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UNIVERSITY OF MARYLAND CENTER for ENVIRONMENTAL SCIENCE

CHESAPEAKE BAY
WATER QUALITY MONITORING PROGRAM
ECOSYSTEM PROCESSES COMPONENT (EPC)

LEVEL ONE REPORT #20 (INTERPRETIVE)

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MARYLAND DEPARTMENT OF NATURAL RESOURCES

MARYLAND CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

ECOSYSTEM PROCESSES COMPONENT (EPC)

LEVEL ONE REPORT NO. 20

INTERPRETIVE REPORT

(July 1984 - December 2002)

PREPARED FOR:

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1. INTRODUCTION

Almost 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 and 2001). 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 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. This report concludes the effort to monitor sediment-water oxygen and nutrient exchanges.

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),

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

and 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. toxicant levels in sediments and organisms,
4. phytoplankton and zooplankton community characteristics (abundances, biomass and primary production rates) and
5. benthic community characteristics (abundances and biomass).

1.1 Conceptual Model of Estuarine Nutrient and 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 benthic recycling of essential nutrients (3) deposition of organic matter from surface to deep waters links these processes of production and consumption, and (4) submerged aquatic vegetation (SAV) communities are responsive to water quality conditions, especially light availability.

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 the processes monitored in this program 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.

Within the context of this model a monitoring study of sediment processes and SAV habitat conditions has been developed. The EPC has been gathering information since 1985. Initial program components included monitoring of Sediment-Water Oxygen and Nutrient Exchanges (SONE; 1985-1997) at multiple locations (8-10) in the bay and tributaries and monitoring of the vertical flux of sediments and organic particulates at one location in the mainstem bay (VFX; 1985-1992). More recently the SONE program was modified to a more spatially intensive effort focused on the Patuxent River (MINI-SONE program; 1996-1999). In 1992, 1995-1997 a small

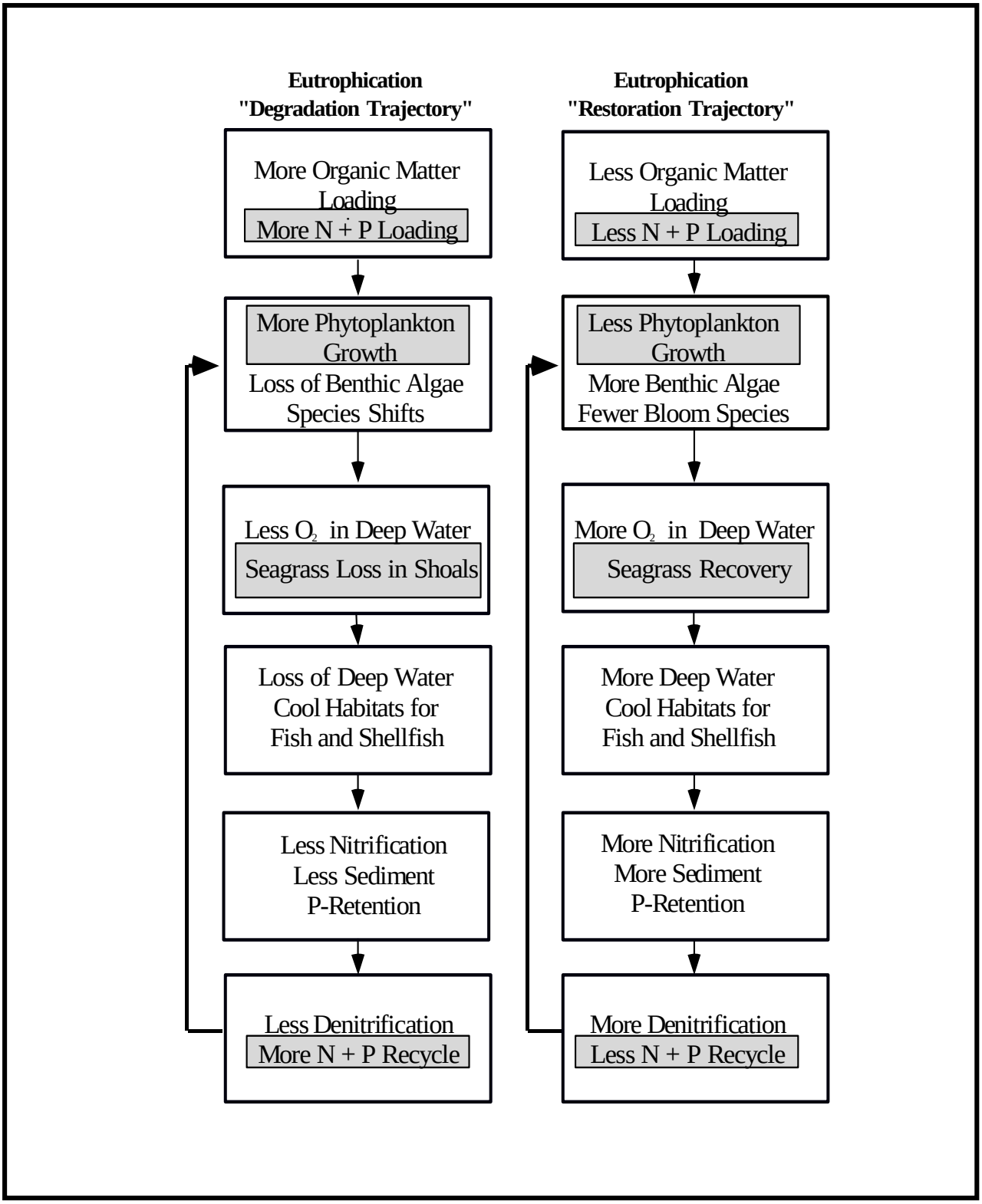

Figure 1-1. A simplified schematic diagram indicating degradation and restoration trajectories of an estuarine ecosystem. Lightly shaded boxes in the diagram indicate past and present components of the EPC program in the Patuxent River and Tangier Sound. (Adapted from Kemp, *pers. comm.*, HPEL)

program was instituted at one location in the Patuxent River to monitor, at high measurement frequencies, dissolved oxygen conditions. Finally, extensive SAV habitat evaluations were initiated in the Patuxent River (1997-1999), were expanded to Tangier Sound during 1999 and further expanded in 2000 to also include the Magothy River. In all of these monitoring activities the working hypothesis is if 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 recolonization will increase and the status of deep water habitats will improve.

1.2 Objectives of the Water Quality Monitoring Program

The EPC of the Maryland Chesapeake Bay Water Quality Monitoring Program conducted monitoring of sediment-water oxygen and nutrient exchanges (MINI-SONE), and evaluated habitat conditions relative to SAV reintroduction. The Patuxent and Magothy River estuaries and Tangier Sound, where EPC efforts were concentrated during the years 2000 and 2001, are areas of particular interest because substantial reductions in nutrient loading rates have been achieved in one system (Patuxent) and SAC community status is of high concern in the others. Measurement of near-shore habitat conditions in the Severn River were added to the 2001 EPC activities.

The EPC has undergone program modification since its inception in 1984 but its overall objectives are consistent with those of other Monitoring Program Components:

1. Characterize the present status of the Patuxent River estuary (including spatial and seasonal variation) relative to sediment-water nutrient exchanges and sediment oxygen consumption rates.

2. Determine the long-term trends that develop in sediment-water nutrient exchanges and sediment oxygen consumption rates in response to pollution control programs in the Patuxent River estuary.

3. Evaluate near-shore water quality conditions relative to SAV habitat across a range of spatial and temporal scales. Near-shore mapping and measurement of water quality conditions was conducted in the Magothy and Severn Rivers. Epiphyte accumulation rates and associated water quality conditions were measured at several sites.

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.

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2. SEDIMENT-WATER OXYGEN AND NUTRIENT EXCHANGES: MINI-SONE

R.M. Stankelis, E.K. Mackelor Bailey, P.W. Smail, F.M. Rohland and W.R. Boynton

2.1 Introduction and Background

Almost two decades of monitoring has shown that nutrient regeneration and release by sediments in many estuaries can be a significant internal source of nutrients to the water column (*e.g.* Boynton *et al*., 1995; Boynton *et al*., 1998). Moreover, sediment nutrient releases have significant potential to negatively affect water quality and living resources. Over the past 18 years the EPC program has monitored sediment flux monthly during summer periods. Previous studies have shown that the highest nutrient released by sediments occurred during the summer months (Boynton *et al.*, 1988). Final sediment-water oxygen and nutrient exchange (SONE) measurements were made in 2002 at four fixed-location stations in the Patuxent River estuary.

Beginning in 1996, the EPC adopted a new technique that increased the spatial resolution of SONE-type measurements. For several years additional sediment-water exchange stations were added to the normal sampling regime to provide better assessments of the range of sediment-water exchanges found within the Patuxent River estuary, especially as a function of water depth. In order to be cost effective, sediment-water exchanges were measured with an abbreviated technique called MINI-SONE. This method monitors a single sediment core instead of the three replicate cores and a blank core previously monitored in the traditional SONE technique. Previous studies had shown that variation among replicate cores from a single location was small compared to variation among sites. Therefore, additional stations, distributed along depth gradients, would provide a more accurate assessment of sediment-water exchanges in the estuary

as a whole, and thus be more useful for evaluating whole ecosystem responses to nutrient management strategies.

This more intensive "mapping" of sediment-water exchanges was conducted during 1996-1999 using the MINI-SONE approach. After 1999, the mapping approach was discontinued but sediment-water exchanges were monitored at the four long-term monitoring stations (BUVA [Buena Vista], MRPT [Marsh Point], BRIS [Broomes Island], and STLC [St. Leonard Creek]) on the Patuxent River with the abbreviated MINI-SONE technique. These data were then merged with previous data sets for the calculation of status and trends at the four long-term monitoring stations.

2.2 Station Locations for MINI-SONE Long-term Patuxent River Station Locations

Four stations, St. Leonard Creek (STLC), Broomes Island (BRIS), Marsh Point (MRPT) and Buena Vista (BUVA) were previously monitored using the full suite of measurements referred to as SONE. These sites are now referred to as the long-term monitoring stations and are monitored using an abbreviated MINI-SONE approach. Station locations sampled during 2002 are shown in Figure 2-1 (See also Table 2-1) as are nearby water quality monitoring stations.

2.3 Sampling Frequency for MINI-SONE

The sampling frequency for MINI-SONE is based on the seasonal patterns of sediment-water exchanges observed in previous studies conducted in the Chesapeake Bay region (Kemp and Boynton, 1980, 1981; Boynton *et al.*, 1982; and Boynton and Kemp, 1985). Previous studies also indicated that short-term temporal (day-month) variation in these exchanges is small; however, considerable differences in the magnitude and characteristics of fluxes appear among distinctively different estuarine zones (*i.e.*, tidal fresh *vs.* mesohaline regions and shallow *vs.* deep areas). In light of these results, the monitoring design adopted for MINI-SONE studies involved four monthly measurements at four stations in June, July, August and September 2002. Sampling dates for these cruises together with alpha-numeric cruise identification codes can be found in Table 2-2.

2.4 Field Methods for MINI-SONE

2.4.1 Water Column Profiles

At each MINI-SONE station, vertical water column profiles of temperature, salinity and dissolved oxygen are measured at 2 meter intervals from the surface to the bottom. Turbidity of surface waters is measured using a Secchi disc.

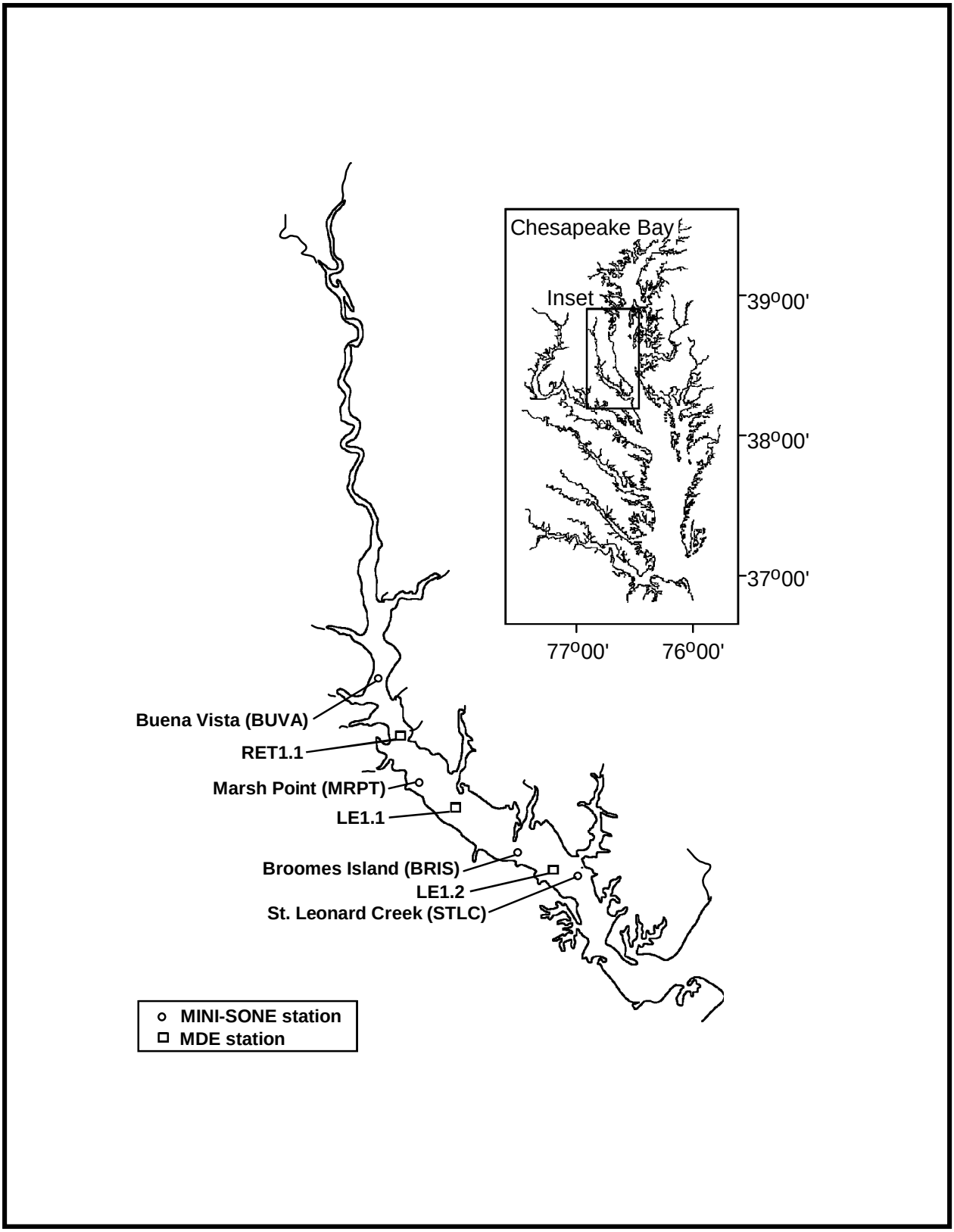

Figure 2-1. Location of four MINI-SONE Stations sampled in the Patuxent River, MD.
Location of stations shown here do not reflect exact geographic locations (See Table 2-1).

Table 2-1. MINI-SONE Station Code, Grid Location and Nearest MDE Station

STATION CODE	LATITUDE (DGPS) NAD 83	LONGITUDE (DGPS) NAD 83	STATION DEPTH (m)	CHESAPEAKE BAY STATION	BAY SEGMENT
Patuxent River					
BUVA	38° 31.050’	76° 39.783’	5.5	RET1.1	RET1
MRPT	38° 26.767’	76° 37.900’	6.9	LE1.1	LE1
BRIS	38° 23.600’	76° 33.067’	15.3	LE1.2	LE1
SLTC	38° 22.817’	76° 30.067’	6.6	LE1.2	LE1

Table 2-2. MINI-SONE Cruise Identifier

CRUISE	DATE	BEGIN DATE	END DATE	RESEARCH VESSEL
MINI-SONE 21	JUN 2002	JUN 13	JUN 13	Orion
MINI-SONE 22	JUL 2002	JUL 19	JUL 19	Orion
MINI-SONE 23	AUG 2002	AUG 16	AUG 16	Orion
MINI-SONE 24	SEP 2002	SEP 23	SEP 23	Orion

2.4.2 Water Column Nutrients

Near-bottom (approximately 1/2 meter above the bottom) water samples are collected using a high volume submersible pump system. Samples are filtered, where appropriate, using 0.7 µm GF/F filter pads, and immediately frozen. Samples are analyzed by Nutrient Analytical Services Laboratory (NASL) for the following dissolved nutrients: ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate ($NO_2^- + NO_3^-$) and dissolved inorganic phosphorus corrected for salinity (DIP or PO_4^{-3}).

2.4.3 Sediment Profiles

At each MINI-SONE station an intact sediment core is used to measure the redox potential (Eh) of the sediment porewater. Sediment redox (mV) is measured at the sediment surface, one and 2 centimeters below the surface and every 2 centimeters thereafter to 10 cm depth. Additionally, surficial sediments are sampled for total and active sediment chlorophyll-*a* to a depth of 1 cm. Particulate carbon (PC), particulate nitrogen (PN), particulate phosphorus (PP), are sampled to a depth of 1 cm.

2.4.4 Sediment Flux Measurements

The protocols used in MINI-SONE flux estimates are an abbreviated set of measurements of the standard SONE techniques. MINI-SONE stations use a single sediment core with no blank. Intact sediment cores constitute a benthic microcosm where changes in oxygen, nutrient and other compound concentrations are determined.

A single intact sediment core is collected at each station using a modified Bouma box corer. These cores are then transferred to a Plexiglass cylinder (15 cm diameter x 30 cm length) and inspected for disturbances from large macrofauna or cracks in the sediment surface. If the sample is satisfactory, the core is fitted with an O-ring sealed top containing various sampling ports, and a gasket sealed bottom (Figure 2-2). The core is then placed in a darkened, temperature controlled holding tank where overlying water in the core is slowly replaced by fresh bottom water to ensure that water quality conditions in the core closely approximate *in situ* conditions.

During the period in which the flux measurements are taken, the cores are placed in a darkened temperature controlled bath to maintain ambient temperature conditions. The overlying water in a core is gently circulated with no induction of sediment resuspension via stirring devices attached to oxygen probes. Oxygen concentrations are recorded and overlying water samples (35 ml) are extracted from each core every 60 minutes during the incubation period. Standard SONE stations are incubated for 4 hours and a total of 5 measurements are taken, while MINI-SONE stations are incubated for 3 hours with a total of 4 measurements taken. As a water sample is extracted from a core, an equal amount of ambient bottom water is added to replace the lost volume. Water samples are filtered and immediately frozen for later analysis for ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate ($NO_2^- + NO_3^-$) and dissolved inorganic phosphorous (DIP or PO_4^{-3}). Oxygen and nutrient fluxes are estimated by calculating the mean rate of change in concentration over the incubation period and converting the volumetric rate to a flux using the volume:area ratio of each core.

2.4.5 Chemical Analyses used in MINI-SONE Element

Methods for the determination of dissolved and particulate nutrients are as follows: ammonium (NH_4^+), nitrite (NO_2^-), nitrite plus nitrate ($NO_2^- + NO_3^-$), and dissolved inorganic phosphorus (DIP or PO_4^-) are measured using the automated method of EPA (1979); particulate carbon (PC) and particulate nitrogen (PN) samples are analyzed using an Elemental Analyzer; particulate phosphorus (PP) concentration is obtained by acid digestion of muffled-dry samples (Aspila *et al.*, 1976); methods of Strickland and Parsons (1972) and Parsons *et al.* (1984) are followed for chlorophyll-*a* analysis.

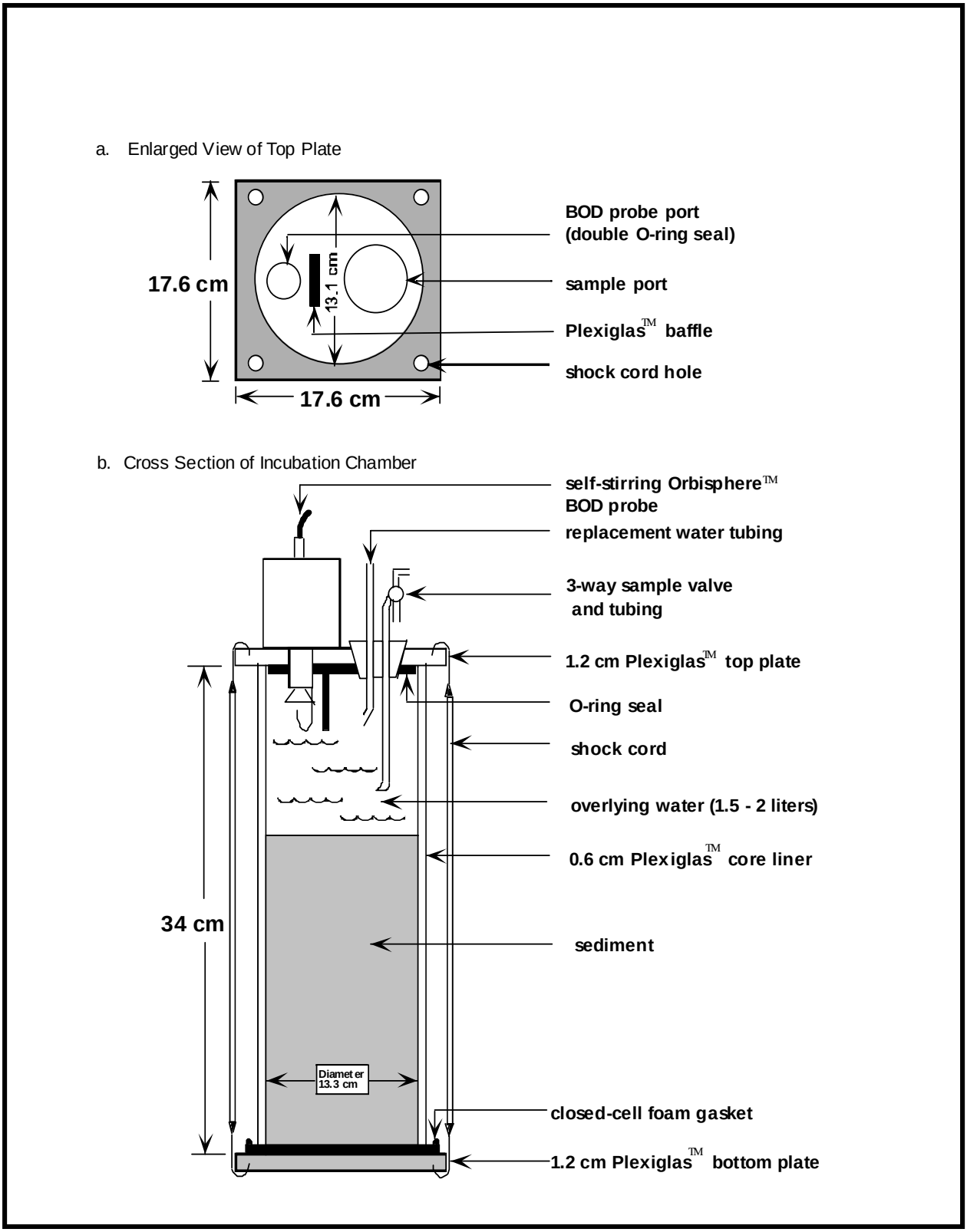

Figure 2-2. Schematic Diagram of the Incubation Chamber
a. Enlarged View of Top Plate.
b. Cross Section of Incubation Chamber

2.5 River Flow

In the Patuxent River, and in other coastal plain estuaries, river flow is often a good indicator of several important external forcing functions that influence estuarine conditions. River flow influences temperature and salinity patterns, circulation and nutrient loading rates. Not only is the magnitude of river flow important, but also the timing of flow events that can affect such processes as nutrient uptake and subsequent deposition of phytodetritus. An examination of inter-annual and monthly flow patterns helps explain variation in estuarine processes such as sediment-water exchanges. Annual average Patuxent river flow was 227 cfs in 2002, 304 cfs in 2001, 315 cfs in 2000, 285 cfs in 1999, 437 cfs in 1998, 412 cfs in 1997 and 704 in 1996; riverflow values for the last four years were below the twenty-four year average of 366 cfs (Figure 2-3.a.).

River flow began to peak during the last quarter of 2002, with the highest monthly value in December (478 cfs). Values recorded in January through October, 2002 were uniformly low and on average were lower than the values recorded for each of these months in 2000 and 2001(Figure 2-3b). Except for the final two months of 2002, flow during this year was exceptionally low. In 2000 the peak flow was recorded in April and in 2001 in June. Many estuarine processes respond to nutrient loading on time scales of weeks to months so the timing of flow events can be an important consideration. In addition, differences in flow also affect the spatial variation found in the river. High flow conditions tend to transport important processes, such as the chlorophyll-*a* maximum, down river compared to lower flow years (Boynton and Kemp, 2000). This may also affect the deposition of labile material to the sediment surface (wherein deposition rates are higher and located further down river in wet years than in years of modest or low flow). In turn deposited material is the primary substrate being decomposed at the sediment water interface and hence directly influences the magnitude of sediment-water exchanges.

2.6 MINI-SONE Sediment-Water Oxygen and Nutrient Fluxes:

2002 Patuxent River Study

Monthly average sediment-water fluxes derived from the complete sediment-water oxygen and nutrient exchanges (SONE) data set (1985 - 2002) are summarized using box and whisker plots (Figures 2-4.1 through 2-4.4) for four flux variables: sediment oxygen consumption (SOC), ammonium (NH_4^+), nitrite plus nitrate ($NO_2^- + NO_3^-$), and phosphate (PO_4^-). Data collected at four stations in the Patuxent River were used to construct these plots. Two stations, Buena Vista (BUVA) and St Leonard Creek (STLC) were sampled during a period of eighteen calendar years (1985 through 2002) while the remaining two stations, Marsh Point (MRPT) and Broomes Island (BRIS), were sampled during a period of fourteen years (1989 through 2002). The order of the four stations in these figures reflects their spatial position in the Patuxent River from the turbidity maximum zone (Buena Vista [BUVA]) to the middle regions of the estuary (Marsh Point [MRPT] and Broomes Island [BRIS]) to the estuary mouth (St. Leonard Creek [STLC]).

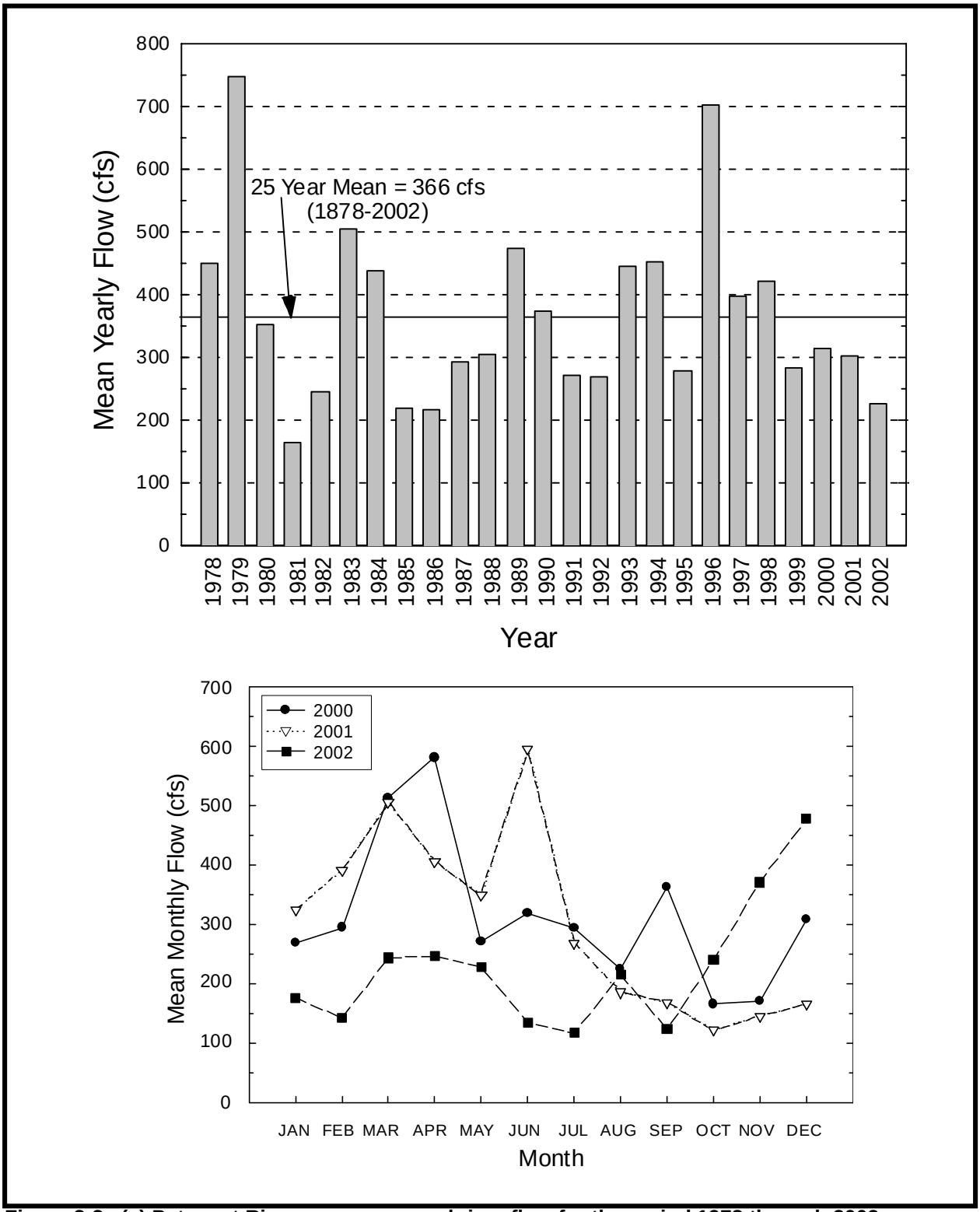

Figure 2-3. (a) Patuxent River average annual river flow for the period 1978 through 2002 (calendar year), at USGS station, 01594440 Patuxent River near Bowie, MD. (b) Patuxent River average monthly river flow from 1999 through 2002 (calendar year), at USGS station, 01594440 Patuxent River near Bowie, MD.

In Figure 2-4 the complete SONE flux data set (1985-2002) was used to produce the box and whisker plots. Sigma Plot software was used to construction the box and whisker plots, a derivation of the original Tukey (1977) box graph. The bottom and top edges of the box are located at the sample 25th and 75th percentiles. The center horizontal line is drawn at the sample median. The central vertical lines, "whiskers", extend from the box as far as the data extends or to a distance of at most 1.5 interquartile ranges, where an interquartile range is the distance between the 25th and the 75th sample percentiles. Any value more extreme than this is marked with a dot. The total number of samples collected at each station and used in the analysis is annotated below each month on the x-axis. The open circles on each graph are the values recorded for each month in 2002.

2.6.1 Sediment Oxygen Consumption (SOC)

Higher than normal dissolved oxygen concentrations in bottom waters (> 3.6 mg l^{-1}) were observed at all stations during 2002. The magnitude of 2002 SOC observations at most stations were noticeably larger (*i.e.* larger negative values). There was no indication of DO-limited SOC during 2002. In dry years, with low river flow, dissolved oxygen concentrations in deep waters tend to be more elevated than usual. Elevated summer bottom water dissolved oxygen conditions result from a complex interaction between water column stratification (less in years of low flow thereby allowing for more atmospheric reaeration of bottom waters via mixing) and more limited amounts of organic matter reaching deep waters and sediments (because of reduced nutrient delivery from diffuse sources and hence lower rates of algal biomass accumulation and subsequent deposition). However, during 2002 we observed that in 12 of 16 SOC measurements were larger than the median value.

2.6.2 Ammonium (NH_4^+) Fluxes

Ammonium fluxes recorded in 2001 as in 2000 were higher than normal releases in July and August at the two up-river stations (BUVA and MRPT). Fluxes reached peak values in July at the two down-river sites (BRIS and STLC). Ammonium fluxes were generally similar to long-term mean values during June and September.

The ammonium flux values during 2002 were lower than in 2001. Maximum values occurred in July or August. The normal pattern of peak fluxes in most years occurred in July at the down-river sites. We have interpreted this pattern as being the result of remineralization of spring bloom organic matter. Decreased fluxes in August and September reflected the decreased supply of labile organic matter to estuarine sediments.

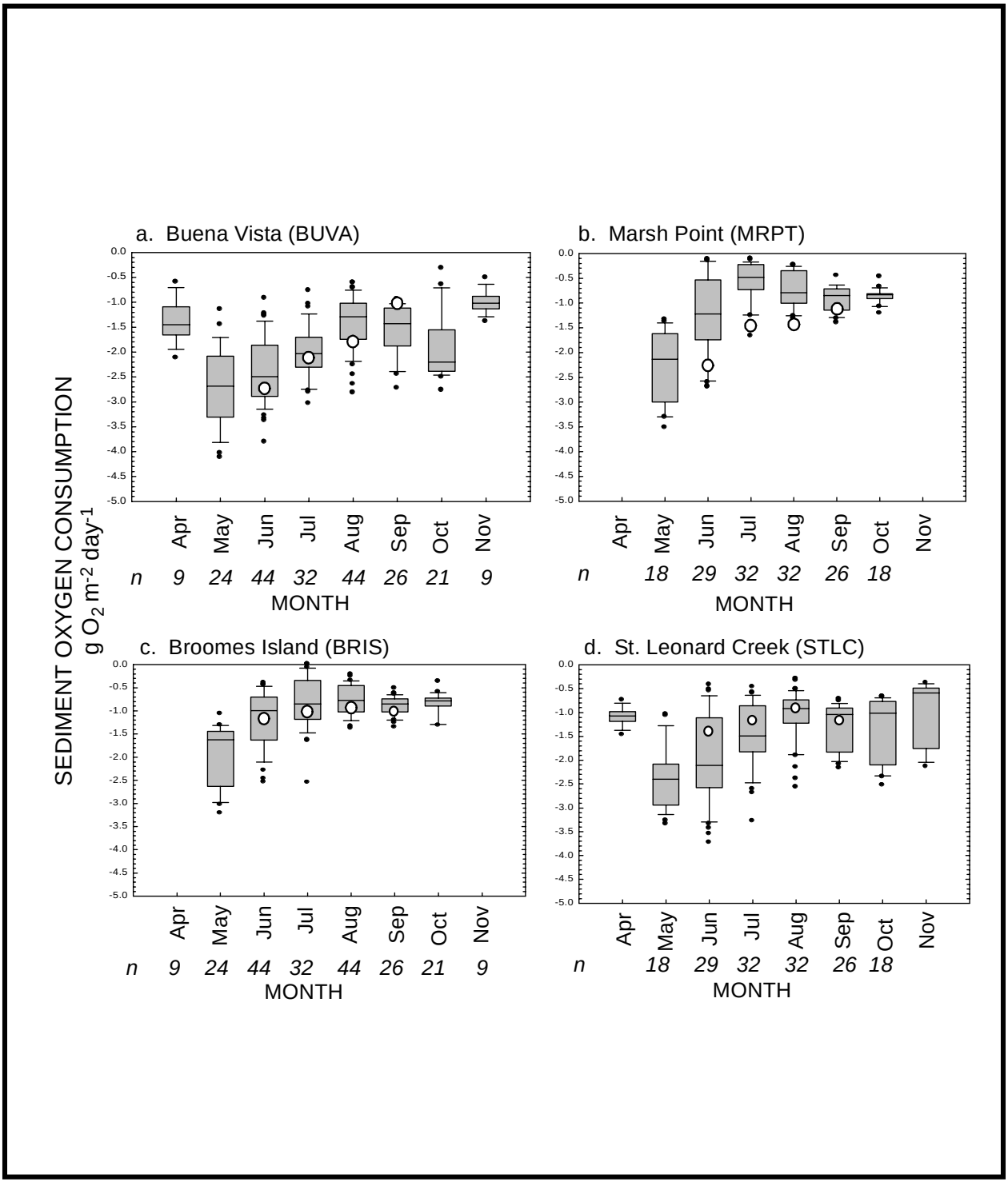

Figure 2-4.1. Box and whisker plots for sediment oxygen consumption (SOC) rates for April to November at four SONE stations located in the Patuxent River.
(a) Buena Vista [BUVA] (b) Marsh Point [MRPT] (c) Broomes Island [BRIS] and (d) St. Leonard Creek [STLC].

The complete SONE flux data set was used to produce the graph. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 2002. September values for all stations only include seven years of data (1991 through 1997). Negative values indicate fluxes from water to sediment. Occasionally hypoxic stations are Broomes Island (BRIS) and Marsh Point (MRPT). Hypoxia is defined here as less than 1.0 mg l^{-1} dissolved oxygen in bottom waters. n indicates the number of samples used to calculate each bar.

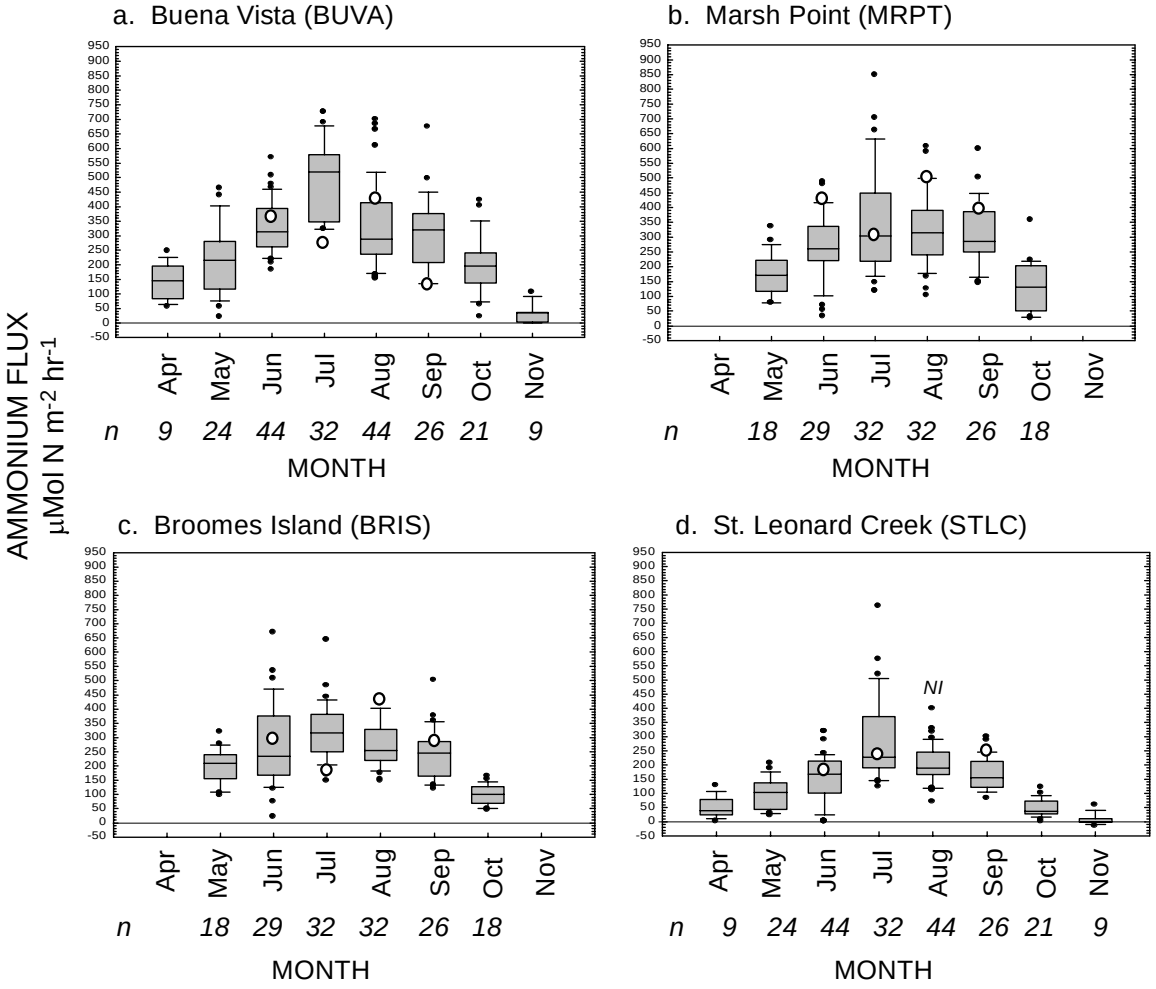

Figure 2-4.2. Box and whisker plots for ammonium (NH_4^+) flux rates for April to November at four SONE stations located in the Patuxent River.
(a) Buena Vista [BUVA] (b) Marsh Point [MRPT] (c) Broomes Island [BRIS] and (d) St. Leonard Creek [STLC].

The complete SONE flux data set was used to produce the graph. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 2002. September values for all stations only include seven years data (1991 through 1997). Negative values indicate fluxes from water to sediment. Occasionally hypoxic stations are Broomes Island (BRIS) and Marsh Point (MRPT). Hypoxia is defined here as less than 1.0 mg l^{-1} dissolved oxygen in bottom waters.
NI indicates that the data were not interpretable, n indicates the number of samples used to calculate each bar.

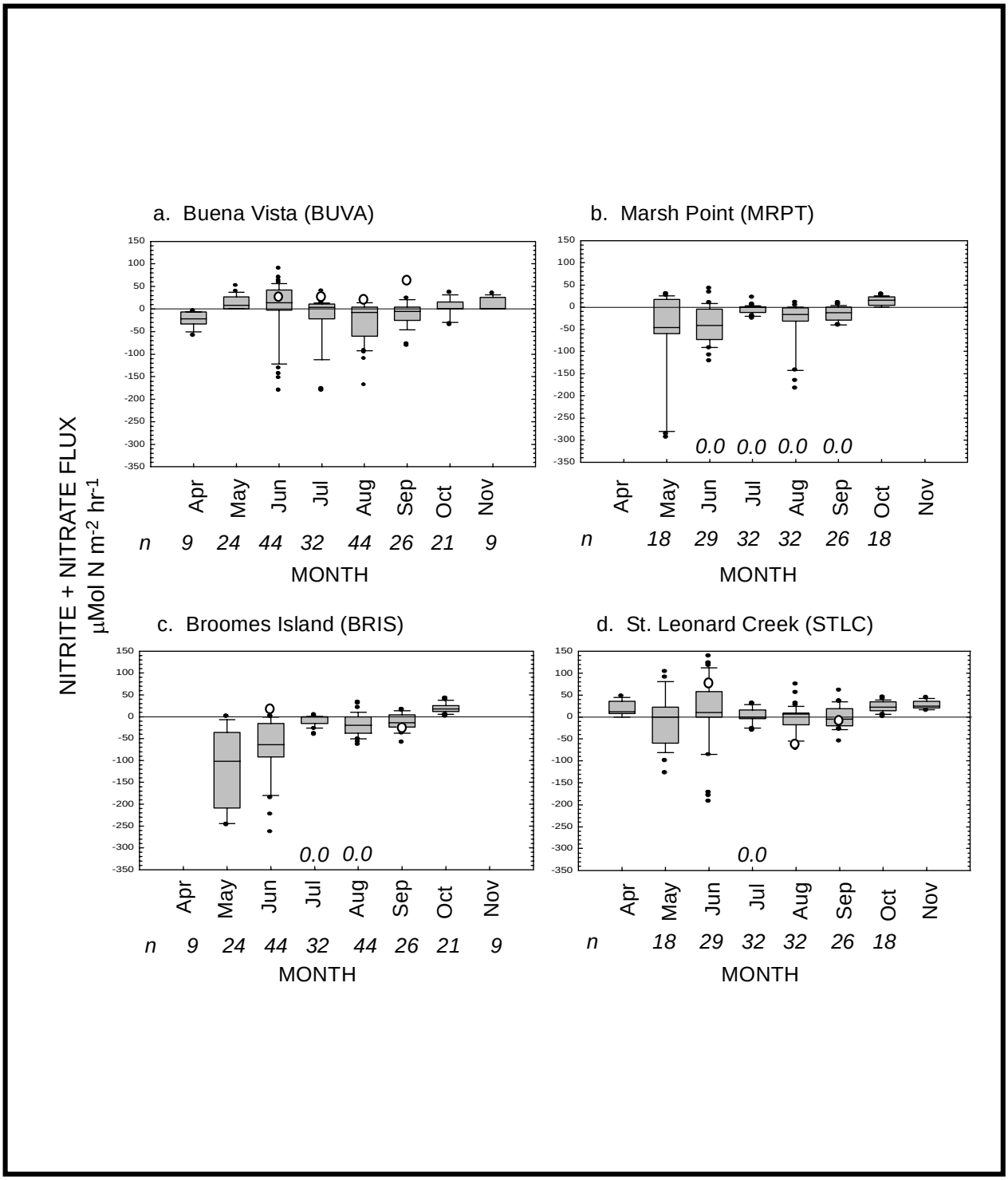

Figure 2-4.3. Box and whisker plots for nitrite plus nitrate (NO_2^- + NO_3^-) flux rates for April to November at four SONE stations located in the Patuxent River.
(a) Buena Vista [BUVA] (b) Marsh Point [MRPT] (c) Broomes Island [BRIS] and (d) St. Leonard Creek [STLC].

The complete SONE flux data set was used to produce the graph. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 2002. September values for all stations only include seven years data, (1991 through 1997) Negative values indicate fluxes from water to sediment. Occasionally hypoxic stations are Broomes Island (BRIS) and Marsh Point (MRPT). Hypoxia is defined here as less than 1.0 mg l^{-1} dissolved oxygen in bottom waters. n indicates the number of samples used to calculate each bar.

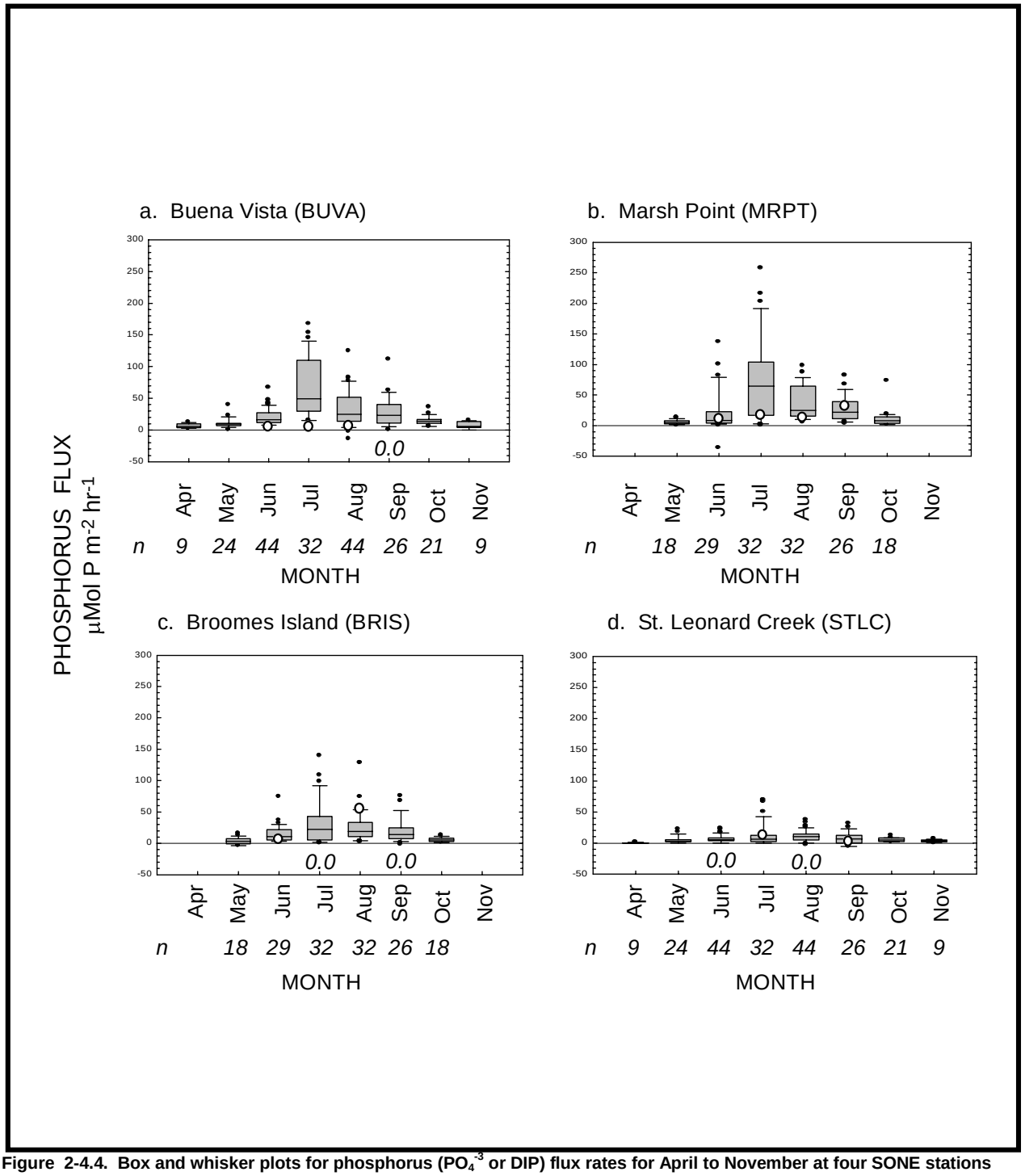

Figure 2-4.4. Box and whisker plots for phosphorus (PO_4^{-3} or DIP) flux rates for April to November at four SONE stations located in the Patuxent River.
(a) Buena Vista [BUVA] (b) Marsh Point [MRPT] (c) Broomes Island [BRIS] and (d) St. Leonard Creek [STLC].

The complete SONE flux data set was used to plot the graph. Monthly values at Broomes Island (BRIS) and Marsh Point (MRPT) are based on data from 1989 through 2002. September values for all stations only include seven years data (1991 through 1997). Negative values indicate fluxes from water to sediment. Occasionally hypoxic stations are Broomes Island (BRIS) and Marsh Point (MRPT). Hypoxia is defined here as less than 1.0 mg l^{-1} dissolved oxygen in bottom waters.
NI indicates that the data were not interpretable, n indicates the number of samples used to calculate each bar.

2.6.3 Nitrite plus Nitrate (NO_2^- + NO_3^-) Fluxes

In general, nitrite plus nitrate (NO_2^- + NO_3^-) fluxes do not constitute a large fraction of the nitrogen exchange between estuarine sediments and bottom waters during summer periods. On occasion, large fluxes from water to sediments do occur but these mainly occur during early spring when NO_3^- concentrations in the water are high. Most fluxes during 2002 were small or near zero. No large fluxes either into or out of sediments were observed.

Even small nitrite + nitrate (NO_2^- + NO_3^-) fluxes from sediments to overlying waters provide a useful indication of sediment conditions. Specifically, production and release of nitrite plus nitrate from sediments is a strong indication that sediment nitrification is occurring. This process requires at least low levels of dissolved oxygen and is hence an indication that surface sediments have been in contact with oxygenated waters. During 2002 13 of 16 nitrite plus nitrate fluxes were either positive or zero. During 1998 (a wet spring) only 5 of 16 flux measurements were indicative of sediment nitrification. To provide additional contrast, during 1996 (an exceptionally high flow year) the overwhelming pattern was nitrite plus nitrate flux (NO_2^- + NO_3^-) from water to sediments which was to be expected during a wet year when water column nitrite plus nitrate (NO_2^- + NO_3^-) concentrations were high. During 1995, a very low flow year, stations in the Patuxent River exhibited relatively high rates of sediment nitrate release. In fact, at the St. Leonard Creek (STLC) station sediments released nitrite plus nitrate through the entire monitoring period, a pattern never before observed. Until 2002 positive fluxes were never observed for the full season at BUVA. During 1999 (another very dry year) nitrite plus nitrate (NO_2^- + NO_3^-) fluxes were predominately positive (12 of 16 fluxes were from sediments to water). These are the types of nitrite plus nitrate (NO_2^- + NO_3^-) fluxes to be expected under reduced nutrient load conditions (as was the case in 1995, 1999 and 2002) both because these conditions favor improved dissolved oxygen conditions in deep waters and sediments and lower concentrations of nitrite plus nitrate (NO_2^- + NO_3^-) in overlying waters. The direction and magnitude of nitrite plus nitrate (NO_2^- + NO_3^-) fluxes between sediments and overlying waters appears to serve quite well as an indicator of sediment quality.

2.6.4 Dissolved Inorganic Phosphorus (PO_4^{-3} or DIP) Fluxes

The spatial and temporal patterns of phosphorus flux in the Patuxent River in 2001 are consistent with the conceptual model of factors controlling these fluxes. Fourteen of 16 values were very low, consistent with well oxygenated bottom waters and oxidized sediments. During 1999, and again in 2001, very low phosphate fluxes were observed at stations having modest to high dissolved oxygen concentrations in bottom waters, emphasizing the strong control dissolved oxygen concentrations have on phosphorus releases from sediments. When bottom water dissolved oxygen concentrations are even somewhat elevated (>1.5 mg l^{-1}) phosphorus is bound by iron oxides at the sediment surface and not released to overlying waters.

2.7 Comparisons Among Sediment-Water Exchanges during 1998-2002

Average summer sediment oxygen consumption (SOC) in 2002 (-1.09 – -1.94 g O_2 m^{-2} day^{-1}) was similar to 2000 (-0.60 – -1.61 g O_2 m^{-2} day^{-1}). There were slight decreases at two of the four stations (*i.e.* BUVA and BRIS) between 1999 and 2000 although the decrease was small and probably not environmentally important. However the change was large at one station, MRPT (Figure 2-5.a.). Fluxes in SOC rates during 2000 were low (-0.6 - -1.61 g O_2 m^{-2} day^{-1}) compared to 1999 (-1.06 – -1.71 g O_2 m^{-2} day^{-1}) the large difference in SOC was probably caused by differences in bottom water DO conditions among these years. In 1999, DO was elevated during the summer period in response to a severe drought. As we have pointed out in a previous report (Boynton *et al.*, 1998), SOC rates are suppressed by low oxygen levels (2000) and enhanced at high oxygen levels (1999). In general, the approximate ranking of SOC rates among stations during 1999 - 2001 was similar to the long term pattern. For example, those stations with higher SOC rates were also those stations having high bottom water DO conditions (*i.e.*, BUVA and STLC). Those stations with low SOC rates had lower DO conditions.

Mean ammonium fluxes in 2002 (221 - 405 µM N m^{-2} hr^{-1}) were higher than the values found in 2001 (302 - 388 µM N m^{-2} hr^{-1}) and similar to those in 2000 (313 – 514 µM N m^{-2} hr^{-1}). At all stations, ammonium flux was greater in 2000 and 2001 than in the drought year of 1999 and was likely due to differences in the size of the phytoplankton bloom between years.

Nitrite plus nitrate (NO_2^- + NO_3^-) flux in 2002 (0 - 32.62 µM N m^{-2} hr^{-1}; Figure 2-5c) was higher at most stations than in 2000 indicating minimal uptake of nitrogen by the sediments. Taking all stations into consideration, mean nitrite plus nitrate flux was more negative (into the sediment) in 2000 compared to 1999. This pattern is thought to have resulted because of higher DO concentrations in deep waters typically associated with low flow, drought years.

Mean phosphate (PO_4^{-3}) fluxes among stations in 2002 (3 - 19 µM P m^{-2} hr^{-1}) were similar to those in 1999. In 2001 fluxes (2 – 60 µM P m^{-2} hr^{-1}) were lower than in 2000 (22 – 105 µM P m^{-2} hr^{-1}), and similar to values observed during 1999 (6 – 39 µM P m^{-2} hr^{-1}; Figure 2-5.d). Dissolved oxygen concentrations at the sediment-water interface probably played a role in regulating PO_4^{3-} fluxes. For example, the maximum mean phosphate (PO_4^{-3}) flux was 105 µM P m^{-2} hr^{-1} in 2000 at Marsh Point (MRPT), which was also the station having low DO conditions (<0.80 mg l^{-1}) during July through September, 2000.

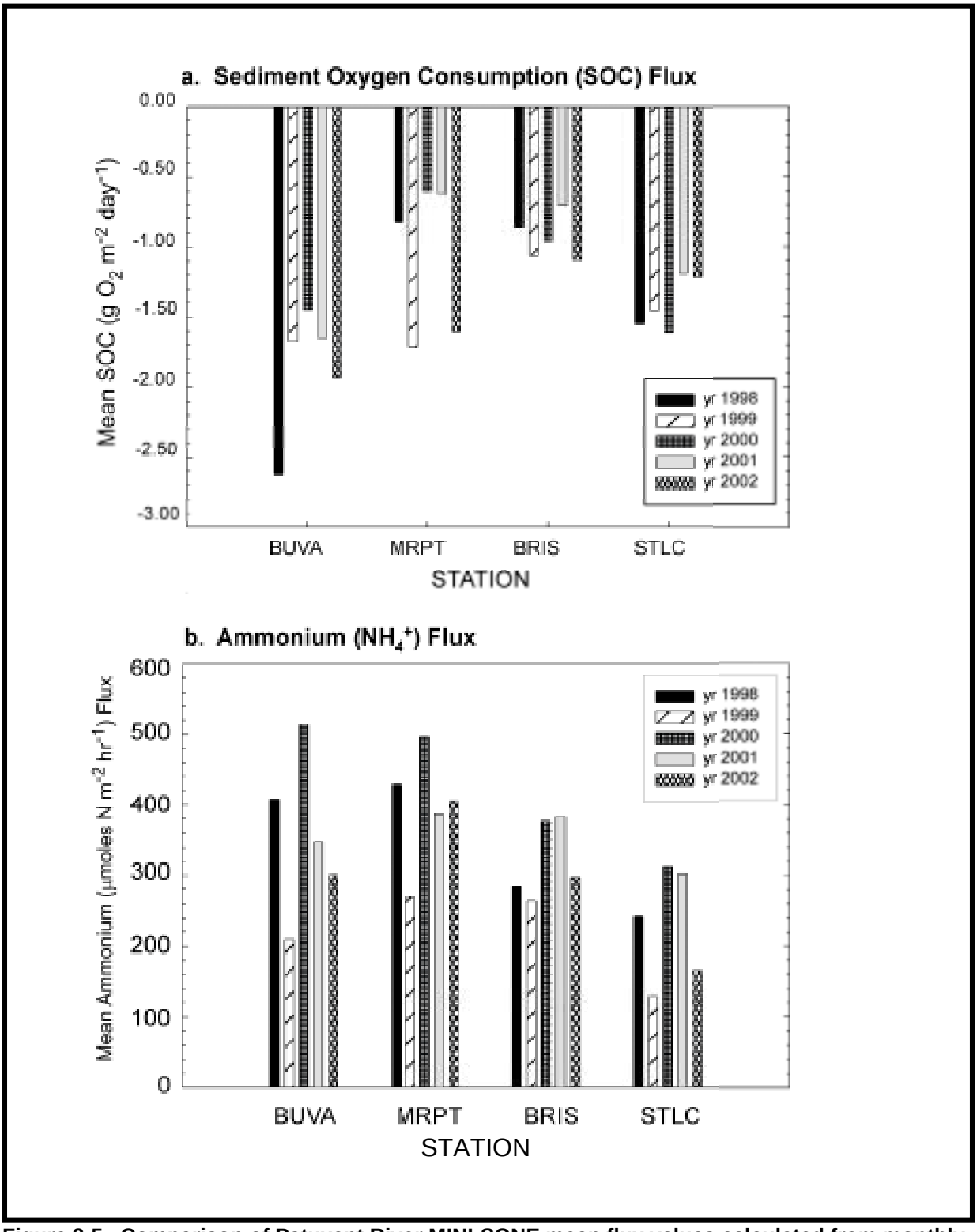

Figure 2-5. Comparison of Patuxent River MINI-SONE mean flux values calculated from monthly measurements from June through September 1998 - 2002 for:

a. sediment oxygen consumption (SOC), and

b. ammonium (NH_4^+) flux.

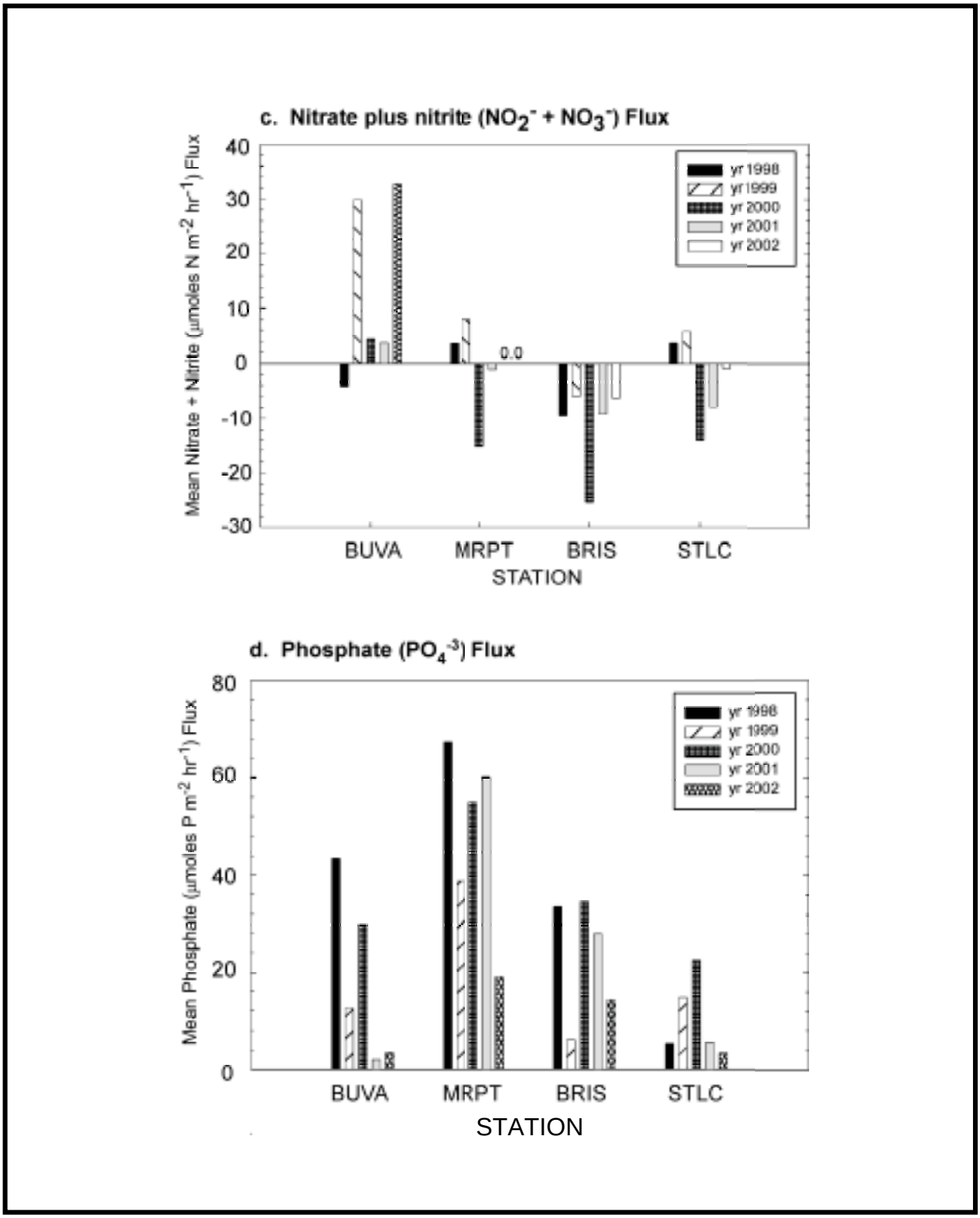

Figure 2-5. Comparison of Patuxent River MINI-SONE mean flux values calculated from monthly measurements from June through September 1998 - 2002 for:
c. nitrite plus nitrate (NO_2^- + NO_3^-), and
d. phosphate (PO_4^{-3}) flux.

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3. SEDIMENT-WATER FLUX STATUS AND TRENDS:

2002 PATUXENT RIVER STUDY

W.R. Boynton and F.M. Rohland

With the signing of *Chesapeake 2000* a commitment was made to continue efforts to achieve and maintain the 40 percent nutrient reduction goal agreed to in 1987, and to adopt goals for the tributaries south of the Potomac River. The major goal is "to achieve and maintain the water quality necessary to support the aquatic living resources of the Bay and its tributaries and to protect human health." A part of the Ecosystem Processes Component (EPC) Program was designed to collect sediment-water flux data and to examine these data in order to identify long-term trends. In previous Interpretive Reports (Boynton *et al.*, 1993, 1994, 1995) results of statistical testing for trends and a time series of important environmental variables (river flow, bottom water dissolved oxygen concentrations and key sediment-water fluxes) were presented and discussed. The figures in Interpretive Report #12 (Boynton *et al.*, 1995) included monthly average data covering the first ten years of the monitoring program (1985 - 1994) collected from six sediment oxygen and nutrient exchanges (SONE) stations. The purpose of these analyses was

to explore the data to determine temporal trends and to provide a basis for relating important environmental conditions to the characteristics of sediment fluxes.

In 1998, a standardized protocol was developed by the Monitoring Program to examine data for status and trend characteristics. This protocol is described below and used in the following sections to characterize the current status of sediment-water exchange processes at four Patuxent River stations and to evaluate the Patuxent River data set for interannual trends. A history of the assumptions and details of procedures used in calculating water quality status and trends in the tributaries of the Chesapeake Bay is provided in Ebersole *et al.* (2002).

3.1 Sediment-Water Quality Status in the Patuxent River

A standardized protocol has been developed for scaling data in order to summarize the status of each parameter (Perry, *pers. comm.*). The status that measures the current conditions at each station is determined by comparison to a benchmark data set comprised of all flux data for January 1985 - December 1990 collected by the EPC-SONE program. The EPC-SONE program has no counterpart in the Virginia section of the bay so the data from Maryland are the only data used in the benchmark data set.

Each station is rated as "***GOOD***," "***FAIR***," or "***POOR***" relative to the benchmark data. These ratings were obtained as follows.

1. For each parameter in the benchmark data set, a transformation is chosen that yields a distribution that is symmetric and reasonably well approximated by the logistic cumulative distribution function (CDF). For the flux parameters, a signed square root transformation was used for all parameters except sediment oxygen consumption (SOC) for which a signed fourth root transformation was used.

2. A logistic CDF based on the mean and variance of each parameter of the benchmark data set is used to perform a probability integral transform on all data in the most recent 3-year period. This results in data in the interval (0,1) which follows a uniform distribution.

3. The 3 year median of this 0-1 data is computed as an indicator of status in the current three year period. The median of n observations taken from a uniform distribution follows a Beta distribution (a symmetric, two parameter distribution) with parameters (m,m) where $m = (n+1)/2$.

The Beta distribution is a two parameter distribution whose density function is defined by the mathematical expression (Patel *et al.*, 1976):

$$f(x;a,b) = \frac{x^{a-1}\,(1-x)^{b-1}}{B(a,b)} \qquad 0 < x < 1,\ a > 0,\ b > 0$$

The function B(a,b) is a beta function which is defined in terms of the gamma function as follows:

$$B(a,b) = \frac{\Gamma(a)\quad\Gamma(b)}{\Gamma(a+b)}$$

If the argument of the gamma function is a positive integer greater than 1, then the gamma function is define as a factorial:

$$\Gamma(a) = (a-1)!$$

which is the definition needed for this application. On other parts of its domain the gamma function is defined by a definite integral (Abramowitz and Stegun, 1972)

If the two parameters a and b are equal, then the beta distribution is symmetric.

The beta distribution arises as the sampling distribution for the median of a sample taken from a uniform distribution (Roussas, 1973). If n observations are taken from a uniform distribution, the median of these n observations will follow a beta distribution with both the a parameter and the b parameter equal to *(n+1)/2.* It is logical that the distribution of the median would be symmetric because the original uniform distribution is symmetric. If for simplicity we define *m = (n+1)/2,* then the median of the uniform data is said to follow a B(m,m) distribution. The mathematical expression is

$$B(x;m,m) = \frac{x^{m-1}\,(1-x)^{m-1}}{B(m.m)}$$

In Chesapeake Bay Program status calculations, the data are transformed to the uniform distribution using the probability integral transform for the log-logistic distribution. The observed median of the transformed data is taken as an indicator of status. The beta density is used to define the probability of observing a similar median from the benchmark population. If the observed median is in the upper 33% of medians from the benchmark population, status is rated as good. If the observed is in the middle 33% status is rated as fair. An observed median in the lower 33% rates as poor.

3.1.1 Notes on the Benchmark

The development of the benchmark for each of the five variables of the EPC-SONE program is different from that used in other portions of the monitoring program. It is most important to note that the stations were not segregated on the basis of salinity zones. As a result of this, every flux measurement made at all four Patuxent River stations was used to develop the benchmark for each parameter. This benchmark is a relative scale, and "good" fluxes cannot necessarily be considered to indicate a recovered system. In other portions of the monitoring program separate benchmarks were developed for tidal fresh, oligohaline, mesohaline and polyhaline areas of the bay using only station data collected within those regions. The EPC-SONE program has three of the four stations monitored classified as mesohaline while the fourth station (Buena Vista [BUVA] in the Patuxent River) can only be classified as oligohaline a small fraction of the time; on an annual average basis this station (Buena Vista [BUVA]) would also be classified as mesohaline. Therefore, a single benchmark is constructed for each of the five variables; in effect, the variable benchmark is synonymous with the mesohaline benchmark.

3.1.2 Notes on the Current Status for the Patuxent River

A median value for the years 2000, 2001 and 2002 was calculated. The use of the last three years of data provides an "***indicator***" value of the status of the parameter relative to measurements taken in the benchmark period. The median value of the last three years of data has the effect of reducing the influence of extreme climatic conditions (*i.e.* very wet or very dry years) since such extremes do not usually occur several years in succession. Since river flow and nutrient loading rates are important variables which either directly or indirectly influence sediment-water exchanges, it is important to note that 2000 exhibited a modest spring peak and low flows through the summer and fall, 2001 was very similar to 2000 with modest peaks in March and June and low river flow values during the second half of the year while 2002 was a dry year with increasing river flow in November and December.

3.1.3 Evaluation of the Current Status for the Patuxent River

i. Sediment Oxygen Consumption (SOC)

The status, for the last five years beginning in 1996 and including the current status (median of 2000, 2001 and 2002 data), of sediment oxygen consumption (SOC) fluxes at the four stations in the Patuxent River are summarized in Figure 3-1.a. It seems appropriate to judge higher values of SOC (SOC reported as a flux of oxygen from water to sediments with a –ve sign) as good in the context of this evaluation for several reasons despite the fact that high SOC rates indicate that sediments are using dissolved oxygen. The main reason for adopting this approach is that SOC rates are responsive to DO concentrations in the water. When DO concentrations in the water are high, SOC rates can be high. Since restoration of increased DO in bottom waters is a goal of the

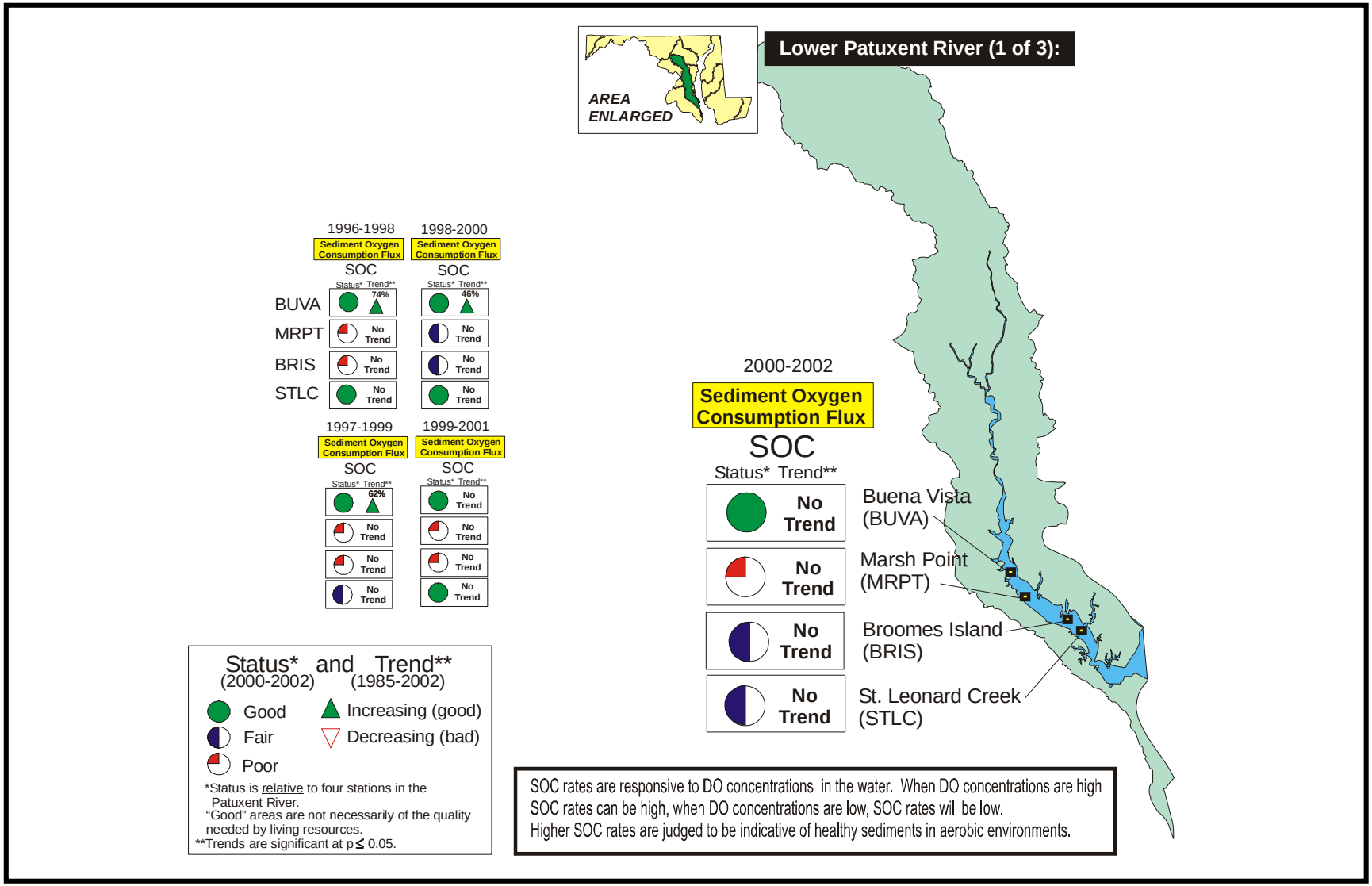

Figure 3-1.a. Map showing status and trends at four stations in the Lower Patuxent River for sediment oxygen consumption (SOC) fluxes (observed data).

Observed data indicates that no river flow adjustments were applied to the raw data.

management program we have adopted the position of treating higher SOC rates as indicative of healthy sediments in aerobic environments. Among the four stations in the Patuxent River, Marsh Point (MRPT) had SOC rates that were poor, two stations, Broomes Island (BRIS) and St. Leonard Creek (STLC) were fair and Buena Vista (BUVA) was in the good range.

Over the last five years the pattern of SOC flux in the Patuxent River has provided substantiation that the benchmark is appropriate. This five-year record summarized in Figure 3-1.a. indicates that SOC fluxes progress from good down-river to fair at the head of the deep water channel at station Marsh Point (MRPT). This pattern would be expected based on proximity to nutrient sources and dissolved oxygen conditions. The station most upriver (and closest to nutrient sources) has a status of good (Buena Vista [BUVA]). This largely results because the water column is well mixed at this station and the propensity for low water column dissolved oxygen (DO) conditions are much reduced at this site. The station at the head of the river (Buena Vista [BUVA] has had a consistent pattern where the status has been good while the station at the mouth (St. Leonard Creek [STLC]) has had a status of good or fair over this five year period. The status at the two mid stations (Marsh Point [MRPT] and Broomes Island [BRIS]) has changed from fair to poor over the five-year period.

ii. Ammonium (NH_4^+)

The status, for the last five years beginning in 1996 and including the current status (median of 2000, 2001 and 2002 data), of ammonium fluxes at the four stations in the Patuxent River is indicated in Figure 3-1.b. In the case of ammonium fluxes it appears appropriate to judge high values as poor because of the well-established direct relationship between ammonium availability and excessive phytoplankton biomass accumulation. All four stations in the Patuxent River were in the poor range during 2002. It should be noted that low river flow years have a strong influence on ammonium fluxes (fluxes decrease). Two of the three years in this analysis exhibited modest to low flows and 2002 was a low flow year. In contrast to river flow and associated nutrient loads, spring chlorophyll-*a* concentrations in the vicinity of Broomes Island (BRIS) were very high in 2000 and 2001. When this material sank to the bottom it provided ample labile organic material to support high NH_4^+ fluxes. The five year record for ammonium summarized in Figure 3-1.b shows an overall poor status for all four stations.

iii. Nitrite (NO_2^-)

The status, for the last five years beginning in 1996 and including the current status (median of 2000, 2001 and 2002 data), of nitrite flux at the four stations in the Patuxent River is indicated in Figure 3-1.c. In the case of nitrite fluxes it appears appropriate to judge high values (positive values) as good because of the well-established linkage between nitrite evolution from sediments and oxidized sediment conditions. The current status is good at all four stations. Stations are expected to change from poor to fair or fair to good when dissolved oxygen (DO) conditions in bottom water improve, even if only enough to allow some nitrification activity to occur. The poor status at Broomes Island (BRIS) in 1999 changed to fair in 2000 and to good in 2002. The

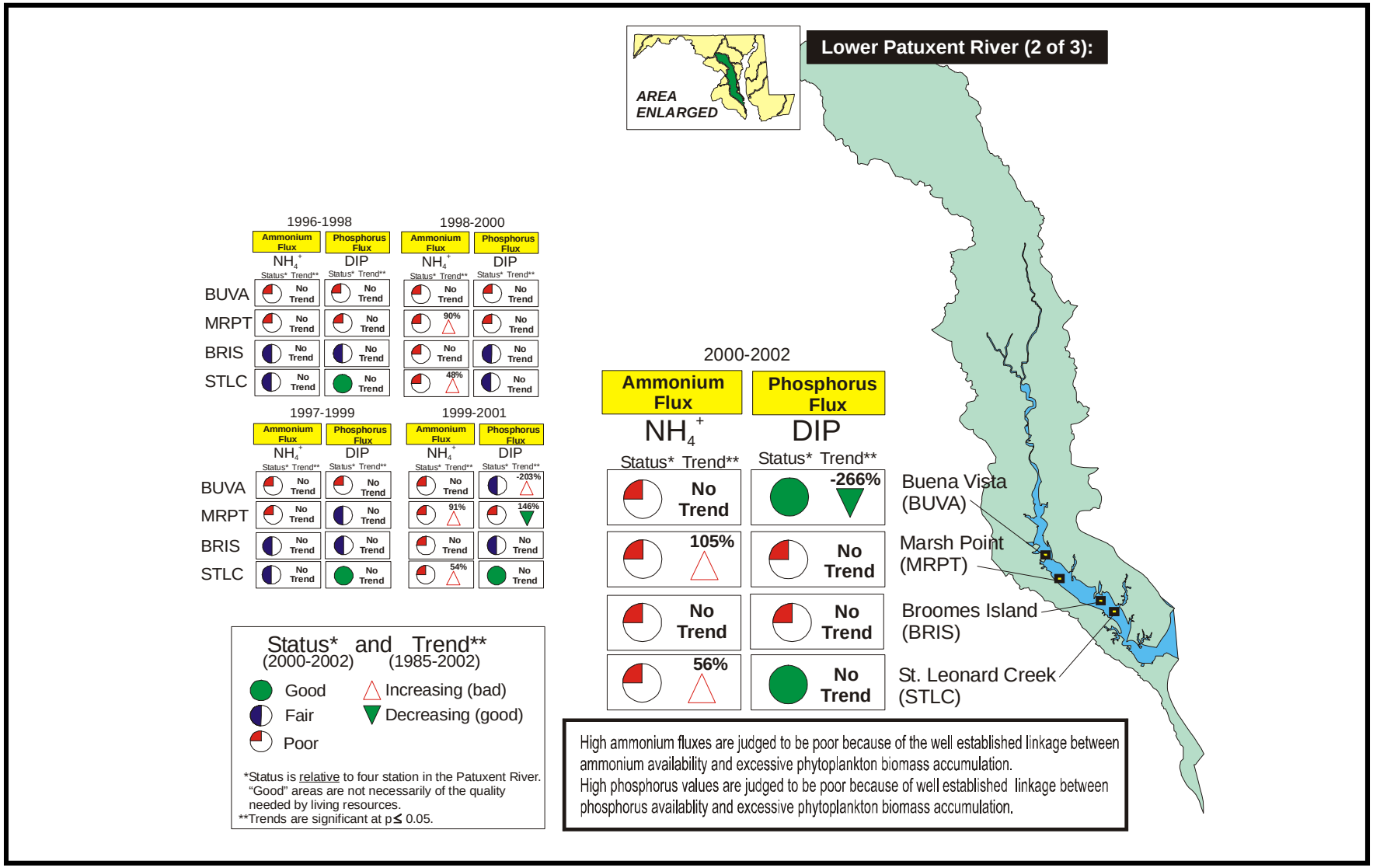

Figure 3-1.b. Map showing status and trends at four stations in the Lower Patuxent River for ammonium (NH_4^+) and phosphorus (PO_4^{-3}) fluxes (observed data).

Observed data indicates that no river flow adjustments were applied to the raw data.

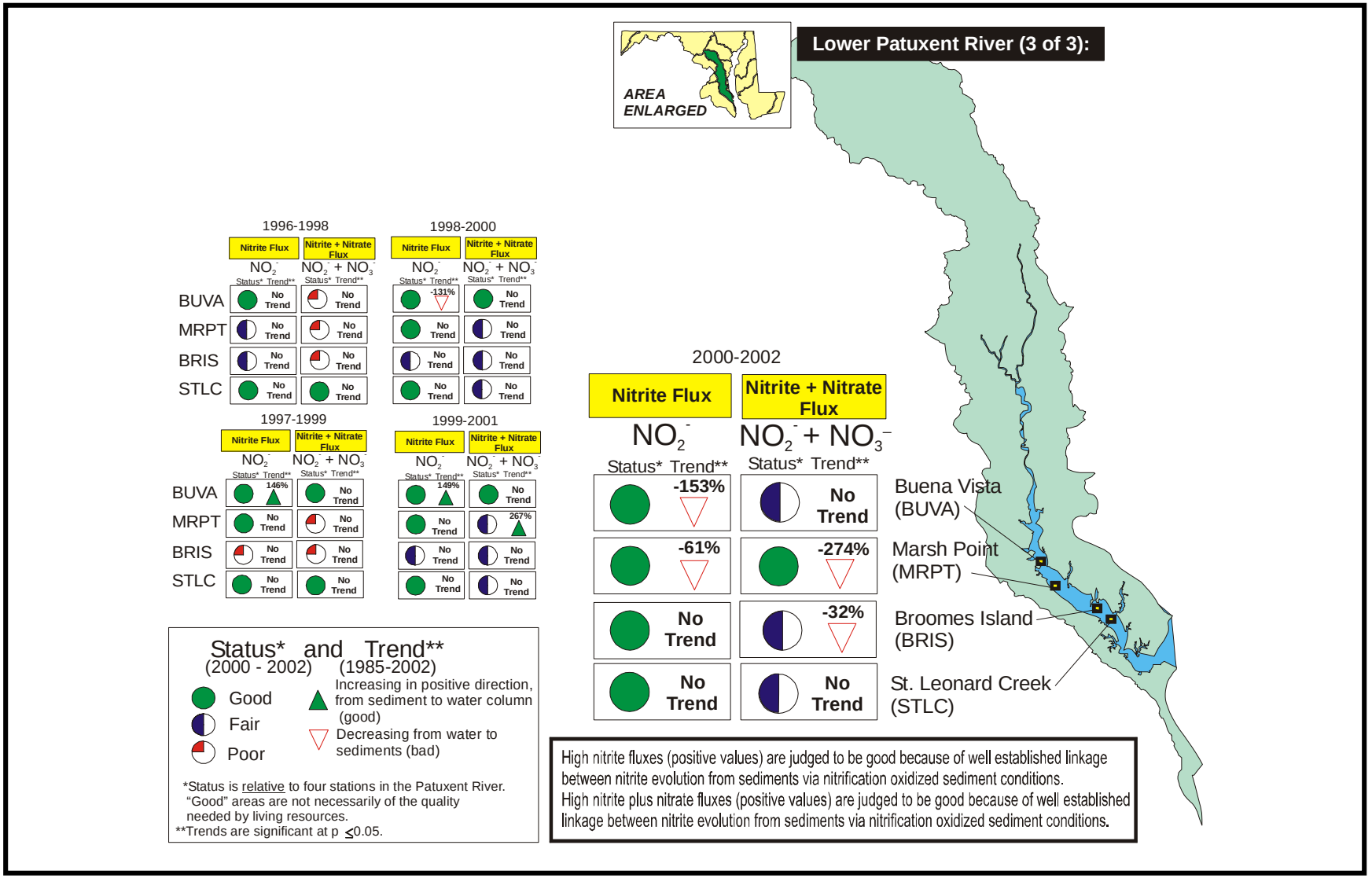

Figure 3-1.c. Map showing status and trends at four stations in the Lower Patuxent River for nitrite (NO_2^-) and nitrite plus nitrate (NO_2^- + NO_3^-) fluxes (observed data).

Observed data indicates that no river flow adjustments were applied to the raw data.

five year pattern shows an improvement of the status at the two mid stations.

iv. Nitrite plus Nitrate ($NO_2^- + NO_3^-$)

The status, for the last five years beginning in 1996 and including the current status (median of 2000, 2001 and 2002 data), of nitrite plus nitrate fluxes at the four stations in the Patuxent River is indicated in Figure 3-1.c. In the case of nitrite plus nitrate fluxes it appears appropriate to judge high values (positive values) as good because of the well established linkage between nitrite plus nitrate evolution from sediments via complete nitrification and oxidized sediment conditions. The current status (2000-2002) shows one station, Buena Vista (BUVA), with a status of good, while the other three stations, Broomes Island (BRIS), Marsh Point (MRPT) and St. Leonard Creek (STLC), are fair. The five year pattern shows some improvement of the status at all four stations.

v. Dissolved Inorganic Phosphorus (PO_4^{-3} or DIP)

The status, for the last five years beginning in 1996 and including the current status (median of 2000, 2001 and 2002 data), of dissolved inorganic phosphorus fluxes at the four stations in the Patuxent River is indicated in Figure 3-1.b. In the case of phosphorus fluxes it appears appropriate to judge high values as poor because of the well-established linkage between phosphorus availability and excessive phytoplankton biomass accumulation. Examining the current status, the two mid-reach stations, Marsh Point (MRPT) and Broomes Island (BRIS), had phosphorus fluxes in the poor range, while St. Leonard Creek (STLC), had phosphorus fluxes in the poor range the station farthest downstream, continued to be good in 2002, as in 2001. The station most upriver, Buena Vista (BUVA) changed from fair to good. It should be noted that high river flow years have a particularly strong influence on phosphorus fluxes (fluxes increase). All three years considered in this evaluation had modest to low (drought) flows. The five-year pattern shows little change in status from year to year.

3.2 Sediment-Water Oxygen and Nutrient Exchanges (SONE) Trends: 2002 Patuxent River Study

A standardized protocol was strongly recommended by the Monitoring Program for determining interannual trends of each parameter (Eskin *et al.*, 1993). This approach used the non-parametric seasonal Kendall test. In results presented here, sediment oxygen and nutrient (SONE) flux data were NOT adjusted for river flow, as is the case for testing other variables for trends within the monitoring program. This adjustment was not attempted because the temporal and spatial linkages between flow and sediment responses have not been clearly established.

3.2.1 Current Testing (Seasonal Kendall Test) for Seasonal Trends: 1985 - 2002 Data from the Patuxent River

Trend analysis is one method that can be used to assess the changes within the Bay system and the effectiveness of programs designed to restore optimum conditions in the Bay as well as prevent deterioration of present conditions. The Seasonal Kendall test is recommended by the Monitoring Program as the preferred statistical procedure for trend assessments. The seasonal Kendall test is non-parametric and is a generalization of the Mann-Kendall test. It is applied to data sets exhibiting seasonality. The test does not assume a specific parametric form. Details of the statistical method are given in Gilbert (1987).

3.2.2 Flux Data Set for Four Patuxent River Stations

Flux data were collected over a period of eighteen years (1985 - 2002) during seven months (April through November) at 4 stations in the Patuxent River (Buena Vista [BUVA], Broomes Island [BRIS], Marsh Point [MRPT] and St. Leonard Creek [STLC]). Flux data typically exhibit strong seasonality that may increase the variance of the data. In order to characterize the data initially, manual QA/QC checks were completed. Extreme outliers were examined and in certain cases these data were discarded. Monthly variation and distribution of flux data are presented using box and whisker plots (Section 2.2.3.1). It has been recommended that for water quality data the median (rather than the mean) be used to determine the center point of the data set, particularly since it is well known that environmental quality data are usually positively skewed (Helsel, 1990). Separate analyzes were performed for each sediment oxygen and nutrient exchange (SONE) variable. A probability level was used to assess the significance of the results using observed data (data not "corrected" for river flow effects), but actual 0.05 p-values are reported in the tables.

3.2.2.1 Results of Kendall Tests for Detection of Inter-Annual Trends for the Patuxent River

Three graphics (Figures 3-1.a., 3-1.b. and 3-1.c.) summarize results of the five flux variables, sediment oxygen consumption (SOC), ammonium (NH_4^+), inorganic phosphorus, nitrite (NO_2^-) and nitrite plus nitrate ($NO_2^- + NO_3^-$) fluxes, measured at four sites (Buena Vista [BUVA], Broomes Island [BRIS], Marsh Point [MRPT] and St. Leonard Creek [STLC]) in the Patuxent River estuary. An overview of the significance of trends is summarized in Table 3-1. Annual values for observed data are presented in Table 3-2.i.

Testing for trends at the annual time scale resulted in five statistically significant results ($p < 0.05$). In the Patuxent River estuary no significant trends were found for sediment oxygen

consumption (SOC) fluxes. A significant increasing trend (at probability level $p < 0.01$) was indicated for ammonium (NH_4^+) at Marsh Point (MRPT) and at St. Leonard Creek (STLC). A significant increasing trend ($p < 0.01$) for nitrite (NO_2^-) was found at Buena Vista (BUVA) and a positive trend ($p < 0.01$) at Marsh Point (MRPT) for nitrate plus nitrite ($NO_2^- + NO^{3-}$). Significant decreasing trend ($p < 0.01$) for dissolved inorganic phosphorus (DIP) was found at Buena Vista (BUVA). During the last eighteen years both wet and dry years have been recorded (relatively high and low diffuse source loading years, respectively) which tend to produce high and low sediment fluxes. Since high/low load years have occurred without pattern, trends are difficult to detect unless they are large and persist for several years.

3.2.2.2 Results of Non-linear Tests for Detection of Inter-Annual Trends for the Patuxent River

Since the data set for sediment fluxes now comprises eighteen years of data, non-linear analyses can provide a broad picture of how each parameter has changed since 1985 (Ebersole *et al.*, 2002). These trends are either U-shaped (decreasing early in the time series, increasing later in the time-series) or the reverse (inverse- U-shaped). A critical point is calculated for each trend.

The regression analyses for linear and non-linear trends are done using the REG procedure of the SAS® Software System (2000). The time variable used as the independent variable is centered so that the linear trend coefficient and the quadratic trend coefficient are independent. In this way the linear trend coefficient will be the same whether or not the quadratic term is in the model. The linear trend displayed in the graphics is predicted values for a simple linear regression of the response variable against the centered time variable. The quadratic trend in the graphics is the predicted values from a multiple linear regression of the response variable against the time variable and the time variable squared. The graphics were created by the GPLOT procedure of the SAS® Software System (2000). All hypothesis tests about the linear and quadratic trends are based on a model with linear and quadratic time components and dummy variables for monthly means to adjust for seasonal trends.

The significant results of the non-linear trend analysis are report in Table 3-2.ii. The significant trends are plotted and shown in Figure 3-2.a – 3-2.e. The most interesting of the five significant trends found is the U shaped trend for ammonium at Buena Vista (BUVA, Figure 3-2.b.). This trend indicated an improving trend for ammonium.

Table 3-1. A condensed summary of significant trends (observed data) detected for sediment-water exchange data using seasonal Kendall Test statistic.

More details can be found in Table 3-2 and Table 3-3.

Observed data indicates that no river flow adjustments were applied to the raw data.

*Significance: * p = 0.05, ** p = 0.01; *** p = 0.001*

NOTE: Upward pointing arrows indicate that the trend was judged as improving;
Downward pointing arrows indicate that the trend was judged as degrading.

Station	Month								ANNUAL
	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	
a. Sediment Oxygen Consumption (SOC; g O_2 m^{-2} day^{-1} yr^{-1})									
BUVA					** ↓				
MRPT				* ↓					
STLC						* ↓			
b. Ammonium (NH_4^+; μM N m^{-2} hr^{-1} yr^{-1})									
BUVA					** ↑	* ↓			
MRPT		* ↑			** ↑				** ↑
STLC					* ↑				** ↑
c. Nitrite (NO_2^-; μM N m^{-2} hr^{-1} yr^{-1})									
BUVA		* ↑		* ↑					** ↑
d. Nitrite plus Nitrate (NO_2^- + NO_3^-; μM N m^{-2} hr^{-1} yr^{-1})									
BRIS			** ↑						
MRPT									** ↑
e. Dissolved Phosphorus (PO_4^{-3}; μM Pm^{-2} hr^{-1} yr^{-1})									
BUVA			* ↓			* ↓			** ↓
MRPT			* ↑						

Table 3-2. Table of annual trends at four stations for four seasonal and an annual variable. Observed data indicates that no river flow adjustments were applied to the raw data.

i. Seasonal Kendall Test Statistics (observed data)

*Significance: * p = 0.05, ** p = 0.01; *** p = 0.001*

STATION	SOC	NH_4^+	NO_2^-	$NO_2^- + NO_3^-$	PO_4^{-3}
St. Leonard Creek (STLC)					
Sign	-43	128	34	-42	-30
p value	0.34	0.003**	0.34	0.36	0.52
Slope	-0.014	3.419	0.182	-0.485	-0.053
Marsh Point (MRPT)					
Sign	-62	96	62	86	60
p value	0.08	0.01**	0.06	0.01**	0.09
Slope	-0.026	14.020	0.321	1.61	1.19
Broomes Island (BRIS)					
Sign	-52	38	3	66	-24
p value	0.14	0.29	0.95	0.05*	0.51
Slope	-0.027	4.019	0.000	0.184	-0.249
Buena Vista (BUVA)					
Sign	-82	33	91	62	-124
p value	0.07	0.47	0.01**	0.17	0.004**
Slope	-0.035	2.642	0.716	0.922	-1.318

ii. Non-linear trend results

*Significance: * p = 0.05, ** p = 0.01; *** p = 0.001*

STATION	PARAMETER	QUADRATIC p-value	TREND	CRITICAL POINT
Buena Vista (BUVA)	SOC	0.005**	U-shape	3 May, 1997
Buena Vista (BUVA)	NH_4^+	0.01**	Inverted U-shape	7 August, 1996
Buena Vista (BUVA)	$NO2^- + NO3^-$	0.0003***	U-shape	26 July, 1992
Buena Vista (BUVA)	DIP	0.0003***	Inverted U-shape	5 February, 1992
Broomes Island (BRIS)	SOC	0.02*	U-shape	12 December, 1996

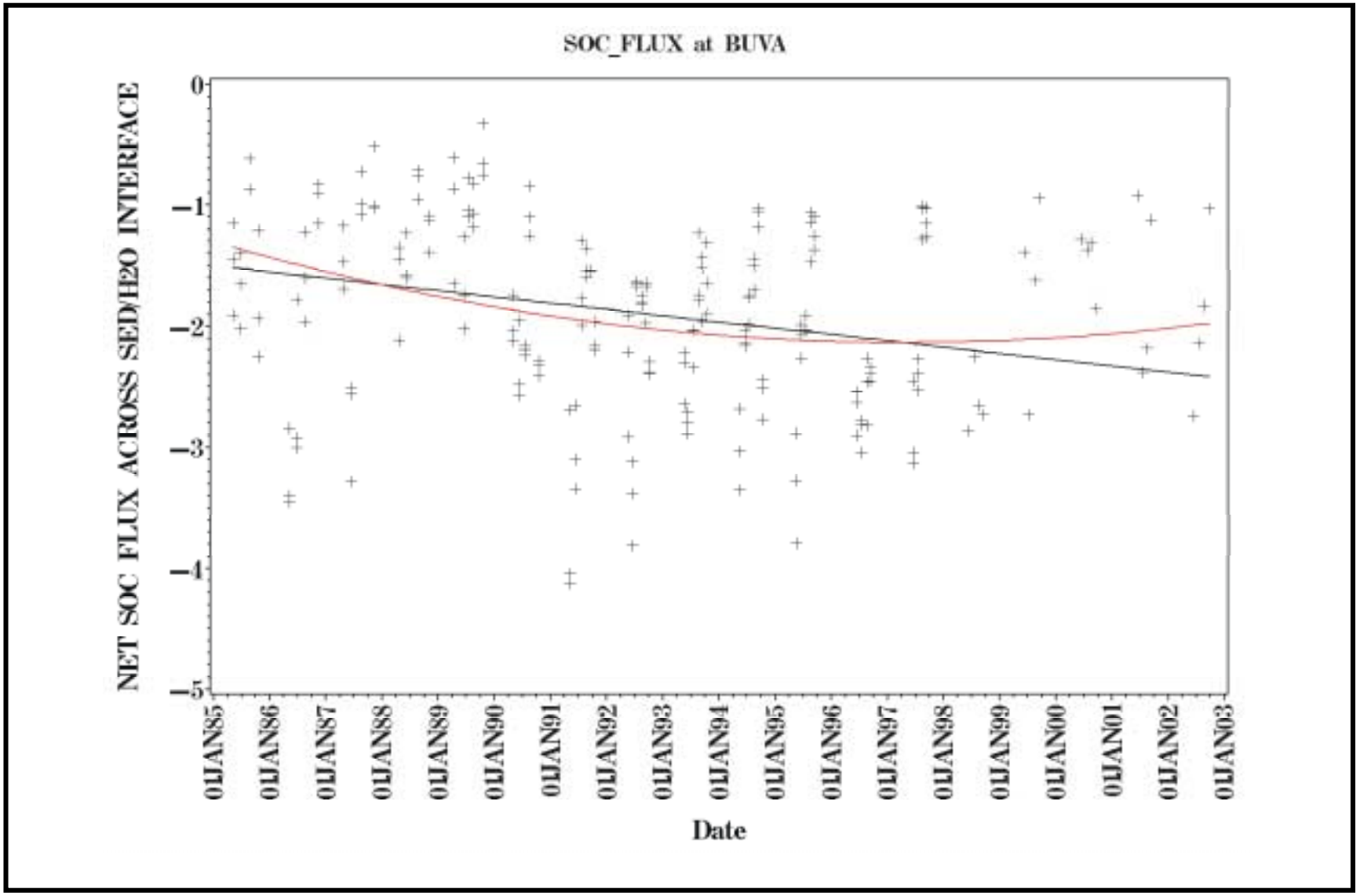

Figure 3-2.a. Plot of sediment oxygen consumption flux data for Buena Vista (BUVA) with both linear and non-linear (U-shaped; quadratic) fit shown.

The significant quadratic p value is 0.005 and the critical point is May 3, 1997.**

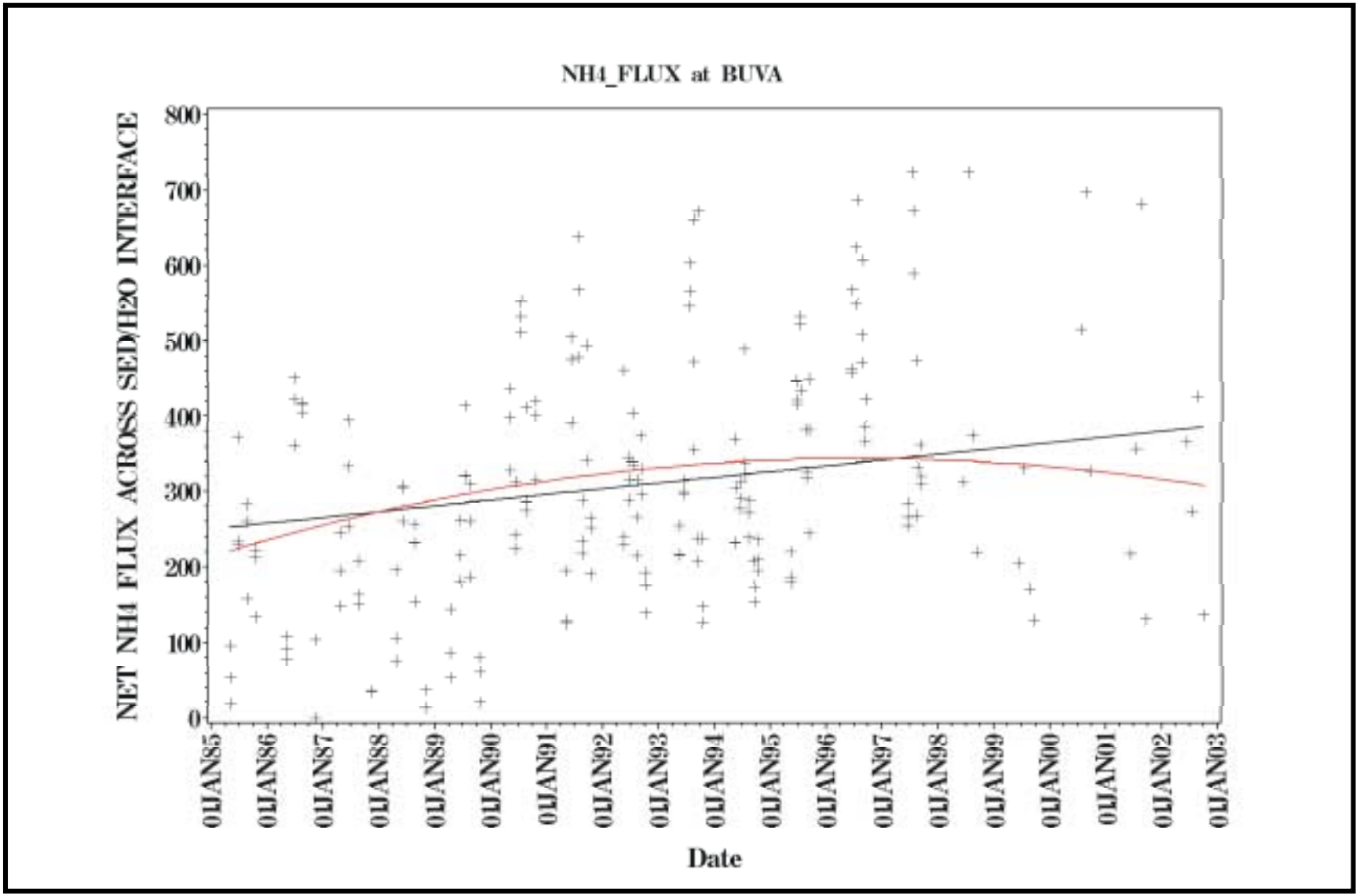

Figure 3-2.b. Plot of ammonium flux data for Buena Vista (BUVA) with both linear and non-linear (inverted U-shape; quadratic) fit shown.

*The significant quadratic p value is 0.01** and the critical point is August 7, 1996.*

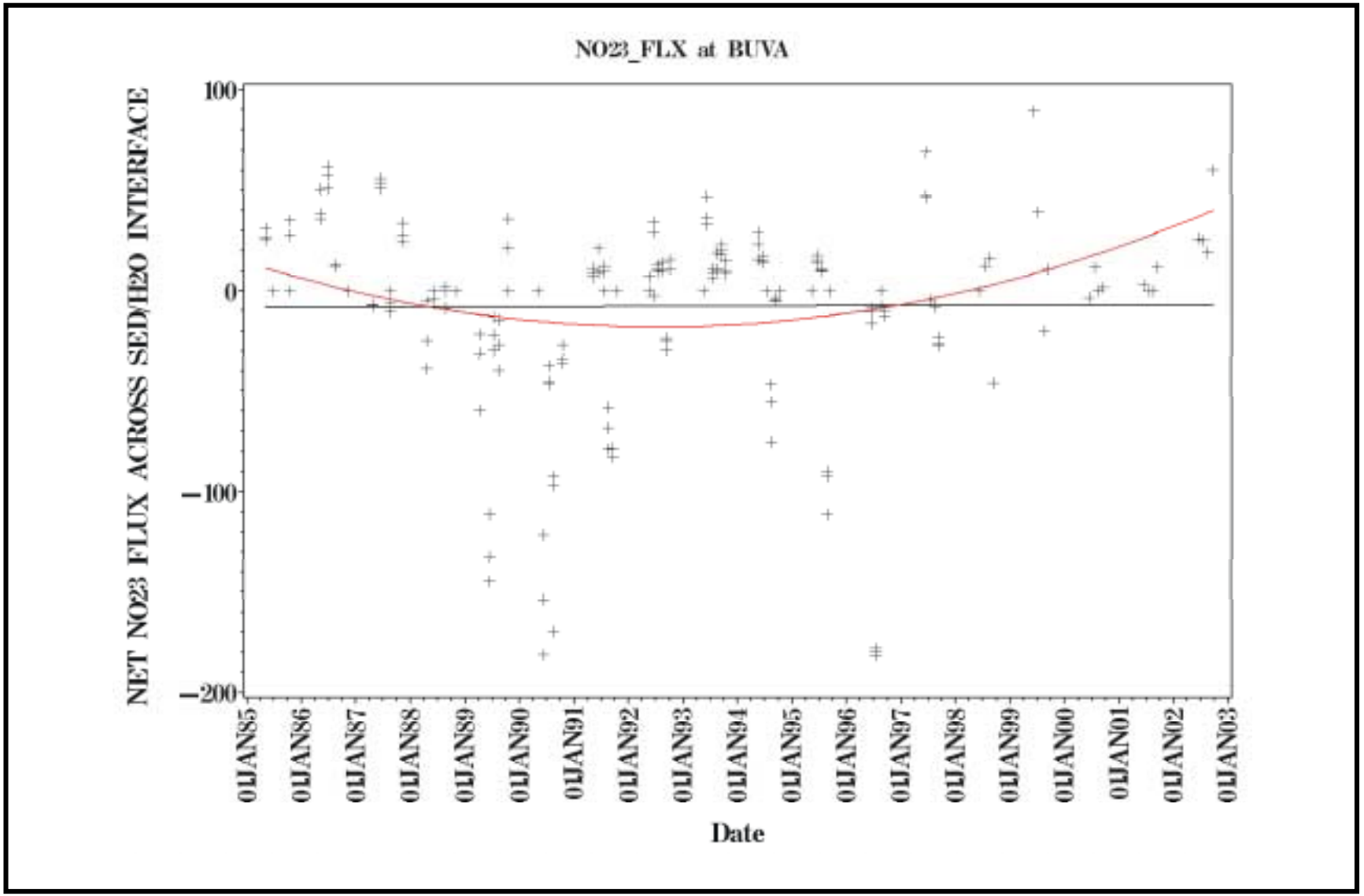

Figure 3-2.c. Plot of nitrate plus nitrite flux data for Buena Vista (BUVA) with both linear and non-linear (U shaped; quadratic) fit shown.
*The significant quadratic p value is 0.0003*** and the critical point is July 26, 1992.*

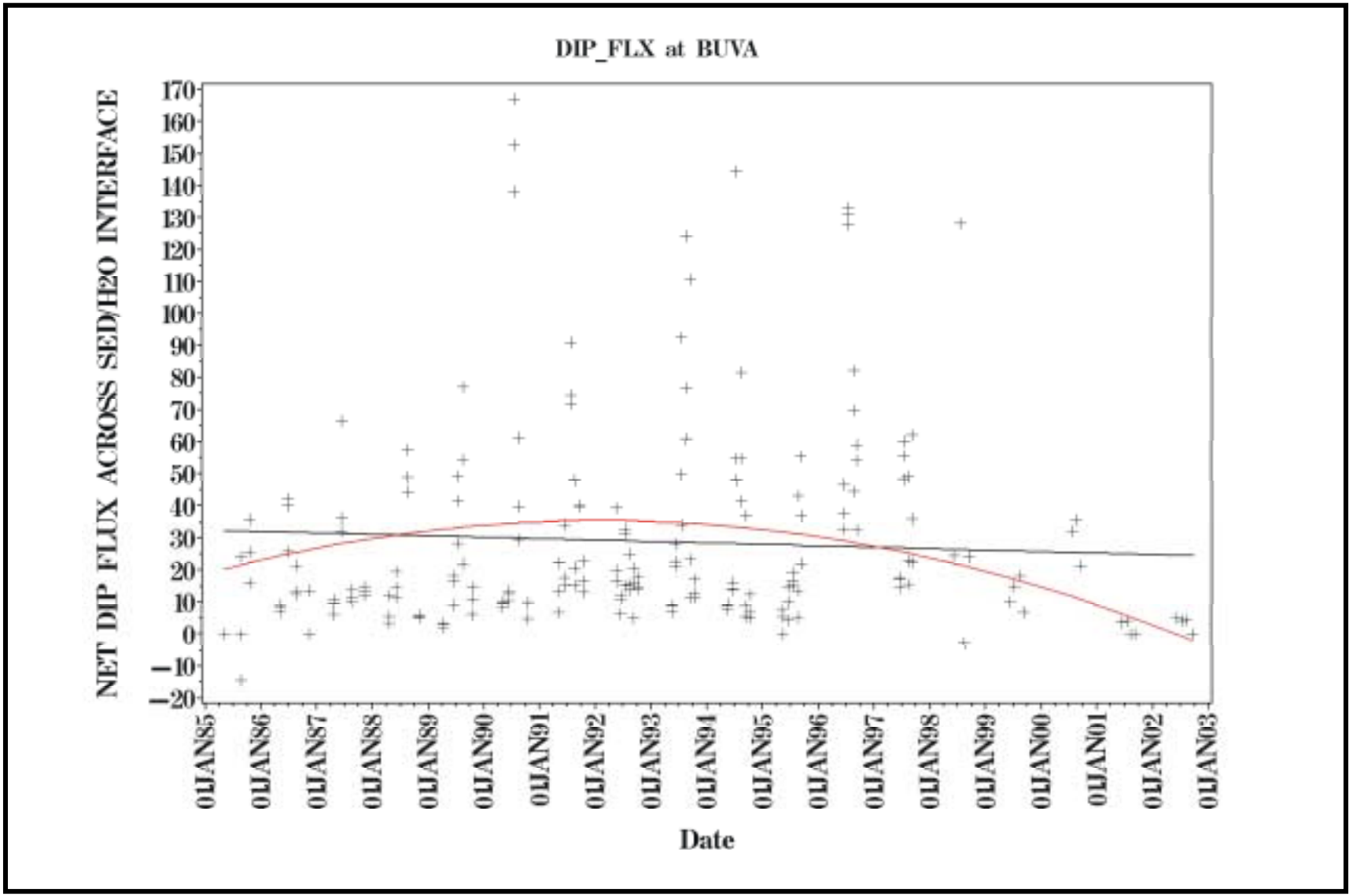

Figure 3-2.d. Plot of phosphorus flux data for Buena Vista (BUVA) with both linear and non-linear (Inverted U shaped; quadratic) fit shown.

*The significant quadratic p value is 0.0003*** and the critical point is February 5, 1992.*

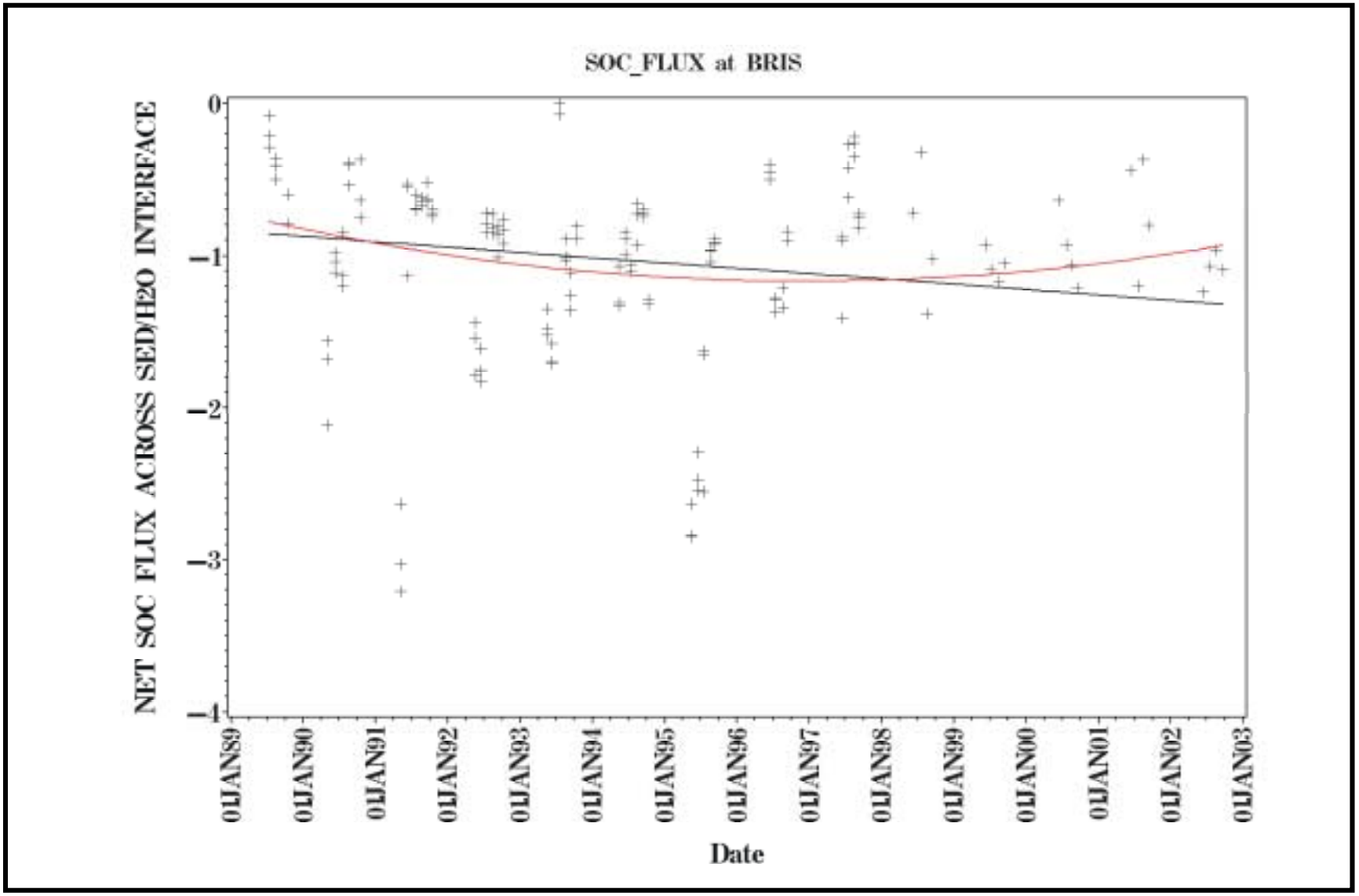

Figure 3-2.e. Plot of sediment oxygen consumption for Broomes Island (BRIS) with both linear and non-linear (U shaped; quadratic) fit shown.

*The significant quadratic p value is 0.01** and the critical point is December 12, 1996.*

3.2.3 Results of Seasonal Kendall Tests for Detection of Monthly Trends for the Patuxent River

The results from the monthly Seasonal Kendall tests are presented as a table using observed rather than flow corrected data (Table 3-3). The Seasonal Kendall Test Statistic value indicates the direction of slope (an implied "+" indicate a positive or increasing slope while "-" indicates a negative or decreasing slope). Different probability levels for significance are indicated in Table 3-3. The *n* value indicates the number of observations used in the analysis**.**

i. Sediment Oxygen Consumption (SOC)

A significant negative (improving) trend continues for sediment oxygen consumption (SOC) at Buena Vista (BUVA) for August, at Marsh Point (MRPT, $p < 0.04$) for July and a significant negative trend at St. Leonard Creek (STLC; $p < 0.05$) for September (Table 3-3.a).

ii. Ammonium (NH_4^+)

A significant trend was indicated for ammonium (NH_4^+) fluxes at $p < 0.01$ in August and $p < 0.05$ at Buena Vista (BUVA; degrading trend). The trends in May and August at Marsh Point (MRPT; degrading trend) and at St. Leonard Creek (STLC) in August (degrading trend; Table 3-3.b) weakened still further ($p < 0.03$).

iii. Nitrite (NO_2^-)

A positive (improving) significant trend was indicated for nitrite (NO_2^-) flux ($p < 0.05$) in the Patuxent River at Buena Vista (BUVA) in May and in July (Table 3-3.c).

iv. Nitrite plus Nitrate ($NO_2^- + NO_3^-$)

A positive (improving) significant trend was indicated for nitrite plus nitrate fluxes ($NO_2^- + NO_3^-$) fluxes ($p < 0.01$) at Broomes Island in June (Table 3-3.d).

v. Dissolved Inorganic Phosphorus (PO_4^{-3} or DIP)

A negative (degrading) trend was found for phosphorus (PO_4^{-3}) flux in June ($p < 0.04$) and in September ($p < 0.05$) at Buena Vista (BUVA) while a positive (improving) significant trend was found for ($p < 0.02$) at Marsh Point (MRPT) in June (Table 3-3.e).

Table 3-3. Table of Monthly Seasonal Kendall Test Statistics (observed data) at four stations for five SONE variables.

Observed data indicates that no river flow adjustments were applied to the raw data.
"." or blank cells in the table indicate that no data were collected or the data were insufficient to perform the analysis.
*Significance: * p = 0.05; ** p = 0.01; *** p = 0.001*

a. Sediment Oxygen Consumption (SOC; g O_2 m^{-2} day^{-1} yr^{-1})

STATION	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
PATUXENT RIVER: Buena Vista (BUVA): 1985 – 2002								
Sign	3	-10	17	-27	-69	16	-9	-3
p value	.	0.28	0.54	0.15	0.01**	0.30	0.24	.
N	3	8	18	14	18	12	7	3
Marsh Point (MRPT): 1989 – 2002								
Sign		-3	7	-38	-20	-5	-3	
p value		0.72	0.71	0.04*	0.30	0.78	1.00	
n		6	13	14	14	12	6	
Broomes Island (BRIS): 1989 – 2002								
Sign		5	16	-17	-23	-22	-11	
p value		0.47	0.36	0.38	0.23	0.15	0.06	
n		6	13	14	14	12	6	
St. Leonards Creek (STLC): 1985 – 2002								
Sign	3	-10	47	-26	-20	-29	-5	-3
p value	.	0.28	0.08	0.17	0.43	0.05*	0.56	.
n	3	8	18	14	17	12	7	3

b. Ammonium (NH_4^+; μM N m^{-2} hr^{-1} yr^{-1})

STATION	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
PATUXENT RIVER: Buena Vista (BUVA): 1985 – 2002								
Sign	-3	10	-10	-3	71	-30	-3	1
p value	.	0.28	0.71	0.91	0.01**	0.05*	0.77	.
n	3	8	17	14	18	12	7	3
Marsh Point (MRPT): 1989 – 2002								
Sign		13	18	9	47	0	9	
p value		0.02*	0.30	0.66	0.01**	1.00	0.14	
n		6	13	14	14	12	6	
Broomes Island (BRIS): 1989 – 2002								
Sign		-3	4	19	-1	12	1	
p value		0.72	0.85	0.32	1.00	0.24	1.00	
n		6	13	14	14	18	6	
St. Leonards Creek (STLC): 1985 – 2002								
Sign	1	-4	32	20	54	20	5	0
p value	.	0.72	0.24	0.25	0.03*	0.19	0.56	.
n	3	8	18	13	17	12	7	3

Table 3-3. Table of Monthly Seasonal Kendall Test Statistics (Observed data) at four stations for five SONE variables (Continued)

Observed data indicates that no river flow adjustments were applied to the raw data.
"." or blank cells in the table indicate that no data were collected or the data were insufficient to perform the analysis.
*Significance: * p = 0.05; ** p = 0.01; *** p = 0.001*

c. Nitrite (NO_2^-; μM N m^{-2} hr^{-1} yr^{-1})

STATION	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
PATUXENT RIVER: Buena Vista (BUVA): 1985 – 2002								
Sign	0	13	-4	43	16	17	6	0
p value	.	0.02*	0.86	0.02*	0.46	0.27	0.23	.
n	1	6	14	14	15	12	5	1
Marsh Point (MRPT): 1989 – 2002								
Sign		3	-1	16	20	13	11	
p value		0.72	1.00	0.29	0.30	0.41	0.06	
n		6	13	13	14	12	6	
Broomes Island (BRIS): 1989 – 2002								
Sign		-3	-13	-4	4	15	4	
p value		0.72	0.44	0.86	1.00	0.34	1.00	
n		6	13	14	14	12	6	
St. Leonards Creek (STLC): 1985 – 2002								
Sign	0	1	-10	8	23	9	3	0
p value	.	1.00	0.62	0.66	0.22	0.58	0.72	.
n	1	6	14	13	14	12	6	1

d. Nitrite plus Nitrate ($NO_2^- + NO_3^-$; μM N m^{-2} hr^{-1} yr^{-1})

STATION	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
PATUXENT RIVER: Buena Vista (BUVA): 1985 – 2002								
Sign	-3	-10	6	32	19	26	-8	0
p value	.	0.28	0.85	0.09	0.46	0.09	0.38	.
n	3	8	18	14	17	12	7	3
Marsh Point (MRPT): 1989 – 2002								
Sign		-5	31	14	26	15	3	
p value		0.47	0.07	0.38	0.17	0.34	0.72	
n		6	13	16	14	12	6	
Broomes Island (BRIS): 1989 – 2002								
Sign		-3	45	16	11	-4	1	
p value		0.72	0.01**	0.30	0.58	0.84	1.00	
n		6	13	14	14	12	6	
St. Leonards Creek (STLC): 1985 – 2002								
Sign	-3	2	-23	10	-42	8	7	-1
p value	.	0.90	0.40	0.57	0.12	0.63	0.38	.
n	3	8	18	13	18	12	7	3

Table 3-3. Table of Monthly Seasonal Kendall Test Statistics (Observed data) at four stations for five SONE variables (Continued).

Observed data indicates that no river flow adjustments were applied to the raw data.
"." or blank cells in the table indicate that no data were collected or the data were insufficient to perform the analysis.
*Significance: * p = 0.05; ** p = 0.01; *** p = 0.001*

e. Dissolved Phosphorus (PO_4^{-3}; μM Pm^{-2} hr^{-1} yr^{-1})

STATION	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
PATUXENT RIVER: Buena Vista (BUVA): 1985 - 2002								
Sign	-3	2	-46	-33	-7	-29	-9	1
p value	.	0.90	0.04*	0.08	0.82	0.05*	0.24	.
n	3	8	16	14	18	12	7	3
Marsh Point (MRPT): 1989 - 2002								
Sign		1	34	1	1	12	11	
p value		1.00	0.04*	1.00	1.00	0.45	0.06	
n		6	13	14	14	12	6	
Broomes Island (BRIS): 1989 - 2002								
Sign		3	-8	-7	-13	-2	3	
p value		0.72	0.67	0.74	0.51	0.95	1.00	
n		6	13	14	14	12	6	
St. Leonards Creek (STLC): 1985 - 2002								
Sign	-2	4	-24	16	-15	-11	1	1
p value	.	0.72	0.38	0.41	0.59	0.49	1.00	.
n	3	8	18	14	18	12	7	3

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4. AN ANALYSIS OF FACTORS REGULATING EPIPHYTE FOULING RATES ON SUBMERGED AQUATIC VEGETATION IN TRIBUTARIES OF CHESAPEAKE BAY

R.M. Stankelis, W.R. Boynton, P.W. Smail and E.K. Machelor Bailey

4.1 Introduction

A number of studies have linked the eutrophication of coastal systems to the decline of submerged aquatic vegetation (SAV) in temperate estuaries worldwide (*e.g.* Den Hartog and Polderman, 1975; Kemp *et al*. 1983; Cambridge and McComb, 1986; Silberstein *et al*., 1986; Orth and Moore 1983, 1984). In what has become the standard paradigm, excess nutrient loading results in elevated phytoplankton growth as well as epiphyte accumulation, both of which reduce light availability to the leaf surface (*e.g.* Kemp *et al*., 1983; Lin *et al*., 1995; Burt *et al*., 1995; Short and Burdick, 1995, Stankelis *et al*., 20003). While water clarity is relatively easy to measure and is often the dominant factor influencing the distribution and extent of SAV beds (Duarte, 1991; Duarte, 1995), excess epiphyte accumulation may further alter the spatial distribution of SAV (Williams and Ruckelshaus, 1993). In recognition of this, a number of studies have quantified the relationship between epiphyte biomass and light attenuation in both mesocom (Kemp *et al.*, 1983; Twilley *et al.*, 1985; Lin *et al*., 1995; Short and Burdick, 1995), as well as field studies (*e.g.* Burt et al, 1995; Boynton *et al.*, 1999; Brush and Nixon, 2002). Although techniques varied among these studies, Brush and Nixon (2002) found relatively robust relationships between epiphyte biomass and light attenuation.

What has often been less clear is the relationship between the nutrient availability and epiphyte fouling rates. While a number of mesocosm studies have found correlation's between epiphyte biomass accumulate rates and nutrient availability (Lin *et al*.,1995; Short and Burdick, 1995), others have shown that second order interactions such as grazer density can mediate the affects of nutrient enrichment (Neckles *et al*., 1993; Williams and Ruckelshaus, 1993). Fewer studies

however, have evaluated the complex interaction between various water quality parameters and epiphyte accumulation rates in the field.

In this study, we used artificial substrates (SAV mimics) deployed within various tributaries of Chesapeake Bay to compare epiphyte fouling rates to a variety of water quality and environmental parameters. The use of artificial substrates allowed us to directly compare fouling rates among locations without the effort of marking and transplanting live SAV. This technique allowed us to standardize measurement techniques among locations both where SAV was abundant and where SAV was absent. This synthesis represents data collected from 1998 through 2002. Funding for limited sampling on the Magothy, Severn and Patuxent Rivers in 2002 was provided through the Ecosystems Processes Component (EPC) of the Maryland Chesapeake Bay Water Quality Monitoring Program. These results are important not only to resource managers seeking to develop water quality standards necessary to maintain the health of SAV ecosystems, but also for those interested in SAV restoration by developing better site selection criteria.

4.2 Materials and Methods

4.2.1 Study Locations

Data were collected from 21 near-shore stations located in several tributaries of Chesapeake Bay, USA (Figure 4-1, Table 4-1). Stations were selected to represent a range of water quality conditions in mesohaline and oligohaline waters. Sampling was conducted during the Chesapeake Bay SAV growing season (April through October), from 1998 through 2002. Because data were collected as part of several different monitoring programs, each station was not sampled every year. Stations were also located to have a mean tidal depth of 1.0-1.2 m. Approximately half of the stations were located in SAV beds composed of the meadow forming species *Zostera marina* or *Ruppia maritima*. The other stations were located in barren areas with no SAV.

4.2.2 Epiphyte Fouling Rates

Estimates of SAV epiphyte accumulation rates were made by exposing artificial substrates to natural fouling for periods of 6-8 days. Sampling was periodically conducted throughout the SAV growing season to measure seasonal changes in fouling rates at each station. Artificial substrates consisted of thin rectangular strips of Mylar® brand clear acetate plastic. Each strip (2.5 cm x 51 cm x 0.7 mil) was attached at one end along the perimeter of the square PVC frame (epiphyte collector array) filled with steel rebar to help it remain flush with the sediment surface (Figure 4-2). 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 yet still allow the strips to move freely with water currents. Each PVC frame was configured to hold a maximum of 6 Mylar® strips. On each sampling date, two representative strips were collected, one for analysis of epiphyte

Table 4-1. Station and region codes for epiphyte study as well as general locations.

Region	Geographic Location	Station Code	Latitude	Longitude	Nearest DNR Station	Bay Segment
Patuxent River	Mouth of Patuxent	SV09	38º 19.016	76º 27.119'	LE1.3	PAXMH
	Hungerford Creek	SV07	38º 20.982'	76º 28.307'	LE1.4	PAXMH
	St. Leonard Creek	SV06	38º 23.709'	76º 29.105'	LE1.2	PAXMH
	South of Broomes Island	SV5A	38º 24.534'	76º 31.299'	LE1.2	PAXMH
	Jack Bay	SV02	38º 28.086'	76º 35.934'	LE1.1	PAXMH
	Buena Vista	SVBA	38º 31.050'	76º 39.783'	RET1.1	PAXMH
Tangier Sound	Janes Island North	JI1G	38º 01.620'	75º 50.509'	ET9.1	BIGMH
	Janes Island South	JI2G	37º 58.249'	75º 52.609'	EE3.2	TANMH
	Smith Island – Big Thoroughfare	SIBT	37º 58.147'	75º 59.553'	EE3.2	TANMH
	Smith Island - Back Cove	SIBC	38º 01.262'	76º 00.133'	EE3.2	TANMH
	South Marsh Island – South Point	SMSP	38º 04.571'	76º 01.653'	EE3.2	TANMH
	Manokin River Geoquaking Creek	MRGC	38º 08.835'	75º 50.349'	ET8.1	MANMH
Lower Potomac River	Piney Point	PRPP	38º 08.307'	76º 30.265'	LE2.2	POTMH
	Sage Point	PRSP	38º 07.413'	76º 25.795'	LE2.2	POTMH
	Judith Sound	PRJS	38º 00.355'	76º 28.082'	LE2.2	POTMH
	Coan Creek	PRCR	37º 59.804'	76º 28.183'	LE2.2	POTMH
Blossom Point	Mouth of Nanjemoy Creek	PR05	38º 08.835'	75º 50.349'	RET2.4	POTOH
Magothy River	Stonington	MGST	39º 03.685'	76º 28.280'	WT6.1	MAGMH
	Whitehurst	MGHW	39º 05.115'9	76º 31.525'	WT6.1	MAGMH
Severn River	Sherwood Forest	SRSF	39º 01.904'	76º 32.776'	WT7.1	SEVMH
	Asquith Creek	SR04	39º 02.302'	76º 32.267'	WT7.1	SEVMH

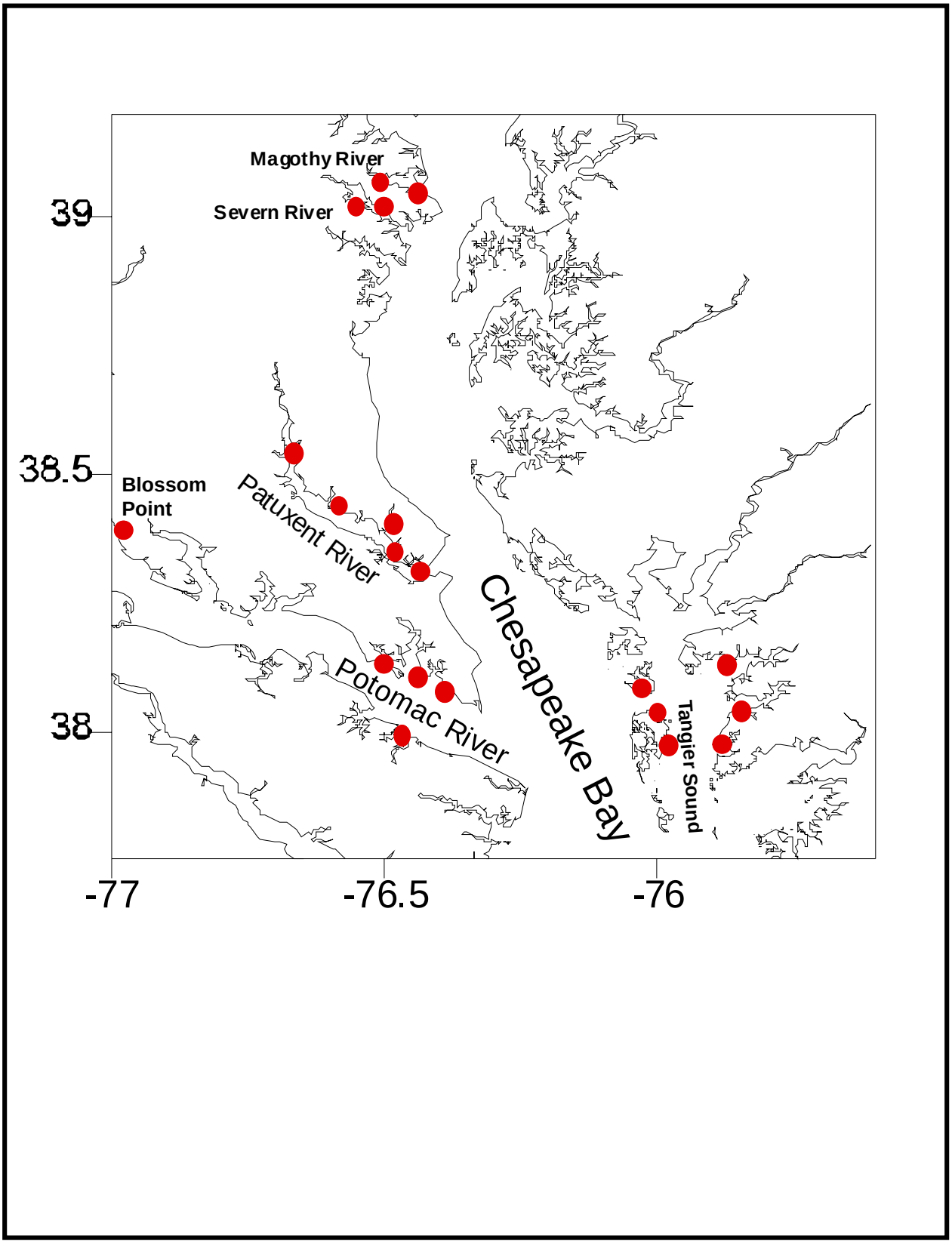

Figure 4-1. Map of SAV epiphyte monitoring locations in Chesapeake Bay Tributaries.

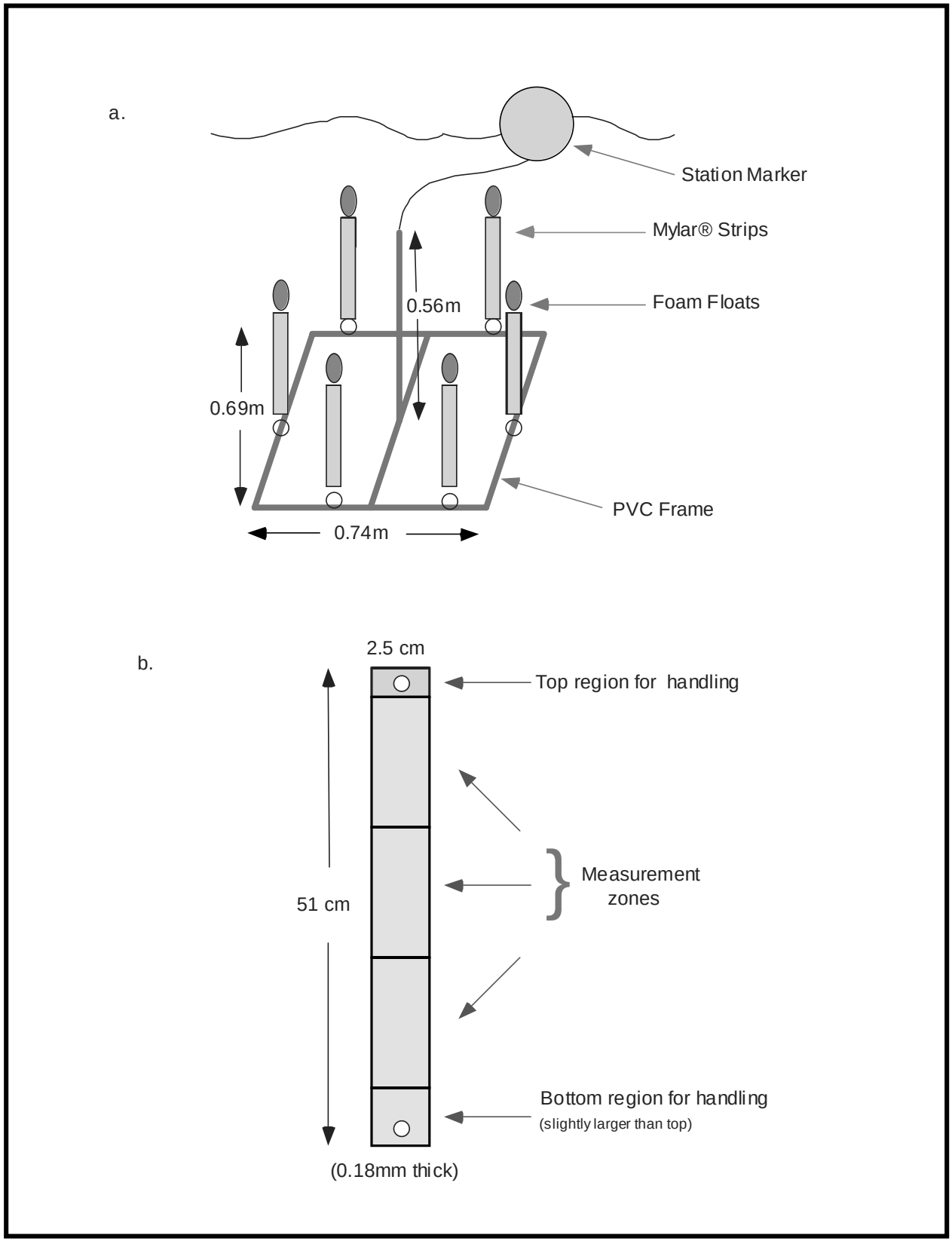

Figure 4-2. Diagrammatic sketch of a) an epiphyte collector array and b) a Mylar® strip (SAV mimic).

chlorophyll-*a*, the other for epiphyte dry mass/inorganic mass. Upon retrieval from the field, a 5" pre-marked center section of each fouled strip was further cut into smaller sections and placed on ice in a 60 ml plastic tube for transport back to the laboratory. Both sections were then frozen until further analysis.

In the laboratory, Mylar® strips collected for the analysis of epiphyte dry mass/inorganic mass were thawed, scraped of all material, and rinsed with distilled water. The mixture of epiphyte material and water was then further diluted to a fixed volume (400-500ml) and thoroughly mixed on a stir plate until homogenized. A small aliquot (10 to 50 ml) was then extracted with a glass pipette and filtered through a pre-combusted 47 mm 0.7 µm (GF/F) glass fiber filter. Once filtered, the pads were immediately frozen until analysis. The total mass of the filtered epiphyte material was then determined gravimetrically upon drying each filter pad to a constant weight. The pads were then combusted again and re-weighed to determine the inorganic content. Measurement of epiphyte total chlorophyll-*a* concentration was done fluourometrically via a method similar to Strickland and Parsons (1972) and Parsons *et al*. (1984). However, no scraping was necessary, because the chlorophyll-*a* was extracted directly off the Mylar® surface. A comparison using this method to the more traditional method of scraping and filtering the epiphyte material found no statistical difference (t-test P> 0.05).

4.2.3 Water Quality Measurements

A suite of water quality parameters were measured at each station during Mylar® strip deployment and retrieval. Water samples were collected at 0.5 m below the water surface. This sampling assumed a well-mixed water column and approximately corresponded to mid-water column depth. Whole water samples were collected with a hand operated bilge pump, and a portion immediately syringe filtered with a 25 mm, 0.7 µm (GF/F) glass fiber filter. Both the filtered portion and the remaining whole water samples were placed on ice for transport back to the laboratory. In the laboratory, whole water portions were filtered on to 47 mm 0.7 µm (GF/F) glass fiber filters and analyzed for total suspended solids concentrations (TSS), as well as total and active chlorophyll-*a* concentrations. The dissolved fraction of the water samples were analyzed for dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP).

Water column light flux in the photosynthetically active range (400 – 700 nm) was measured with a *Li-Cor* LI-192SA underwater quantum sensor at three discrete water depths in order to calculate water column light attenuation (Kd, m^{-1}). Estimates of water clarity were also measured with a secchi disk. Measurements of water column dissolved oxygen concentrations, temperature, and salinity were made with a YSI-600 or 6920 DATASONDE at 0.5 m below the water surface. In addition, SAV presence or absence was also noted at each deployment.

4.2.4 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.

4.2.5 Data Analysis

CART® classification and regression tree software (Salford Systems V 5.0) was used to construct regression trees to uncover the complex structure of the data related to the prediction of both epiphyte dry mass and epiphyte chlorophyll-*a* accumulation rates. Since much of the data were non-normally distributed, and did not meet the requirements of parametric statistics, CART analysis was an efficient method to look for patterns in the data compared to multiple regression models. As CART® works by recursive binary partitioning of data seeking to minimize the variance within groups, it allowed us to partition the data and examine possible important causal factors influencing epiphyte accumulation rates. CART generates a number of competing trees and then selects the most efficient decision or regression tree based upon a number of selected criteria. This model used a variety of water quality parameters including, DIN, DIP, percent light through the water (PLW), temperature, salinity, tributary, and the presence or absence of SAV, among others. Models were constructed using both least squares (LS) and least absolute deviation (LAD) estimators using a total data set of 527 complete sets of water quality and epiphyte observations.

4.3 Results

4.3.1 Water Quality

The values of most water quality parameters exhibited significant variation within this study. Dissolved inorganic nitrogen (DIN) concentrations ranged from 0.03 to 28.1 μM N, and dissolved inorganic phosphorus (DIP) concentrations ranged from 0.05 to 3.4 μM P. For these parameters, most values were found on the low end of the distribution, resulting in log-normal distributions (Figure 4-3a, 4-3b). For other parameters such as temperature, and percent light thought the water (PLW) the distribution of values were much less skewed, although still non-normally distributed (Figure 4-3c, 4-3d).

Most parameters exhibited varying degrees of spatial and temporal variation. Short-term (week to week) temporal variation was quite common; however, significant seasonal shifts in some parameters were also observed. For example, DIN concentrations were much higher in the spring compared to other seasons, and DIP concentrations were much lower in the spring

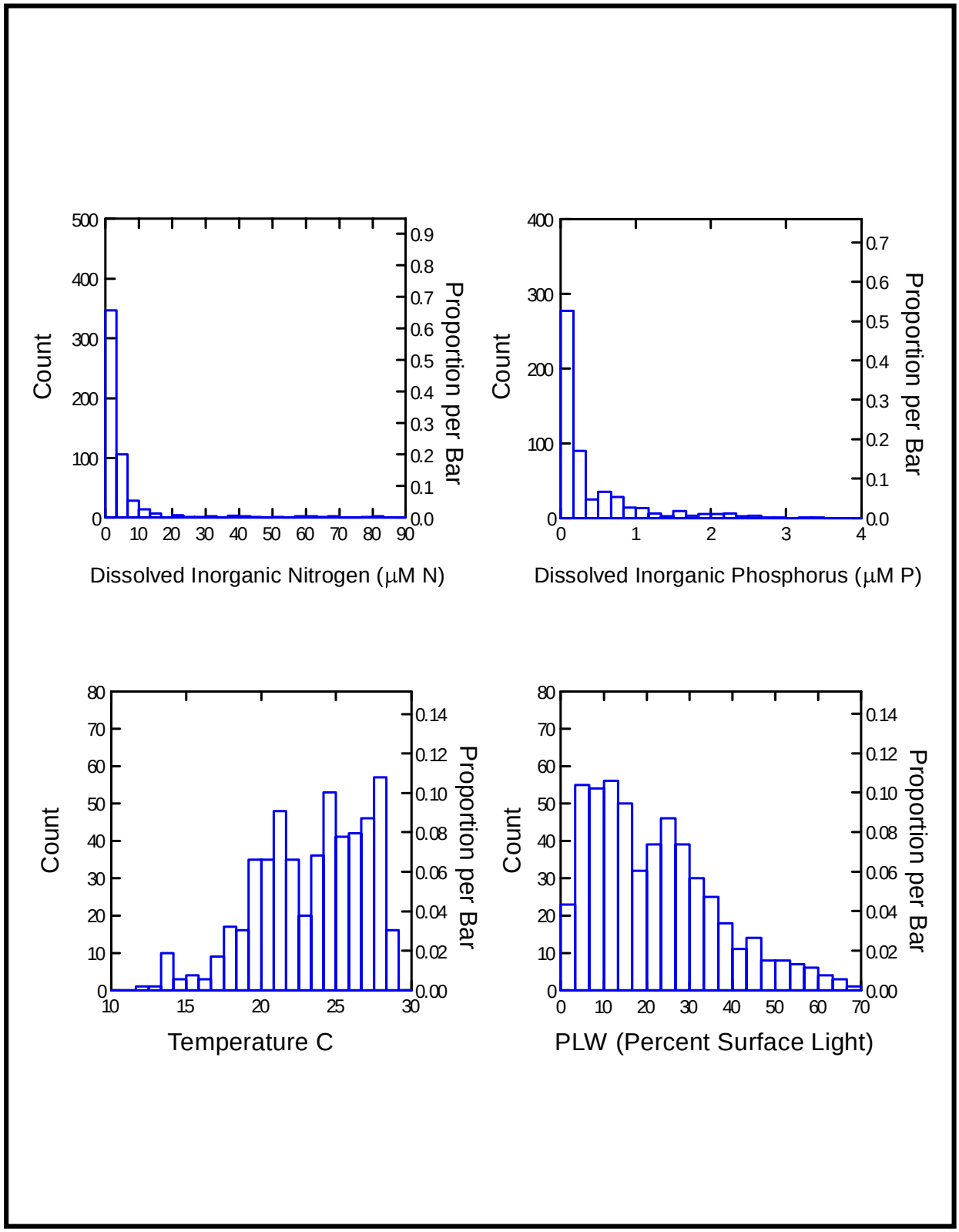

Figure 4-3. Distribution of water quality parameters a) dissolved inorganic nitrogen, b) dissolved inorganic phosphorus, c) temperature, and d) percent light through the water column (PLW).

compared to other seasons (Figure 4-4). Variation in light availability as measured by percent light through the water column (PLW) was primarily spatial in that most sites tended to be either clear or turbid. Values ranged from 0.05% (SVBA fall 1999, storm event) to 67% (SV09 spring 2002) of surface light reaching 1 m depth. Variation in water temperature was almost exclusively seasonal in nature, and because sampling was limited to the period between April through October, water temperatures only ranged from 12 to 29 °C (Figure 4-3d). Variation in salinity was a product of both temporal and spatial variation with values ranging from 2.

4.3.2 Epiphyte Accumulation

Epiphyte dry mass accumulation rates varied from essentially zero to 12.15 mg cm^{-2} $week^{-1}$, while epiphyte total chlorophyll-*a* accumulation rates also varied from zero to 24.5 µg chl*a* cm^{-2} $week^{-1}$ and both were log-normally distributed (Figure 4-5a, 4-5b). Both epiphyte dry mass (mg cm^{-2} $week^{-1}$) and epiphyte total chlorophyll-*a* (µg cm^{-2} $week^{-1}$) accumulation rates exhibited both temporal and spatial variation. Typically, fouling rates were lower in the spring compared to both the summer and fall (Figure 4-6). Short-term (week to week) variation was also observed at most locations, although the magnitude of this variation was much less than that observed seasonally at each location. Based upon existing relationships between epiphyte dry mass and light attenuation (Stankelis *et al.*, 2003) this range of epiphytic fouling translates into light attenuations of 0 to 100% of light exposure. During the summer, epiphyte dry mass still varied substantially among sites with values ranging from 0.02 to 9.8 mg cm^{-2} $week^{-1}$ suggesting that while temperature may be important, other factors may also influence epiphyte fouling rates. Epiphyte dry mass was also significantly correlated with total chlorophyll-*a* concentration (r^2 = 0.35, Figure 4-7). Although 2002 was a drought year, substantial variation in epiphyte fouling rates were found among the locations sampled. Figure 4-8, shows the distribution of epiphyte dry mass accumulation rates among seasons and stations sampled.

4.3.3 Regression Tree Results

The optimal regression tree generated by CART® using a least squares sorting criteria for epiphyte chlorophyll-*a* accumulation rates resulted in a tree with 9 terminal nodes (Figure 4-9) and an r^2 of 0.11 (calculated as, 1-relative resubstitution cost = 1-0.89. In this decision tree, data were first split at a temperature of 25.1 °C, resulting in two groups with very different mean fouling rates. Below 25.1 °C (n = 334), the mean chlorophyll-*a* fouling rate was 0.63 µg cm^{-2} $week^{-1}$ while above 25.1 °C (n = 193) the mean fouling rate was 3 times higher at 1.85 µg cm^{-2} $week^{-1}$. Below 25.1 °C, data were further sorted at a temperature of 21.2 °C. Below 21.17 °C (n = 156) the mean chlorophyll-*a* fouling rate was only 0.28 µg cm^{-2} $week^{-1}$ regardless of light or nutrient availability. Above 21.2 °C, data were further split at a DIN concentration of 12.7µM N where epiphyte fouling (mean = 3.3 µg cm^{-2} $week^{-1}$) can become quite elevated despite relatively moderate temperatures. Although the number of observations in this group was low (n = 8), it shows that dissolved nutrient concentrations can have an important impact on fouling rates. Above 25.1 °C, a small group (n = 9) separated out with extremely high fouling rates (mean 7.1 µg cm^{-2} $week^{-1}$) below 25.3 °C. However, this split was not likely the result of any important

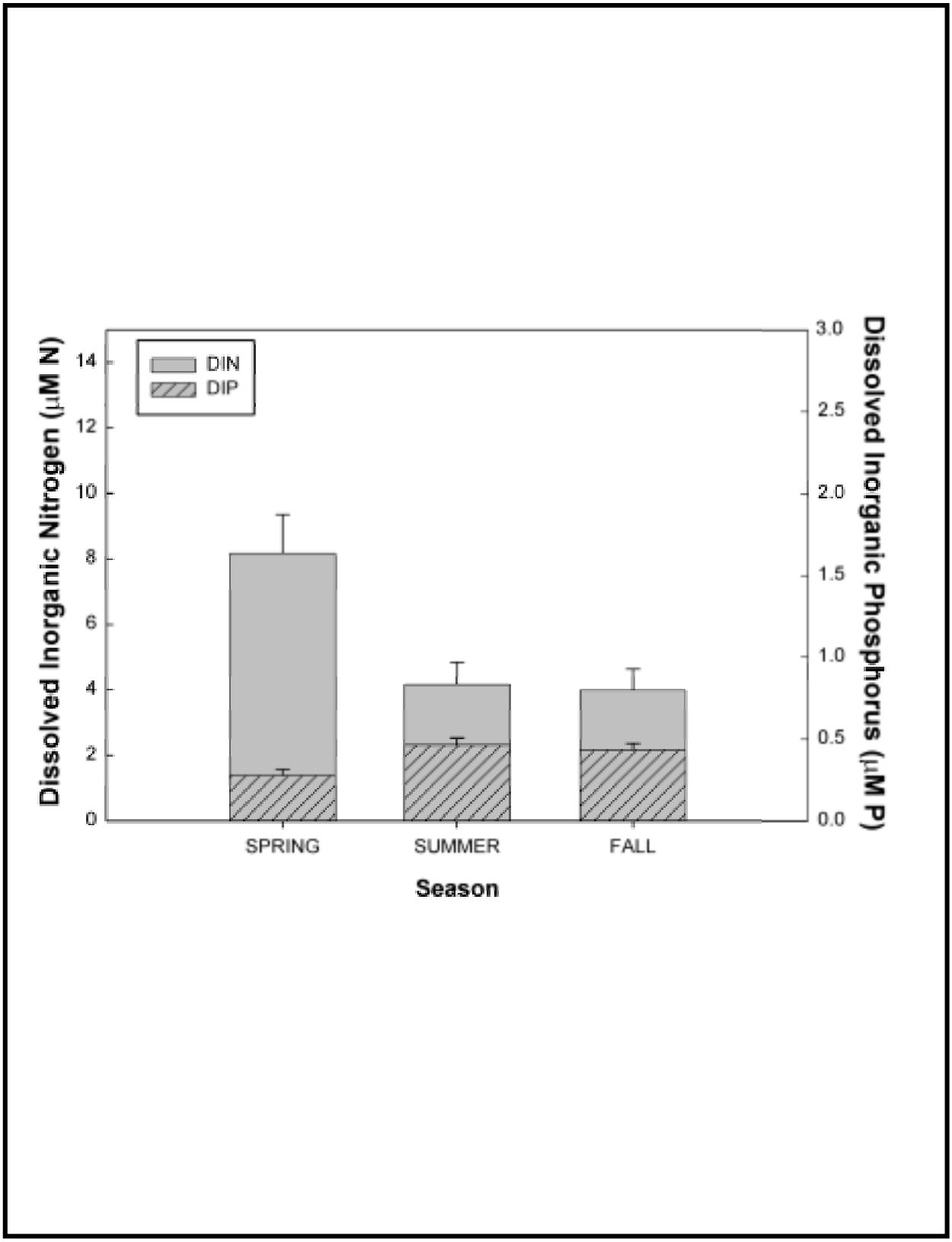

Figure 4-4. Seasonal mean dissolved inorganic nitrogen and phosphorus concentrations.

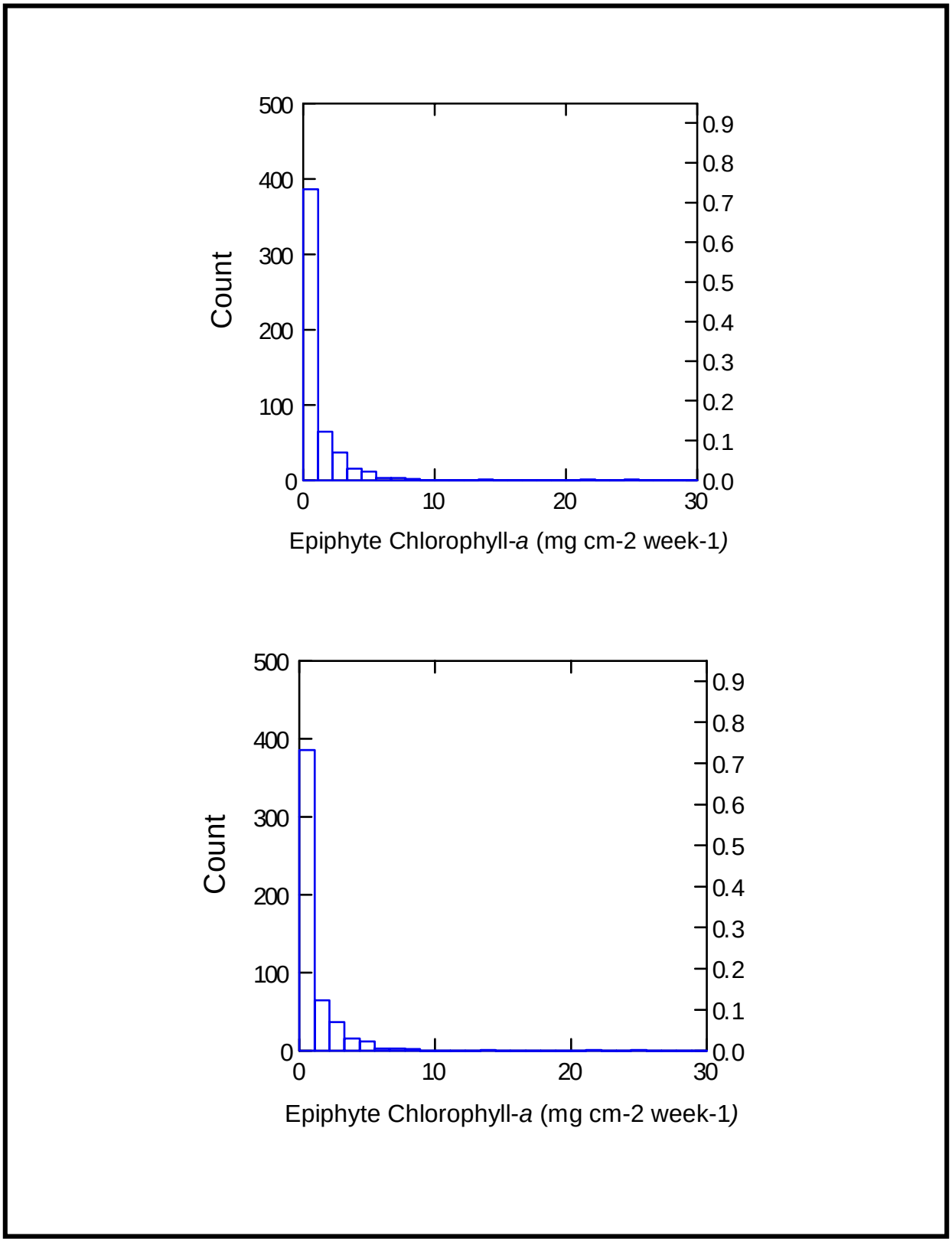

Figure 4-5. Distribution of a) epiphyte dry mass accumulation rates, and b) epiphyte chlorophyll-*a* accumulation rates.

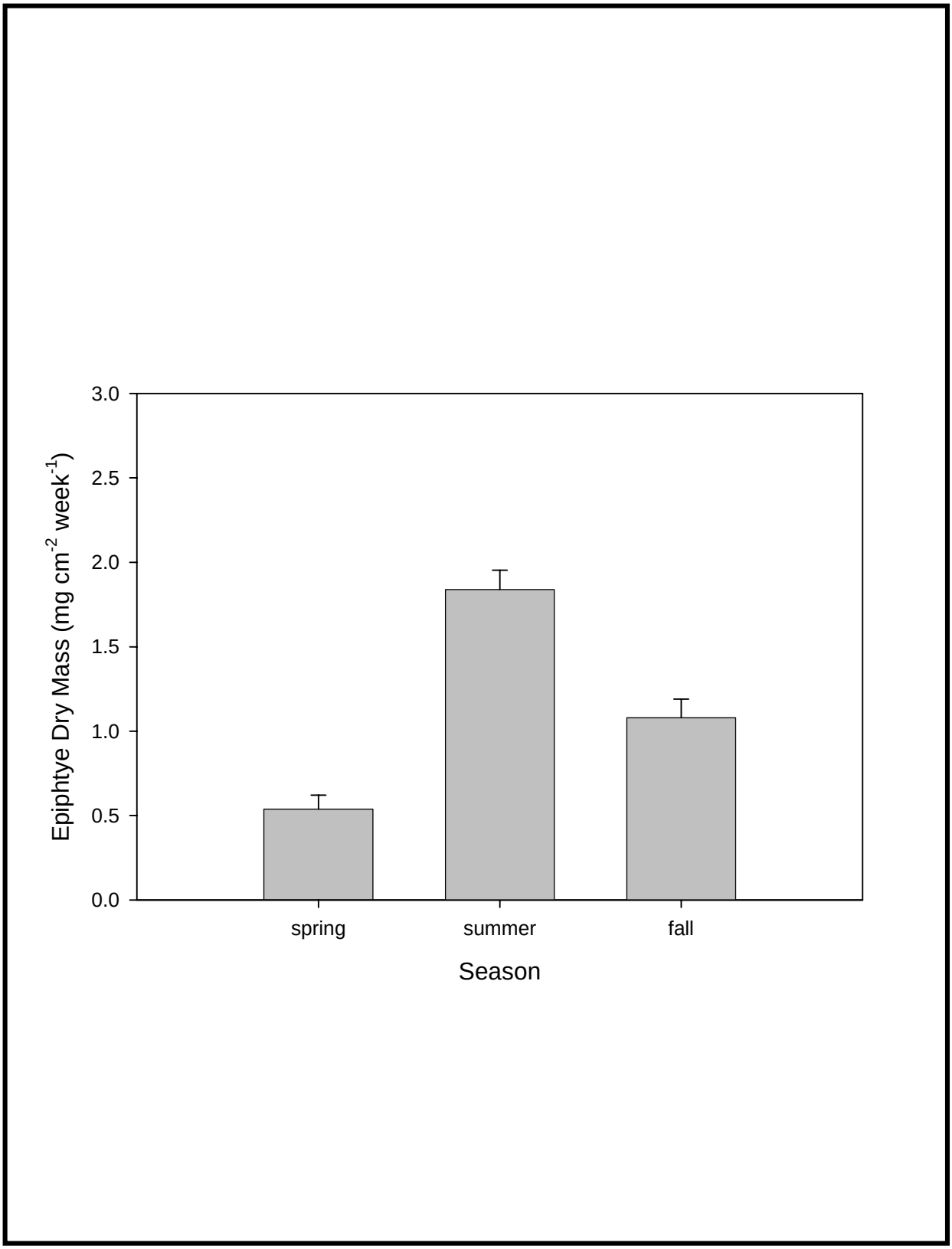

Figure 4-6. Seasonal mean epiphyte dry mass fouling rates.

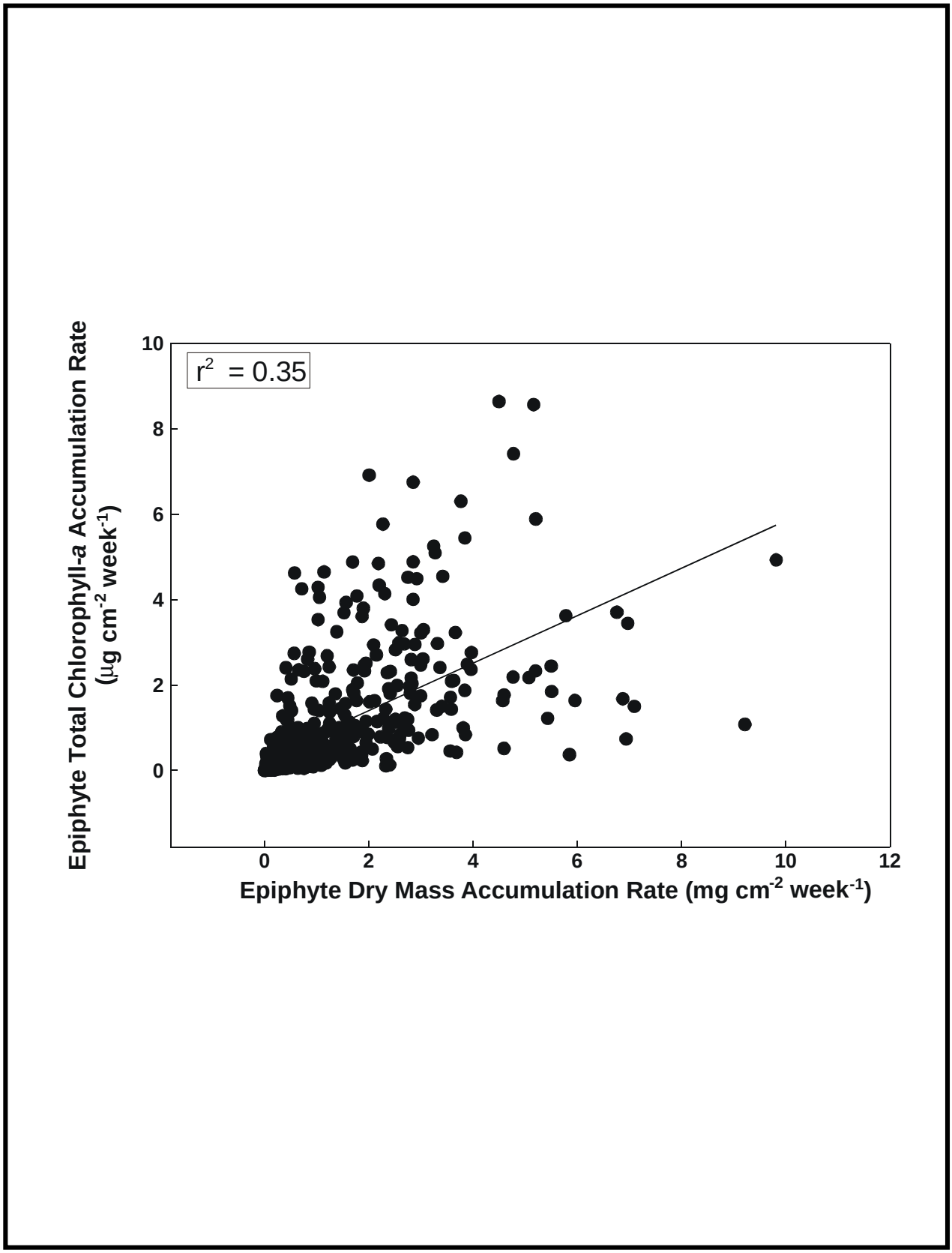

Figure 4-7. Scatter plot of epiphyte total chlorophyll-*a* accumulation vs. epiphyte dry mass.

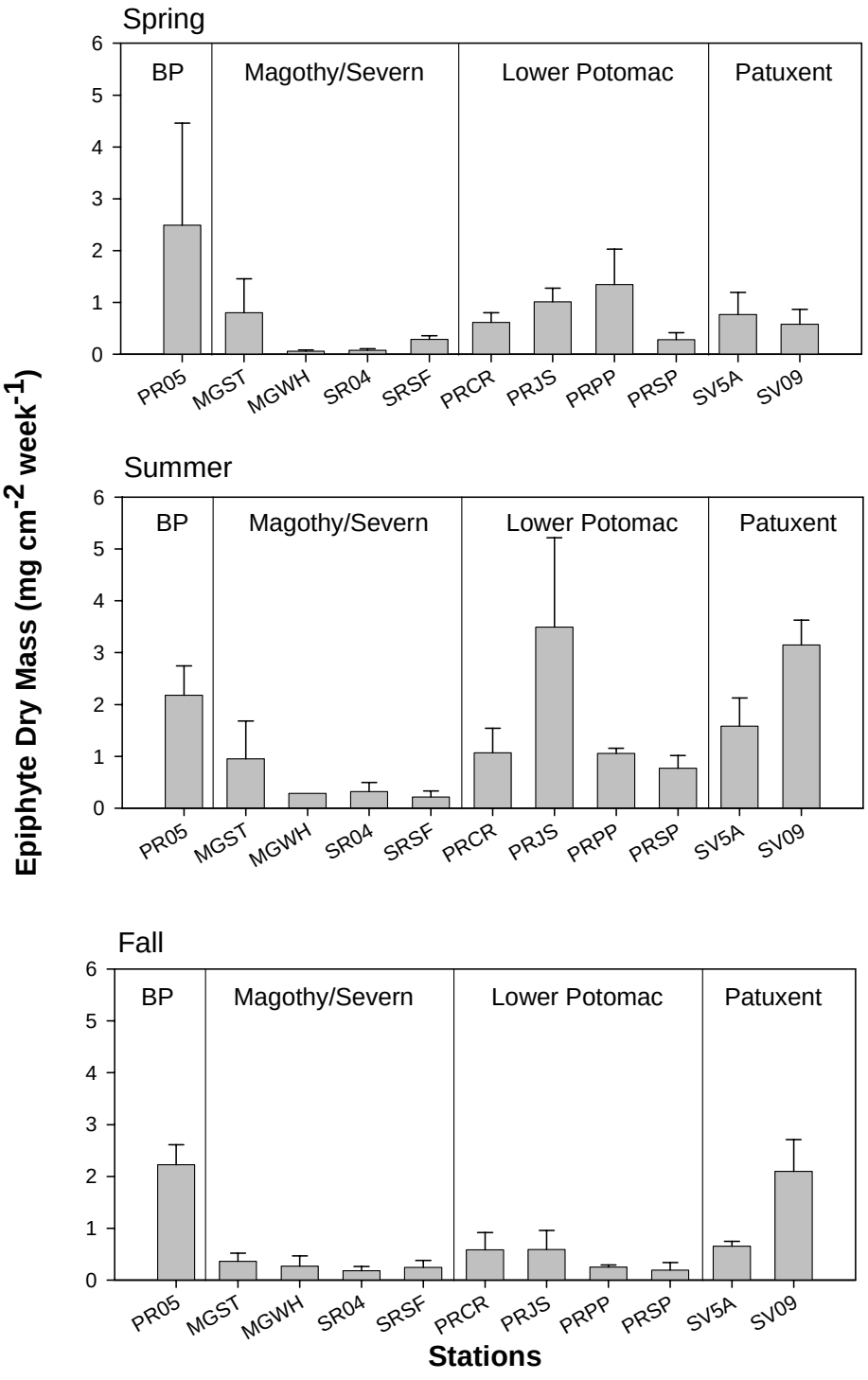

Figure 4-8. 2002 mean (+/- 1SE) epiphyte total dry mass accumulation rates on Mylar® strips deployed for *in-situ* exposures of 6-8 days at Blossom Point, Magothy, Severn, Lower Potomac, and Patuxent Rivers in a) spring, b) summer and c) fall.

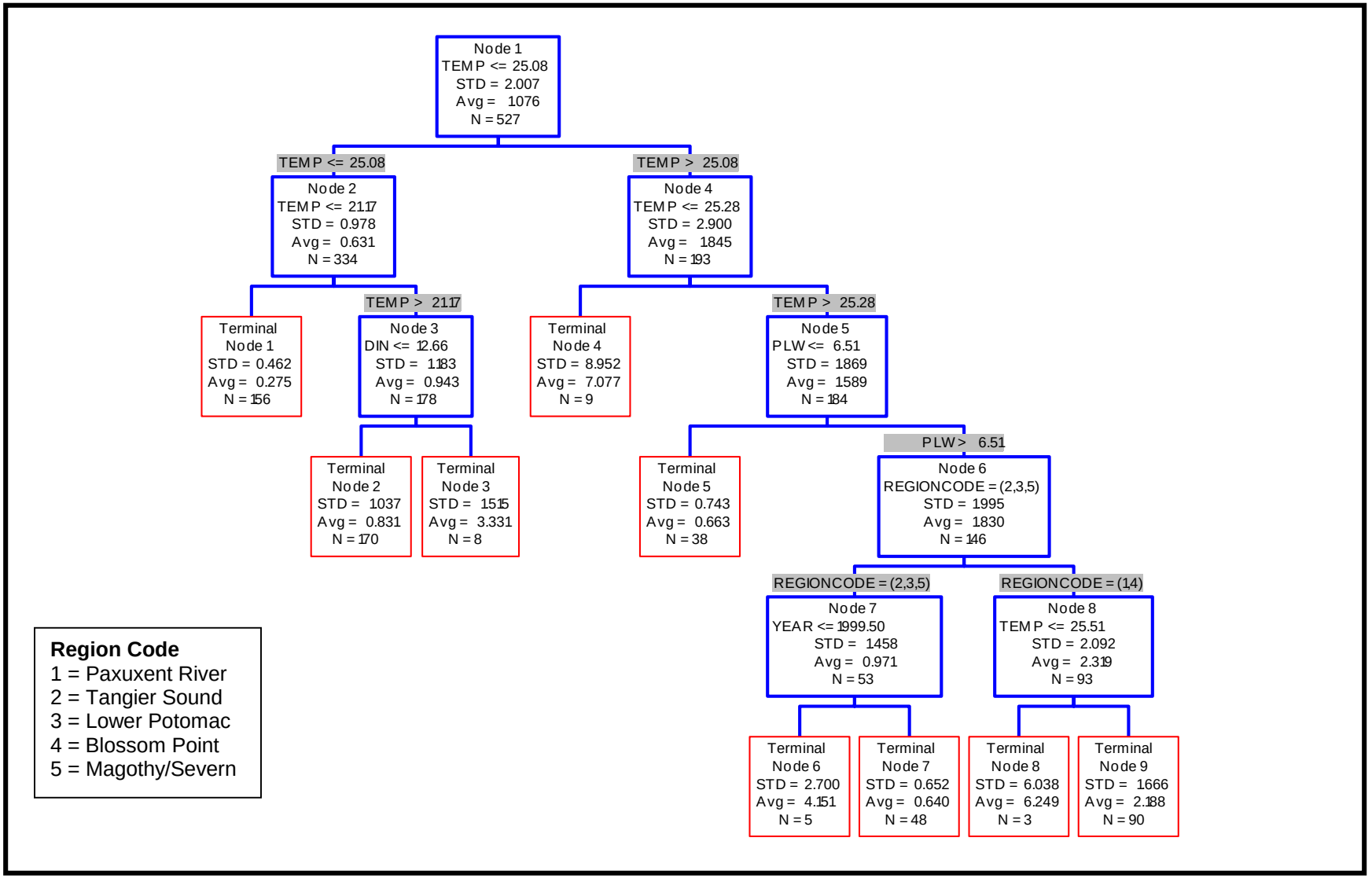

Figure 4-9. Regression tree for epiphyte total chlorophyll-*a* accumulation rates using least squares sorting criteria.

ecological changes occurring at this temperature, but a consequence of other factors not measured in this study, about which more will be discussed later. The remaining data (above 25.3 °C, n = 146) further sorted at a PLW of 6.5% surface light. Below this level, the mean epiphyte chlorophyll-*a* accumulation rate (0.97 μg cm^{-2} $week^{-1}$) was much reduced compared to the mean rate (2.3 μg cm^{-2} $week^{-1}$) at higher light levels. Finally, data were sorted by region, then year or temperature at the final terminal nodes.

A regression tree generated for epiphyte dry mass, using least squares produced a very simple tree with a single split at 25.1 °C that was not very informative. Because least squares estimators may be sensitive to a few extremely high values (outliers), a regression tree was generated using epiphyte dry mass median values and a LAD estimator. With this method, a larger decision tree was generated that was similar in many ways to the tree generated for epiphyte chlorophyll-*a* with 5 terminal nodes and an equivalent r^2 value of 0.14 (Figure 4-10). In this tree, dry mass fouling was first sorted at a temperature of 25.1°C. As with epiphyte chlorophyll-*a,* the median epiphyte dry mass accumulation rate below 25.1°C (0.4 mg cm^{-2} $week^{-1}$, n = 330) was dramatically lower than the median value above 25.1°C (1.6 mg cm^{-2} $week^{-1}$, n = 195). In a pattern similar to epiphyte chlorophyll-*a*, epiphyte dry mass fouling was again sorted into two groups at approximately 21 °C (Figure 4-7). Below this temperature, the median fouling rate was smaller (0.24 mg cm^{-2} $week^{-1}$, n = 160), compared to the group between 21°C and 25°C (0.64 mg cm^{-2} $week^{-1}$, n = 170). Above 25.1 °C, epiphyte dry mass separates again into the same regions as epiphyte chlorophyll-*a* with Blossom Point and the Patuxent River grouping together, and Tangier Sound, the lower Potomac, Magothy and Severn Rivers grouping together. As before, these tributaries may be grouping together because of a process or mechanism not measured in this study.

4.4 Discussion

A number of studies have shown that epiphytic fouling of SAV leaves can have the potential to significantly reduce the amount of light reaching the leaf surface (e.g. Brush and Nixon, 2002). Throughout the Chesapeake Bay SAV growing season (April – October), we found epiphyte fouling rates ranging from essentially zero, to more than 20.0 μg chl*a* cm^{-2} $week^{-1}$ (Figure 4-11). Only a fraction of these high fouling rates are necessary to attenuate nearly100% of available light after a weeks' time (Stankelis *et al.*, 2003). Variation in these rates was both temporal (seasonal and weekly) and spatial in nature. Strong seasonal shifts in fouling rates as well as consistent differences among specific locations were among the broad patterns identified.

The CART analysis of fouling rates and simultaneous water quality conditions show that water temperature imposes the primary restraint on epiphyte fouling rates. However, the minimum water temperatures needed to stimulate high fouling rates was surprising high. Water temperatures below 21.2 °C, generally did not support high fouling rates (mean = 0.28 μg chl*a* cm^{-2} $week^{-1}$, n = 156) regardless of nutrient or light availability. As a consequence, most measurements made in early spring were extremely low. This limitation appears to be an

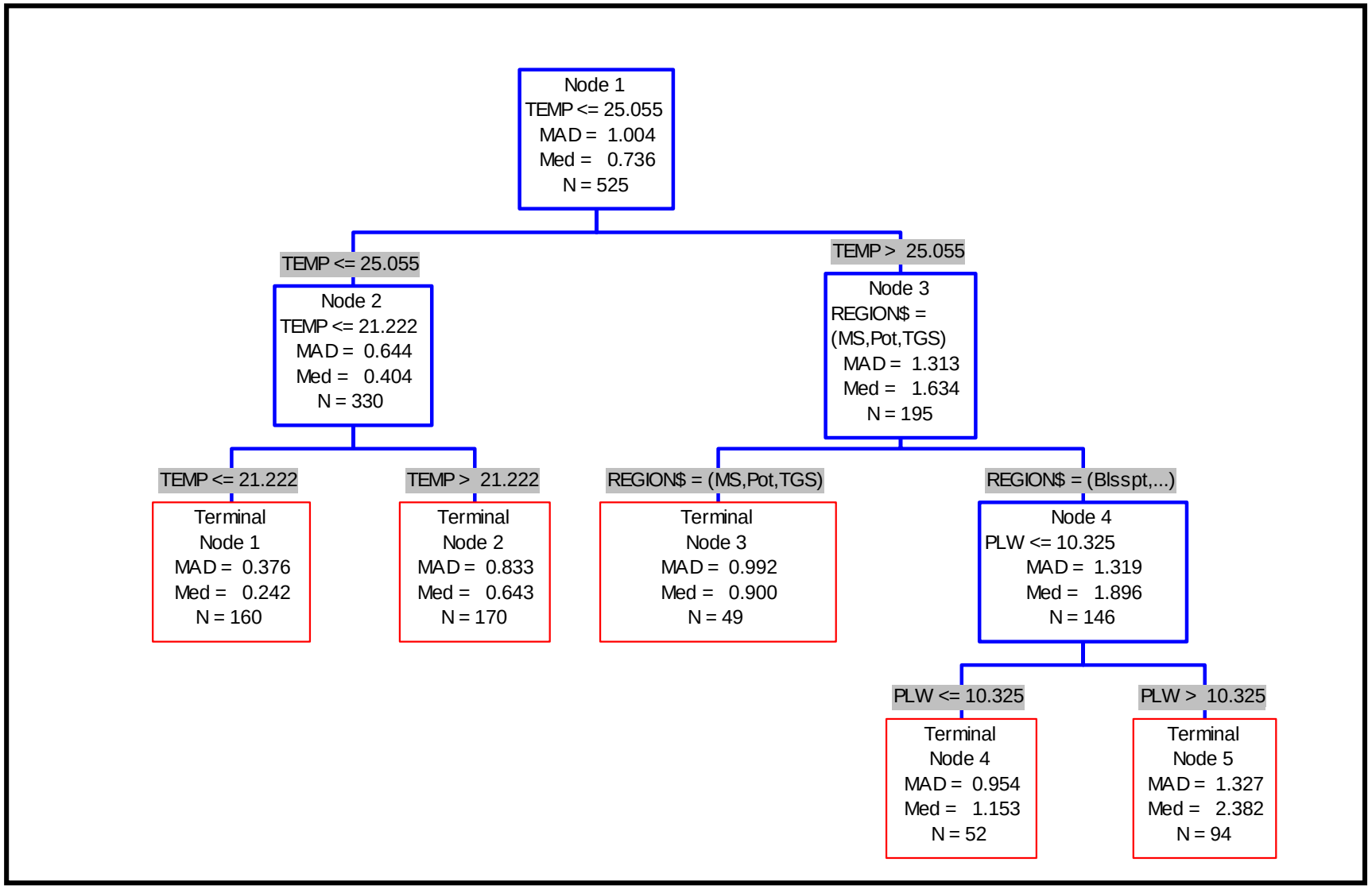

Figure 4-10. Regression tree generated for epiphyte dry mass accumulation using least absolute deviation (LAD) sorting criteria.

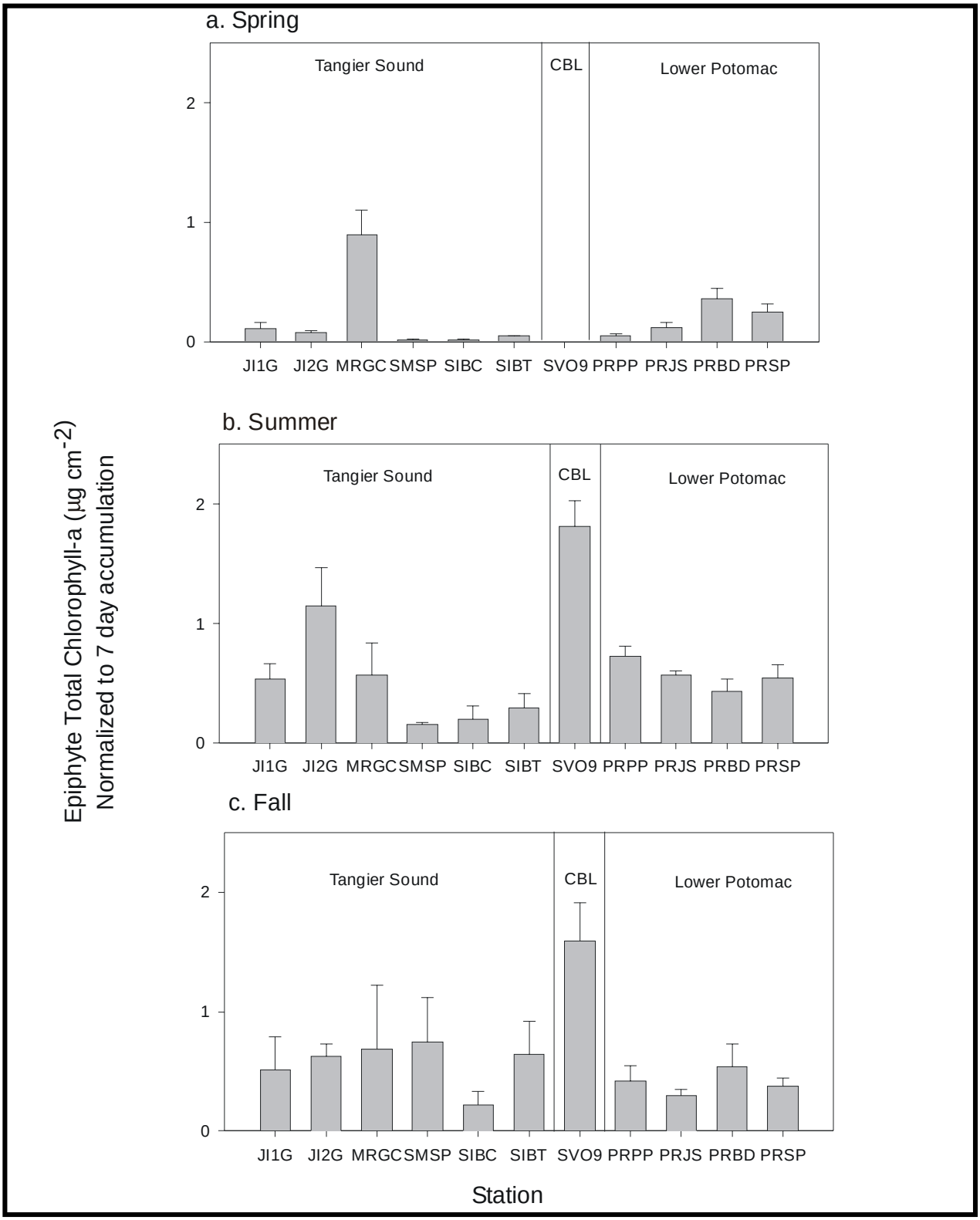

Figure 4-11. Mean (+/- 1SE) epiphyte total chlorophyll-*a* accumulation rates on Mylar® strips deployed for *in-situ* exposures of 6-8 days in a) spring, b) summer and c) fall in Tangier Sound, the Patuxent River, and the lower Potomac River, 2002.

advantage for SAV species such as *Z. marina* that have an active growing season in early spring prior to high epiphyte loading. At water temperatures between 21.2 °C and 25.1 °C the mean epiphyte chlorophyll-*a* accumulation rates more than triple to 0.94 µg chl*a* cm^{-2} $week^{-1}$. At these higher temperatures it appears that a variety of other parameters can be responsible for stimulating high fouling rates as well. For example, within this group, high DIN concentrations (> 12.7 µM N) can support extremely high fouling rates (mean = 3.3 µg chl*a* cm^{-2} $week^{-1}$, n=8). These high values were found at stations PR05 at Blossom Point (on the Potomac) and SV09 at the mouth of the Patuxent River. While a number of other locations had moderately high DIN concentrations in this temperature range, other parameters such as light availability (either because of turbid water or short-term weather patterns) limited the rate at which epiphytes accumulated. However, the recognition that extreme fouling rates are possible at moderately low temperatures given high nutrient concentrations could have important consequences for SAV growth or recovery, even if these high fouling rates are not sustained over the entire SAV growing season. Moore *et al.* (1997) found relatively short pulses of highly turbid water could negatively impact SAV populations. Similarly, even short intervals with extremely high fouling rates stimulated by temporarily high nutrient concentrations could depress light availability to the leaf surface sufficiently to impair SAV growth or survival.

At water temperatures above 25.1 C, the mean epiphyte fouling rate was 1.85 µg chl*a* cm^{-2} $week^{-1}$ (or 1.63 mg dry mass cm^{-2} $week^{-1}$). Applying these values to the existing relationships between epiphyte biomass and light attenuation (Stankelis *et al.*, 2003) this corresponds to 67 % light attenuation at the leaf surface. However, within this group there is a significant amount of variation among locations and sampling events. For example, epiphyte fouling at station SV09 at the mouth of the Patuxent River was consistently among the highest recorded (mean 3.1 µg chl*a* cm^{-2} $week^{-1}$), while stations such as PRSP and JI2G with similar light and nutrient concentrations had much lower fouling rates (0.48 and 1.4 µg chl*a* mass cm^{-2} $week^{-1}$ respectively). Further, some stations recorded very low fouling rates as expected when light levels were extremely low. With the exception of a spurious terminal node (node #4, Figure 4-7.), CART further separated the groups by light availability at a PLW of 6.5%. Thus even though water temperatures and nutrient concentrations were high, fouling rates remained depressed at low light levels (mean = 0.66 µg chl*a* cm^{-2} $week^{-1}$, n = 38). At such low light levels it would be expected that SAV will be impacted as well.

In regression trees developed for both epiphyte chlorophyll-*a* (Figure 4-6) and epiphyte dry mass (Figure 4-7), fouling rates were further separated by region when temperature and light were not limiting. In both decision trees, epiphyte fouling at Blossom Point and the Patuxent River were twice as high as those sites in the lower Potomac, Tangier Sound or the Magothy and Severn Rivers. Within both groups however, there remained significant variation among sites and sampling intervals. For example, Figure 4-8 shows the site-to-site variation in 2001 mean dry mass fouling among some of the stations sampled. One possible explanation for differences in fouling rates among sites could be the presence or absence of SAV, which could potentially modify the local environment sufficiently to influence epiphyte fouling rates (Bartelson, 1988). However, CART did not group data based upon SAV density. As a further exploration, we calculated light availability at the leaf surface (PLL) using a method similar to Batuik *et al.* (2000) and plotted that data against light availability through the water column (PLW, Figure 4-

12). Using an analysis of covariance (ANCOVA) we found no significant difference between epiphyte fouling rates and the presence or absence of SAV ($p > 0.05$). However it must be noted that SAV at all of these stations was of a meadow forming species which may have limited ability to modify their local environment compared to canopy forming species. As such, differences among sites could overwhelm any actual modifications by local SAV beds in this analysis. An alternate explanation for differences in epiphyte fouling rates among locations was also explored by creating a multiple linear regression using the subset of data sorted by CART for warm temperatures (> 25.3 C) and high light availability (> 6.5% PLW) to look for any influences of nutrient concentration. However this analysis did not detect any relationship between nutrient concentration and epiphyte fouling rate ($p > 0.01$).

While nutrient concentrations did not appear to be an important factor influencing epiphyte fouling rates, there is data to suggest that nutrient delivery rates could be an important consideration that was not measured directly in this study. Thomas and Cornelisen (2000), found that flow rate influences epiphyte nutrient uptake. Further, a pilot study conducted at CBL in 2500 liter mesocosms evaluating the effect of flow on epiphyte fouling rates indicated that even subtle differences in flow could influence epiphyte fouling rates given relatively moderate nutrient concentrations. Therefore it seems logical that differences in nutrient transport or delivery among sites could be an important factor responsible for the variation in fouling rates observed in the field study. Lastly, a number of studies have shown that epiphtye grazers can reduce epiphyte standing stock, when present in sufficient numbers (Neckles *et al.*, 1993). While no quantitative survey of macrofauna was performed as part of this study, an abundance of gammarid amphipods were frequently found on the Mylar strips upon retrieval. No observable differences were found between strips with high or low epiphyte biomass. It is not known whether these species actually graze on the epiphytic material or not. It may also be possible, that the macroinvertebrate species likely to graze on epiphyte are not found in sufficient numbers in mesohaline waters.

The data sorting created by CART provides the best possible fit for the data and provides some insight into the responsible mechanisms but only takes into account those parameters measured. As a consequence, within each terminal node there remains variation in fouling rates that cannot be explained by this model. Based upon field observations, epiphtye fouling rates can vary on a weekly basis even though water quality parameters may not vary substantially during that time. Other factors such as solar irradiance or wave energy may modify the expected results dramatically. Water temperature appears to be a primary driver of epiphyte accumulation rates when temperatures are relatively low. High fouling rates may negatively impact SAV growth and survival, but based upon this field study neither nutrient concentration or the presence or absence of SAV play a major role in controlling their growth. The ultimate impact that epiphyte fouling rates have on SAV also depends on the plastochrome interval (PI) or leaf turnover rate. Although fouling rates are significantly lower during the spring compared to the summer or fall, leave turnover rates are also lower, further increasing the impact of epiphyte accumulation. Given the presence of SAV at several sites with high fouling rates it appears that SAV within Chesapeake Bay have a certain capacity to withstand epiphyte accumulation and still thrive.

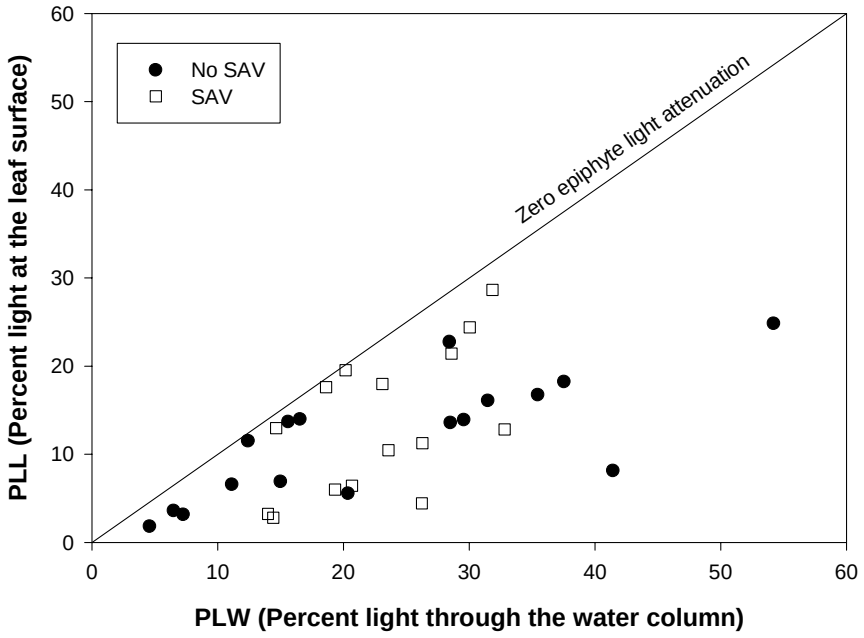

Figure 4-12. Comparison of PLL vs. PLW between stations located in Tangier Sound, the lower Potomac, and the Patuxent River, with healthy SAV populations and those without in 2002. *Diagonal line represents the 1:1 or zero epiphyte attenuation limit.*

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5. HIGH RESOLUTION MAPPING OF SURFACE WATERS

P.W. Smail, R.M. Stankelis, E.K. Machelor Bailey and W.R. Boynton

5.1 Introduction

During 2002 we evaluated patterns in surface water quality using the DATAFLOW V mapping system in the Magothy and Severn Rivers. DATAFLOW V was deployed from a small research vessel and provided for high-resolution spatial mapping of surface water quality. Our cruise tracks covered both shallow (<2.0m) and deeper waters, and sampling was weighted to the littoral zone that represented habitat critical to Submerged Aquatic Vegetation (SAV) and associated organisms. Traditional water quality monitoring has been conducted almost exclusively in deeper channel waters, and conditions in these areas do not adequately represent shallow zones. Thus, it was important to collect water quality data in both habitats to determine the extent of gradients in water quality parameters. The DATAFLOW V 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. At this rate a field crew could quickly characterize a system, but slower speeds naturally improved resolution, which is of particular importance if the goal is to focus on particular trouble spots.

5.2 Methods, Locations and Sampling Frequency

5.2.1 DATAFLOW V

DATAFLOW V 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 Figure 5-1. Surface water (0.6m deep) is collected through a pipe ("ram") deployed from the transom of the vessel. Assisted by small bilge pumps, water is passed through a bubble-trapping device to ensure that no air bubbles are conveyed to the sensors. It then proceeds through a flow meter and finally to an array of water quality sensors which recorded the water quality variables, time, and geographic position. The total system water volume was approximately 3.8 liters.

DATAFLOW V surveys are conducted from a CBL vessel and a typical cruise uses a complement of two field technicians to perform sampling operations and safe navigation. The DATAFLOW V package consisted of a water circulation system that is sampled at a prescribed rate by a Yellow Springs, Inc. 6600 Data SONDE combined with a YSI 650 Datalogger. The 650 also recorded positional data with an accuracy of approximately 10 meters from a Garmin e-Trex GPS unit utilizing an NMEA 0183 v. 2.0 data format. This sensor provided data on dissolved oxygen, temperature, conductivity and salinity, as well as turbidity and fluorescence (from which chlorophyll-*a* concentration is derived). Depth data were collected with an auxiliary Garmin 168 global positioning system with a built-in depth sounder. The Garmin 168 GPS transmitted NMEA 0183 version 2.3 formatted data to a Wescor RDT 3200 portable computer using Procomm Plus communication software. Data files were merged by time stamp at a later date using a SAS software routine. 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. Twin "Rule Pro Series" bilge pumps provided approximately 8-12 liters per minute of flow to the system. The system can operate on a single pump.

During the course of a cruise, the crew stopped at established, individual calibration stations located along the cruise track where the vessel was anchored and whole water samples were taken from the water circulation system. The Nutrient and Analytical Services Laboratory at Chesapeake Biological Laboratory (CBL) analyzed this water sample for dissolved nutrient content, concentrations of total suspended and volatile solids, and chlorophyll-*a*. The crew also measured turbidity using a Secchi disk, and determined the concentration of photosynthetically active radiation (PAR) in the water column using *Li-Cor*® quanta sensors. These calibration stations provided enhancement to the high-resolution description of a tributary, and provided analytical lab values used to verify instrument parameter values derived during the cruise. The data that were collected substantially improved the characterization of water quality conditions in the near shore habitats as well as system-wide water quality.

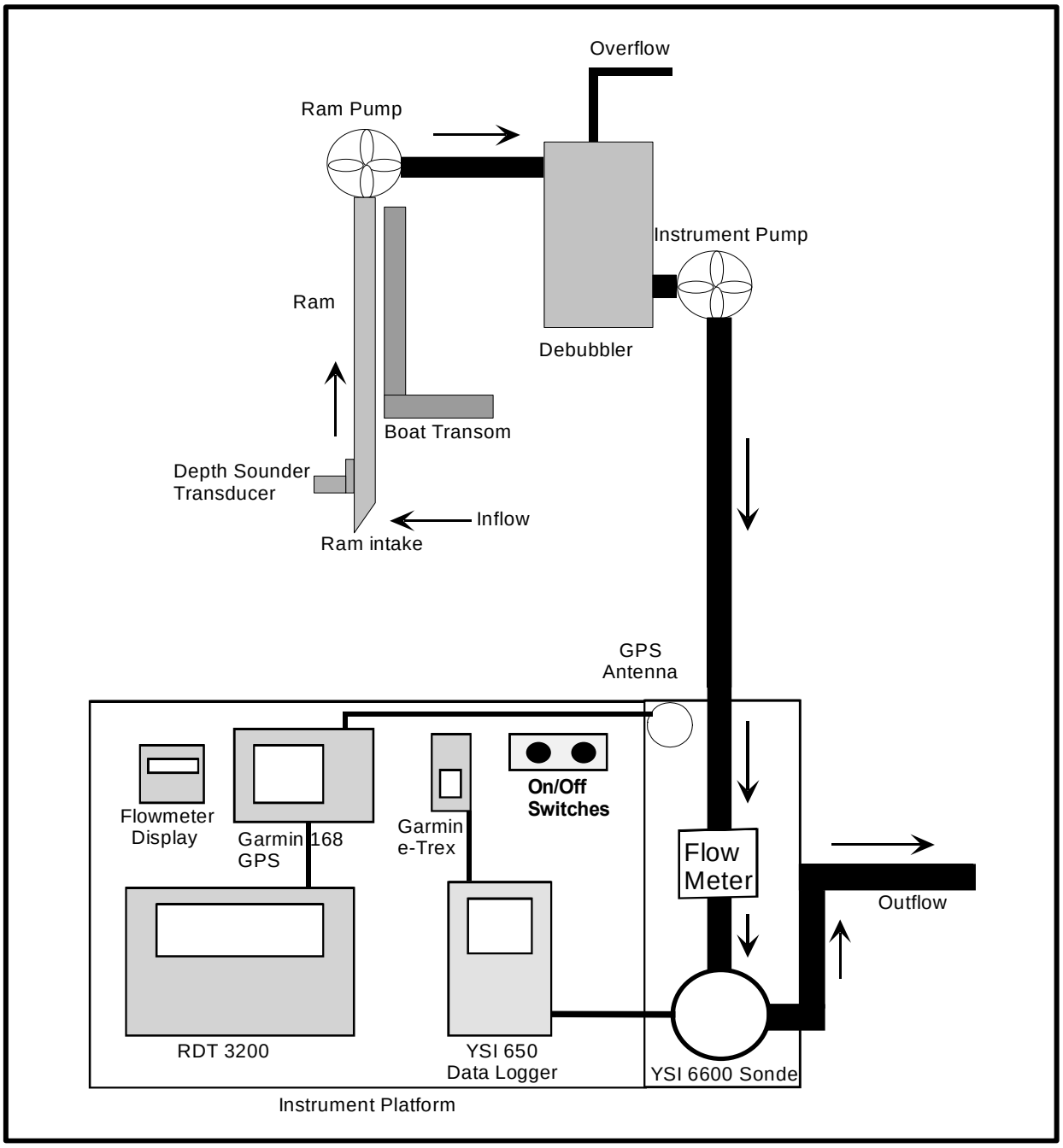


Figure 5-1. Schematic diagram of DATAFLOW V illustrating the path of water through the instrument.

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 into the debubbler. The debubbler fills and overflows, forcing out air and excess water through the overflow hose. A second instrument pump further boosts the sample water to the sensors. The water flows through a paddle-wheel type flow meter that will trigger a horn if the flow rate falls below 3 lpm. The water then enters a flow-through chamber where it is sampled by the YSI 6600 datasonde sensors. The water is then discharged overboard. The displays for the instruments, including the YSI 650 Datalogger, Garmin 168 GPS/Depthsounder, Garmin e-Trex GPS unit, flow meter display, and RDT 3200 are located on the instrument platform.

5.2.2 Sampling locations and frequency

Dataflow cruises were performed bi-weekly on both the Magothy and Severn Rivers. A total of thirteen cruises were completed on the Severn and eleven on the Magothy during 2002. The cruise dates are listed in Table 5-1. Cruise tracks were chosen to provide reasonable coverage of each water body while sampling both near-shore and mid-river waters. A sample cruise track is shown for each river in Figure 5-2. In both the Magothy and Severn Rivers, eight calibration stations were sampled. The selection of calibration station locations in each region was made first, to sample the greatest possible range of water quality conditions found during each cruise and second, 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 Chesapeake Bay Program water quality monitoring stations within each region, and these stations were sampled during each cruise. The coordinates for those stations are listed in Table 5-2.

Table 5-1. DATAFLOW cruise dates in 2002.

Region	Spring	Summer	Fall
Magothy River	4/10, 4/24, 5/09, 5/22, 6/05, 6/19	7/02, 7/16, 8/14, 8/28	9/12, 9/25, 10/10
Severn River	4/11, 4/26, 5/08, 5/23, 6/06, 6/20	7/03, 7/17, 8/08, 8/15, 8/29	9/13, 9/26, 10/09

Table 5-2. Location of DATAFLOW calibration stations
(stations coincident with Chesapeake Bay Program water quality monitoring stations noted with *)

Region	Station	Latitude (deg mins)	Longitude (deg mins)
Magothy River	MG01	39º03.482’ N	76º26.105’ W
	MG02	39º03.189’ N	76º26.934’ W
	MGST	39º03.672’ N	76º28.212’ W
	MG04* (WT6.1)	39º04.588’ N	76º30.211’ W
	MGWH	39º05.094’ N	76º31.512’ W
	MG06	39º05.189’ N	76º28.870’ W
	MG07	39º05.321’ N	76º26.048’ W
	MG08	39º04.683’ N	76º27.349’ W
Severn River	SR01	39º58.088’ N	76º26.105’ W
	SR02	39º00.162’ N	76º26.934’ W
	SR03* (WT7.1)	39º00.438’ N	76º30.334’ W
	SRSF	39º01.914’ N	76º32.712’ W
	SR05	39º02.295’ N	76º32.995’ W
	SRBO	39º04.914’ N	76º36.666’ W
	SR07	39º02.253’ N	76º34.151’ W
	SR08	39º01.232’ N	76º31.593’ W

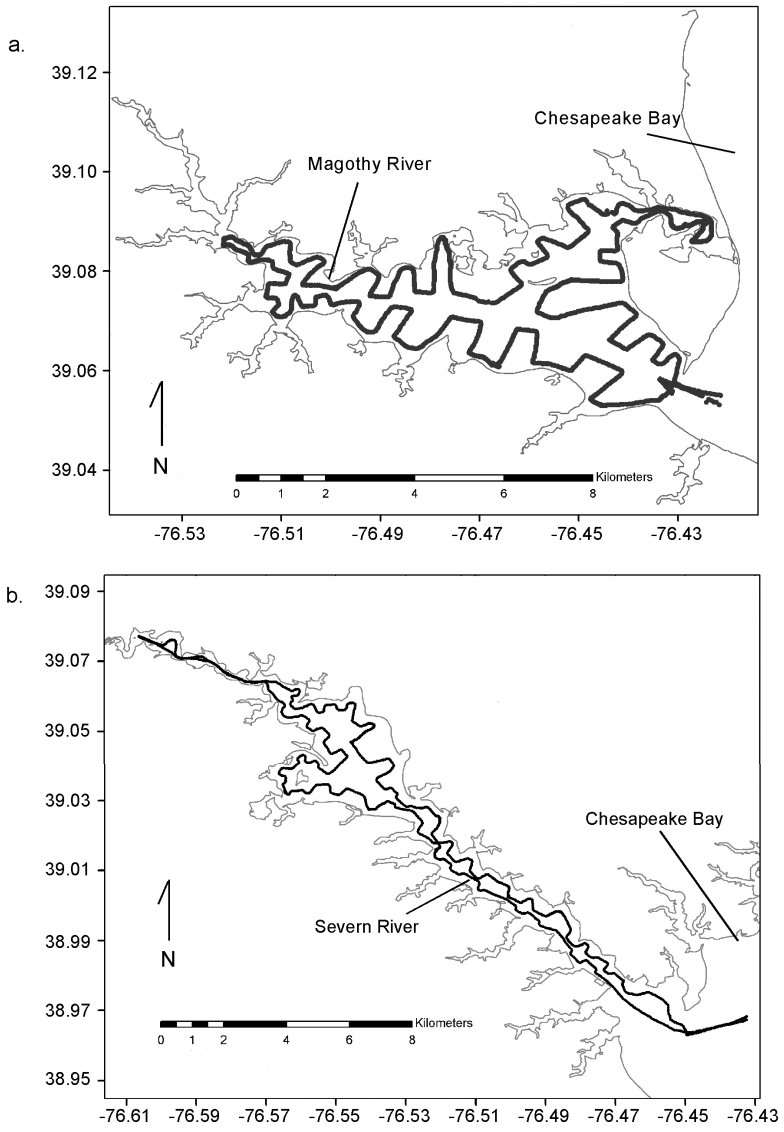


Figure 5-2. Typical DATAFLOW cruise tracks for

a. Magothy River, June 5, 2002 and

b. Severn River, May 8, 2002.

5.2.3 Calibration Stations

At each calibration station, a series of measurements and whole water samples were taken. Locations of the calibration stations are found in Figure 5-3. Secchi depths were recorded and *Li-Cor*® quanta sensors were used to determine the amount of photosynthetically available radiation (PAR) available in the water column. These data are used to determine the water-column light attenuation coefficient (Kd), and subsequently, the new "percent light through water" (PLW) parameter for SAV habitat requirements (Batiuk *et al.*, 2000). Secchi and Kd values were also regressed against YSI data SONDE turbidity sensor (NTU) output. Whole water samples were taken, later filtered in the lab, and sent for analysis by the Nutrient and Analytical Services Lab 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 total chlorophyll-*a* sensor output. Water samples were also filtered on station for NASL analysis to determine concentrations of dissolved nutrients. These nutrients included dissolved inorganic nitrogen (DIN; summation of NH_4^+, NO_2^-, NO_3^-) and dissolved inorganic phosphorus (DIP). A detailed explanation of all field and laboratory procedures is given in the annual CBL QAPP documentation (Rohland *et al.*, 2001).

5.2.4 Contour Maps

Contour maps were generated using the ESRI ArcGIS 8.1.2 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 Simple Kriging routines 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 V 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 propwash).

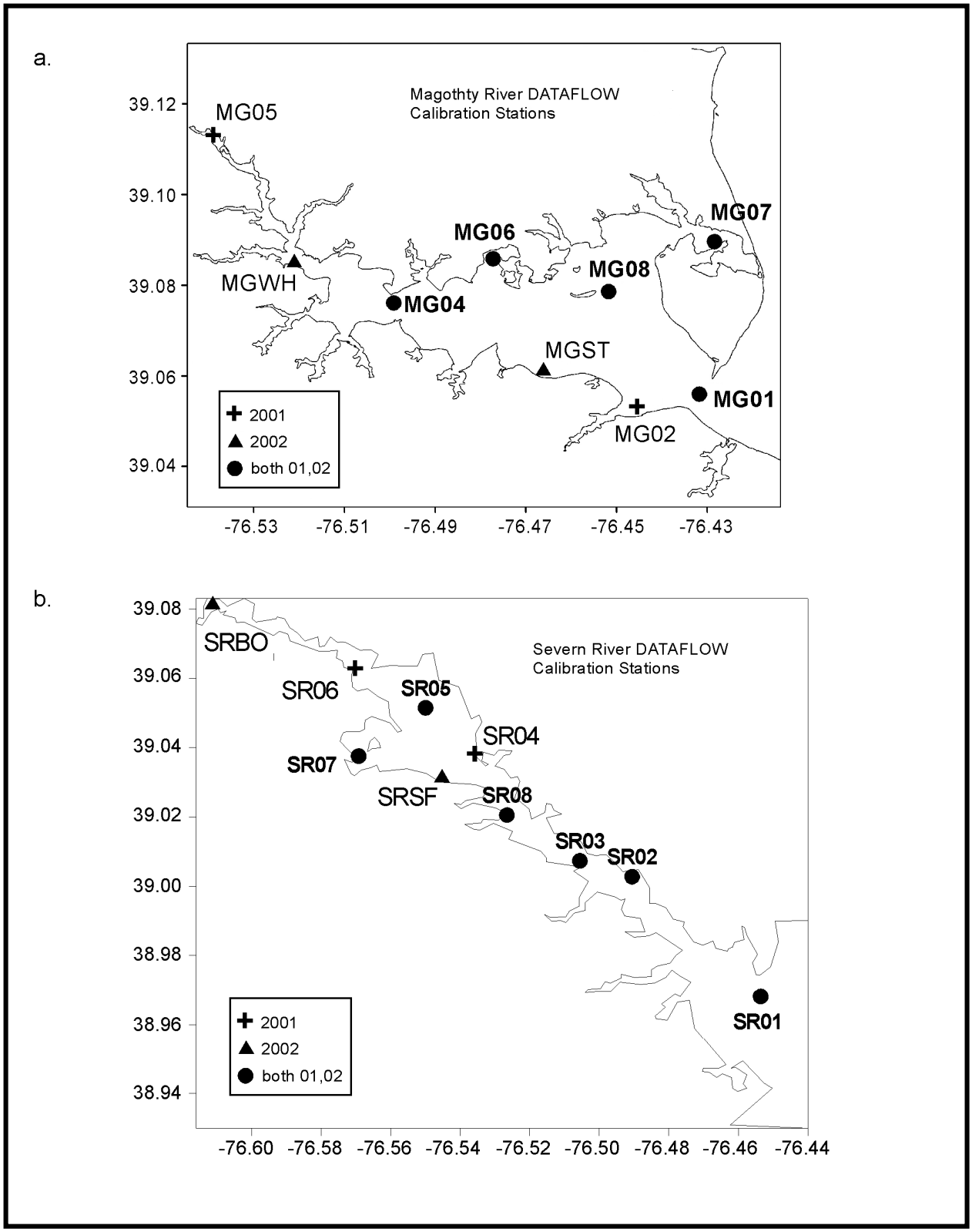


Figure 5-3. Calibration Stations on the
a. Magothy River, and
b. Severn River.

5.3 Results

5.3.1 Dissolved Nutrient Data

Water column dissolved inorganic nitrogen (DIN) and phosphorus (DIP) were measured biweekly from April to October at 16 calibration stations (8 per river) on the Severn and Magothy Rivers. Some changes were made in sampling location from 2001 to 2002 (Figure 5-3). Mean, range (minimum and maximum), and median values of DIN and DIP were calculated at each station throughout the season for the Magothy and Severn Rivers in 2002 (Table 5-3). Magothy River mean and median DIN concentrations were higher than corresponding Severn River concentrations in 2002. DIN ranged from 0.29 to 29.6 μmol in 2002. DIP ranged from 0.04 to 4.80 μmol in 2002. Most DIN values were < 20 μmol and most DIP values were < 0.5 μmol (Figure 5-4). A simple log transformation of the data allowed for more normal distributions. Two-way ANOVAs were conducted to test for significant differences between river systems for both DIN and DIP using the transformed data. Data for site SRBO was excluded since this site was much farther upriver from the other sites and regularly exhibited much higher nutrient concentrations. A significant difference was found for DIN between rivers ($p = 0.001$, $\alpha = 0.05$).

Table 5-3. Dissolved Nutrient Concentrations from the Magothy and Severn Rivers, April – October 2002.

Magothy River		MG01	MG02	MGST	MG04	MGWH	MG06	MG07	MG08
Dissolved Inorganic Nitrogen (µmol N)	Mean	9.84	8.06	6.39	4.12	5.18	3.33	6.37	7.04
	Range	(0.51 - 22.7)	(0.79 - 17.7)	(0.42 - 14.8)	(0.51 - 11.1)	(0.55 - 15.9)	(0.45 - 15.7)	(0.52 - 16.5)	(0.44 - 23.1)
	Median	8.90	7.86	5.52	3.32	4.33	1.47	4.20	4.27
Dissolved Inorganic Phosphorus (µmol P)	Mean	0.22	0.15	0.17	0.14	0.83	0.22	0.11	0.15
	Range	(0.04 - 0.85)	(0.05 - 0.68)	(0.06 - 0.64)	(0.05 - 0.33)	(0.05 - 4.80)	(0.04 - 1.24)	(0.05 - 0.22)	(0.07 - 0.60)
	Median	0.14	0.10	0.11	0.10	0.17	0.11	0.10	0.11

Severn River		SR01	SR02	SR03	SRSF	SR05	SRBO	SR07	SR08
Dissolved Inorganic Nitrogen (µmol N)	Mean	9.69	6.56	4.80	2.10	2.28	3.28	1.64	3.70
	Range	(0.31 - 29.6)	(0.36 - 22.4)	(0.38 - 19.9)	(0.44 - 4.7)	(0.47 - 7.0)	(0.29 - 25.2)	(0.55 - 3.5)	(0.35 - 13.7)
	Median	5.97	5.93	4.07	1.43	1.42	1.15	1.42	2.72
Dissolved Inorganic Phosphorus (µmol P)	Mean	0.27	0.21	0.19	0.26	0.25	0.16	0.19	0.22
	Range	(0.05 - 0.62)	(0.05 - 0.76)	(0.04 - 0.72)	(0.05 - 0.89)	(0.05 - 1.08)	(0.07 - 0.28)	(0.04 - 0.56)	(0.05 - 0.93)
	Median	0.19	0.13	0.13	0.15	0.12	0.14	0.11	0.12

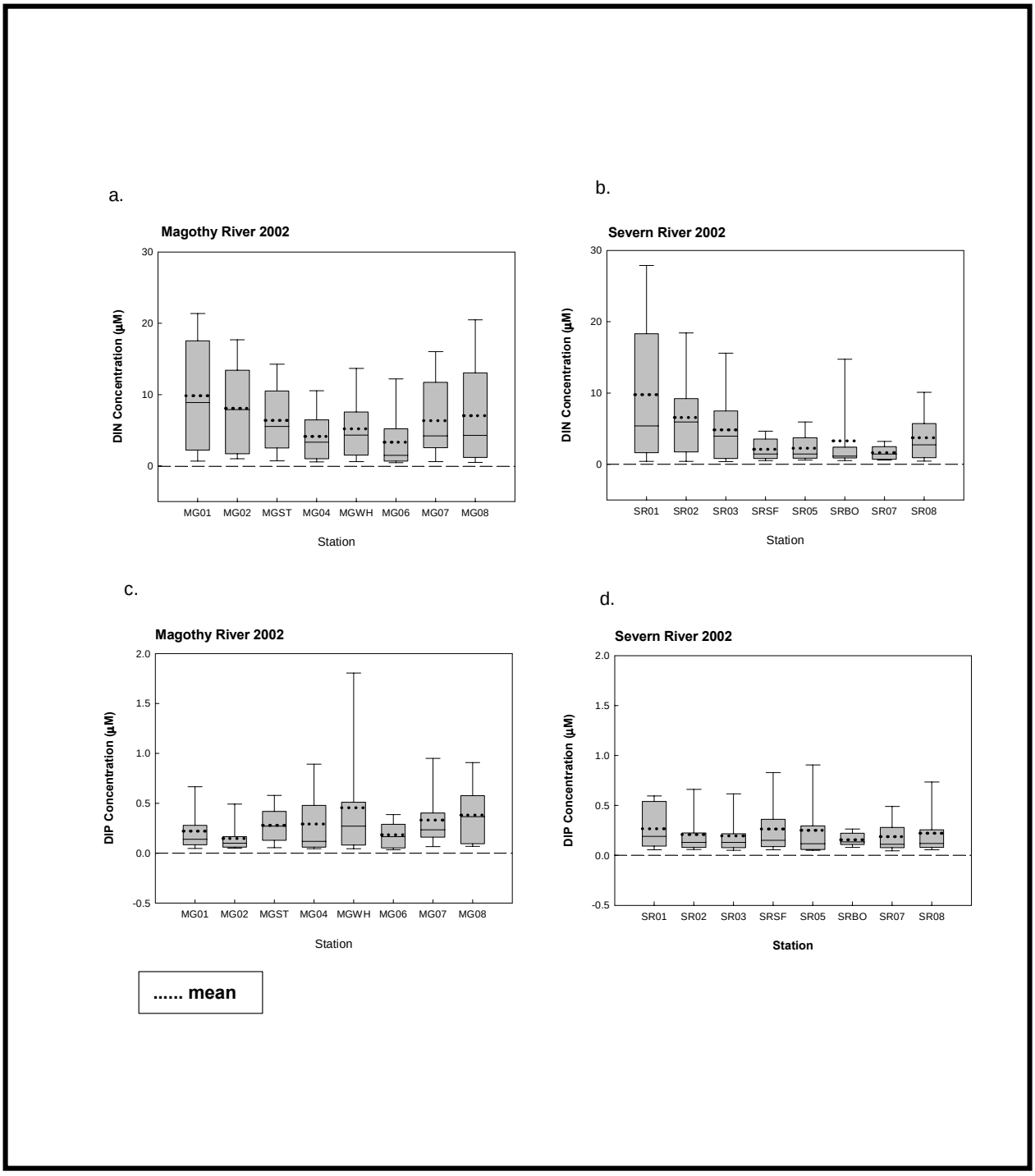


Figure 5-4. Nutrient Concentrations for

- **a. Magothy River Dissolved Inorganic Nitrogen,**
- **b. Severn River Dissolved Inorganic Nitrogen,**
- **c. Magothy River Dissolved Inorganic Phosphorus, and**
- **d. Severn River Dissolved Inorganic Phosphorus.**

5.3.2 Calibration Data

Chlorophyll-*a* regressions were completed in which data collected from the YSI SONDE was compared to total chlorophyll-*a* values determined by Nutrient Analytical Services Laboratory (NASL) from the water sample collected at the calibration stations. On the Severn River, the regressions were very strong. An example is shown in Figure 5-5, where the July 3, 2002 cruise on the Severn River had an r^2 of 0.99. When all the Severn River cruises for 2002 were combined, analysis produced an r^2 of 0.88. The predictability of this data may be enhanced by the strong gradient created by the inclusion of the Ben Oaks station (SRBO; see Figure 5-3.b for location of SRBO), which represents an extreme of chlorophyll-*a* concentration on nearly every cruise.

Magothy River regressions were not as strong as those for the Severn River. For example, a regression of data for a single cruise on September 25, 2002 produced an r^2 of 0.75, while a regression of data from all Magothy River cruises from 2002 produced an r^2 of 0.76. Perhaps this is a result of the lack of significant gradients as one sees on the Severn River. The chlorophyll-*a* data from the Magothy River simply did not exhibit the same range of values as observed from the Severn River.

Regression analyses were also performed to examine the relationship between turbidity measured by the YSI sensor (NTU) versus the light attenuation coefficient (Kd) derived through *Li-Cor*® measurements. These regressions were not as strong as those observed for chlorophyll-*a*, although one should keep in mind that both values are field observations and therefore subject to some field-based measurement error. A single cruise on the Severn River on May 9, 2002 produced an r^2 of 0.88 (Figure 5-6.c.), while all Severn cruises combined produced an r^2 of 0.74 (Figure 5-6.d.). A single cruise on the Magothy River on May 8, 2002 produced an r^2 of 0.71 (Figure 5-6.a.), while all Magothy River cruises combined produced an r^2 of 0.24 (Figure 5-6.b). The lack of a significant relationship for all cruises on the Magothy River between NTU and Kd might again result from the lack of significant gradients in that particular system.

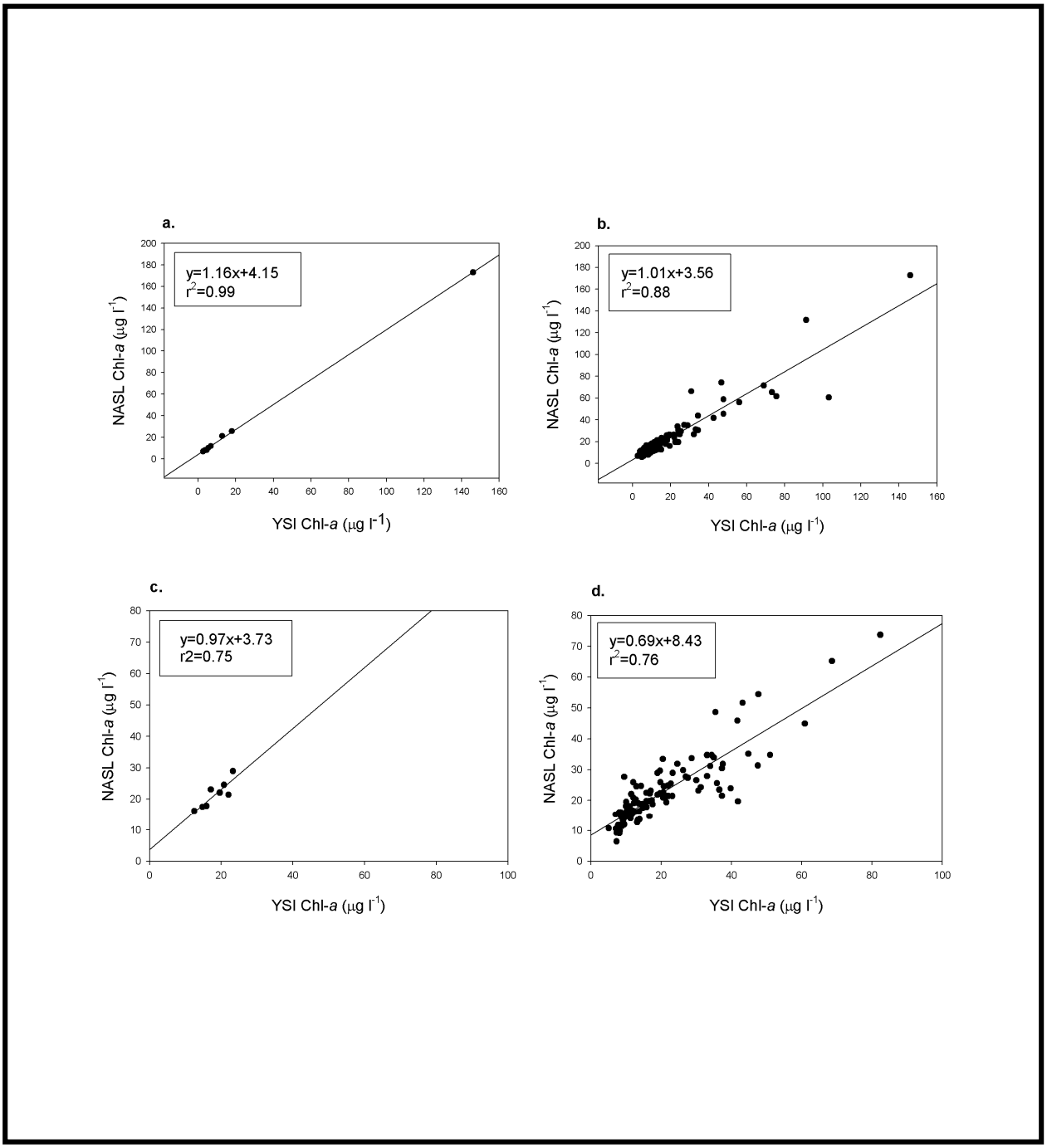


Figure 5-5. Regression analyses performed on relationship of sensor and lab values of chlorophyll-*a* of single and combined cruises on the Severn and Magothy Rivers. Illustrations are as follows:

a. Severn River, July 3, 2002,

b. Severn River, all cruises combined,

c. Magothy River, September 25, 2002, and

d. Magothy River, all cruises combined.

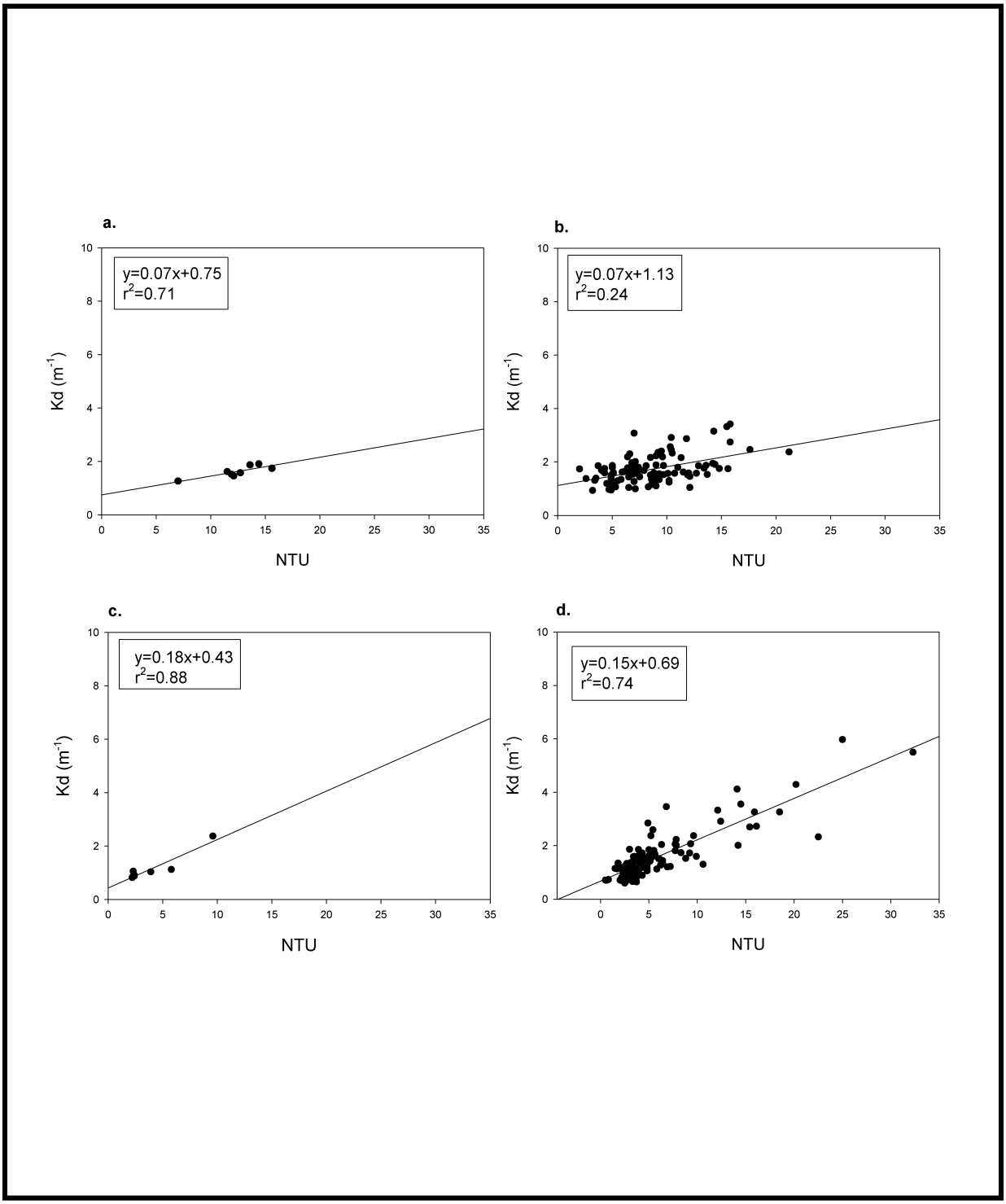


Figure 5-6. Regression analyses performed on relationship of sensor turbidity (NTU) and light attenuation coefficient (Kd) values of single and combined cruises on the Severn and Magothy Rivers. Illustrations are as follows:

- **a. Magothy River, May 9, 2002,**
- **b. Magothy River, all cruises combined,**
- **c. Severn River, May 8, 2002, and**
- **d. Severn River, all cruises combined.**

5.4 Discussion

5.4.1 Seasonal Variations in Spatial Patterns

Significant differences in spatial patterns were observed between cruises throughout the 2002 sampling season. Of particular note is the increase in chlorophyll-*a* concentration in the upper extent of the Severn River during the course of the 2002 season (Figure 5-7). It should be noted that these contour maps were created using methods previously outlined in this report, and that data were manually binned for comparison.

Figure 5-8 further illustrates the general lack of a gradient in chlorophyll-*a* concentration for the Magothy River. After the peak concentrations of the spring, the estuary appeared rather well mixed. It should also be noted that the Chesapeake Bay Program criteria for SAV habitat requires a maximum concentration of no more than 15 $\mu g\ l^{-1}$ of chlorophyll-*a*. Figure 5-9 depicts calibration station data for all cruises for a particular set of stations chosen that are representative of upriver, midriver, and downriver sites. Again, the Ben Oaks (SRBO) station on the Severn River exhibited the largest range and highest concentration of chlorophyll-*a*. The MG04 midriver calibration station on the Magothy River exhibited a curious range of total suspended solids values.

5.4.2 Differences in Near-shore and Off-shore Waters

It is important to analyze the differences between near-shore shallow water habitat and deeper, off-shore waters. These data have ramifications for cruise track design and targeted monitoring of specific habitats. As indicated by these data, three times as many observations were made in deeper waters. Standard error of the mean was also lower among the deeper water samples. It is interesting to note that both chlorophyll-*a* concentrations and turbidity were higher in the shallow waters for this particular cruise.

Table 5-4. Comparisons of shallow (≤2 meter depth) and deep (>2 meter depth) for: a) chlorophyll-*a* ($\mu g\ l^{-1}$) and b) turbidity (NTU). Severn River cruise, 26 September, 2002. Samples where no depth data were recorded (due to cavitation or other noise) were omitted.

a.

Chlorophyll-*a*	Observations	Mean	Median	Std. Error
Shallow	1010	17.3	9.7	0.51
Deep	3030	13.9	12.0	0.14

b.

Turbidity	Observations	Mean	Median	Std. Error
Shallow	1010	7.4	3.4	0.78
Deep	3030	4.7	3.4	0.06

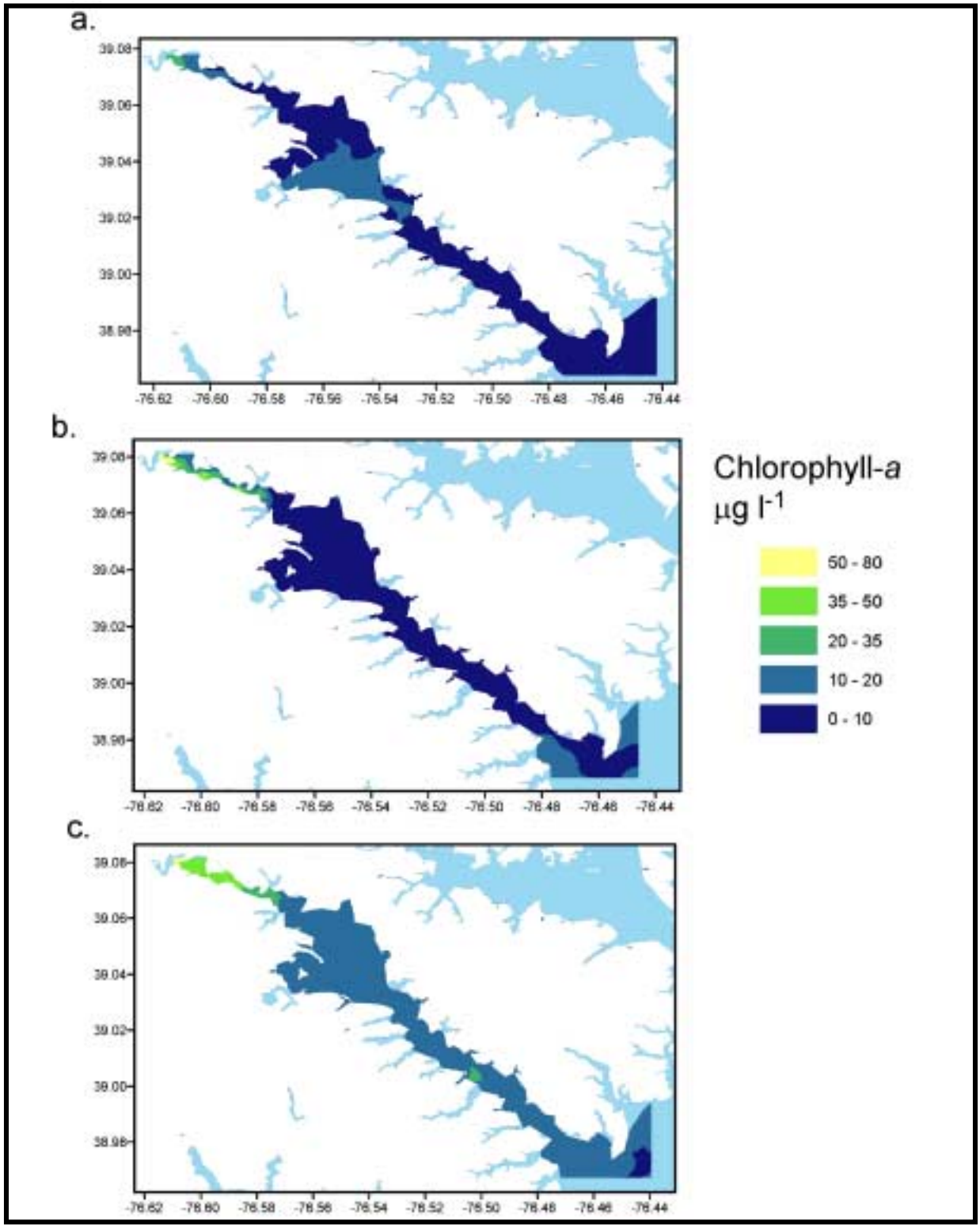


Figure 5-7. Seasonal differences between chlorophyll-*a* concentration on three cruises on the Severn River.

a. May 8, 2002

b. July 3, 2002

c. September 26, 2002

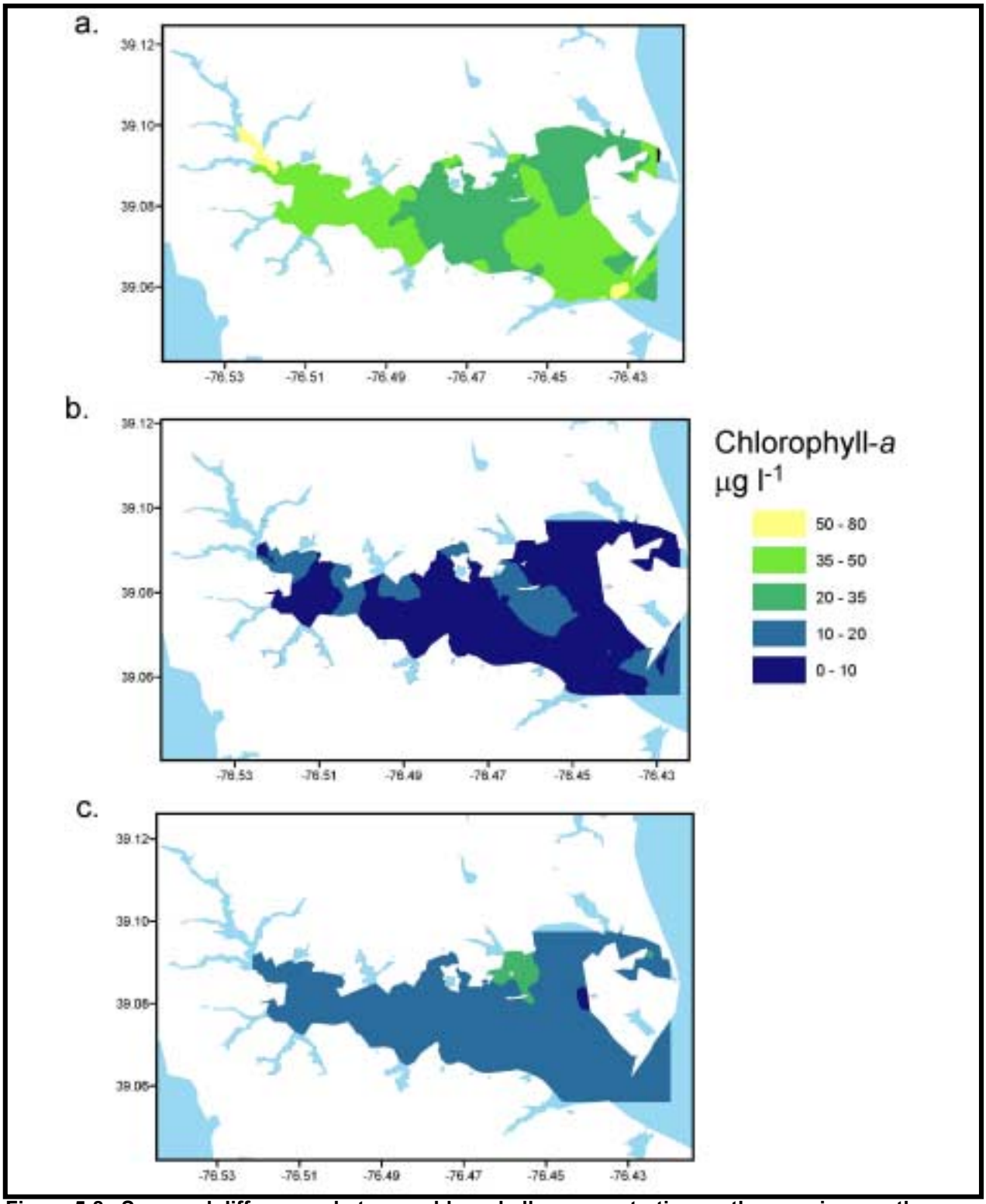


Figure 5-8. Seasonal differences between chlorophyll-*a* concentration on three cruises on the Magothy River.

a. May 9, 2002

b. July 2, 2002

c. September 25, 2002

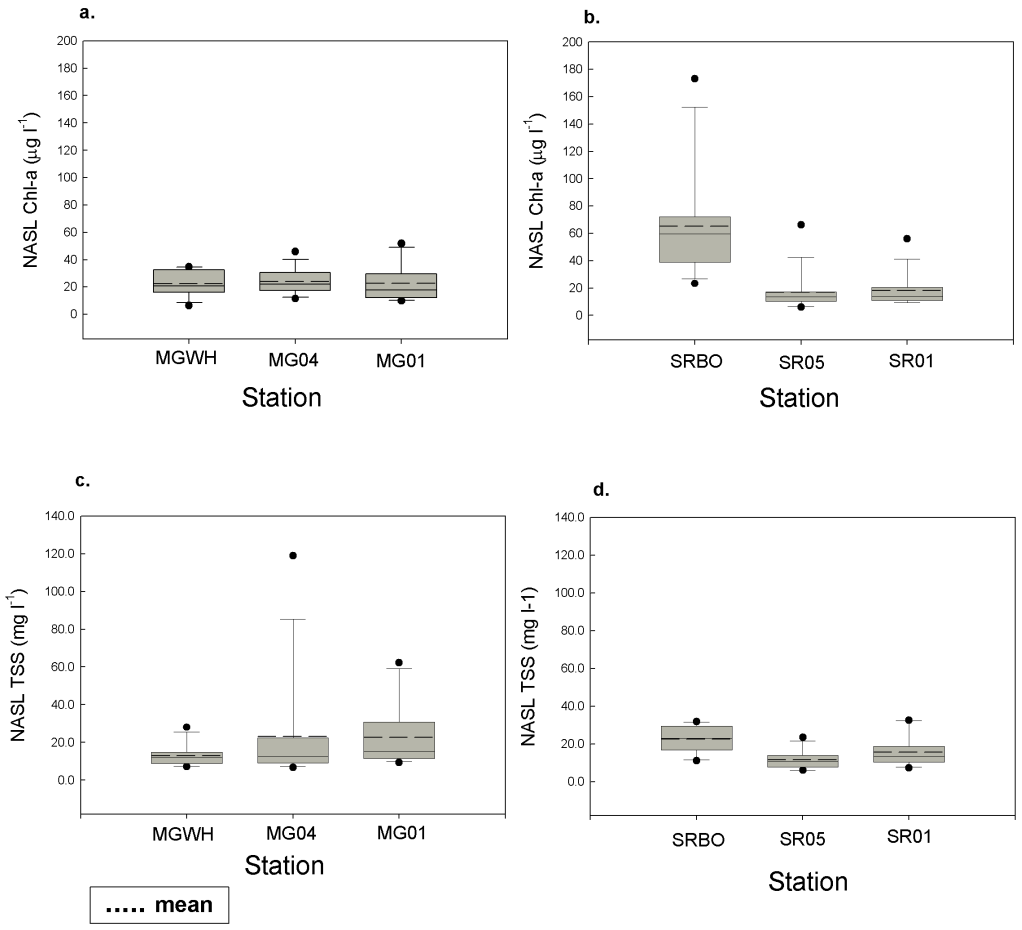


Figure 5-9. Distribution of data for selected calibration stations on each river for all 2002 cruises combined. The stations represent upriver (MGWH, SRBO), midriver (MG04, SR05), and downriver (MG01, SR01) locations.

- **a. Magothy River chlorophyll-*a* concentrations,**
- **b. Severn River chlorophyll-*a* concentrations,**
- **c. Magothy River total suspended solids (TSS) concentrations, and**
- **d. Severn River TSS concentrations.**

5.4.3 Derivation and Application of Correction Coefficients

Calibration correction coefficients derived through regression analyses of observational and laboratory data from individual DATAFLOW V cruises provided for more accurate analysis. The formula for the slope of the line derived from the regression was used to correct the observed YSI chlorophyll-*a* concentration data. See section 5.3.2 for discussion of calibration data. Figure 5-10 shows a curve for the cruise on the Magothy River on May 9, 2002. Two contour maps show uncorrected (Figure 5-11.a.) and corrected (Figure 5-11.b.) from that same cruise (May 9, 2002) illustrating sensor derived chlorophyll-*a* concentration and the impact of correcting that output to laboratory values.

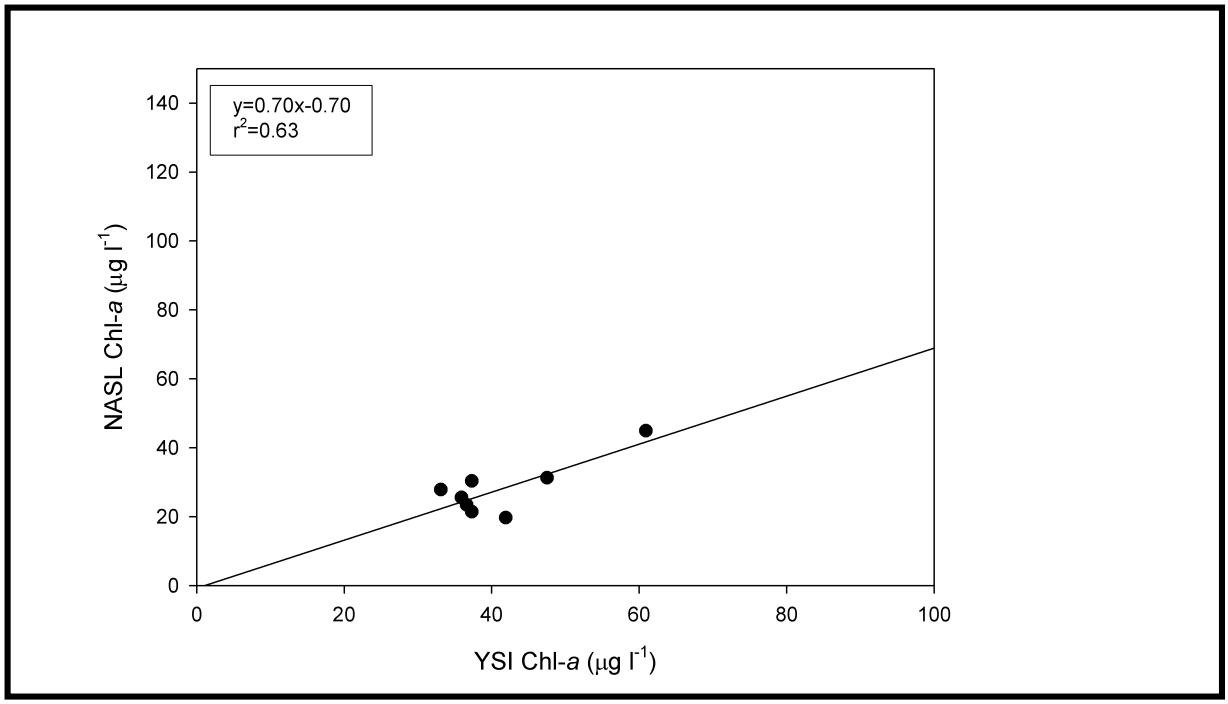


Figure 5-10. Regression of sensor output data versus laboratory derived values for chlorophyll-*a* concentration during a cruise on the Magothy River on May 9, 2002.

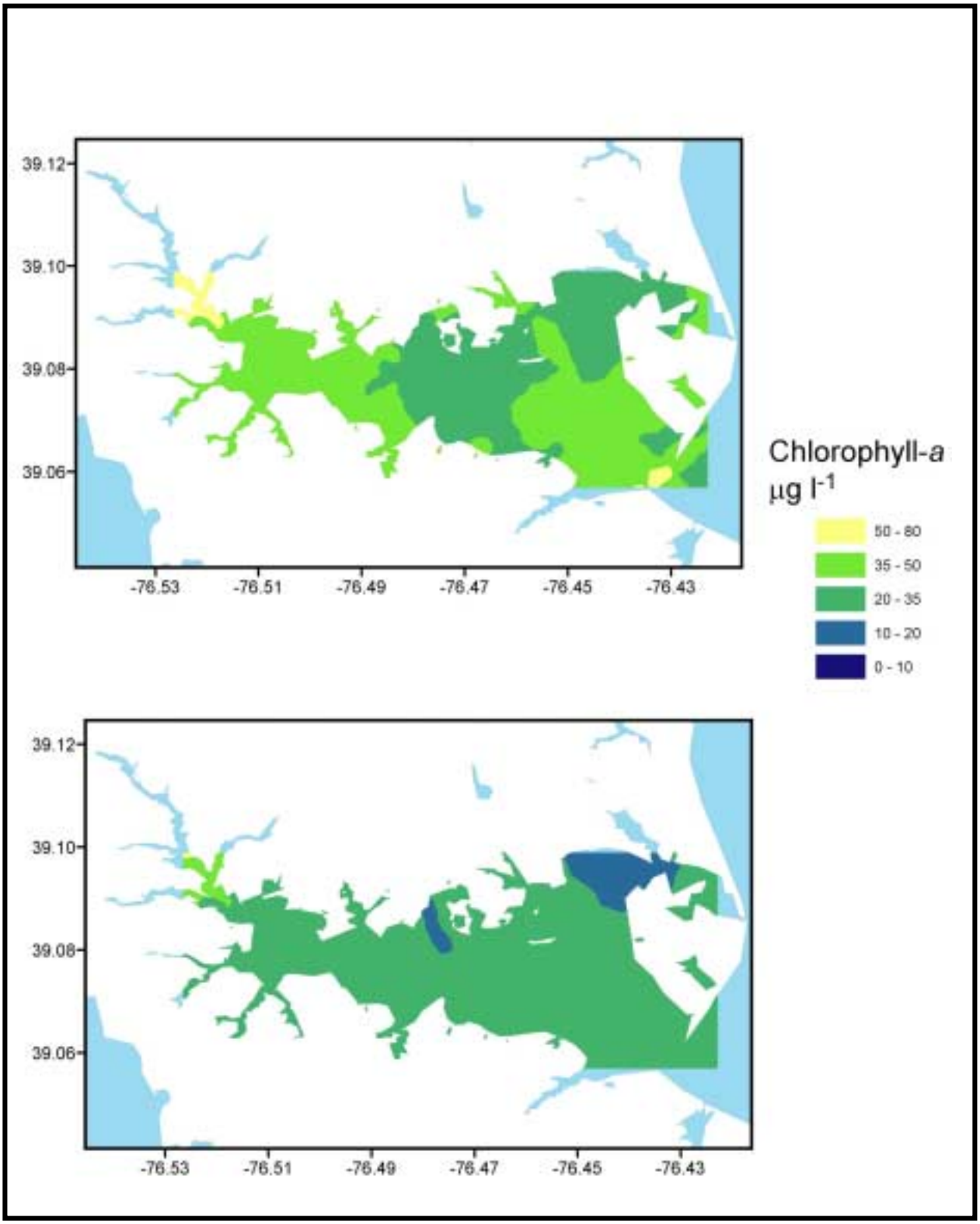


Figure 5-11. Differences between

a. uncorrected (top) and

b. corrected (bottom) datasets when producing interpolation maps.

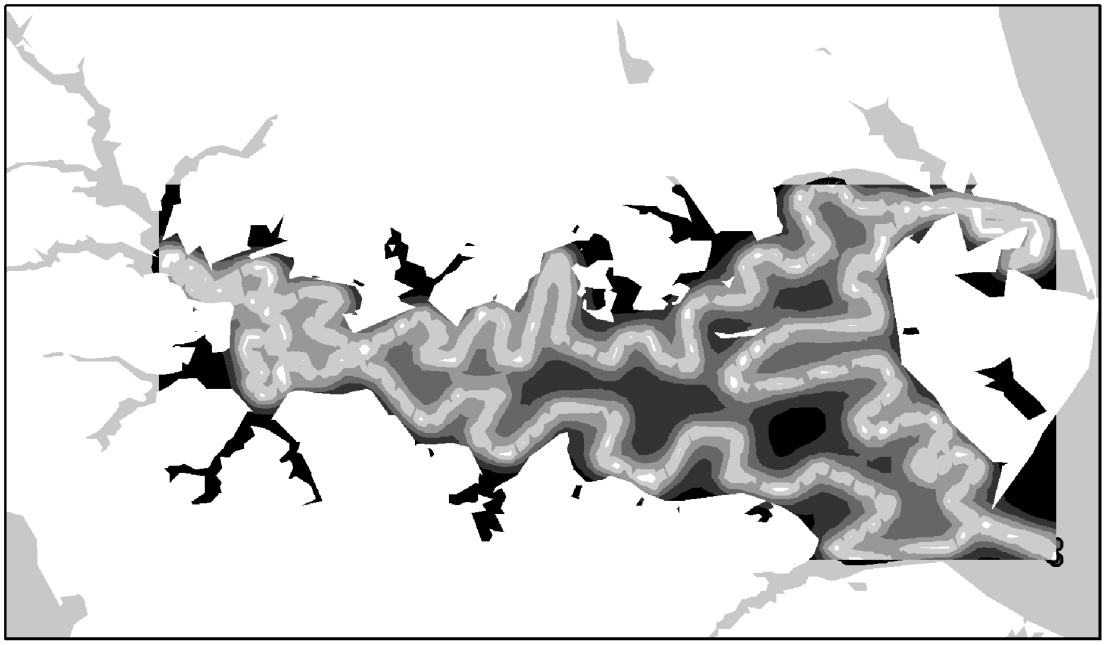
5.4.4 Sources of Error with Interpolated Maps

In order to use DATAFLOW as a tool for habitat assessment, it becomes necessary to understand and quantify all errors associated with these estimates. As mentioned above, calibration error can be a significant factor in sensor output evaluation. However, interpolation error can also be an important component. Figure 5-12 illustrates the increase in error associated with interpolation on a typical DATAFLOW V cruise. While the "square-wave" cruise pattern represents an attempt to improve interpolation of water quality parameters on a river-wide scale, interpolation error increases with the distance from the actual cruise path. The magnitude of this error will also vary with the magnitude of water quality gradients measured on each cruise.

While there is certainly substantial error associated with this new technology, emphasis must be placed on the relationship between laboratory values and sensor output. Correlation coefficients derived from individual or grouped cruises might be used to develop and then apply a correction factor for each tributary during interpolation, providing for a more accurate representation of that tributary (Table 5-5). The error generated in the field can be reduced through further development and refinement of the sampling apparatus and application of newer technologies. Sampling strategies might also be adapted to emphasize the benefits of DATAFLOW, which might include focusing on rapid response and data collection on trouble spots within a given tributary, (*e.g.*, the extent of an algal bloom event), rather than the rapid, but coarse characterization of an entire system. While this system wide characterization represents a substantial improvement over traditional fixed-station water quality sampling, DATAFLOW remains an emergent technology that requires equipment, methods, and data analysis homologation in order to become an effective management tool.

Table 5.5. Error Associated with Spatially Intensive Monitoring (Dataflow)

Source	Error	Possible Solution
Analytical		
Sensor Output vs. Laboratory Analysis	See included discussion regarding Calibration Issues	Incorporate regressions into data analysis and factor into predictions.
Interpolation	Varies significantly with distance of interpolated point from discrete sample (see fig.)	Establish best methods and protocol for interpolation.
Field		
Vessel Speed	45m ±5m @ 20kts.	Establish optimum sampling speed
Position Accuracy	15m ±5m	DGPS (3-5m) or WAAS (<3m) enabled system
Sample Residence Time	Approx. 3 seconds (20kts. ≈10m/sec; therefore, 30m)	Reduce residence time through modifications to sampling apparatus.



Legend

Prediction Standard Error Map

[M052202].[CHLOR]

Filled Contours

0 - 1.02605855

1.02605855 - 1.88458323

1.88458323 - 2.60292888

2.60292888 - 3.20398355

3.20398355 - 3.92232919

3.92232919 - 10.2503624

Figure 5-12. Illustration of the increase in error associated with interpolation on a typical Dataflow cruise. The error is obviously highest in the tributaries where the vessel did not venture, while the "square-wave" cruise pattern represents an attempt to improve interpolation of water quality parameters on a river-wide scale.

5.5 Future Directions

There is no question that the DATAFLOW V system represents a novel and attractive technology for evaluating water quality characteristics of the Chesapeake Bay and its tributaries. With any new technology, there are certainly limitations, some of which have been examined in this report; however, further study of the technology and refinement of technique will improve the DATAFLOW system. We will increase the flow rate to reduce sample residence time, adopt WAAS enabled GPS equipment to improve spatial accuracy, and improve the software interface as part of our continued research and development of the DATAFLOW system.

Sampling technique might change as well. Cruise tracks might be modified to concentrate more on the critical shallow water habitat, while maintaining a pattern that would still provide for adequate interpolation quality. These and other issues must be discussed if DATAFLOW is to be developed into a management tool to establish or enforce Bay Program criteria.

It has been suggested that DATAFLOW can also serve as a foundation for even more advanced sampling technologies, including real-time mapping and interpolation of sensor data using GIS software. These represent logical development of the system, but present incarnations of the DATAFLOW system should continue to be stringently examined and evaluated in order to provide the most accurate and precise data for both scientists and managers.

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6. MANAGEMENT SUMMARY

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 and 2002), and the analyses presented in this report, the following observations are provided that have relevance to water quality management.

Nutrient loading rate estimates for the Patuxent River were again reviewed for the period 1985-2000 as a portion of a synthesis effort supported, in part, by the UMD CES IAN Program. A summary of that review is again included because changes in these loads are of central interest in the Bay Program. Fall line loads of TP (which include above fall line point source inputs) have decreased dramatically between 1984 and 1995 (4-5 fold); recent loads would have been even lower except for relatively high inputs associated with flood events (*e.g.* May 1989, March 1993 and March 1994 and much of 1996, and 1998). Because of the severe drought during 1999, TP loads during 1999 were among the lowest on record and we assume that these loads were also very low during the 2002 drought. Fall line TN loads have also decreased over this period but not nearly as much as TP loads; similar increased loads of TN were associated with flood events. The regression of TN load versus time is significant ($p < 0.01$) for both the full period of time and the post 1989 period with annual load decreases of about 230 kg year^{-1}. TN loads were also reduced during 1999, again because of the effects of the drought in reducing diffuse source run off of TN. There is unequivocal evidence that substantial nutrient load reductions at the fall line have occurred in recent years. However, it also appears that in the years following the installation of 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 1990's were wetter than the earlier years, and partly because the middle and lower portions of the Patuxent basin have been rapidly developing. 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.

Dissolved oxygen conditions in the Patuxent River were examined using monthly data collected at the four long-term sediment-water exchange (MINI-SONE) stations. In general dissolved oxygen conditions in deep water at the deeper sites (MRPT and BRIS) were fair to good in 2002. For example, dissolved oxygen remained above 3.0 mg l $^{-1}$ at all stations during June – September 2002. During the drought year of 1999 DO never decreased below 2.7 mg l^{-1} indicating the importance of flow and nutrient loads on DO conditions.

Sediment–Water Oxygen and Nutrient exchanges measured during 2002 were largely comparable with those measured during 1999 (also a drought year) and the similarities are consistent with the conceptual model of how sediment-water exchanges are regulated in estuarine systems. For example, SOC rates were larger during most of the 1999 and

2002 sampling period compared to 2001. These enhanced values very probably resulted because dissolved oxygen concentrations in deep water were higher during 1999 and 2002 than in some previous years or during 2001. SOC rates become limited (reduced in magnitude) when bottom waters are depleted in dissolved oxygen. These results also suggest that these systems are very responsive to nutrient load changes.

Ammonium (NH_4^+) fluxes were also smaller in 2002 than during 2001 and were similar to those observed during the 1999 drought. The relatively low fluxes observed during 1999 were very probably a response to reduced nutrient loads associated with drought conditions. The large reductions in ammonium flux between adjacent years of high (1998) and low (1999 and 2002) nutrient load is also instructive. This annual-scale response by sediments to loading conditions indicates that while sediments are the largest storage of nutrients in these systems, the portion of the stored material that is biologically active is not large enough to influence fluxes in subsequent years. In short, this is evidence for relatively limited nutrient memory and the potential for rapid (year rather than decade scale) responses to management actions.

Positive sediment nitrate and nitrite fluxes (fluxes directed from sediments to the water column) are a definite sign of sediment nitrification activity, a microbial process converting ammonium to nitrite and then to nitrate and one that requires that oxygen be present. Positive nitrate fluxes are a sign of good sediment quality. Positive (or even zero) fluxes were observed during 1999 and 2002 for most of the sampling period. However, during 2001 fewer positive sediment nitrate and nitrite fluxes were observed, consistent with generally lower DO conditions. We continue to believe that the presence of positive nitrate flux is a good tool for monitoring the general biogeochemical health of sediments.

During 2002, inorganic phosphate fluxes (PO_4^{3-} or DIP) were similar to those observed during the 1999 drought year. During the drought year DIP fluxes were near or below the long-term average at all sites. Experimental studies involving phosphorus flux and dissolved oxygen (DO) conditions indicated a tight negative relationship between flux and DO status. When dissolved oxygen conditions improve, phosphorus flux decreases. In addition, these experimental studies indicated that the time needed for estuarine sediments to respond to decreased phosphorus loads is probably quite short (weeks to months) despite large storages of particulate phosphorus in sediments (Jasinski, 1995). It appears that sediment phosphorus fluxes have responded to reduced inputs of phosphorus and that sediments do not contain active phosphorus reserves that can sustain high sediment releases much beyond the annual time scale.

During 2002 a comparison ***of littoral zone habitats*** was made for several locations and regions within the mesohaline portion of the Bay focusing on the parameters important to submerged aquatic vegetation (SAV). The goal of this investigation was to accurately measure and characterize many of the complex and interacting parameters necessary for SAV growth and survival in these shallow water habitats. This included measurement of the five water quality parameters (DIN, DIP, Kd, TSS, Chl-*a*) determined most important for growth and survival of SAV, and comparison of measured values to the habitat limits

specified by the USEPA (USEPA, 2000). In addition, comparisons of epiphyte fouling rates were made between regions as well as between locations with healthy SAV populations and those without in the Patuxent and Potomac Rivers. Dissolved nutrient concentrations (DIN, DIP) were in general below the SAV mesohaline habitat limits at all stations. However, on a regional basis, the other parameters (Kd, TSS, Chl-*a*) were very close to the established SAV habitat limits. Within each region, significant differences were found among stations in many of the parameters measured with some stations consistently meeting the SAV habitat criteria while others consistently did not. Epiphyte fouling rates were also quite variable among stations within each region but many rates were in excess of required SAV light requirements.

High spatial resolution water quality data was collected in the Magothy and Severn Rivers in 2002 using the **DATAFLOW V** mapping system. The goal of this effort was to identify the spatial and temporal scales of water quality variability in these systems and to further develop this method of data collection for enhanced near-shore and tributary monitoring. The information collected on thirteen Severn and eleven Magothy River cruises provided the data necessary to explore and develop the most appropriate ways of using and validating this data. While this evaluation process is not yet complete, several important results have been found. The spatial patterns found on both rivers were very dynamic. Large changes in both the concentration and distribution of turbidity and chlorophyll-*a* were found between successive bi-weekly cruises, suggesting that sampling at longer intervals would not adequately capture the variation in these systems. Calibration of DATAFLOW sensor output to laboratory-based analysis of water samples during a single cruise can provide the best estimate of water quality (r^2 up to 0.99 for Chl-*a*) given that a wide range of values are encountered during each cruise. However, when water quality conditions are relatively homogenous during a single cruise, calibration can still be accomplished with a small loss of accuracy by using relatively robust relationships derived when multiple cruises are combined. These results will provide some information to help guide the standardization of DATAFLOW data processing. Interpretation of data led us to identify potential areas of improvement in sampling methods. These included issues of spatial resolution and residence time of water in the DATAFLOW system. Making these improvements helped refine the system. The data gathered during these cruises appeared to test well against traditional laboratory analyses. Finally, our confidence in DATAFLOW as an assessment tool has increased, as we better understand calibration procedures and develop standardized operation procedures.

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Appendix A: Field Manual

Field Manual for the Collection of Epiphyte Data:
How to Monitor Epiphytes

M. Ceballos and R. Stankelis

Field Manual for the Collection of Epiphyte Data:
How to Monitor Epiphytes

M.A.C. Ceballos and R.M. Stankelis

Introduction

Submerged aquatic vegetation (SAV) are true plants rooted to the sediment surface. They are particularly sensitive to the amount of light that reaches the surface of their leaves. Under certain circumstances, microscopic algae along with a matrix of bacteria, dirt, and detritus can accumulate on the leaves of SAV and filter a significant amount of the light before it reaches the leaf surface. These algae growing on the surface of the leaves for support are called ***epiphytes***. While water clarity can readily be measured using something as simple as a secchi disk, measurement of the amount of epiphytic material is more complicated because it takes time for this material to accumulate. In this document a simple, yet robust method for measuring epiphyte accumulation rates is described. This method uses artificial substrates (Mylar® strips) as a substitute for living SAV. It has already been used extensively in many tributaries of Chesapeake Bay to estimate the impact epiphytic fouling will have on SAV populations. This data is not only useful for monitoring the health of existing SAV populations, but can also be used as a diagnostic tool to help choose appropriate sites for SAV restoration.

1. Important Considerations

There are several important considerations when beginning an assessment of epiphyte fouling rates. The first is driven by the way epiphytes accumulate on the surface of plants and artificial substrates. In general, epiphytes accumulate slowly at first and then increase rapidly over time. Eventually they reach a maximum biomass and level off. However, studies comparing the use of artificial substrates with live SAV found that the amount of material on the living plants is very different from the artificial substrates. This is primarily because living plants will not tolerate extremely large amounts of epiphytes on their surface. After a certain point, the plants simply break off or die. Thus it is important to limit the amount of time the artificial substrates are actually in the water. **Mylar® strips should not be left in the water for more than 6 to 10 days.** After that time, there are large differences between the amount of material on live plants compared to Mylar® strips and the data become difficult to interpret.

The second important consideration, is the monitoring location. The vast majority of SAV in Chesapeake Bay occurs at water depths less than 2 meters. As most studies completed to date on epiphyte fouling rates in Chesapeake Bay have been done in water a meter deep**, it is highly recommended that the epiphyte collection arrays (see next section) be deployed in water 1 meter deep at mean tide (or as close as possible to 1 meter).** A slight variation is acceptable, however it is extremely important to document the actual water depth. It is equally important that the actual monitoring site not be located within the shadow of a pier or other structure that will artificially block out any sunlight. Consultation with Maryland Department of Natural Resources will provide guidance concerning other questions about locations for epiphyte monitoring. The following sections describe the construction and deployment of epiphyte collection arrays.

2. Constructing the Epiphyte Collector Array

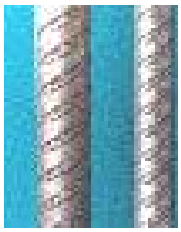
Equipment Needed

~15ft PVC pipe 1”
4 PVC T-fittings 1”
4 PVC Elbow-fittings 1”
~30ft Soft steel reinforcing bar (amount needed may vary depending on rebar width)
PVC Plastic Cement/Solvent Glue
PVC Cleaner/Primer
Paper Towels/Rags
Tape Measure
Sharpie Marker -medium
Power Drill ⅜” and Drill Bits ¼” & ⅛”
Tubing Cutter (or Hacksaw)
Utility Knife
~3ft Triple Strand Filament Polyester Line ¼”
Pool "Noodle" Float ~3” Diameter with ¾" center hole (or other Floating Marker Device)
6 Small Eye Screws/Bolts ½" brass screw-eye
6 Duolock Snaps Cabela’s 1-1¼” length

Handy Conversion Table

To Convert:	To:	Multiply By:
Inches (“)	Millimeters (mm)	25.4
Inches (“)	Centimeters (cm)	2.54
Feet (ft)	Meters (m)	0.305
Millimeters (mm)	Inches (“)	0.039
Centimeters (cm)	Inches (“)	0.394
Meters (m)	Feet (ft)	3.28

Assembly Protocols (See Figure 1)



Create a roughly square PVC frame (~0.69m x 0.74m) with a vertical PVC shaft (~0.56m) in the center of the square to hold up to six Mylar® strips (see example to left). Apply plastic pipe cleaner/primer to the ends of the pipes, and to the insides of the fitting sockets. Primer dulls glossy surfaces and ensures a good seal/hold. Prior to applying the plastic cement/glue to the PVC base pieces, drill several small drain holes throughout the bottom and fill the base pipes with rebar. Solvent glue each joint by applying a thick coat of plastic cement to the end of the PVC pipe. Apply a thin coat of solvent glue to inside surface of the fitting socket. ***Work quickly!*** Solvent glue hardens in about 30 seconds. Once all pieces have been glued together, allow around 30 minutes for joints to dry. Attach a line to the center shaft with a foam float to serve as a station marker to help locate the collector at a later date. Any foam float will work, for example a foot long piece of pool noodle. Pool noodles are long, fluorescent spongy tubes used as flotation devices in swimming pools that can be purchased at K-Mart or Wal-Mart. Attach the small eye screw/bolts to the PVC base pieces. Make sure to space them evenly throughout the base square in order to minimize the soon to be attached Mylar® strips from touching each other when floating in the water (see Figure 1.a below). Finally attach duolock snaps to each eye hook.

3. Preparing the Artificial Substrata or Epiphyte Strips

Equipment Needed

Transparent 0.18mm thick (0.001") Mylar® Polyester Plastic
Cabela's 1-1¼" length. Duolock Snaps
Tape Measure or Ruler
Sharpie Marker - medium
Foam Rubber Pipe Insulation
Utility Knife or Scissors
Large paper cutter
Hole Punch
Small plastic zip ties (99mm)

Assembly Protocols

******Transparent sheets of Mylar® polyester plastic can be purchased through many plastics supply companies. However, the minimum order for this material will be quite large and will be enough for several thousand strips. The material should be one "mil" thick (0.001"), this is an industry standard. Mylar® is used as it will not dissolve with acetone used during chlorophyll-*a* analysis.

Cut Mylar® strips 1" wide (2.5cm) by 20" long (51cm, the typical width of the Mylar® sheet purchased). ***Care should be taken to make the strips as uniform as possible. That means that both the bottom and top of the strip should not deviate from 1" by more than 1/16". This is very important, because after the strips are deployed, they are not measured, and the area is assumed to be accurate. A strip that is larger or smaller in size will alter the results of the study and may not fit into the storage tubes.***

Mark strips with a sharpie creating three measurement zones ~25cm long (see Figure 1.b). Punch a hole at each end of the Mylar® strip using a hole punch.

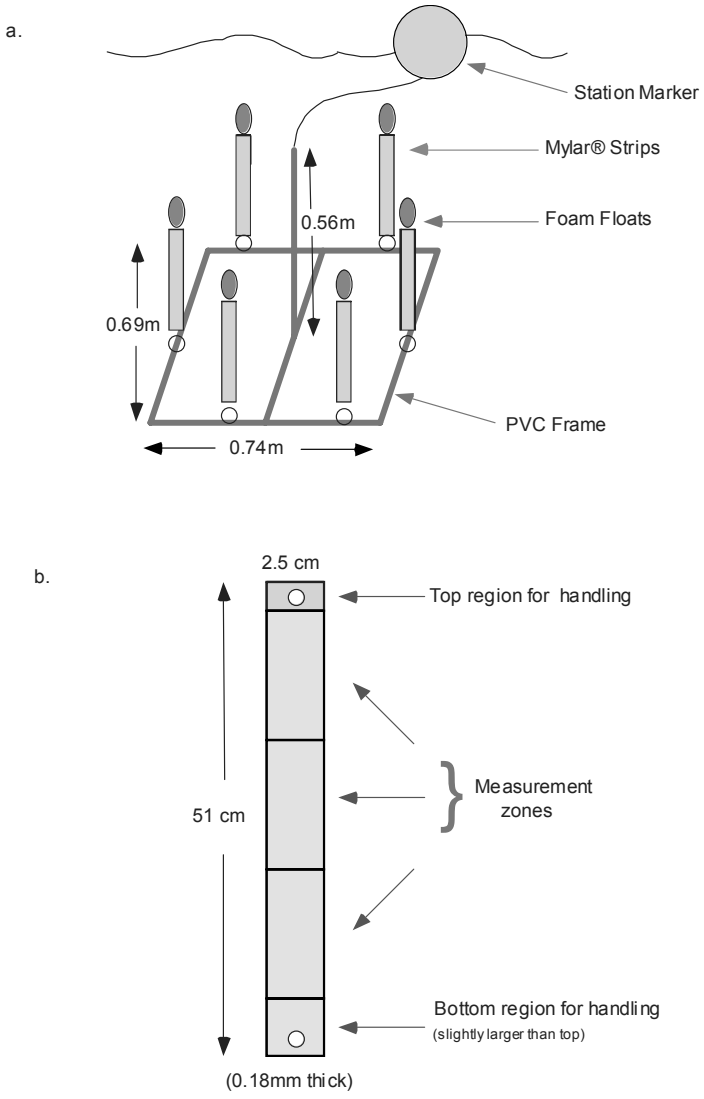


Figure 1. Diagrammatic sketch of
a) epiphyte collector array and
b) Mylar® strip.

Make small foam floats by cutting small pieces (~3.5cm x 3.3cm) of foam rubber pipe insulation. Secure duolock snaps to the small foam floats. Attach the duolock snap floats to the top of each strips (see example to left) using the zip tie. This is threaded though the center of the float and then firmly attached to the snap lock. This helps to the maintain the Mylar® strip in a vertical position in the water at the same time allowing the strips to move freely in the water column

Photograph of a clean Mylar® strip, with 6” ruler for reference.

4. Deploying Epiphyte Collector Arrays

Equipment Needed

Data Sheet or Waterproof Notepad
Pencil
Epiphyte Collector Array(s)
6 Epiphyte Strips per Collector
Needlenose Pliers
Long Handled Boat Pole with Hook*
Waders or Wet Suit*
Shallow draft boat*

Deployment Protocols

Epiphyte collector arrays are deployed at designated sites for a standard period of time (6-10 days) in order to measure epiphytic fouling rates. These sites can be accessed by wading into the water or from a vessel if appropriate. The equipment necessary will depend on the access to the site.

At the epiphyte station location, make a visual assessment and record the environmental conditions at the site (include site name, date, weather conditions, water surface conditions, air temperature, etc.). Prior to deploying the epiphyte collector array, attach the 6 epiphyte strips to the duolock snaps at the base of the collector. Use needlenose pliers if it is difficult to open or close the duolock snaps. During the deployment of the collector array hold all of the strips by the small foam floats on top to ensure that none of them get caught or tangled. Holding the strips and the center shaft slowly place the collector array on the bottom floor of the station. Verify that the collector is flat and stable. Make sure that the strips are floating unobstructed and are not wrapped around the collector. Finally check that the station marker, the foam float at the end of the line attached to the collector shaft, is easily visible in order to allow for easy location of the collector at a later date.

Key Points:

1. Epiphyte collector array should be deployed in water approximately 1 meter deep at mid-tidal stage.

2. It is important if at all possible to collect corresponding water quality data directly at the site during deployment and retrieval. The most important measurements are water clarity using either a secchi disk or a Li-Cor® quantum photo sensor, water temperature and salinity. If at all possible it is recommended that a water sample be collected for measurement of dissolved nutrient concentrations, chlorophyll-*a*, total suspended solids (TSS) and total volatile solids (TVS).

5. Sampling the Epiphyte Collector Arrays: Field Collection Procedures

Equipment Needed

Data Sheet or Waterproof Notepad
Pencil
Cooler
Ice Packs or crushed ice
Sharpie Marker –medium
Labeled Sterile Plastic Centrifuge Tubes 50ml
Needlenose Pliers
Scissors
Waders/Wet Suit*
Shallow draft boat*
Long Handled Boat Pole w/Hook*

Field Collection Protocols

On each sampling date it is recommended that at least one strip is collected for each analysis of epiphyte dry mass and epiphyte chlorophyll-*a*. Replicate strips (3 of each) are valuable if time and funds are available. Ahead of time label all 50ml centrifuge tubes with station location codes or names (such as BP03), the collection date (MM-DD-YY), and desired analyses (ETVS or ECHLA). These can be purchased from Fisher or VWR.

At the epiphyte station location, take a visual assessment and record the environmental conditions at the site (include site name, date, weather conditions, water surface conditions, air temperature, etc.). Depending on site accessibility the *equipment necessary for sampling will vary.

Before retrieving the epiphyte strips it is important to collect the water quality data before the water or sediment has been disturbed. If you are wading to the station, make sure to move slowing and sample for water clarity and the other parameters in the up-current direction. If sampling from a boat make sure to minimize and disturbance from the prop and wait a few minutes until the water has cleared up.

When sampling the epiphyte strips it is vitally important that the epiphyte strips are not scraped or damaged before they are cut and stored in the centrifuge tubes. In general, the material clinging to the strips will hold on tightly when moved around in the water or air, but can easily be scraped off. If the section of the strip that is being collected is scraped in any way or looks like it may have been scraped it should be discarded.

If possible while the strips and collector are still in the water, gently remove the Mylar® strips from the array and sample. If it is not

possible to keep the collector in the water and sample it because you are on a boat, use a long handled boat pole to hook the large foam float at the end of the line attached to the collector shaft. Gently pull the collector out of the water and grab hold of all the strips by the small foam floats to ensure none of them get scrapped, smudged or damaged during this process. Secure the collector on the boat. Gently remove a Mylar® strip from the array. Detach and sample one strip at a time. Each time choose the best strip to sample by first looking at all the strips and selecting the one that has the least amount of scratches or rub marks. ***Only handle the strips from the sides (like you would hold a negative or slide) or the top or bottom to avoid putting your fingers on the strip epiphyte material to be sampled.*** Cut and remove the middle 1/3 marked section with scissors. Cut this sample section in half and place it in a 50ml plastic labeled centrifuge tube for analysis of total dry mass/inorganic mass. In addition, if epiphyte chlorophyll-*a* analyses are to be performed, cut the middle (1/3 marked section) section into 4 small strips. Take care ***not to put your fingers inside the containers or lids during this process***. Place all centrifuge tube samples in a cooler with ice packs or ice ***immediately*** to keep them dark and cool during transportation to your laboratory freezer. Freeze sample immediately upon arrival at your laboratory until shipping to NASL or laboratory of choice.

If you are going to deploy the epiphyte collector again, take off all old strips and follow the **Deployment Protocols** in the previous section 4 of this manual. Do not reuse old strips!

6. Processing Organic/Inorganic Epiphyte Material: Laboratory Procedures

Equipment Needed

2 Stainless Steel Forceps
Graduated Beakers 1000mL (depends on the number of samples to process)
Carboy w/spigot Filled w/DI H_2O
Gonzo Plexi-glass/Wood Scraping Unit with Hole to fit Graduated Cylinders 500ml
Water Bottle– filled with DI H_2O
2 Small Plastic Rulers (tapped on one end)
White Label Tape
Sharpie Marker – fine/medium
Kimwipes
Paper Towels
Magnetic Stir Plates & Bars (depends on the number of samples to process)
Glass Pipete 2ml & Pipet Filler

Notes

Both chlorophyll-*a* (ECHLA) and total dry mass/inorganic dry mass (ETVS) samples are placed in individually labeled 50ml plastic centrifuge tubes during retrieval. The samples are then frozen until processing. At this point, ECHLA samples are ready to be processed at NASL or a laboratory of choice (refer to **8. Delivery of Field Collection Samples to NASL** or **Shipping Procedures**; page A-13). The Mylar® strip sections collected for total dry mass/inorganic mass analysis (ETVS) are first processed via the scraping protocols described below and then analyses are performed by NASL or laboratory of choice (refer to **8. Delivery of Field Collection Samples to NASL** or **Shipping Procedures;** page A-13).

Scraping Protocols

Select the plastic centrifuge tube ETVS samples for processing. Start defrosting the samples by taking them out of the freezer and placing each one in a 1000 ml graduated beaker. Using the tape and marker, label each beaker with the sample date and station. This is a very important step, since in the Boynton laboratory we normally do not start scraping ETVS until later in the field season, and there can be several dates when samples were collected at the same station.

Take the first sample to be scrapped and place the graduated beaker in the Plexi-glass/Wood Scraping Unit. The beaker should fit snuggly in the Plexi-glass/Wood Scraping Unit base hole (see picture above). Take the centrifuge tube containing the sample and fill it with deionized water. Empty the contents onto the Plexi-glass/Wood Scraping Unit. If sample strip pieces do not slide out with the water, use forceps to gently remove them from the centrifuge tube. Scrap all material off the strip pieces using a small blue plastic ruler. Make sure you only scrap with the end of the ruler that is not taped to keep your hands from contaminating the sample. Rinse the centrifuge tube with deionized water until all the material has been removed from the centrifuge tube. Rinse the Plexi-glass area of the Scraping Unit with deionized water until all the material has been collected in the attached 1000 ml graduated beaker. Scrapped material and rinse water are then diluted to a fixed volume (200-400 ml) in the labeled graduated beaker. Write the fixed volume amount on the tape label with the sharpie marker.

The solution is mixed as thoroughly as possible on a magnetic stir plate until homogenized. A small aliquot (10-50 ml) is then extracted with a glass pipette and filtered through two 47 mm filter pads. ETVS samples are filtered in the same way as TVS samples (refer to **7. Filtration of Epiphyte Total Volatile Solids (ETVS) Samples [**page A-11] for detailed **Filtering TVS Protocols**). Make sure all information is written on the data sheets corresponding to the original collection dates. Once filtered, the pads are frozen and will remain in the freezer until delivered to NASL or a laboratory of choice (refer to **8. Delivering Field Collection Samples to NASL** or **Shipping Procedures;** page A-13). This process is repeated for each plastic centrifuge tube ETVS sample taken out of the freezer.

7. Filtration of Epiphyte Total Volatile Solids (ETVS) Samples: Laboratory Procedures

Equipment Needed

TVS Filter Pads, Whatman GF/F Circles, 47mm, Cat. No. 1825 047, prenumbered, combusted, weighed, and supplied by NASL (Cheryl Clark).
Filter Holder Funnels 250-300mL & clamps for nonmagnetic funnels
Filtration Unit: Gonzo 4 Place PVC Vacuum Manifold or 2 Place Glass Flask Assembly
Vacuum Pump
2 Stainless Steel Forceps
Graduated Cylinder 25 ml
Graduated Cylinder 50 ml
Glass Pipete 25mL & Pipet Filler
Water Bottle– filled with DI H_2O
Pre-labeled Foil Packet, ETVS (white label)
Kimwipes
Sample Baggie--labeled/dated (see sample)
Paper Towels
Sharpie Marker – fine/medium

Filtering Protocols

General Filtering Notes:

1) Do **not** allow the vacuum pump pressure to exceed 7-10 psi.
2) Make sure all information (volume amounts and pad numbers) is written on the data sheets corresponding to the original collection dates.
3) Use forceps only. Do **not** contaminate the filter pads or the inside of the foil packets by touching them with your fingers.
4) Be very gentle with the filter pads to avoid tearing or ripping. If a filter pad is torn, include all pieces in the foil packet.
5) Normally two filter pads are filtered for TVS to minimize human error.

EpiphyteTotal Volatile Solids (ETVS):

Prepare two white labels for each ETVS/TVS samples to be filtered (see example to right). Make sure you use a laser printer when creating these labels to ensure the ink does not run.

BP03 *(station name)* **10/1/02 (***collection date)*

ETVS Pad#_____ Vol._____

Normally two filter pads are filtered for each TVS sample. It is important to filter the same volume through each pad to minimize possible errors. Since each pre-numbered, combusted, weighed filter pad is placed in an individually labeled foil packet, it is not crucial to filter the same volume through each pad. Center a pre-numbered, combusted, weighed 47mm GFF filter pad on the filter holder (frit) ***number side down*** if a number is visible. Secure the filtration funnel/cup to the frit. After sample rinsing the appropriate glass pipette or cylinder, filter a

known volume of water through the filtration unit until significant coloration develops on the filter (start with 10 to 50ml depending on sample). Clogging the filter pad is not recommended or necessary. ***Rinse the top portion (the funnel or cup) of the filter unit twice with deionized water after the initial volume has filtered through the pad.*** This rinses out salt and the remaining water sample.

Using 2 pairs of forceps and without touching the material on filter, fold the filter in half with the filtered material on the inside of the fold. Remove the folded pad from the filtration unit with forceps and place inside a pre-labeled aluminum foil packet (see example to left). Do not touch the filter pad or the inside of the foil pouch with your fingers. Sometimes the folded filter pad will pop open as you are attempting to place it in the foil packet. If this occurs, use forceps to hold the folded filter pad and then fold the aluminum packet closed. Make sure that only the outside of the folded pad (area ***without*** filtered material directly on it or visible) is touching the foil. If you have not already done so, fold down both sides of the aluminum packet closed. Record the filter pad number and total amount filtered on each foil packet and on the corresponding data sheet.

Label a zip lock freezer bag using a black sharpie marker. The label should include the type of analysis to be performed (*e.g.* TVS) and the laboratory name. Place the foil packets in the labeled freezer baggie and freeze as soon as possible. ***Once frozen, foil packets should NOT be allowed to thaw and refreeze.*** Frozen foil packets will remain in the freezer until delivered to NASL or a laboratory of choice (refer to **8. Delivery of Field Collection Samples to NASL** or **Shipping Procedures;** page A-13).

8. Delivery of Field Collection Samples to Nutrient Analytical Services Laboratory (NASL)

Protocols for Delivery of Samples to NASL

Boynton Laboratory Procedures: Once a week all samples in the laboratory freezer should be sent to NASL for analysis. Sort all samples by analysis type (ECHLA or ETVS/TVS). Label a zip lock freezer bag using a black sharpie marker. The label should include the grant name, grant number, type of analysis desired, the Boynton laboratory name, and the number of samples in the bag (see example to left). All of these samples are counted individually.

Boynton	***30***
Blossom Pt.	
25467	***TVS***

Take your labeled zip lock bags upstairs to NASL's main freezer. The main freezer has a log sheet attached to the door (see sample log below).

Date Received	Organization Agency	Number	NH4	NO2	NO2+3	PO4	Silicate	TDN TDP	DOC	PC PN	PP	TSS	TVS
10/5/02 30770	Boynton DNR								30			*ECHLA* 15	
mailto:wilson@cbl.umces.edu													

All samples must be accounted for on this log sheet before being deposited in the appropriate NASL freezers. Chlorophyll-*a* samples must be placed in Nancy Kaumeyer's freezer (note: never place samples in the door of Nancy's freezer, as all finished work is placed there). All other samples can be placed in the main NASL freezer wherever there is space. A staff member of NASL can help make room if no space is available. After NASL finishes their analyses, data will be made available via the p-drive and the manila file folder labeled **BOYNTON** in the small NASL office next to the stairs.

For a complete description of the analytical methodologies performed by NASL at UMCES CBL, refer to D'Elia *et al.* (1977) NASL Standard Operating Procedures updated May 1997.

Shipping Procedures: After completing a three week epiphyte collection series, UPS or FedEx (over night) a cooler filled with -40C ice packs or dry ice and labeled sample centrifuge tubes. Please include a copy of the data sheet and any notes. It is recommended that the package be sent over night to NASL on either Monday or Tuesday.

For a complete description of the analytical methodologies performed by NASL at UMCES CBL, refer to D'Elia *et al.* (1977) NASL Standard Operating Procedures updated 5/1997.

Laboratory of Choice: If using another laboratory for final analysis, contact them for a description of their protocols for delivery of field collection samples, shipping procedures, and analytical methodologies.

Literature Cited

D'Elia, C.F., E.E. Connor, N.L. Kaumeyer, C.W. Keefe, K. V. Wood and C.F. Zimmerman. 1997. Nutrient Analytical Services Laboratory Standard Operating Procedures. Technical Report Series No. 158-97. Chesapeake Biological Laboratory (CBL), Box 38, Solomons, MD 20688-0038.

Appendix B:

A Cautionary Tale of SAV Restoration:
Eelgrass in the Patuxent Estuary

R.M. Stankelis, W.R. Boynton, J.M. Frank, and others

A CAUTIONARY TALE OF SAV RESTORATION:

Eelgrass in the Patuxent Estuary

(A summary of a presentation made to the SAV Workgroup February 2003)

Robert Stankelis, Walter Boynton, Jerry Frank, and others

Abstract

The failure of eelgrass (*Z. marina*) test-plots (1998-2002) to survive at the mouth of the Patuxent River has shown that careful site selection does not always guarantee restoration success. Water quality conditions at this transplant site have been consistently better than the mesohaline habitat requirements established for SAV in Chesapeake Bay. From 1997 to 2002, growing season median values for light attenuation coefficients have been well below established habitat requirements indicating light availability through the water column should be adequate for SAV survival. Growing season median values for secondary water quality parameters (DIN, DIP, TSS and Chl*a*) have also been below habitat limits. However, field measurements of epiphtye light attenuation at this location indicate high epiphytic fouling rates measured from May through September may significantly reduce available light to the leaf surface thus contributing to SAV transplant failure. Mesocosm studies have shown that even under moderate nutrient concentrations, variation in the magnitude of nutrient transport past leaf surfaces strongly affects epiphyte accumulation rates. Although SAV has historically been found at this location, the current hydrodynamic and nutrient regime of this now barren sand-flat likely produces higher nutrient transport rates (to relatively isolated SAV transplants) compared to earlier conditions when water velocities were reduced because of dense SAV communities. As a consequence, measures of nutrient transport may be just as important for predicting epiphyte fouling rates as nutrient concentrations.

Acknowledgements

Maryland Department of Natural Resources for funding support. We also thank many tireless colleagues involved with the field collection and processing of data related to the epiphyte assessment study. Finally we thank the CBL Nutrient Analytical Services Laboratory for all their assistance and guidance in processing samples.

1. Introduction

Careful site selection for SAV restoration typically includes assessment of numerous criteria prior to committing to any large-scale restoration activity. However, even sites that appear to comply with established criteria may still be poor choices for SAV restoration due to the strength of auxillary or secondary factors that have a strong influence at those particular locations. Based upon the high failure rate of many SAV restoration projects, it appears that an assessment of the strength of secondary effects may be an important consideration. The results of eelgrass transplant experiments at the mouth of the Patuxent Estuary (DNR station SV09) provide an example where long-term survival of transplants has remained elusive due to high rates of epiphyte fouling that were not predicted from current models[1]. We further suggest that additional parameters be included in the site selection process to better predict where high epiphyte fouling rates may occur.

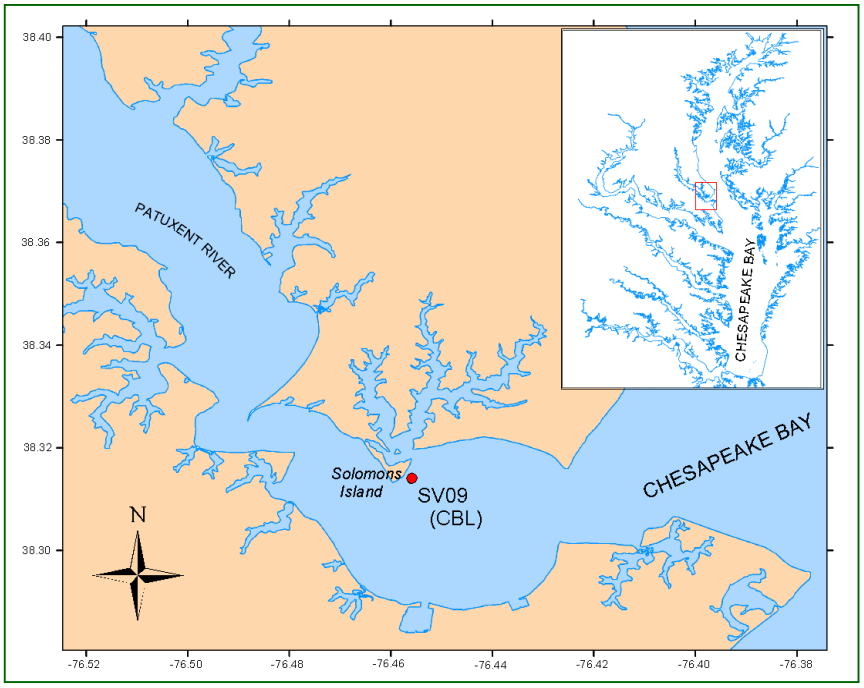
Proper site selection is critical to success of any restoration project.

"Selecting an appropriate planting site is perhaps the single most important step in the process." Fonseca et al. 1998.

Typical habitat criteria to be evaluated

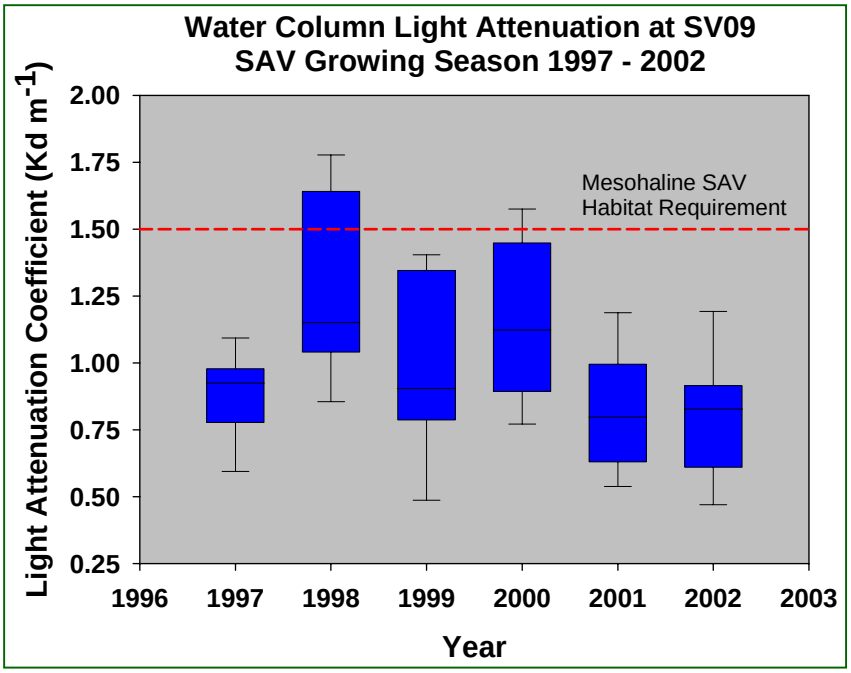
- Adequate water quality and light conditions
- Historical presence of SAV
- Acceptable sediment characteristics
- Absence of extreme bioturbation or grazing

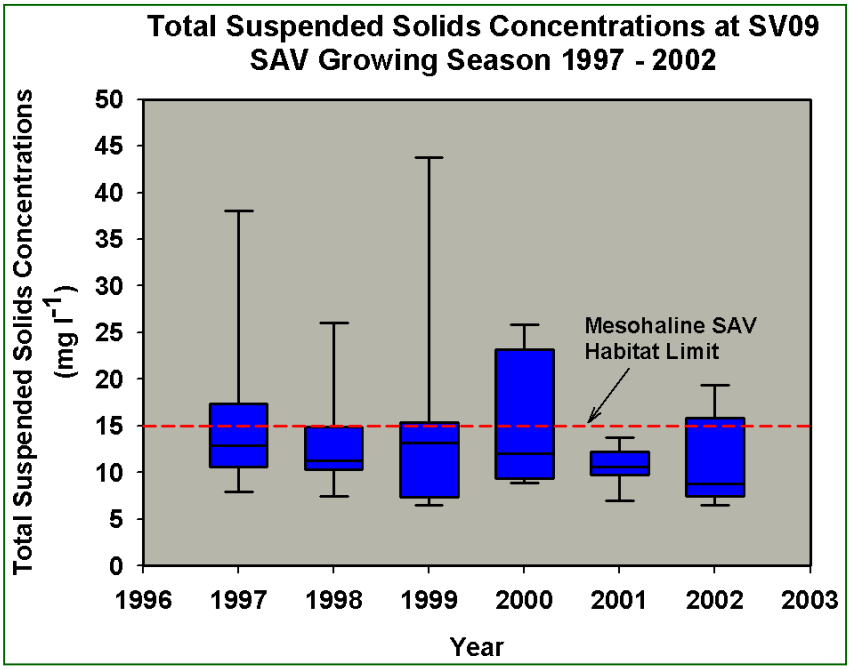
Location of our study site SV09



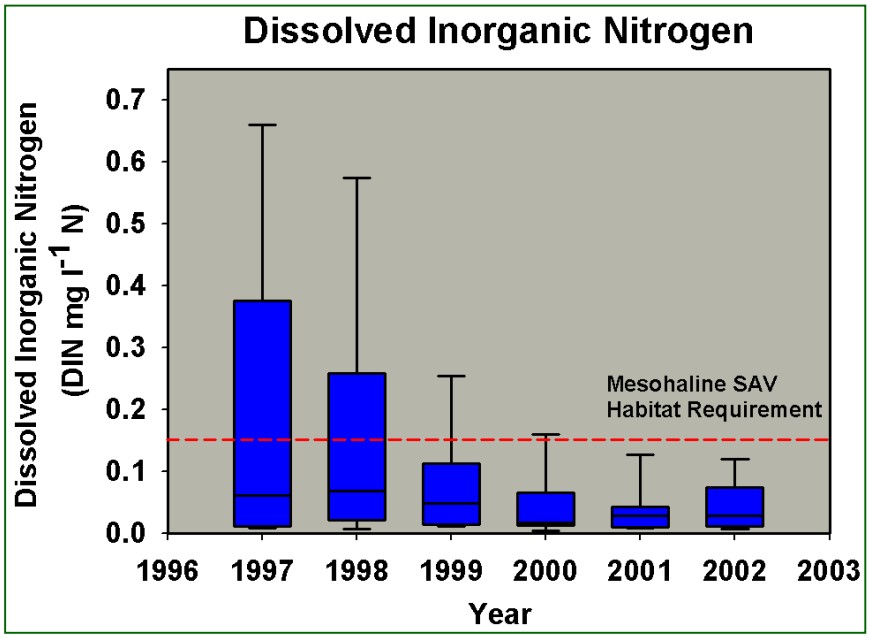
2. Water Quality

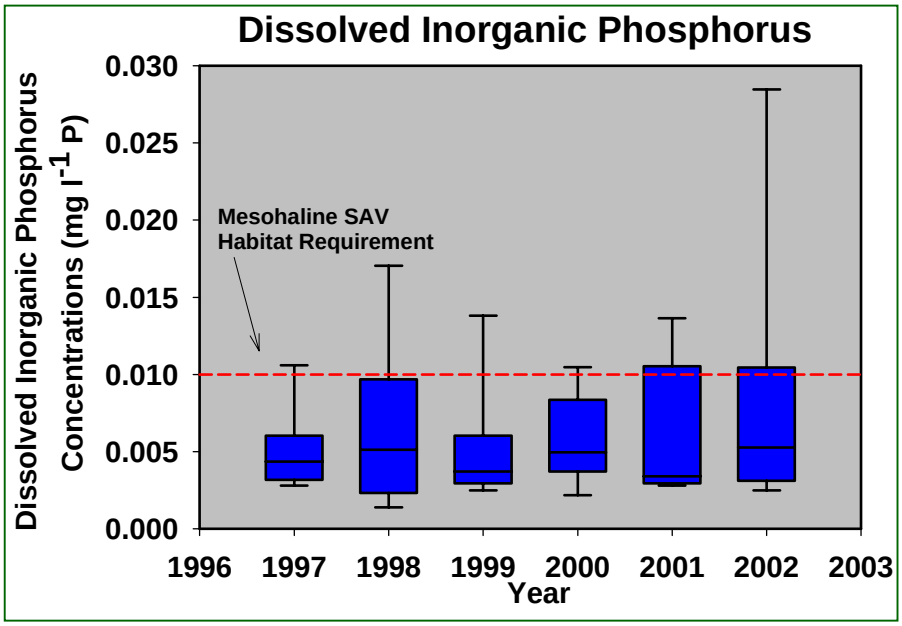
Data show that both water clarity (Kd) and total suspended solids are below established habitat limits set by the USEPA for the mesohaline region of Chesapeake Bay.





Dissolved nutrient concentrations appear to be within mesohaline habitat limits established by the USEPA.



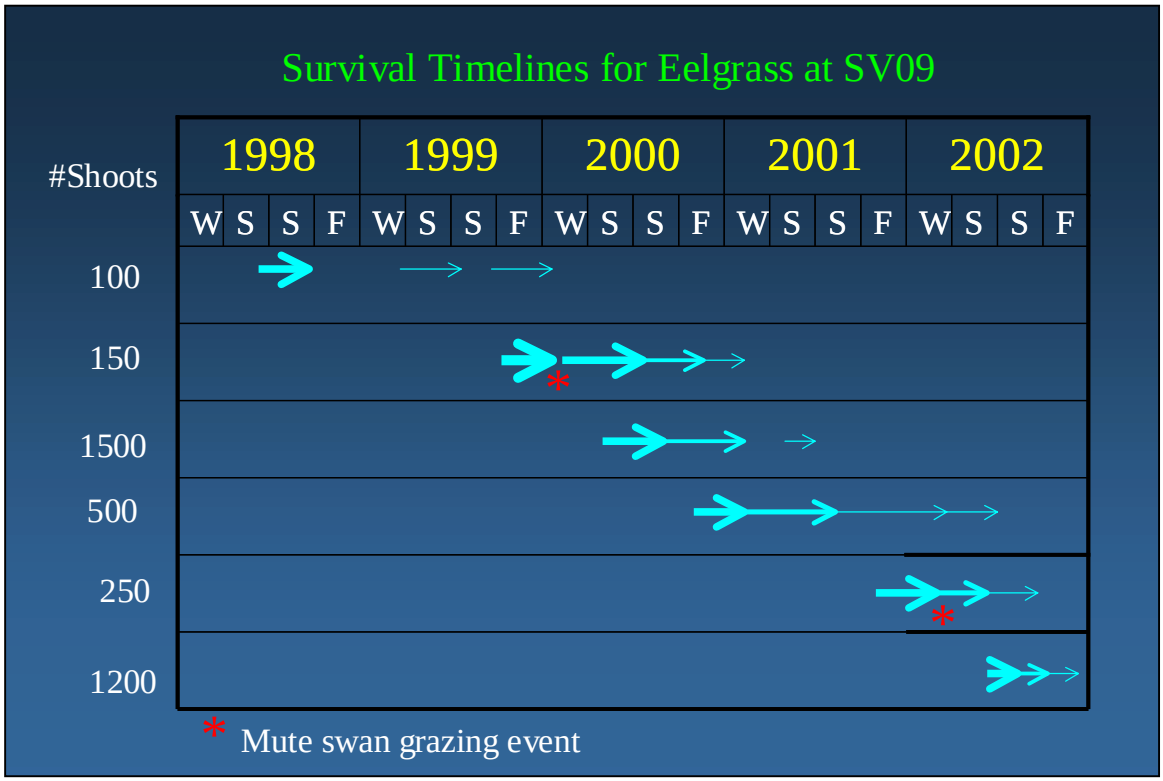


3. Historical SAV Presence

While SAV was abundant at Solomon's Island in 1938 (top photo), it was also present until the early 1970's. Today, the area is a barren sand flat with no natural recruitment of eelgrass (bottom photo).

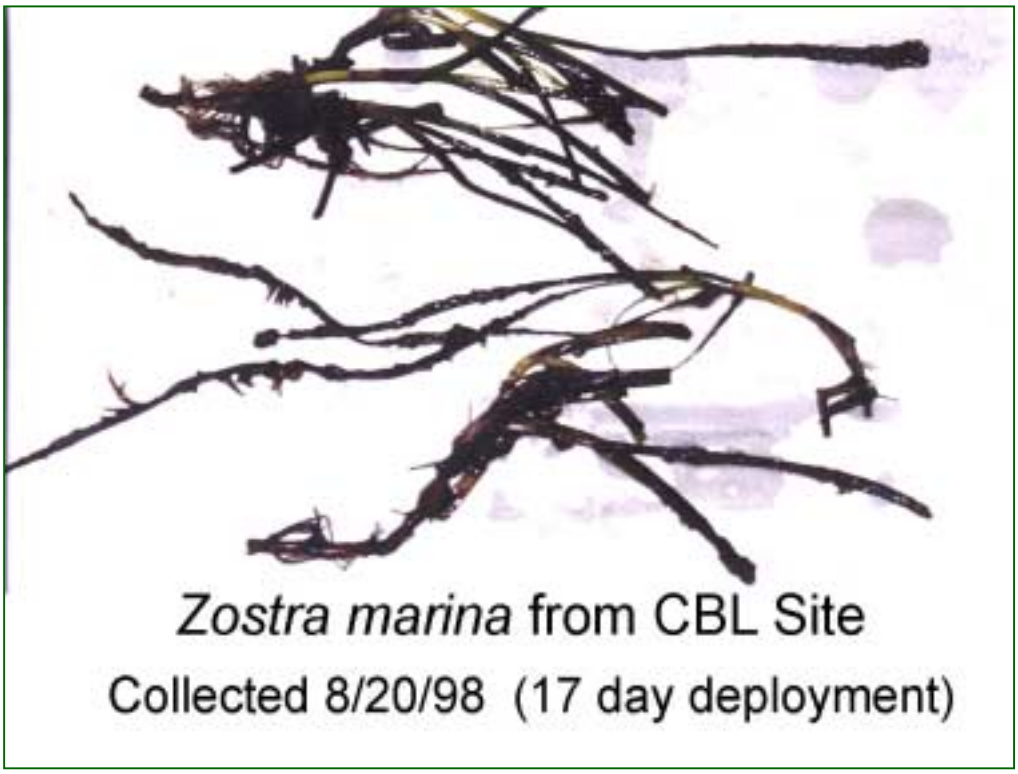
4. Eelgrass Transplant Survival

Despite apparently adequate water quality and sediment conditions, eelgrass test plots have not shown any significant long-term survival. While some transplants did have greater than 80% survival after 6 months, and some plants survived for more than 1 year, the use of short-term assessments to gauge transplant success would be misleading.



Line breaks signify lack of above ground biomass observed.
Line thickness roughly represents percent survival

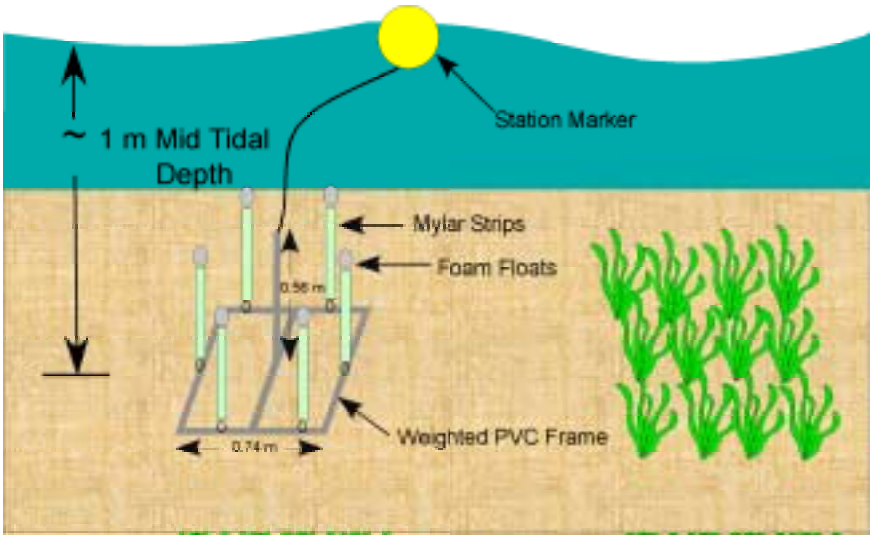
Why have the eelgrass transplants not survived?
Extreme epiphyte fouling?

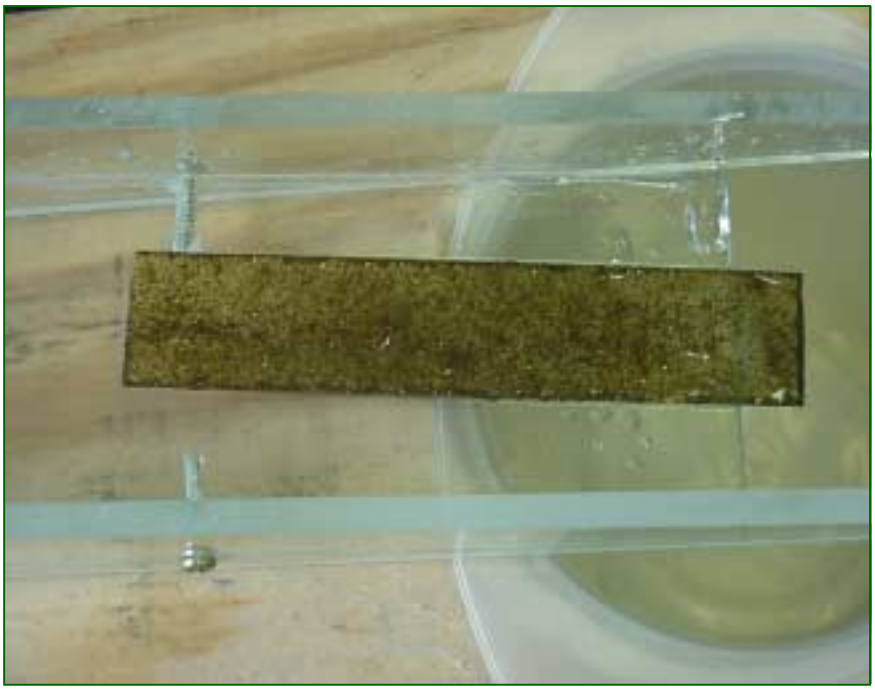


5. Assessment of Epiphyte Fouling

In order to easily and accurately measure epiphyte accumulate rates and associated light attenuation, we deployed thin strips of Mylar® plastic for periods of 6-8 days. In previous studies, no significant difference in fouling rate was found between Mylar strips and live SAV for short-term exposures. An example of a fouled strip after a week of exposure is shown below.

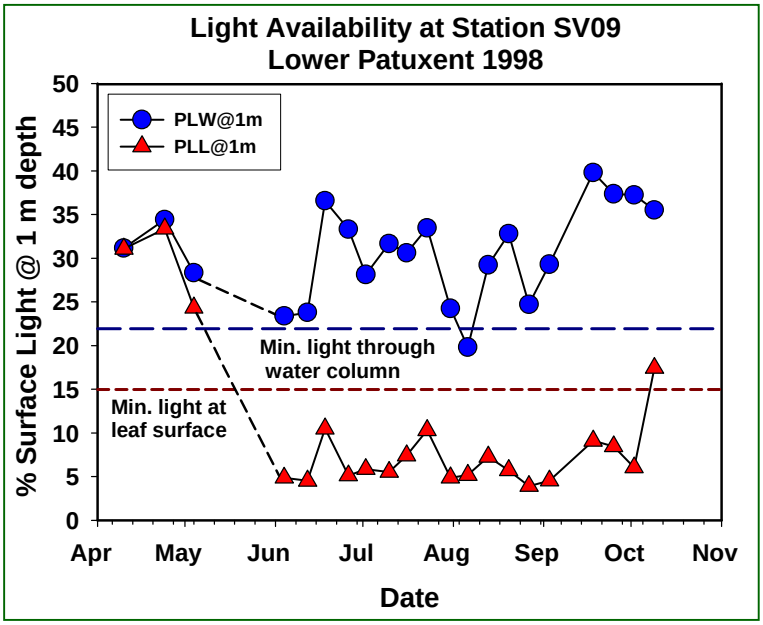
Diagram of Epiphyte Collector Array

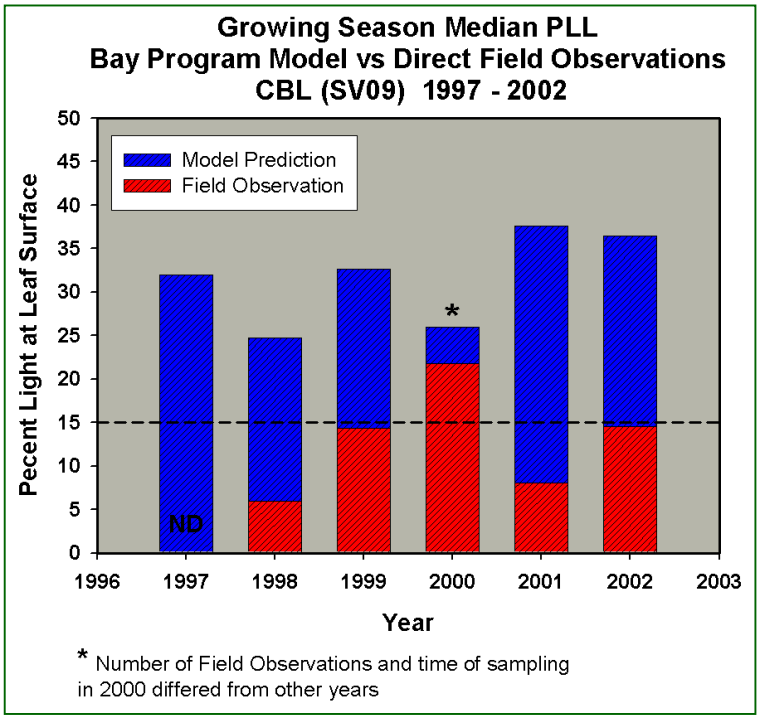




Results of Epiphyte Fouling Measurements:

During 1998, light attenuated by epiphytes reduced the percent of surface light available to the leaf surface (PLL) far below what was available at that depth (PLW) for most of the SAV growing season as well as below levels considered necessary for SAV survival (Batuik *et al*., 2000). A comparison between observed values using Mylar strips to the best available model predictions (Batuik *et al.*, 2000) show that model predictions suggest adequate light availability, while actual measurements show much lower light availability at the leaf surface.





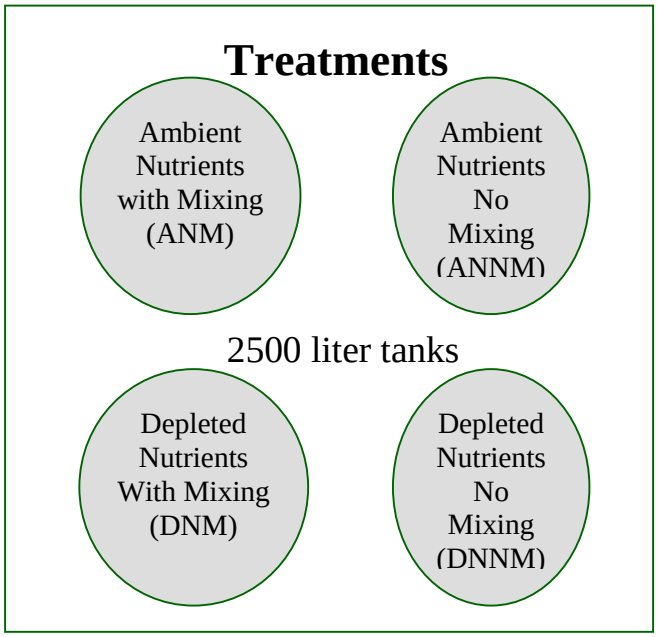
Why are epiphyte fouling rates so high at station SV09?

Hypothesis: Given adequate light, and moderate nutrient concentrations (below Chesapeake Bay SAV habitat limits), nutrient delivery to epiphytes will be diffusion limited and therefore influenced by water transport past the epiphyte surface.

Test of the Hypothesis:
A mesocosm experiment was conducted to measure the effects of changes in water flow rate and nutrient concentration on epiphyte accumulation rates.

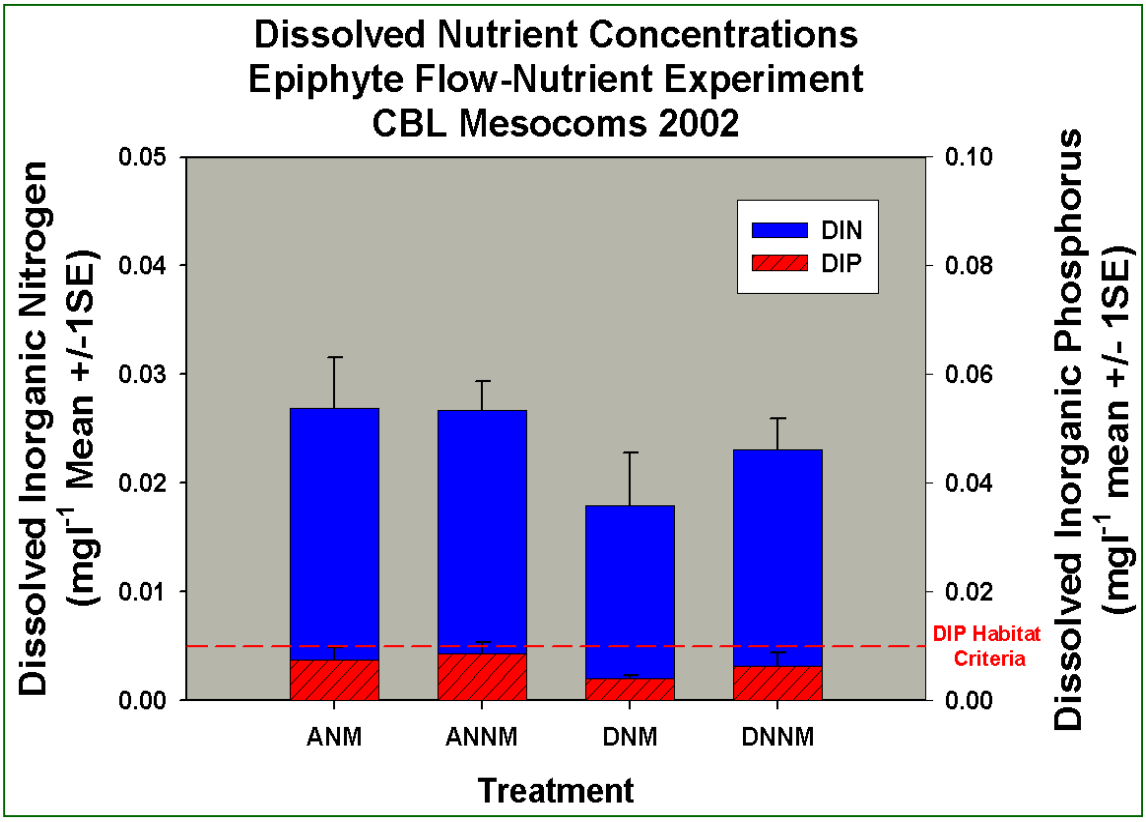
Mesocosm Flow/Nutrient Epiphyte Experiment
(Experiment Summary)

- 4 treatments (shown right) haphazardly assigned block location for each of 4, 7-day runs.
- Changes in flow created by submersible pumps set for 2hrs on/2hrs off.
- Depleted nutrients supplied from holding tank with algal draw-down of nutrient concentrations. Ambient tanks exchanged 50% daily with fresh bay water.
- Results assessed by epiphyte biomass accumulation on Mylar strips after 1 week.



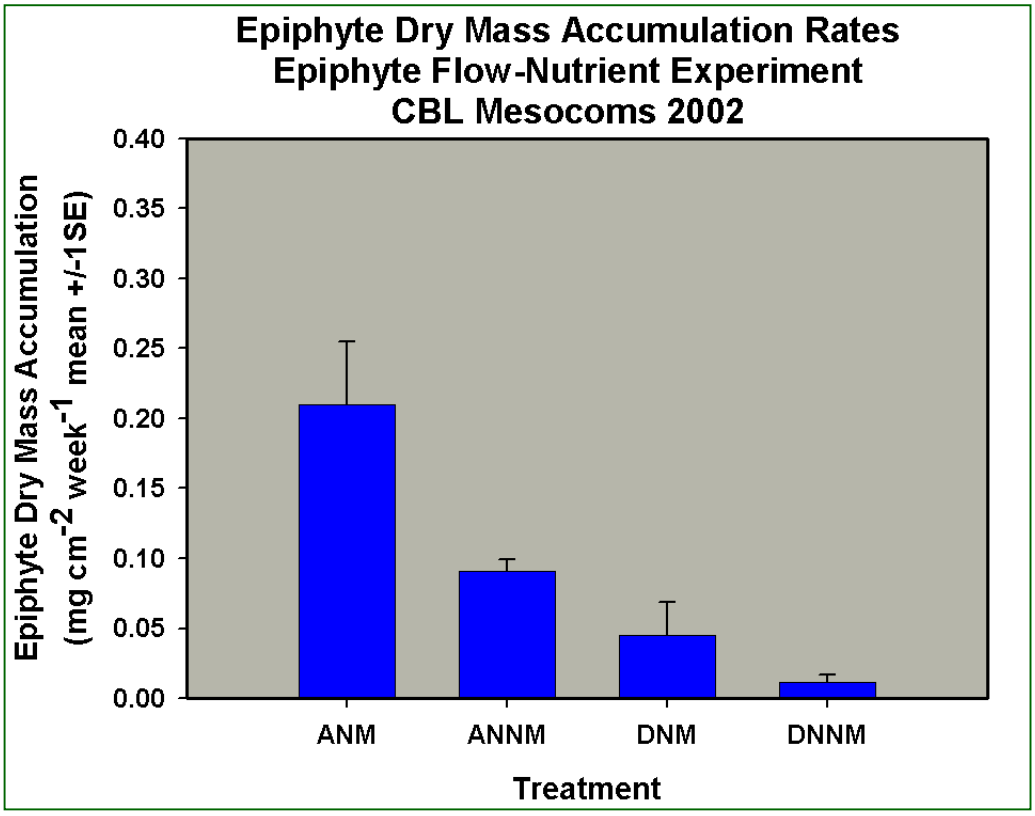
6. Results:

- Differences in dissolved nutrient concentrations among tanks were subtle, but followed an expected pattern.
- Concentrations in treatment DNM were the lowest due to draw-down effects within the tank.
- Concentrations in DNNM were next highest due to restricted uptake. Concentrations in treatments ANM, ANNM similar and the highest measured due to daily additions of fresh bay water.
- All concentrations were below maximum habitat criteria.



Results Continued:

- Epiphyte accumulation rates were sensitive to both flow and nutrient concentration, despite subtle differences in nutrient concentration among treatments.



7. Conclusions:

- Careful site selection must include transplant test-plots with a minimum of a yearly follow-up evaluation to provide the best information prior to large-scale restoration.
- Field observations of epiphyte fouling rates at station SV09 differed significantly from model output and are likely a significant contributor to transplant failure at this location.
- Given adequate light and temperature, epiphyte accumulation rates are sensitive to nutrient transport rates (flow) as well as nutrient concentration.
- Current Chesapeake Bay Program model estimates for light availability to SAV (PLL) may be improved with the inclusion of a site specific flow-rate calibration factor.

References Cited:

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.

Fonseca, M.S., W.J. Kenworthy and G.W. Thayer. 1998. Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters. NOAA's Coastal Ocean Program, Decision Analysis Series No. 12. U.S. Dept. of Commerce. NOAA Coastal Ocean Office.