. Fundamental to IAN's problem solving approach is the achievement of a balance between management, monitoring and research. The newsletter provides the scope for the CORe IAN projects for 2002-3, and begins to define what IAN will and will not attempt to accomplish, and identifies some of the challenges facing Chesapeake Bay.

HEALTHY CHESAPEAKE WATERWAYS

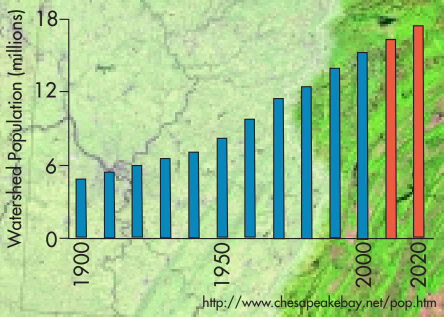


*This science newsletter focuses on the role of the Integration and Application Network (IAN) in achieving healthy Chesapeake waterways. This is the first in a series of IAN newsletters on topical issues and is directed towards the scientific and technical audience. IAN is a collection of scientists interested in **solving**, not just studying environmental problems. The intent of IAN is to inspire, manage and produce timely syntheses and assessments on key environmental issues, with a special emphasis on Chesapeake Bay and its watershed. IAN is an initiative of the faculty of the University of Maryland Center for Environmental Science, but will link with other academic institutions, various resource management agencies and non government organizations. Healthy Chesapeake Waterways is a vision for the freshwater, tidal and estuarine portions of Chesapeake Bay and its watershed. The vision is not affiliated with any particular institution, agency or non government organization, but can be used by anyone interested in achieving healthy Chesapeake waterways.*

CHESAPEAKE WATERSHED

The Chesapeake watershed extends north almost to the Finger Lakes in New York, includes much of Pennsylvania and Virginia, virtually all of Maryland and portions of West Virginia and Delaware. The Appalachian Mountains make up most of the western watershed boundary.

CHESAPEAKE WATERSHED POPULATION



The human population in the Chesapeake watershed has increased from approximately 5 million in 1900 to greater than 15 million currently, which corresponds to 10 busloads of people arriving every day for the past 100 years!

CHESAPEAKE FACTS

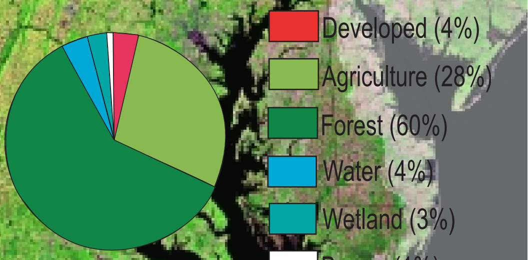
CHESAPEAKE WATERSHED

- **Area: ~ 64,000 sq. miles (165,000 sq. km) (The size of Missouri)**
- **Length: ~360 miles (580 km)**
- **Width: ~180 miles (290 km)**
- **Average Elevation: ~1000 feet (300 m)**
- **Max. Elevation: ~4700 feet (1400 m)**

CHESAPEAKE BAY

- **Area: ~5,200 sq miles (13,000 sq. km) (The size of Connecticut)**
- **Length: ~200 miles (315 km)**
- **Width: ~3-35 miles (5-56 km)**
- **Average Depth: ~30 feet (8.5 m)**
- **Maximum Depth: ~150+ feet (46+ m)**

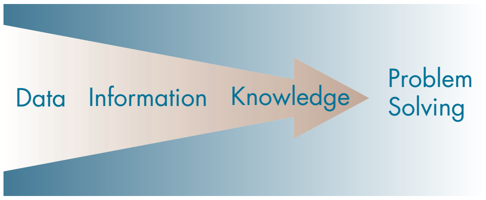
CHESAPEAKE LAND USE



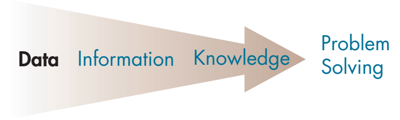
Watershed and Bay area and elevation from digital elevation model with 30m resolution; Bay length, width and average depth from National estuarine Atlas (NOAA, 1985); maximum depth from NOAA Chart 1990 and B. Boicourt (pers. comm); Land use from Chesapeake Bay Program web site (http://www.chesapeakebay.net).

http://chesapeake.usgs.gov/images/cbimag2.jpg

DATA FLOW CRITICAL TO HEALTHY WATERWAYS



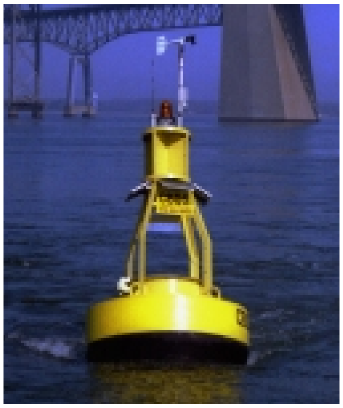
Large amounts of data are used to generate smaller amounts of information. Information is integrated into kernels of knowledge that are applied to environmental problems. The continued flow of data from collection to analysis, integration, and ultimately, application is crucial for achieving Healthy Chesapeake Waterways. The Integration and Application Network will strive to facilitate this process.

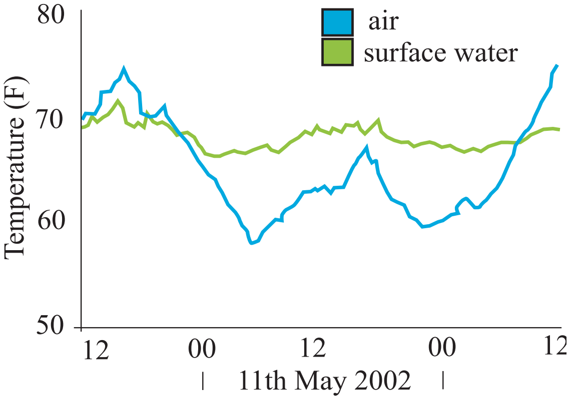

Data Information Knowledge Problem Solving

OBSERVATION REVOLUTION

Data gathering capabilities are dramatically increasing

New innovations and technological advances have made it possible to collect unprecedented amounts of environmental data. In particular, two kinds of data collection have fueled the observation revolution: remote sensing and in situ sampling.

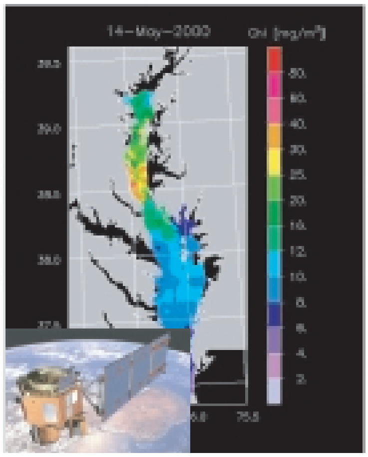




IN SITU SAMPLING

Many sensors can be left in situ (in place), automatically collecting data. This has allowed for continuous data streams, revealing fine scale patterns (hours to days). An example is the Chesapeake Bay Observing System (CBOS), which provides real time atmospheric and oceanographic data from in and around Chesapeake Bay.

www.cbos.org



http://www.cbrsp.org

http://www.eoc.csiro.a/hswww/EOC_data.htm

REMOTE SENSING

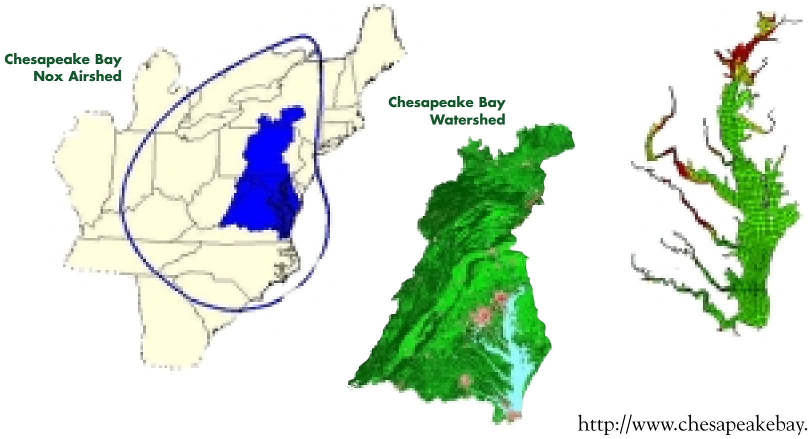
Sensors mounted on aircraft and satellites enable large scale, synoptic sampling. An increasing diversity of sensors is now deployed on an increasing diversity of aircraft and satellites, making remote sensing imagery more available and less expensive.


Data Information Knowledge Problem Solving

INFORMATION GENERATION

Capacity for data analysis is increasing

The challenge of coping with ever larger data streams to generate useful information has led to the development of various quantitative tools, aided by the continuous increase in computing power. Quantitative models are increasingly being used for various data analyses, as well as spatial analyses including geographic information systems (GIS).

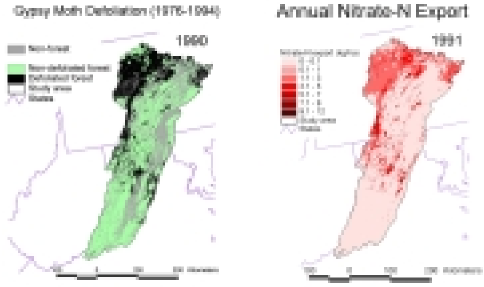


Linked models which predict nutrient inputs to Chesapeake Bay from the airshed and watershed and the effect of these nutrient inputs on the estuary have been formulated.

http://www.chesapeakebay.net/wqcmodeling .htm

QUANTITATIVE MODELS

Quantitative models aim to capture and simplify interacting and complex processes. Chesapeake models estimate the delivery of nutrients and sediments to the Bay by considering atmospheric inputs (airshed model), watershed inputs (watershed model) and processing of these inputs (estuarine models).



Spatial analysis using a geographic information system were used to relate the enhanced runoff of nitrate (NO$_3^-$) from a forest that had been rapidly defoliated by gypsy moths (Eshleman et al., Hydrological Processes, in review).

SPATIAL ANALYSIS

An effective technique to synthesize large multi-dimensional data sets is to create maps in which the individual data points can be linked both geographically and conceptually to other data points. These geographic information systems rely on various spatial statistical analyses to produce scientifically rigorous maps.

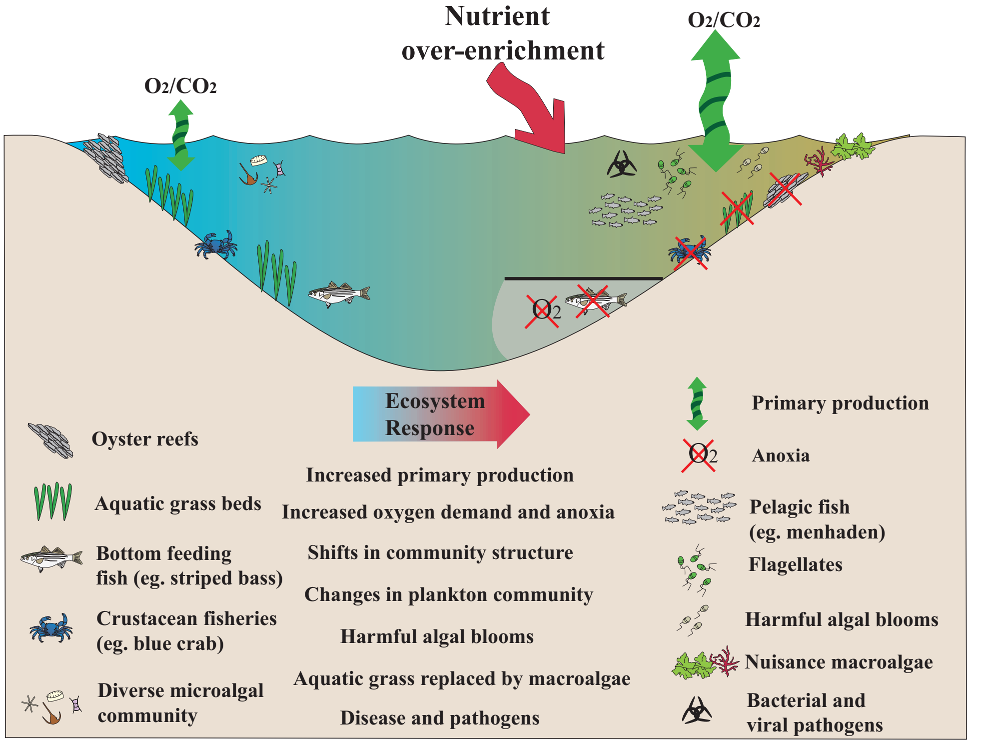
Data Information **Knowledge** Problem Solving

KNOWLEDGE BUILDING

Synthesis and visualization techniques are underutilized

Greater amounts of information, from diverse sources, have increased the difficulty of achieving effective synthesis. However, the need for obtaining an integrated view is increasingly essential to build knowledge and feed into applications of this knowledge. Synthesized information with good visualizations is critically needed, but is often lacking.

Developing consensus among scientists can be difficult due to different discipline-based perspectives. Yet, a consensus of what is reasonably well understood can be achieved, as well as identifying contentious issues and gaps in knowledge (= future research needs). Providing an integrated perspective to make recommendations explicitly linked to environmental outcomes provides a solid foundation for well informed decision making. Simplified conceptual diagrams are a useful tool in synthesis, visualization and communication.



A simplified conceptual model of ecosystem responses to nutrient over-enrichment in Chesapeake Bay

Data Information Knowledge **Problem Solving**

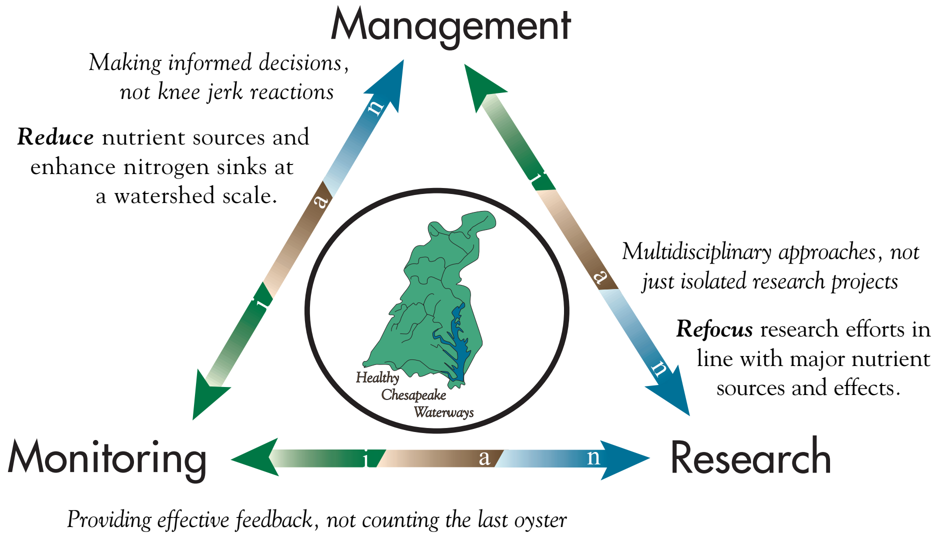
PROBLEM SOLVING

An integrated and applied approach is needed

A FOCUS ON NUTRIENTS

It is proposed that we focus research, monitoring and management activities on nutrient over-enrichment, a major environmental problem in Chesapeake Bay and its watershed. But there are a myriad of environmental problems in the streams, rivers and estuaries that make up the Chesapeake waterways—why focus specifically on nutrient over-enrichment?

- Without losing sight of the complexity of environmental issues facing Chesapeake Bay and its watershed, a nutrient focus will help integrate research, monitoring and management activities. Other environmental issues (such as fishing, dredging, invasive species and diseases) affect nutrient cycling and their influence needs to be evaluated and managed.
- Management interventions regarding nutrients have the potential to effect positive results over reasonable time scales (years, not decades or centuries).
- Nutrient over-enrichment has been directly implicated in Chesapeake Bay anoxia and harmful algal blooms.
- Solving the nutrient over-enrichment problem involves diffuse and point sources, solutions that also reduce other contaminants.



Making informed decisions, not knee jerk reactions

Reduce nutrient sources and enhance nitrogen sinks at a watershed scale.

Multidisciplinary approaches, not just isolated research projects

Refocus research efforts in line with major nutrient sources and effects.

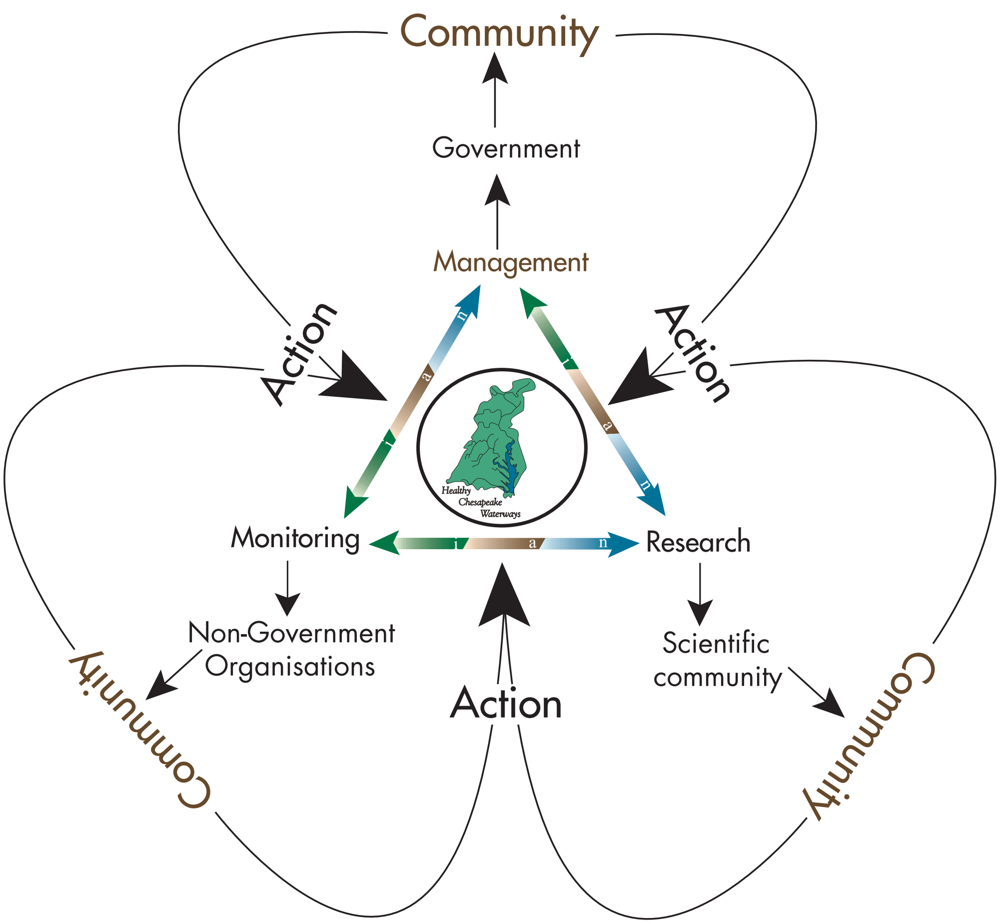
Providing effective feedback, not counting the last oyster

Report on effectiveness of nutrient management actions.

INTEGRATION AND APPLICATION NETWORK

Meeting the coastal management challenge

Our coastal management challenge is to cope with increasing population pressures without irreversibly damaging coastal ecosystems. Chesapeake Bay is the most studied estuary in the world, yet major problems persist. Better integration and application of scientific findings is critically needed. The Integration and Application Network will facilitate various synthesis activities (e.g. workshops, publications, presentations). Specific projects to be undertaken in the next year include the following projects: Communication and Data Exchange (CODEX), On-line conceptual diagrams, Report cards, and an eChesapeake web portal.



In order to SOLVE environmental problems, science within the Chesapeake watershed needs the following features: Shared vision (e.g., Healthy Chesapeake Waterways), Organized individuals (e.g., Chesapeake Bay and watershed organizations), Linked and balanced approach (management, research and monitoring), Varied communication (internal and external) and Effective actions (community responses to environmental problems). The Integration and Application Network will focus on the links and communication aspects of environmental problem solving.

COMMUNICATION AND DATA EXCHANGE

Communication and Data Exchange (CODEX) will consolidate various data on the Chesapeake watershed, with particular emphasis on geographical information system (GIS) data. It will utilize land use maps, remote sensing data, photographs, conceptual diagrams, and animations to produce a functional, web-accessible and searchable data resource.

ON-LINE CONCEPTUAL DIAGRAMS

A simple software program will be developed for general use that will allow users to 'click and drag' various icons to create conceptual diagrams. Visual conceptual diagrams can be very effective at presenting fundamental messages in a clear and concise format.

REPORT CARD

A geographically explicit report card on Cheseapeake Bay and its watershed will be produced, based on rigorous scientific results. This report card will use ecosystem health indicators that are based on management objectives and help focus future research and management.

eCHESAPEAKE WEB PORTAL

A typical web search on "Chesapeake Bay" results in over 300,000 sites and a bewildering amount of information, but little context in which to place this information. A portal that provides both a geographical context as well as a conceptual framework for the key Chesapeake web sites will be created.

Science newsletters produced through IAN will provide a vehicle for direct expression of a scientific perspective on coastal management issues. These newsletters will synthesize scientific findings and therefore augment, not replace, various other science communication activities. The style and format of these newsletters will be similar to this initial Healthy Chesapeake Waterways newsletter.

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- **Foster** problem-solving using integration of scientific data and information
- **Support** the application of scientific understanding to forecast consequences of environmental policy options
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integration application network

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