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MARYLAND CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

ECOSYTEMS PROCESSES COMPONENT (EPC)

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1.0 INTRODUCTION

W.R. Boynton

1.1 Background

Two decades ago an historic agreement led to the establishment of the Chesapeake Bay Partnership whose mandate was to protect and restore the Chesapeake Bay ecosystem. The year 2000 saw the signing of *Chesapeake 2000,* a document that incorporated very specific goals addressing submerged aquatic vegetation (SAV) restoration and protection and the improvement and maintenance of water quality in Chesapeake Bay and tributaries rivers.

The first phase of the Chesapeake Bay Program was undertaken during a period of four years (1984 through 1987) and had as its goal the characterization of the existing state of the bay, including spatial and seasonal variation, which were keys to the identification of problem areas. During this phase of the program the Ecosystems Processes Component (EPC) measured sediment-water oxygen and nutrient exchange rates and determined the rates at which organic and inorganic particulate materials reached deep waters and bay sediments. Sediment-water exchanges and depositional processes are major features of estuarine nutrient cycles and play an important role in determining water quality and habitat conditions. The results of EPC monitoring have been summarized in a series of interpretive reports (Boynton *et al.* 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003 and 2004). The results of this characterization effort have confirmed the importance of deposition and sediment processes in determining water quality and habitat conditions. Furthermore, it is also now clear that these processes are responsive to changes in nutrient loading rates.

The second phase of the program effort, completed during 1988 through 1990, identified interrelationships and trends in key processes monitored during the initial phase of the program. The EPC was able to identify trends in sediment-water exchanges and deposition rates. Important factors regulating these processes have also been identified and related to water quality conditions (Kemp and Boynton, 1992; Boynton *et al.* 1991).

In 1991 the program entered its third phase. During this phase the long-term 40% nutrient reduction strategy for the bay was reevaluated. In this phase of the process, the monitoring program was used to assess the appropriateness of targeted nutrient load reductions as well as provide indications of water quality patterns that will result from such management actions. The preliminary reevaluation report (Progress Report of the Baywide Nutrient Reduction Reevaluation, 1992) included the following conclusions: nonpoint sources of nutrients contributed approximately 77% of the nitrogen and 66% of the phosphorus entering the bay; agricultural sources were dominant followed by forest and urban sources; the "controllable" fraction of nutrient loads was about 47% for nitrogen and 70% for phosphorus; point source reductions were ahead of schedule and diffuse source reductions were close to projected reductions; further efforts were needed to reduce diffuse sources; significant reductions in phosphorus concentrations and slight increases in nitrogen concentrations have been observed in some areas of the bay; areas of low dissolved oxygen have been quantified and living resource water quality goals established; simulation model projections indicated significant reductions in low dissolved oxygen conditions associated with a 40% reduction of controllable nutrient loads.

During the latter part of 1997 the Chesapeake Bay Program entered another phase of re-evaluation. Since the last evaluation, programs have collected and analyzed additional information, nutrient reduction strategies have been implemented and, in some areas, habitat improvements have been accomplished. The overall goal of the 1997 re-evaluation was the assessment of the progress of the program and the implementation of necessary modifications to the difficult process of restoring water quality, habitats and living resources in Chesapeake Bay. During this portion of the program, EPC has been further modified to include intensive examination of SAV habitat conditions in several regions of the Chesapeake Bay in addition to retaining long-term monitoring of sediment processes in the Patuxent estuary. The previous report, *EPC Level 1 Interpretive Report No. 20*, concluded the effort to monitor sediment-water oxygen and nutrient exchanges (Boynton, *et al.* 2003).

Chesapeake 2000 involves the commitment of the participants *"to achieve and maintain the water quality necessary to support aquatic living resources of the Bay and its tributaries and to protect human health."* More specifically, this Agreement focuses on: 1) living resource protection and restoration; 2) vital habitat protection and restoration; 3) water quality restoration and protection; 4) sound land use and; 5) stewardship and community engagement. The current EPC program has activities that are aligned with the habitat and water quality goals described in this agreement.

The Chesapeake Bay Water Quality Monitoring Program was initiated to provide guidelines for restoration, protection and future use of the mainstem estuary and its tributaries and to provide evaluations of implemented management actions directed towards alleviating some critical pollution problems. A description of the complete monitoring program is provided in:

Magnien *et al.* (1987),

Chesapeake Bay program web page http://www.chesapeakebay.net/monprgms.htm

DNR web page http://www.dnr.state.md.us/bay/monitoring/eco/index.html.

In addition to the EPC program portion, the monitoring program also has components that measure:

1. Freshwater, nutrient and other pollutant input rates,
2. chemical and physical properties of the water column,
3. phytoplankton community characteristics (abundances, biomass and primary production rates) and
4. benthic community characteristics (abundances and biomass).

1.2 Conceptual Model of Water Quality Processes in Chesapeake Bay

During the past two decades much has been learned about the effects of both natural and anthropogenic nutrient inputs (*e.g.*, nitrogen, phosphorus, silica) on such important estuarine features as phytoplankton production, algal biomass, seagrass abundance and distribution and oxygen conditions in deep waters (Nixon, 1981, 1988; Boynton *et al.* 1982; Kemp *et al.* 1983; D'Elia *et al.* 1983; Garber *et al.* 1989; Malone, 1992; and Kemp and Boynton, 1992). While our understanding is not complete, important pathways regulating these processes have been identified and related to water quality issues. Of particular importance here, it has been determined that (1) algal primary production and biomass levels in many estuaries (including Chesapeake Bay) are responsive to nutrient loading rates, (2) high rates of algal production and algal blooms are sustained through summer and fall periods by recycling of essential nutrients that enter the system during the high flow periods of the year, (3) the “nutrient memory” of estuarine systems is relatively short (one to several years) and (4) submerged aquatic vegetation (SAV) communities are responsive to water quality conditions, especially light availability, that is modulated both by water column turbidity regimes and epiphytic fouling on SAV leaf surfaces.

Nutrients and organic matter enter the bay from a variety of sources, including sewage treatment plant effluents, fluvial inputs, local non-point drainage and direct rainfall on bay waters. Dissolved nutrients are rapidly incorporated into particulate matter via biological, chemical and physical mechanisms. A portion of this newly produced organic matter sinks to the bottom, decomposes and thereby contributes to the development of hypoxic or anoxic conditions and loss of habitat for important infaunal, shellfish and demersal fish communities. The regenerative and large short-term nutrient storage capacities of estuarine sediments ensure a large return flux of nutrients from sediments to the water column that can sustain continued high rates of phytoplanktonic growth and biomass accumulation. Continued growth and accumulation supports high rates of deposition of organics to deep waters, creating and sustaining hypoxic and anoxic conditions typically associated with eutrophication of estuarine systems. To a considerable extent, it is the magnitude of these processes that determines water quality conditions in many zones of the bay. Ultimately, these processes are driven by inputs of organic matter and nutrients from both natural and anthropogenic sources. If water quality management programs are instituted and loadings of organic matter and nutrients decrease, changes in the magnitude of these processes are expected and will serve as a guide in determining the effectiveness of strategies aimed at improving bay water quality and habitat conditions. The schematic diagram in Figure 1-1. summarizes this conceptual eutrophication model where increased nitrogen (N) and phosphorus (P) loads result in a water quality degradation trajectory and reduced N and P loads lead to a restoration trajectory. There is ample empirical evidence for the importance of N and P load variation. For example, water quality and habitat conditions change dramatically between wet and dry years, with the former having degradation trajectory characteristics and the latter, restoration trajectory characteristics (Boynton and Kemp, 2000; Hagy et al. 2004). Within the context of this model a monitoring component focused on SAV and other near-shore habitat and water quality conditions has been developed and was fully operational in the Patuxent River estuary during 2004.

Specifically, this program involved monthly, detailed surface water quality mapping using the DATAFLOW system, high frequency (15 minute intervals) monitoring of selected water quality variables at four fixed sites located from tidal fresh to mesohaline portions of the Patuxent, and SAV planting (via seeds) and monitoring of SAV epiphytic growth at Patuxent River sites.

In all of these monitoring activities the working hypothesis is if anthropogenic nutrient and organic matter loadings decrease, the cycle of high organic deposition rates to sediments, sediment oxygen demand, release of sediment nutrients, continued high algal production, and high water column turbidity will also decrease. As a result, the potential for SAV re-colonization will increase and the status of deep-water habitats will improve.

1.3 Objectives of the Water Quality Monitoring Program

The EPC has undergone program modification since its inception in 1984 but its overall objectives have remained consistent with those of other Monitoring Program Components. The objectives of the 2003 EPC program were as follow:

1. Characterize the present status of the Patuxent River estuary (including spatial and seasonal variation) relative to ***near-shore habitat and water quality conditions***. This portion of the program (ConMon) involved deployment of recording sensor systems at four locations along the salinity gradient of the Patuxent River estuary.

2. Evaluate the variation in spatial and temporal scales of water quality in both near-shore and off-shore areas of the Patuxent River estuary using the DATAFLOW mapping system.

3. Measure ***epiphyte accumulation rates*** on SAV mimics and associated water quality conditions at several sites in the Patuxent River estuary, extending the developing time series of this important SAV habitat indicator process.

4. ***Integrate the information*** collected in this program with other elements of the monitoring program to gain a better understanding of the processes affecting water quality of the

Chesapeake Bay and its tributaries and the maintenance and restoration of living resources.

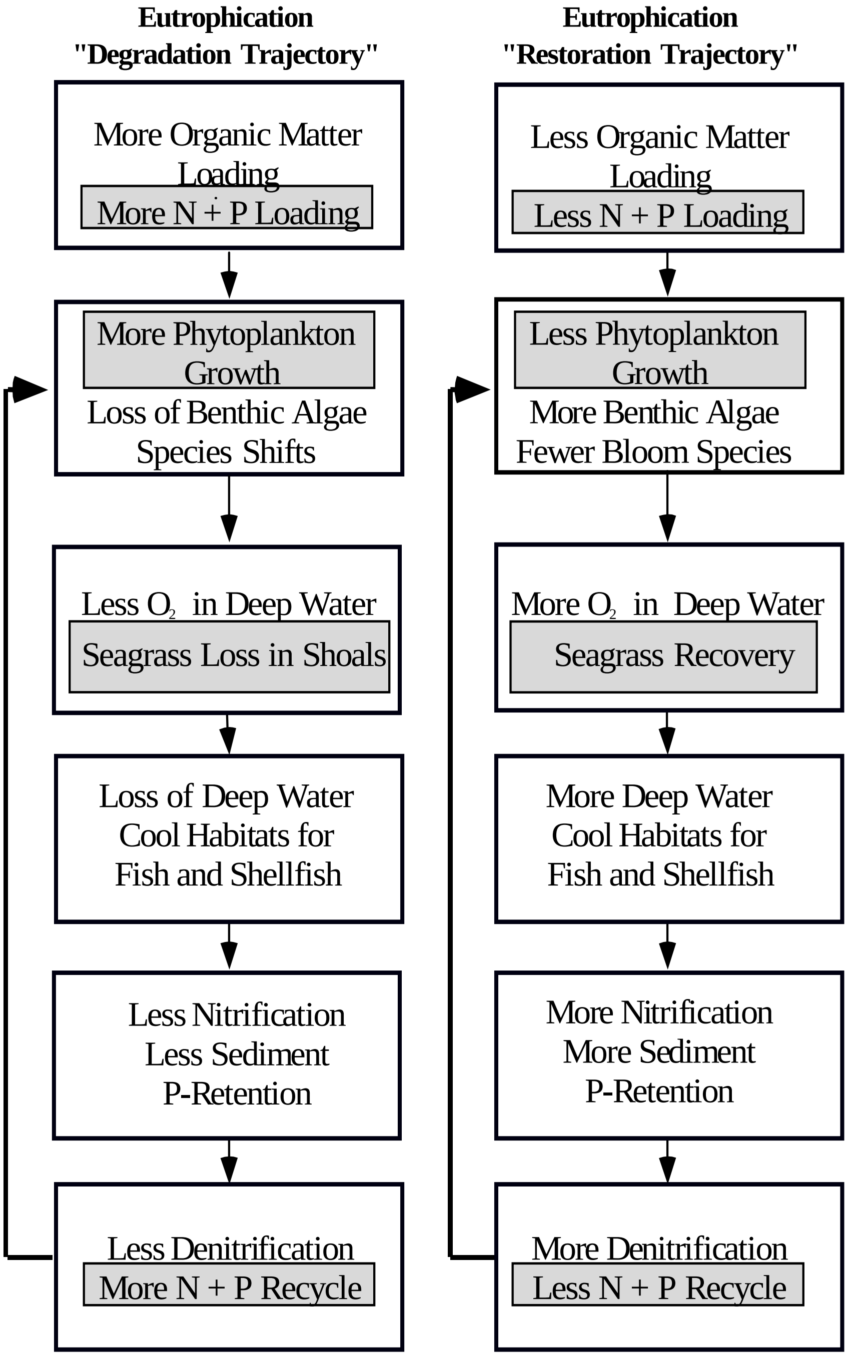

Figure 1-1. A simplified schematic diagram indicating degradation and restoration trajectories of an estuarine ecosystem. Lightly shaded boxes in the diagram indicate past and present components of the EPC program in the Patuxent River and Tangier Sound. (Adapted from Kemp,

1.4 Cited Literature

Boynton, W.R., J.M. Barnes, F.M. Rohland, L.L. Matteson, L.L. Magdeburger, J.D. Hagy III, J.M. Frank, B.F. Sweeney, M.M. Weir and R.M. Stankelis. 1997. Ecosystem Processes Component Level 1 Interpretive Report No. 14. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCEES]CBL 97-009a.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, F.M. Rohland, D.A. Jasinski, J.D. Hagy III, L.L. Magdeburger and B.J. Weaver. 1996. Ecosystem Processes Component Level 1 Interpretive Report No. 13. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCEES]CBL 96-040a.

Boynton, W.R., J.H. Garber, W.M. Kemp, J.M. Barnes, L.L. Matteson, J.L. Watts, S. Stammerjohn and F.M. Rohland. 1990. Ecosystem Processes Component Level 1 Interpretive Report No. 7. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 90-062.

Boynton, W.R., J.H. Garber, W.M. Kemp, J.M. Barnes, J.L. Watts, S. Stammerjohn and L.L. Matteson. 1989. Ecosystem Processes Component Level 1 Interpretive Report No. 6. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 89-080.

Boynton, W.R. and W.M. Kemp. 2000. Influence of River Flow and Nutrient Loads on Selected Ecosystem Processes: A Synthesis of Chesapeake Bay Data, p. 269-298. *In:* J.E. Hobbie, [Ed.], *Estuarine Science: A Synthetic Approach to Research and Practice*, Island Press, Washington, D.C.

Boynton, W.R., W.M. Kemp and J.M. Barnes. 1985. Ecosystem Processes Component Level I Data Report No. 2. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 85-121.

Boynton, W.R., W.M. Kemp and C.W. Keefe. 1982. A comparative analysis of nutrients and other factors influencing estuarine phytoplankton production, p. 69-90. *In:* V.S. Kennedy, [Ed.], *Estuarine Comparisons*, Academic Press, NY.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, F.M. Rohland, D.A. Jasinski and H.L. Kimble. 1993. Ecosystem Processes Component Level 1 Interpretive Report No. 10. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 93-030a.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, F.M. Rohland, D.A. Jasinski and H.L. Kimble. 1994. Ecosystem Processes Component Level 1 Interpretive Report No. 11. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 94-031a.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, J.L. Watts, S. Stammerjohn, D.A. Jasinski and F.M. Rohland. 1991. Ecosystem Processes Component Level 1 Interpretive Report No. 8. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 91-110.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, J.L. Watts, S. Stammerjohn, D.A. Jasinski and F.M. Rohland. 1992. Ecosystem Processes Component Level 1 Interpretive Report No. 9. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 92-042.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, F.M. Rohland, L.L. Magdeburger and B.J. Weaver. 1995. Ecosystem Processes Component Level 1 Interpretive Report No 12. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 95-039.

Boynton, W.R., W.M. Kemp, J.H. Garber and J.M. Barnes. 1986. Ecosystem Processes Component Level 1 Interpretive Report No. 3. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 86-56b.

Boynton, W.R., W.M. Kemp, J.H. Garber, J.M. Barnes, L.L. Robertson and J.L. Watts. 1987. Ecosystem Processes Component Level 1 Interpretive Report No. 4. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 88-06.

Boynton, W.R., W.M. Kemp, J.H. Garber, J.M. Barnes, L.L. Robertson and J.L. Watts. 1988. Ecosystem Processes Component Level 1 Interpretive Report No. 5. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 88-69.

Boynton, W.R., R.M. Stankelis, E.H. Burger, F.M. Rohland, J.D. Hagy III, J.M. Frank, L.L. Matteson and M.M. Weir. 1998. Ecosystem Processes Component Level 1 Interpretive Report No. 15. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 98-073a.

Boynton, W.R., R.M. Stankelis, J.D. Hagy III, F.M. Rohland, and J.M. Frank. 1999. Ecosystem Processes Component Level 1 Interpretive Report No. 16. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 99-0070a.

Boynton, W.R., R.M. Stankelis, J.D. Hagy, F.M. Rohland, and J.M. Frank. 2000. Ecosystem Processes Component Level 1 Interpretive Report No. 17. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 00-0174.

Boynton, W.R., R.M. Stankelis, F.M. Rohland, J.M. Frank and J.M. Lawrence. 2001. Ecosystem Processes Component Level 1 Interpretive Report No. 18. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 01-0088.

Boynton, W.R. and F.M. Rohland (*eds.*); R.M. Stankelis, E.K. Machelor Bailey, P.W. Smail and M.A.C. Ceballos. 2003. Ecosystem Processes Component (EPC). Level 1 Interpretive Report No. 20. Chesapeake Biological Laboratory (CBL), Univ. of Maryland Center for Environmental Science, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 03-303. [UMCES Technical Series No. TS-419-03-CBL].

Boynton, W.R., R.M. Stankelis, P.W. Smail and E.K. Bailey. 2004. Ecosystem Processes Component (EPC). Maryland Chesapeake Bay Water Quality Monitoring Program, Level 1 report No. 21. Jul. 1984 - Dec. 2003. Ref. No. [UMCES] CBL 04-086. [UMCES Technical Series No. TS-447-04-CBL].

D'Elia, C.F., D.M. Nelson, and W.R. Boynton. 1983. Chesapeake Bay nutrient and plankton dynamics: III. The annual cycle of dissolved silicon. Geochim. Cosmochim. Acta **14**:1945-1955.

Garber, J.H., W.R. Boynton, J.M. Barnes., L.L. Matteson., L.L. Robertson., A.D. Ward and J.L. Watts. 1989. Ecosystem Processes Component and Benthic Exchange and Sediment Transformations. Final Data Report. Maryland Department of the Environment. Maryland Chesapeake Bay Water Quality Monitoring Program. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No.[UMCEES]CBL 89-075.

Hagy, J.D., W.R. Boynton, C.W. Keefe, and K.V. Wood. 2004. Hypoxia in Chesapeake Bay, 1950-2001: Long-term Change in Relation to Nutrient Loading and River Flow. Estuaries **27**(4):634-658.

Kemp, W.M. and W.R. Boynton. 1992. Benthic-Pelagic Interactions: Nutrient and Oxygen Dynamics. *In:* D.E. Smith, M. Leffler and G. Mackiernan [Eds.], *Oxygen Dynamics in the Chesapeake Bay: A synthesis of Recent Research.* Maryland Sea Grant Book, College Park, MD, p. 149-221.

Kemp, W.M., W.R. Boynton, J.C. Stevenson, R.W. Twilley and J.C. Means. 1983. The decline of submerged vascular plants in Chesapeake Bay: summary of results concerning possible causes. Mar. Tech. Soc. J. **17**(2):78-89.

Magnien R.E. ***et al.*** 1987. Monitoring for management actions. First Biennial Report. The Maryland Office of Environmental Programs, Chesapeake Bay, Water Quality Monitoring Program, Baltimore, MD.

Malone, T.C. 1992. Effects of Water Column Processes on Dissolved Oxygen Nutrients, Phytoplankton and Zooplankton. *In:* D.E. Smith, M. Leffler and G. Mackiernan [Eds.], *Oxygen Dynamics in the Chesapeake Bay: A synthesis of Recent Research*. Maryland Sea Grant Book, College Park, MD, p. 149-221.

Nixon, S.W. 1981. Remineralization and nutrient cycling in coastal marine ecosystems, p. 111-138. *In:* B.J. Neilson and L.E. Cronin [Eds.], *Estuaries and Nutrients*. Humana Press, Clifton, NJ.

Nixon, S.W. 1988. Physical energy inputs and comparative ecology of lake and marine ecosystems. Limnol. Oceanogr. **33** (4, part 2), 1005-1025.

Progress Report of the Baywide Nutrient Reduction Reevaluation, Chesapeake Bay Program. 1992. U.S. Environmental Protection Agency for the Chesapeake Bay Program [CSC.LR18.12/91

2.0 High Resolution Temporal Monitoring (CONMON)

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2.1 Introduction

As part of the Chesapeake Bay Program’s shallow water monitoring program, the Ecosystems Processes Component (EPC) deployed YSI datasondes at four locations in the Patuxent River for the second consecutive year. Data were collected from March through November 2004 at two lower mesohaline locations and from April through October at the remaining two stations. These datasondes continuously monitored (CONMON) and recorded data every 15 minutes throughout this period with greater than 10,000 observations at each location. These datasondes were located in shallow water sites and recorded data at approximately 0.5m above the sediment surface. The purpose of these measurements was to characterize the near-shore environments within the mesohaline and oligohaline regions of the estuary and provide a temporal comparison to the spatially intensive DATAFLOW mapping that is also part of the new monitoring program. These instruments recorded temperature, salinity, dissolved oxygen (DO), fluorescence (converted to chlorophyll), pH and turbidity. These data will be necessary for determining compliance to newly created habitat criteria in Chesapeake Bay and its tributaries. Further, this information can be used to calculate open water metabolism statistics that can be a valuable metric to gauge an ecosystem’s response to changes in nutrient loading rates.

2.1.1 Criteria Assessment

High resolution temporal data provided the necessary information to evaluate water quality conditions across a variety of temporal scales and allow accurate assessment of conditions necessary for the health of living resources. The Chesapeake Bay Program has recently developed a series of water quality criteria based upon several different living resource uses. For regions designated as shallow water (< 2m depth) minimum criteria have been developed for dissolved oxygen concentrations, light availability, and chlorophyll concentrations. For dissolved oxygen, criteria include a 30 day mean DO concentration of 5.0 mg l^{-1}, a 7 day mean of 4.0 mg l^{-1}, and an instantaneous DO concentration of 3.2 mg l^{-1}. The water clarity criteria, (or light availability) is defined as the growing season median for a percent of surface light (22% for mesohaline and polyhaline regions and 13% for oligohaline regions) that reaches a defined depth. Short-term events with low water clarity, are perhaps not as critical as short-term low dissolved oxygen events to living resources, yet can still be important events that affect SAV populations (Moore, et al. 1997). The ability to measure short-term phytoplankton bloom events is also critical to evaluating the health of an ecosystem and assess its compliance to water quality standards. The Chesapeake Bay Program is currently developing a narrative for chlorophyll criteria in various regions of the bay during different seasons.

2.1.2 Open Water Ecosystem Metabolism

Estimates of ecosystem metabolism are useful indexes of ecosystem function that provide insight into rate processes operating within an estuary. Both ecosystem production and respiration have been shown to be responsive to changes in the nutrient status of an estuary (Hagy et al. 1997), and can be used as valuable metrics by which to gauge how an estuary is responding to changes in nutrient loading. This may be particularly important for managers seeking to show how estuaries respond to changes in policy.

While a variety of methods have been developed to calculate total ecosystem production and respiration, the use of high frequency dissolved oxygen data developed by Odum and Hoskins (1958) has become increasingly popular (e.g., D'Avanzo, 1996; Hagy, 1999; Caffrey, 2003). The advent of accurate and reliable instrumentation has made this possible, and provides a means to estimate these parameters at a variety of time scales with relatively low cost. Hagy et al. (1999) used this method to compare metabolism estimates on the Patuxent River estuary at Benedict MD, using both current and historical data to show how the metabolic state of the Patuxent River estuary has changed from 1962 to 1998. Caffrey (2003) used similar data from the National Estuarine Research Reserve (NERR) system to compare the ecosystem status of estuaries across the country. Because we deployed these instruments along the axis of the estuary in both a wet and a normal flow year, we can demonstrate the sensitivity of these ecosystem parameters across an estuary as well as between years. We believe these parameters can be useful descriptors of ecosystem function that can be adapted for dissemination to the general public and can provide added value to the data already being collected as part of the near-shore monitoring program around Chesapeake Bay.

2.2 Methods

2.2.1 Locations and sampling schedule

In 2004, the EPC collected high frequency temporal measurements (continuous monitoring CONMON) of surface water quality at 4 fixed locations on the Patuxent River estuary. These sites were located at the end of the CBL pier in Solomons, just south of Broomes Island at Pin Oak Farm, Benedict MD, and Kings Landing Park (Fig 2-1). A description of each station, station names, as well as geographic coordinates is listed in Table 2-1.

Table 2-1. Continuous monitoring locations, names and descriptions.

Station locations	**DNR Station name**	**Lattitude dd.dddd**	**Longitude dd.dddd**	**First Deployment**	**Final Retrieval**
Kings Landing Park pier Huntingtown MD	PXT0311	38.6263	-76.6768	4/09/04	10/29/04
Benedict MD Tony's River House pier	XED0694	38.5100	-76.6775	4/09/04	10/29/04
Pin Oak Farm Pier St. Leonard MD	XDE4587	38.4088	-76.5218	3/03/04	11/29/04
Chesapeake Biological lab pier Solomons MD	XCF9029	38.3167	-76.4526	3/01/04	11/29/04

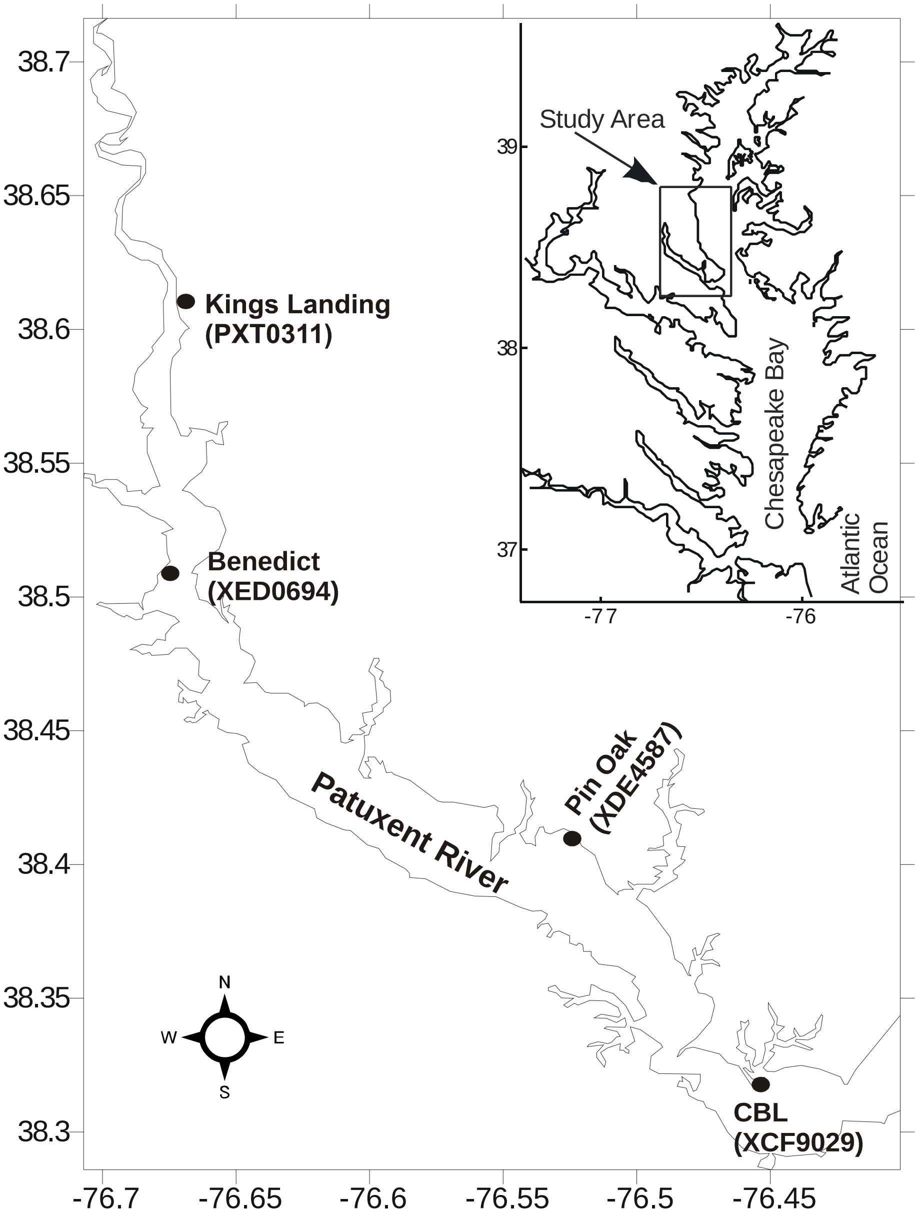


Figure 2-1. Map of EPC continuous monitoring locations in 2004 along with DNR station names.

2.2.2 Field Methods

High frequency data were collected with Yellow Springs International (YSI) 6600EDS model datasondes suspended at a fixed depth of 1.0m above the sediment surface at all locations. In addition, the datasondes at the Pin Oak location were equipped with an older style YSI turbidity probe (model 6026), while the other locations were equipped with the newer style 6136 probe. All other sensors were identical among these locations. All instruments were deployed within a 4” diameter, perforated, PVC housing which was bolted to a pier to protect the instrument and prevent vandalism (Fig. 2-2). These PVC tubes were also painted with anti-fouling paint to prevent epiphyte growth which could affect sensor readings. Datasondes were configured to collect dissolved oxygen concentrations (DO), temperature, conductivity, pH, fluorescence, and turbidity every 15 minutes.

Instruments were generally left in-situ for periods of 7-10 days before they were replaced with freshly calibrated instruments. Both the replacement instrument and the instrument to be retrieved were left in the water for at least 2 concurrent sets of measurements to ensure a complete continuous record and to compare data records from both instruments. In addition, a third datasonde was used as an auxiliary check on temperature, conductivity and DO. All laboratory calibration of the datasondes was done in compliance with YSI recommendations and in agreement with procedures used by Maryland DNR. Sensor accuracy and specifications are listed in Rohland et al. (2004).

In addition to the sensor data, a water column light profile was completed in order to calculate the water column light attenuation coefficient (kd). Light flux data in the photosythetically active range (PAR) was collected at 3 to 5 discrete water depths (0.1m to 1.0m) with a LiCor 192SA (2 pi) quantum sensor. A LiCor 190SA deck cell was also used to correct for any changes in solar radiation during the measurements. Each recorded measurement at a specific water depth was a 15 second running average to smooth out chatter in the data. Additional weather, sea-state, and secchi depth data were recorded as indicated in Rohland et al. (2004).

At each instrument deployment site, a whole water sample was collected with a Nisken bottle lowered to the sensor depth, and transferred to a sample bottle for later analysis. Each water sample was placed on ice in a cooler for transport back to laboratory prior to further processing. Filtering of the whole water sample was done in compliance with the standard operating procedures of the Nutrient and Analytical Services Laboratory (NASL) at CBL. Finally, all field data were then transcribed to an approved MD DNR field sheet for submittal to DNR.

2.2.3 Water Column Nutrient Analysis

In the laboratory, whole water samples were filtered for the following parameters at every other instrument retrieval (approximately twice monthly). Water column parameters included: ammonium, nitrate plus nitrite, phosphate, silicate, total suspended solids (TSS) and volatile suspended solids (VSS), water column chlorophyll, total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), particulate carbon, nitrogen and phosphorus (PC/PN/PP), particulate inorganic phosphorus (PIP), and dissolved organic carbon (DOC). All chemical analysis was done by NASL except for water column chlorophyll, and that variable was analyzed by the Department of Mental Health and Hygiene (DHMH). Chemical analyses completed by NASL followed procedures outlined in NASL standard operating procedures.

2.2.4 Quality Assurance Procedures

All high frequency data downloaded from the datasondes were plotted to identify outliers or anomalous readings. In addition, several datasonde readings collected at the beginning and end of each deployment were compared to another calibrated instrument (deployed at that time) in order to check for possible instrument drift prior to data transfer to Maryland DNR. This procedure was similar to that followed by Maryland DNR, and is documented in Smail *et.al.*, (2004). Datafiles were further processed by an “Excel” macro supplied by MD DNR which electronically flags observations exceeding certain criteria and provides for input of fixed error codes and comments. Both raw data and proofed data were sent to MD DNR in electronic format. Nutrient data were supplied electronically from the Nutrient and Analytical Services Laboratory (NASL) following their standard protocols.

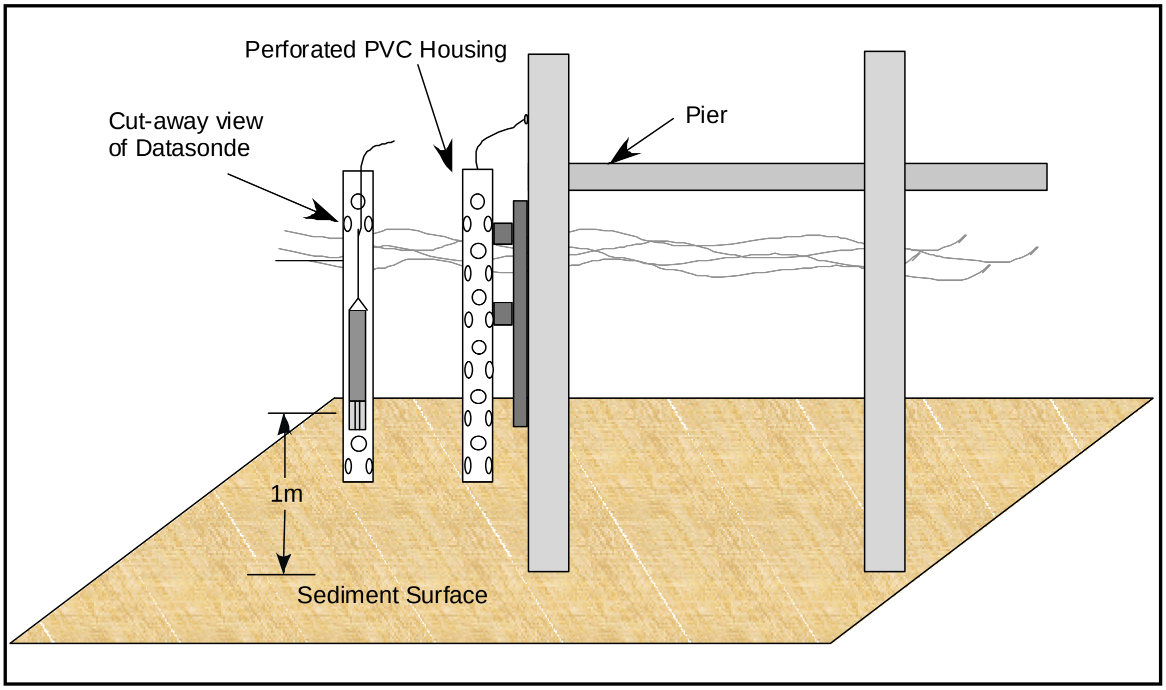


Figure 2-2. Diagrammatic sketch of the continuous monitoring setup in 2004 at stations located at CBL, Pin Oak, Benedict, and Kings Landing on the Patuxent River estuary.

2.2.5 Open Water Metabolism Parameter Calculations

The standard estuarine (aquatic) paradigm assumes that oxygen concentrations within a homogeneous body of water exhibit a characteristic diurnal curve, with concentrations rising during sunlight hours as gross production (Pg) outstrips respiration (Rn), followed by declining concentrations during the late evening and night as respiration consumes oxygen. Net ecosystem metabolism is the difference between gross production and night respiration and is a measure of whether a system is net autotrophic or net heterotrophic. A description of each metabolic parameter is shown in Table 2-2. The basis for the calculation of these metrics is the change in oxygen concentration between successive sets of measurements. However, because physical processes such as diffusion across the air-water interface operate, a diffusion correction factor must be applied to the raw oxygen concentration data. For these calculations, a constant exchange coefficient of 0.5 g O_2 m^{-2} hr^{-1} at 100% saturation deficit was used (Kemp and Boynton, 1980). Further, the validity of these calculations rely on the assumption that the mass of water passing by the sensor is vertically and laterally homogeneous and subject to the same biological processes. A brief summary of the steps involved in the calculations are shown below.

1) Times for sunset and sunrise were obtained from the US Naval Observatory for each day and merged with the datasonde data by date and time. Sunrise/sunset data can be downloaded at: http://aa.usno.navy.mil/data/docs/RS_OneYear.html

2) Changes in DO concentration between successive measurements (flux) were calculated and corrected for air-water exchange based upon percent DO saturation using the following relationship:
Air-sea exchange = 0.5* time interval*(100-DOsaturation)/100

3) A new metabolic date was assigned for each set of observations between successive sunrise to sunrise rather than the calendar date.

4) Observations occurring between sunset and sunrise were labeled as night, while observations during daylight hours were divided into three categories. Those observations occurring between sunrise and the minimum daytime DO concentration were labeled predawn. Those observations occurring after the maximum DO concentration but before sunset are labeled predusk. The remaining daytime observations were labeled day.

5) For each labeled portion of the day (Predawn, Day, Predusk, and Night) corrected changes in DO concentration (flux) were added and converted into a daily rate for each of the metabolic parameters listed in table 2-2.

Table 2-2. Summary of metabolic parameter definitions.

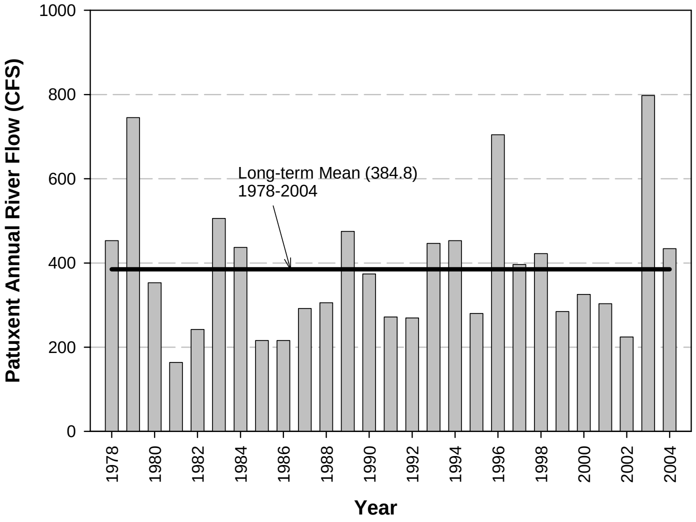
Parameters	**Definition**
Rn	Night respiration (g O_2 m^{-3} day^{-1}) between sunset and sunrise.
Rn hr^{-1}	Night respiration rate (g O_2 m^{-3} hr^{-1}) mean hourly O_2 consumption Between sunset and sunrise.
Pa	Net oxygen production (g O_2 m^{-3} day^{-1}) between sunrise and sunset.
Pa*	Net oxygen production (g O_2 m^{-3} day^{-1}) during period of net autotrophy between DO min and max for each day.
Pg	Gross oxygen production (g O_2 m^{-3} day^{-1}) between sunrise and sunset, assuming daytime and nighttime respiration rates are equal.
Pg*	Gross oxygen production during period of net autotrophy (g O_2 m^{-3} day^{-1}), assuming daytime and nighttime respiration are equal.

2.3 Results

2.3.1 Descriptions of High Resolution Temporal Data

Because 2003 was a very high flow year, comparisons between 2004 and 2003 provide the opportunity to compare how the Patuxent estuary responded to changes in river flow and associated factors such as nutrient loading and salinity. Since the time period for the deployment of datasondes was greater in 2004 compared to 2003, only those dates of mutual deployment were used for statistical and graphical comparison. This time period was approximately June 20th through October 31th of each year.

a) Annual Flow



b) Monthly Flow

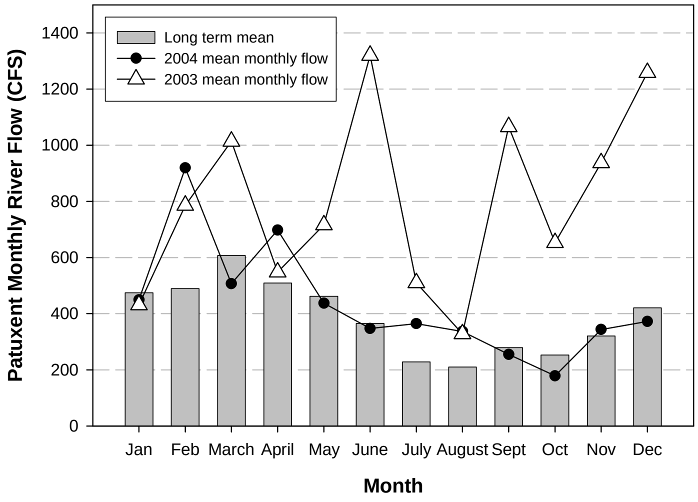


Figure 2-3. a) Patuxent River annual mean flow rate (cubic feet per second, CFS) and long-term mean at Bowie MD from 1978-2005, and b) Patuxent River Long-term monthly mean river flow from 1978-2004, and 2004 monthly river flow at Bowie MD. All data collected by USGS available at: http://waterdata.usgs.gov/md/nwis/dv/?site_no=01594440&agency_cd=USGS.

2.3.1.1 Temperature

During the June through October period, water temperatures exhibited a variety of spatial patterns that were consistent among both years. For example, median and maximum temperatures were highest at Kings Landing and lowest at CBL in both 2003 and 2004 (Fig. 2-4, Table 2-3). In addition, in both years, the greatest range of water temperatures was observed at Kings Landing, while the lowest was found at CBL (Fig. 2-4, Table 2-3). Maximum temperatures at all sites were lower in 2004 compared to 2003. In addition, median values were also lower in 2004 compared to 2003 for all sites except CBL (Table 2-3). The patterns likely reflect the declining impact of Chesapeake Bay water at progressively more up-river locations.

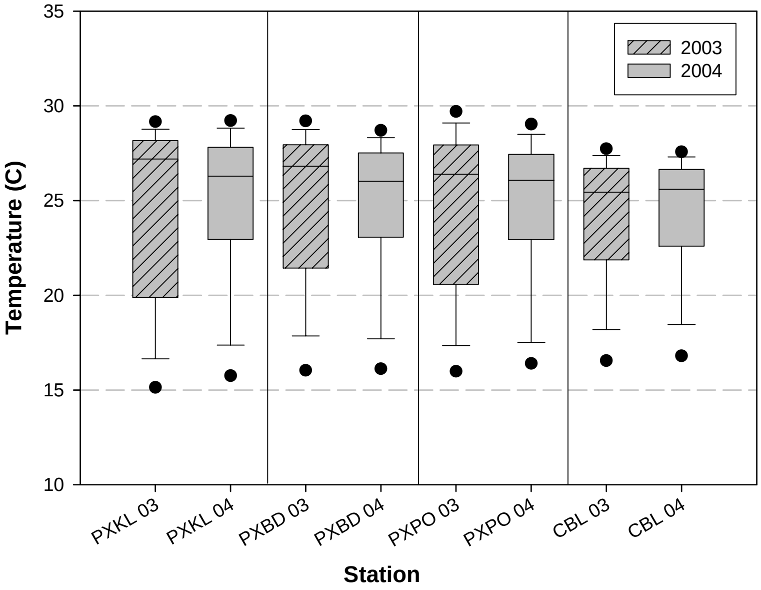


Figure 2-4. Box and whisker plots for water temperature from CONMON sites in 2003 and 2004. Only data from each year that was collected during the same time period was used (June 20 – Oct 30). *Box ends represent 25th and 75th percentiles, while lines represent median values. Whiskers are 10th and 90th percentiles, and dots are 5th and 95th percentiles.*

Table 2-3. Description of water temperature at CONMON sites in 2003 and 2004. Only data from 6/20 through 10/30 of each year.

(°C)	Kings Landing		Benedict		Pin Oak		CBL	
Year	2003	2004	2003	2004	2003	2004	2003	2004
Mean	24.58	24.92	24.83	24.81	24.64	24.76	24.02	24.35
Median	27.19	26.28	26.81	26.02	26.39	26.1	25.43	25.6
Max	31.1	30.86	31.5	31.08	32.13	31.17	29.66	29.45
Min	13.34	13.83	14.19	15.08	13.26	14.95	15.16	16.00
variance	23.60	16.89	18.07	14.11	19.71	14.77	12.37	10.35

2.3.1.2 Salinity

Several spatial and temporal patterns in salinity were consistently observed in both years. As expected, in both years, median salinities decreased with distance from the river mouth (Fig. 2-5, Table 2-4). However the range of values observed during the June through October period was not consistent among years. For example, the highest range observed in 2003 (8.63) was found at the Benedict site, while in 2004 it was found at the CBL site (8.03). However there were measurable differences observed at each station between years. At all stations, median values were higher in 2004 compared to 2003 (Fig. 2-5, Table 2-4).

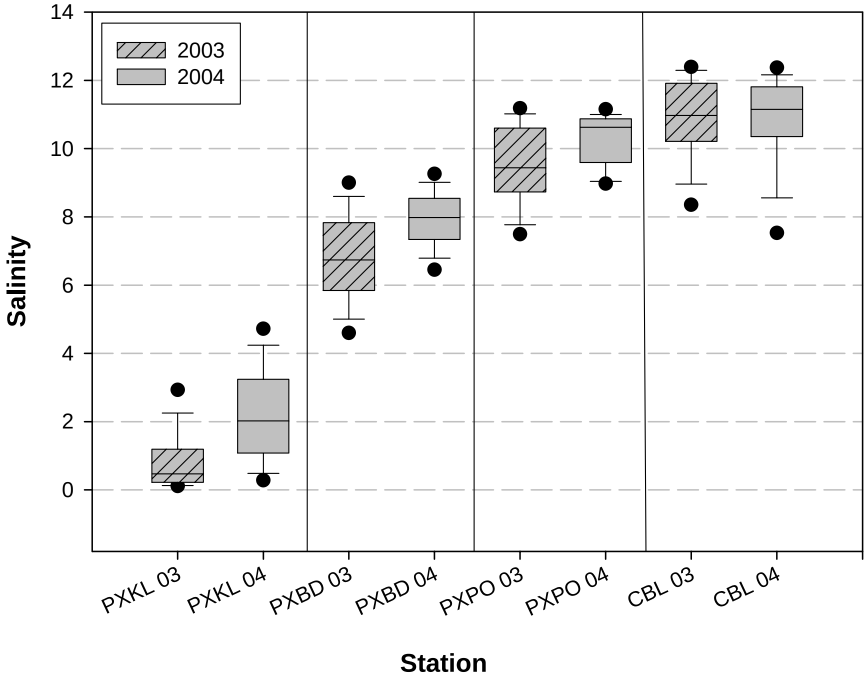


Figure 2-5. Box and whisker plots for salinity from CONMON sites in 2003 and 2004. Only data from each year that was collected during the same time period was used (June 20 – Oct 30). *Box ends represent 25th and 75th percentiles, while lines represent median values. Whiskers are 10th and 90th percentiles, and dots are 5th and 95th percentiles.*

Table 2-4. Description of salinity at CONMON sites in 2003 and 2004. Only data from 6/20 through 10/30 of each year.

(°C)	Kings Landing		Benedict		Pin Oak		CBL	
Year	2003	2004	2003	2004	2003	2004	2003	2004
Mean	0.87	2.3	6.80	7.93	9.53	10.29	10.84	10.79
Median	0.47	2.12	6.74	7.98	9.44	10.65	10.97	11.15
Max	5.69	6.68	11.03	10.82	11.72	11.43	13.07	12.87
Min	0.04	0.04	2.4	4.36	6.34	8.14	7.34	4.84
variance	0.89	1.93	1.85	0.74	1.34	0.58	1.56	2.29

2.3.1.3 Dissolved Oxygen

During the June through October time period, median dissolved oxygen (DO) concentrations at all stations remained above 5 mg l^{-1} in 2003 and 2004 (Table 2-5). However, at the three down-river stations (Benedict, Pin Oak, and CBL) median concentrations were lower in 2003 compared to 2004 (Table 2-5). In addition, the frequency of low DO observations was also higher in 2003 compared to 2004 at those same down-river stations. The percent of DO concentrations below 5 mg l^{-1} at Benedict declined from 38% to 21%, while at Pin Oak it declined from 10% to 4%, and at CBL it declined from 22% to 0.3% between 2003 and 2004 (Table 2-5). The reverse pattern was observed at Kings Landing. The median DO concentration was lower and the frequency of low DO observations was higher in 2004 compared to 2003. Less than 1% of observations at Benedict were below 2 mg l^{-1} during 2003 and 2004, while PO had less than 1% of observations below 2 mg l^{-1} in 2003. No other stations had observations below 2 mg l^{-1}.

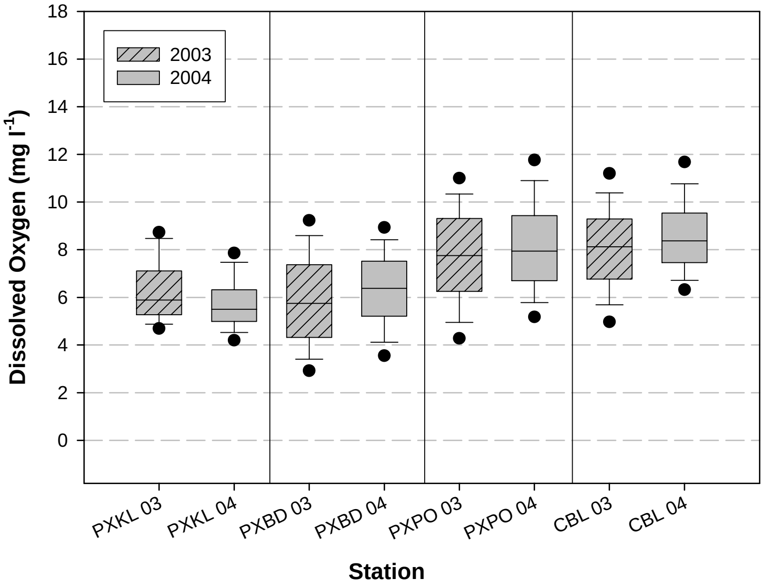


Figure 2-6. Box and whisker plots for dissolved oxygen concentrations from CONMON sites in 2003 and 2004. Only data from each year that was collected during the same time period was used (June 20 – Oct 30). *Box ends represent 25th and 75th percentiles, while lines represent median values. Whiskers are 10th and 90th percentiles, and dots are 5th and 95th percentiles.*

Table 2-5. Description of dissolved oxygen concentrations at CONMON sites in 2003 and 2004. Only data from 6/20 through 10/30 of each year was compared.

(°C)	Kings Landing		Benedict		Pin Oak		CBL	
Year	2003	2004	2003	2004	2003	2004	2003	2004
Mean	6.26	5.72	5.91	6.36	7.70	8.18	8.094	8.61
Median	5.89	5.51	5.75	6.38	7.75	7.95	8.12	8.37
Max	9.85	9.08	15.74	14.43	14.12	16.33	16.07	17.03
Min	3.94	2.75	1.04	0.43	1.1	2.03	2.3	4.41
variance	1.64	1.21	4.11	2.91	4.36	4.36	3.55	2.75

2.3.1.4 Chlorophyll (fluorescence)

For the June through August time period, the temporal pattern of water column chlorophyll concentrations was very similar in both 2003 and 2004. In both years baseline concentrations were relatively low, but were punctuated by periods of much higher chlorophyll concentrations (algal blooms). In Figure 2-7, the asymmetry of the box and whisker plots reflect this pattern. In both years, median concentrations remained below 15 µg l^{-1} at all stations (Table 2-6). However, the maximum concentrations observed were much higher in 2003 compared to 2004 at the three down-river stations (Table 2-6). For example, at both Benedict and Pin Oak, YSI recorded concentrations were at or above the maximum reading of 500 µg l^{-1} in 2003 compared to 76.7 µg $l^{-1}$and 195.2 µg l^{-1} respectively in 2004. While the opposite pattern was true at Kings Landing, lower concentrations in 2003 were likely the result of higher flow, pushing phytoplankton further downstream.

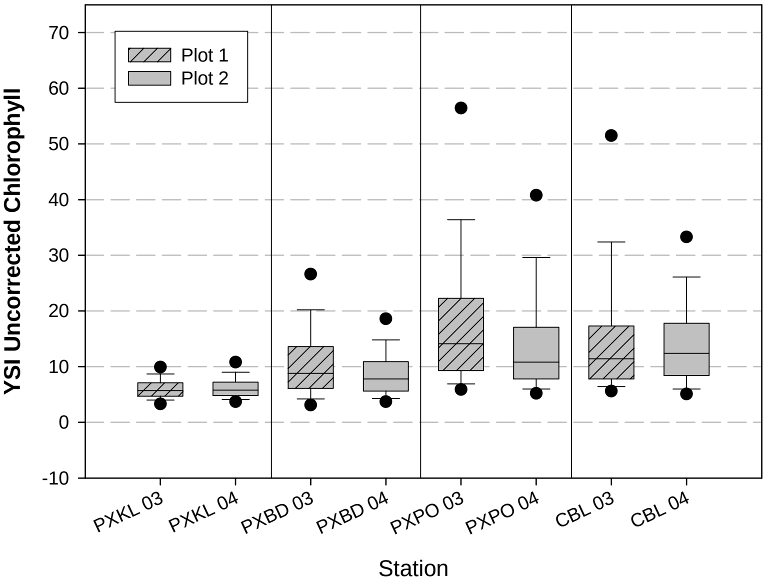


Figure 2-7. Box and whisker plots for YSI uncorrected chlorophyll from CONMON sites in 2003 and 2004. Only data from each year that was collected during the same time period was used (June 20 – Oct 30). *Box ends represent 25th and 75th percentiles, while lines represent median values. Whiskers are 10th and 90th percentiles, and dots are 5th and 95th percentiles.*

Table 2-6. Description of YSI uncorrected chlorophyll (µg l^{-1}) at CONMON sites in 2003 and 2004. Only data from 6/20 through 10/30 of each year.

(°C)	Kings Landing		Benedict		Pin Oak		CBL	
Year	2003	2004	2003	2004	2003	2004	2003	2004
Mean	6.04	6.58	11.59	9.14	20.93	15.38	17.13	14.90
Median	5.7	5.9	8.8	7.8	14.1	10.9	11.4	12.4
Max	31.6	111.6	500	76.7	500	195.2	436.8	173.7
Min	1.4	2.2	0.1	1.3	1.3	2.4	2.2	2.5
variance	4.3	17.91	144.9	33.24	700.63	179.63	396.24	107.45

2.3.1.5 Turbidity

In 2004 as in 2003, there was a strong increasing gradient in turbidity moving from the mouth to up-river locations. Despite the higher than average river flow in 2003, there was virtually no difference in median turbidity values at each of the sites in 2004 except for Pin Oak which was twice as high compared to 2003 (Table 2-7). These observations further indicate that water clarity is primarily driven by suspended sediment rather than chlorophyll concentrations which did respond to increased nutrient loading in 2003. Maximum values recorded at each site did not show a consistent pattern between 2003 and 2004 further indicating the influence of wind driven re-suspension events rather than a biological control of turbidity. For a detailed description of how this data applies to SAV habitat criteria see chapter 4 of this report.

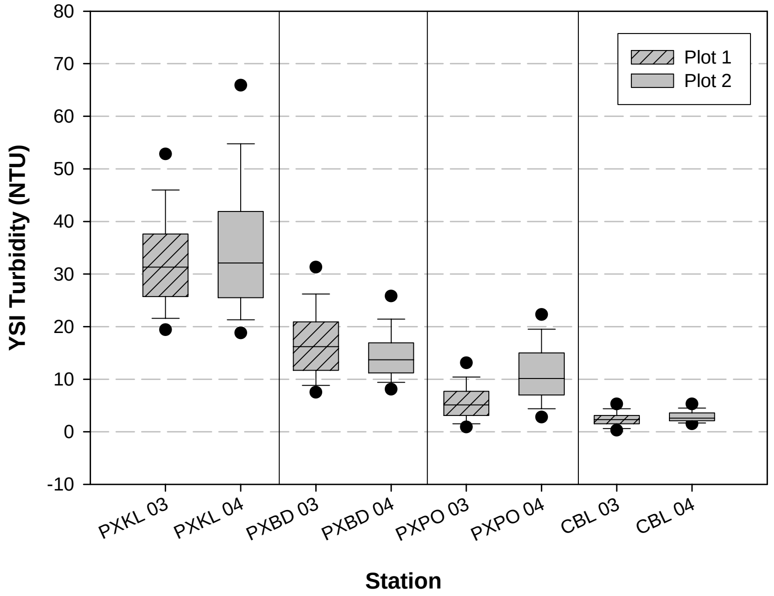


Figure 2-8. Box and whisker plots for YSI turbidity from CONMON sites in 2003 and 2004. Only data from each year that was collected during the same time period was used (June 20 – Oct 30). *Box ends represent 25th and 75th percentiles, while lines represent median values. Whiskers are 10th and 90th percentiles, and dots are 5th and 95th percentiles.*

Table 2-7 Description of YSI turbidity at CONMON sites in 2003 and 2004. Only data from 6/20 through 10/30 of each year. *Symbol "<" reflects values below detection limit.*

(°C)	Kings Landing		Benedict		Pin Oak		CBL	
Year	2003	2004	2003	2004	2003	2004	2003	2004
Mean	32.99	36.05	17.42	15.22	5.90	11.38	2.49	2.96
Median	31.3	31.6	16.2	13.7	5.1	10.2	2.3	2.6
Max	254.2	232.8	133.9	178.6	64.5	117.1	44.4	16.2
Min	12.7	10.8	1.6	3.8	<	1.1	<	0.8
variance	131.09	290.05	78.15	69.01	20.80	38.45	2.94	1.71

2.3.2 Open Water Ecosystem Metabolism

Because of the interaction of Bay, River, and harbor water at the CBL site, we believe the assumption of a homogeneous body of water was often strongly violated. Therefore, data collected at the CBL site are not presented here. While these assumptions may not always be strongly adhered to at the other locations, we generally believe departures were small or infrequent enough to provide valid results. Data were also eliminated where daily gross production rates were negative, and nightly respiration rates were positive. It was assumed that these rates were calculated from data that did not meet the assumptions of this method. Over the course of these deployments 2-7% of the respiration measurements were eliminated, while 3-19% of the gross production measurements were eliminated. Further, when gross production to respiration ratios (Pg/Rn) were calculated, values in excess of 10 were excluded from the calculations. These high values were generated from extremely low estimates of respiration and were somewhat arbitrarily removed so as not to bias the seasonal means based on a few exceptionally high values.

Over the period monitored, respiration rates generally increased in summer and began to decline again in the fall (Fig 2-9). This temporal pattern was likely in response to increases in water temperature throughout the summer season and temperature declines in the fall. While we do not have direct measurements of labile organic matter, enhanced substrate availability during the warm periods of the year probably also contributed to higher rates. A similar pattern was observed on the Hudson River by Howarth et al. (1992), and at the Benedict location by Hagy et al. (1999). During the 2004 summer period (June through August) nighttime respiration at Kings Landing averaged -2.18 g O_2 m^{-3} day^{-1}, while at Benedict, average respiration was -2.99 g O_2 m^{-3} day^{-1}, and at Pin Oak average respiration was -2.13 g O_2 m^{-3} day^{-1} (Table 2-8). Average gross production during that same period was 1.42 g O_2 m^{-3} day^{-1} at Kings Landing to 5.15 g O_2 m^{-3} day^{-1} at Benedict, and 5.05 g O_2 m^{-3} day^{-1} at Pin Oak (Table 2-8). The gross production at each of these sites was also higher in 2003 compared to 2004 (Table 2-8). However, the differences were greater at Benedict and Pin Oak (almost 2 g O_2 m^{-3} day^{-1}) compared to Kings Landing, (0.41 g O_2 m^{-3} day^{-1}). Since both mean respiration and production were higher in 2003 compared to 2004, the ratio of gross production to respiration (Pg/Rn) better illustrates the metabolic dynamics present at each location. For example, during 2003 and 2004 the Pg/Rn ratio at Kings landing was -0.90 and -0.613 respectively, while at Benedict it was -1.67 and -1.64, and at Pin Oak it was -2.62 and -2.65. These data show that even during under different nutrient loading conditions, each of these locations has a particular metabolic character.

While the 2004 mean summer respiration rates were slightly different among sites, the maximal rates found at each site were very different. For example, at Kings Landing the maximum respiration rate was only -3.40 g O_2 m^{-3} day^{-1}, but at Benedict, the maximum respiration was -7.0 g O_2 m^{-3} day^{-1}, and 29% of the observations were greater than 3.40 g O_2 m^{-3} day^{-1} (Fig 2-9). Large differences were also seen in the maximal rates of daily gross production (Pg) among locations. For example, at Benedict, Pg in excess of 15 g O_2 m^{-3} day^{-1} was recorded on several days, while at Kings Landing the maximum value was only 3.8, g O_2 m^{-3} day^{-1} (Fig 2-10).

Table 2-8. Comparison of annual metabolic parameters calculated from CONMON high-frequency DO observations in 2003 and 2004 during summer months (June 20 – August 30).

Station	Years	Metabolic Parameters			
		Nighttime Respiration (Rn)	Net Daytime DO Production (Pa)	Gross Daytime DO Production (Pg)	Ratio Pg/Rn
Kings Landing	2003	-2.03	-1.11	1.83	-0.90
	2004	-2.18	-2.04	1.42	-0.613
Benedict	2003	-3.94	0.84	7.00	-1.67
	2004	-2.99	-0.48	5.15	-1.64
Pin Oak	2003	-3.31	1.81	6.92	-2.62
	2004	-2.13	1.81	5.05	-2.65

Table 2-9. Long term record of open water ecosystem metabolism estimates for Benedict Maryland for June 1th through September 15th. ** Data from Hagy et al. 1999. ** Calculations for 2003 estimates ranged from June 20th through Sept 15th.*

Year	Weather Condition	**Metabolic Parameters**			
		Nighttime Respiration (Rn)	Net Daytime DO Production (Pa)	Gross Daytime DO Production (Pg)	Ratio Pg/Rn
1964*		-2.6			
1992*		-4.1			
1996*	Wet	-3.44	0.28	5.07	-1.47
1997*	Average	-2.62	0.12	3.93	-1.50
1998*	Average	-2.70	-0.18	3.78	-1.4
2003**	Wet	-3.77	0.61	6.35	-1.55
2004	Average	-2.87	-0.48	4.63	-1.52

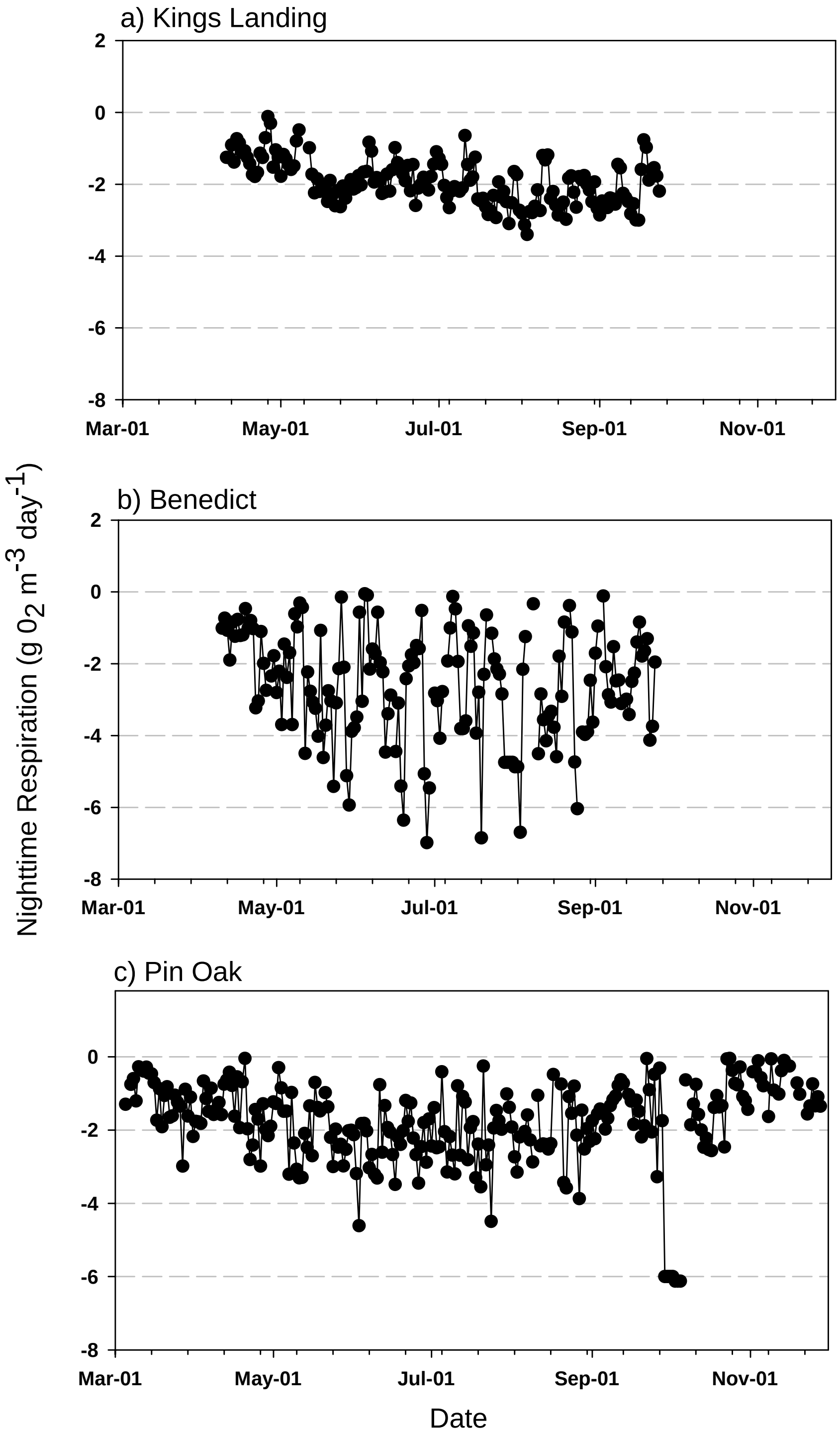


Fig 2-9. Nightly respiration rates for a) Kings Landing, b) Benedict, and c) Pin Oak in 2004

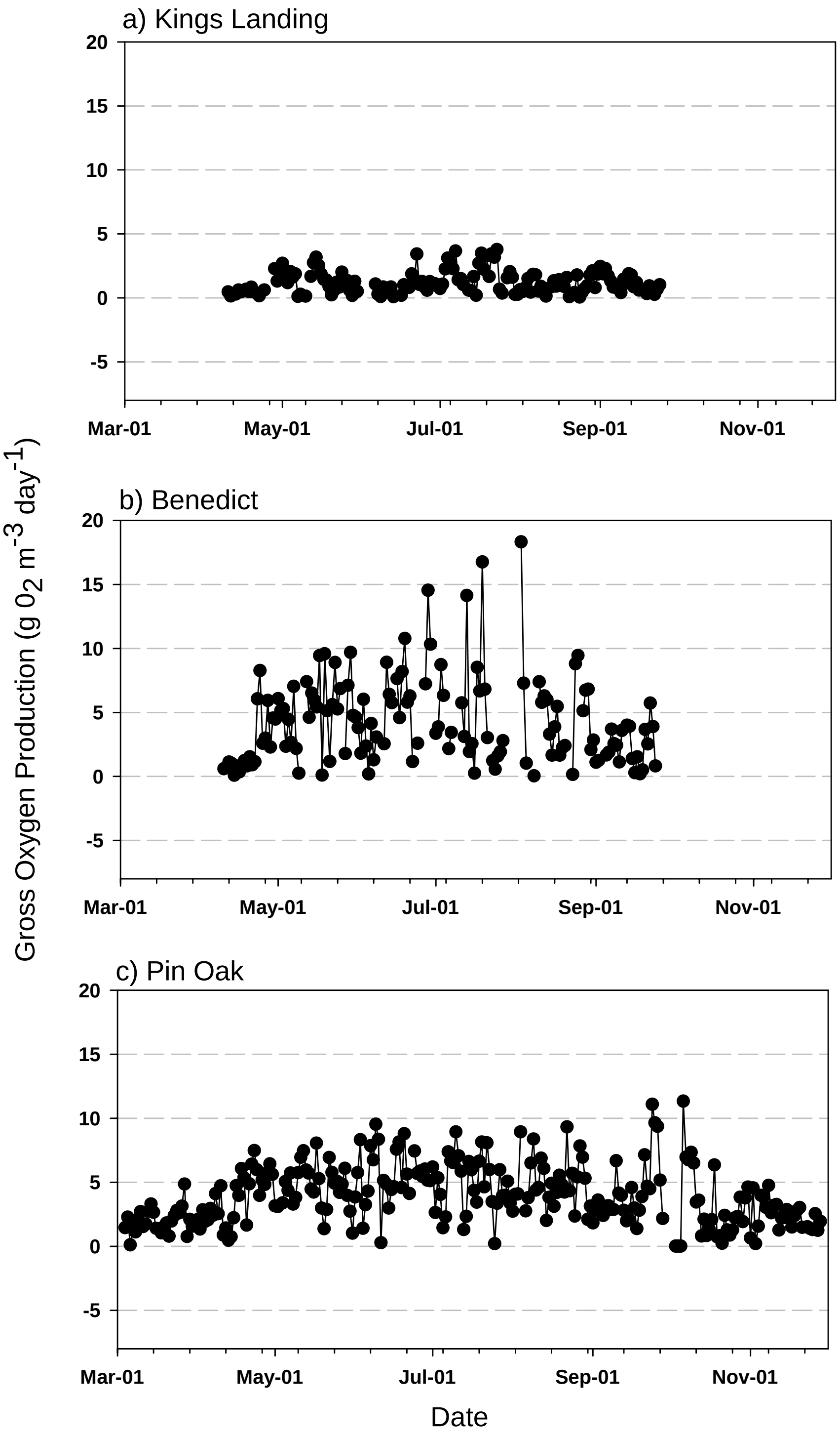


Fig 2-10. Daytime oxygen production rates for a) Kings Landing, b) Benedict, and c) Pin Oak in 2004.

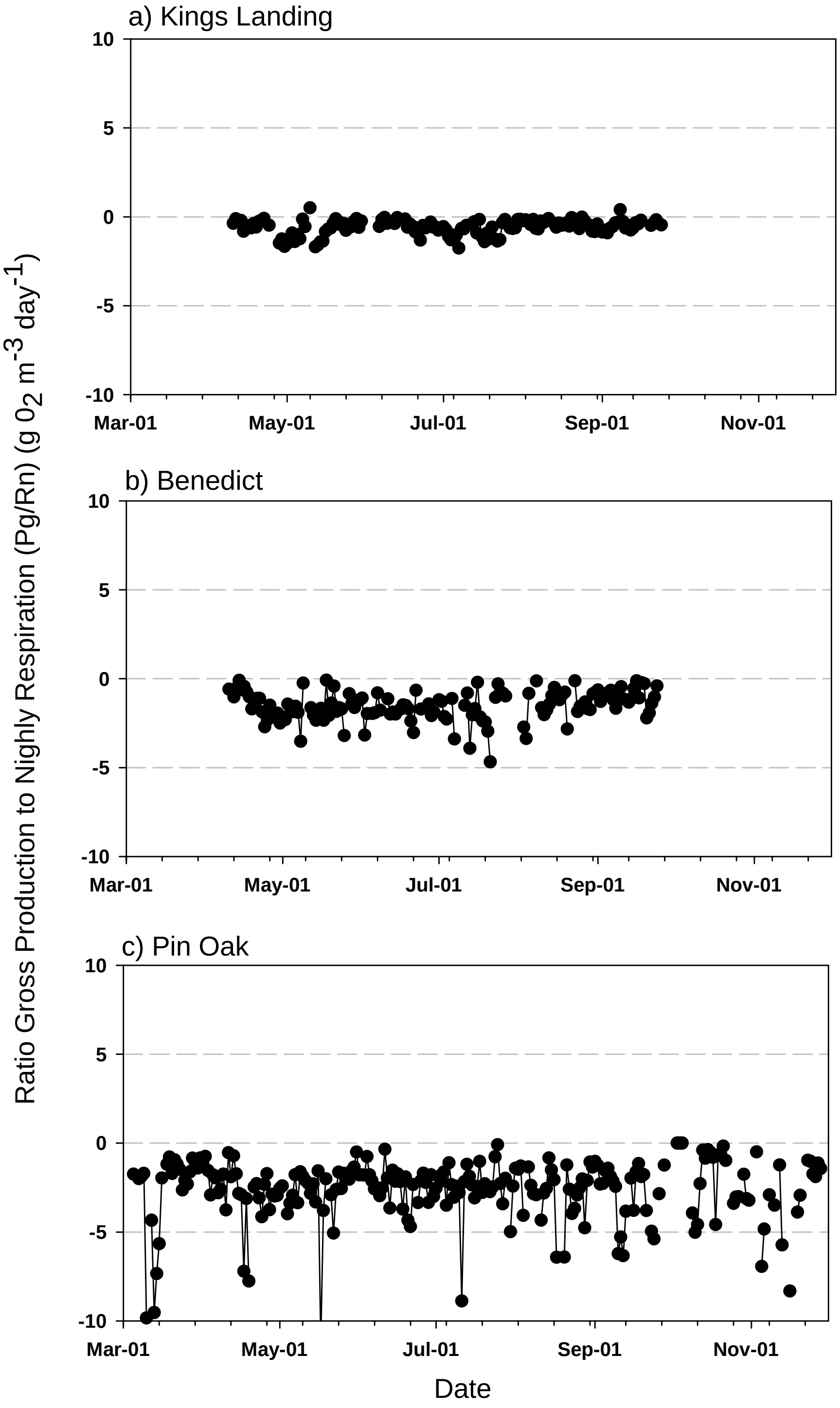


Fig 2-11. Ratio of Daily gross production to Night respiration (Pg/Rn) for a) Kings Landing, b) Benedict, and c) Pin Oak in 2004.

2.5 Discussion

Because estuarine water quality conditions can be highly variable across several time scales, high resolution temporal monitoring is critical to both assessing compliance to water quality criteria, as well as providing data for an enhanced understanding of estuarine processes. Periodic, but intense, water quality events can have important consequences for living resources. Short lived anoxic or hypoxic events may not be observed with traditional monitoring techniques yet can be extremely important for a variety of pelagic or benthic species. By collecting data during these short-term events we gain a better understanding of the estuarine processes involved and may be able to develop a better way to control or prevent undesirable conditions. Further, with high frequency data, we are able to distinguish subtle changes in water quality conditions or ecosystem function as a response to different nutrient loading conditions. These results may provide important information to resource managers seeking to get the best results from various management decisions.

In 2004, dissolved oxygen conditions at all 4 Patuxent River monitoring stations were overall quite good. During the entire monitoring period, none of the 3 down river stations experienced any 7 day or 30 day averages below the established habitat limits of 4.0 mg l^{-1} and 5.0 mg l^{-1} respectively. Even at Kings landing, the 7 day criteria was only exceeded on two days, while the 30 day average was exceeded on 20 days. The instantaneous criteria of 3.2 mg l^{-1} was rarely exceeded as well. Even at Benedict which had the highest frequency of low DO observations, only 3.2% of the observations fell below that limit. At Kings Landing and Pin Oak, less than 1% of the observations fell below the instantaneous limit. At CBL, the lowest DO concentration observed was only 4.4 mg l^{-1}. These results were not surprising considering that these monitoring sites are located in relatively shallow, well flushed areas.

However, a comparison of overall statistics at these stations between 2003 and 2004, show that increased nutrient loading can have a noticeable effect on the frequency of low DO events even at well flushed stations. Not only are the median DO concentrations lower in 2003 compared to 2004 at the three down-river stations (Table 2-5), the frequency of low DO events was also higher (Table 2-10). For example in 2003, 7.3% of observations were below 3.2 mg l-1 at Benedict, while only 3.2% of the observations fell below that limit in 2004. Similar reductions in the frequency of low DO events were also at the other two down-river stations in 2004 compared to 2003. This difference would likely be more pronounced within other areas of the river not experiencing such well mixed conditions.

Light availability as measured by the YSI sensors at these 4 stations did not show any consistent pattern between 2003 and 2004. Median NTU values at Kings Landing and CBL were essentially unchanged between 2003 and 2004 (Table 2-7), while the median value at Pin Oak was twice as high in 2004 (10.2 NTU) compared to 2003 (5.1 NTU). In contrast, turbidity at Benedict was higher in 2003. These results suggest that water clarity in these shallow locations may be highly influenced by local wind and weather conditions that re-suspend sediment into the water column rather than by flow related effects. Because water clarity criteria is based upon the percent of surface light reaching a specified depth (< 2m), we must convert YSI turbidity units from NTU to a light attenuation coefficient (Kd). A detailed analysis of this data for SAV habitat criteria is shown in Chapter 4 of this report.

Water column chlorophyll values, as measured by the YSI sensors, indicate that of all the stations, only Pin Oak had a median value slightly greater in 2003 compared to 2004 (14.1 $\mu g\ l^{-1}$ vs. 10.9 $\mu g\ l^{-1}$). However, the maximum observed values at each station were much different in 2003 compared to 2004 and reflect algal bloom events that may have been missed with traditional bi-weekly sampling. The intensity of these bloom events was much greater in 2003 compared to 2004 at the three down-river stations, with maximum values exceeding the range of the sensors (> 500) at both Benedict and Pin Oak. The reverse pattern was seen at Kings landing with the maximum value recorded in 2004. These high intensity bloom events, while possibly short-lived, can still have important consequences for living resources in the area and highlight the importance of high frequency monitoring for assessing these near-shore habitats.

Differences in nutrient loading rates to the Patuxent River between 2003 and 2004 were reflected in several metabolic parameters calculated from dissolved oxygen data and provide added value and insight into how the estuary responds to change. Mean summer respiration rates at Benedict and Pin Oak were both higher in 2003 compared to 2004. Again the reverse was true at Kings Landing which may reflect a greater flushing of water past that location in 2003 compared to 2004. At all stations, mean summer gross production Pg was higher in 2003 compared to 2004. A comparison of respiration and production estimates from the Benedict location from 1996 to 2004 (Table 2-9), show that both respiration and production were higher under increased loading conditions. Calculations of net ecosystem metabolism (Net production – Respiration) were negative at all stations in both years and ranged from -0.32 g O_2 m^{-3} day^{-1} at Pin Oak in 2004 to -4.22 g O_2 m^{-3} day^{-1} at Kings Landing in 2004. These results appear to be consistent with estimates made among other regional estuaries using similar data where higher respiration rates relative to production rates are found in oligohaline locations compared to meso or polyhaline locations (Caffrey, 2004). These results provide a summary statistic that can be used to judge how estuaries are responding the changes resulting from management decisions, particularly those related to nutrient load reductions.

The production and respiration rates observed in the Patuxent are in the moderate to high range when compared to similar measurements made in other coastal and estuarine areas (Boynton and Kemp, 2005). A review by Nixon (1995) also indicates these values to be in the eutrophic but not the dystrophic range. Thus, these measurements indicate a eutrophic system, more respiratory at up-river sites and more autotrophic at measohaline sites. Overall, the system, especially in the area upstream of Sheridan Point appears to be generally heterotrophic (P/R ratios <1.0). These measurements confirm, on a process basis, a problem observed in the water quality model being used by the State of Maryland for Patuxent River TMDL development (Fisher et al. 2005). The model predicts higher than observed DO in surface waters in the above mentioned zones of the estuary and the modelers have not yet been able to make the model capture real DO conditions. There has been considerable discussion as to why DO conditions are lower than expected in this zone of the estuary. The metabolism data presented here clearly indicate that water column (and possible benthic as well) respiration in excess of plankton production is the likely answer. If this is the case, a source of organic matter needs to be identified and this source is very likely the extensive tidal marshes of the upper Patuxent. Greene (2005) and Boynton et al. (2005; see also chapter 5 in this report) have reported that these marshes permanently remove significant amounts of N and P but these marshes would also export significant amounts of organic matter that could support enhanced water column and benthic respiration.

We have yet to “fine-tune” the metabolism measurements. This step really has three aspects and we are beginning to address all of them. The first has to do with parsing collected data into periods (generally either a daylight or nighttime period) when the needed assumption for the computation are met and those in which there are serious departures from these assumptions. This step will take some serious effort and we have compiled several ideas and approaches for making these determinations in an automated fashion. The second step has to do with fashioning a “user-friendly” front end for the metabolism algorithm so that data from a variety of CONMON sites could be readily and reliably subjected to these computations. This effort has not yet started but we have identified several investigators who have an interest in doing this. Finally, we need to develop a “cartoon-like” diagram that can convey to the general public the meaning of these measurements of community metabolism and link metabolism to management actions and to seasonal or annual climate conditions. We have had great success in making this linkage for a site in the Patuxent and hopefully we can make similar linkages for other portions of the bay where CONMON sites exist.

2.5 Cited Literature

Boynton, W. R. and W. M. Kemp. 2005. Nitrogen in Estuaries, p.xx-xx. In: E. Carpenter, D. Capone, D. Bronk and M. Mulholland (eds.). Nitrogen in the Marine Environment. Academic Press, NY.

Caffrey, J. M. 2003. Production, respiration and net ecosystem metabolism in U.S. estuaries. Environmental monitoring and Assessment 81:207-219.

Caffrey, J.M. 2004. Factors controlling net ecosystem metabolism in U.S. estuaries. Estuaries. 27(1):90-101.

D'Avanzo C., J. N. Kremer, S.C. Wainright. 1996. Ecosystem production and respiration in response to eutrophication in shallow temperate estuaries. Mar Ecol Prog Ser. 141:263-274.

Fisher, T. R., J. D. Hagy III, W. R. Boynton, and M. R. Williams. 2005. Cultural eutrophication in the Choptank and Patuxent estuaries of Chesapeake Bay. Limnol. Oceanogr. (in press).

Greene, S. 2005. Tidal Freshwater and oligohaline tidal marshes as nutrient sinks in the Patuxent River estuary, Maryland. MS Thesis, University of Maryland, College Park, MD xxp.

Hagy, J.D., W.R. Boynton, R.M. Stankelis, and J. M. Frank. 1999. Patuxent River high frequency monitoring in pp 126-149. W.R. Boynton and F.M. Rohland (eds.) Ecosystem Processes Component Level 1 Interpretive Report No 16. Chesapeake Biological Laboratory, University of Maryland System. Ref. No. [UMCES]CBL 99-0070a. [UMCES Technical Series No. TS-190-99-CBL].

Howarth, R.W., R. Marino, R. Garritt, D. Sherman. 1992. Ecosystem respiration and organic carbon processing in a large, tidally influenced river: the Hudson River. Biogeochemistry. 16:83-102.

Kemp, W.M., W.R. Boynton. 1980. Influence of biological and physical processes on dissolved oxygen dynamics in an estuarine system: implications for measurement of community metabolism. Estuarine and Coastal Marine Science. 11:407-431.

Moore, K. A., R. L. Wetzel, and R.J. Orth. 1997. Seasonal pulses of turbidity and their relations to eelgrass (*Zostera marina* L.) survival in an estuary. Journal of Experimental Marine Biology and Ecology. 215:115-134.

Nixon, S. W. 1995. Coastal marine eutrophication: A definition, social causes, and future concerns. Ophelia 41: 199-219.

Odum, H.T., C.M. Hoskin. 1957. Metabolism of a laboratory Stream Microcosm. Inst. Mar. Sci., Univ. Texas. 5:16-46.

Smith, S.V., J.T. Hollibaugh. 1997. Annual Cycle and Interannual variability of ecosystem metabolism in a temperate climate embayment. Ecol. Mon. 67:509-533.

Sweeney, B.F. 1995. Community metabolism in the Patuxent River estuary: 1963 – 1969 and 1992. Masters Thesis. University of Maryland. 83p.

3.0 Spatially Intensive Shallow Water Quality Monitoring of the Patuxent River

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3.1 Introduction

During 2004 we evaluated patterns in surface water quality using the DATAFLOW VI mapping system in the Patuxent River. The monitoring effort of 2004 marked the second year of a three year shallow water monitoring sampling cycle for the Patuxent River estuary. DATAFLOW VI was deployed from a small research vessel and provided high-resolution spatial mapping of surface water quality variables. Our cruise tracks included both shallow (<2.0m) and deeper waters, and sampling was weighted towards the littoral zone that represented habitat critical to Submerged Aquatic Vegetation (SAV) and associated organisms.

Traditional water quality monitoring in Chesapeake Bay, and in tributary estuaries such as the Patuxent, has been conducted almost exclusively in deeper channel waters, and conditions in these areas do not adequately represent water quality conditions in shallow zones. Thus, it was important to collect water quality data in both shallow water and deeper off-shore habitats and to determine the extent of gradients in water quality parameters between these areas of the estuary. The DATAFLOW cruise track covered as much area as possible, in both shallow and deeper portions of the system. The vessel traveled at approximately 20 knots, or 10 meters per second and collected data at 3 second intervals which amounts to about one observation made every 30 meters.

3.2 Methods, Locations and Sampling Frequency

3.2.1 DATAFLOW VI

DATAFLOW VI is a compact, self-contained surface water quality mapping system, suitable for use in a small boat operating at speeds of up to 20 knots. A schematic of this system is shown in Fig 3-1. DATAFLOW VI differed from version 5.5 through the addition of a wireless display and miniature, ruggedized PC data-logger, which eliminated the need for separate depth and YSI data-loggers. The 2004 data and data format are identical to that gathered in 2003. Surface water (approximately 0.5m deep depending on vessel speed and angle of plane) was collected through a pipe ("ram") deployed from the transom of the vessel. Assisted by a high-speed pump, water was passed through a hose to a flow meter and then to an inverted flow-through cell to ensure that no air bubbles interfere with sampling or data sonde performance. Finally, the water sample moved to an array of water quality sensors which recorded the water quality variables, time, and geographic position. The total system water volume was approximately 3.0 liters.

DATAFLOW surveys were conducted from a CBL vessel and typically involved two field technicians to perform sampling operations and safe navigation. The DATAFLOW package consisted of a water circulation system that is sampled at a prescribed rate by a Yellow Springs, Inc. 6600 DataSonde combined with a ruggedized minicomputer running data-logging software. This sensor provided data on dissolved oxygen, temperature, conductivity and salinity, as well as turbidity and fluorescence (from which we derived chlorophyll-a concentration).The computer also recorded spatial position and depth data with an accuracy of approximately 10 meters from a Garmin 168 GPS/Depthsounder unit utilizing an NMEA 0183 v. 2.0 data format. Data files were output in a comma and space delimited format. Although the flow rate does not affect any of the sensor readings, decreased flow is an indication of either a partial blockage or an interruption of water flow to the instrument and affects the water turnover rate of the system. An inline flow meter wired to a low-flow alarm alerted the operators of potential problems as they occurred. The low-flow alarm was set to 3.0 liters per minute. A single 1100 gallon per hour "Rule Pro Series" pump provided approximately 20-25 liters per minute of flow to the system. During the course of a cruise, the vessel stopped at established, calibration stations located along the cruise track. While anchored, whole water samples were taken from the water circulation system. The Nutrient Analytical Services Laboratory (NASL) at Chesapeake Biological Laboratory (CBL) analyzed this water sample for dissolved nutrient content, concentrations of total suspended and volatile solids, and chlorophyll-*a*. Samples were also taken and analyzed for chlorophyll-*a* by the Maryland Department of Health and Mental Hygiene (MD DHMH), and these data were transmitted directly from MD DHMH to Maryland DNR. The crew also measured turbidity using a Secchi disk, and determined the flux of Photosynthetically Active Radiation (PAR) in the water column using Li-Cor quanta sensors. These calibration stations provided additional enhancement of the high-resolution description of a tributary, and provided laboratory values with which we verified instrument parameter values obtained during the cruise. The data that were collected substantially improved characterization of water quality conditions in the near shore habitats as well as system-wide water quality.

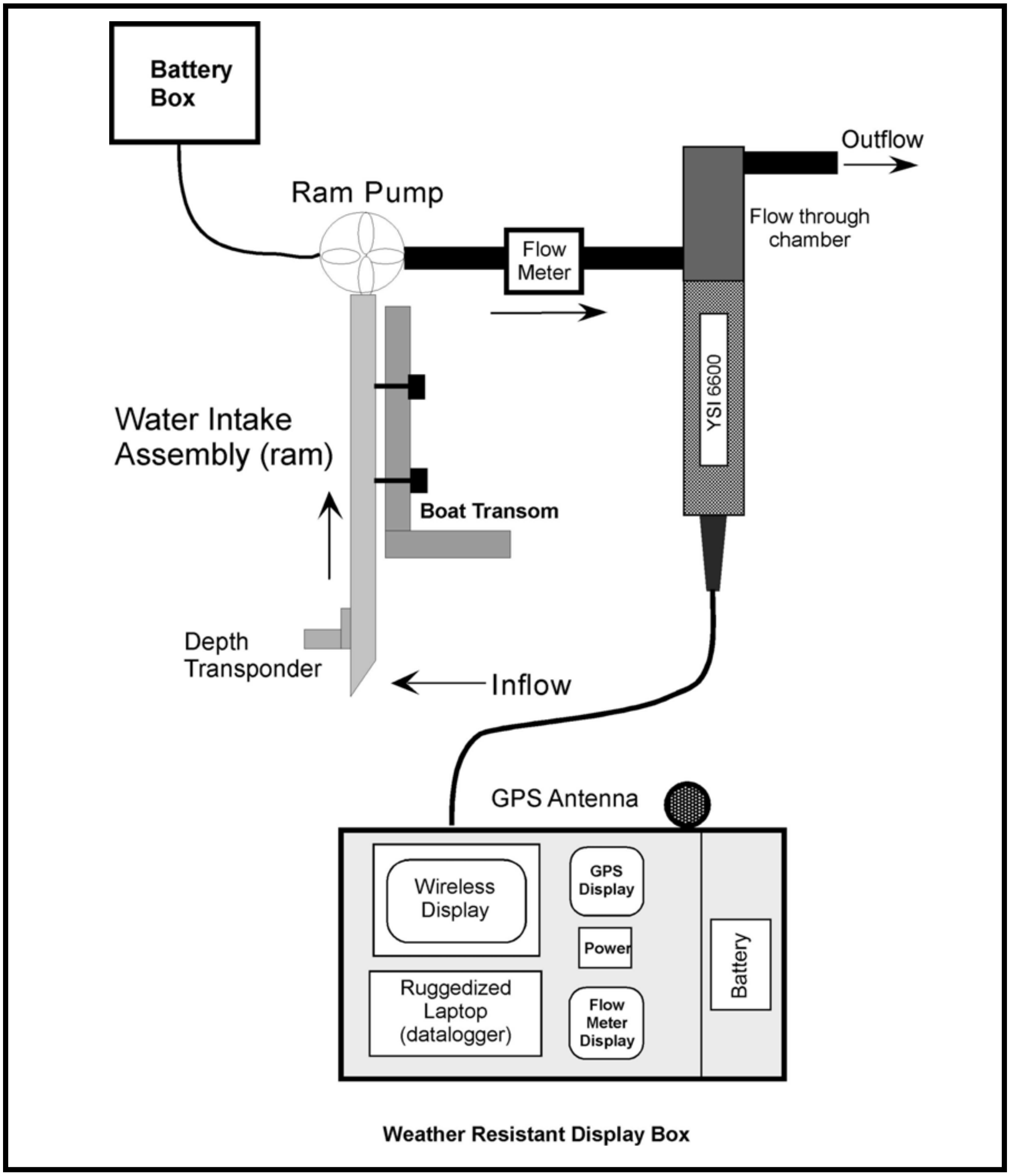


Figure 3-1. Schematic diagram of DATAFLOW VI illustrating the path of water through the instrument. *Seawater is drawn up through the ram behind the transom of the research vessel. A centrifugal pump mounted on the ram (ram pump) boosts the flow. The water flows through a paddle-wheel type flow meter that triggers a horn if the flow rate falls below 3 l min-1, and then to an inverted flow-through chamber where it is sampled by the YSI 6600 datasonde sensors. The inverted mount is used in order to evacuate any air bubbles in the system. After sampling, the water is discharged overboard. The displays for the instruments, including the Wireless Display for the Ruggedized Laptop, Garmin 168 GPS/Depthsounder, and flow meter are located on the instrument platform.*

3.2.2 Sampling locations and frequency

DATAFLOW cruises were performed on a monthly basis on the lower (mesohaline) and upper (tidal fresh and oligohaline) portions of the Patuxent River estuary, for a total of sixteen cruises during 2004. Typically, the lower Patuxent (Cedar Point to Benedict – Mesohaline Region) was sampled on the first day, and the upper Patuxent (Benedict to Jug Bay – Tidal Fresh and Oligohaline Region) on the second, though severe weather or other contingencies occasionally required rescheduling. Two of the cruises (March and November) were truncated, covering an area from Solomons to Broomes Island in order to capture early and late season data for SAV restoration efforts at CBL and Jefferson Patterson Park. The cruise dates are listed in Table 3-1. Cruise tracks were chosen to provide a reasonable coverage of each water body while sampling both near-shore and mid-river waters. A sample cruise track is shown for each region in Figure 3-2. The selection of calibration station locations in each region was made to sample the greatest possible range of water quality conditions found during each cruise and to sample a broad spatial area. Every effort was made to maintain the same location of calibration stations between cruises. The location of several calibration stations were also chosen to correspond to Maryland DNR long-term fixed and continuous monitor water quality monitoring stations within each segment, and these stations were sampled during each cruise. The coordinates for those stations are listed in Table 3-2.

Table 3-1. DATAFLOW cruise dates in 2004.

Region	Spring	Summer	Fall
Patuxent River	3/23, 4/12, 4/27, 5/10, 5/11, 6/7, 6/8	7/13, 7/14, 8/10, 8/11	9/13, 9/14, 10/6, 10/7, 11/16

Table 3-2. Location of DATAFLOW calibration stations.

*coincident with DNR Long-Term Fixed Station water quality monitoring stations †coincident with DNR Continuous Monitoring instrument stations **Coordinates are in NAD 83**.

Region	Station	Latitude (deg mins)	Longitude (deg mins)
Patuxent River	PXNS01	38° 17.046' N	76° 23.274' W
	PXDF10*	38° 18.756' N	76° 25.332' W
	SV09†	38° 19.002' N	76° 27.156' W
	PXDF09*	38° 20.388' N	76° 29.094' W
	PXPO†	38° 24.528' N	76° 31.308' W
	PXDF08*	38° 25.368' N	76° 36.126' W
	PXBD†	38° 30.600' N	76° 40.650' W
	PXDF05*	38° 34.866' N	76° 40.602' W
	PXDF06	38° 31.518' N	76° 39.840' W
	PXDF02	38° 33.630' N	76° 39.630' W
	PXKL†	38° 37.578' N	76° 40.608' W
	PXDF03	38° 41.220' N	76° 41.748' W
	PXDF01	38° 45.426' N	76° 41.958' W

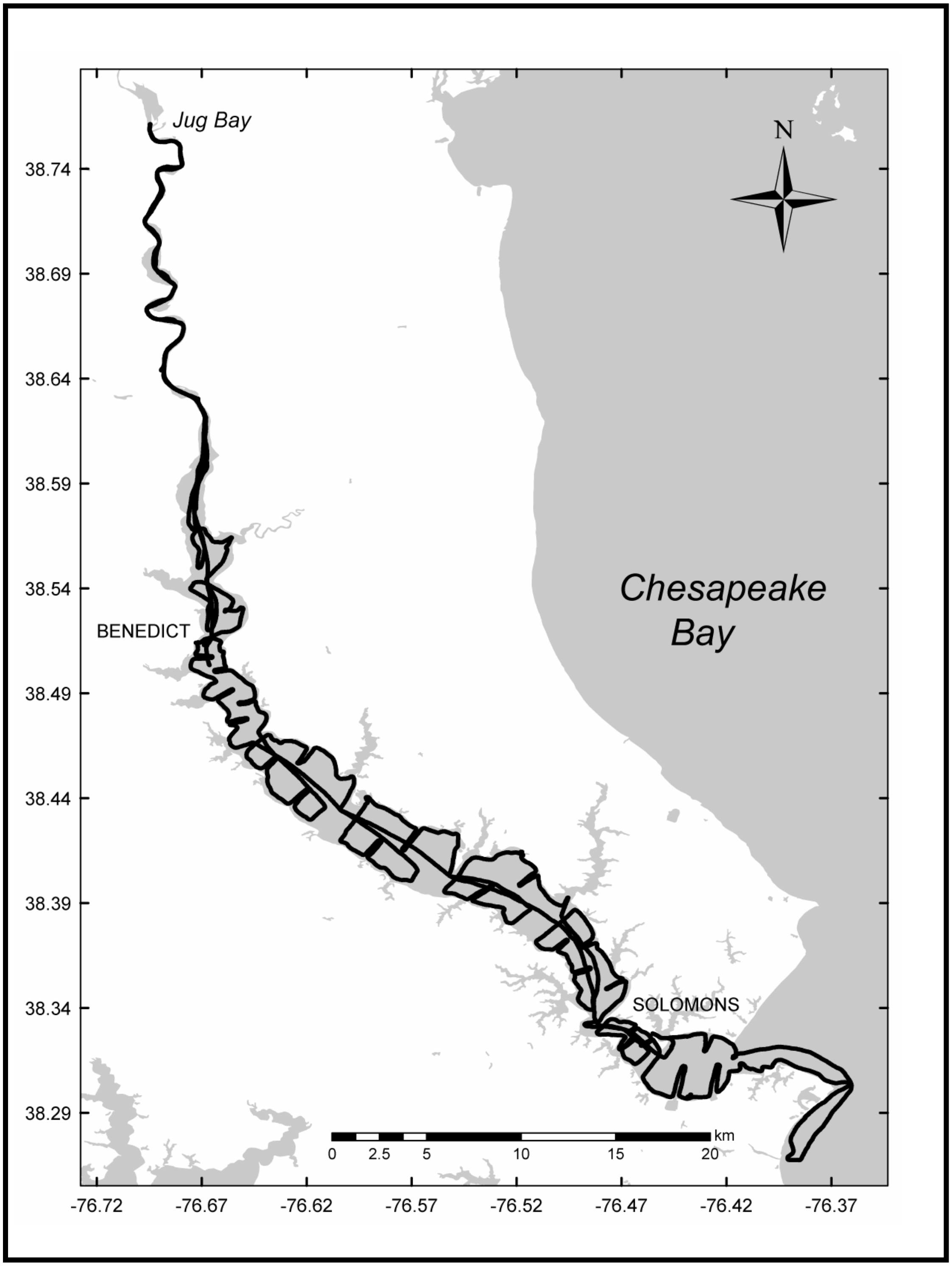


Figure 3-2. Typical DATAFLOW cruise track for the Patuxent River, October, 2004.

3.2.3. Calibration Stations

At each calibration station, a series of measurements were made and whole water samples collected. Locations of the calibration stations are found in Figure 3-3. Secchi depths were recorded and Li-Cor quanta sensors were used to determine the amount of photosynthetically active radiation (PAR) in the water column. These data were used to determine the water-column light attenuation coefficient (Kd), and subsequently, the new "percent light through water" (PLW) parameter for SAV habitat requirements (USEPA, 2000). YSI datasonde turbidity sensor output (NTU) was individually regressed against Secchi depth and Kd. Values. Whole water samples were taken, later filtered in the lab, and sent for analysis at NASL at CBL for both total and active chlorophyll-*a* values, as well as total suspended solids (TSS) and total volatile solids (TVS). These chlorophyll-*a* values were compared against chlorophyll sensor output. Water samples were also filtered on station for later NASL analysis to determine concentrations of dissolved nutrients. These nutrients included dissolved inorganic nitrogen (DIN; summation of ammonium [NH_4^+], nitrite [NO_2^-], nitrate [NO_3^-]) and dissolved inorganic phosphorus (DIP). Other nutrients analyzed included Dissolved Organic Carbon (DOC), Particulate Carbon (PC), Particulate Phosphorus (PP), Particulate Inorganic Phosphorus (PIP), Total Dissolved Nitrogen (TDN), Total Dissolved Phosphorus (TDP), and Silicate (Si). A detailed explanation of all field and laboratory procedures is given in the annual CBL QAPP documentation (Rohland et al. 2004).

3.2.4 Contour Maps

Contour maps were generated using the ESRI ArcGIS 8.3 software suite to assist in the interpretation of spatial patterns of different water quality parameters. Examples of these maps are found in this report. Interpolation was accomplished using the Ordinary Kriging routine in the Geostatistical Analyst extension within the ArcGIS software. Interpolation technique is subject to much discussion regarding effectiveness and veracity of representation, so these maps are provided to illustrate only one method used to visualize patterns found in the chosen dataset. Datasets were also plotted using the ArcGIS software to reveal route events during individual cruises. Since each sample from the DATAFLOW system is recorded as a discrete point in space and time, this proved to be a useful quality assurance tool to remove erroneous data (e.g., extreme turbidity values due to vessel grounding or propeller induced wash). Each map was interpolated from discrete measurements taken during each DATAFLOW cruise. If multiple datapoints were spatially indistinguishable, the interpolation routine would use the average of these coincidental points.

The usefulness of linear regressions to accurately translate YSI sensor output to universally recognized standards requires that a sufficient range of data be present in order to obtain a high correlation between variables. This can be accomplished by using data collected from a single cruise, or by combining data from multiple cruises, and locations. The rationale for using data from a single cruise comes from the assumption that the specific components leading to water column light attenuation (or species if measuring chlorophyll) will be more similar within a single cruise compared to data collected over the entire season, resulting in a better fit of the data. In contrast, when data are combined over a whole season, or from different locations, there is a greater chance that the relationship between the two measurement variables will vary among cruises, thus leading to an overall lower correlation. However in circumstances where the observed gradient (turbidity or chlorophyll) within a single cruise is relatively small compared to the resolution and accuracy of the instruments, a higher correlation may be achieved by combining the data from multiple cruises. We present examples of these issues below.

3.2.5. Data QA/QC Procedures

The data gathered with DATAFLOW underwent QA/QC processes approved by managers and researchers from Maryland and Virginia through Chesapeake Bay Program Tidal Monitoring and Analysis Workgroup meetings (Rohland et al. 2004). Data files were formatted and checked for erroneous values using a macro developed by Maryland DNR for Microsoft Excel. The QA/QC process ensured that extreme values resulting from data concatenation error (a function of how the instrument data are logged) or turbidity spikes resulting from operating a vessel in shoal areas could be flagged in the proofed dataset. Data are also visually inspected using ArcGIS where specific values can be compared with calibration data and the cruise log in order to eliminate obvious erroneous values as described above. Combined datasets from the entire sampling season were also plotted in order to reveal extreme values or other temporal patterns.

3.2.6. Cumulative Frequency Distributions

Given the vast amount of data collected during spatially intensive shallow water monitoring cruises, we can apply novel methods with which to analyze these data. One such method is the development of cumulative frequency distributions which are formulated in order to determine how much of a given area complies or exceeds a specific Bay Program water quality criterion, such as water column light availability, dissolved oxygen concentration, or chlorophyll-*a* concentration. These methods have been discussed by researchers at the Virginia Institute of Marine Science, the Chesapeake Bay Program, and Maryland DNR in the context of submerged aquatic vegetation habitat, water quality data interpolation, and water quality mapping and continuous monitoring data. In this report turbidity data gathered on mapping cruises on the Lower Patuxent river during 2004 were examined in order to experiment with this novel approach to habitat assessment.

The NTU output of the datasonde was first converted to a unit of measure applicable to assessing light availability in the context of Bay Program criteria, namely Kd. Using regression data from current and previous observations on the lower Patuxent river, we derived a correlation between NTU and Kd wherein 10 NTU was equivalent to 1.5 Kd: the threshold value for shallow water column light availability in mesohaline littoral habitats. Instrument data were then sorted using this threshold value and establish both the percent of total number of shallow water observations during each cruise and the number and percentage of these observations that exceeded the threshold value for a given cruise. These results are illustrated in Figure 3-23.

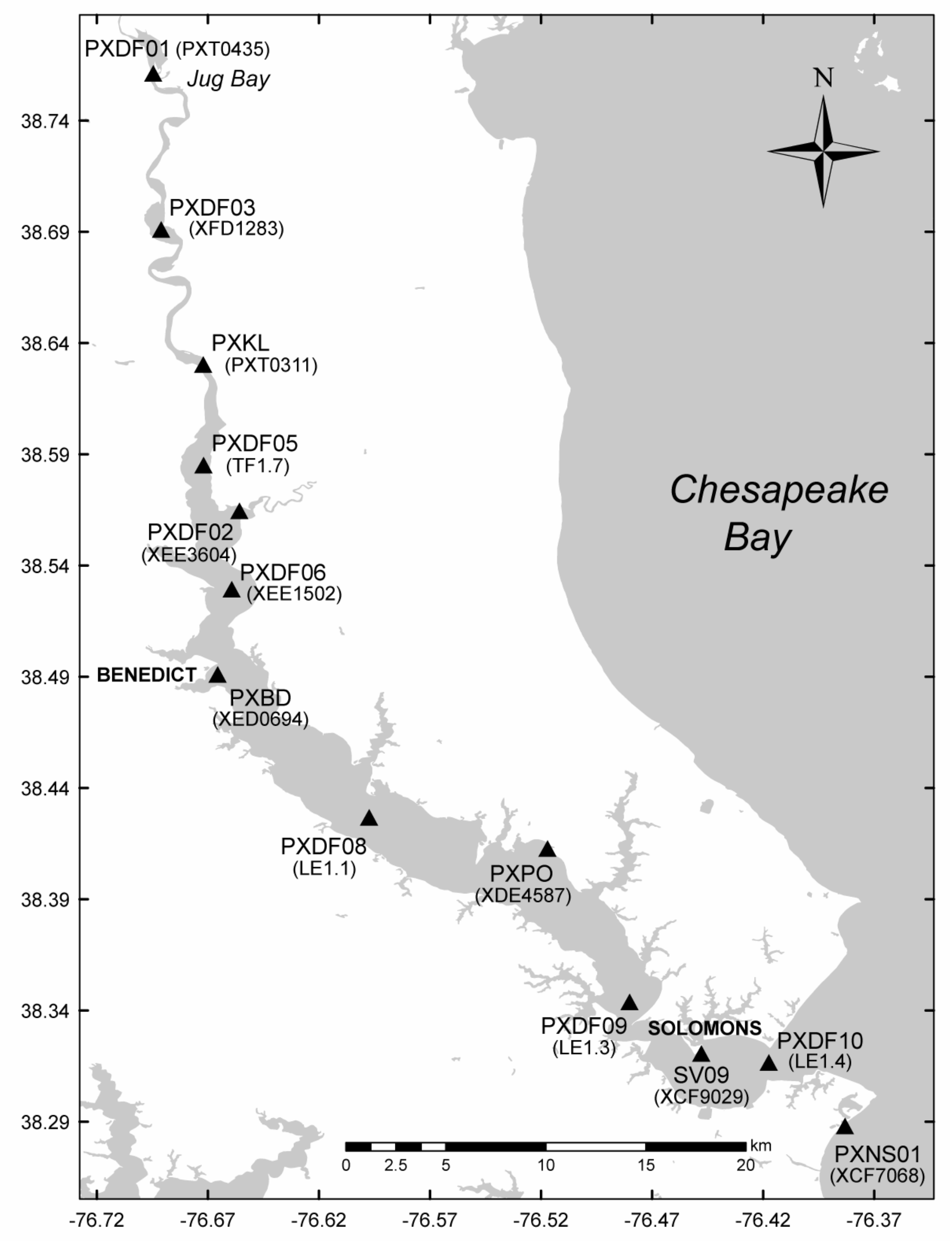


Figure 3-3. DATAFLOW calibration stations on the Patuxent River estuary, 2004.

3.3 Results

3.3.1. Fixed Calibration Station Nutrient Concentrations

A wide range of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) concentrations was observed in both the upper and lower portions of the Patuxent River estuary. Summary statistics for surface water dissolved nutrient concentrations at each calibration station are shown in Table 3-3.

Table 3-3. Mean, Median, Minimum and Maximum DIN and DIP concentrations at calibration stations on the Patuxent River estuary, 2004.

Lower Estuary		**PXNS01**	**PXDF10**	**SV09**	**PXDF09**	**PXPO**	**PXDF08**	**PXBD**
Dissolved Inorganic Nitrogen (µM N)	Mean	26.81	25.58	22.97	22.27	18.38	12.91	17.23
	Median	32.50	31.57	29.57	25.64	10.86	5.32	8.64
	Min	2.49	4.83	0.55	0.74	1.10	0.72	1.46
	Max	54.07	53.21	52.14	53.79	53.57	55.07	71.50
Dissolved Inorganic Phosphorus (µM P)	Mean	0.16	0.20	0.19	0.31	0.21	0.51	1.24
	Median	0.08	0.08	0.11	0.29	0.19	0.35	1.40
	Min	0.06	0.03	0.04	0.03	0.05	0.03	0.30
	Max	0.47	0.58	0.66	0.76	0.40	1.20	1.97

Upper Estuary		**PXDF06**	**PXDF02**	**PXDF05**	**PXKL**	**PXDF03**	**PXDF01**
Dissolved Inorganic Nitrogen (µM N)	Mean	14.89	15.05	24.15	33.77	35.79	40.81
	Median	14.14	6.93	17.00	24.57	29.79	28.71
	Min	3.33	2.54	12.14	14.14	9.64	23.93
	Max	32.57	38.79	46.71	56.07	63.36	76.43
Dissolved Inorganic Phosphorus (µM P)	Mean	1.47	1.35	1.85	1.15	0.90	0.45
	Median	1.72	1.42	1.47	1.21	0.83	0.40
	Min	0.25	0.31	0.80	0.94	0.44	0.25
	Max	2.44	1.91	4.80	1.33	1.44	1.13

The highest median DIN value from the Lower Patuxent was observed at site PXNS01 near Cedar Point and the Patuxent Naval Air Station. The second highest median value was observed at site PXDF10, a deepwater station near the mouth of the Patuxent River. The highest median DIP value for the Lower Patuxent was observed at site PXBD, as in

2003. This station is coincident with a Continuous Monitoring site, and is located near the transition zone between the mesohaline and tidal fresh regions of the Patuxent River, as delineated by the Chesapeake Bay Program.

The highest median DIN value on the Upper Patuxent was observed at site PXDF03. This station is located near Jones Pt. near the mouth of Hall Creek. The highest median DIP value on the same segment of the Patuxent was observed at site PXDF06, just south of Gods Grace Ptoint on the Calvert shoreline.

Other water column nutrient concentration distributions are illustrated in Figures 3-4 through 3-7. Observed ammonium values did not exhibit a general upriver trend this year as they did in 2003, while observed Nitrite + Nitrate concentrations appeared to increase in an up-river direction. The lower Patuxent had generally lower Nitrite + Nitrate water column concentrations, though the ranges were rather wide (Figure 3-5). Observed water column Dissolved Organic Carbon concentration increased in an upstream direction, as was observed in 2003, while Particulate Carbon (PC) concentration did not exhibit any discernable trend (Figure 3-6). Site SV09 had the widest range of PC values, where we also observed the widest range and highest concentrations of observed instrument and extracted total chlorophyll-*a* concentrations. Median values for Total Dissolved Nitrogen were higher in the upper Patuxent, though Total Dissolved Phosphorus water column concentrations ranged widely, particularly in the transition zone near Benedict between the lower and upper portions of the Patuxent estuary (Figure 3-7).

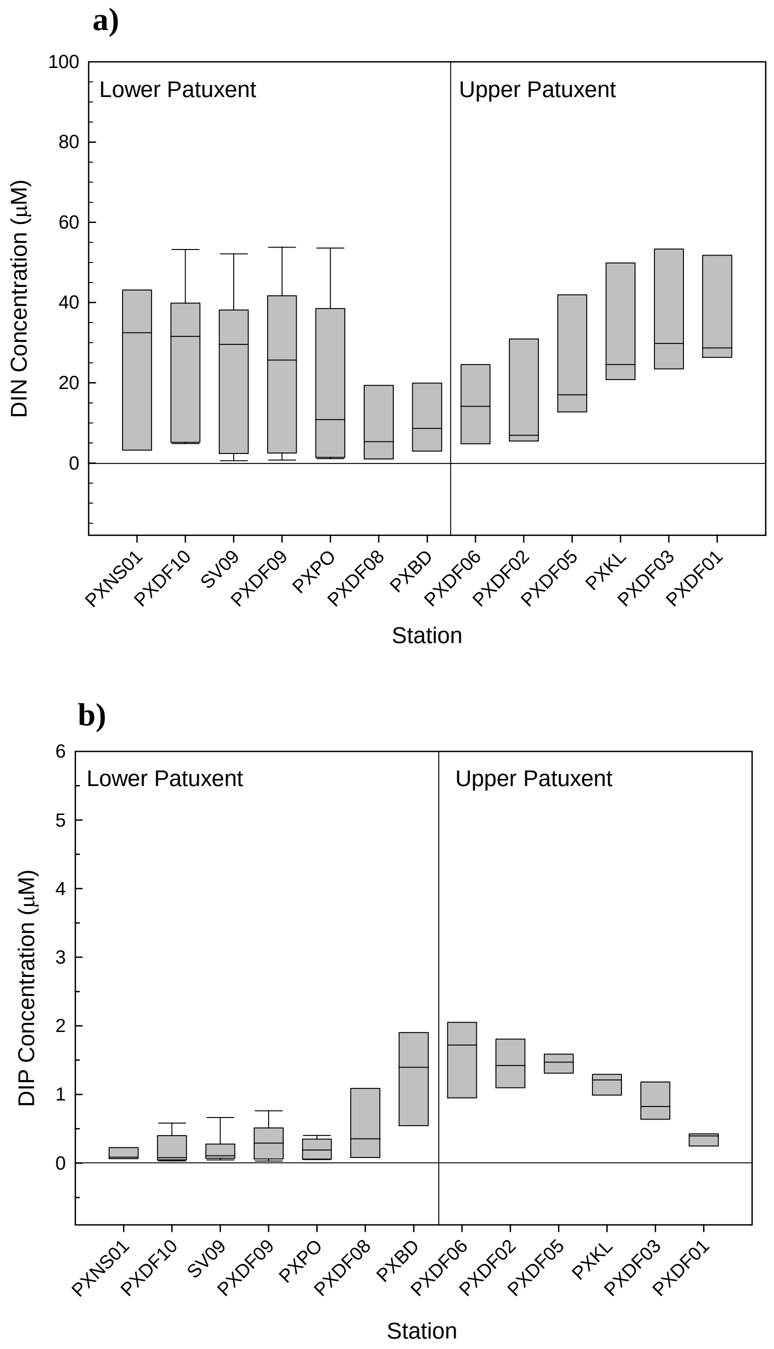


Figure 3-4. Distributions of (a) dissolved inorganic nitrogen (DIN) and (b) dissolved inorganic phosphorus (DIP) concentrations at calibration stations on the Patuxent River estuary, 2004. Box ends represent 25th and 75th percentiles, while horizontal lines represent median values; whiskers represent 10th and 90th percentiles where additional cruises provided sufficient data.

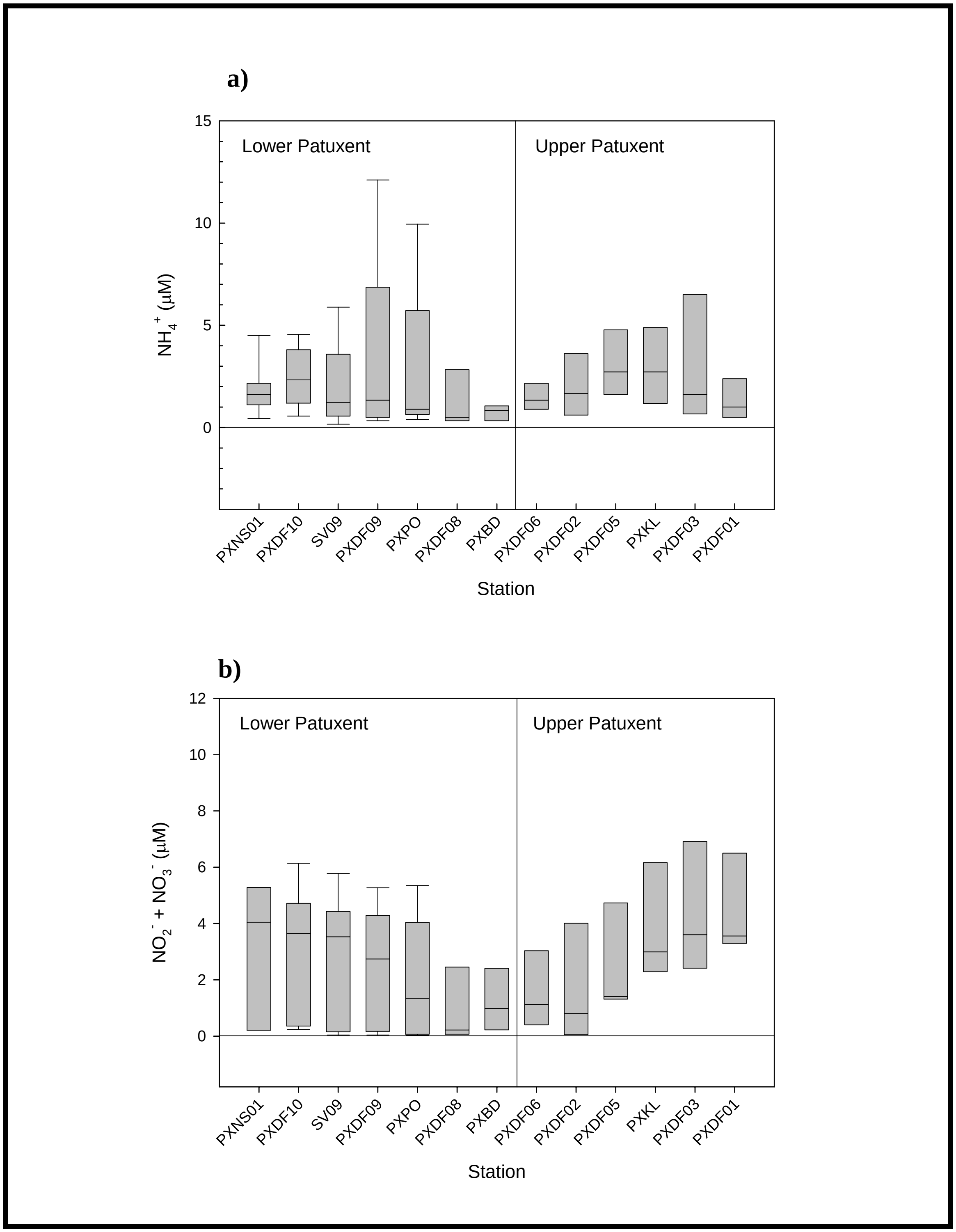


Figure 3-5. Distributions of (a) ammonium and (b) nitrite + nitrate concentrations at calibration stations on the Patuxent River estuary, 2004. Box ends represent 25th and 75th percentiles, while horizontal lines represent median values; whiskers represent 10th and 90th percentiles where additional cruises provided sufficient data.

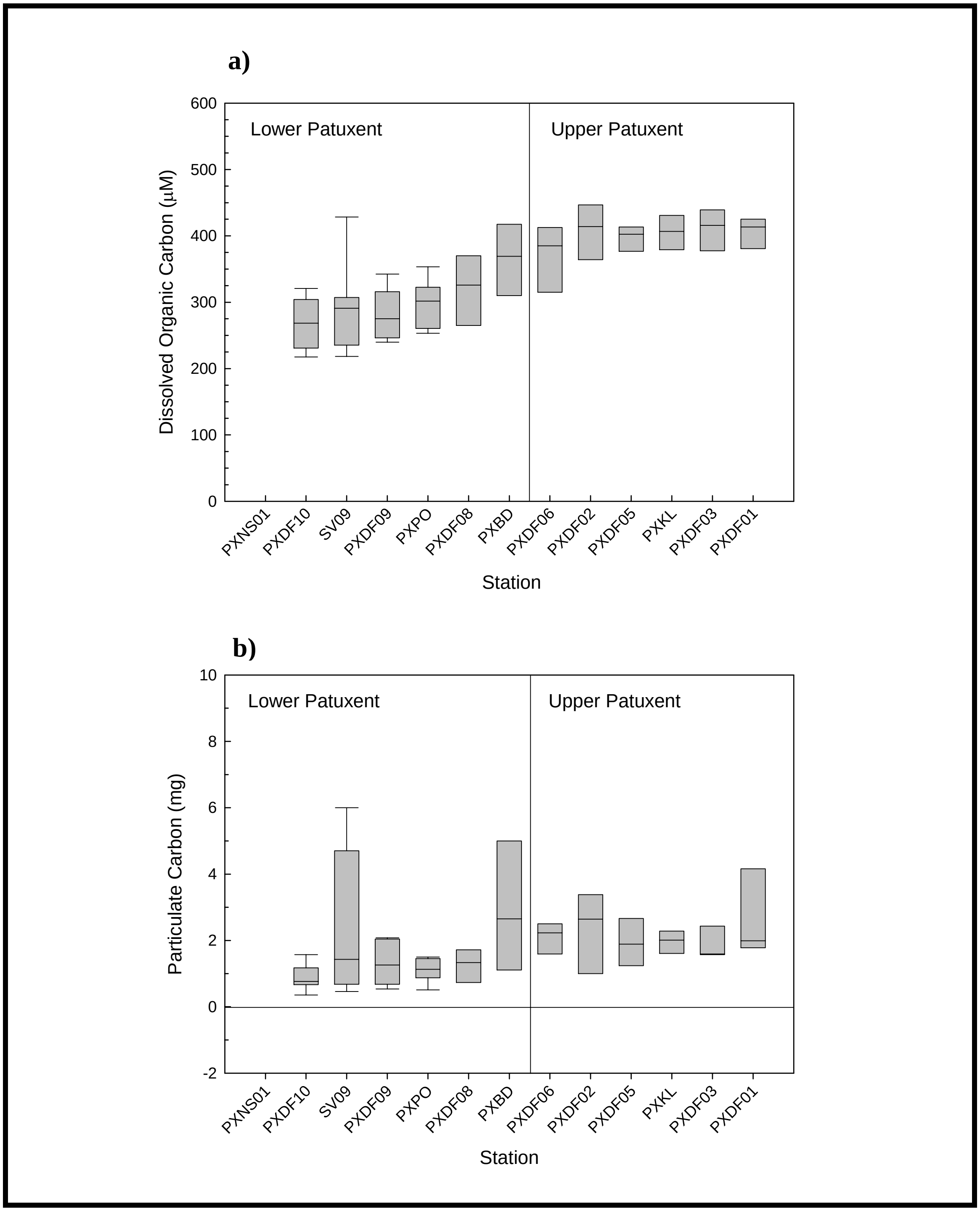


Figure 3-6. Distributions of (a) dissolved organic carbon concentration and (b) particulate carbon concentration at calibration stations on the Patuxent River estuary, 2004. Box ends represent 25th and 75th percentiles, while horizontal lines represent median values; whiskers represent 10th and 90th percentiles where additional cruises provided sufficient data.

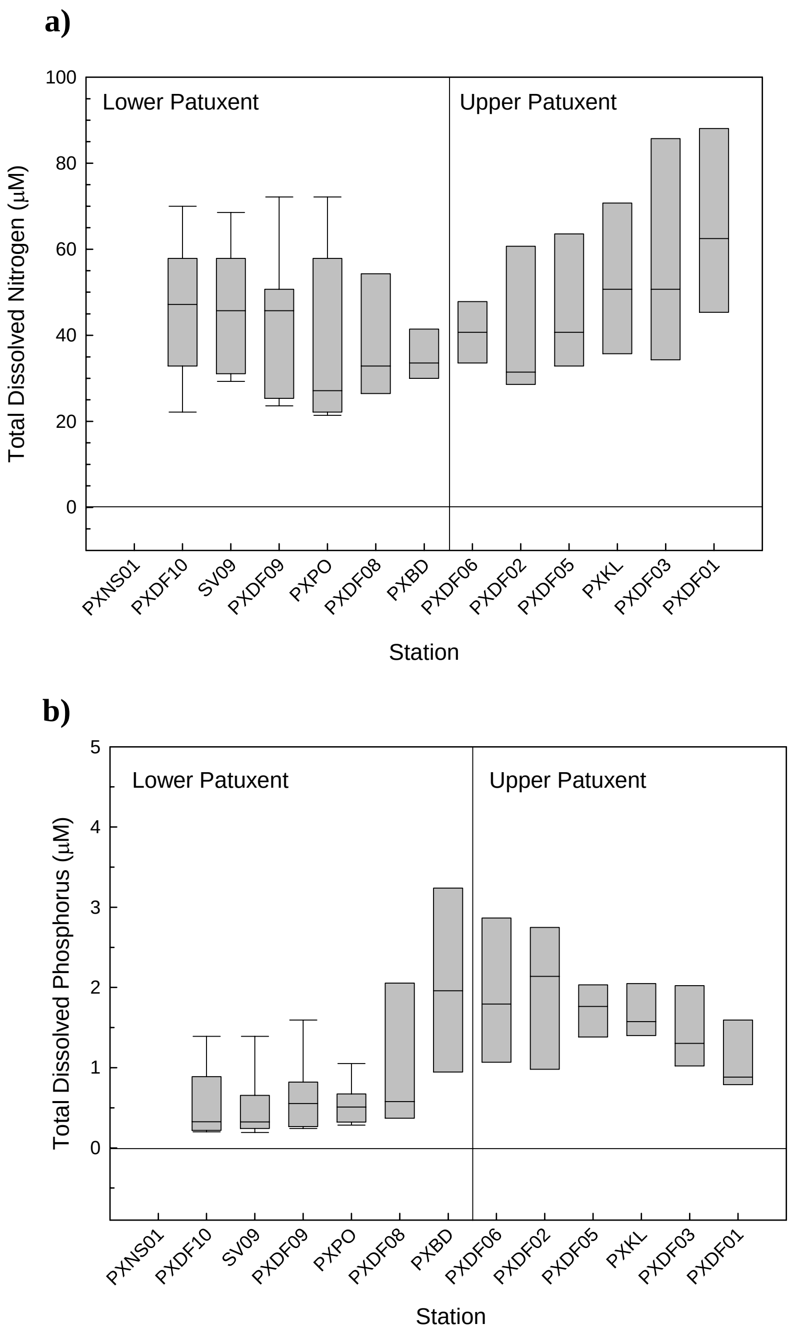


Figure 3-7. Distributions of (a) total dissolved nitrogen and (b) total dissolved phosphorus concentration by calibration station on the Patuxent River estuary, 2004. Box ends represent 25th and 75th percentiles, while horizontal lines represent median values; whiskers represent 10th and 90th percentiles where additional cruises provided sufficient data.

3.3.2 Physical Conditions

Salinity values measured with the DATAFLOW system (> 118,000 observations) exhibited a large, but not unexpected, range of values. The minimum salinity recorded was 0.06 in the upper Patuxent estuary near Lyons Creek Wharf on April 27, 2004, while the maximum value was 13.4 near Cedar Point in the lower Patuxent estuary near the river mouth on July 13. The median salinity value for the whole dataset was 9.1. Overall, DATAFLOW surface water pH values ranged from a minimum 6.63 near Hunting Creek on July 14 and a maximum of 8.98 near the southern end of Jug Bay on May 11. Median surface water pH for the entire dataset was 7.88. DATAFLOW surface water dissolved oxygen concentrations also varied substantially throughout the entire season with a minimum of 3.65 mg l^{-1} mid-river between Broomes Island and Battle Creek on July 14 and maximum of 15.10 mg l^{-1} on October 16 at the same location. The maximum concentration was observed during algal bloom conditions. Dissolved oxygen concentrations below 5.0 mg l^{-1} were found predominantly mid-channel in the lower Patuxent estuary during the June, July, August, and September cruises, and in the upper Patuxent Estuary between Benedict and Jones Point during the same periods. Median surface water dissolved oxygen concentration for the 2004 season was 7.80 mg l^{-1}. Surface water temperatures had a wide range in the lower estuary, while the upper estuary had less variability. (Fig. 3-9b). DATAFLOW data showed a minimum surface water temperature was 6.85 C in the lower estuary at the mouth of the Patuxent between Drum and Fishing Points on March 23 (6.25 C on the same day near Cedar Point in the Bay proper) and the maximum of 31.82 C near Potts Point in the upper estuary on July 14. DATAFLOW optical turbidity ranged from a low of the instrument resolution value of 0.10 NTU at the CBL research pier on November 16 and a maximum of 113.5 in the upper estuary north of Lower Marlboro near Hall Creek on June 8. DATAFLOW sampling data for *in vivo* chlorophyll had a minimum of the instrument resolution value of 0.1 µg l^{-1} in the lower estuary between Hungerford and Hellen Creeks on May 10 and a maximum of 368.1 µg l^{-1} in the upper estuary near Buena Vista at Gods Grace Point on June 8.

Fixed station calibration data observed in 2004 reinforced the presumption that higher turbidity in the upper Patuxent results primarily from seston, rather than high concentrations of primary producers. The area in the vicinity of Benedict and Chalk Point (near station PXBD) continued to be a bloom ‘hotspot.’ A measurement related to turbidity, Mean Light Attenuation Coefficient (Kd) values were also much higher in the upper Patuxent (Figure 3-12). These Kd values would be used to examine instrument turbidity output and Secchi disk observations as outlined in the following section.

Observed salinity and pH values decreased, as would be expected, in an upstream direction (Figure 3-8). Stations PXDF03 and PXDF01 remained relatively fresh throughout the sampling season, without a great deal of variability. The buffering effects of higher salinities in the lower estuary resulted in a relatively constant pH values. Variability in pH values was higher in the upper, less saline Patuxent (Figure 3-8b). Dissolved oxygen concentrations were generally higher in the lower estuarine segment, possibly due to generally higher production and less turbidity; however, with this increased production, came greater excursions in DO range, but no *fixed station* DO concentration was below the CBP Habitat criterion of 5.0 mg l^{-1} (Figure 3-9). Site PXPO, near Jefferson Patterson Park on the Calvert County shoreline, had one of the greatest ranges of surface water DO concentration and coincided with a Continuous Monitoring station, while SV09 also exhibited a wide range of DO concentrations. Fixed station surface water temperature ranged between 6° C and 28° C during the course of the sampling season for the entire Patuxent River estuary, while median observed temperatures were somewhat lower in the upper Patuxent segment stations. The colder extremes observed in the lower Patuxent might be the result of early and late supplemental cruises designed to coincide with SAV observations and sampling.

The parameters of total suspended solids (TSS), and light attenuation (Kd) were only measured at the fixed stations, therefore represent a much smaller dataset compared to DATAFLOW data. Stations PXDF01 in the upper estuary and PXNS01 in the lower estuary exhibited the highest range of TSS values (Fig. 3-11a). TSS values were consistent with more turbid conditions found in the upper estuary, but values in the lower estuary showed a not insignificant range, perhaps owing to algal bloom events in the open waters or wind driven mixing in the near shore regions. Seasonal median Kd values typically increased at upstream stations, as illustrated in Fig. 3-11b. The highest Kd value was found at station PXDF01, and was more than likely the result of high concentrations of suspended sediment which is typical of this site near Jug Bay. The lowest Kd value was recorded at station PXNS01 near the Patuxent Naval Air Station in the lower estuary.

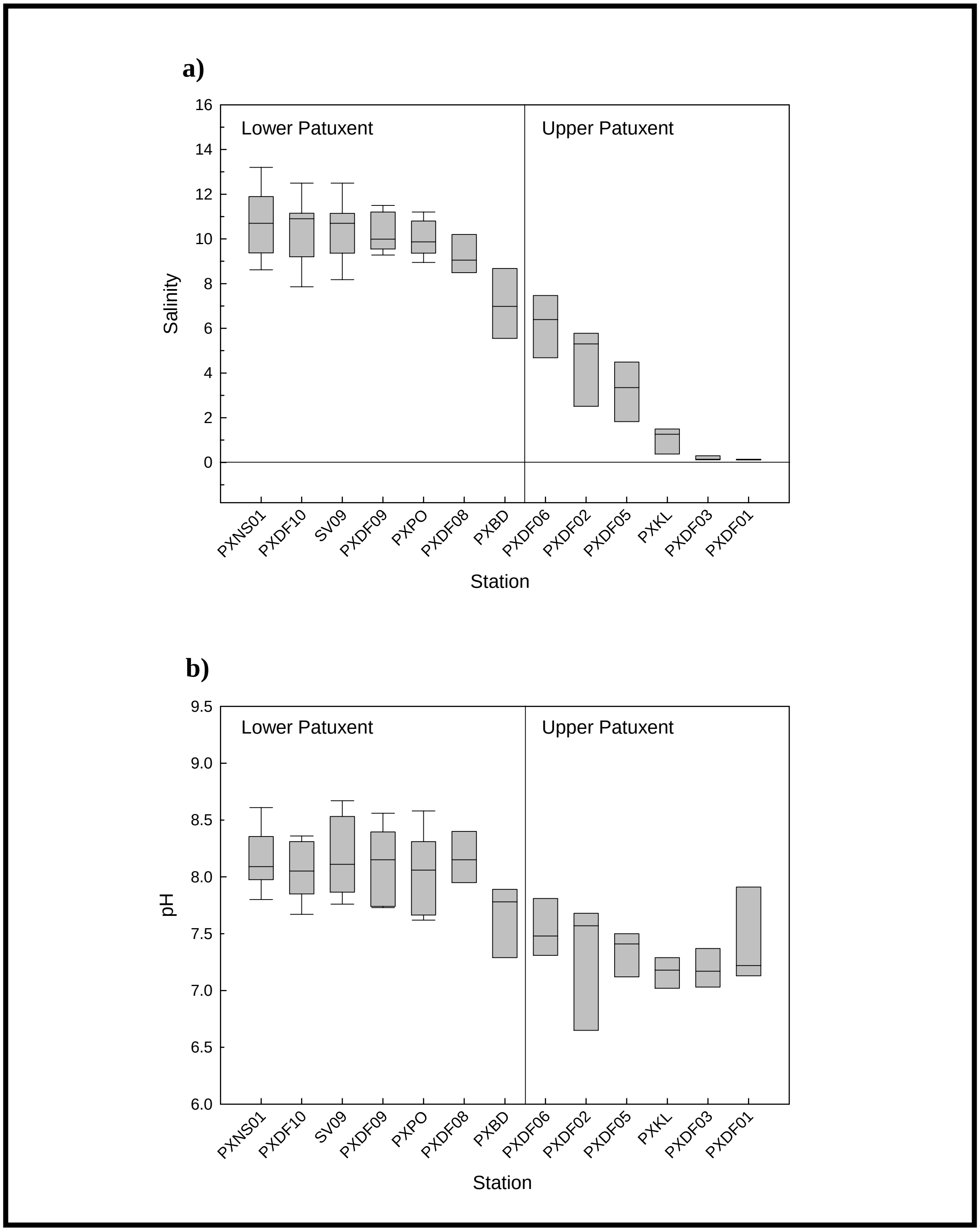


Figure 3-8. Distributions of (a) salinity and (b) pH values for calibration stations on the Patuxent River estuary, 2004. Box ends represent 25th and 75th percentiles, while horizontal lines represent median values; whiskers represent 10th and 90th percentiles where additional cruises provided sufficient data.

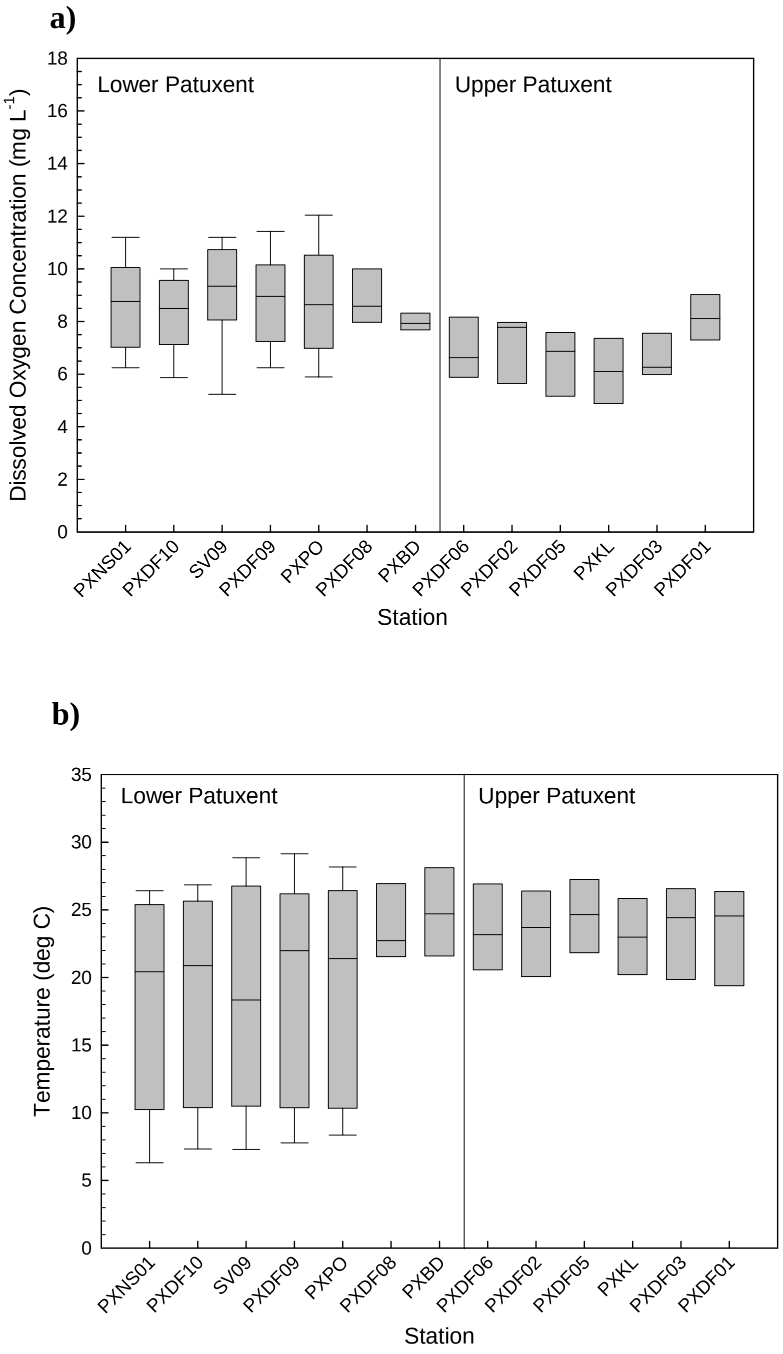


Figure 3-9. Distributions of (a) dissolved oxygen concentrations and (b) temperature at calibration stations on the Patuxent River estuary, 2004. Box ends represent 25th and 75th percentiles, while horizontal lines represent median values; whiskers represent 10th and 90th percentiles where additional cruises provided sufficient data.

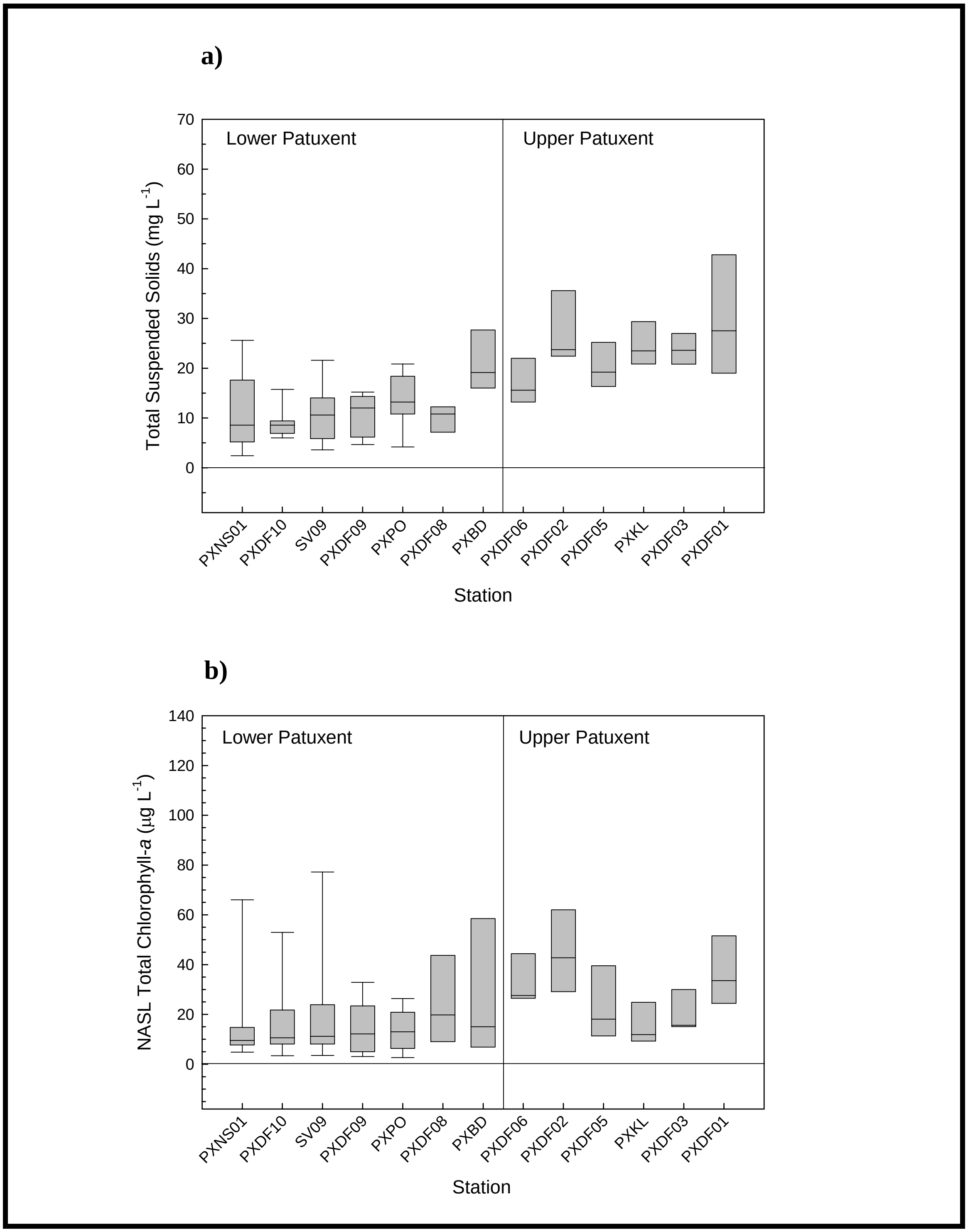


Figure 3-10. Distributions of (a) instrument turbidity and (b) instrument chlorophyll concentration at calibration stations on the Patuxent River estuary, 2004. Box ends represent 25th and 75th percentiles, while horizontal lines represent median values; whiskers represent 10th and 90th percentiles where additional cruises provided sufficient data.

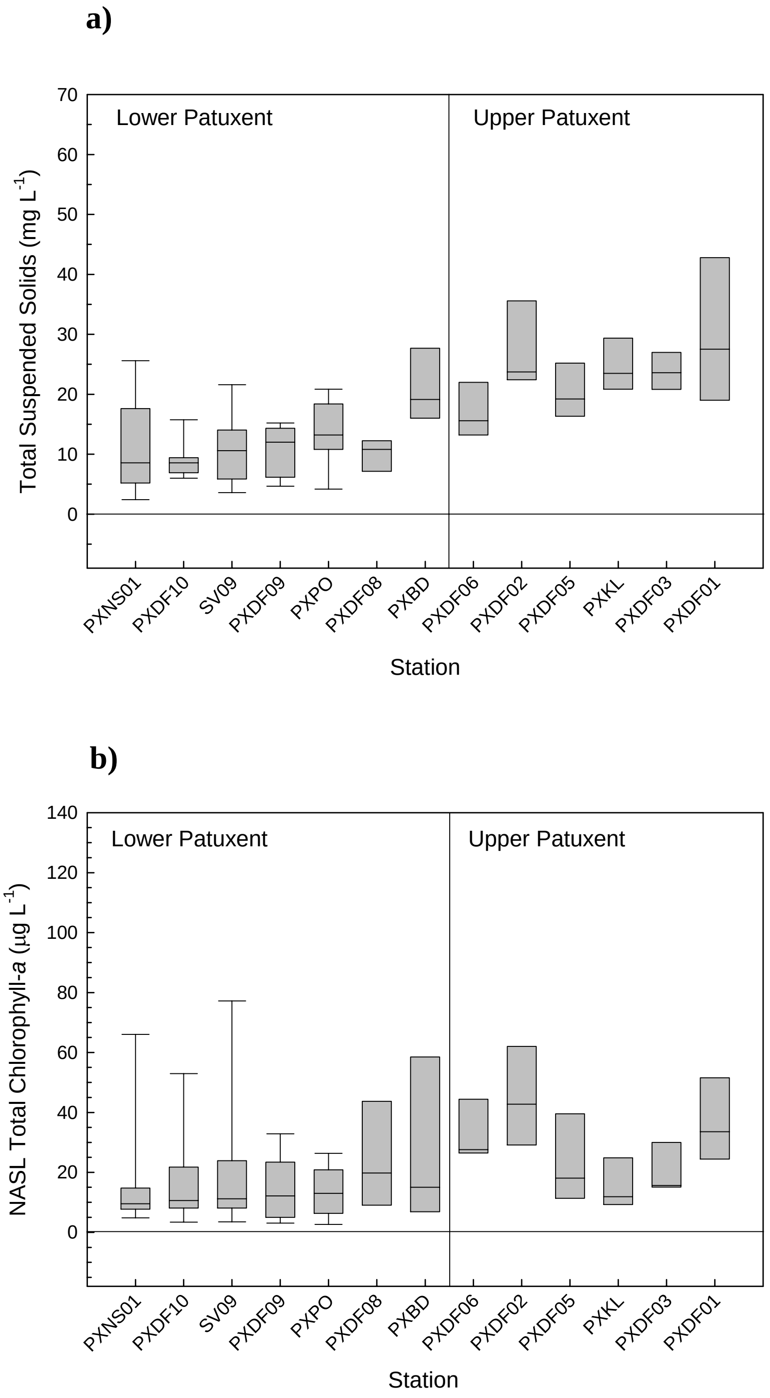


Figure 3-11. Distributions of (a) total suspended solids concentrations and (b) NASL extracted total chlorophyll-*a* concentrations at calibration stations on the Patuxent River estuary, 2004. Box ends represent 25th and 75th percentiles, while lines represent median values; whiskers represent 10th and 90th percentiles where additional cruises provided sufficient data.

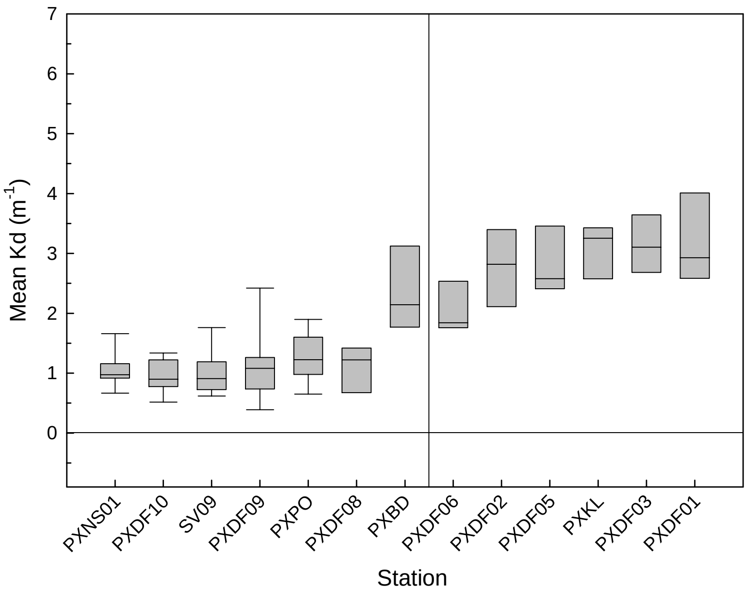


Figure 3-12. Distribution of mean Kd (light attenuation coefficient) at calibration stations on the Patuxent River estuary, 2004. Box ends represent 25th and 75th percentiles, while horizontal lines represent median values; whiskers represent 10th and 90th percentiles where additional cruises provided sufficient data.

3.3.3. Data Translations and Regressions

For all 2004 Patuxent River data, regressions of YSI data-sonde chlorophyll versus laboratory derived total chlorophyll-*a* values (collected at calibration stations) were well correlated (r^2 of 0.78, Fig. 3-13). This correlation compares favorably to the relationship derived from 2003 data.

Regression analyses were also performed to examine the relationship between turbidity measured by the YSI sensor (NTU) versus the mean light attenuation coefficient (Kd) derived through Li-Cor measurements, as well as the inverse of Secchi observations. All 2004 cruises produced an r^2 of 0.74 for Mean Kd versus YSI output, and an r^2 of 0.78 for Secchi versus YSI output (Figure 3-14). These regressions might also be strengthened by the strong gradients observed over the length of the Patuxent River estuary.

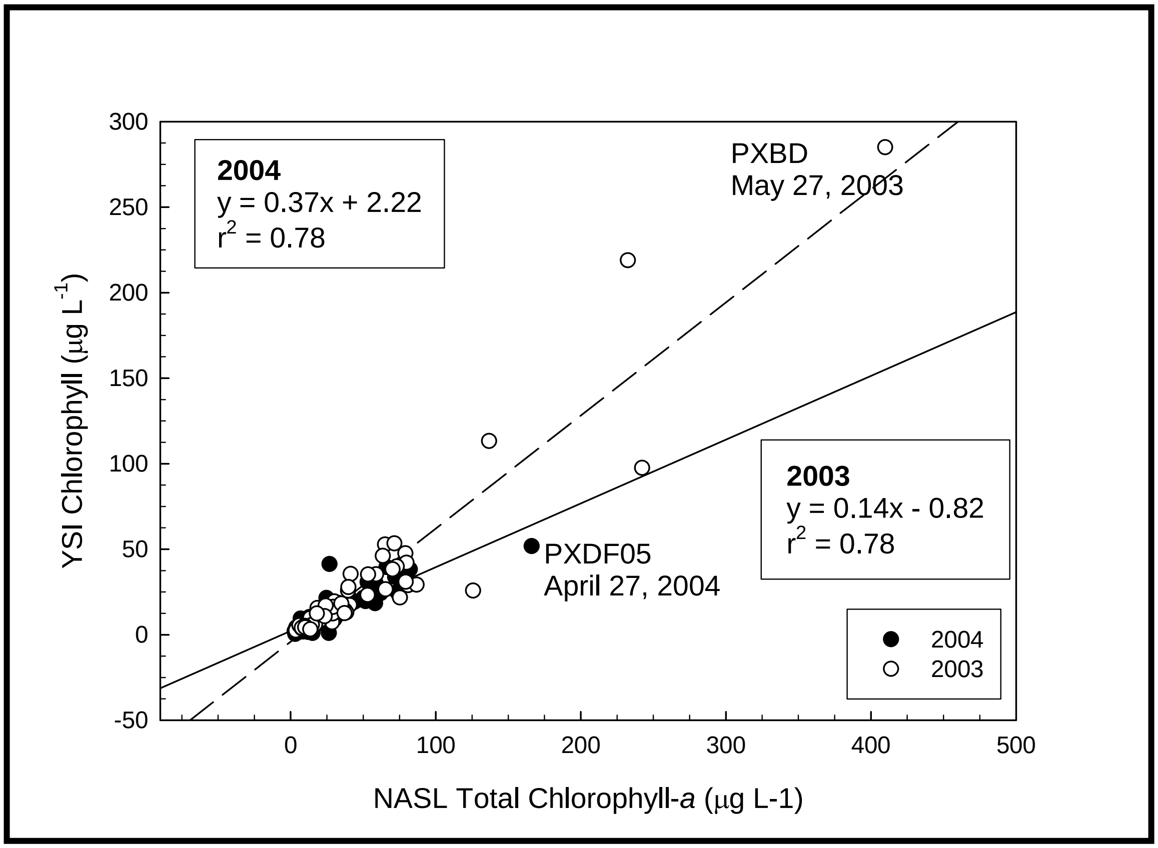


Figure 3-13. Correlation between laboratory extracted total chlorophyll-*a* and YSI data-sonde chlorophyll concentrations on the Patuxent River estuary, 2003 and 2004.

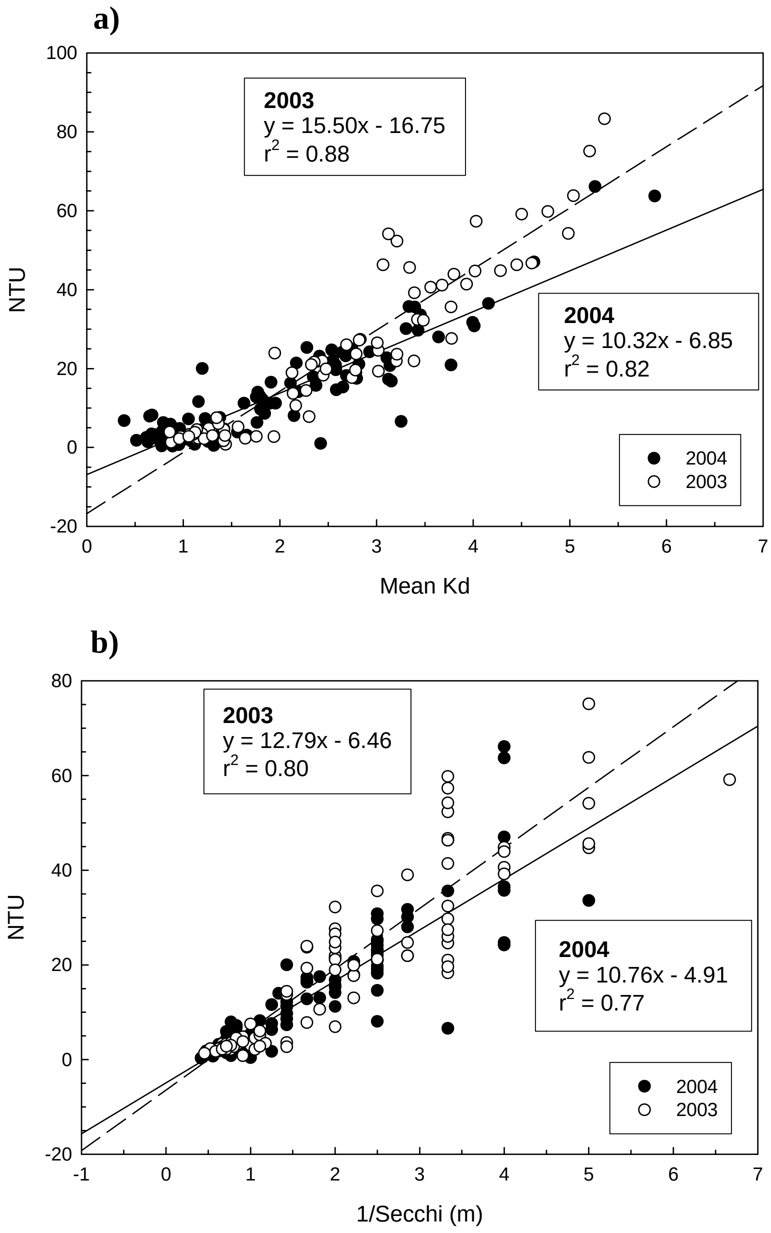


Figure 3-14. Relationships between (a) NTU and mean Kd, and (b) NTU and secchi^{-1} for calibration stations on the Patuxent River estuary, 2003 and 2004.

3.3.4 Surface Water Mapping

Two sets of maps contrasting two different parameters (turbidity and chlorophyll-a) were generated using desktop mapping software. One set includes the upper Patuxent and the other includes the lower Patuxent. In each comparison, the figures represent a set of observations for a cruise that took place in June, 2004, and a cruise in October, 2004. Specific dates for cruises on the upper and lower estuary are included on the maps. These maps help to illustrate the differences between the lower and upper portions of the estuary, as well as seasonal effects. For instance, one can see in the first two figures how high summer chlorophyll concentrations can affect turbidity in the lower estuary, while turbidity for the same cruise in the upper estuary is not caused by algal blooms.

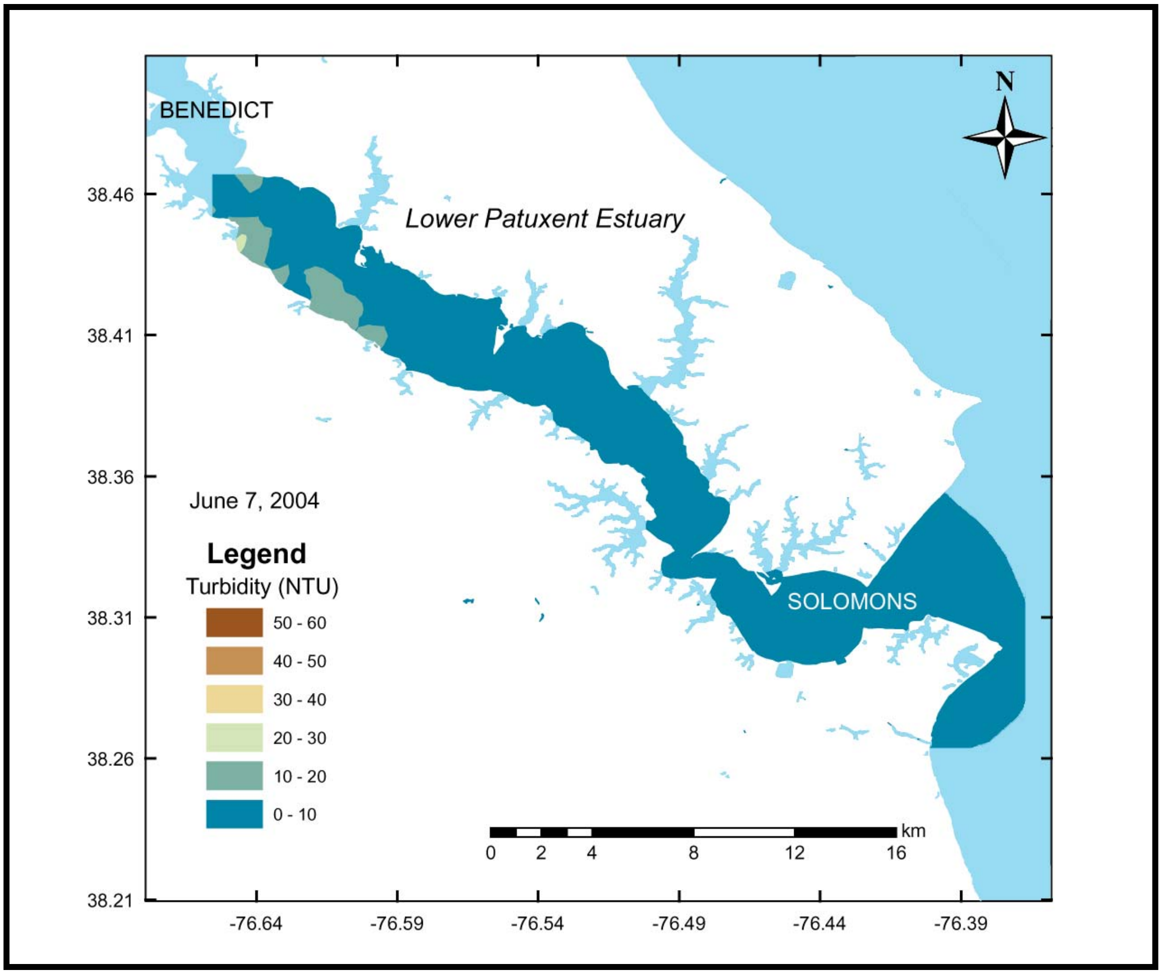
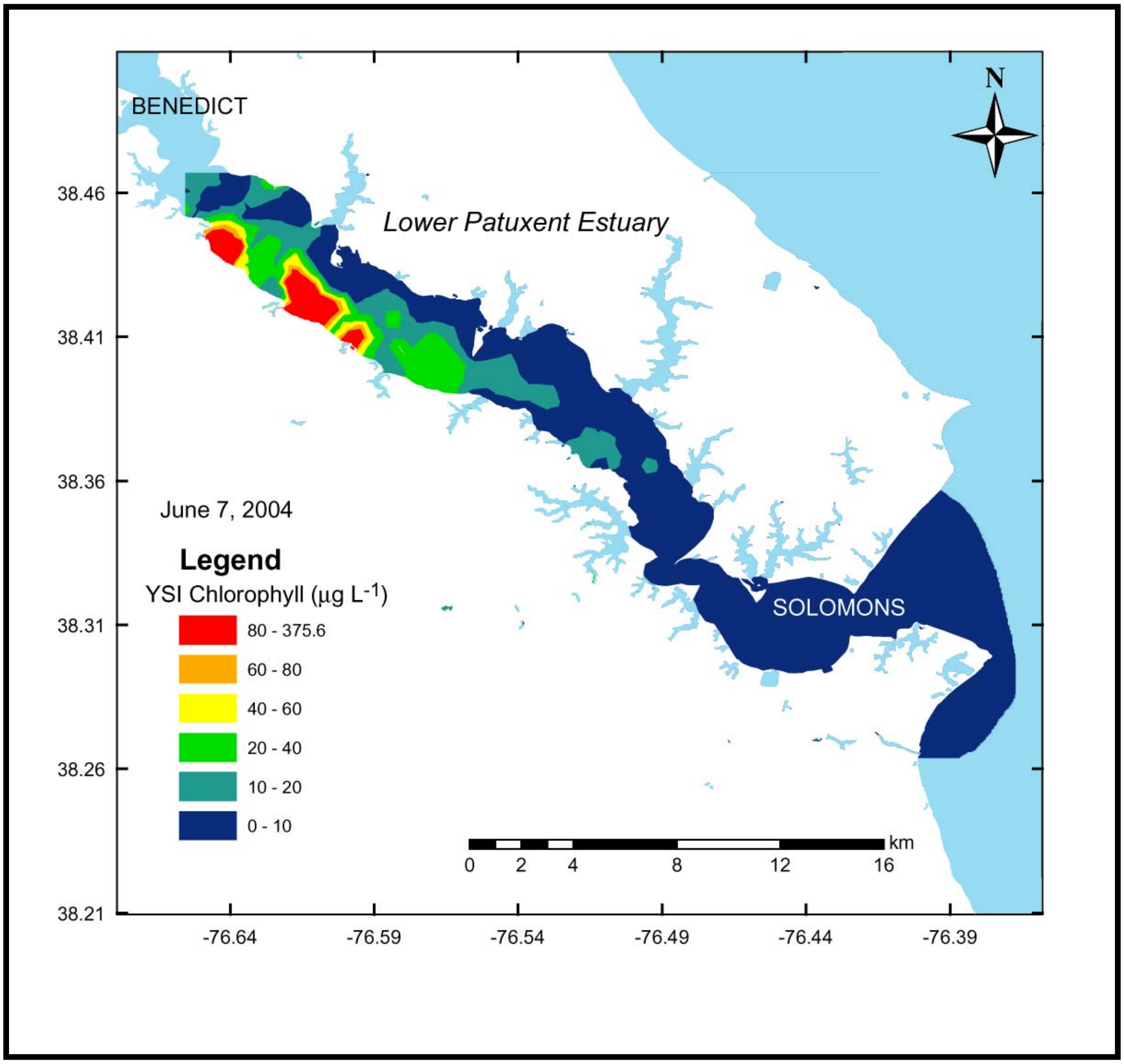


Figure 3-15. Interpolated map of surface water instrument turbidity during a summer cruise on the lower Patuxent River estuary demonstrating the relative homogeneity of surface waters in the lower estuary with the notable exception of the area near Benedict.



June 7, 2004

Figure 3-16. Interpolated map of surface water instrument chlorophyll concentration during a summer cruise on the lower Patuxent River estuary which shows the frequently seen bloom conditions in the vicinity of Benedict and Sheridan Point.

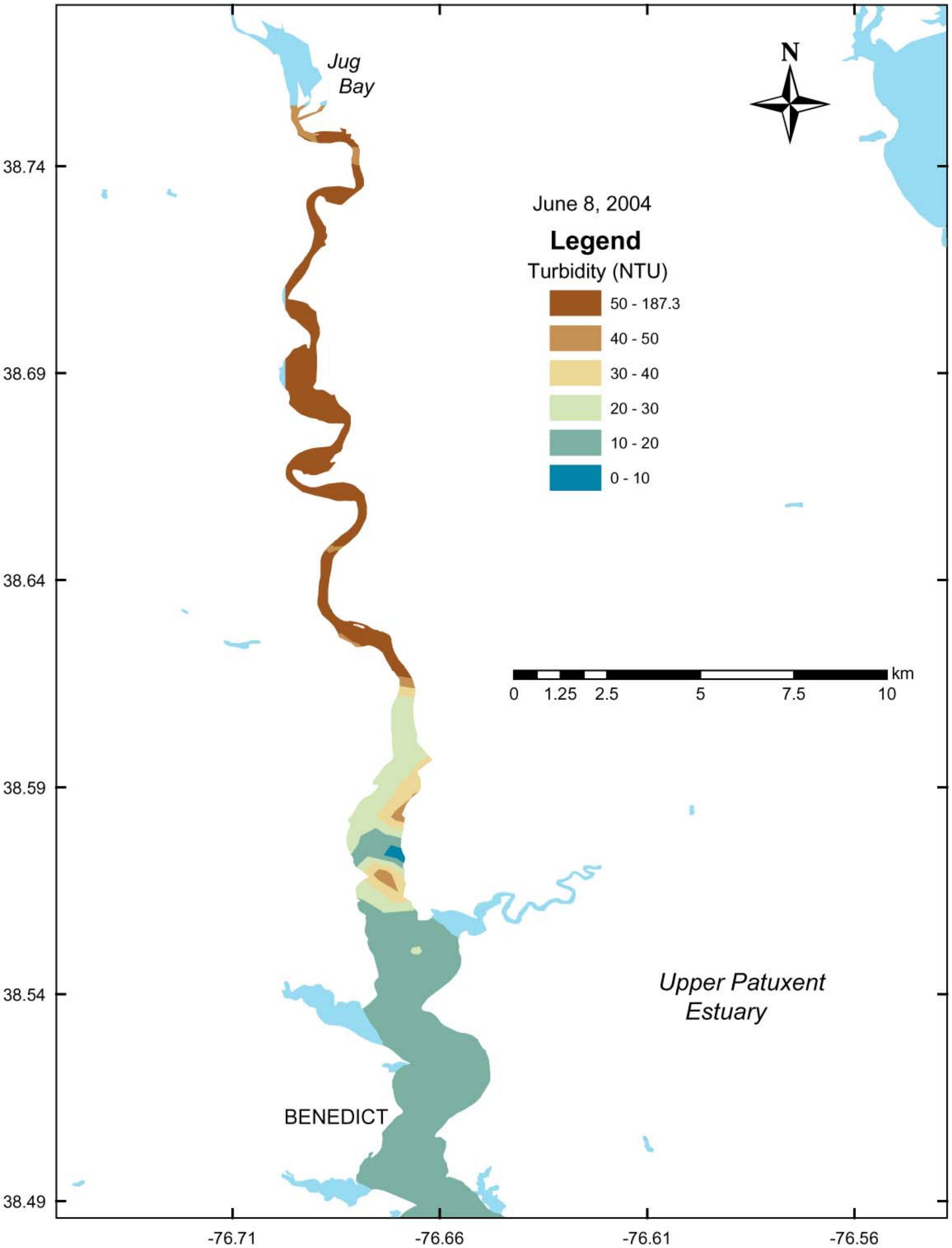


Figure 3-17. Interpolated map of surface water instrument turbidity during a summer water quality mapping cruise on the upper Patuxent River estuary that shows the typically turbid conditions of the upper reaches of the Patuxent.

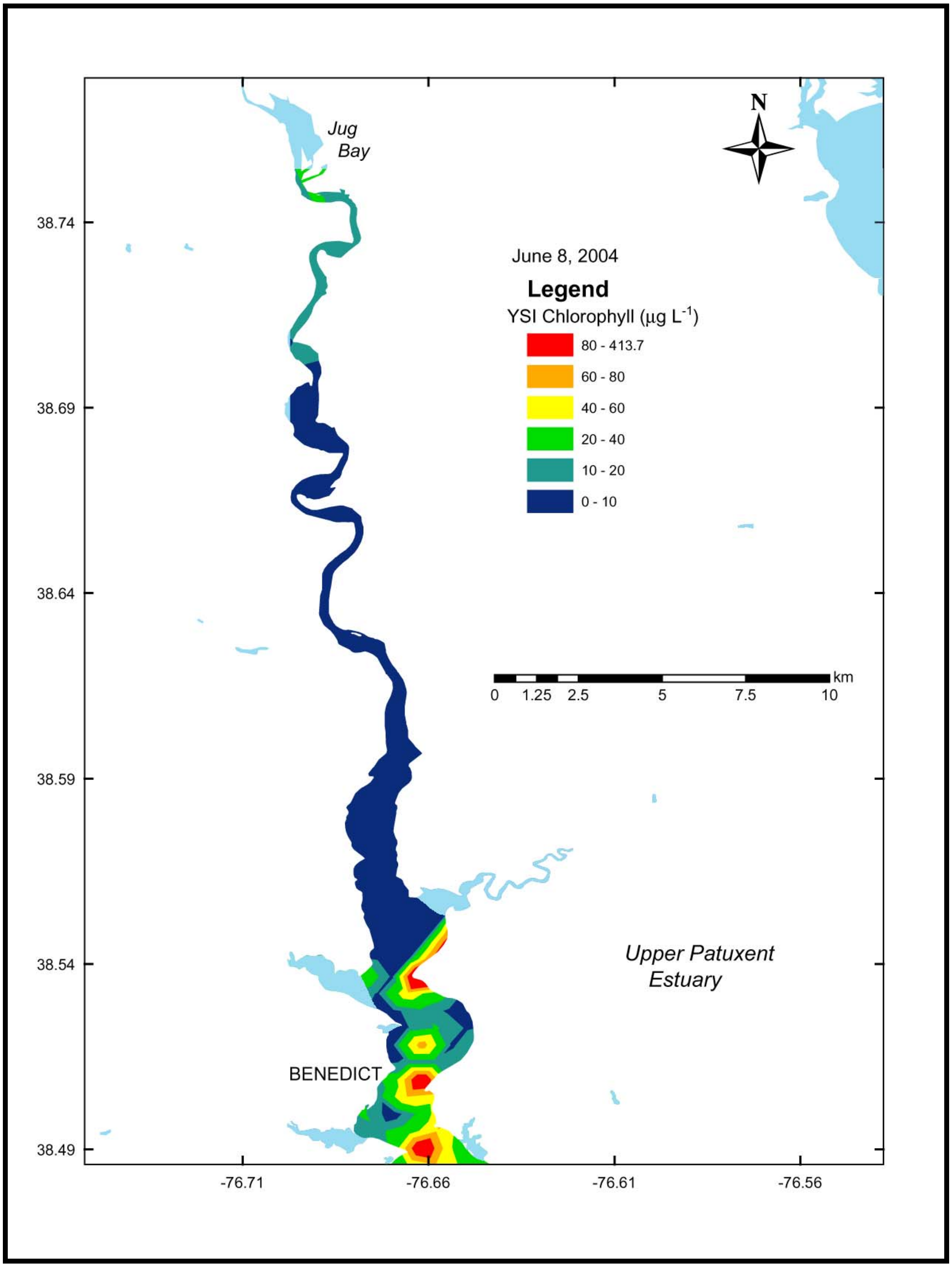


Figure 3-18. Interpolated map of surface water, instrument chlorophyll concentration during a summer water quality mapping cruise on the upper Patuxent River estuary showing typical high total chlorophyll conditions in the transition zone near Benedict.

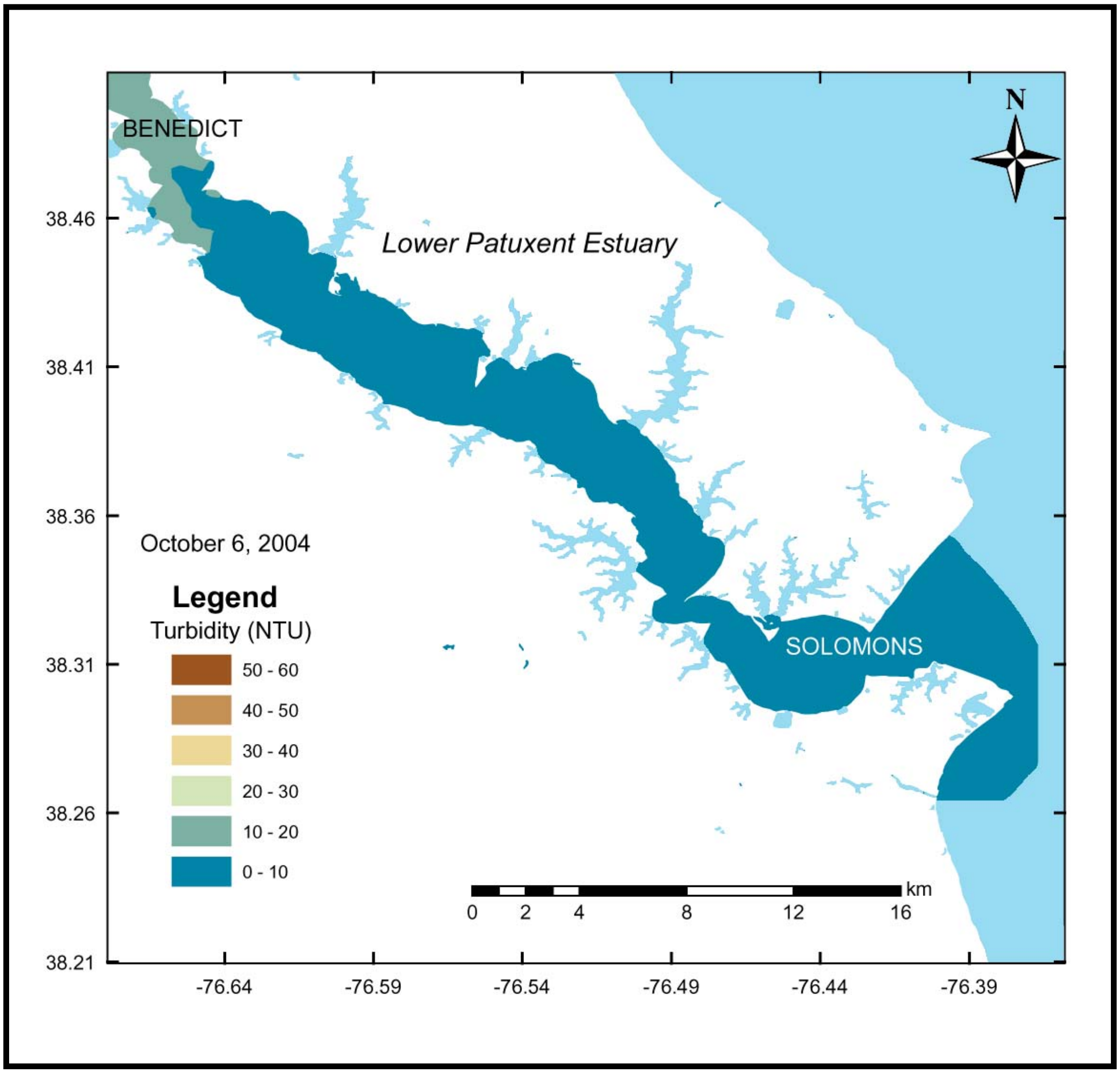


Figure 3-19. Interpolated map of surface water instrument turbidity during a fall cruise on the lower Patuxent estuary, the conditions of which are remarkably similar to that of the summer example, *supra*.

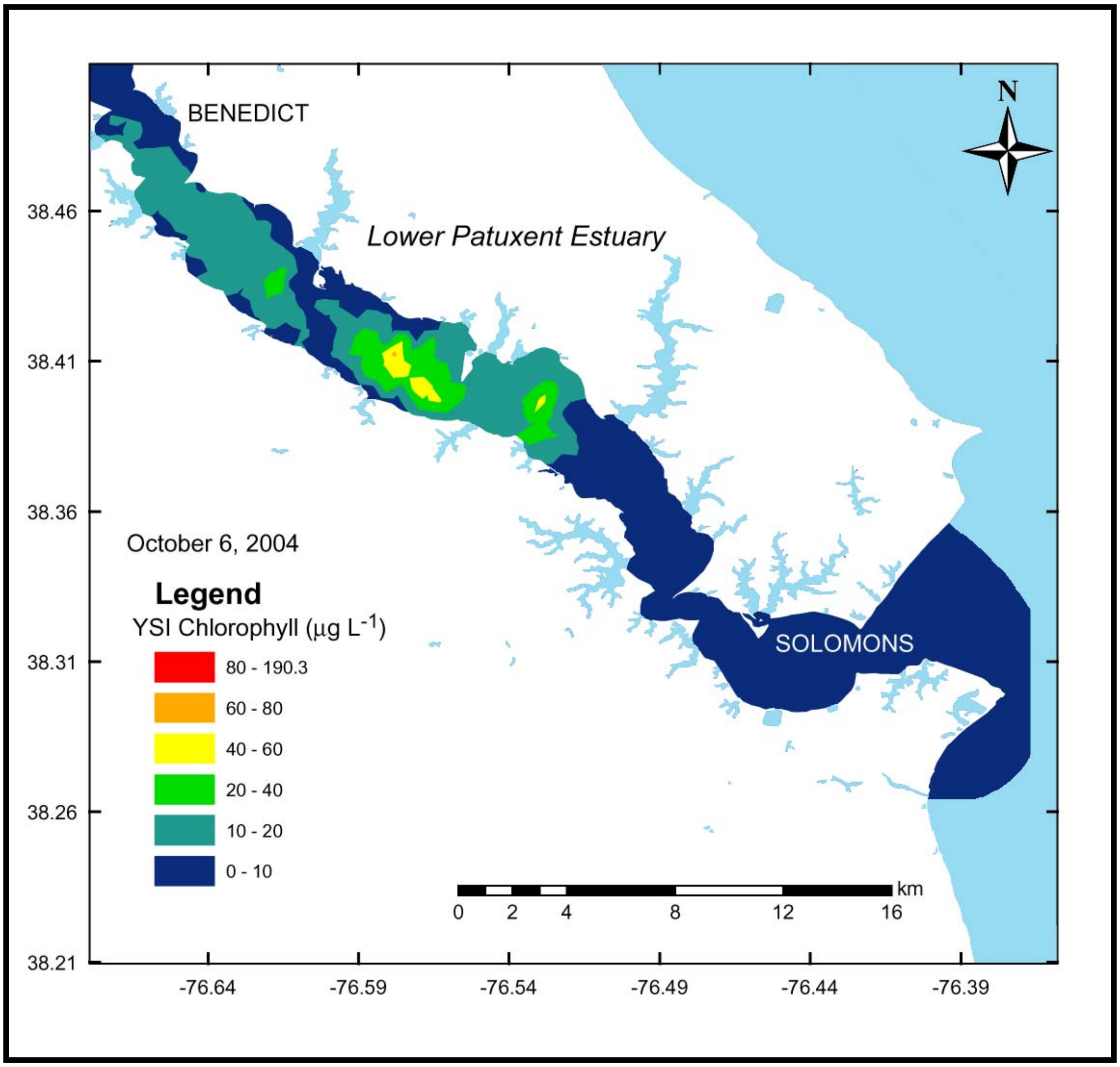


Figure 3-20. Interpolated map of surface water instrument chlorophyll concentration during a fall cruise on the lower Patuxent estuary showing elevated total chlorophyll concentrations in the middle reaches of the lower estuary.

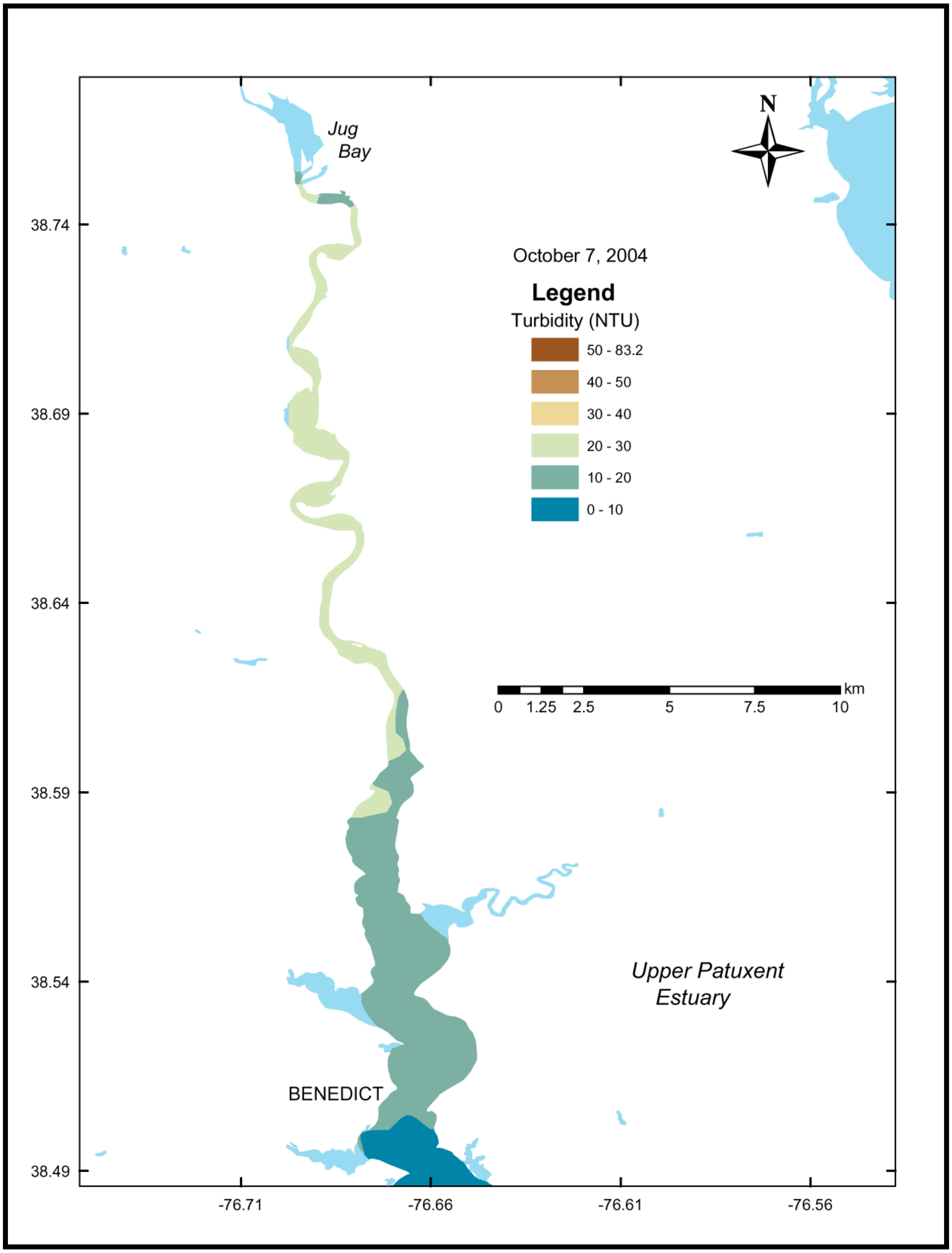


Figure 3-21. Interpolated map of surface water instrument turbidity during a fall cruise on the upper Patuxent River estuary. Compare with similar figure showing summer turbidity conditions in upper reaches of the Patuxent.

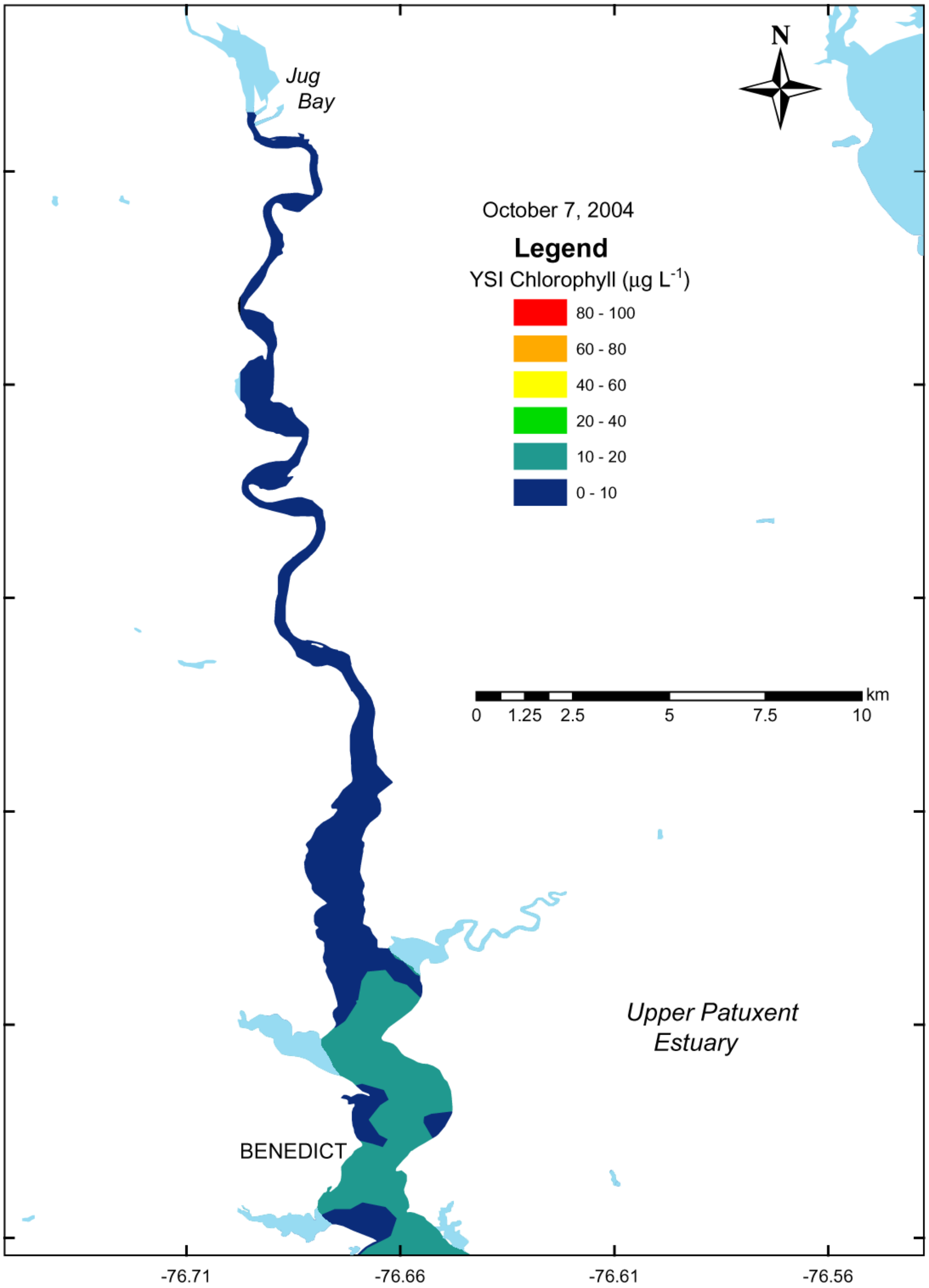


Figure 3-22. Interpolated map of surface water chlorophyll concentration during a fall cruise on the upper Patuxent River estuary which shows slightly elevated total chlorophyll concentrations near Benedict.

3.3.5 Habitat Assessment and Cumulative Frequency Distributions

The percentage per cruise of observations where NTU > 10 is presented in Figure 3-23a This illustration serves as a guide to the number of observations that exceeded the shallow water habitat (<2.0m) requirement for light availability. The highest percentages were observed in late summer and early fall, and the lowest were observed during a truncated cruise in November. This low percentage observed during this last cruise in November might have resulted from a combination of a truncated cruise track as well as seasonally less turbid waters. The percentage of observations in exceedence of habitat requirement criteria (which acts as a proxy for percentage of *area* in exceedence) and the percentage of time an area is in exceedence was evaluated in order to determine how much and how often the shallow water regions of the lower estuary exceeded the habitat light requirement. These results are illustrated in Fig. 3-23b. Calculations made from actual observations would be compared to a curve generated for each tributary which indicates area of allowable exceedence (usually about 10% , but this can vary with management strategy). The curve shown on the figure is a hypothetical criteria line shown for heuristic purposes Data are summarized in Tables 3-4. Interpolated data were also evaluated using the same thresholding technique, but were examined spatially using a comparison of polygonal areas (see Fig. 3-24). Table 3-5 summarizes these observations.

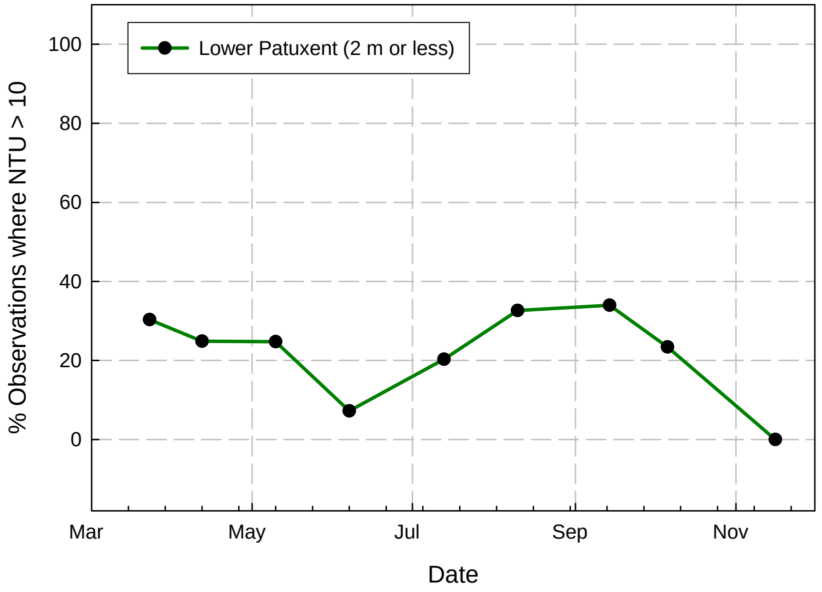
Table 3-4. Shallow water observations organized by cruise date.

Cruise Date	Observations	Obs. in Exceedence	% Obs. in Exc.
3/23/04	1062	322	30.3
4/12/04	2773	690	24.9
5/10/04	792	196	24.8
6/7/04	1589	115	7.2
7/13/04	2034	413	20.3
8/10/04	2283	745	32.6
9/14/04	2857	971	34.0
10/6/04	2858	669	23.4
11/16/04	694	0	0.0

Table 3-5. Shallow water area in exceedence, organized by cruise dates.

Cruise Date	Total Area (ha.)	Exceedence Area (ha.)	% Area in Exc.
3/23/04	1479	549	37.1
4/12/04	3133	628	20.0
5/10/04	3133	522	16.7
6/7/04	3133	677	21.6
7/13/04	3133	58	1.9
8/10/04	3133	409	13.1
9/14/04	3133	740	23.6
10/6/04	3133	482	15.4
11/16/04	1479	0	0.0

a) Percent of DATAFLOW Observations by Cruise NTU > 10



Regression results indicate that 10 NTU is approx. 1.5 Kd.

b) Cumulative Frequency Distribution

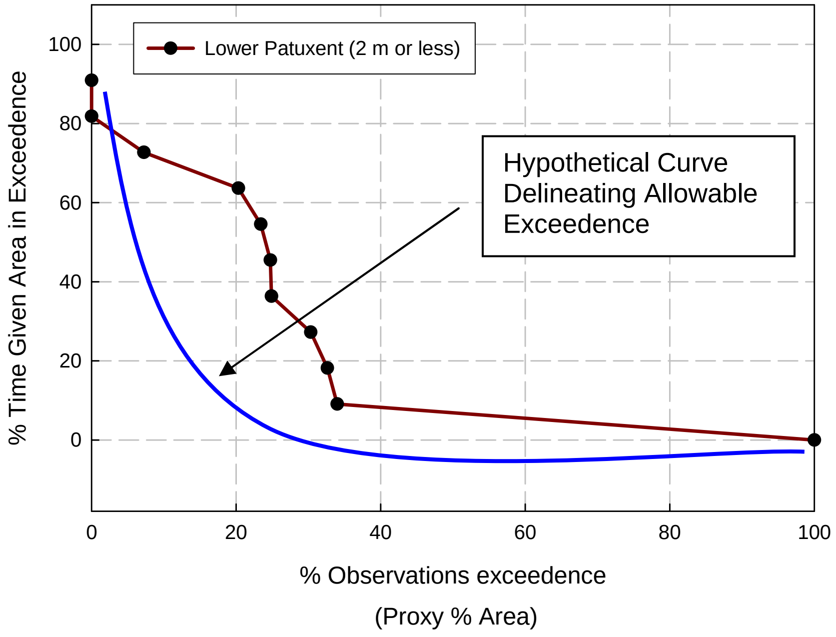


Figure 3-23. These figures illustrate (a) percentage of surface water mapping data where NTU >10, and (b) a cumulative frequency distribution developed from those data. Data were from sampled areas on the lower Patuxent river in 2004 where depth was two meters or less.

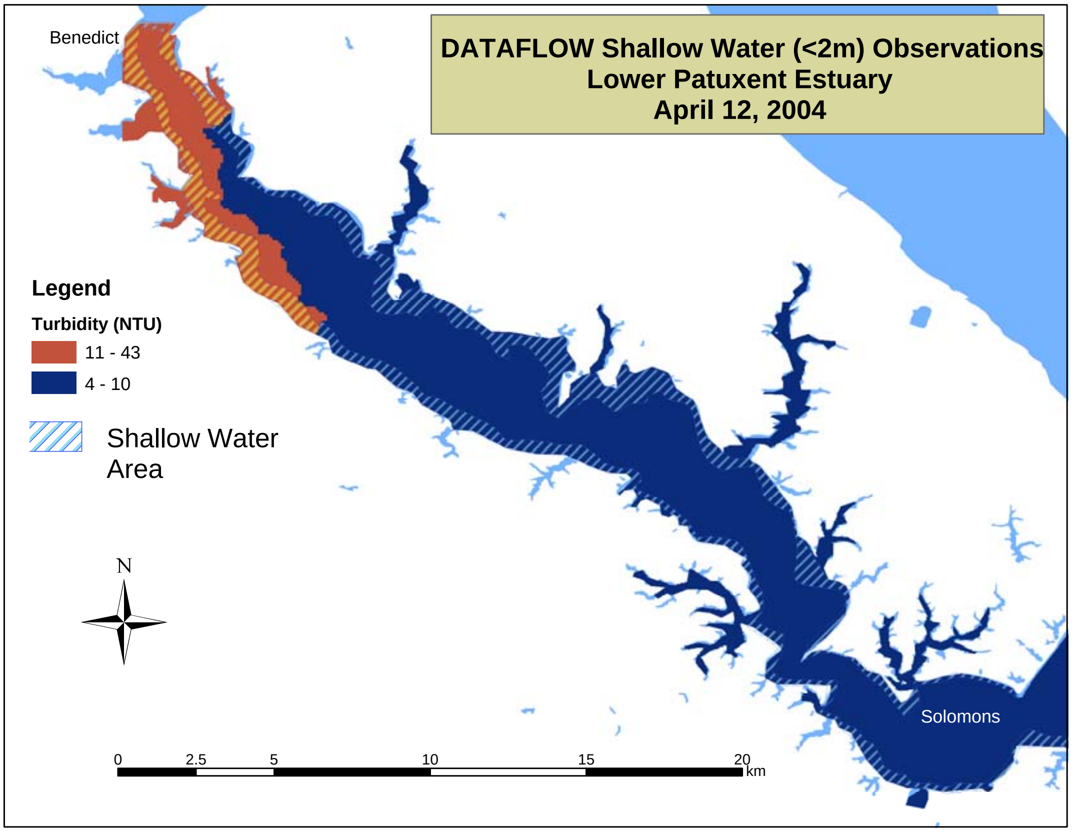


Figure 3-24. Interpolated map of surface water turbidity on the lower Patuxent River in the context of ‘pass-fail’ habitat assessment for a particular cruise in April, 2004. The cross-hatching indicates the area of the river where sampling was undertaken and depth is two meters or less (littoral zone). This map was interpolated using the same techniques as the others in this report; however, data were placed into two (rather than multiple) bins to illustrate threshold habitat requirements.

3.4 Discussion

The sampling conducted during 2004 was the second year of a three year Spatially Intensive Water Quality Mapping cycle under the Shallow Water Monitoring program. Some of the trends observed in 2003 were less evident in 2004, particularly the dissolved nutrient concentration comparisons at calibration stations in the upper and lower estuary. Of particular interest is the concentration of dissolved inorganic phosphorus (DIP) which is highest in the transition zone between the mesohaline and oligohaline portions of the river near Benedict, and in particular at station PXDF06. Within this same region of the estuary, dissolved inorganic nitrogen (DIN) concentrations were comparatively low. Physical data observations and mapping data reflected similar patterns to those seen in 2003. The region north and south of Benedict appears to be a very active zone in terms of chlorophyll accumulation. At certain times during the sampling season, distinct ‘patchiness’ could be observed in this section of the estuary; anecdotal observations of algal blooms by CBL scientists on other research cruises were corroborated by DATAFLOW data collected on mapping cruises. The most likely explanation for these patterns of DIN, DIP and chlorophyll-*a* is as follows. In the Benedict region of the estuary, water column turbidity decreases, enhancing phytoplankton growth and chlorophyll-*a* accumulation. Phytoplankton growth requires both N and P and tends to decrease concentrations, as observed for DIN. However, DIP release from sediments is generally very high in estuaries, such as the Patuxent, in the region where sea salts become abundant. In this case, the supply of DIP from sediments exceeds phytoplankton demand and DIP concentrations increase.

Spatially Intensive Water Quality Mapping systems such as DATAFLOW have begun to reach maturity as the instrument packages are more widely used throughout the Chesapeake Bay research and monitoring community. It also appears that the DATAFLOW system continues to represent a novel and attractive technology for evaluating surface water quality characteristics of the Chesapeake Bay and its tributaries, particularly when coupled with a high temporal resolution sampling effort such as CONMON.

The question remains, however, how scientists and managers will apply the millions of observations gathered during a sampling cycle to scientific study and research or management of Chesapeake Bay and its tributaries. One obvious obstacle is utilizing these data in the context of Bay Program criteria established over twenty years ago when few, if any, envisioned a sampling effort which could gather thousands of observations in a single day, or instruments that can log dissolved oxygen concentrations at fifteen minute intervals for thirty day periods. Interpolated maps provide illustrative guidance to estuarine trends and other management issues, but there exists academic and practical debate regarding interpolation techniques and mapping software packages. Real-time interpolation of mapping data might also be developed in the near future and provide another tool for better understanding spatial patterns. Establishment of cumulative frequency distribution curves is also a promising technique to apply data gathered from spatially and temporally intensive monitoring efforts and be used to describe individual tributaries in the context of compliance with water quality criteria. Specific sampling techniques and statistical evaluation methods are still matters for debate, as is the scientific and legal defensibility of these new technologies.

Finally, there is currently some unknown degree of temporal variability associated with the spatial patterns of water quality generated from DATAFLOW cruises. We currently know, based on mapping completed in several tributaries, that water quality conditions can change very substantially on a bi-weekly to monthly basis. However, the fidelity of spatial distributions on shorter time-scales is largely unknown. There has been effort expended to examine temporal scales of variability measured with the CONMON system (Mark Trice, pers. comm.) and to extend this information into a spatial format. However, there are obvious limitations to this approach. We suggest that some limited effort be directed towards examining the shorter-scale (day to week) scales of spatial variability in a few selected sites. Those sites would be those representing typical areas of the Maryland tributary network and thus allow for extrapolation to other, non-measured, areas. For example, there are a good number of small tributaries (e.g., Severn River) and larger tributaries (e.g., Patuxent). In some there are small salinity gradients while in others the gradients are large and thus might require several test sites. In the high turbidity areas we suspect higher degrees of temporal fidelity because phytoplankton production is so light limited and thus other features of water quality might change slowly as well. Such an effort would help address questions concerning the degree of confidence we place in a single spatial representation of water quality conditions and this has obvious implications for deciding when and where water quality conditions can be deemed acceptable or not acceptable.

3.5 Cited Literature

Batiuk, R.A., P. Bergstrom, M. Kemp, E. Koch, L. Murray, J.C. Stevenson, R. Bartleson, V. Carter, N. B. Rybicki, J.M. Landwehr, C. Gallegos, L Karrh, M Naylor, D Wilcox, K.A. Moore, S. Ailstock and M. Teichberg. 2000. Chesapeake Bay Submerged Aquatic Vegetation Water Quality and Habitat-Based Requirements and Restoration Targets: A Second Technical Synthesis. United States Environmental Protection Agency, Chesapeake Bay Program, Annapolis, MD.

Rohland, F.M., W.R. Boynton, R.M. Stankelis, P.W. Smail and E.M. Bailey. 2004. Maryland Chesapeake Bay Water Quality Monitoring Program. Ecosystem Processes Component (EPC). Work/Quality Assurance Project Plan for Water Quality Monitoring in Chesapeake Bay for FY2004. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCES] CBL 03-135.

4.0 Submerged Aquatic Vegetation (SAV) Habitat Evaluation

R.M. Stankelis, E.M. Bailey, W.R. Boynton, E. Buck, K. Johnson, P.W. Smail, H. L. Soulen, S. Stein

4.1 Introduction

It is generally agreed that light availability is the most critical resource limiting the extent and distribution of SAV populations (e.g. Duarte, 1991). For example, a number of studies have demonstrated that SAV epiphytes can substantially reduce the amount of available light reaching the leaf surface (e.g., Burt et al. 1995; Stankelis et al. 1999; Brush and Nixon, 2002; Stankelis et al. 2003). However, epiphyte loads can be modified to a great extent by a variety of factors including epiphyte grazer density (e.g. Neckles et al. 1993; Williams and Ruckelshaus, 1993), water column light availability (Stankelis et al. 2003), nutrient availability (Kemp et al. 1983; Burt et al. 1995), wave action and leaf turnover rates. As a result of this inherent complexity, field monitoring remains an important tool for understanding why SAV thrives, survives or declines at specific locations. In Chesapeake Bay, field monitoring is particularly important because of the large range of conditions found within the Bay and its tributaries. For example, in some Chesapeake Bay tributaries, modest reductions in nutrient loading has been achieved in recent years resulting in improved water quality conditions (e.g. Boynton et al. 1995). Yet, many of these tributaries, including the extensive mesohaline portion of the Patuxent River, that were historically populated with SAV have not shown significant recovery (VIMS, 2002).

In 1997, the EPC began an ambitious and diversified study of the near-shore water quality conditions important to SAV growth and survival. The primary goal of the near-shore water quality evaluation was to measure a suite of water quality parameters in the shallow near-shore habitat to assess compliance with established SAV habitat requirements (Batuik et al. 1992; Batuik et al. 2000; Kemp et al. 2004) and to directly measure epiphyte fouling rates using artificial substrates. Annual studies have been conducted in the Patuxent estuary, with varying scope and extent since 1997, and provide a time series of data that has become quite unique. In 1998, a study was conducted to compare epiphyte fouling rates on live SAV to fouling on artificial substrates (Mylar® strips). Results of this study suggested that Mylar® strips could be used as an acceptable surrogate for live plants in order to estimate light attenuation from epiphytic fouling

(Stankelis et al. 1999). Despite some potential limitations, artificial substrates can be used effectively to compare the effects of differing water quality conditions on epiphyte accumulation rates and light attenuation when live plants are not available (e.g., Burt et al. 1995, Stankelis et al. 1999). In addition, artificial substrates can be standardized between sites, and provide a quick assessment of epiphyte growth potential at SAV restoration sites.

In the 2004 field season, the EPC measured water quality conditions and epiphyte fouling rates at two locations in the lower Patuxent Estuary. These locations, CBL (SV09) and Pin Oak (SV5A), were monitored for 4 consecutive weeks each, in the spring, summer and fall of 2004. These sites are also under active consideration for large-scale SAV restoration.

4.2 Methods

4.2.1 Station Locations and Sampling Frequency

In 2004, 2 stations were monitored in the lower Patuxent River estuary (Fig 4-1, Table 4-1). Both of these stations have been studied since 1997, and have been the location of SAV restoration activities. In 2004, high frequency temporal monitoring (CONMON) was also conducted at these sites. Sampling was conducted for 4 consecutive weeks each in the spring, summer and fall. During each sampling block, three weekly epiphyte samples were collected for a total of 9 weekly measurements (Table 4-1). This sampling schedule was designed to measure seasonal variation in epiphyte fouling rates in a cost effective manner. Additional sampling was conducted in the lower Potomac at Judith Sound (PRJS) under a different contract but is included here for comparative purposes.

Table 4-1 Station codes, grid location, DNR CONMON station names, and sampling dates in 2004.

Geographic Location	Station Codes	Geographic Coordinates (NAD 83)		DNR CONMON Station name	Sampling Dates (retrieval)
		Lattitude	Longitude		
Patuxent	SV09 (CBL) SV5A(Pin Oak)	38º 19.016 38º 24.625	76º 27.119 76º 31.351	XCF9029 XED4587	Spring 5/17, 5/24, 6/1 Summer 7/23,7/30, 8/6 Fall 9/23, 10/1, 10/8
Potomac Judith Snd	PRJS	38º 00.355	76º 28.082	None	Spring 5/21, 5/28, 6/3 Summer7/23, 7/30, 8/6 Fall 9/23, 10/1, 10/8

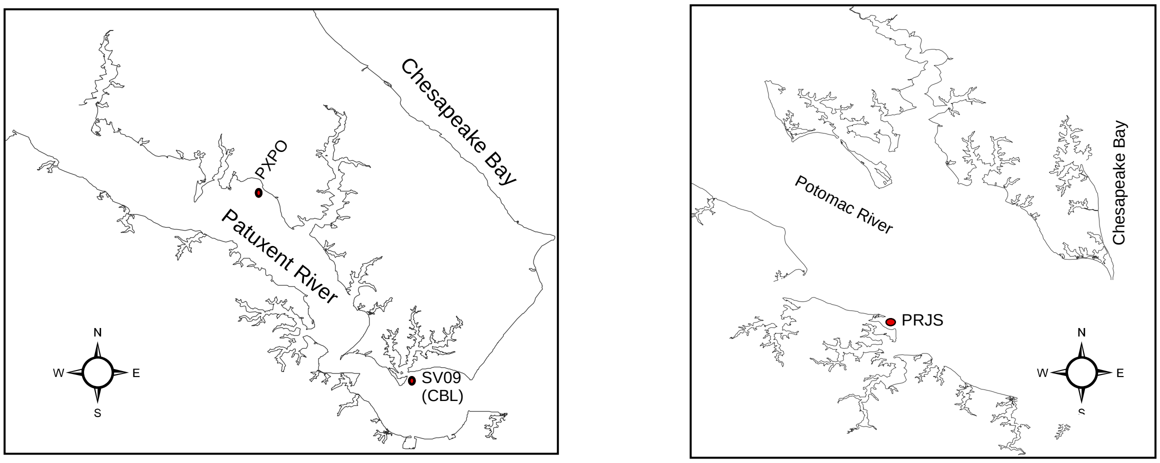


Figure 4-1. Location of Submerged Aquatic Vegetation (SAV) monitoring stations as well as nearest DNR monitoring sites in the Patuxent Estuary and Potomac Estuary, in 2004.

4.2.2 Field Methods

4.2.2.1 Water Quality

Temperature, salinity, conductivity, and dissolved oxygen measurements were made with a Yellow Springs International (YSI) 600R, YSI 6920 or YSI 6600 multi-parameter water quality monitor suspended at 0.5 meters below the water surface. Water column turbidity was estimated with a secchi disk where possible, while water column light flux in the photosynthetically active frequency range (PAR) was measured with a *Li-Cor* LI-192SA underwater quantum sensor and LI-190 deck sensor. When possible, measurements were collected at a minimum of three discrete water depths in order to calculate water column light attenuation (Kd). Weather and sea-state conditions, such as air temperature, percent cloud cover, approximate wind speed and direction, total water depth, and wave height, were also recorded.

Whole water samples were collected at approximately 0.5 meters below the water surface by using a hand held bilge pump, the outflow from the DATAFLOW intake, or by dipping a sample bottle in the water. The whole water samples were placed in coolers for transport back to the laboratory for further processing. In the laboratory, a portion was filtered for dissolved nutrient concentrations with a 25mm, 0.7 µm (GF/F) glass fiber filter. The filtered portion was analyzed by the Nutrient Analytical Services Laboratory (NASL) for ammonium (NH_4^+), nitrate (NO_2^-), nitrite plus nitrate ($NO_2^- + NO_3^-$) and phosphate (PO_4^{-3}). Whole water portions were also filtered in the laboratory using 47 mm, 0.7 µm (GF/F) glass fiber filters and were transferred to NASL for analysis of total suspended solids (TSS), total volatile solids (TVS), total and active chlorophyll-*a* concentration. Total chlorophyll-*a* also includes chlorophyll-*a* plus breakdown products.

4.2.2.2 Epiphyte Growth Measurement Method

In order to assess the light attenuation potential of epiphytic growth on the leaves of submerged aquatic vegetation (SAV) artificial substrata, thin strips of Mylar® polyester plastic, were deployed at each sampling location for a period of 6 to 8 days. Each collector array (Figure 4-2) consisted of a square PVC frame with a vertical PVC shaft in the center of the square. To this shaft was attached a line with a small surface float that allows for easy location of the collector. Each collector array held up to six strips per deployment. Mylar® strips (2.5 cm wide x 51 cm long and 0.7 mil thick) were attached to the frame so that the top was allowed to move freely in the water column. Small foam floats (~3.5 x 3.3 cm) were attached to the top of each strip to help maintain a vertical position in the water column at all times.

On each sampling date, six replicate Mylar® strips were collected. Three to be analyzed for chlorophyll-*a* mass, and three for total dry mass/inorganic dry mass. While suspended in the water, Mylar® strips were gently removed from the array and cut with scissors to remove the middle 1/3 marked section (64.5 cm^2, Figure 4-2). This section was once again cut in half, and placed in a 60 ml plastic centrifuge tube which was placed in a cooler for transport back to the laboratory. The samples were immediately frozen upon arrival at the laboratory prior to further processing.

Upon thawing, the Mylar® strip sections collected for dry mass/inorganic mass analysis were scraped of all material and rinsed with distilled water. Scraped material and rinse water were diluted to a fixed volume (300 - 500 ml). The solution was mixed as thoroughly as possible on a stir plate until homogenized. A small aliquot (10 to 50 ml) was then extracted with a glass pipette and filtered through a 47 mm, 0.7 µm (GF/F) glass fiber filter. Once filtered, the pads were immediately frozen and delivered to NASL for analysis. Samples collected for epiphyte chlorophyll-a concentrations did not require further processing because the chlorophyll-a was extracted directly off the Mylar® surface via a method similar to Strickland and Parsons (1972) and Parsons *et al*. (1984). A comparison using this method to the more traditional method of scraping and filtering the epiphyte material found no statistical difference (Stankelis et al. 1999).

4.2.3 Chemical Analysis Methodology

Methods for the determination of dissolved nutrients were as follows: ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate ($NO_2^- + NO_3^-$), and dissolved inorganic phosphorus (DIP or PO_4^-) were measured using the automated method of EPA (1979). Methods of Strickland and Parsons (1972) and Parsons *et al.* (1984) were followed for chlorophyll-*a* analysis. Total suspended solids (TSS) and total volatile solids (TVS) were measured with a gravimetric method.

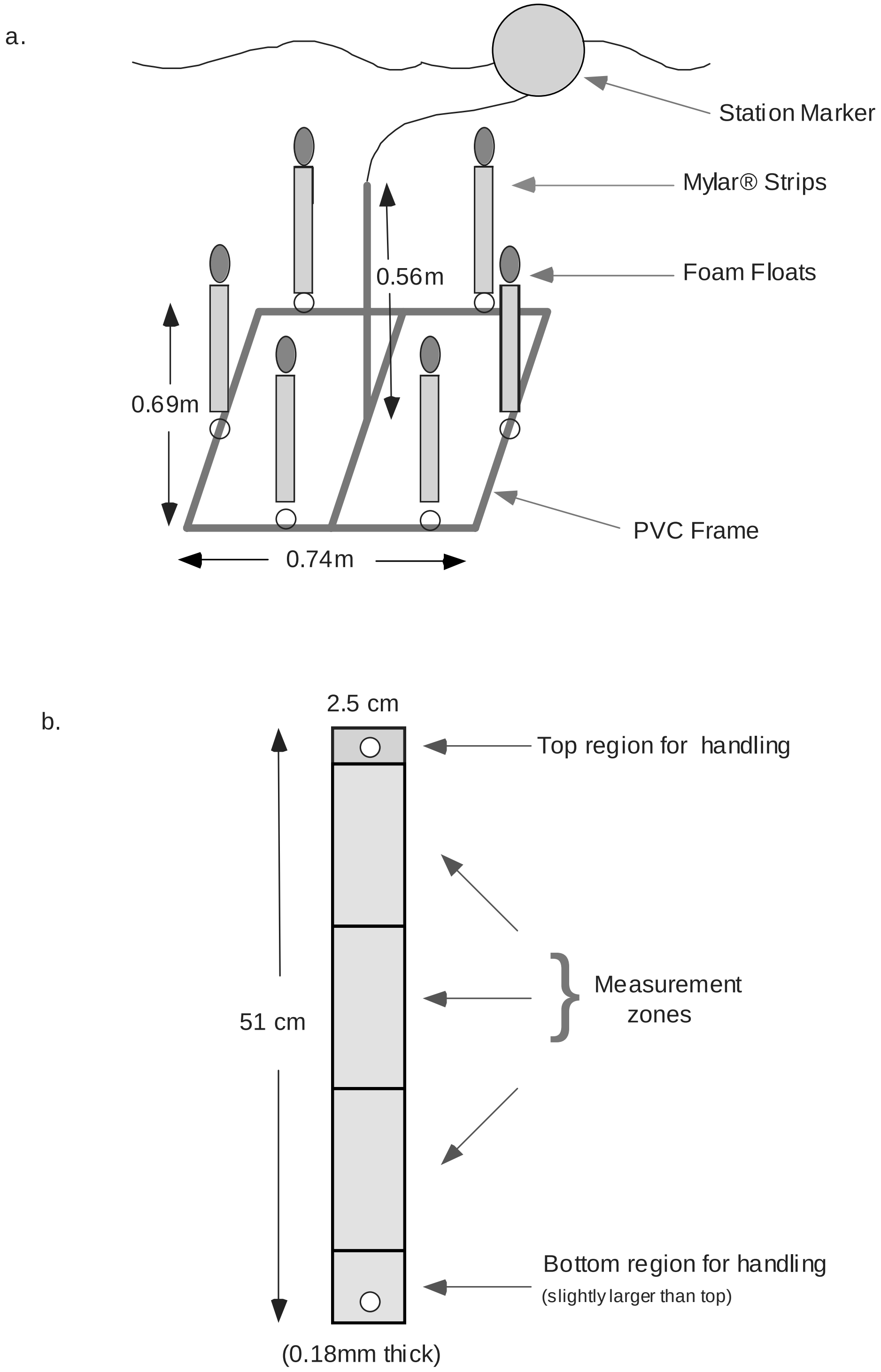


Figure 4-2. Diagram of SAV Epiphyte Collector Array.

a. Epiphyte Collector Array

b. Mylar® strips

4.2.4 Estimating light Epiphyte Light Attenuation

Estimates of epiphyte light attenuation were calculated using epiphyte dry mass and the existing relationships between dry mass and light attenuation (Fig. 4-3 a,b). These relationships were developed using direct measurements of epiphyte light attenuation and dry mass accumulated on Mylar® strips deployed at a number of locations from 1997 to 1999 (Boynton *et al*. 1998; Stankelis *et al.* 1999; Boynton *et al.* 2000). These estimates along with corresponding measurements of water column light attenuation (Kd) allow us to calculate the percent of surface light reaching the depth of the SAV blade through the water column (PLW) and the percent surface light reaching the blade of SAV through the epiphyte layer at the leaf surface (PLL). Calculations of these metrics defined by the Chesapeake Bay Program (Batuik et al. 2000) are shown below in Table 4-2.

Table 4-2. Calculation of % Surface Light Reaching Leaf Surface (PLL)

$PLW = (I_Z/I_0)*100 = 100*[e^{-kd*Z}]$

$PLL = [e^{-kd*Z}][1-LA/100]$

Where: Iz = Light flux (PAR) at depth

I_0 = Light flux (PAR) at surface

LA = Epiphyte light attenuation

Z = Observation depth (m)

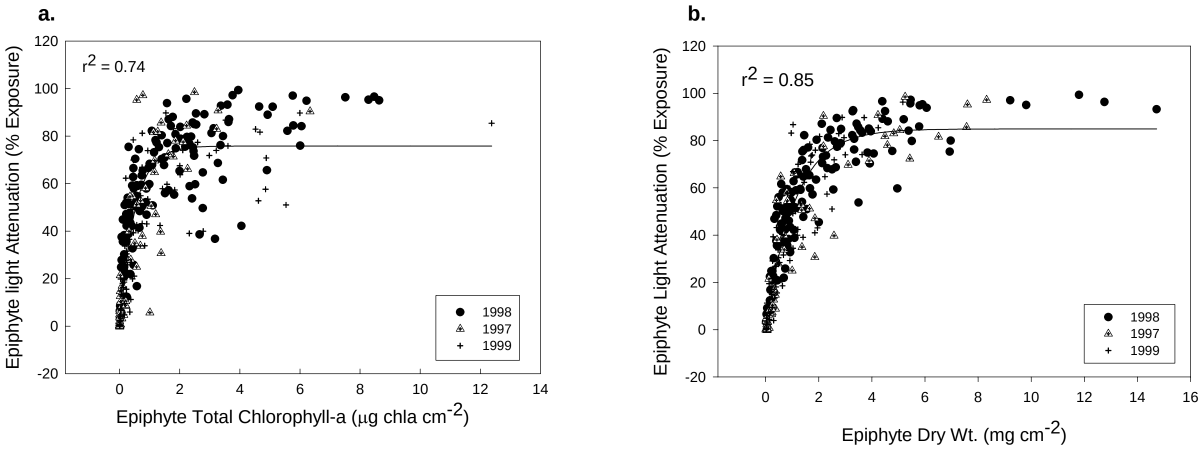


Figure 4-3. (a) Epiphyte light attenuation vs. epiphyte chlorophyll-a, where light attenuation = $77.36*(1-e^{-2.082 * \text{Epi Chla}})$ and (b) epiphyte light attenuation vs. epiphyte dry mass where Light Attenuation = $84.634*(1-e^{-0.963 * \text{Epi drywt}})$.

4.3 Results

4.3.1 Water Quality conditions

2004 was an average flow year with Patuxent River monthly mean flow and annual flow very close to the long term average (Fig. 2-3). Dissolved inorganic nitrogen (DIN) concentrations were higher at these sites in 2004 compared to 2003. The median DIN concentration at Pin Oak was 0.185 mg l^{-1}, while at CBL it was 0.357 mg l^{-1} (Fig 4-4). Both values were above the recommended habitat requirement of 0.15 mg l^{-1} (Batuik et al. 2000). Median dissolved inorganic phosphorus (DIP) concentrations at Pin Oak and CBL were both far below the recommended habit limit of 0.01 mg l^{-1} (0.003 and 0.002 mg l^{-1} respectively) (Fig 4-4).

Growing season median water column light attenuation (Kd) values were 0.89 m^{-1} at CBL, and 1.22 m^{-1} at Pin Oak (Fig. 4-5a). Both were below recommended mesohaline habitat limits (Batuik, et al. 2000), and were lower in 2004 compared to 2003 (Stankelis et al. 2004). Water clarity was also greatest at both sites in the spring compared to summer and fall. During the summer, water clarity at Pin Oak frequently fell below the recommended habitat limit (Fig 4-5b). This temporal pattern may influence SAV survival at this location when added to thermal stress during the summer.

4.3.2 Epiphyte Fouling

The temporal patterns of epiphyte fouling were very similar to those seen in other years, with rapidly increasing fouling rates as water temperatures exceed 20°C in the spring (Fig. 4-6). Fouling rates remained generally high through the summer and fall with the lowest dry mass fouling rate during that time (0.7 mg cm^{-2} $week^{-1}$) still capable of blocking 47% of the available light before it reaches the leaf surface. The highest dry mass fouling rates at CBL were found during the summer, while the highest dry mass fouling rates at Pin Oak were found during the last spring deployment at the beginning of June (Fig. 4-6a). Week to week variability was similar at both locations and was comparable to that seen in previous years (Boynton and Stankelis, 2004). Despite higher than normal flow in 2003, Patuxent River dry mass fouling rates in 2004 were higher than those found in 2003 with the exception of Pin Oak during the summer (Fig. 4-7). This pattern was also true for the Potomac River Judith Sound station (PRJS) as well.

Using data from our spring-summer-fall blocked sampling design, we calculated median values for both percent light through the water (PLW) and percent light at the leaf surface (PLL). In 2004, PLW at CBL was dramatically higher (29%) compared to Pin Oak (14%). In addition, 2004 median PLW values at both stations were similar those in 2003 (Fig. 4-8). However, increased epiphyte fouling in 2004 compared to 2003, reduced PLL values at both stations. For example, at CBL, median PLL was reduced from 25% in 2003 to 14% in 2004. While at Pin Oak, median PLL was reduced from 8% in 2003 to 6% in 2004.

4.4 Discussion

The long term record in both water clarity and epiphyte fouling at Pin Oak and CBL reflect an ecosystem that responds dramatically to changes in nutrient loading. From 1998 to 2004, median water clarity or PLW (calculated from the blocked sampling design) has varied dramatically. For example, in 2002, one of the driest years on record, median PLW at CBL was 48%. In contrast, in 1998, during a slightly higher than average flow year, median PLW at CBL was 26% (Fig 4-8). Similar patterns were seen at Pin Oak with median PLW ranging from 39% in 2002 to 14% in 2004. Moreover, median epiphyte fouling rates have also varied substantially between years. When epiphyte fouling and water clarity are converted to PLL values, available light has also varied dramatically among years. At CBL, median PLL values have ranged from 25% in 2003 (a record flow year), to 4% in 1998 (Fig 4-8). While at Pin Oak, median PLL values ranged from 22% in 2002, to 4% in 1998. Throughout this record, median PLL values appear to fluctuate around the recommended minimum PLL value of 15%, where in some years water quality conditions (plus fouling) appear adequate for SAV survival, and in others extremely poor.

As noted in previous reports (Boynton and Stankelis, 2004), these estimates of median PLL were calculated from a series of weekly blocked measurements in the late spring, summer and fall and do not take into account conditions early or late in the season. In order to address this concern, we created site specific models for epiphyte fouling based upon results from a number of previous epiphyte related analyses (Stankelis et al. 2003; Smail et al. 2004). In this model, we use previously derived regression relationships to calculate daily PLW values from YSI datasonde turbidity data collected at Pin Oak and CBL. Secondly, we use daily water temperature (also recorded with YSI datasondes) to estimate daily epiphyte dry mass (for a weeks accumulation) using long-term data from each site. Previous attempts to regress epiphyte fouling against water temperature using pooled data were unsuccessful because of the varying importance of other factors such as water clarity or water flow among different locations. Lastly, because the results of a classification and regression tree analysis (CART) indicate minimal epiphyte fouling when water temperatures fall below 20 °C, we assigned a zero value to those days even though the site specific regression models may indicate otherwise. These daily estimates of epiphyte fouling are plotted against daily temperature, as well as PLL estimates calculated from the actual epiphyte measurements (Fig. 4-9). These plots show fairly good agreement between the blocked PLL estimates and the modeled estimates. The exception occurs where the actual data indicates much more light reaching the leaf compared to the model estimates (Fig 4-9). There are several potential reasons for this discrepancy. First, because epiphyte fouling is typically low during this time, PLL is driven by water clarity alone and the regression relationship between NTU vs. Kd may be biased under very clear water conditions (generally $Kd<1$). As a result, the daily estimates of water clarity (PLW) may be biased on the low end toward slightly lower values. Secondly, estimates of Kd made for the blocked design are based upon measurements taken at one time during the day, while the daily estimate of NTU from the datasondes is an average of 96 observations throughout the day. As a result, there is potential for some discrepancy; nevertheless, when growing season medians are calculated from each method, the results are extremely similar and only differ by 2% (Table 4-3). Therefore, we believe the estimates of growing season median PLL calculated from the blocked data are the easiest way to evaluate near-shore areas for SAV habitat conditions.

In order to evaluate SAV habitat conditions using this method, it is important to note that using estimates from this type of field sampling may represent a worst case scenario. For example, these estimates are based upon light reaching a depth of 1m, whereas many species of SAV have blades or shoots that receive light further up in the water column. This may be especially important for species such as *Ruppia maritima* which produce long reproductive shoots during periods of high fouling. As a result, these shoots may receive high levels of light because of their proximity to the surface. This is supported by the observation that several small beds of *R. maritima* have been observed at Pin Oak from the spring of 2003 to the spring of 2005 (personal observations) despite median PLL estimates for that location of 8% in 2003 and 6% in 2004. While these beds have not expanded, they have survived, despite estimates suggesting they should not. Also, these estimates are based upon weekly epiphyte accumulation rates. Even species such as *Zostera marina* may be able to produce new blades at a high enough rate to mitigate the effects of moderate amounts of fouling. Lastly, these estimates have been made from data collected at locations where SAV is absent or extremely sparse. This isolation may result in fouling rates that are higher than would be found within large SAV beds. Because of these considerations, it may be prudent to use these data carefully and accept a particular location for SAV restoration activities only if fouling rates are consistently low or moderate during several years, or restoration activities are occurring at depths considerably less than 1m.

Table 4-3. 2004 growing season median values for percent light through the water (PLW) and percent light at the leaf surface (PLL) using both actual blocked data and modeled data at CBL and Pin Oak locations.

	CBL (SV09)		**Pin Oak (SV5A)**	
Statistic	**Blocked**	**Modeled**	**Blocked**	**Modeled**
PLW	**28.8**	**27.5**	**14.4**	**18.2**
PLL	**14.3**	**13.9**	**5.7**	**7.7**

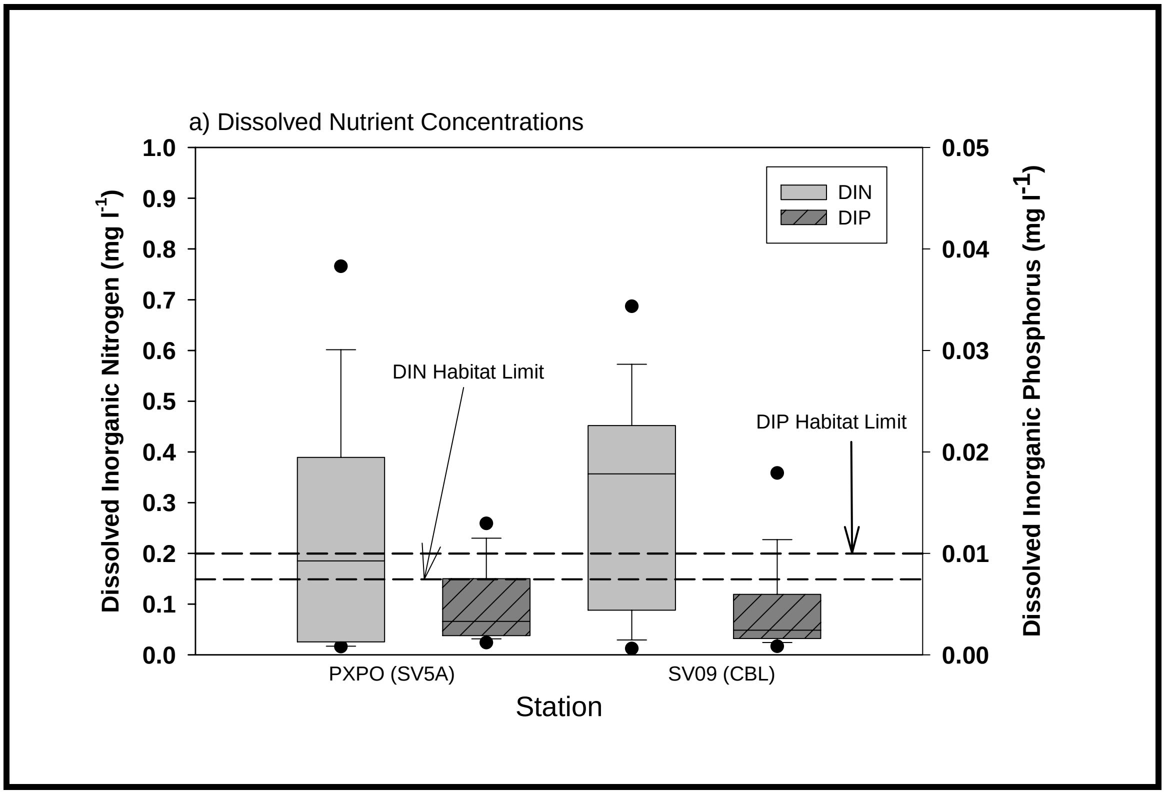
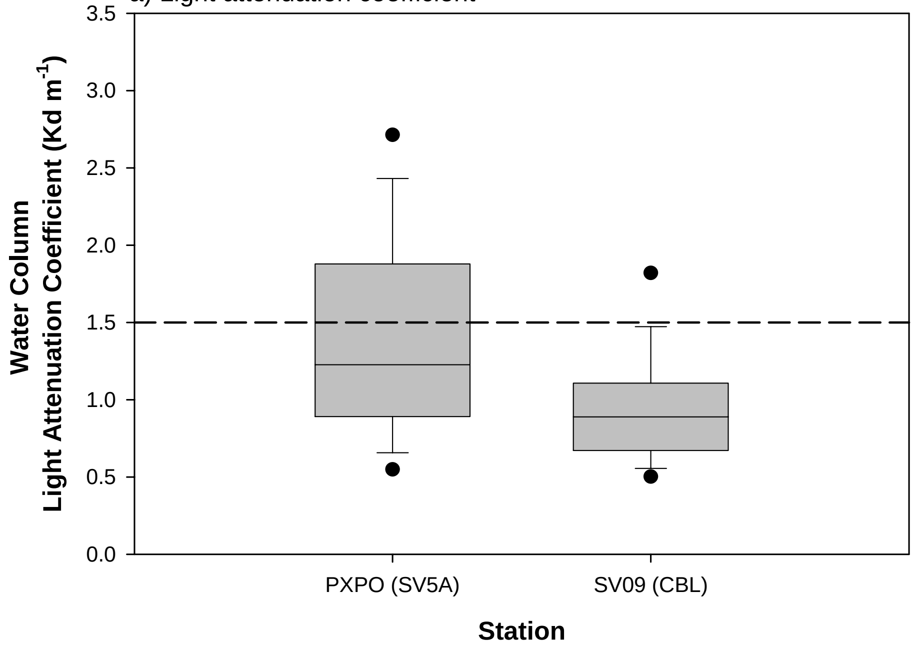


Figure 4-4. Patuxent River dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) concentrations during the eelgrass growing season in (March – Nov) 2004. *Box ends represent 25th and 75th percentiles, while lines represent median values. Whiskers are 10th and 90th percentiles, and dots are 5th and 95th percentiles.*

a) Light attenuation coefficient



b) Light Attenuation coefficient vs date

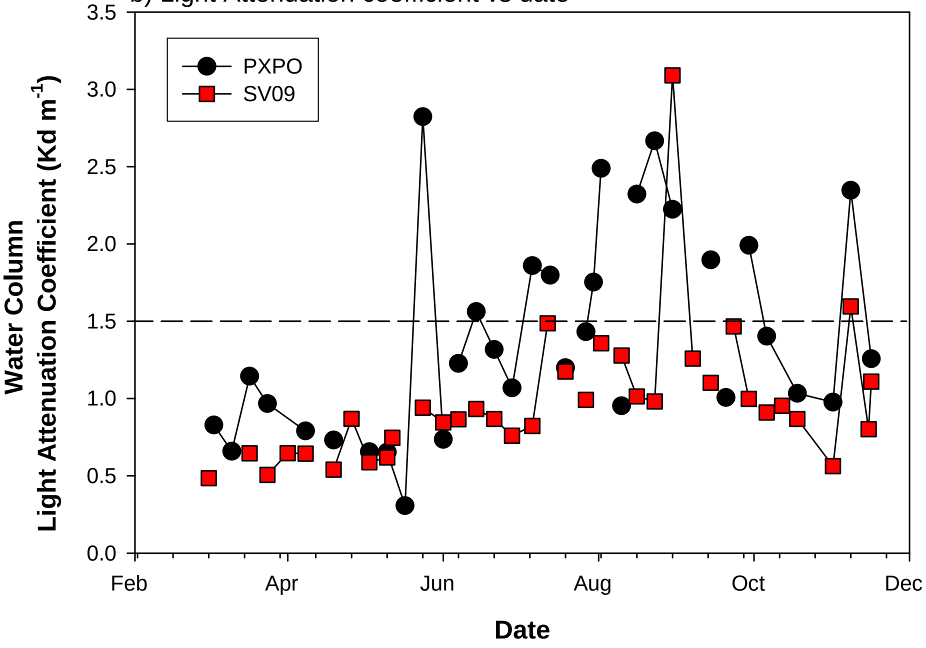
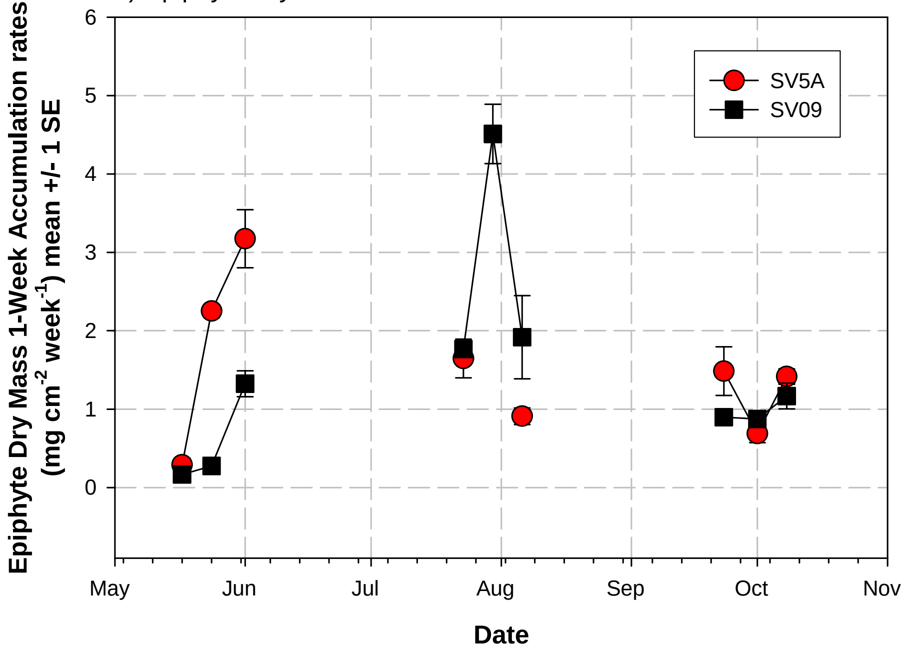


Figure 4-5. a) Box and whisker plot of Patuxent River light attenuation coefficient (Kd) from March through November 2004, and b) Patuxent River light attenuation vs. date. *Box ends represent 25th and 75th percentiles, while lines represent median values. Whiskers are 10th and 90th percentiles, and dots are 5th and 95th percentiles. Dashed lines represent mesohaline SAV habitat criteria.*

a) Epiphyte Dry Mass



b) Epiphyte Chlorophyll-a

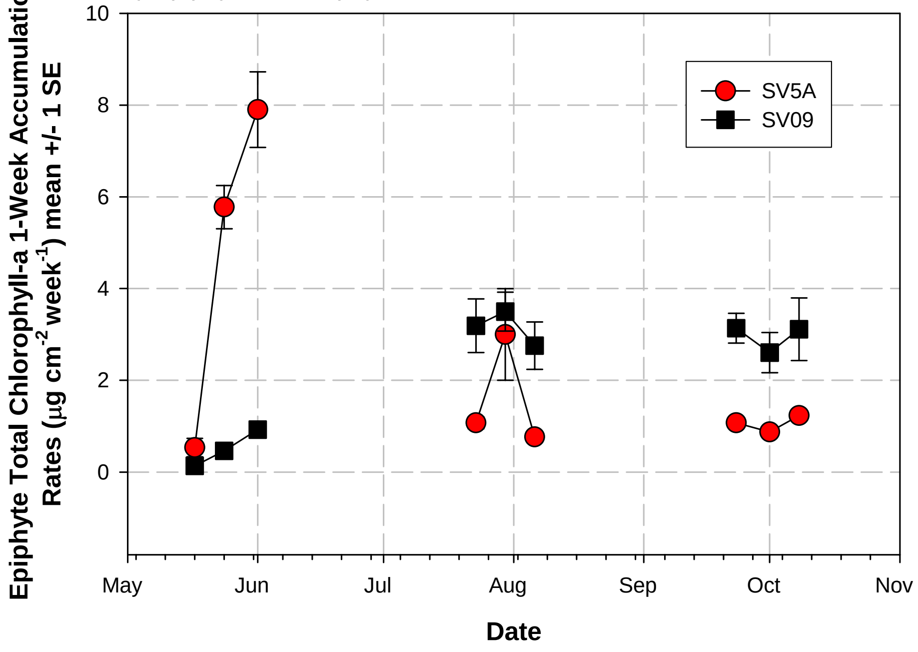


Figure 4-6. a) Epiphtye dry mass accumulation rate and b) epiphyte chlorophyll-a mass accumulation rate at stations SV09 (CBL) and SV5A (Pin Oak) in the spring, summer and fall of 2004.

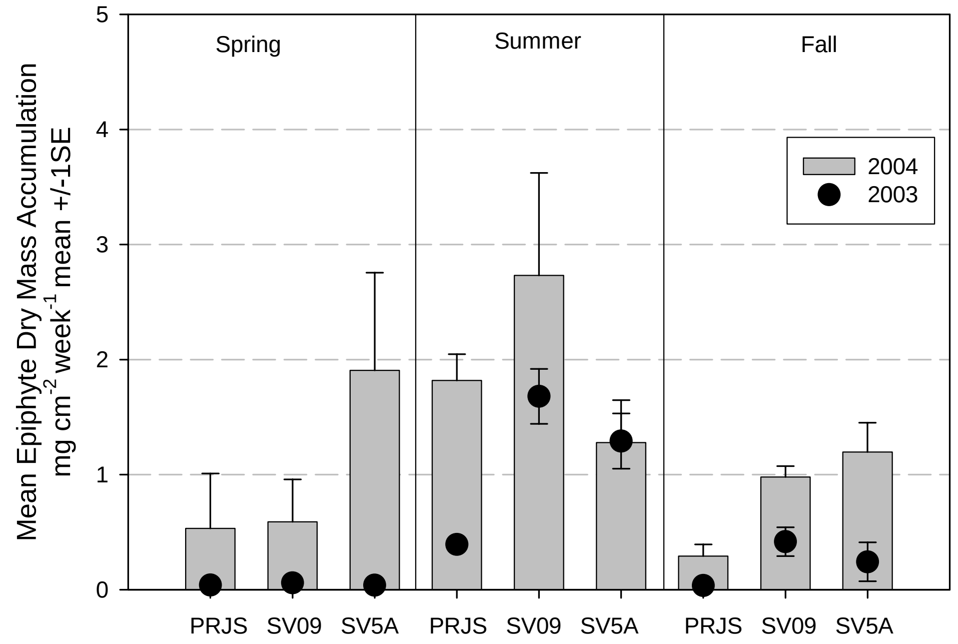


Figure 4-7. Seasonal mean epiphyte dry mass accumulation rates at DNR Patuxent `River stations SV09 (CBL), and SV5A (Pin Oak) in 2003 and 2004. Station PRJS (Potomac River at Judith Sound) shown for comparative purposes.

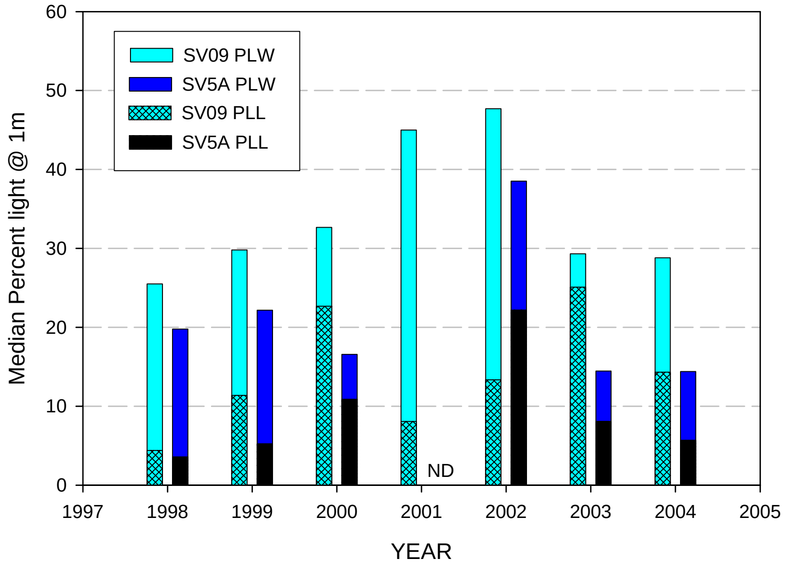


Figure 4-8. Median percent surface light reaching to 1m depth (PLW) and to the leaf surface (PLL) at long-term stations SV09 (CBL), and SV5A (Pin Oak), in the lower Patuxent Estuary.

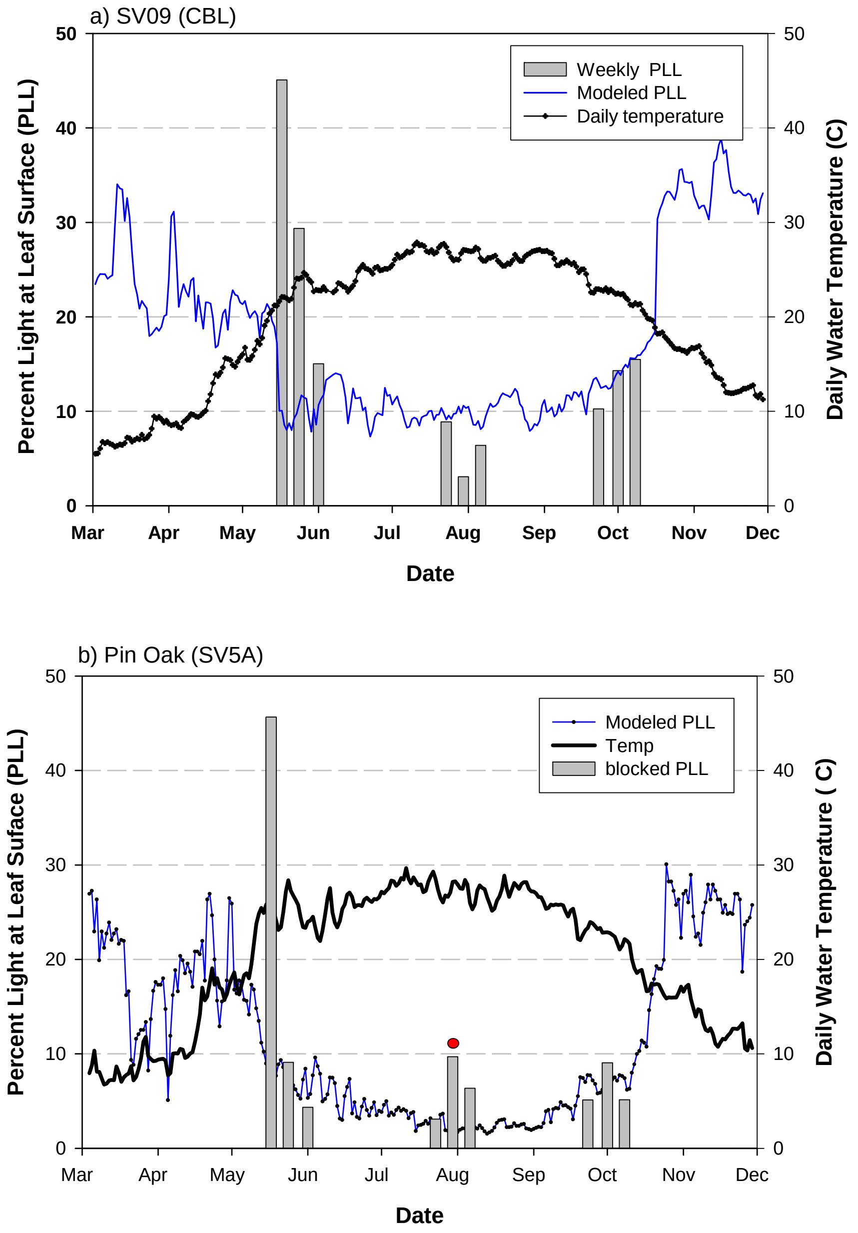


Figure 4-9. Modeled daily median PLL vs. weekly blocked PLL measurements calculated from epiphyte dry mass at a) SV09 and b) Pin Oak in 2004. *PLL for the Pin Oak mid-August deployment was calculated from epiphyte chlorophyll, rather than dry mass.*

4.5 Cited Literature

Batuik, R.A., R.J. Orth, K.A. Moore, W.C. Dennison, J.C. Stevenson, L.W. Staver, V. Carter, N.B. Rybicki, R.E. Hickman, S. Kollar, S. Beiber, P. Heasly. 1992. Chesapeake Bay submerged aquatic vegetation habitat requirements and restoration goals: a technical synthesis. USEPA, Chesapeake Bay Program, Annapolis, MD, USA. 186 pp.

Batuik, R., P. Bergstrom, M. Kemp, E. Koch, L. Murray, C. Stevenson, R. Bartleson, V. Carter, N. Rybicki, J. Landwehr, C. Gallegos, L. Karrh, M. Naylor, D. Wilcox, K. Moore, S. Ailstock, and M. Teichberg. 2000. Chesapeake Bay submerged aquatic vegetation water quality and habitat-based requirements and restoration targets: A second technical synthesis. CBP/TRS 245/00. EPA 903-R-00-014, US EPA Chesapeake Bay Program, Annapolis, MD.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, F.M. Rohland, L.L. Magdeburger and B.J. Weaver. 1995. Ecosystem Processes Component Level 1 Interpretive Report No 12. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 95-039.

Boynton, W.R., R.M. Stankellis, F.M. Rohland, L.L. Matteson, J. Frank, N.H. Burger, J.D. Hagy and M.M. Weir. April 1998. Ecosystem Processes Component (EPC). Level One Report #15, Interpretive Report. (July 1984 - December 1997). Prepared for Maryland Department of Natural Resources. Annapolis, MD. Ref. No. 98-073a.

Boynton, W.R., R.M. Stankelis, J.D. Hagy, F.M. Rohland and J.M. Frank. 2000. Maryland Chesapeake Bay Water Quality Monitoring Program. Ecosystem Processes Component (EPC). Level One Report No. 17. Interpretive Report. (July 1984 - December 1999). Prepared for Maryland Department of Natural Resources. Annapolis, MD. [UMCES Technical Report Series No. TS-252-00-CBL].

Boynton, W.R. and R.M. Stankelis (*eds.*); R.M. Stankelis, E.K. Machelor Bailey, P.W. Smail and M.A.C. Ceballos, J. Cammarata. 2004. Ecosystem Processes Component (EPC). Level 1 Interpretive Report No. 20. Chesapeake Biological Laboratory (CBL), Univ. of Maryland Center for Environmental Science, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 04-086. [UMCES Technical Series No. TS-447-04-CBL].

Brush, M.J. and S.W. Nixon. 2002. Direct measurements of light attenuation by epiphytes on eelgrass *Zostera marina*. Marine Ecology Progress Series. 238:73-79.

Burt, J.S., G.A. Kendrock, R.J. Masini and C.J. Simpson. 1995. Light and Posidonia sinuosa seagrass meadows in the temperate coastal waters of Western Australia: II. Effect of epiphyte species assemblage and biomass on attenuating light to the leaf surface. Department of Environmental Protection, Perth, Western Australia. Technical Series 62.

Duarte, C.M. 1991. Seagrass depth limits. Aquatic Botany 40:363-377.

Kemp, W.M. W.R. Boynton, J.C. Stevenson. R.W. Twilley and J.C. Means. 1983. The decline of submerged vascular plants in Chesapeake Bay: summary of results concerning possible causes. Mar. Tech. Soc. J. 17(2):78-89.

Kemp, WM; Batiuk, R; Bartleson, R; Bergstrom, P; Carter, V; Gallegos, CL; Hunley, W; Karrh, L; Koch, EW; Landwehr, JM. 2004. Habitat Requirements for Submerged Aquatic Vegetation in Chesapeake Bay: Water Quality, Light Regime, and Physical-Chemical Factors. Estuaries. 27(3):363-377.

Neckles, H.A., R.L. Wetzel, and R.J. Orth. 1993. Relative effects of nutrient enrichment and grazing on epiphyte-macrophyte (*Zostera marina* L.) dynamics. Oecologia, 93:285-295.

Parsons, T.R., Y. Maita and C.M. Lalli. 1984. Determination of chlorophylls and total carotenoids: Spectrophotometric method. pp.101 - 112 *in* Parsons, T.R., Y. Maita and C.M. Lalli. A manual of chemical and biological methods for seawater analysis. Pergamon Press, Oxford.

Stankelis, R.M. W.R. Boynton and J.M. Frank 1999. Submerged aquatic vegetation (SAV) habitat evaluation. pp 77-117. W.R. Boynton and F.M. Rohland (eds.) Ecosystem Processes Component Level 1 Interpretive Report No 16. Chesapeake Biological Laboratory, University of Maryland System.

Stankelis, R.M., M.D. Naylor, and W.R. Boynton. 2003. Submerged Aquatic Vegetation in the Mesohaline Region of the Patuxent Estuary: Past, Present and Future Status. Estuaries 26(2A): 186-195.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis. Fish. Res. Bd. Can. Bull. 167 (second edition).

US Environmental Protection Agency (EPA). 1979. *US EP A Method 440.0. Determination of Carbon and Nitrogen in Sediments and Particulates of Estuarine/Coastal Waters Using Elemental Analysis.* Revision 1.4. National Exposure Research Laboratory, Office of Research and Development, US Environmental Protection Agency: Cincinnati, OH.

Virginia Institute of Marine Sciences (VIMS). 2002. Historical SAV Distribution (1971-2001). Available at http://www.vims.edu/bio/sav/historical.html

Williams, S.L. and M.H. Ruckelshaus. 1993. Effects of nitrogen availability and herbivory on eelgrass, *Zostera Marina*, and epiphytes. Ecology 74(3):904-918.

5.0 MANAGEMENT SUMMARY

W.R. Boynton

Based on a review of previous Ecosystem Processes Component (EPC) Reports (Boynton *et al.* 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, and 2003), analyses presented in this report, and data from other sources, the following observations are provided that have relevance to water quality management.

Nutrient Loads to the Patuxent River estuary

Nutrient loading rates for the Patuxent River were again reviewed for the period 1978-2004. This information comes from a synthesis effort supported, in part, by the UMD-CES-IAN Program, by a grant from NSF designed to better understand nutrient transport between the land and salty estuarine waters and from the River Input Monitoring Program. Since nutrient load reductions are a cornerstone element of the Chesapeake Bay Program it is useful to examine relevant aspects of loads in the Patuxent River estuary.

Fall line loads of phosphorus (P) (which include above fall line point and diffuse source inputs) have decreased dramatically between 1978 and 1985 (4-5 fold) following implementation of P-removal at sewage treatment plants and the P-ban in detergents (Fig. 6-1). Fall line loads of P have remained quite low since 1985 but do exhibit spike-like increases during particularly wet years (e.g., 1996 and 2003). Total phosphorus (TP) loads during the last twenty years were also much reduced compared to earlier years with a few notable exceptions (1989, 1993, 1994, 1996, and 2003). It appears that TP loads are especially responsive to local climate conditions. Loads were larger during wet years because P tends to be transported in association with sediment particles. Thus, TP loads are particularly high during wet years when sediments are eroded and transported to the river system. One of many remaining questions to be resolved concerns the fate of P introduced into the estuary as particulate inorganic P. In this form P is not directly available to biological communities. So, is this material largely stored in the system with little biological consequences or are there mechanisms that transform this P component into biologically active forms? Current research in the Patuxent (Jordan, Boynton and Cornwell, NSF supported) on this issue is underway. The basic hypothesis of this effort is that sediment-attached P is slowly transported, via repeated cycles of sediment deposition and resuspension, from tidal fresh zones of the river to the oligohaline regions. In the latter region, mechanisms exist to release the bound P (sulfate reduction) to the water column in a form (DIP) available to biota. A recent review of sediment P releases in a variety of estuarine and coastal marine systems indicates that P releases reach a peak in the upper mesohaline reaches of estuaries, consistent with the mechanisms indicated above (Bailey 2005). Thus, the mechanisms of P entry into the estuary contrast sharply with those of nitrogen (N) (most N enters as nitrate [NO_3^-]; most P enters as particulate phosphorus [PP]) as does the degree of biological availability (N immediately available at point of entry; P availability delayed until released from sediments in the salty portion of the estuary). It is currently not clear if occasional large PP loads (e.g., as in wet years of

1996 and 2003) have effects in subsequent years. At present, it is clear that TP loads are small during dry years but substantial during wet years and that most of this P travels in association with inorganic sediments.

Fall line nitrogen loads have also generally decreased during the period 1978 – 2004 but not nearly as much as phosphorus loads (Fig. 6-1). Increased loads of N were associated with flood events (e.g., May 1989) and high flow years (e.g., 1996 and 2003) and lower loads were associated with both the institution of BNR at sewage treatment plants (post 1992) and with low flow years (e.g., 1999 and 2002). A simple linear regression model of total nitrogen (TN) load versus time was significant ($p < 0.05$) for the period of record (1978 - 2003). For a shorter period of record (1989 – 2002) annual TN loads decreased at a rate of about 230 kg $year^{-1}$ (about 5% of the total TN load to the full estuarine system). The latter regression model was not significant when 2003 load data were included, largely because loads were so high during 2003.

There is unequivocal evidence that nutrient load reductions at the fall line have occurred in recent years. However, it also appears that in the years following the installation of biological nitrogen removal (BNR) capabilities (post-1993) at the large sewage treatment plants in the Patuxent (all but one of which are located above the fall line) diffuse source loading of TN below the fall line has increased, partly because the late 1990s and 2003 were wetter or much wetter than earlier years, and partly because the middle and lower portions of the Patuxent basin have been rapidly developing (see Chapter 5, this Report). Preliminary estimates of annual nitrogen loading to the full Patuxent system appear to not have changed between the pre (1985-1990) and post-BNR years (1993-2000). This is disappointing and clearly indicates that attention needs to be directed at reduction of diffuse sources and further reductions in point sources.

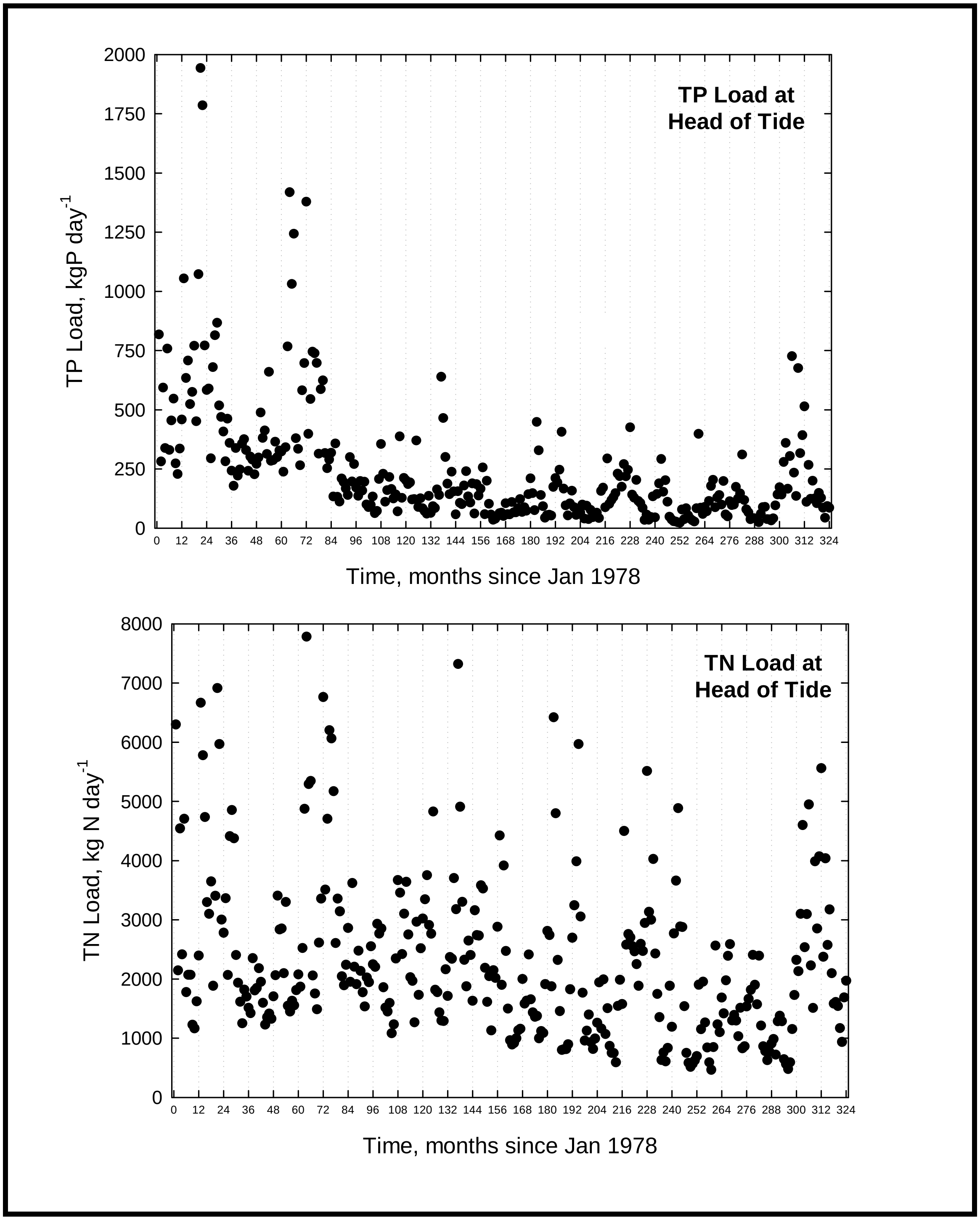


Figure 6-1. Summary of average annual total phosphorus (TP) and total nitrogen (TN) loads at the fall line of the Patuxent River estuary. Data are from the USGS River Input Monitoring Program

Littoral Zone SAV Habitat Evaluations

During 2004 a comparison of littoral zone habitats was continued for two locations within the lower mesohaline portion of the Patuxent Estuary. The goals of this effort was to accurately measure and characterize some of the complex and interacting parameters necessary for submerged aquatic vegetation (SAV) growth and survival in these shallow waters. These measurements included both water quality conditions and epiphyte fouling rates. The five water quality parameters (dissolved inorganic nitrogen [DIN], dissolved inorganic phosphorus [DIP], light attenuation coefficient [Kd], total suspended solilds [TSS], total chlorophyll-*a* [Chl-*a*]) determined most important for growth and survival of SAV were routinely measured and seasonal median values compared to established habitat limits (Batuik et al. 2000). Conditions during 2004 were not as wet as 2003 but median dissolved nutrient concentrations (DIN, DIP) were in excess of the SAV mesohaline habitat limits at both stations. Median values for Kd were also below established SAV habitat limits. These 2004 median values were more severe than levels found in recent wet years (e.g., 1998, 2003). These parameters appear to be somewhat responsive to changes in annual rainfall and measurably improved conditions have been recorded in dry years (1999, 2002) at these locations. It was unexpected that conditions during 2004 would be less suitable for SAV growth than during 2003, an exceptionally wet year. There may be some inter-annual lags in the system and that would explain this pattern. An alternate explanation is that much of the growing season water quality condition is based on winter-early spring water flow. In that case, 2003 and 2004 were not so different, both being wet during the early portion of the year. Despite 20 plus years of monitoring it is still difficult to accurately assess the importance to SAV of nutrient loads coming from terrestrial sources during different seasons of the year. However, it appears that epiphyte fouling rates in the lower Patuxent are not as responsive to changes in nutrient loading as water quality conditions. From 1998 to 2003 epiphyte fouling rates have remained extremely high in the lower mesohaline Patuxent despite high interannual variation in nutrient loading. These rates substantially reduce the amount of light reaching the leaf surface during much of the SAV growing season and no doubt reduce the likelihood of SAV success in this region.

Despite the current poor prognosis for SAV in the lower Patuxent estuary there is evidence that SAV can rapidly respond to improved water quality conditions (Carter and Rybicki, 1986). Changes in the abundance of SAV in the tidal fresh portion of the Patuxent River have been correlated with improvements in sewage treatment and provide hope for future restoration in the lower Patuxent. While the total area available for SAV in the tidal fresh portion of the river remains small (2.0 km^2 < 1m depth) compared to the mesohaline estuary (20.9 km2 < 1m depth), improvements in water quality that began in 1993 due to upgrades in sewage treatment coincided with a resurgence of SAV in that region. For example, in 1992 prior to upgrades in sewage treatment, no SAV was recorded in that area. In 1993, 8.8 hectares (ha) were found in that area, and by 1994, 53.7 ha were recorded. While we cannot conclusively state that resurgence of SAV was a direct result of improved water quality conditions, the relationship seems likely. If nutrient delivery to the lower Patuxent estuary can be reduced, it seems probable that SAV will become established in greater abundance in this area.

Finally, a modeling exercise was undertaken to refine estimates of epiphyte fouling rates. Results indicated substantial agreement with field observations and close agreement with earlier methods confirmed that the blocked design used earlier captures essential features of fouling rates. Further improvements will likely depend on measurement of additional variables, especially any related to the intensity of water and nutrient transport in the littoral zone. We continue to recommend that these measurements be made at a variety of littoral zone sites in Chesapeake Bay.

High Spatial Resolution Water Quality Measurements

High spatial resolution water quality data were collected in the Patuxent River estuary in 2004 using the **DATAFLOW VI** mapping system. The goal of this effort was to identify the spatial and temporal status and scales of water quality variability in this system and to further develop this method of data collection for enhanced near-shore and tributary monitoring for adequate SAV habitats. The 2004 effort was the second year in a three year monitoring activity.

The information collected on seven cruises provided the data necessary to explore and develop the most appropriate ways of using and validating this data set. While this evaluation process is not yet complete, several important results have been found and these include: (1) there was again a clear response in several variables to the general weather conditions of 2004 versus the wetter conditions of 2003. Chlorophyll-a concentrations were not as high during several portions of the 2004 summer as they were in 2003 when values reached as high as 300 µg/l; (2) while there are significant point sources of N and P to this system, diffuse sources are very important and in a wet year, such as 2003, they dominate the nutrient input signature. Clearly, considerable nutrient input reductions could be achieved via control of diffuse sources. However, the late winter-early spring nutrient input characteristics were similar between years. This might explain the enhanced nutrient concentrations often observed at calibration stations during 2004 (3) spatial variability was again substantial, especially in the mesohaline estuary, and this variability was evident along the main axis of the estuary (as expected) as well as in the cross-estuary direction. In the case of SAV habitat characterization using DATAFLOW VI technology it continues to seem prudent to include both offshore as well as nearshore data collection tracks; (4) the upper estuary was characterized by high levels of turbidity, even though 2004 was not as wet a year as 2003. Because of the high turbidity phytoplankton growth was suppressed to some extent. If phytoplankton can be thought of as a primary biogeochemical engine, and if their activity is reduced in the upper estuary, we might expect reduced levels of variability in both time and space for other water quality variables associated with plankton metabolism. Two years of DATAFLOW mapping suggest this to be the case. However, SAV were present in the upper estuary and seemed to thrive by growing in the very shallow areas that characterize much of the upper estuary. In fact, these areas supporting SAV growth are far too shallow (30 – 80 cm) for DATAFLOW measurements; (5) the additional nutrient and other water quality sampling conducted at calibration sites substantially augments spatial and temporal understanding of these distributions. When the third year of this monitoring program is completed these data will form an excellent standard by which to judge conditions in the future.

CONMON Monitoring

High frequency water quality monitoring was conducted at four distinctive fixed locations in the Patuxent River estuary including a site at the upper reaches of salt penetration, at the downstream end of the oligohaline region, and in the upper and lower mesohaline regions. The installation, calibration, maintenance and data management issues associated with this effort have been resolved and the program has functioned very smoothly. Ecosystem Processes Component of the Maryland Water Quality Monitoring Program stopped making these measurements at the end of 2004 and this activity was transferred, with all equipment, to Maryland DNR.

In this report we have continued to suggest several approaches for developing status and performance indicators using these data that would augment traditional indicators of status and trends. It is important to note that median dissolved oxygen concentrations remained above 5 mg $^{-l}$ at all four locations during 2004. Concentrations were higher during 2004 compared to 2003 and this is consistent with the conceptual model linking freshwater (and nutrient) inputs to water quality conditions. The frequency of low dissolved oxygen (DO) conditions was also reduced in 2004 compared to 2003. Peak chlorophyll-a concentration were also generally lower during 2004 than in 2003, again consistent with the conceptual model linking inputs of nutrients to water quality conditions and supporting the general contention that estuaries, such as the Patuxent, are very responsive to input changes.

We have initiated the process of computing metabolic parameters (e.g., community production and community respiration) based on high frequency monitoring. There was additional evidence gained suggesting that we can, using these variables, discern inter-annual and inter-seasonal changes related to nutrient loading and flow regimes. In addition, current estimates are consistent with those made in the Patuxent in earlier years. There are several important and difficult steps remaining before we can recommend that such computations be made a regular part of the monitoring program and be up-graded for use on the DNR web page (Eyes on the Bay). First, we need to develop a user-friendly front end to the SAS program currently in use. This is not an especially difficult task but the right person needs to be identified. We have had preliminary discussions with several individuals and will continue this effort. Second, we need to develop a computational scheme that will respond appropriately when basic assumptions concerning the high frequency data are violated. At present, estimates are computed even when basic assumptions are violated and these are then manually removed from the set of metabolism estimates. We need to find a reliable technique for either removing these data or correcting data and thereby remove the effect of the violated assumptions. The major issue here has to do with a water mass moving past the sonde sensors that has a metabolic history different than the water mass measured during most of a diel period. We are optimistic that solutions to both these issues can be found and implemented

5.1 Cited Literature

Bailey, E. 2005. Nutrient and oxygen fluxes in estuarine and coastal marine systems: literature review and data report. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 05-XXX.

Batuik, R., P. Bergstrom, M. Kemp, E. Koch, L. Murray, C. Stevenson, R. Bartleson, V. Carter, N. Rybicki, J. Landwehr, C. Gallegos, L. Karrh, M. Naylor, D. Wilcox, K. Moore, S. Ailstock, and M. Teichberg. 2000. Chesapeake Bay submerged aquatic vegetation water quality and habitat-based requirements and restoration targets: A second technical synthesis. CBP/TRS 245/00. EPA 903-R-00-014, US EPA Chesapeake Bay Program, Annapolis, MD.

Boynton, W.R., J.H. Garber, W.M. Kemp, J.M. Barnes, J.L. Watts., S. Stammerjohn and L.L. Matteson. 1989. Ecosystem Processes Component Level 1 Interpretive Report No. 6. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 89-080.

Boynton, W.R., J.H. Garber, W.M. Kemp, J.M. Barnes, L.L. Matteson, J.L. Watts, S. Stammerjohn and F.M. Rohland. 1990. Ecosystem Processes Component Level 1 Interpretive Report No. 7. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 90-062.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, J.L. Watts, S. Stammerjohn, D.A. Jasinski and F.M. Rohland. 1991. Ecosystem Processes Component Level 1 Interpretive Report No. 8. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 91-110.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, J.L. Watts, S. Stammerjohn, D.A. Jasinski and F.M. Rohland. 1992. Ecosystem Processes Component Level 1 Interpretive Report No. 9. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 92-042.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, F.M. Rohland, D.A. Jasinski and H.L. Kimble. 1993. Ecosystem Processes Component Level 1 Interpretive Report No. 10. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 93-030a.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, F.M. Rohland, D.A. Jasinski and H.L. Kimble. 1994. Ecosystem Processes Component Level 1

Interpretive Report No. 11. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 94-031a.

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, F.M. Rohland, L.L. Magdeburger and B.J. Weaver. 1995. Ecosystem Processes Component Level 1 Interpretive Report No 12. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 95-039

Boynton, W.R., W.M. Kemp, J.M. Barnes, L.L. Matteson, F.M. Rohland, D.A. Jasinski, J.D. Hagy III, L.L. Magdeberger and B.J. Weaver. 1996. Ecosystem Processes Component Level 1 Interpretive Report No. 13. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 96-040a.

Boynton, W.R., J.M. Barnes, F.M. Rohland, L.L. Matteson, L.L. Magdeburger, J.D.Hagy III, J.M. Frank, B.F. Sweeney, M.M. Weir and R.M. Stankelis. 1997. Ecosystem Processes Component Level 1 Interpretive Report No. 14. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. [UMCEES] CBL Ref. No. 97-009a.

Boynton, W.R., R.M. Stankelis, E.H. Burger, F.M. Rohland, J.D. Hagy III, J.M. Frank, L.L. Matteson and M.M. Weir. 1998. Ecosystem Processes Component Level 1 Interpretive Report No. 15. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 98-073a.

Boynton, W.R., R.M. Stankelis, J.D. Hagy III, F.M. Rohland and J.M. Frank. 1999. Ecosystem Processes Component Level 1 Interpretive Report No. 16. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 99-0070a.

Boynton, W.R., R.M. Stankelis, J.D. Hagy, F.M. Rohland and J.M. Frank. 2000. Ecosystem Processes Component Level 1 Interpretive Report No. 17. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 00-0174.

Boynton, W.R., R.M. Stankelis, F.M. Rohland, J.M. Frank and J.M. Lawrence. 2001. Ecosystem Processes Component Level 1 Interpretive Report No. 18. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 01-0088.

Boynton, W.R., R.M. Stankelis, F.M. Rohland, J.M. Frank, J.M. Lawrence and B.W. Bean. 2002. Ecosystem Processes Component Level 1 Interpretive Report No. 19. Chesapeake Biological Laboratory (CBL), University of Maryland System, Solomons, MD 20688-0038. Ref. No. [UMCES]CBL 02-0152a.

Carter, V., N. Rybicki. 1986. Resurgence of Submersed Aquatic Macrophytes in the Tidal Potomac River, Maryland, Virginia, and the District of Columbia. Estuaries. 9(4B):368-375.