Synthesis of data from the National Estuarine Research Reserve System-Wide Monitoring Program for the Mid-Atlantic Region

A Final Report Submitted to

The NOAA/UNH Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET)

Submitted by

Dr. Mark J. Brush
Dr. Kenneth A. Moore
Ms. Elizabeth D. Condon
Virginia Institute of Marine Science
College of William and Mary
PO Box 1346, Gloucester Point, VA 23062

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CICEET

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1. Expanded Executive Summary and Key Findings

The purpose of this project was to conduct a new synthesis of National Estuarine Research Reserve (NERR) System-Wide Monitoring Program (SWMP) data for sites within the Mid-Atlantic bioregion. The goal of the synthesis was to distill the large, 22-site, 11-year database with 15-minute resolution into useful information for scientists and managers about structure and function in shallow marine ecosystems typical of the NERR reserves. Our primary objectives were to (1) develop a methodology for aggregating the 15-minute water quality and monthly nutrient data at longer time scales suitable for comparisons among sites and reserves, (2) classify sites across the bioregion into objective groupings and analyze for regional trends, (3) characterize sites within reserves according to the particular gradient within each system (e.g. estuarine salinity or nutrient load gradients), (4) compute total system metabolism from water quality and meteorological data specifically incorporating the effects of variable wind speed; and (5) quantify the response of these shallow water systems to interannual variability in freshwater flows.

Key Findings

- Temporal data reduction into bulk seasonal averages was a reliable method for conducting broad-scale, system-level analyses across the bioregion and within reserves.

- Seasonal averages were generally insensitive to missing data and directly proportional to seasonal medians.

- Across the entire region, sites consistently grouped into three major categories characteristic of traditional estuarine salinity gradients: (1) low salinity, low turbidity, (2) intermediate salinity, high turbidity, and (3) high salinity, low turbidity.

- Three Mid-Atlantic reserves (Jacques Cousteau, Delaware, and Virginia) encompass entire or some fraction of these full gradients, while two (Hudson and Maryland) contain sites within one ecotype (tidal and non-tidal fresh).

- Seasonal averages of water quality and nutrient/chlorophyll parameters across all sites and three hydrologically different years (2002-04) resulted in predictable trends typical of estuarine ecosystems.

- Additional within-reserve variability could be attributed to localized anthropogenic impacts, surrounding land use, and presence of submerged aquatic vegetation and/or adjacent tidal marshes.

- Sites were generally net heterotrophic across the region with only three sites – two with extensive SAV beds – being net autotrophic.

- Variations within heterotrophic sites could be attributed to the presence of extensive marshes, urban development, and relatively open waters.

- For reserves characterized by typical estuarine salinity gradients, interannual variations in salinity, dissolved oxygen, nutrients, chlorophyll, and metabolism were related to freshwater flow in many cases either monotonically or with optima at intermediate flows.

2. Project Development

a) Abstract

Conservation and restoration of coastal marine ecosystems requires up-to-date syntheses of information relative to the condition of these systems at multiple temporal and spatial scales, as well as inter-comparisons among the various systems in a region. The purpose of this project was to conduct a third synthesis of SWMP data specifically focused on the Mid-Atlantic bioregion (New York through Virginia) to characterize gradients, interrelationships among sites, and controlling factors at the scale of (1) individual reserves and (2) the entire bioregion. Specific objectives included development of a methodology for aggregating the 15-minute water quality and monthly nutrient data at longer time scales suitable for comparisons among sites and reserves, to conduct analyses across the bioregion and within reserves, to update past methods of computing net ecosystem metabolism from SWMP data, and to assess the role of freshwater inputs in controlling interannual variability in water quality.

We reduced the high frequency SWMP water quality and meteorological data and monthly nutrient/chlorophyll data into a series of averages at a variety of temporal scales. Results demonstrated the reliability of temporal data reduction into bulk seasonal averages for the purposes of conducting broad-scale, system-level analyses across the bioregion and within reserves. Seasonal averages were generally insensitive to missing data and directly proportional to seasonal medians. Across the entire region, sites consistently grouped into three major categories: (1) low salinity, low turbidity, (2) intermediate salinity, high turbidity, and (3) high salinity, low turbidity. These sites typify the upstream tidal fresh, freshwater-estuarine transition, and meso- to polyhaline regions of traditional estuarine salinity gradients. Within the Mid-Atlantic, three reserves (Jacques Cousteau, Delaware, and Virginia) encompass entire or some fraction of these full gradients, while two (Hudson and Maryland) contain sites within one ecotype (tidal and non-tidal fresh). Analysis of water quality and nutrient/chlorophyll parameters across these major site groupings produced predictable trends typical of estuarine systems, as did analyses of sites within reserves with full estuarine salinity gradients. Additional variability was readily explained by localized anthropogenic impacts, surrounding land use, and presence of submerged aquatic vegetation (SAV) and/or adjacent tidal marshes. Sites were generally net heterotrophic across the region with only three sites – two with extensive SAV beds – being net autotrophic. Variations within heterotrophic sites were explainable by the presence of extensive marshes, urban development, and relatively open waters. Interannual variations in salinity, dissolved oxygen, nutrients, chlorophyll, and metabolism were related to freshwater flow in many cases either monotonically or with optima at intermediate flows, presumably reflecting a tradeoff between nutrient loading and dilution through flushing.

b) Introduction

Expanding shoreline and watershed development and population growth in the Mid-Atlantic region of the U.S. has led to increased nutrient loading and sedimentation in coastal lagoons, bays and estuaries in this region (Nixon 1995; De Jonge et al. 1995; Boynton et al. 1996), with resultant degradation of water quality and loss of important system resources such as marshes, SAV beds and fisheries (Orth and Moore 1983; Lathrop and Bognar 2001; Kennish et al. 2007). Conservation and restoration of these systems requires up-to-date syntheses of information relative to the condition of these systems at multiple temporal and spatial scales, as well as inter-comparisons among the various systems in the region. These syntheses are needed to not only evaluate the patterns of response to anthropogenic watershed conditions but also seasonal and episodic stresses related to variations in weather conditions and storms.

The System-Wide Monitoring Program (SWMP) of the National Estuarine Research Reserve (NERR) system is an ideal source of high frequency data on a variety of water quality and related parameters (Kennish 2004). The 27 reserves around the U.S. maintain a network of multiparameter YSI datasondes and meteorological stations which collect data in 15 minute intervals; discreet samples for chlorophyll-*a* and nutrient concentrations are collected monthly and occasionally more frequently at the same sites. Previous syntheses of SWMP data covered the periods of 1995-2000 (Wenner et al. 2001; Sanger et al. 2002; nerrs.noaa.gov/monitoring/synthesis.html) and focused on broad scale interrelationships between SWMP monitoring information and NERRs geographic regions. An additional five years of data are now available for analysis as well as data from entirely new stations since the last synthesis.

The purpose of this project was to conduct a third SWMP synthesis focused on interrelationships among the five reserves in the Mid-Atlantic region, which have more similar geographic, oceanographic and climatological conditions than those in other reserves around the country. Linkages to important living resources are also much more similar. For example, in four of the five reserves submerged aquatic vegetation is an important habitat that has demonstrated significant declines in recent decades as watershed and coastal development has increased (Orth and Moore 1983; Kennish et al. 2007). SAV declines are also an import management issue in the Delaware Inland Bays. These declines have occurred as part of system-wide declines in both estuarine and coastal areas, particularly due to reductions in in-water light penetration resulting from excessive algal blooms and suspended sediments (Dennison et al. 1983; Kemp et al. 2004). In addition, invasive SAV species as well as invasive macroalgae have become significant components of shallow water areas in all of these mid-Atlantic systems in recent years. Their relationships to nutrient and light conditions and their resultant effects on important habitat conditions such as dissolved oxygen levels are important issues that need to be investigated.

Storms also play critical roles as important stressors through their direct physical effects, as well as their effects on watershed inputs of sediments and nutrients. The degree and duration of the response of shallow water quality conditions to these events are important management considerations, as they will provide insights into the need and effectiveness of land use and storm water management practices. Finally, the coastal science and management communities need tools to forecast system responses to environmental forcing. While predictable relationships between water quality or ecosystem processes (e.g. primary production) and forcing (e.g. freshwater inputs, nutrient loading) have been found in some shallow systems (e.g. Boynton et al. 1996; Valiela et al. 1997), they remain elusive in many others (e.g. Borum and Sand-Jensen 1996; Nixon et al. 2001). The NERR system now has an 11-year record of water quality data at several sites which can be used to test these relationships across widely varying shallow marine systems.

c) Objectives

This report presents results from a third SWMP synthesis which focused specifically on the reserves of the Mid-Atlantic region, including the following reserves: Hudson River (HUD) in New York, Jacques Cousteau / Mullica River (MUL, recently renamed JAC) in New Jersey, Delaware (DEL), Chesapeake Bay – Maryland (CBM), and Chesapeake Bay – Virginia (CBV) (Fig. 1). The goal of the synthesis was to analyze SWMP water quality, nutrient/chlorophyll, and meteorological data at the scale of (1) individual reserves and (2) the entire bioregion. Specific objectives were to:

- Develop a methodology for aggregating the 15-minute water quality and monthly nutrient data at longer time scales suitable for comparisons among sites and reserves;
- Classify sites across the bioregion into objective groupings and analyze for regional trends;
- Characterize sites within reserves according to the particular gradient within each system (e.g. estuarine salinity or nutrient load gradients);
- Compute total system metabolism from water quality and meteorological data specifically incorporating the effects of variable wind speed; and
- Quantify the response of these shallow water systems to interannual variability in freshwater flows.

d) Methods

<u>*Study Sites*</u>*:* The five reserves of the Mid-Atlantic region (Fig. 1) cover a range of coastal systems from tidal fresh creeks to coastal lagoons and a range of salinities from zero to around 30 PSU, exhibit a range of anthropogenic impact from relatively pristine to highly urbanized, and contain a wide variety of habitats from extensive beds of submerged aquatic vegetation (SAV), adjacent tidal marshes, and bare sediments (Table 1). Each reserve presently maintains four water quality and nutrient/chlorophyll stations and a

single meteorological station as part of the SWMP. This report also includes data from discontinued stations in the Delaware (DELPB) and Maryland (CBMJB, CBMPR) reserves. Appendix A contains Google Earth images of each reserve, Appendix B contains detailed descriptions of each monitoring site, and Appendix C contains land use maps in the watersheds surrounding the SWMP stations.

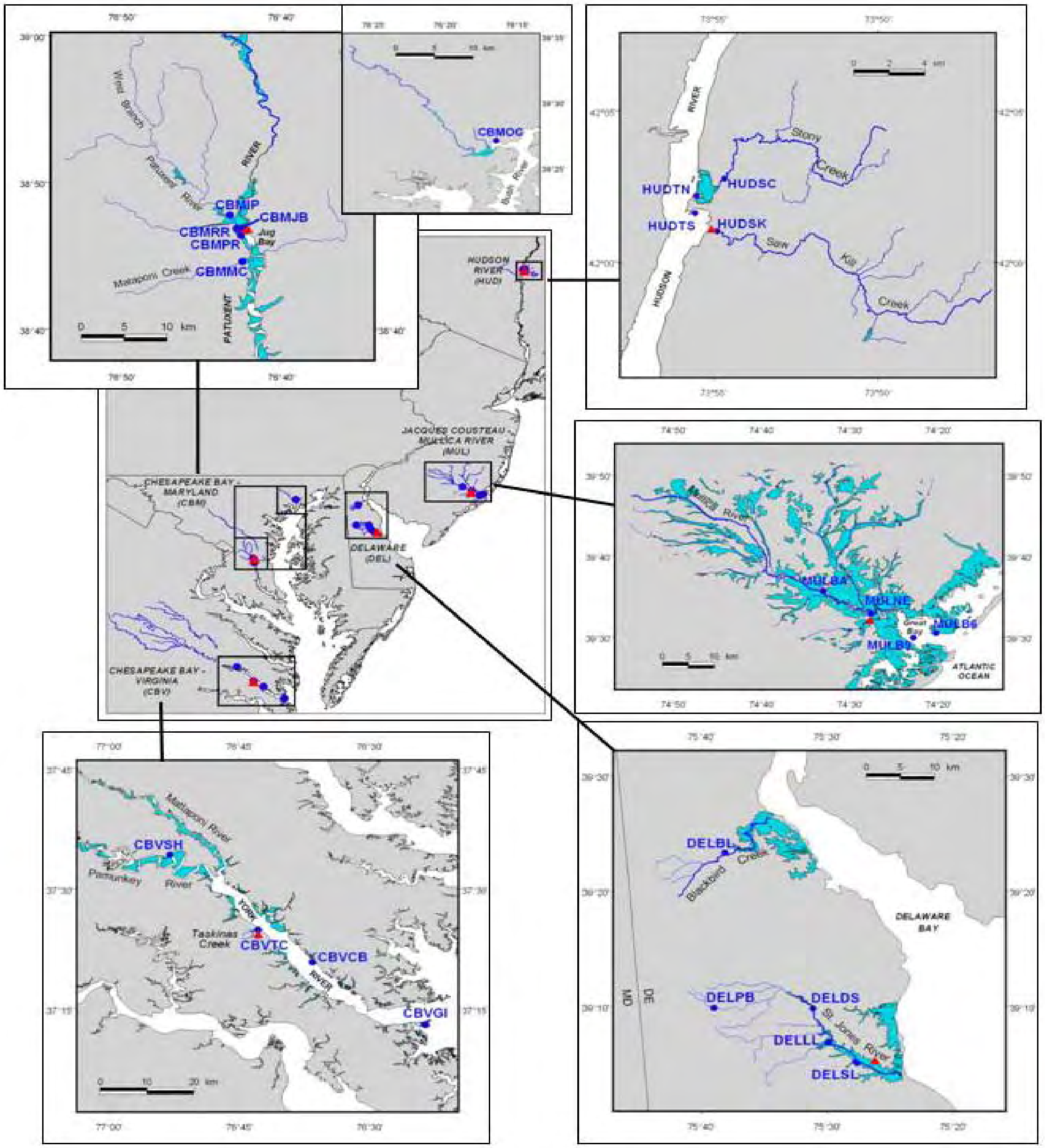

Fig. 1. Mid-Atlantic region National Estuarine Research Reserves. Water quality/nutrient stations are marked by blue circles and textual labels; weather stations are marked by red triangles. Rivers and wetlands (teal polygons) were obtained from the National Hydrography Dataset (USGS) medium resolution coverages. Station prefixes for the Jacques-Cousteau reserve were recently changed from “MUL” to “JAC”.

Stations within the Hudson River reserve are entirely fresh; two are tidal fresh within coves off the main river and characterized by extensive SAV and adjacent marshes, and the other two are in the non-tidal tributary creeks entering these coves. Land use is primarily forested and agricultural. The Maryland reserve is similarly dominated by tidal fresh stations within the Jug Bay component; the only site with measurable salinity is to the north in the Otter Creek component. Many of the sites are also dominated by SAV beds and have extensive adjacent tidal marshes. The Jug Bay watershed is also a mix of forested and agricultural land; the Otter Creek site also includes heavy residential development. The Jug Bay sites are additionally situated along an anthropogenic gradient downstream of a wastewater treatment facility above station CBMIP on the West Branch of the Patuxent River.

Sites at the other three reserves are generally situated along estuarine salinity gradients from either very low salinity (Jacques Cousteau) or tidal fresh (Delaware, Virginia)

Table 1. Mid-Atlantic reserves, sites, and their major characteristics. See Appendices B and C for additional details.

Reserve	SWMP Station	Adjacent Marsh	SAV	Dominant Landuse	Type of System
Hudson River	HUDSC			Forest / Agriculture	Non-tidal Creek
	HUDSK			Forest / Agriculture	Non-tidal Creek
	HUDTN	X	X	River/marsh edge	Intertidal marsh
	HUDTS	X	X	River/marsh edge	Embayment
Jacques Cousteau (Mullica River)	MULBA	X		Forested	Tidal river [a]
	MULNE	X		Forested	Tidal river [a]
	MULB6	X		Open water	Bay
	MULB9	X		Open water	Bay
Delaware	DELBL	X		Forest / Agriculture	Tidal creek [a]
	DELDS			Urban (Dover, DE)	Non-tidal river
	DELLL			Urban / Agriculture	Tidal river [a]
	DELSL	X		Agriculture / Residential	Tidal river [a]
Chesapeake Bay – Maryland [b]	CBMIP		trace	Urban / Forest / Agric.	Tidal river
	CBMJB	X		Forest / Agriculture	Tidal creek
	CBMMC		X	Forest / Agriculture	Tidal creek
	CBMOC	X	X	Urban / Forest / Agric.	Estuarine
	CBMPR	X		Forest / Agriculture	Tidal river
	CBMRR		X	Forest / Agriculture	Tidal river
Chesapeake Bay - Virginia	CBVSH	X		Forest / Agriculture	Tidal river
	CBVTC	X		Forest / Agriculture	Tidal creek [a]
	CBVCB			Forest / Agriculture	Open estuarine
	CBVGI	X	X	Marsh / Open water	Estuary mouth

[a] These tidal creeks/rivers are estuarine at these stations (i.e. a mixture of fresh and salt water).
[b] Within the Jug Bay component of the Maryland reserve, CBMIP is considered impacted as it is 1 km downstream from a wastewater treatment facility. CBMMC is considered as a reference site, with CBMJB, CBMPR, and CBMRR intermediate between these end-members. CBMJB was moved to CBMRR in 2003. CBMPR was discontinued after 2002 and CBMIP and CBMMC were initiated in 2003.

stations to mesohaline (Delaware), polyhaline (Virginia), and almost fully marine (Jacques Cousteau) end-members. Watersheds of the Jacques Cousteau and Virginia reserves are dominated by forested land while land use around the Delaware reserve is more similar to that around the Hudson and Maryland reserves. The Delaware sites along the St. Jones River are also situated along a gradient of anthropogenic impact from the uppermost site at the city of Dover to the downstream site almost at the entrance to Delaware Bay. Several sites within these three reserves are surrounded by extensive tidal marshes, but only CBVGI lies within extensive SAV beds.

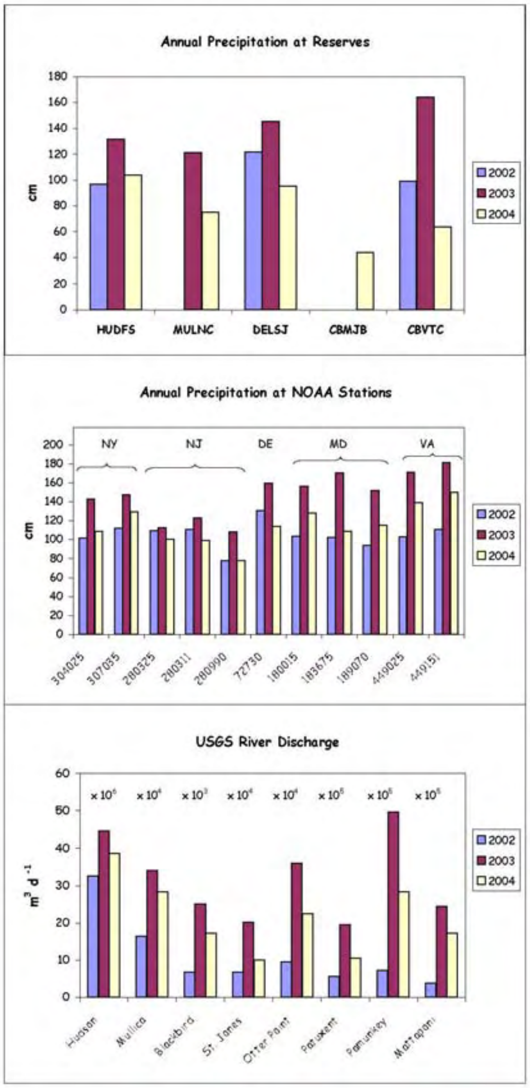

Fig. 2. Annual precipitation at each reserve (top) and annual average river discharge upstream of the SWMP stations (bottom), 2002-04. Due to large SWMP data gaps, rainfall data from auxiliary NOAA stations across the region were also obtained (middle). See Fig. 3 for station locations.

Data Synthesis and Temporal Averaging: Yearly files of water quality, nutrients/chlorophyll, and meteorological data from all sites at each Mid-Atlantic reserve were compiled from the NERRs Centralized Data Management Office (CDMO) website (cdmo.baruch.sc.edu). Historical daily average freshwater volume transports were obtained from the closest upstream USGS gauges (when available) on each river or stream flowing past a SWMP station. Gauges do not exist on Stony Creek and Saw Kill in New York, so Hudson flow had to be used as a proxy for these sites. Similarly, there are no gauges on Mattaponi Creek or the West Branch of the Patuxent River in Maryland, so Patuxent River flow had to be used as a proxy. There is also no gauge on Taskinas Creek in Virginia, so the Mattaponi and Pamunkey Rivers were used as proxies.

We focused on the time period 2002-2004, as these years came after the previous two SWMP syntheses, cover the time period when all current sites at each reserve (except Maryland in 2002) were instrumented with data sondes, and represent widely different hydrologic conditions across the entire mid-Atlantic region (2002 – dry; 2003 – wet; 2004 – average) (Fig. 2). Data from all available years (1995 - 2005) as well as discontinued stations DELPB, CBMJB, and CBMPR were obtained for analyses of the effects of flow on interannual variations in water quality.

Daily, monthly, and annual averages were computed for water temperature, salinity, turbidity, pH, dissolved oxygen (DO) in both mg L^{-1} and percent saturation, depth, wind speed, precipitation, and river flow. Monthly and annual average chlorophyll-*a* and dissolved inorganic nitrogen and phosphorus (DIN, DIP) concentrations were computed from the monthly and semi-monthly grabs (diel data were excluded). DIN was computed by summing the concentrations of NH_4^+ and NO_x^- whenever possible; however in some cases NO_2^- was missing and assumed negligible. We also computed daily minimum DO concentration (mg L^{-1} and % saturation), ratios of chlorophyll-*a*:phaeophytin, DIN:DIP, and NO_x:NH_4, and the daily excursions of temperature, salinity, DO (mg L^{-1} and % saturation), turbidity, and depth as the difference between the maximum and minimum observed values each day.

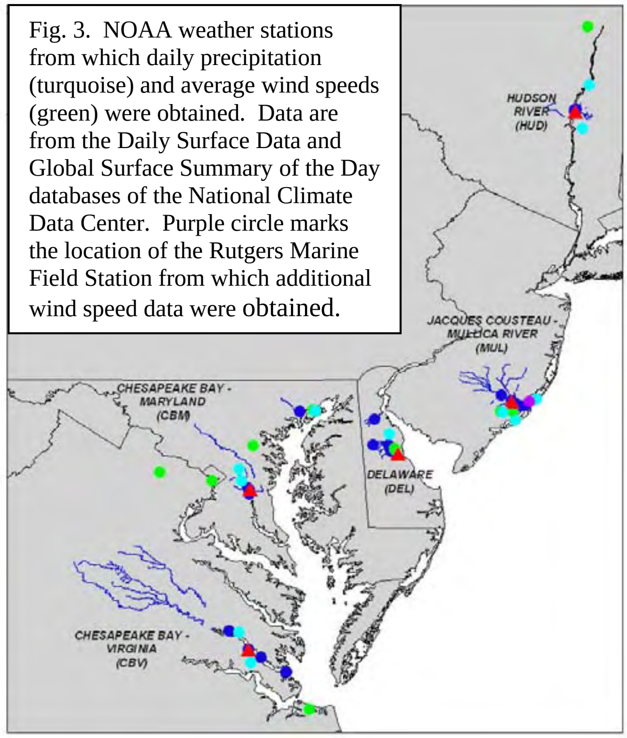

Fig. 3. NOAA weather stations from which daily precipitation (turquoise) and average wind speeds (green) were obtained. Data are from the Daily Surface Data and Global Surface Summary of the Day databases of the National Climate Data Center. Purple circle marks the location of the Rutgers Marine Field Station from which additional wind speed data were obtained.

In order to compare sites within reserves and across the entire region, and to identify physical factors which could help group sites with similar characteristics, we used the daily averages of all measured and derived parameters listed above to compute seasonal averages. The averaging period was determined by examination of available data for each parameter for the entire three-year period. An example is given in Figure 4; the complete set of plots are in Appendix D.

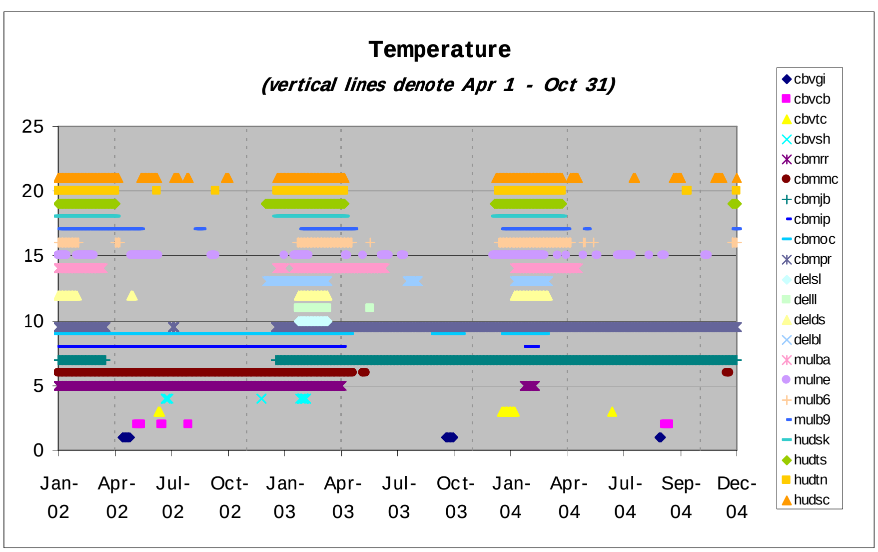

Fig. 4. Sample plot showing dates with missing water temperature data for the period 2002-2004 for all mid-Atlantic sites. Y-axis values are simply site number as ordered in the legend. Plots for additional parameters are in Appendix D.

Since the more northern sites frequently have to remove their sondes during winter, we decided to focus on the period from April through October of each year to avoid most data gaps. Remaining gaps did not appear to be biased to any particular part of the season, so all available April-October data were used to compute the seasonal averages. It could be argued that averages should be taken only for time periods when data were available at all 20 stations. We decided against this on the basis of two issues: (1) there is no reason to assume that particular events in the time series happen at the same time at all sites across the entire region, and (2) such a method would result in the loss of far too much information.

April-October averages were compared to medians to ensure averages were appropriate. In all cases the relationships were linear and tightly constrained, and slopes for all but turbidity were close to unity so we proceeded with averages (Fig. 5). The lower slope for turbidity is the result of frequent spikes in these time series in response to storms or other mixing events.

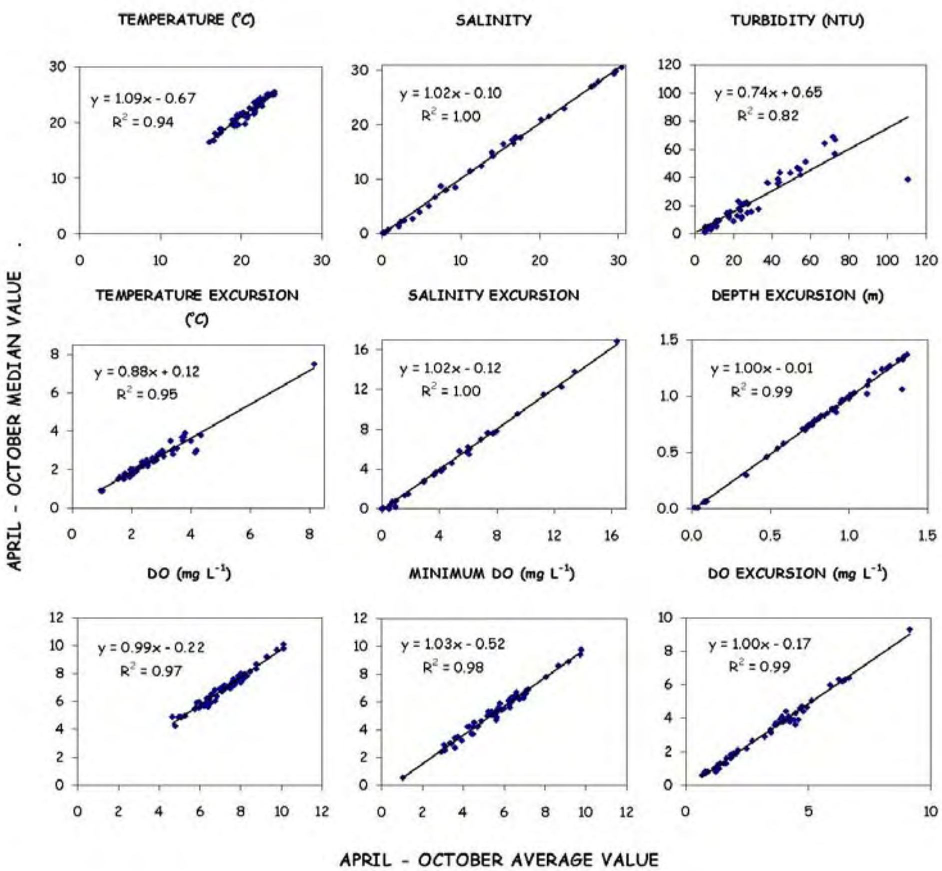

Fig. 5. Relationship between the average and median of all April-October daily values. Each plot contains points for each year (2002-04) at each station.

A final issue with the seasonal averages is the degree to which they may become biased by missing data and require elimination from subsequent analyses. For each combination of year and station, we computed the fraction of available data during the April-October period (number of days with data ÷214) and ranked the results in increasing order (Fig. 6). The x-intercepts on Figure 6 are primarily due to Maryland stations having data in some years but not in others as two sites were moved and new sites added after 2002.

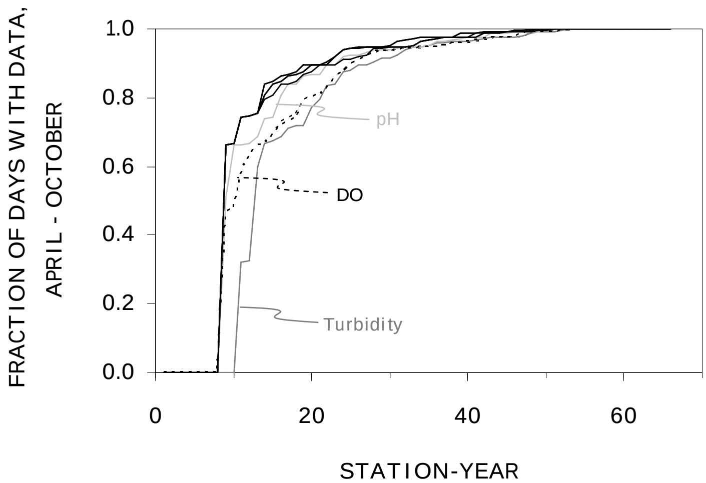

Fig. 6. Cumulative distributions of available data by parameter. DO line includes all expressions (mg L^{-1}, % saturation, minimum, and excursion). Solid black lines include temperature, salinity, and the excursions of temperature, salinity, and depth.

Taking this into account, there were very few instances when stations had data fewer than 60% of the days between April and October. The effect of these missing days on the seasonal average was tested by randomly selecting from 50 to 95% of the daily average values of selected parameters from April through October at each station in 2004. At 5% increments, 100 independent, random subsets of the data were selected and averaged for comparison to the overall mean ± 5% and 10%. Complete results are included in Appendix E, but an example is given in Figure 7. In almost all cases except for turbidity, using only 50% of the data resulted in a mean value within 10% of the true mean; in many cases the result was within 5% of the true mean. Based on these results, we proceeded by using all available April-October data in the following analyses.

Regional Classification and Analysis Within and Among Reserves: Prior to developing groupings of similar sites across the entire region, we looked for the physical parameters most likely to exhibit large differences across the five reserves. This was accomplished with three approaches: (1) analyzing gradients in each Apr-Oct average across the region, (2) generating parameter-parameter scatter plots for all possible combinations of the Apr-Oct averages, within each year and for the entire three-year period, and (3) performing Principal Components Analysis (PCA) on the Apr-Oct averages. Candidate parameters were then used in hierarchical cluster analysis (SPSS) to produce groups of physically similar sites across the entire region. Due to large interannual variability in parameter values, especially salinity, over the three year period, sites were clustered for each year separately. Clusters were derived using a variety of parameter combinations. Since medians appeared to be more appropriate for turbidity we clustered using both averages and medians.

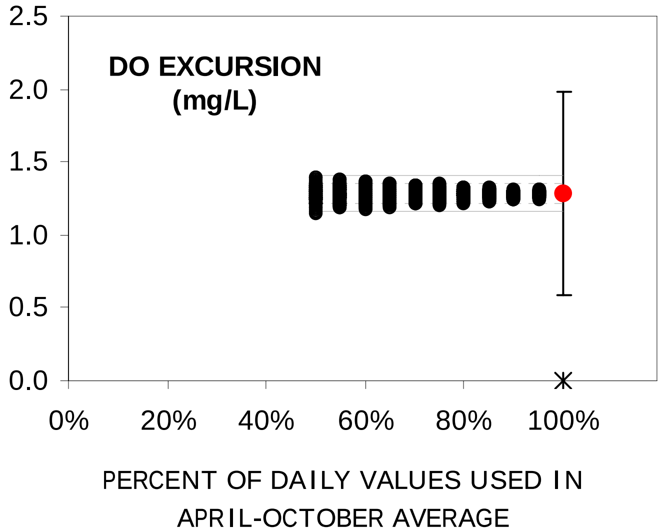

Fig. 7. Effect of missing water quality (YSI) data on the April-October 2004 average of DO excursion at CBMIP. See text for description of calculation and Appendix E for complete results. Red point indicates the mean using all Apr-Oct data; error bars denote standard deviations of all Apr-Oct values. Asterisk indicates the overall percent of available data from April-October (out of 214 days). Gray dashed lines enclose the region within 5% of the overall mean; gray solid lines enclose the region within 10% of the overall mean.

Box plots of all parameters were produced for each year. One set was grouped by regional clusters as determined above to look for further similarities among groups; a second set was grouped by reserve to examine site-specific gradients.

Net Ecosystem Metabolism: While past SWMP syntheses have focused on computing system metabolism using the free-water O_2 technique (Caffrey 2004), they relied on a single estimate of the rate of air-sea O_2 diffusion. However, this rate is known to vary with wind speed and tidal current velocity and has been shown to vary among systems, especially in shallow estuaries of differing geomorphology and exposure (Raymond and Cole 2001; Kremer et al. 2003; Zappa et al. 2003). Our intention in the present project was to improve on the original metabolic calculations using variable rates of air-sea exchange based on SWMP meteorological data.

Net daily ecosystem metabolism (NEM) was computed for each site in each year (2002-2004). Water quality data (15 or 30 minute, as available) were merged with corresponding wind and irradiance data from each site. NEM was computed as the change in DO concentration over each measurement interval, using the 15 or 30 minute measured water depth at each site to take into account the effect of tidally-varying depth and short-term depth variations on metabolic rates (Lucas & Cloern 2002). The rate of air-sea O_2 diffusion (k_{O2}, m h^{-1}) was computed using the regression of Marino & Howarth (1993), which computes the exchange coefficient as a function of wind speed:

$$k_{O2} = \frac{e^{(1.09+0.249 \cdot W)}}{100} \tag{1}$$

where W is the average hourly wind speed (m s^{-1}). This regression was based on a compilation of literature estimates from multiple systems and thus should be generally applicable. Marino & Howarth (1993) also provided 95% confidence intervals around their regression which allows one to test the sensitivity of the NEM calculation to site-specific variability in Equation 1, as well as variability due to other factors such as tidal velocity. Rates of NEM computed over each sampling interval were then integrated into daily rates unless there was a gap greater than three hours; in these cases NEM was not computed for those days.

For the New Jersey and Maryland sites, we could only compute metabolism beginning in October 2002 and July 2003, respectively, as these reserves did not collect meteorological data prior to those dates. We experimented with obtaining external wind data for the missing periods from nearby NOAA stations as well as the Rutgers Marine Field Station (see Fig. 3). Fifteen minute or hourly wind speeds are usually not readily available, but even daily average wind speeds were poorly correlated among sites (Fig. 8). We therefore decided it was better not to use these external wind sources and limit the computation to the period of SWMP meteorological observations.

Daily NEM at each site was averaged from April to October. These seasonal averages had to be used rather than total Apr-Oct metabolism since data gaps were not consistent across all sites. Daily values were also used to produce box plots by cluster and reserve, and variations were analyzed with particular attention to the presence of SAV and tidal marshes.

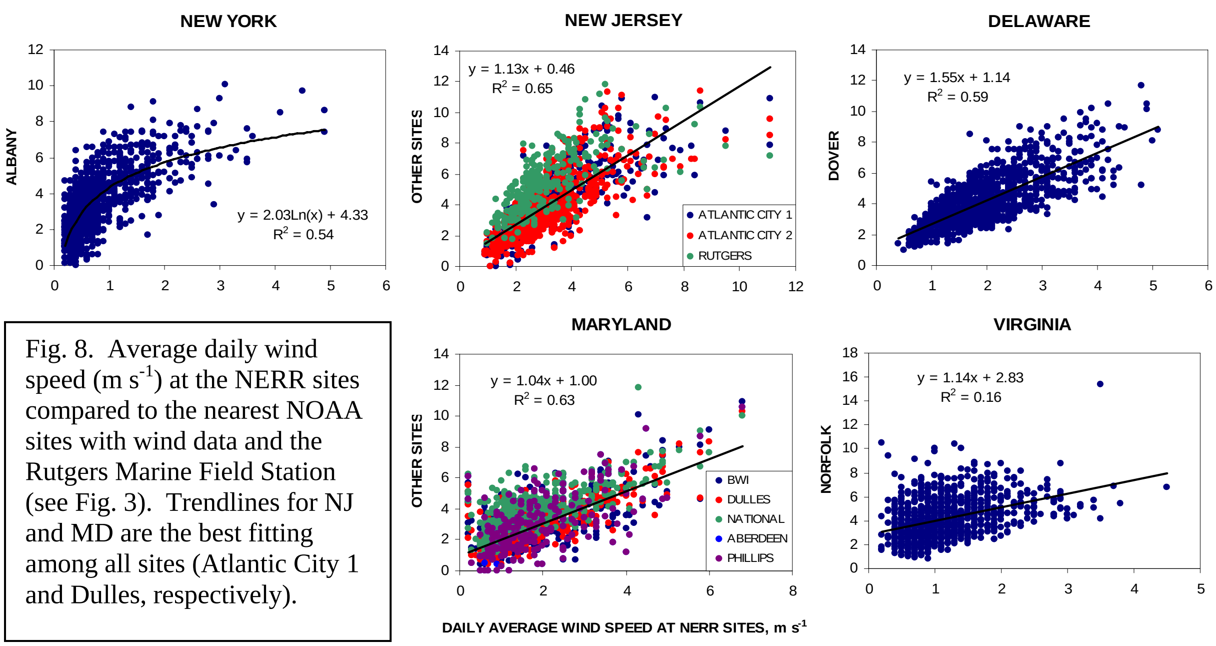

Fig. 8. Average daily wind speed (m s^{-1}) at the NERR sites compared to the nearest NOAA sites with wind data and the Rutgers Marine Field Station (see Fig. 3). Trendlines for NJ and MD are the best fitting among all sites (Atlantic City 1 and Dulles, respectively).

e) Results and Discussion

Monthly Average Annual Cycles: Monthly averages of water quality, nutrient/chlorophyll, precipitation, and river flow data were initially produced to explore the typical annual cycles at each station and variability among the three hydrologically different years. While not discussed further here, a complete set of figures is provided in Appendix F as a resource.

Regional Classification and Analysis: Parameters with the greatest range across all sites, and therefore most likely to be useful in separating sites into clusters with similar characteristics were salinity, turbidity, depth, the daily excursions of salinity and depth, and the ratio of depth excursion to depth (Fig. 9). Out of all possible combinations of physical water quality parameters, however, salinity, turbidity, and salinity excursion were the only ones to produce a clear separation among all Mid-Atlantic sites (Fig. 10).

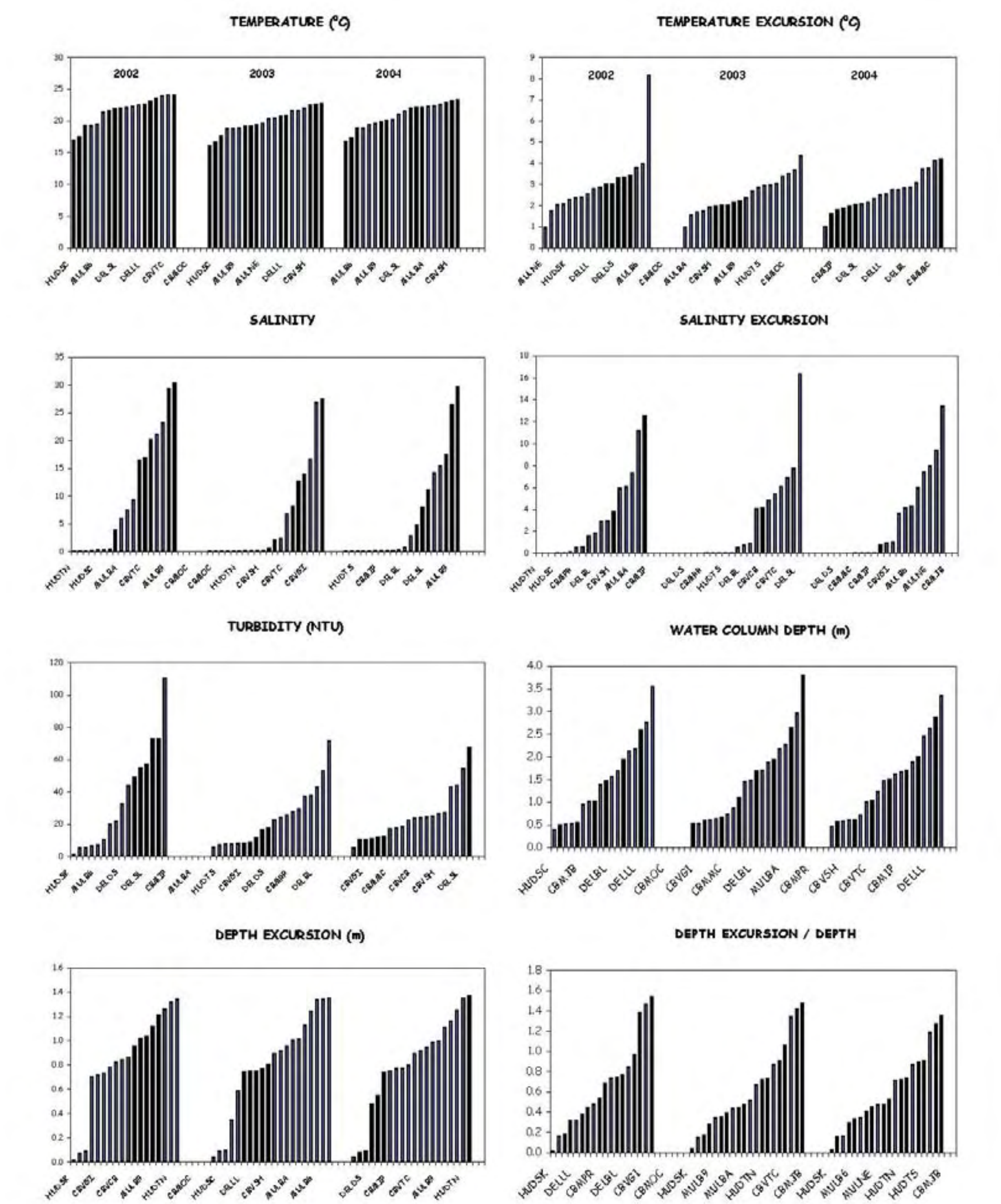

Fig. 9. April-October averages in ascending order by year.

Sites appeared to fall into three main groups with the following characteristics:

- low salinity, low turbidity
- low to intermediate salinity, high turbidity
- high salinity, low turbidity

The mid-salinity, turbid sites also tended to have the greatest daily salinity excursions, reflecting their position in the riverine-estuarine transition of each reserve.

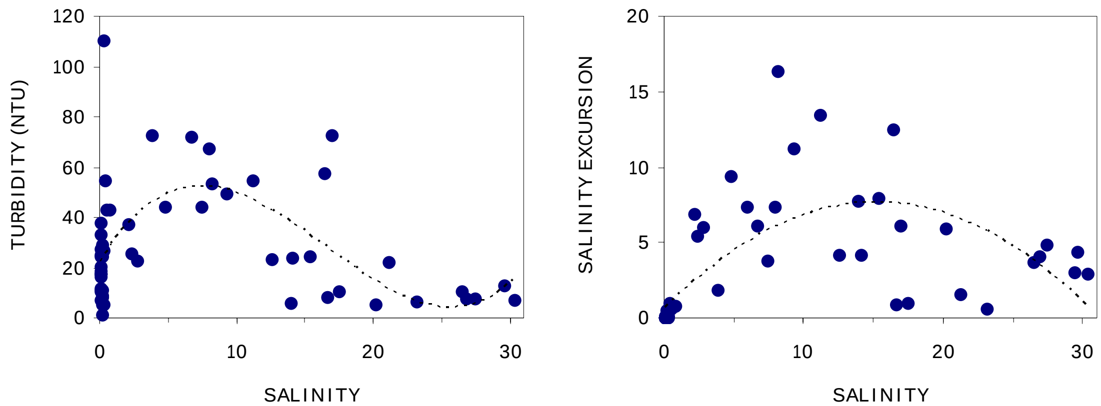

Fig. 10. Example of parameter-parameter scatter plots showing the two clearest groupings of sites.

Surprisingly, the PCA suggested a rather different order of parameters as being important, although all four components were required to explain 85% of the variance (Fig. 11). Cluster analysis using all parameters, however, did not result in clear groupings of sites so we proceeded with salinity, turbidity, and salinity excursion.

	Component			
	1	2	3	4
DEPTH'	.783	-.540	.098	-.005
EXC/DEPTH	.148	.952	-.003	.122
TEMP	.052	.723	.546	.000
SAL	.795	.143	-.087	-.089
TURB	-.097	.168	.873	.390
DEPTH_EXCU	.779	.229	.179	.152
TEMP_EXCUR	.040	.077	.100	.955
SAL_EXCUR	.491	-.060	.698	-.378

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 6 iterations.

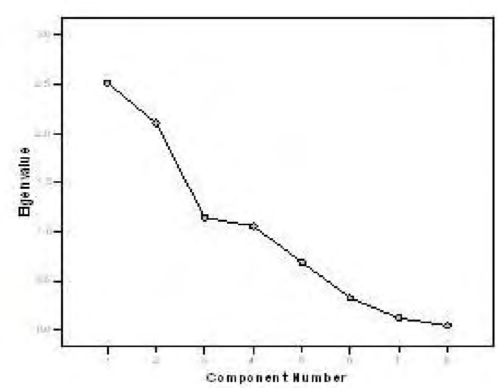

Fig. 11. Rotated component matrix and Scree plot from PCA on all three years of April - October averages.

Clusters were clearest for salinity and turbidity (e.g. Fig. 12) and were nearly identical when salinity excursion was included as a third variable or when only salinity and salinity excursion were included. While the average values of salinity and turbidity varied among years, cluster identity was preserved across years (Fig. 13). Clusters were similar when using medians instead of averages, but less well defined (i.e. less distinction between Clusters 1 and 2).

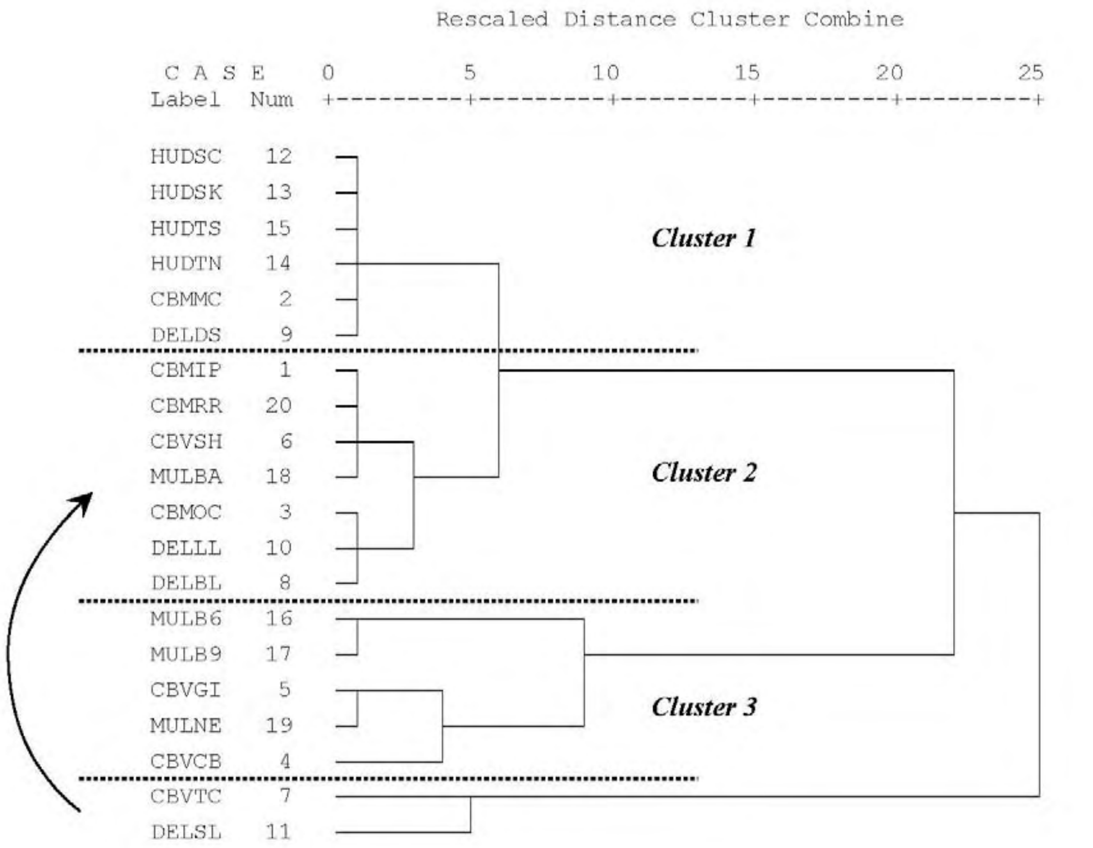

Fig. 12. Cluster dendogram for 2003 based on average salinity and turbidity. Cluster boundaries based on this and other years are shown with broken horizontal lines. Based on results from other years, CBVTC and DELSL belong in Cluster 2.

To examine similarities among clusters and sites within each cluster, box plots of daily average values for each parameter at each station were produced. The complete set of box plots is presented in Appendix G. Sites in the intermediate cluster generally display the lowest pH and O_2 and highest chlorophyll and nutrient concentrations (e.g. Fig. 14). The high chlorophyll at many of these intermediate transition stations appears to reflect the high nutrient concentrations at the sites as well as a Redfield Ratio close to 16 (Fig. 15). Nutrient concentrations at the majority of the Mid-Atlantic sites appear to be watershed-driven rather than recycled *in situ*; N:P ratios are high at most sites and NO_x:NH_4 ratios are high in Clusters 1 and 2 (Fig. 16). Only in Cluster 3 and CBVTC do the NO_x:NH_4 ratios consistently remain below two.

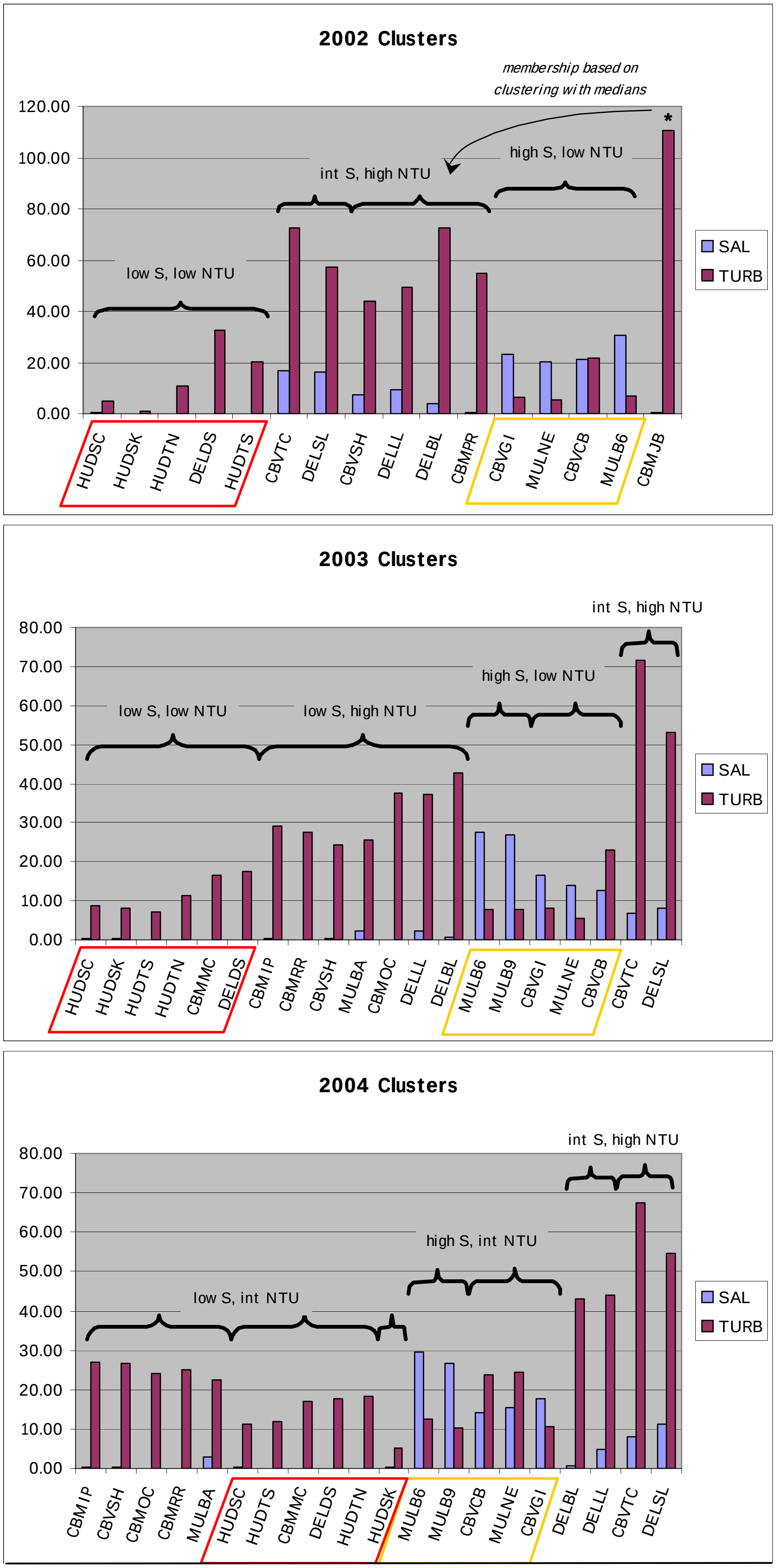

Fig. 13. Average values of salinity and turbidity grouped by cluster and year. Sites in the two end-member clusters are outlined in red (low S, low NTU) and gold (high S, low NTU). The intermediate cluster is frequently divided into two separate sub-clusters.

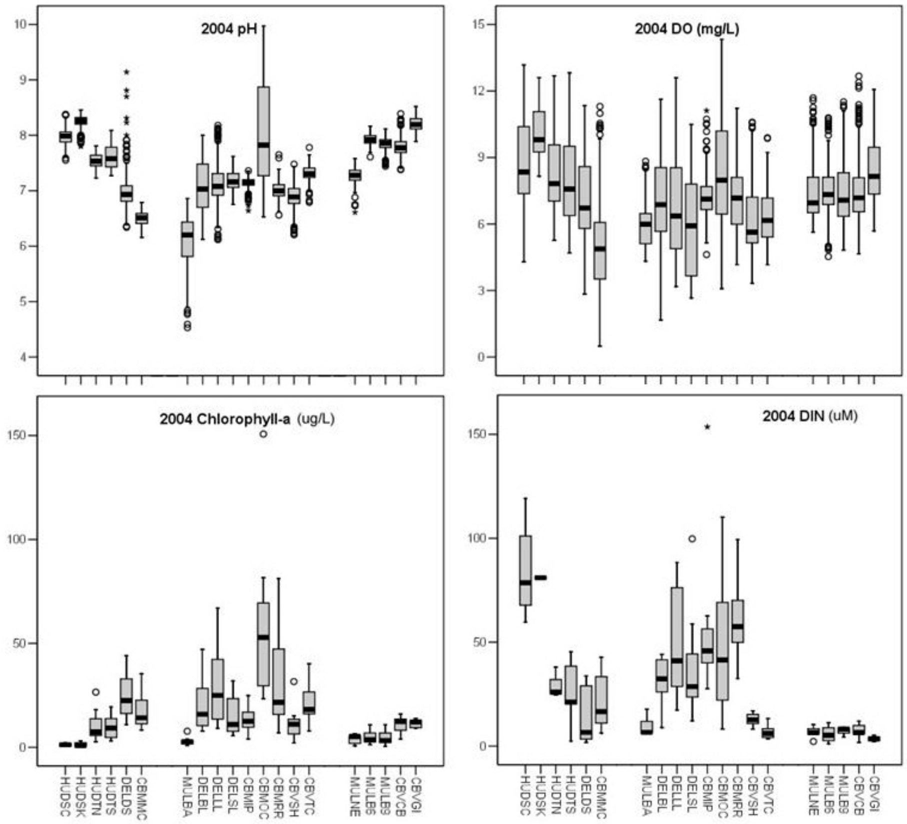

Fig. 14. Example of box plots (Apr-Oct daily averages) for pH, O_2, Chl-*a*, and DIN in 2004. Stations are organized by cluster with gaps between the three groups. Boxes encompass the interquartile range (IQR), horizontal bar denotes the median, and whiskers encompass the full range of data excluding outliers (circles: 1.5-3x IQR from the upper or lower edge of the box) and extreme cases (asterisks: >3x IQR). See Appendix G for a complete set of box plots.

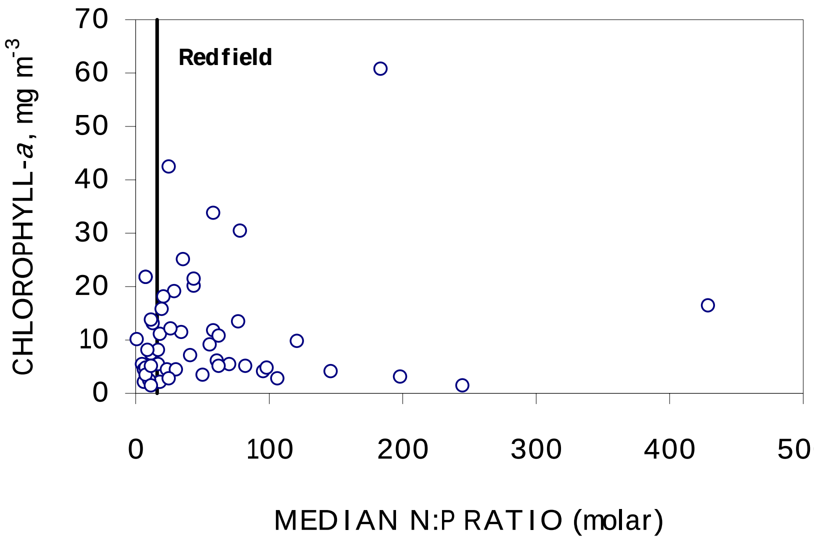

Fig. 15. Average chlorophyll and median N:P ratio observed for Apr-Oct at all sites in all three years. Plot is nearly identical for average N:P ratios.

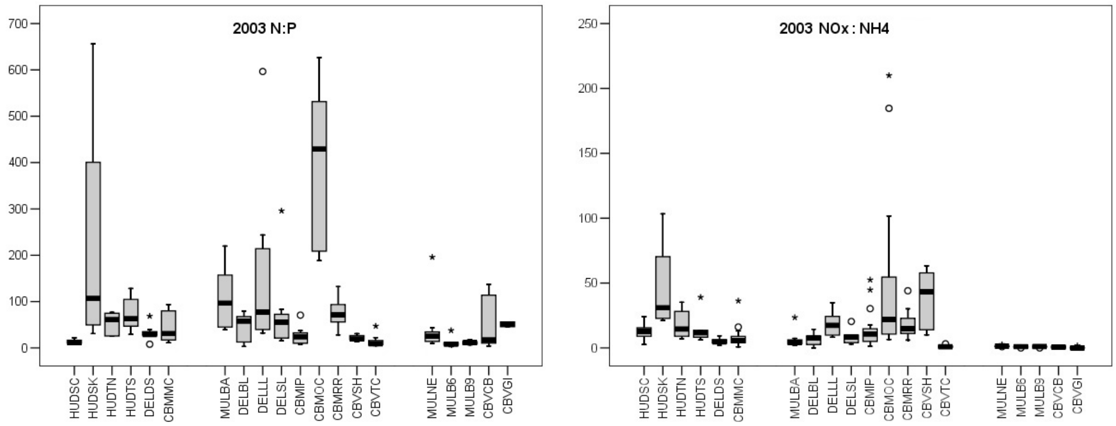

Fig. 16. 2004 box plots of N:P and NOx:NH4 molar ratios organized by cluster.

Parameter-parameter scatter plots by cluster and year (and for all stations combined) were also produced to examine within and between cluster trends. Plots by cluster and year did not add any extra information so only plots with all stations and years combined are shown here. pH is highly variable among tidal fresh systems, but appears positively related to salinity outside of these sites (Fig. 17a), while daily average DO appears weakly related to pH (Fig. 17b). The occurrence of hypoxia in these systems (measured as minimum daily O_2) is correlated to water temperature and turbidity (Fig. 18a-b). Further, it appears that the greatest range of both O_2 and daily minimum O_2 (including the most hypoxic sites) occur at the freshest sites (Fig. 18c). Additionally, daily minimum O_2 also appears related to average chlorophyll concentrations, reflective of the substrate for system respiration (Fig. 18d).

Chlorophyll and nutrients tend to decrease under an exponential envelope with increasing salinity (Fig. 19a-b). Chlorophyll distributions with respect to temperature appear to mirror the physiological response of phytoplankton growth rates to temperature (Fig. 19c). Finally, sites with greater chlorophyll tend to display the greatest diel O_2

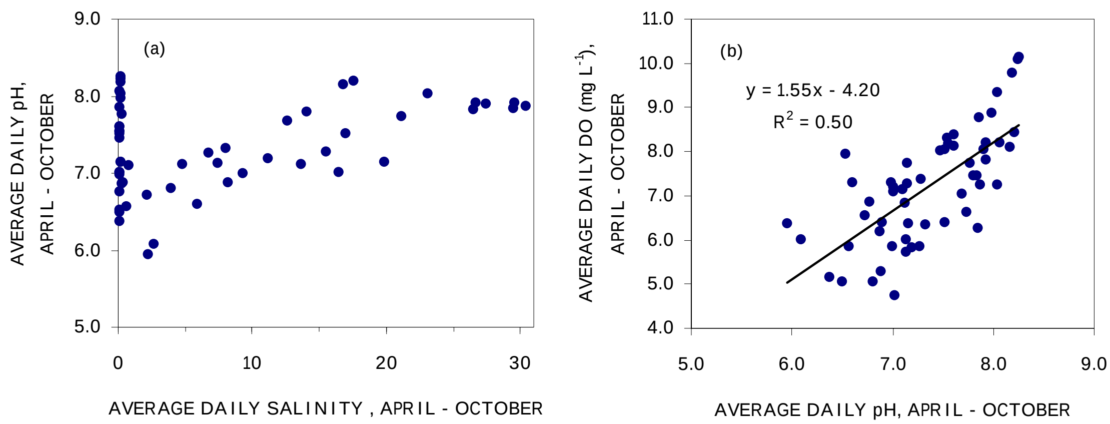

Fig. 17. Relationships between April-October salinity, pH, and DO, 2002-04.

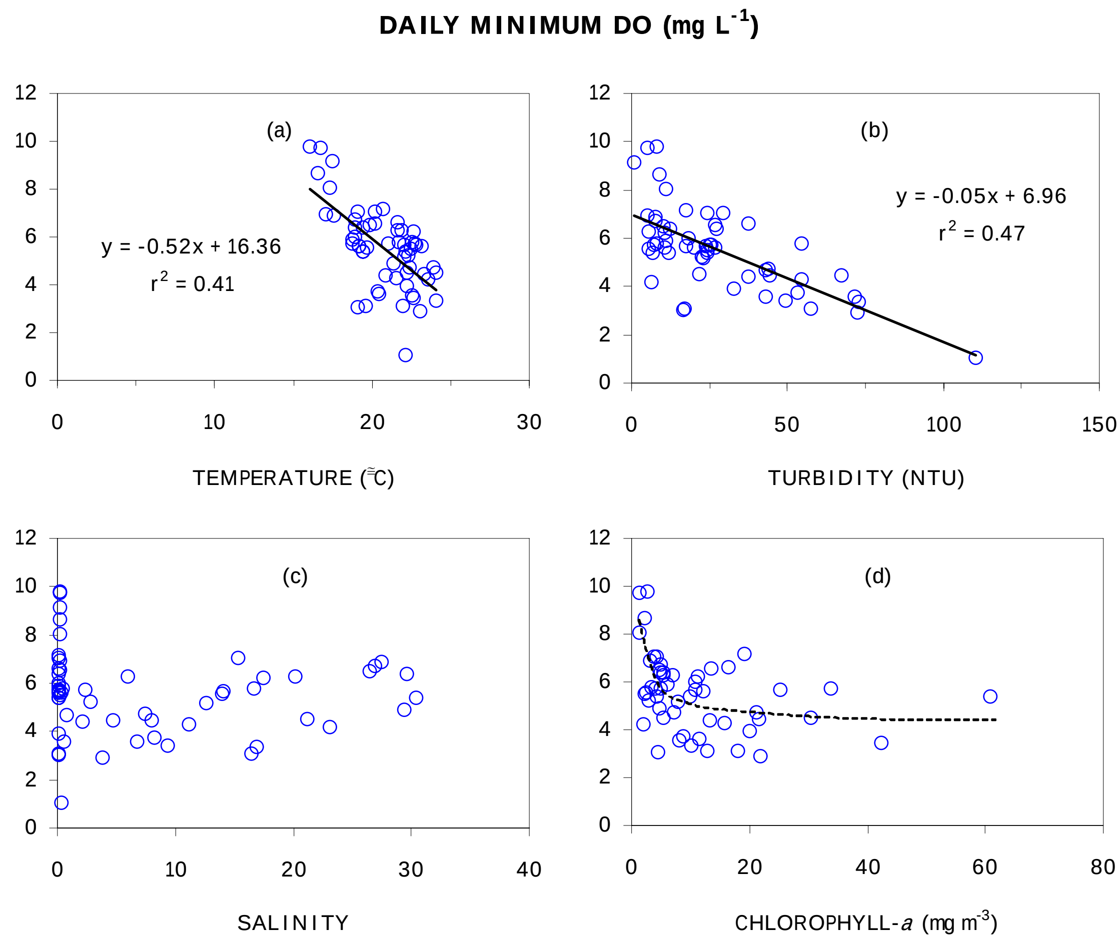

Fig. 18. Sample scatter plots for daily minimum O_2 concentration (mg L^{-1}, Apr-Oct) for all stations in all years.

excursions (Fig. 19d), suggesting they are the most productive but also the sites of greatest night respiration.

Patterns Within Reserves: The various Mid-Atlantic reserves differ in how stations are distributed relative to environmental impacts and natural gradients (Table 1). While the Jacques Cousteau, Delaware, and Virginia sites are generally situated along estuarine salinity gradients, the Hudson and Maryland sites are generally restricted to a single ecotype, i.e. tidal and non-tidal fresh. Superimposed on these trends are gradients of anthropogenic impact from a wastewater treatment facility upstream of CBMIP, extensive development upstream of CBMOC, and the urban region surrounding DELDS in Dover. Finally, sites and reserves are further distguished by the presence or absence of SAV and adjacent tidal marshes and/or the dominant land use in the watershed (Table 1). To address patterns within reserves, all box plots were reordered by reserve rather than cluster. A complete set of plots is in Appendix H.

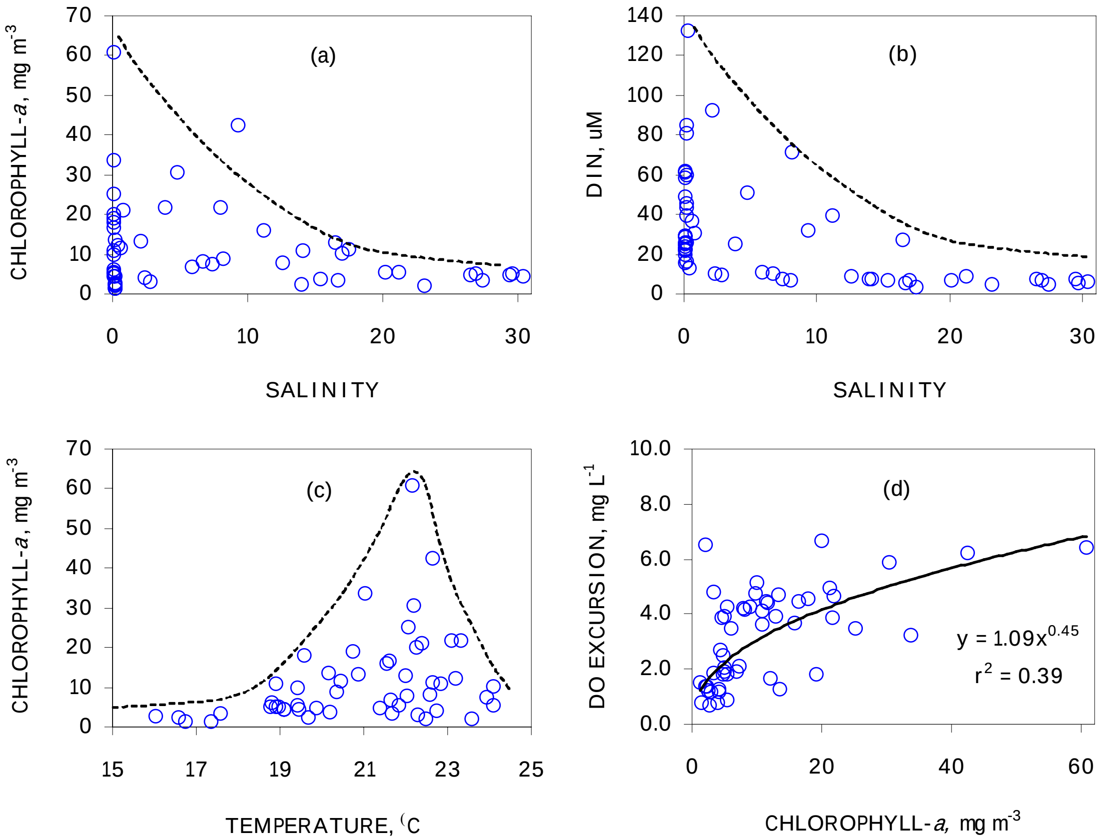

Fig. 19. More sample scatter plots for daily average values (Apr-Oct) for all stations in all years.

Figure 20 makes clear the two types of reserves in the Mid-Atlantic: estuarine gradients and tidal/non-tidal fresh. Further, the end-members of the salinity gradients range from mesohaline to nearly fully saline. When sites are ordered in this way, the latitudinal gradient in temperature is clearly evident, although interrupted especially at MULB6 and MULB9 by the cool oceanic waters entering Great Bay, NJ (Fig. 21a). Similarly, the increase in watershed sediment erosion and consequent turbidity as one moves south through the Mid-Atlantic is evident (Fig. 21b). pH follows the salinity gradients at the MUL, DEL, and CBV reserves (Fig. 21c). The only

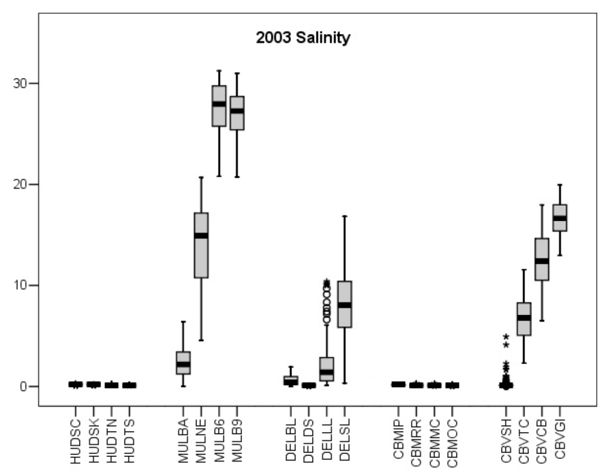

Fig. 20. Box plot of 2003 salinity ordered by reserve.

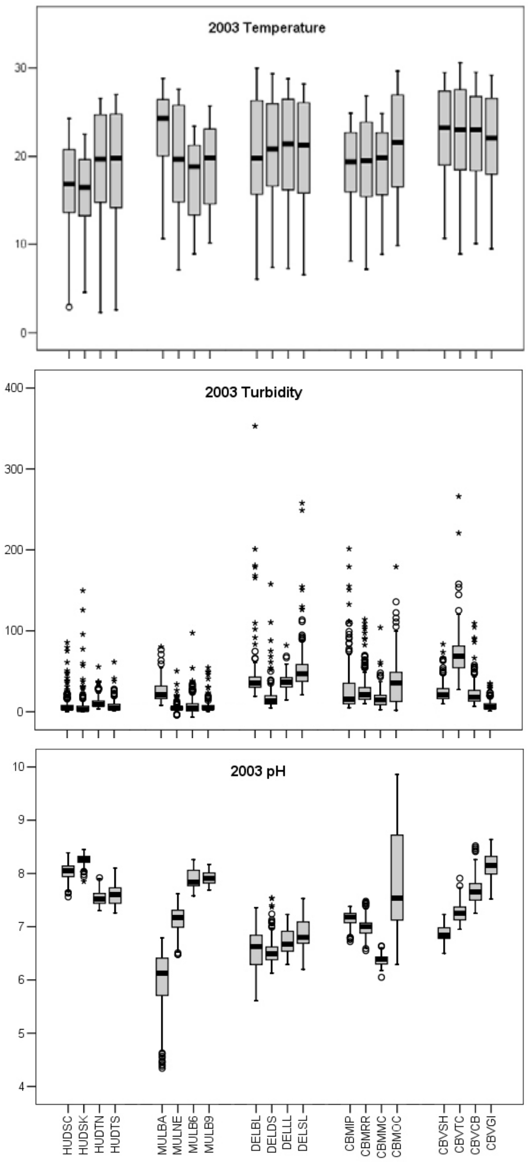

Fig. 21. Box plots of 2003 temperature (°C), turbidity (NTU), and pH ordered by reserve.

estuarine site in Maryland (CBMOC) has the highest pH, and the others – which lie along a gradient downstream of a wastewater facility – decrease with increasing distance from the plant (upstream of CBMIP).

Patterns of dissolved oxygen concentrations (both mg L^{-1} and % saturation) and daily DO minima were consistent across all reserves. DO increases in the Virginia reserve moving downstream from the tidal fresh region with its abundance marshes to polyhaline regions of the York River. Similarly, DO is higher in Great Bay at the New Jersey reserve and lower upstream, presumably due to a watershed with the greatest cover of upland wetlands (see Appendix C). Contrary to what was expected, DO in the Delaware and Maryland reserves is actually highest at the sites closest to Dover and the wastewater plant, respectively (DELDS, CBMIP) and decreases downstream (and with increasing salinity in Delaware). This could perhaps be due to stimulation of primary production by anthropogenic nutrient inputs at the impacted sites combined with dilution downstream and increasing marsh area in Delaware. The pattern runs opposite a trend of increasing SAV coverage downstream in Maryland, however. DO at the Hudson site is higher in the tributary creeks than in the embayments, presumably due to the extensive marsh cover at the latter sites.

DIN concentrations are highest at the upstream stations of the HUD, MUL, and CBV reserves and decrease downstream (Fig. 23). Patterns are similar for DIP except in New Jersey where concentrations increase, suggesting

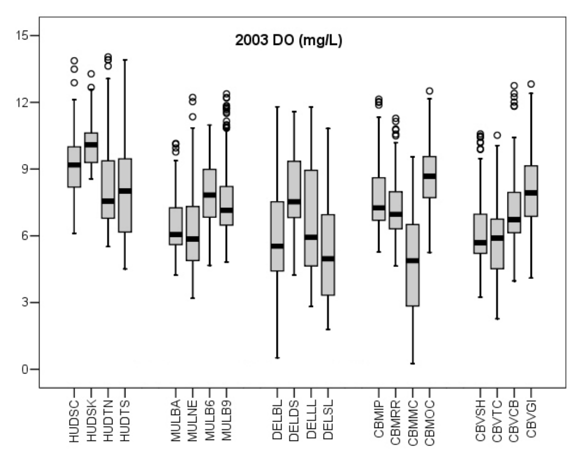

Fig. 22. Box plots of 2003 DO and Minimum DO ordered by reserve.

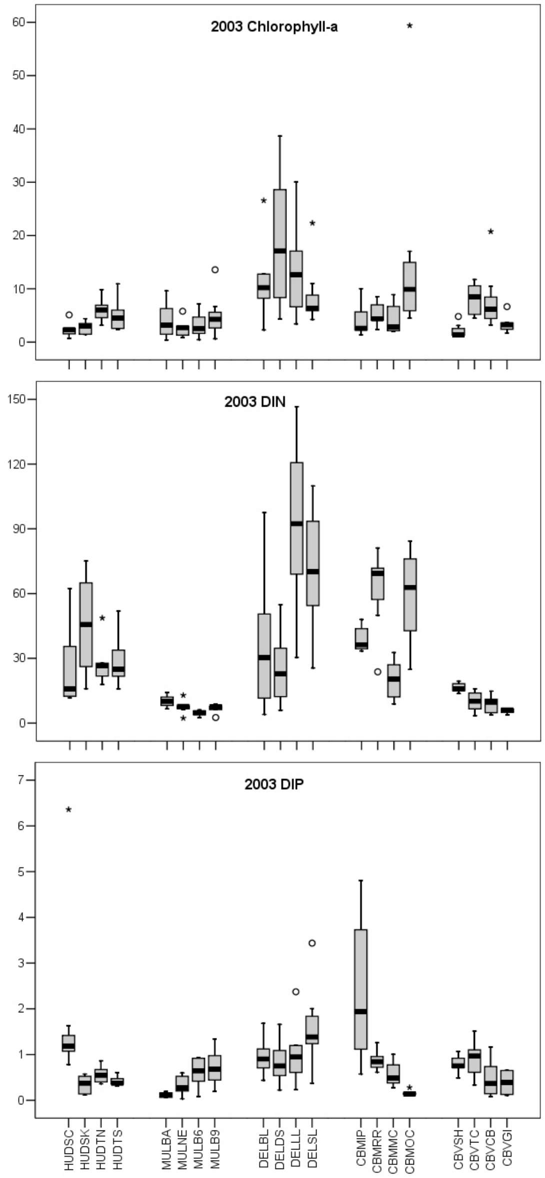

Fig. 23. Box plots of 2003 chlorophyll-*a* (mg m^{-3}), DIN (uM), and DIP (uM) ordered by reserve.

enhanced release either from sediments or desorption from suspended material. Chlorophyll concentrations tend to increase downstream in the HUD and MUL reserves while the higher flows in the Pamunkey and Mattaponi Rivers in Virginia actually flush phytoplankton out of the most upstream station.

DIN concentrations are highest at the HUD, DEL, and CBM reserves, all of which have the most developed watersheds (Table 1). Elevated DIN in DEL and CBM is likely a reflection – although displaced downstream – of the anthropogenic impacts upstream of DELDS and CBMIP. The wastewater treatment facility near the Maryland site appears to be an especially large source of DIP. These anthropogenic inputs appear to have an effect on phytoplankton primarily in the Delaware reserve, which has the highest chlorophyll concentrations.

Finally, the DELBL and CBMOC sites are in separate systems from the others (Fig. 1) and little has been said about them. The DELBL site appears to behave quite similarly to its counterpart mid-estuary site in the St. Jones River (DELLL) (Figs. 20-23). Metadata for the CBMOC site describe it as being representative of ”extreme shallow water habitats”, and it is characterized by very shallow depths (< 1 m at low tide), extensive marsh and SAV coverage, and watershed development. Water quality at this site appears to reflect these characteristics; among the Maryland sites CBMOC has the highest DO and chlorophyll-*a* concentrations, among the highest DIN concentrations, and the greatest daily DO excursion (Figs. 22-23, Appendix H).

Net Ecosystem Metabolism: Estimates of daily NEM were highly variable in time (Fig. 24a). Since the exact relationship between wind speed and air-sea exchange coefficient (e.g. Eq. 1) is variable depending on the study system and other physical parameters (e.g. current velocity) (Raymond and Cole 2001; Kremer et al. 2003; Zappa et al. 2003), we estimated the sensitivity of the NEM calculation to the exact equation for the air-sea exchange coefficient. Values computed with Marino & Howarth's (1993) average regression between wind and k_{O2} were compared to values computed with Marino & Howarth's lower and upper 95% confidence limits on the average regression (Fig. 24b). While the magnitude of computed NEM was sensitive, the sign (i.e. net autotrophic vs. net heterotrophic) was not.

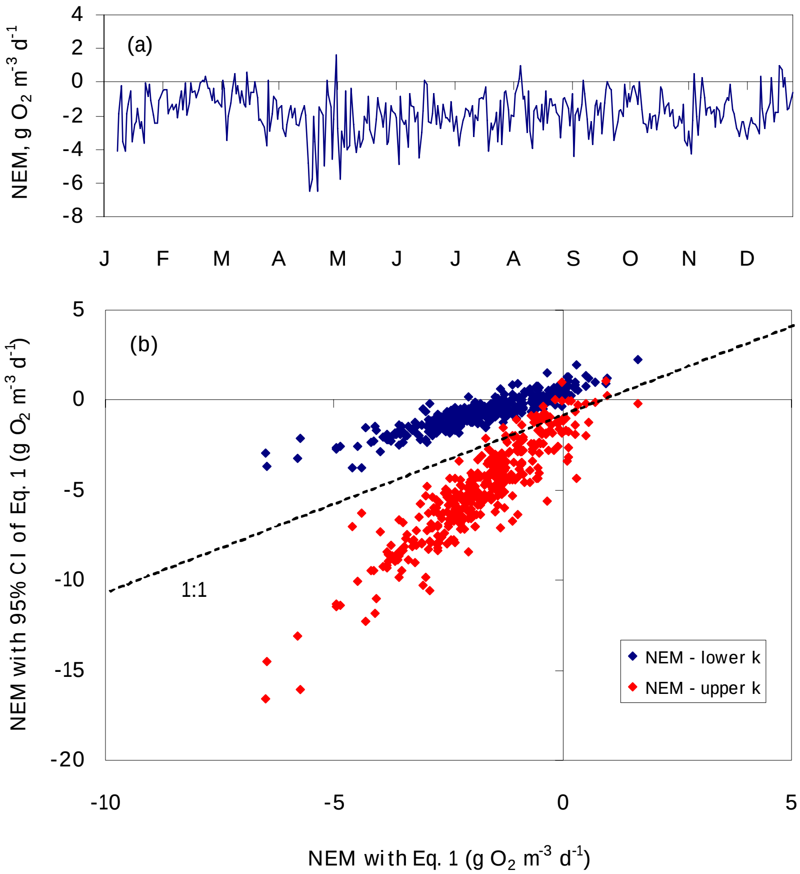

Fig. 24. (a) Typical time series of computed NEM. Example is from Virginia's Taskinas Creek site for 2004. (b) Sensitivity of the NEM calculation for Taskinas Creek to the air-sea exchange coefficient (k_{O2}). See text for details.

The mid-Atlantic sites were generally net heterotrophic, with the more open, high salinity/low turbidity sites being closest to metabolic balance as a group (Fig. 25). Exceptions were the highly impacted DELDS and CBMMC sites which were sometimes strongly heterotrophic. NEM at both the MUL and CBV reserves increased with distance down the salinity gradient. As with other parameters, seasonal average rates of NEM were highly variable at fresh sites but were positively related to salinity outside of these sites (Fig. 26). Dominant habitat type appears to play some role in determining the balance between net autotrophy and heterotrophy, but it does not appear to be the only determinant (Fig. 27). Over the three year study period, only three sites were net autotrophic; two have extensive SAV beds but also fair amounts of fringing marshes. Freshwater sites with SAV beds were all

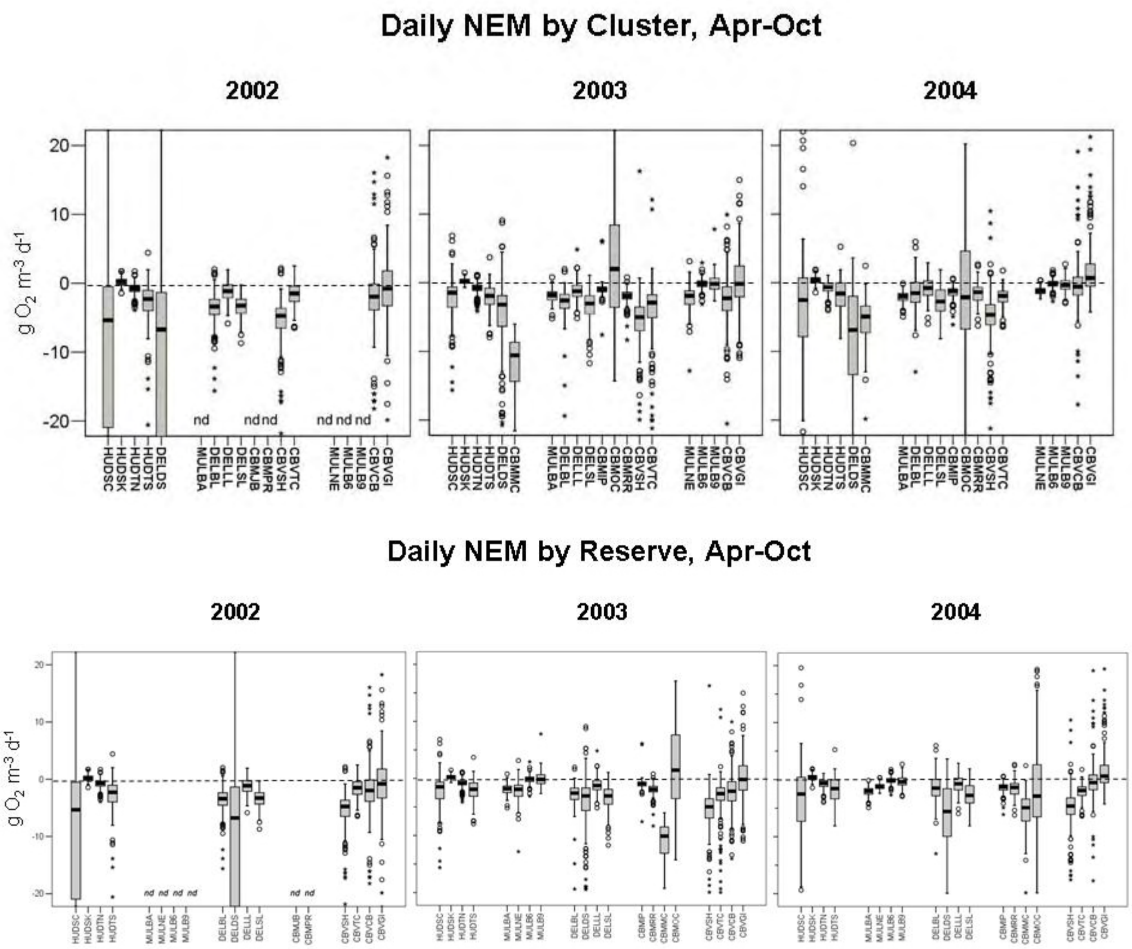

Fig. 25. Box plots of NEM organized by cluster (top) and reserve (bottom).

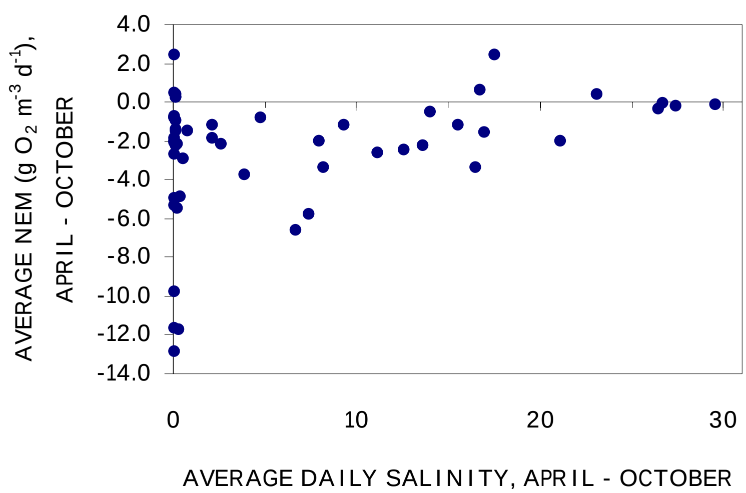

Fig. 26. Relationship between April-October average salinity and NEM, 2002-04.

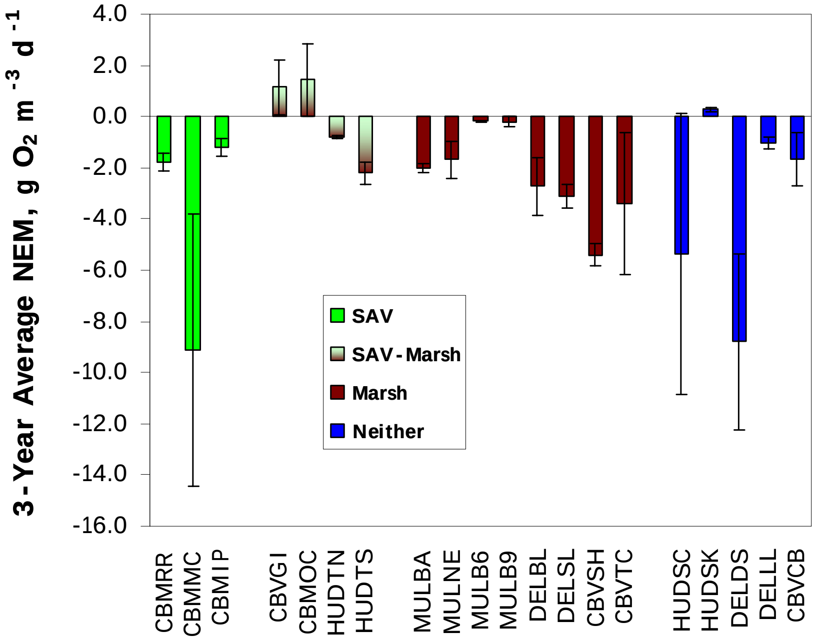

Fig. 27. Average of 2002, 2003, and 2004 NEM (Apr-Oct averages) with standard deviation, separated according to dominant habitat type.

heterotrophic, whether they had extensive tidal marshes or not, with the most negative site (CBMMC) also displaying the worst water quality (see above). All sites with extensive adjacent marshes and no SAV were net heterotrophic, although the relatively deep and open water sites MULB6 and MULB9 were nearly in metabolic balance. The strong heterotrophy at DELDS is not surprising due to its urban setting.

Interannual Variability and Response to Freshwater Flow:

It was striking that both region-wide and reserve-specific patterns in water quality parameters were consistent across all three years in a large number of cases (Appendix G-H). Nevertheless, it is reasonable to expect a major determinant of interannual variability at the NERRs sites to be the rate of freshwater inflow from upstream rivers and creeks, as larger Mid-Atlantic estuaries have been shown to be highly dependent on flow (e.g. Sin et al. 1999). All available SWMP data were compiled (1995-2005 for water quality; 2002-2005 for nutrients/chlorophyll) for computation of April-October averages and regression against river flow. Since flow rates across the different reserves and even between rivers within the DEL and CBM reserves spanned multiple orders of magnitude (e.g. Hudson River vs. Blackbird Creek), all annual average flows (*Q*) were expressed as Z-scores relative to the 1995-2005 mean flow:

$$Z_{flow} = \frac{Q_n - \overline{Q}}{s} \qquad (2)$$

where *n* is the particular year and $\overline{Q}$ and *s* are the 1995-2005 mean flow and standard deviation, respectively.

Successful relationships to flow were not found for either the Hudson or Maryland reserves. However, the three sites with estuarine gradients did display some dependence on flow. Not surprisingly, salinity at all sites except the tidal fresh stations in Delaware was negatively related to freshwater flow (Fig. 28).

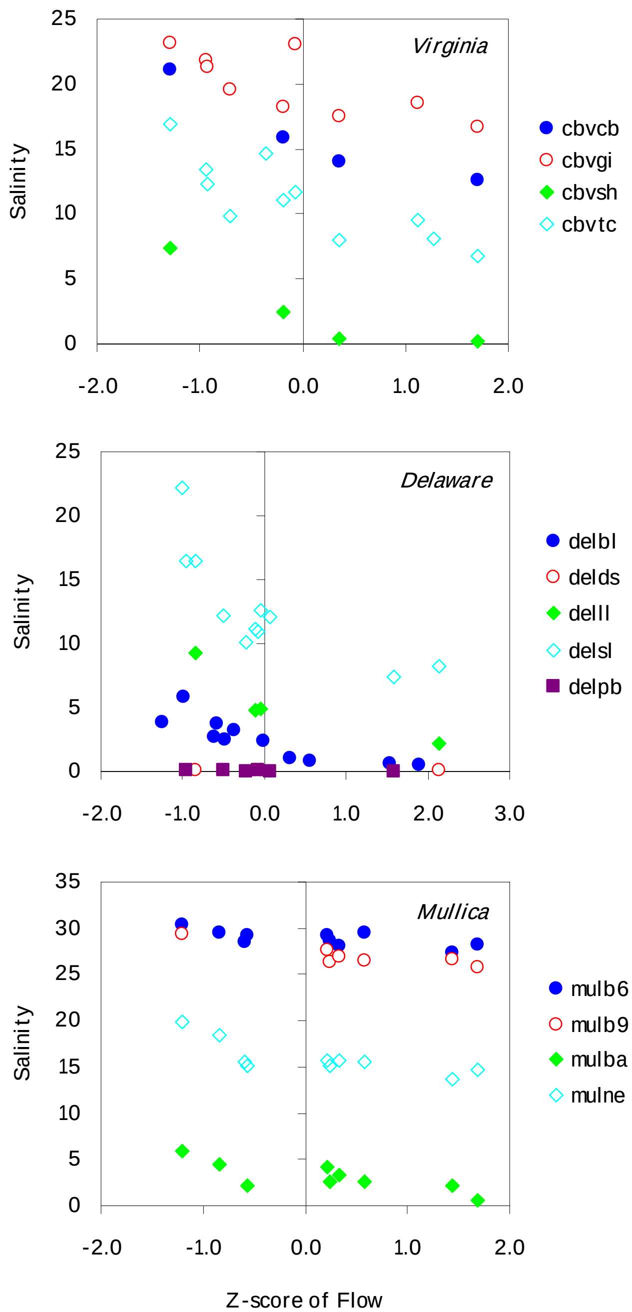

Fig. 28. Response of Apr-Oct average salinity to interannual variations in freshwater flow.

DIN did not appear related to flow at the CBV and MUL reserves, except for a possible negative relationship at MULNE (Fig. 29-30). However, DIP exhibited the same hyperbolic response at all stations in the two reserves. It is unclear what is causing this response, but chlorophyll follows the inverse pattern in Virginia, suggesting initial bloom stimulation as flows increase followed by dilution at higher flows. It may be that DIP is simply tracking the chlorophyll response. Chlorophyll at the upriver New Jersey sites appears to follow a dilution response as flows increase. DIN concentrations were positively related to flow at the two downstream Delaware sites, and chlorophyll data suggest either simple dilution with increasing flow or initial increases followed by dilution (Fig. 31).

Turbidity was sensitive to interannual variations in flow only at the Delaware reserve. Values decreased with increasing flows, presumably due to increased flushing (Fig. 32).

DO conditions tended to improve at intermediate and/or higher flows. In Virginia, average and minimum DO tended to have an intermediate optimum at least at some sites, corresponding to a reduced number of days with low oxygen concentrations at intermediate flows (Fig. 33). As for chlorophyll-*a*, this suggests that intermediate flows stimulate carbon fixation and the net production of oxygen, while lower flows do not

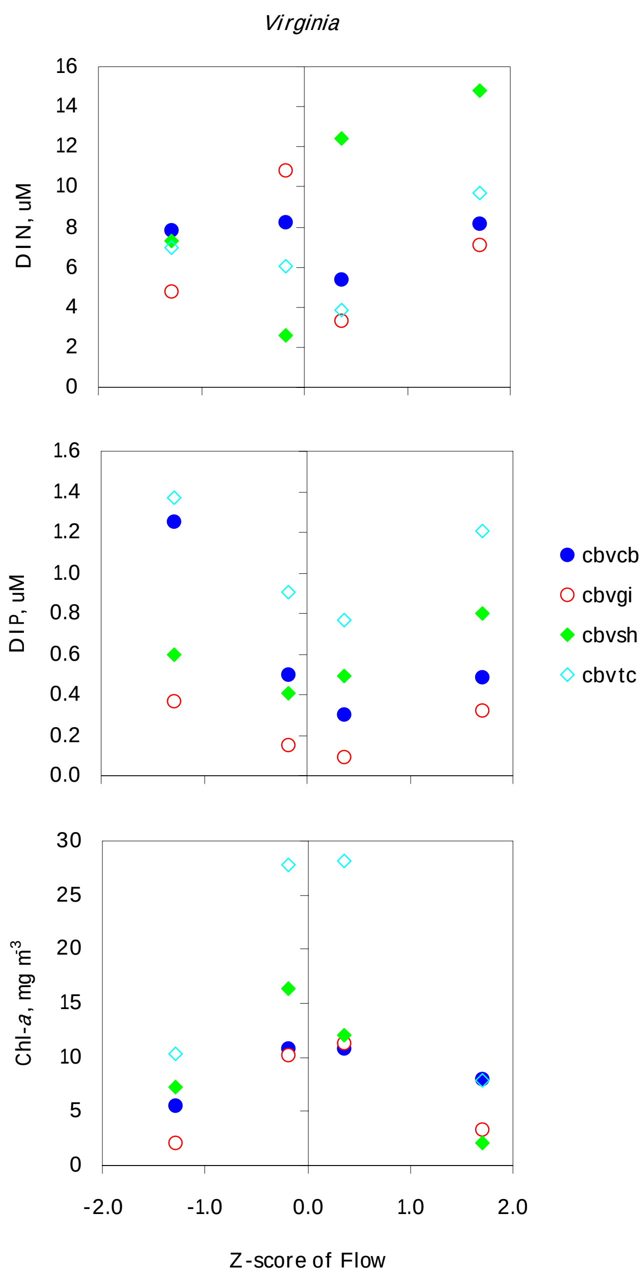

Fig. 29. Response of nutrients and chlorophyll to flow, Virginia Reserve.

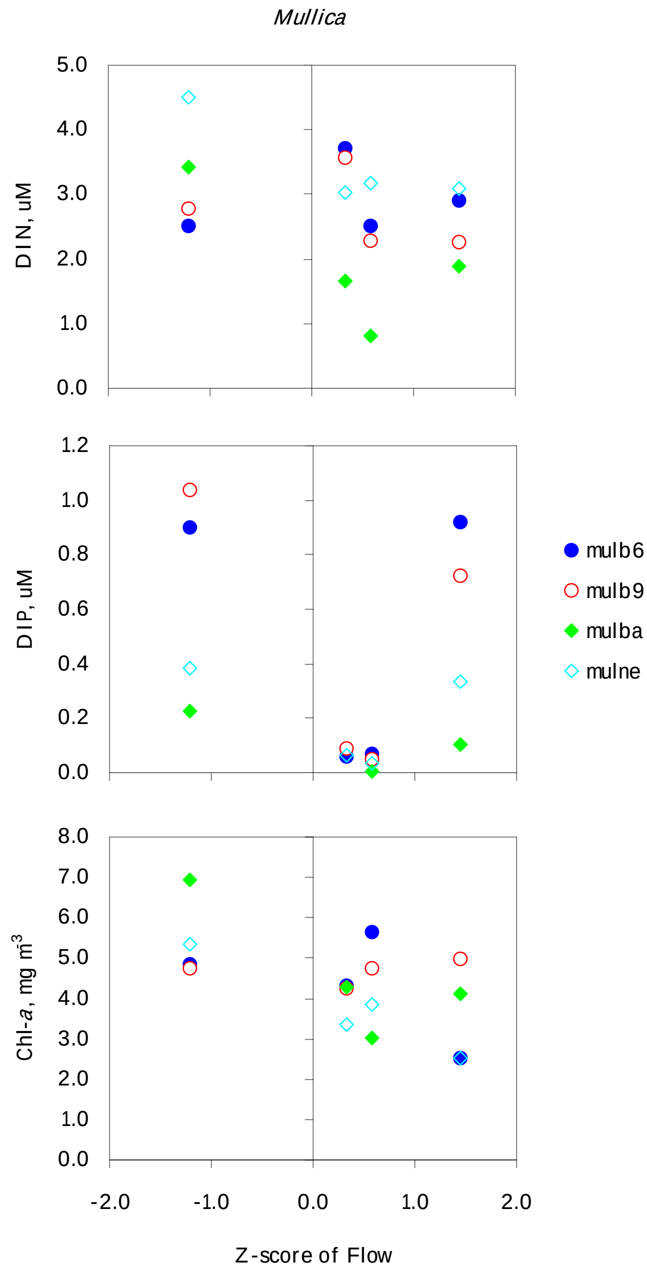

Fig. 30. Response of nutrients and chlorophyll to flow, New Jersey Reserve.

stimulate as much primary production and higher flows flush producers too rapidly from the system. Similarly, higher flows tended to be associated with improved DO conditions at some Delaware (DELBL, DELDS, DELLL) and New Jersey (MULB6, MULB9) sites (Figs. 34-35, respectively). While only computed for three years, trends of system metabolism were consistent with those for chlorophyll and DO in three of the sites, with highest values at intermediate rates of freshwater input (Fig. 36).

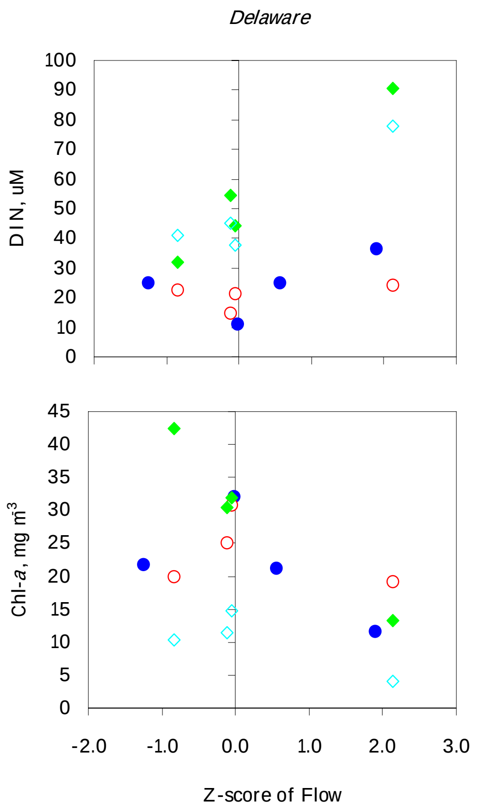

Fig. 31. Response of DIN and chlorophyll to flow, Delaware Reserve.

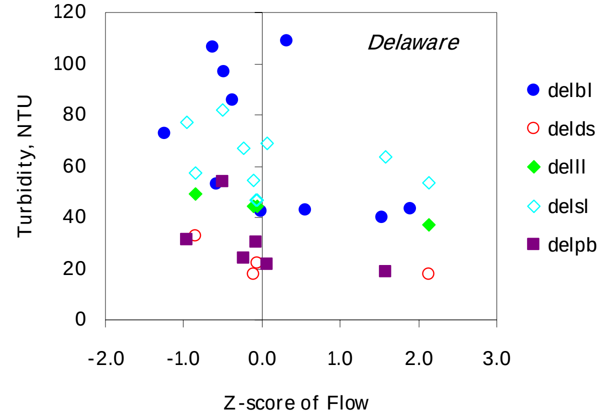

Fig. 32. Response of turbidity to flow, Delaware Reserve.

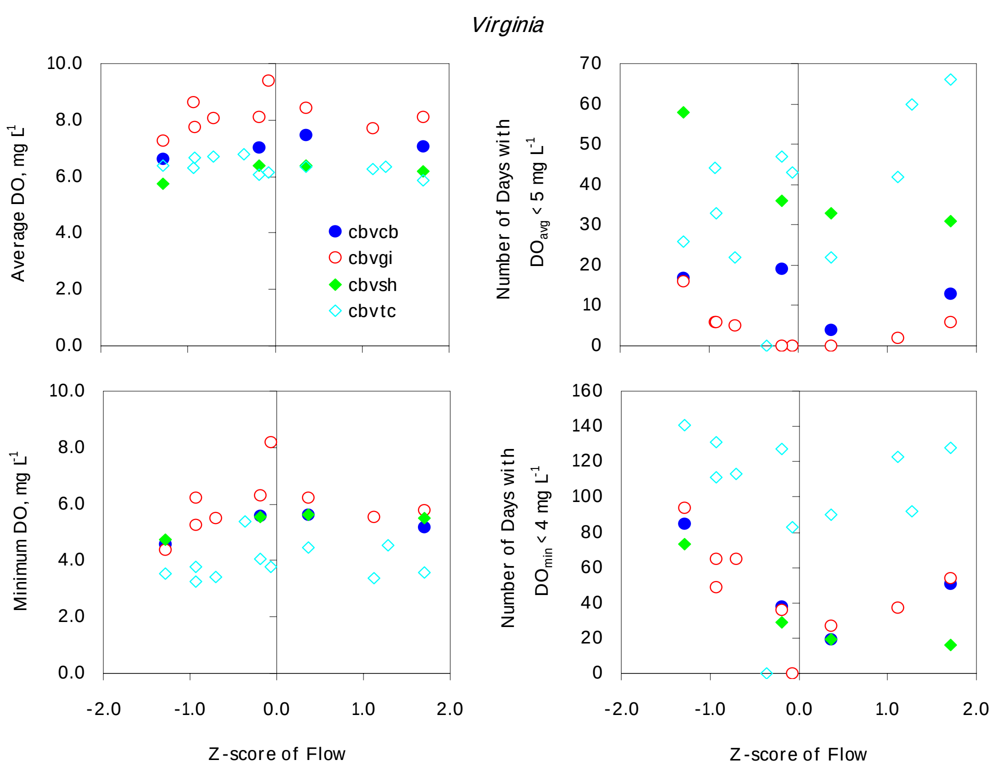

Fig. 33. Response of DO to flow, Virginia Reserve.

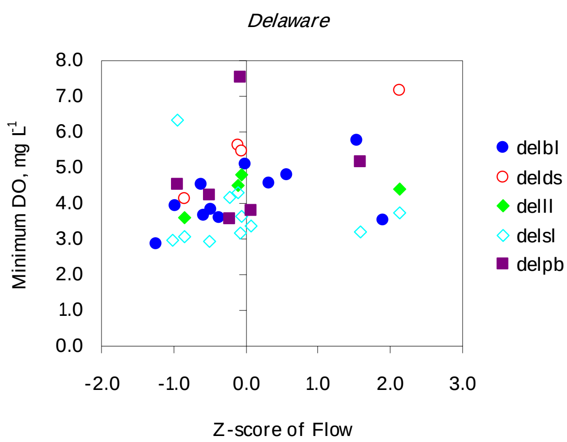

Fig. 34. Response of DO to flow, Delaware Reserve.

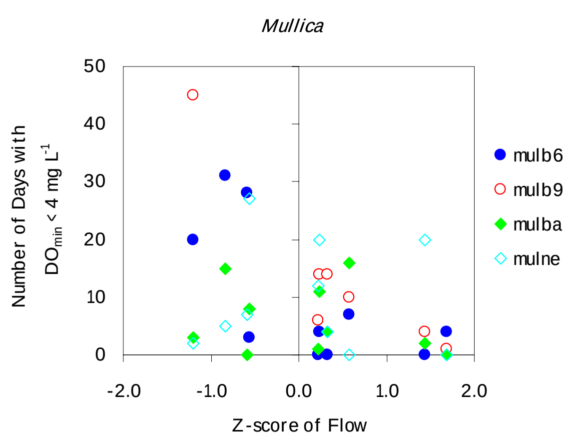

Fig. 35. Response of DO to flow, New Jersey Reserve.

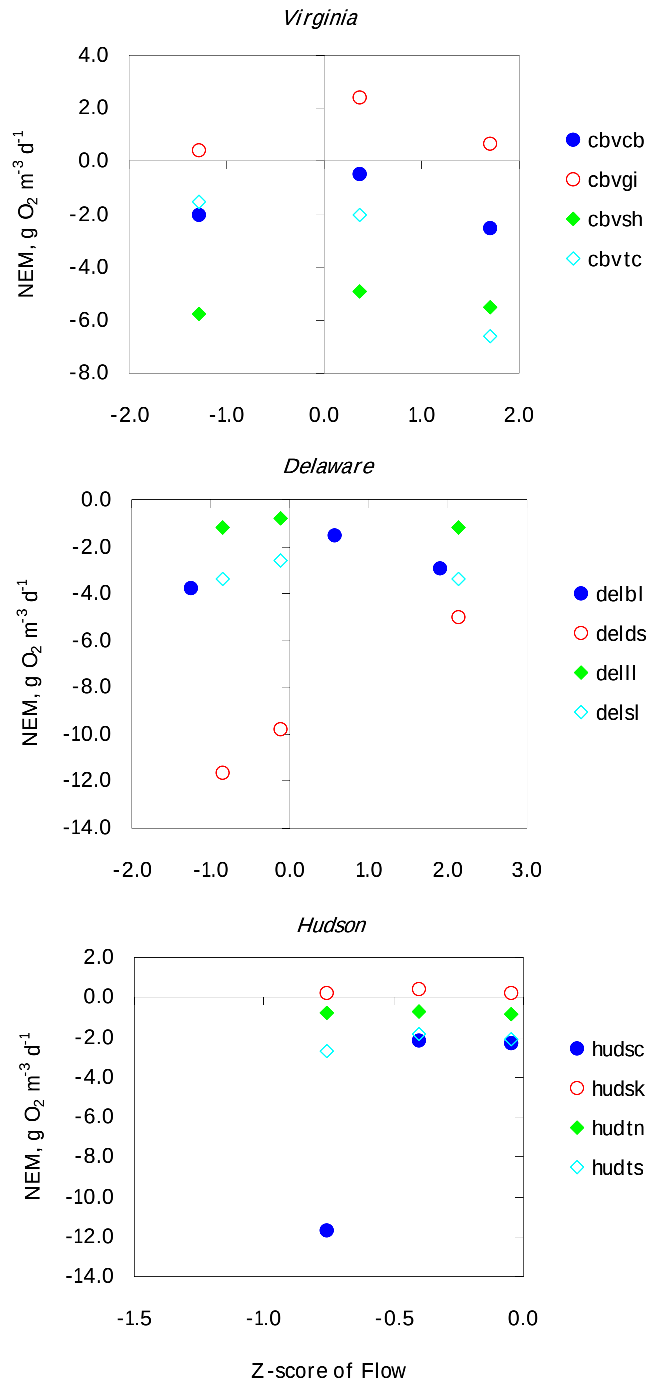

Fig. 36. Response of average daily NEM to flow in the Virginia, Delaware, and Hudson Reserves.

f) Conclusions

Results of this third round of SWMP synthesis specifically for the Mid-Atlantic region have demonstrated the reliability of temporal data reduction into bulk seasonal averages for the purposes of conducting broad-scale, system-level analyses across (1) the entire Mid-Atlantic bioregion and (2) individual reserves. Seasonal averages were generally insensitive to missing data and directly proportional to seasonal medians. Across the entire region, sites consistently grouped into three major categories: (1) low salinity, low turbidity, (2) intermediate salinity, high turbidity, and (3) high salinity, low turbidity. These sites typify the upstream tidal fresh, freshwater-estuarine transition, and meso- to polyhaline regions of traditional estuarine salinity gradients. Within the Mid-Atlantic, three reserves (Jacques Cousteau, Delaware, and Virginia) encompass entire or some fraction of these full gradients, while two (Hudson and Maryland) contain sites within one ecotype (tidal and non-tidal fresh).

Analysis of water quality and nutrient/chlorophyll parameters across these major site groupings produced predictable trends typical of estuarine systems, as did analyses of sites within reserves with full estuarine salinity gradients. Additional variability was readily explained by localized anthropogenic impacts, surrounding land use, and presence of SAV and/or adjacent tidal marshes. Estimates of NEM were generated that take into account the effect of wind speed on rates of air-sea exchange as well as tidally-varying water depth. Sites were generally heterotrophic across the region with only three sites – two with extensive SAV beds – being net autotrophic. Variations within heterotrophic sites were explainable by the presence of extensive marshes, urban development, and relatively open waters. Interannual variations in salinity, DO, nutrients, chlorophyll, and NEM could be related to freshwater flow in many cases within the reserves with full estuarine salinity gradients. In several instances parameter concentrations tended to increase with increasing flow and in some cases exhibited intermediate optima, presumably reflecting a balance between nutrient delivery and dilution through flushing.

3. Utilization

a) End User Application

This final report will be distributed to the Directors and Research Coordinators at each Mid-Atlantic NERR for distribution within their program and externally as they see fit. All datasets (e.g. monthly and daily averages, metabolism, etc) and graphical results generated during this project will be freely available upon request. This report will be revised into one or more manuscripts for publication in scientific journals.

b) Intellectual Property and Partnerships

N/A

c) Knowledge Exchange

- Workshops and trainings.

  Drs. Moore and Brush attended a regional meeting of the mid-Atlantic NEERS Research Coordinators in May 2005 to discuss project objectives and identify areas of greatest interest to each RC. Final reports will be distributed to each reserve.

- Conference presentations, small group presentations, and tradeshows.

  Project results have been included as parts of the following oral presentations:

  Brush, M.J. 2005. The role of benthic-pelagic coupling in the development of seasonal hypoxia / anoxia at three spatial scales in the Chesapeake Bay. Estuarine Research Federation biennial meeting, Norfolk, VA.

  Brush, M.J. 2005. An innovative, hybrid empirical-mechanistic modeling capability in support of estuarine systems analysis and ecosystem-based management. Virginia Institute of Marine Science, Gloucester Point, VA.

  Brush, M.J. 2005. An innovative, hybrid empirical-mechanistic modeling capability in support of estuarine systems analysis and ecosystem-based management. Chesapeake Biological Laboratory, Solomons, MD.

  Brush, M.J. 2007. Dissolved oxygen dynamics at three spatial scales in the Chesapeake, with some lessons from Narragansett Bay. Invited seminar, University of Maryland Integration and Application Network, Annapolis, MD.

  Project results will be included in the following upcoming poster:

  E.D. Condon, M.J. Brush, and K.A. Moore. 2007. Hurricanes and Hypoxia: Analyzing Responses of Shallow-Water Systems to Storms Using High-Frequency Data. Estuarine Research Federation, Providence, RI.

- Manuscripts (with citations) published or submitted to refereed journals.
  None at this time.

- Students that worked on the project:
  Mr. Ben Lawson, and undergraduate at Old Dominion University who works in Dr. Brush's lab, provided assistance in some of the data processing and analysis.

4. Next Steps to Application

This project was a synthesis of existing data, so there is no relevant technological application.

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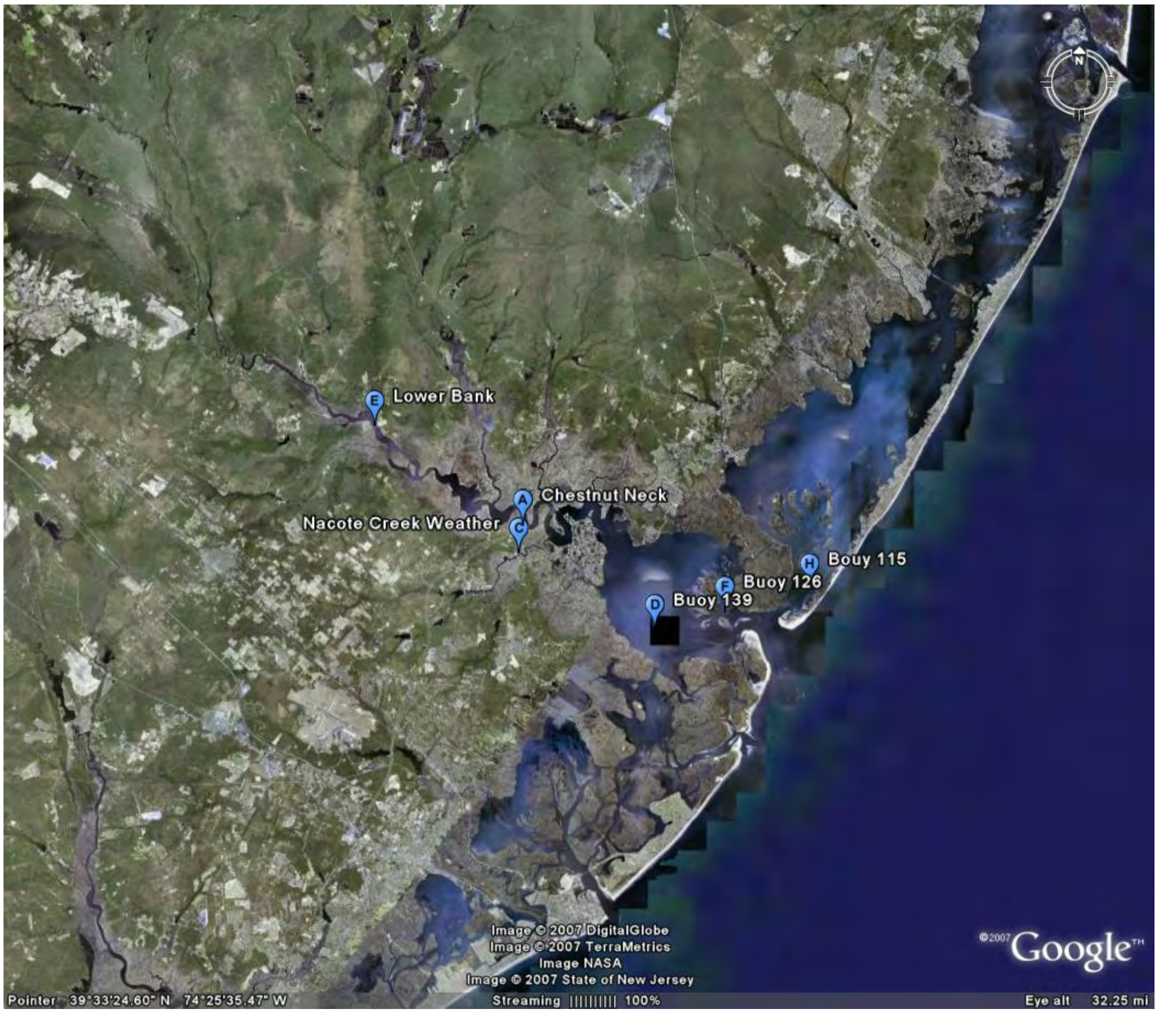
Appendix A. Google Earth images of each Mid-Atlantic Reserve.

Hudson NERR:

Jacques Cousteau NERR:



Delaware NERR:

Chesapeake Bay-
Maryland NERR:

Chesapeake Bay-Virginia NERR:

Appendix B. Site Descriptions.

Five NERR sites (Fig. 1) were included in this synthesis, with four of the five sites (Chesapeake Bay, Virginia; Chesapeake Bay, Maryland; Delaware Bay; and Jacques Cousteau Reserve, New Jersey) characterized as "Mid Atlantic" in previous analyses (Wenner et al., 2001; Caffrey, 2004). The Hudson River, New York reserve was grouped in the "Northeast" region in previous analyses. The following site descriptions were compiled from the metadata associated with SWMP water quality, nutrient, and meteorological data at each reserve.

Hudson River NERR (HUD):
The Hudson River, New York NERR site is a network of four wetlands located along 100 miles of the Hudson River estuary. The SWMP has monitoring stations at four sites in the Tivoli Bays watershed in Dutchess County: Saw Kill Creek, Tivoli South, Tivoli North, and Stony Creek. Saw Kill and Stony Creeks are respectively the main tributaries of Tivoli South and Tivoli North Bays. The Hudson River is tidal freshwater at Tivoli Bays, with average tidal range of 3.9 feet.

Tivoli South Bay (42° 01'37.336" N, 73° 55' 33.445" W) is a large, shallow cove on the eastern shore of the Hudson River. The bay is a tidal freshwater wetland with intertidal mudflats exposed at low tide; depth ranges from 0.5 to 2.5 m. A network of creeks and pools is beginning to form in the bay's shallows and mudflats. Non-tidal freshwater input includes that of a large upland tributary (Saw Kill Creek) and a few small perennial streams. During the growing season (June-September), the subtidal area of the bay is dominated by the invasive floating macrophyte *Trapa natans* (Eurasian water chestnut). The tidal swamp between Tivoli South and Tivoli North Bays is a mixed deciduous community with a well-developed shrub layer and abundant moss species. Clay bluffs and rocky islands support mixed forests dominated by oak, hickory, eastern hemlock, and pine. Tivoli South Bay has a soft, silt/clay bottom, with low sedimentary concentrations of PCBs. The Tivoli South Bay site consists of 2-20% impervious surface, with >50% of the habitat consisting of a mix of natural vegetation and harvested area (Wenner et al., 2001). The soil type is clay loam. Shellfish beds, SAV beds, and emergent vegetation are abundant, with 25-50% forest cover (Wenner et al., 2001).

Saw Kill Creek (42° 01'01.543" N, 73° 54' 53.589" W) is the major tributary flowing into Tivoli South Bay. Its watershed is 26.6 square miles; land use in watershed includes forested (51.1%), agricultural (25.8%), and urban (16.5%) areas. Water depth at the site ranges from 0.5 – 2.0 m. The creek is non-tidal; freshwater inputs consist of smaller creeks in the watershed. Creek discharge ranges from 2×10^{-5} to 1.2 m^3/sec. The bottom is mostly rocky, with a sand loam soil type (Wenner et al., 2001). Shellfish beds, SAV beds and emergent vegetation are sparse at the site, with 25-50% forest cover (Wenner et al., 2001). High concentrations of nitrate and phosphate have previously been documented in Saw Kill Creek.

Tivoli North Bay (42° 02' 11.56464" N, 73° 55' 31.16645" W) is less than one mile north of Tivoli South Bay. The site is predominantly intertidal marsh with a well-developed network of tidal creeks and pools. The marsh is freshwater tidal with emergent marsh vegetation; depth range of 0.5 – 3.0 m at sampling location. The freshwater tidal marshes are dominated by the cattail *Typha angustifolia*, spatterdock, and invading purple loosestrife and common reed. The subtidal shallows support communities of submerged water celery; freshwater intertidal mudflat and shore communities are also present. Non-tidal freshwater input includes that of a large upland tributary and a few small perennial streams. The bottom type is soft, silt/clay, with low sedimentary concentrations of PCBs.

Stony Creek (42° 02’ 45.556” N, 73° 54’ 40.237” W) is the main tributary flowing into Tivoli North Bay. The creek’s watershed is 23 square miles and is dominated by agricultural land use. The creek’s depth range is 0.5 to 1.5 m. The bottom of the creek is solid rock. A small swamp at the mouth of the creek is a mixed deciduous community with a well-developed shrub layer and abundant moss species. High concentrations of nitrate and phosphate have previously been documented in Saw Kill Creek.

Jacques Cousteau NERR (JAC, formerly MUL):
The Jacques Cousteau National Estuarine Research Reserve (JNERR) at the Mullica River-Great Bay estuary is located on the south-central coastline of New Jersey. The estuary is near Tuckerton, New Jersey about 14 km north of Atlantic City. Water is the predominant habitat in the reserve, covering 27,599 ha (~ 60% of the area). Marsh covers an additional 13,034 ha (>28% of the area). Forest covers 4,616 (~10%), and developed landscape, which is relatively sparse, covers 553 ha (~1% of the area). Domestic development is concentrated in two small communities, Mystic Island and Tuckerton, whose boundaries extend to within 3 km of the margin of Great Bay. There are five monitoring stations in the Reserve: Lower Bank and Chestnut Neck sites are in the Mullica River, Buoy 126 and 139 are in Great Bay, and Buoy 115 in Little Egg Harbor. Buoy 115 is a nutrient monitoring station and does not have a water quality datasonde.

Buoy 126 (39° 30.479’ N, 74° 20.308’ W) is located 3 km from Little Egg Inlet on the eastern side of Great Bay. The site is 100 m from the nearest land – a natural marsh island. Buoy 126 is the closest monitoring station to Little Egg Inlet. Great Bay is 7 km long (mainstream linear dimension), has an average depth of 3 m MHW, and an average width of 6.75 km. Tides at Buoy 126 are semidiurnal and range from 0.68 m to 1.55 m (average 1.07 m). At the sampling site, the depth is 4.23 MHW and the width is 3.5 km. Creek bottom habitats are fine to coarse sand with no bottom vegetation but extensive blue mussel (*Mytilus edulis*) beds surrounding the site. All upland areas near the sampling site are natural marsh islands that are state or federally owned and protected areas. There are strong tidal currents in the area (2-3 knots). Groundwater inputs from the margins of the estuary and surface flow from the Mullica River account for most of the fresh water affecting the site. Freshwater inputs from local precipitation and marsh surface runoff are of secondary importance. Activities potentially impacting the site include recreational boating, fishing, and clamming. There is <2% impervious surface in the area, with no harvested/developed land, and >50% vegetation (Wenner et al., 2001). Shellfish beds are abundant, SAV beds are absent, and emergent vegetation is abundant, with <25% forest cover (Wenner et al., 2001). This is a relatively deep area that has never been dredged, but is about 0.5 km from an area in the Intracoastal Waterway that is dredged regularly. The dredged material is coarse sand.

Buoy 139 (39° 29.883'N, 74°22.873'W) is 4 km from Buoy 126 on the western side of Great Bay; about 1-2 km from land. The closest landform is an extensive saltmarsh about 1.5 km wide, bordering the upland area. This area is dredged every 5 to 6 years by the U.S. Corps of Engineers to maintain the channel at a depth of about 2.5 meters. The average depth is 2.47 m with a range of 1.77 to 3.29 m. The surrounding Bay depth is 1-2 m, with a tidal range of 1.77 to 3.29 m. The site has maximum currents of about 1.5 knots. Most fresh water affecting the site from groundwater inputs along the margins of the estuary as well as surface flow from the Mullica River. The bottom consists of muddy sand with little shell.

Chestnut Neck (39° 32.872' N, 74° 27.676' W) is 12 km up the Mullica River from the mouth, which begins at a line drawn between Graveling Point and Oysterbed Point on the northwestern side of Great Bay. The river is 250 m wide at this site, and the average depth is 6 m. The tidal range is 0.5 – 2.5 m, and tidal currents are less than 1 knot during ebb and flood tide. Freshwater input is mainly from groundwater and land runoff. The sediment type is sandy, and this site has never been dredged.

Lower Bank (39° 35.618' N, 74° 33.091'W) is in the Mullica River, 13 km upriver of Chestnut Neck location. The river is 200 m wide at this point. The northern shore of the river has banks about 5 m high; the southern shore has an extensive marsh and fresh water wetland area about 300 km wide. This site is characterized by deep water (averaging 1.6 m with a tidal range of 0.6 to 2.5 m). There are fast tidal currents, just over 1 knot. Freshwater input is primarily from groundwater and watershed runoff. Sediment type is fine sand. The northern bank of the river is sparsely developed with single-family houses. There is <2% impervious surface, with <20% of the land harvested/developed, and the habitat is >50% vegetated. Shellfish beds and SAV beds are absent, and emergent vegetation is abundant, with >50% forest cover (Wenner et al., 2001).

Delaware NERR (DEL):
The Delaware National Estuarine Research Reserve is comprised of two component sites, the St. Jones River and Blackbird Creek components. Both components are located along the Delaware Bay coast. St. Jones River is the southernmost component, located in central Delaware, east of the state capitol, Dover. The Blackbird Creek component is located to the north, in the unincorporated area of Southern New Castle County.

The St. Jones River component includes the salt marsh and open water habitats typical of Delaware Bay. It includes tidal brackish-water and salt marshes, and open water of creek, river and bay areas, buffered by freshwater wooded fringe, farmlands and meadows. 90% of the tidal wetlands are classified as Zone 1 (dominated by saltmarsh cordgrass). Patches of Zone II (dominated by saltmeadow cordgrass and saltgrass) combine to form a salt hay community scattered through higher elevations. Big cordgrass and common reed are found along creekside levees and in backmarsh near the upland edge. Wetland areas upstream of Route 113 at Scotton Landing are vegetated primarily by mixed stands of *Spartina alterniflora* and *Spartina cynosuroides* (cordgrass). Wetland shrub species (groundselbush and marsh elder) also occur in tidal wetland areas of higher elevation. Limited palustrine forested wetlands occur at the head of numerous tidal creek tributaries to the St. Jones River.

Scotton Landing (39° 05’05.9160” N, 75° 27’38.1049” W) is located in the Lower St. Jones River at the Scotton Landing Public Fishing Pier, just upstream of DE Route 113. At the sampling site, the river is 40 m wide and the depth is 3.2 m MHW. The tidal range is 1.13 (Spring mean) to 1.26 m (neap mean). The sediment is clayey silt with no bottom vegetation. The dominant marsh vegetation near the sampling site is *Spartina alterniflora* and the dominant upland vegetation includes riparian forest and agricultural crops. Upland land near the sampling site is primarily agriculture and residential uses. Activities that potentially impact the site include a public boat ramp and freshwater runoff from the relatively urbanized area upstream. Pollutants in the area include PCBs. Wenner et al. (2001) characterized the Scotton Landing site as having 2-20% impervious surface, with >20% of the land harvested/developed, and >50% of the habitat developed. Shellfish beds and SAV beds are absent, and emergent vegetation is abundant. There is <25% forest cover, and the soil type is sand loam (Wenner et al., 2001).

Lebanon Landing (39° 06’ 51.8” N, 75° 29’ 57.1” W) is located in the mid portion of the St. Jones River, upstream of Scotton Landing, where the river depth is 3.0 m and the width is 28 m. Tidal range is 0.671 m (Neap mean) to 0.855 m (Spring mean). The sediment is clayey silt with no bottom vegetation. The site is influenced by freshwater runoff from the relatively urbanized area upstream. Pollutants in the area include PCBs.

Division Street (39° 09’ 49.4” N, 75° 31’ 08.7” W) is located in the upper portion of the St. Jones River near the USGS station on Division Street. The river width is 26 m and the depth is 0.6 m MHW at the site. The site is nontidal. The sediment type is clayey silt with no bottom vegetation. The site is fresh water and is influenced by urban freshwater runoff.

Penrose Branch (39° 09’ 52.77” N, 75° 39’ 01.52” W) is located in the headwaters of the St. Jones Basin, north of Dover. At the sampling site, the depth is 0.1 m, width is 6 m. The branch is 4.7 km long, and the depth range of the branch is 0.1 – 1 m. The site is principally a forested wetland tributary system with no bottom vegetation. Bottom habitat consists of leaf litter and lower portions of emergent aquatic vegetation. There are some agriculture land uses along the subcatchments. The site is nontidal freshwater.

The Blackbird Creek component includes freshwater wetlands, ponds and forest lands. It is located upstream from Delaware Route 9 at Taylors Bridge, in New Castle County. The creek drains a portion of southern New Castle County, a predominantly rural area, consisting of wetlands, forests and agricultural lands. Blackbird Creek flows into the Delaware River just upstream from Delaware Bay, and includes freshwater tidal and non-tidal wetlands and brackish-water marshes. The easternmost seaward quarter of the reserve is a saltmarsh cordgrass marsh dominated by *Spartina alterniflora* and the common reed. In the slightly higher elevations, vegetation includes saltmeadow cordgrass, big cordgrass, salt grass, salt wort, high tide bush, and groundsel bush. The upland fringe is mixture of shrub and tree species, including hardwoods and softwoods. Most of the lower Blackbird Creek estuary has been overrun by phragmites, forming dense, monotypic cover over vast expanses of wetlands. The creek is 25.8 km long (mainstream linear dimension), has an average depth of 3 m MHW, and an average width of about 90 m.

The Blackbird Landing site (39° 23' 19.5196" N, 75° 38' 09.5882" W) is located in the upper Blackbird Creek at Blackbird Landing Road. At the sampling site, the depth is 1.8 m MHW and the width is 110 m. Bottom habitats are predominantly silt and clay, with no bottom vegetation. The dominant upland vegetation near the site is *Spartina alterniflora*, and the dominant upland vegetation types are tidal swamp and upland forest. The site is influenced by freshwater runoff from unimpacted forested areas intermixed with agricultural land uses and a small amount of low-density development. There is sporadic refuse dumping in the area, but generally there is very little pollutant presence in the area. Tidal range is from 1.12 m (Spring mean) to 1.13 m (Neap mean). Wenner et al. (2001) characterized the site as having <2% impervious surface, with >20% of the land area harvested or developed, and >50% of the habitat a mixture of vegetated/harvested land. Soil type is clay loam. Shellfish beds and SAV beds are absent, and emergent vegetation is abundant (Wenner et al., 2001).

Chesapeake Bay-Maryland NERR (CBM):
The Chesapeake Bay, Maryland reserve consists of three components, two of which have SWMP water quality monitoring stations. Both components are on the western side of Chesapeake Bay: the Jug Bay component is located 20 miles from Washington, D.C., in the tidal headwaters of the Patuxent River. The Otter Point Creek component is 19 miles northeast of Baltimore, Maryland, in the tidal headwaters of the Bush River along the upper western shore of the Chesapeake Bay.

The Patuxent River Park, Jug Bay, Railroad Bridge, Mataponi Creek, and Iron Pot Landing sites are all located in the Jug Bay component, in the Patuxent River watershed. There is one site in the Otter Point Creek component. The Jug Bay site was moved to Railroad Bridge in 2003 due to the shallow nature of the Jug Bay site. The Patuxent River site was also not sampled after 2002. Sampling at Mataponi Creek and Iron Pot Landing began in 2003.

Mataponi Creek (38° 44.599'N, 76° 42.446'W) is in the Jug Bay Component of the Reserve, in a small tributary off the upper tidal headlands of the Patuxent River, Maryland. The site is 2.4 km upstream from the mouth of Mataponi Creek, in the midchannel of the creek, which is 7 km wide at that point. The site is located along the main channel of creek, so water quality is reflective of the water flowing along the main portion of the creek. The mean tidal fluctuation is 0.6 m. Sediment is soft, with abundant and dense submerged macrophytes during summer months, influencing water quality during this time. There is limited anthropogenic activity in this area; therefore, Mataponi Creek is considered a “reference” water quality site for the Reserve.

The Patuxent River Park site (38° 46’23.5” N, 76° 42’32.5” W) is on the west side of Jug Bay, in the upper tidal headwaters of the Patuxent River, which is 50 m wide at this point. The site is located along the main channel of the Patuxent River, 1.5 km downstream of the confluence of the Western Branch tributary with the Patuxent. There are extensive riparian buffers along the portion of the river that flows through the site. The site is approximately 3 km downstream from a large wastewater treatment plant that discharges directly into the Western Branch tributary. The average depth at the site is approximately 2 m, and the tidal range is approximately 0.5 m. The sediment is silt-clay, extremely fine and easily resuspended, with no bottom vegetation. The dominant marsh vegetation near the sampling site includes cattails and wild rice. The dominant upland vegetation is mixed hardwood forest. Wenner et al. (2001) characterized the dominant habitat as “Fresh marsh”, with <2% impervious surface, >20% of the adjacent land harvested/developed, and >50% of the adjacent land cover a combination of natural vegetation and agricultural land. Shellfish beds are absent, SAV is sparse, and emergent vegetation is abundant at this site, with >50% forest cover (Wenner et al., 2001). This site was not sampled after 2002.

Railroad Bridge (38° 46.877’N, 76° 42.822’W) is in the mainstem of the upper tidal headwaters of the Patuxent River, slightly upstream (0.3 km) from the former Patuxent River site. This site was moved from the Jug Bay site in 2003 because of the shallow nature of the old site. This section of the Patuxent River is approximately 70 m wide and average depth at the site is 1.4 m. Mean tidal fluctuation is approximately 0.6 m. The bottom habitat is soft sediment, with submerged macrophyte grassbeds evident in shallow areas (<0.5 m MLW) during summer months. The site is along the main channel of the Patuxent River; roughly 1 km downstream of the confluence of Western Branch tributary and the Patuxent River mainstem, thus water quality is influenced by Western Branch and its large wastewater treatment plant.

The Jug Bay site (38° 46’50.6” N, 76° 42’29.1” W) is located in a shallow tidal creek adjacent to the Patuxent River, slightly upstream (0.3 km) from the former Patuxent River site. The site is in a shallow creek that is tidally infiltrated by a backwater marsh adjacent to the Patuxent River mainstem. At low tide, the marsh becomes a large mud flat with very little standing water. The creek ranges from 2-5 m in width at this site, with depth averaging 0.75 m. Tidal range is 0.5 m on average. Sediments are silt-clay, very fine and flocculent, with no bottom vegetation. Surrounding vegetation includes wild rice, cattails, arrow arum, arrowhead, pickerelweed, spatterdock, rose mallow, and *Phragmites* sp. (Wenner et al. 2001). Upland vegetation includes mixed hardwood forests of oaks, hickory, sweet gum, American beech, poplars, red maple, sassafras, and Virginia pine. The sub-canopy includes American holly, sweet bay, musclewood, flowering and silky dogwood, witch hazel, smooth alder, red maple, and black gum. Due to the shallow nature of the site, the sonde was periodically exposed at very low tides. Large fluctuations in temperature and dissolved oxygen were noted, which are typical of extreme shallow water in marsh environments. The sewage treatment plant mentioned in the Patuxent River site description is also upstream of the Jug Bay site. Wenner et al. (2001) characterized the habitat as "Fresh marsh", with <2% impervious surface, >20% of the adjacent land harvested/developed, and >50% of the adjacent land cover a combination of natural vegetation and agricultural land. Shellfish beds are absent, SAV is sparse, and emergent vegetation is abundant at this site, with >50% forest cover (Wenner et al., 2001). The site was moved to Railroad Bridge in 2003 due to the shallow nature of the Jug Bay site.

Iron Pot Landing (38° 47.760'N, 76° 43.248'W) is in the Jug Bay reserve, 2.09 km upstream from the mouth of Western Branch where it empties into the Patuxent River. The river is approximately 15 m wide at this point and flows through extensive riparian buffers. Both banks of river are flanked by hardwood flora. Bottom habitat is soft sediment, and narrow submerged macrophyte grassbeds are occasionally evident in shallow areas downstream during summer months. Tides are semi-diurnal, with a mean tidal fluctuation of 0.6 m. Iron Pot Landing is considered an "impacted" site, because it is 1 km downstream of the large wastewater treatment plant effluent discharge site. Sampling at this site began in 2003.

The Otter Point Creek site (39° 27.047'N, 76° 16.474'W) is within the Otter Point Creek Component of the Reserve, in the tidal headwaters of the Bush River along the upper western shore of the Chesapeake Bay. The Bush River drains much of Harford County, including the rapidly growing town of Bel Air. The Otter Point Creek Component is a large but shallow tidally flooded marsh with average depths less than 1 m on low tide. Tides are semi-diurnal and have a mean range of about 0.3 m. Average water levels are lower in winter due to north and northwest winds that increase the egress from Chesapeake Bay. Bottom habitat is extremely soft sediment, with submerged macrophyte grassbeds inundating the site during summer months, creating a dense and almost impenetrable ground cover. Sediments are extremely fine and flocculent. Water quality at the site represents extreme shallow water habitats, with large fluctuations in temperature and dissolved oxygen. Domination of dense SAV communities from June-October likely influences water quality during these months. This site is thought to be representative of the Otter Point Creek Component during most of the year, except during summer months when the dense submerged macrophyte communities influence the site.

Chesapeake Bay-Virginia NERR (CBV):
The Chesapeake Bay, Virginia NERR reserve is located in the York River system, a tributary of the Chesapeake Bay. Four water quality sites are located within the reserve: Goodwin Islands, which is at the mouth of the York River; Claybank and Taskinas Creek, which are in the York; and Sweethall Marsh, in the Pamunkey River, a tributary of the York. The sites include a variety of habitats and are along a salinity gradient.

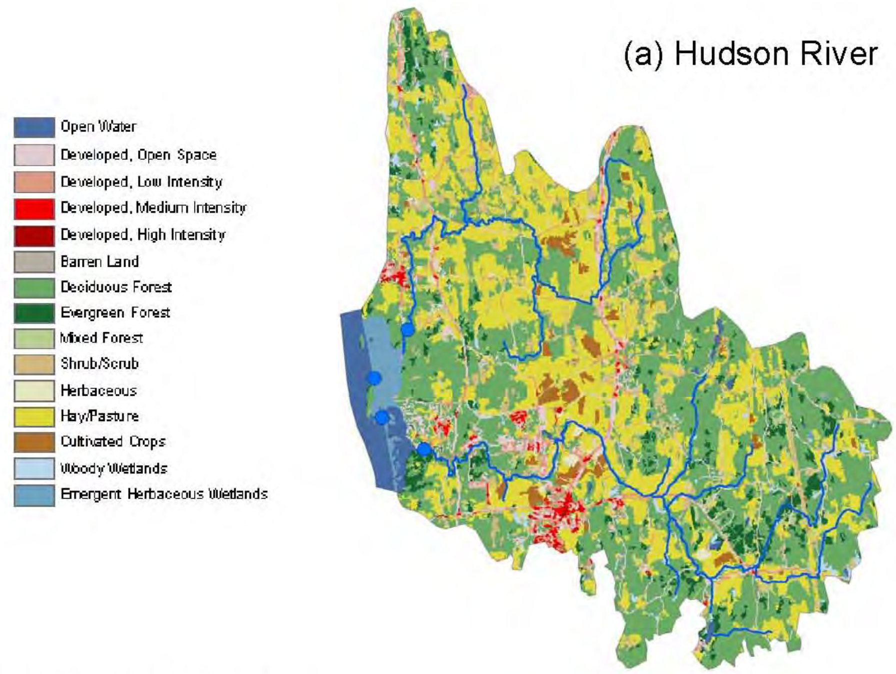
The Goodwin Islands site (37° 13' N; 76° 23' W) is a 315 ha (777 acre) archipelago of salt-marsh islands in shallow estuarine waters on the southern side of the mouth of the York River. The islands are surrounded by inter-tidal flats, 121 ha (300 acres) of submerged aquatic vegetation (SAV) beds, a constructed oyster reef, and shallow open waters. The salt marsh vegetation is dominated by salt marsh cordgrass (*Spartina* *alterniflora*) and salt meadow hay (*Spartina patens*). The forested wetland ridges are dominated by estuarine scrub/shrub vegetation. Upland ridges on the largest island are dominated by mixed oak and pine communities. The sampling station is located approximately 400 m from shore, in a shallow embayment on the southeastern side of the main island (Wenner et al., 2001). The station is in water approximately 1 m deep, among SAV beds dominated by eelgrass (*Zostera marina*) and Widgeon grass (*Ruppia maritima*). Tides are semi-diurnal, averaging 0.7 m (0.4 – 1.1 m range). Water circulation patterns around the islands are influenced by York River discharge and the wind patterns of Chesapeake Bay. The site is relatively pristine, with human activities in the area limited to light recreational and commercial boating and commercial fishing. Wenner et al. (2001) characterized the dominant habitat near the Goodwin Islands site as Eelgrass, and reported <2% impervious surface, no harvested or developed land, and >50% vegetation in the watershed. Shellfish beds, SAV beds, and emergent vegetation were abundant. The soil type is sand loam, and annual precipitation ranges from 0.5-1.3 m (Wenner et al. 2001).

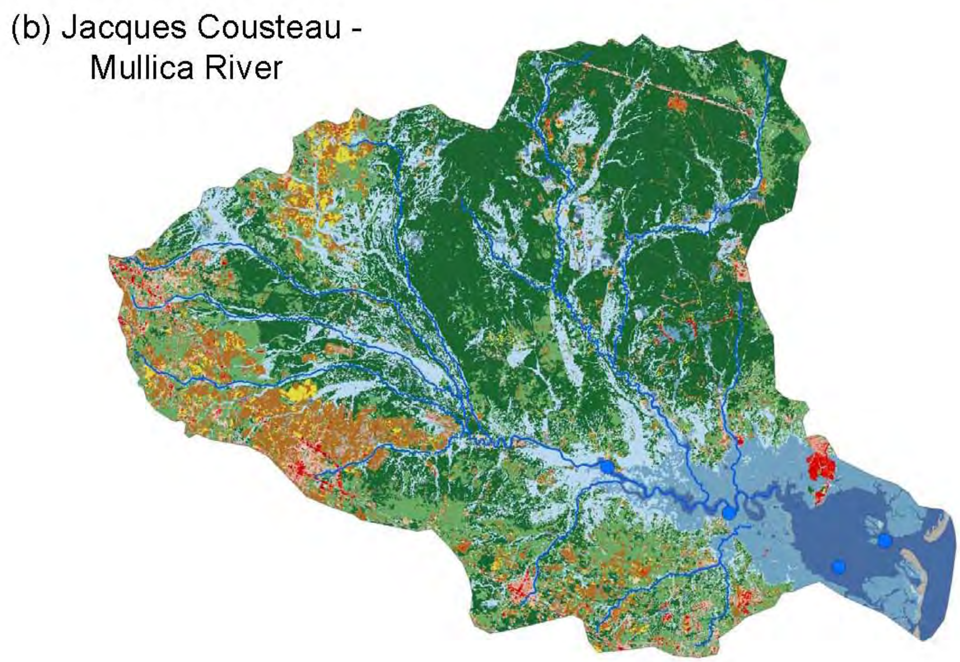
The Claybank site (37° 20' 51.58" N, 76° 36' 37.52" W), is within the mesohaline portion of the York River estuary, approximately 26 km upriver from the mouth of the river. The station is located along the north shoreline of the estuary, in a shallow (<2m) littoral area approximately 300-400 meters wide. The area was vegetated with SAV prior to 1972 but has remained unvegetated since that time. The shoreline consists of a narrow fringe of salt marsh with some areas armored with bulkhead or stone. The sampling station is influenced by a secondary turbidity maximum that moves back and forth in a region of about 20-40 km from the mouth of the York River estuary. The site is exposed to strong winds from the northwest and re-suspension of sediment during storm events can be high. The tidal range is 0.85 m on average, and the sediment type is muddy sand. This site has not been included in previous syntheses by Wenner et al. (2001), or others.

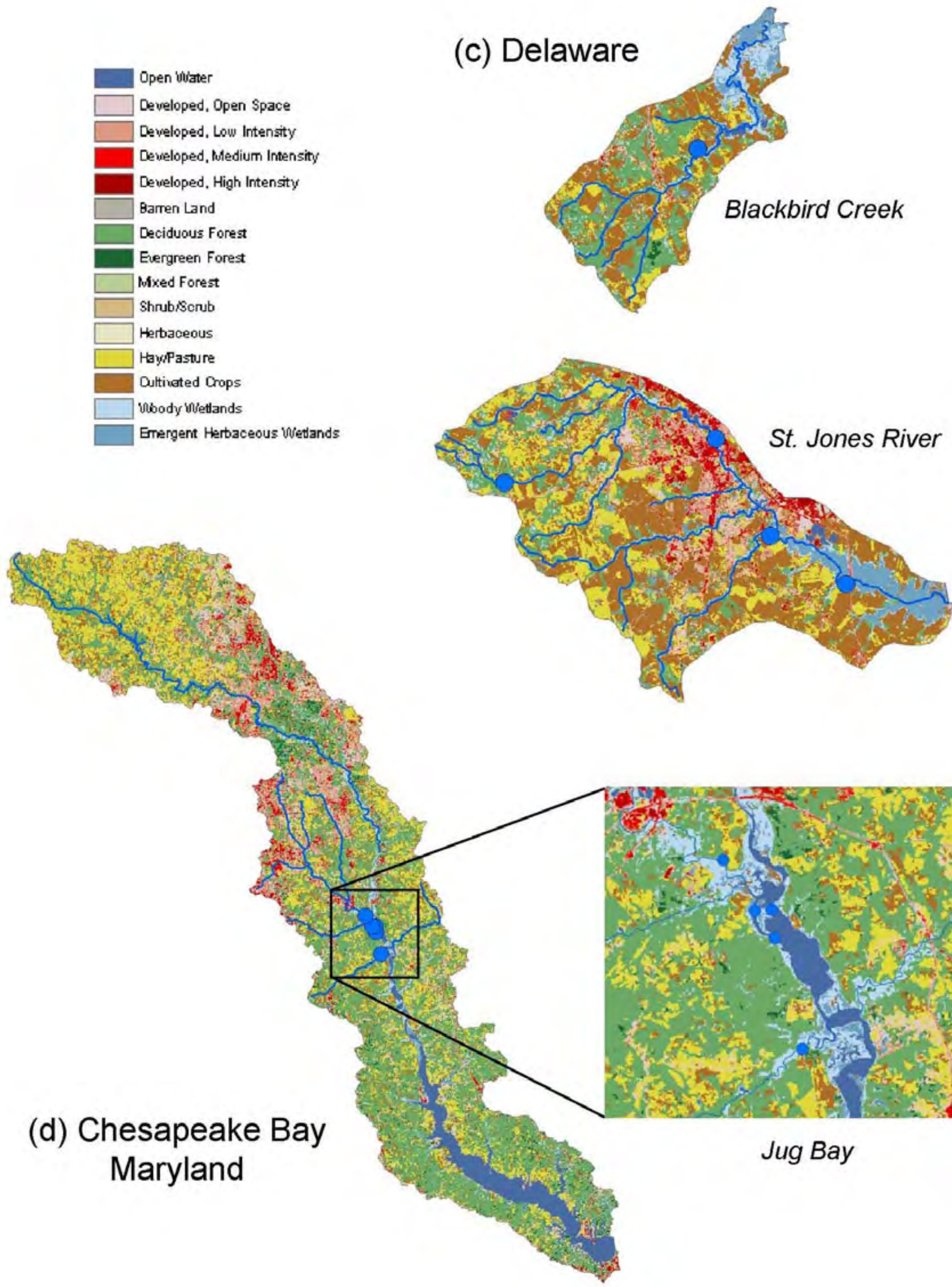
The Taskinas Creek site (37° 24' N; 76° 42') is located in a small subestuary of the York River on the southern side of the river, 44 km from the mouth of the York River. The site is in York River State Park, near the town of Croaker, Virginia. The watershed is representative of an inner coastal plain rural watershed, with forested and agricultural land uses with an increasing residential land use component. Taskinas Creek is approximately 2 m deep and 20 m wide towards the lower end of the creek, with small feeder streams draining into the non-tidal portion of the creek. The feeder streams drain oak-history forests, maple-gum-ash swamps, and freshwater marshes. There are freshwater mixed wetlands in upstream reaches of creek, with three-square (*Scirpus americanus* and *S. olneyi*) and big cordgrass (*Spartina cynosauroides*) found in the middle marsh reaches. Lower marsh reaches are salt marsh vegetation dominated by *Spartina alterniflora*. Tides at Taskinas Creek are semi-diurnal, ranging from 0.4-1.2 m, averaging 0.85 m. Fine sediments dominate the sub-tidal substrate. Wenner et al. (2001) characterized the habitat as Fresh marsh, and found that the watershed had <2% impervious surface, <20% harvested/developed land, with >50% of the habitat vegetated. Shellfish beds and emergent vegetation were abundant, and SAV beds were sparse. Annual participation ranged from 0.5-1.3 m (Wenner et al., 2001).

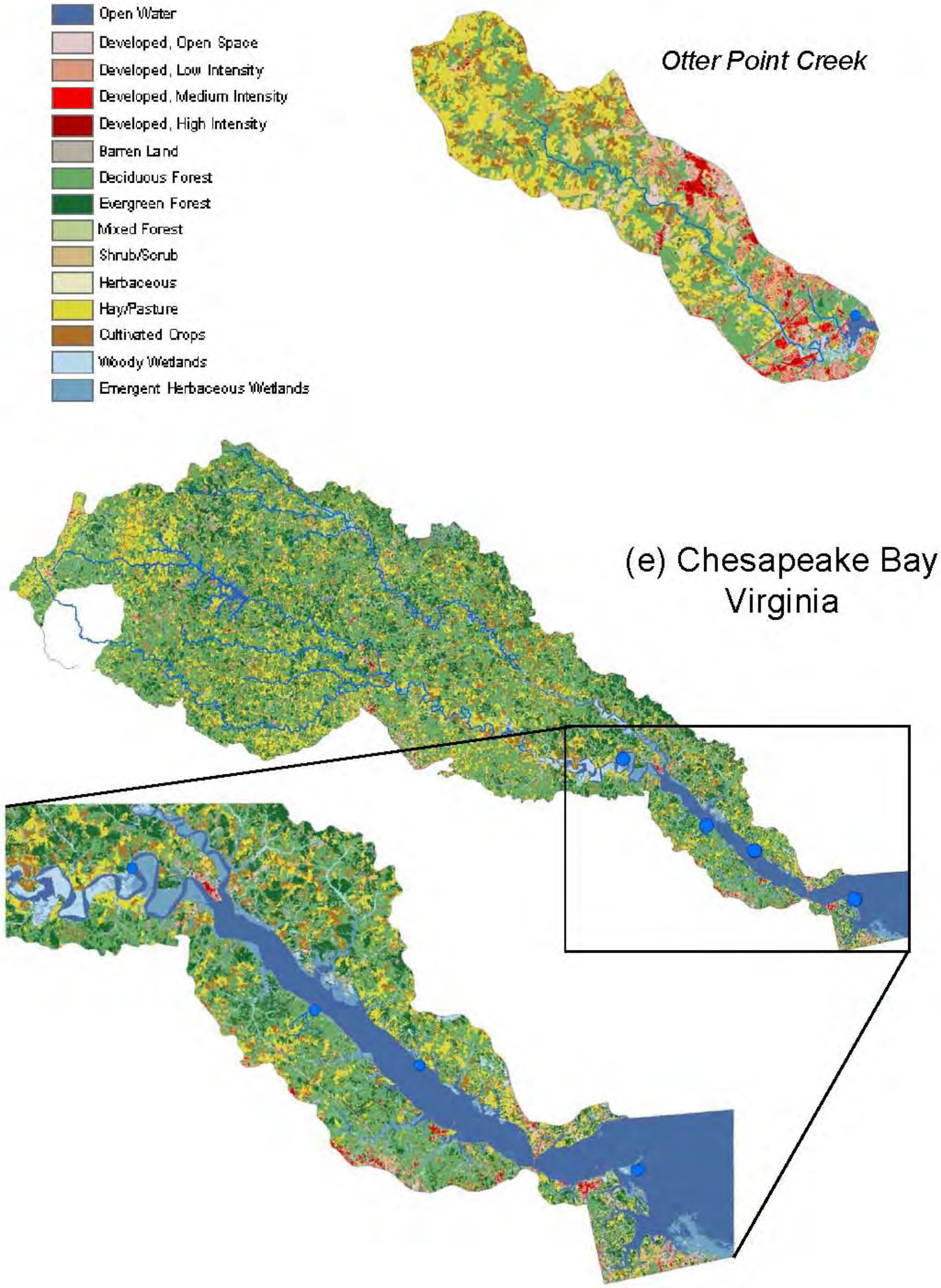
The Sweet Hall Marsh site (37° 34’ N; 76° 50’ W) is in the Pamunkey River, 83 km from the mouth of the York River and 35 km from West Point, where the Pamunkey converges with the Mattaponi River to form the York River. The reserve is 353 ha (871 acres) in area and includes 331 ha (818 acres) of emergent fresh-water marsh, 14 ha (35 acres) of permanently flooded broad-leaved forested wetlands and approximately 4 ha (9 acres) of scrub-shrub. The vegetation in the creekbank zone consists of Arrow arum, smooth cordgrass, big cordgrass, smartweeds, rice cutgrass, wild rice, water hemp, water dock, Walter’s millet, and marsh milkweed. The levee zone is dominated by creekbank species, sedges, reed grass, rushes, cattail, marsh mallow, and panic grass. The low marsh interior is dominated by arrow arum. Sensitive jointvetch (*Aeschenomene virginica*), a candidate for federal listing as endangered species, is found in the Sweet Hall Marsh reserve. The mean tidal range in at the site is 0.9 m.

Appendix C. 2001 National Land Cover Data (EPA) maps within the watersheds of each Mid-Atlantic reserve. Approximate watershed boundaries were digitized from medium resolution National Hydrography Dataset (USGS) line files. NERRs-SWMP water quality stations are shown with blue circles.

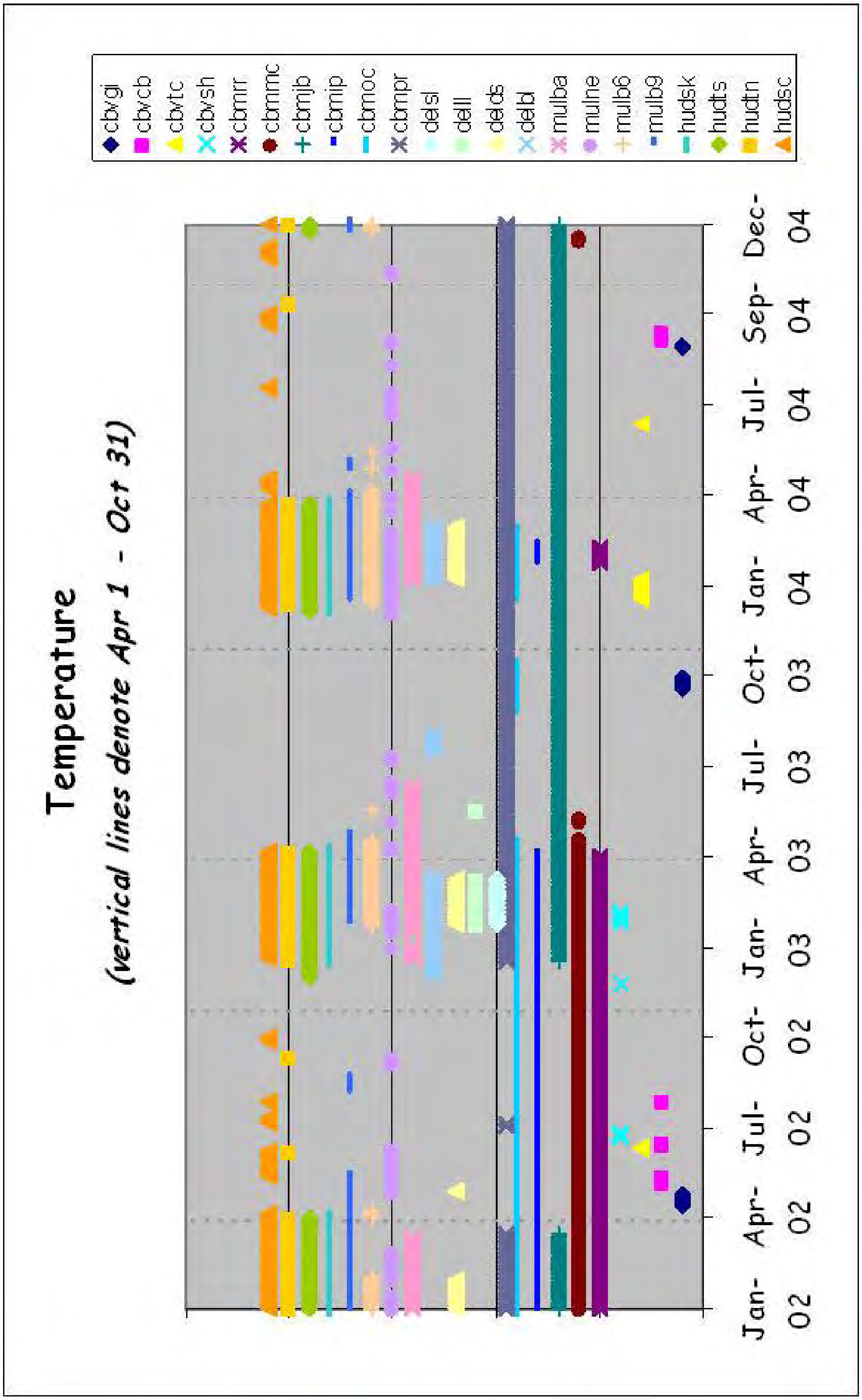


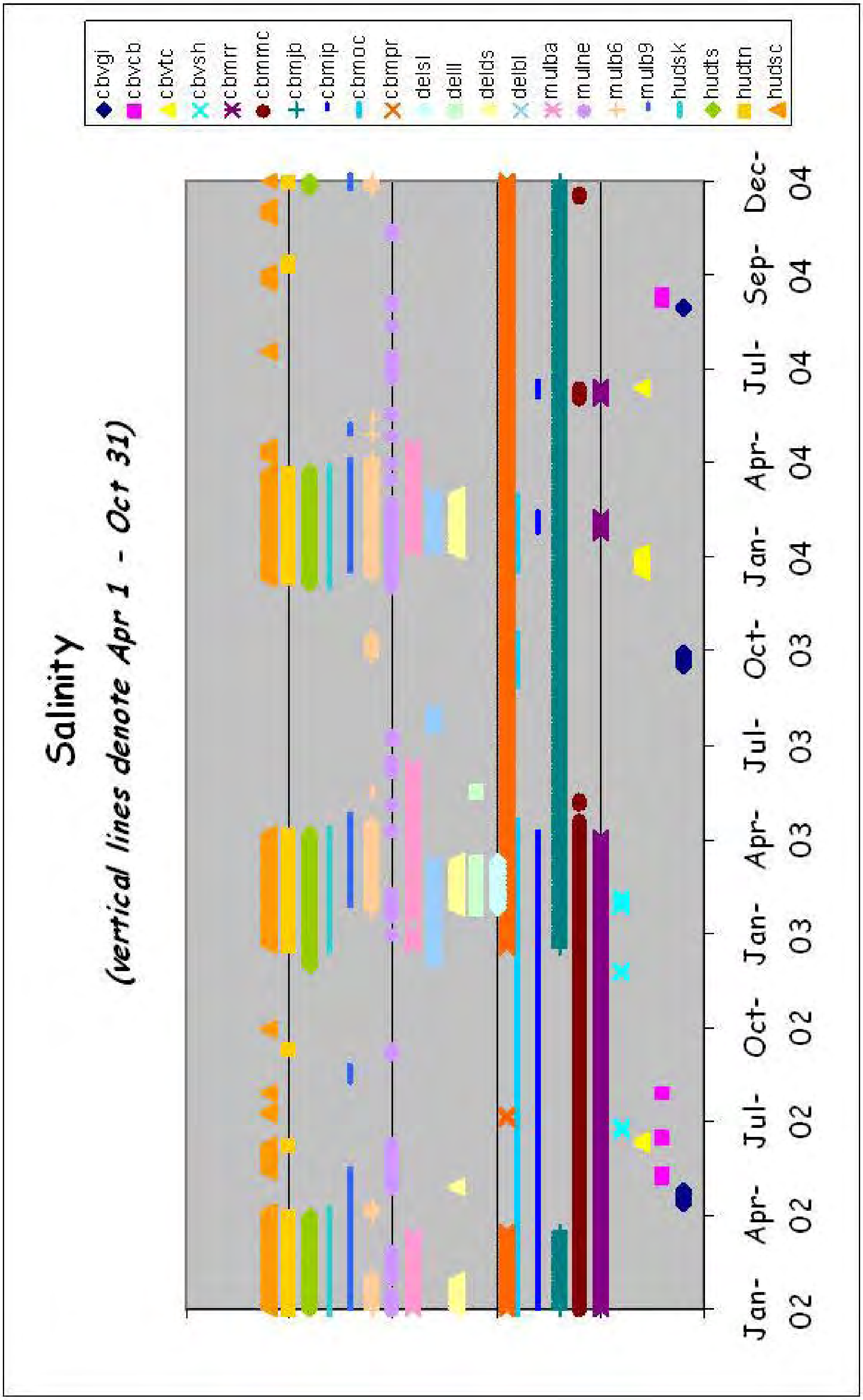


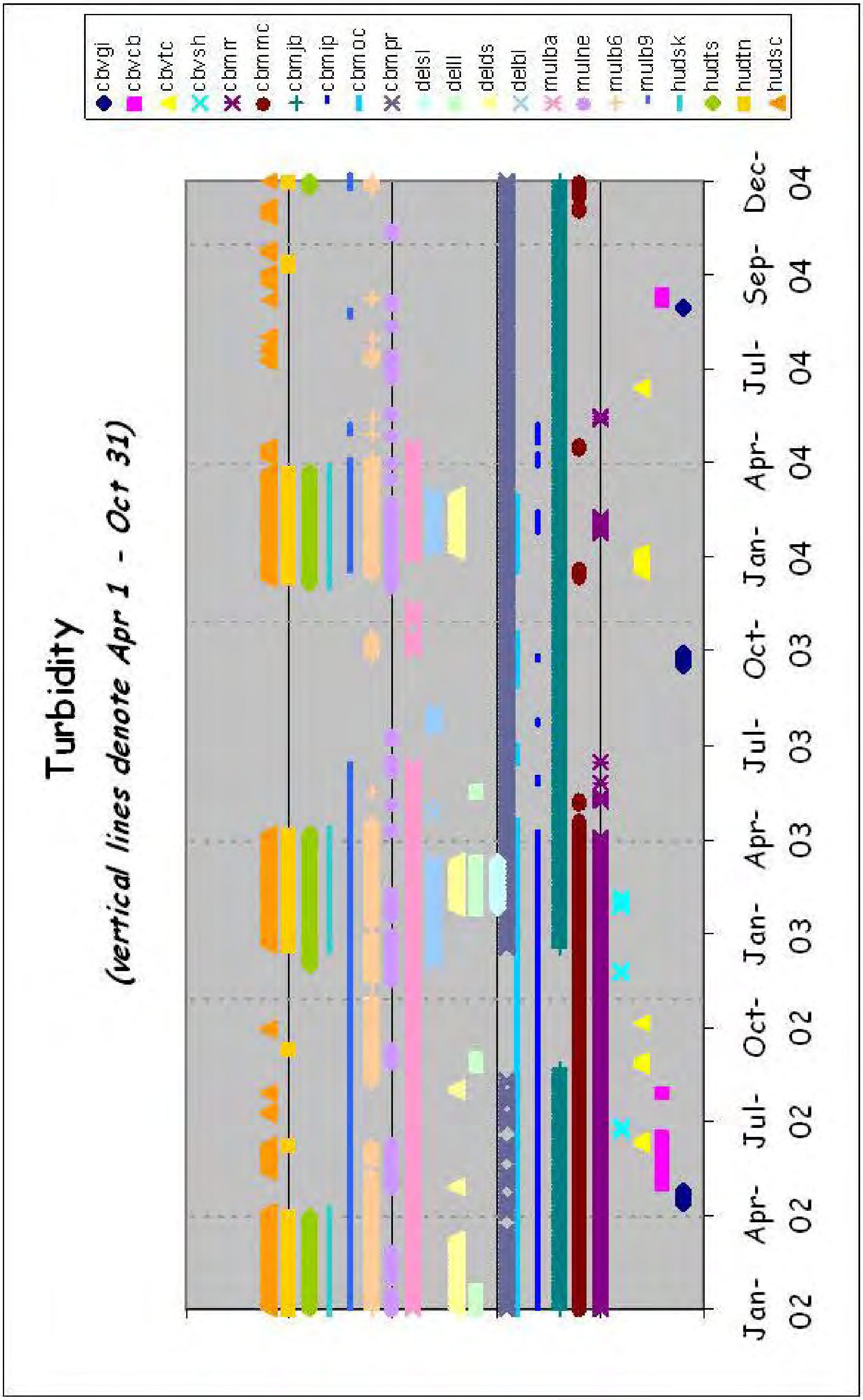

Open Water
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Herbaceous
Hay/Pasture
Cultivated Crops
Woody Wetlands
Emergent Herbaceous Wetlands
(c) Delaware
Blackbird Creek
St. Jones River
(d) Chesapeake Bay
Maryland
Jug Bay

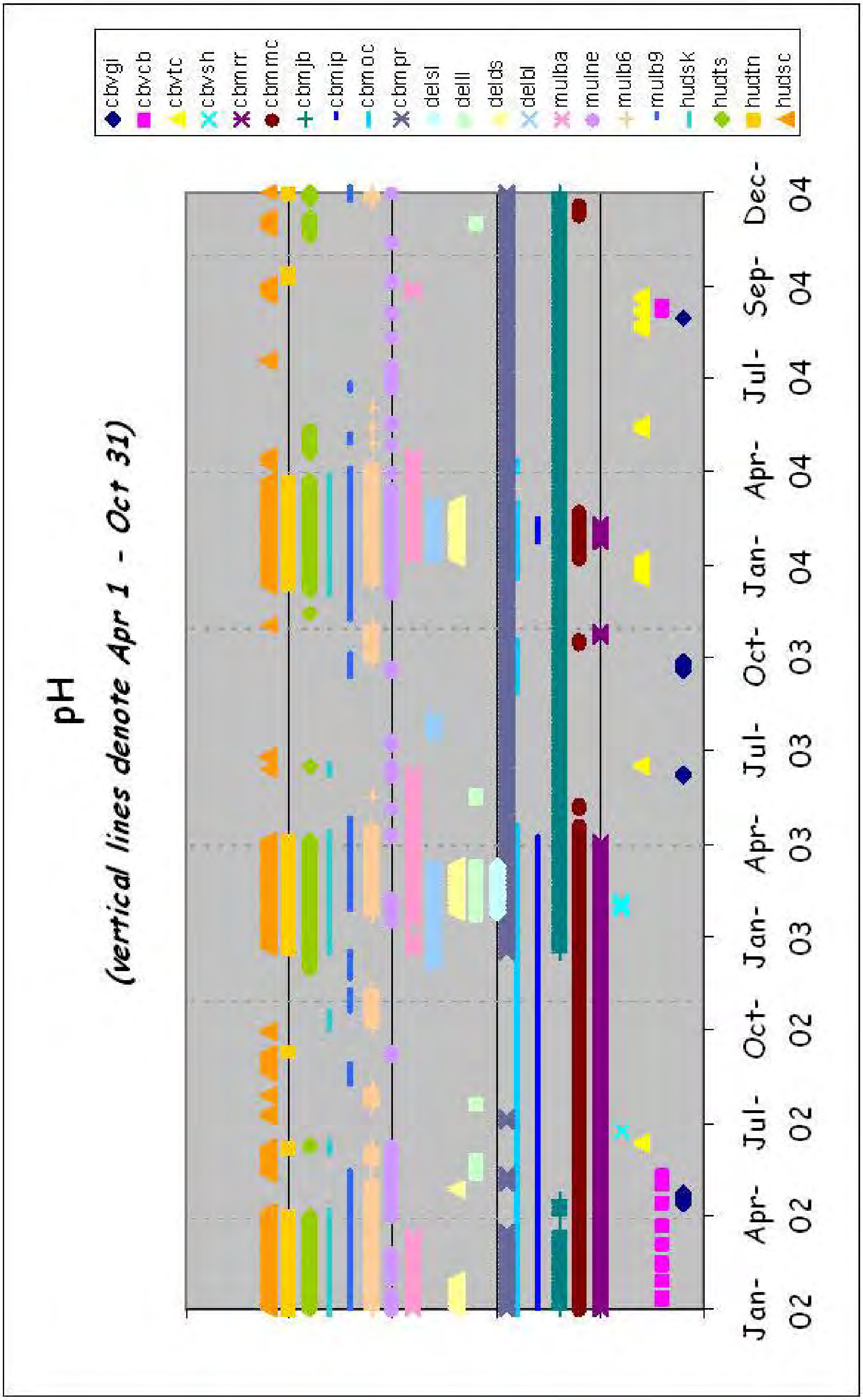

Open Water
Developed, Open Space
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Herbaceous
Hay/Pasture
Cultivated Crops
Woody Wetlands
Emergent Herbaceous Wetlands
Otter Point Creek
(e) Chesapeake Bay
Virginia

Appendix D. Missing water quality and nutrient data by site. Plotted points indicate a day in which data were not recorded or erroneous.

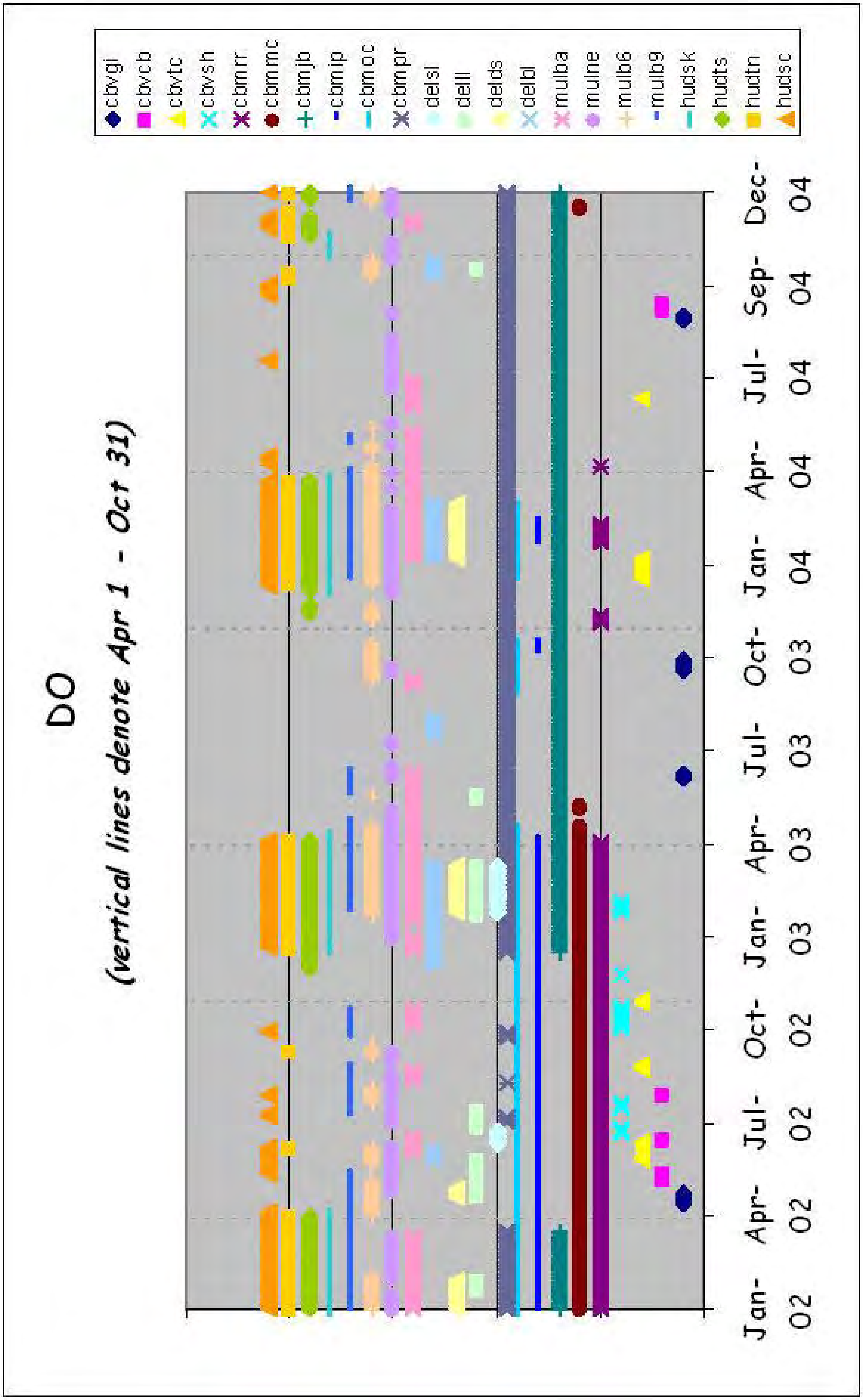


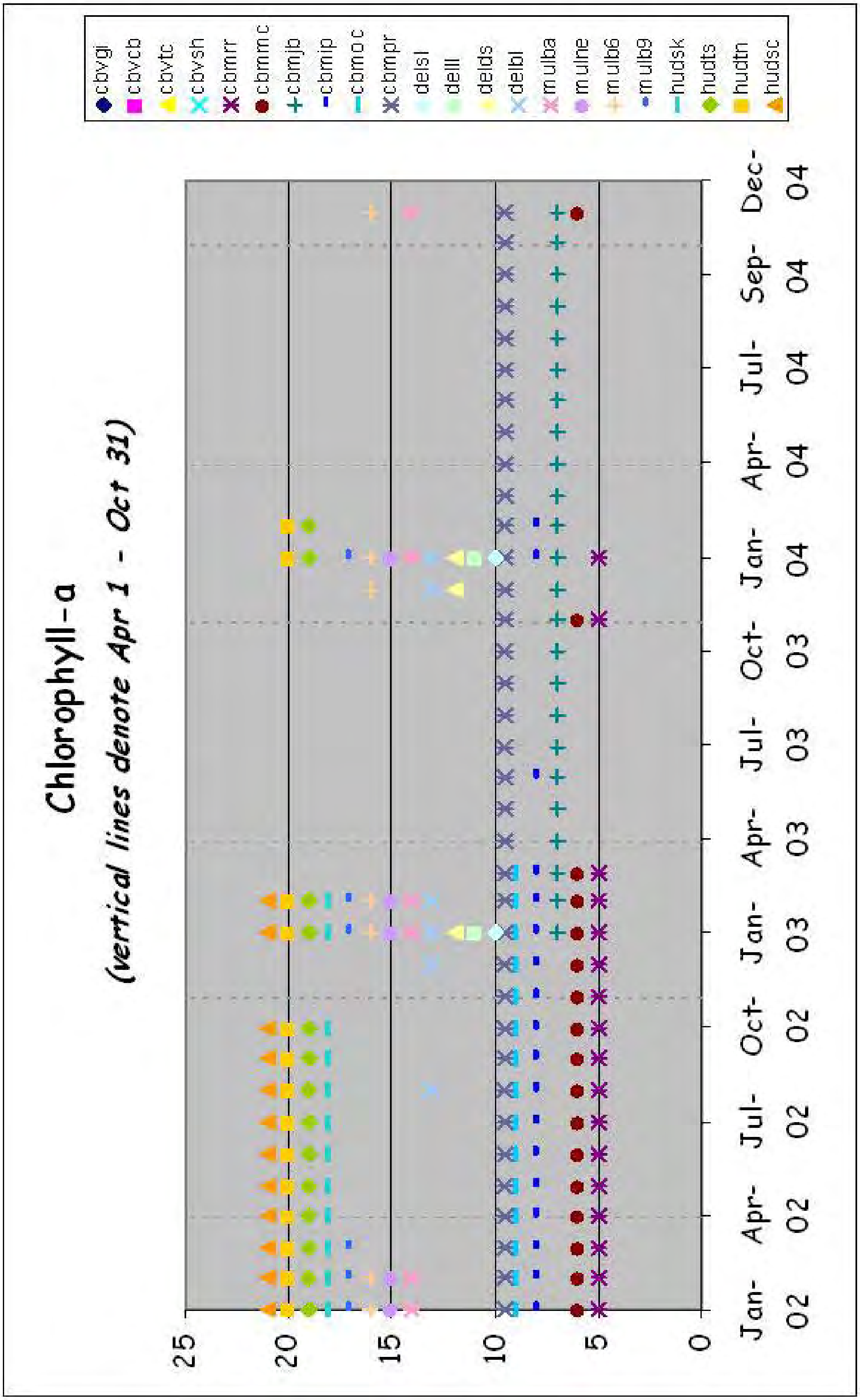

Salinity
(vertical lines denote Apr 1 - Oct 31)
cbvgi
cbvcb
cbvtc
cbvsh
cbmrr
cbmmc
cbmjb
cbmip
cbmoc
cbmpr
delsl
delll
delds
delbl
mulba
mulne
mulb6
mulb9
hudsk
hudts
hudtn
hudsc
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Sep-04
Dec-04


Turbidity
(vertical lines denote Apr 1 - Oct 31)
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Sep-04
Dec-04
cbvgi
cbvcb
cbvtc
cbvsh
cbmrr
cbmmc
cbmjb
cbmip
cbmoc
cbmpr
delsl
delll
delds
delbl
mulba
mulne
mulb6
mulb9
hudsk
hudts
hudtn
hudsc

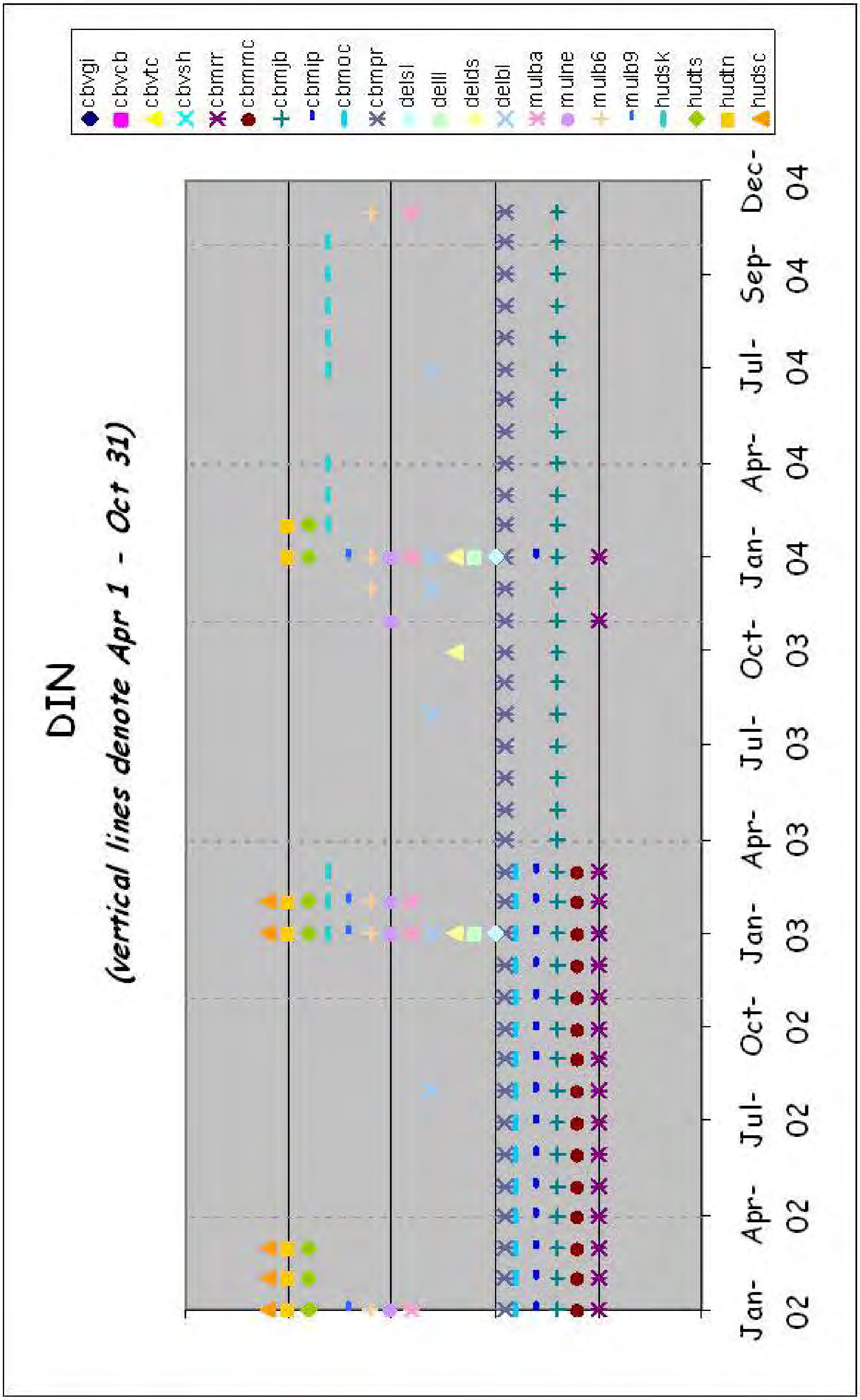


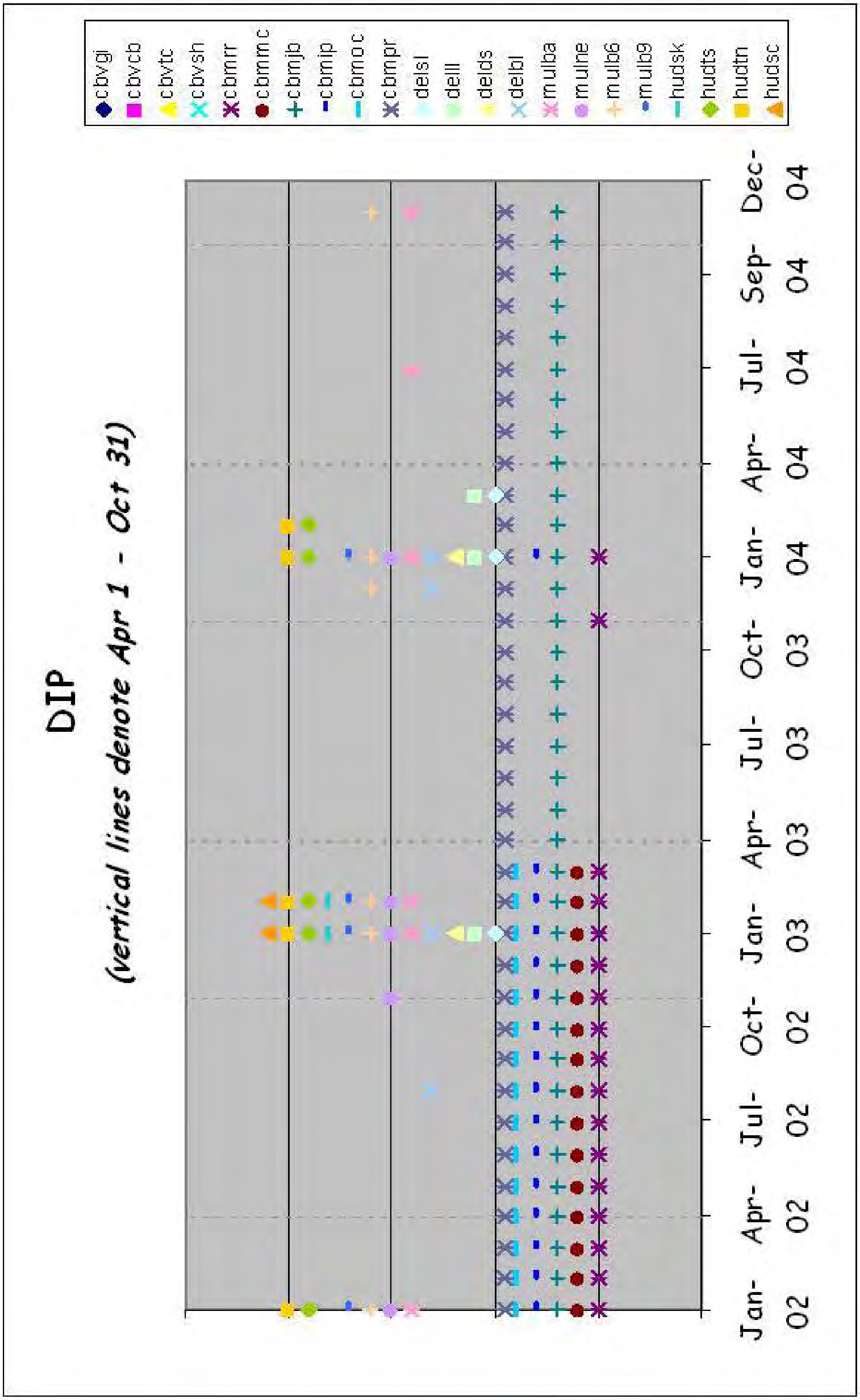
pH
(vertical lines denote Apr 1 - Oct 31)
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Sep-04
Dec-04
cbvgi
cbvcb
cbvtc
cbvsh
cbmrr
cbmmc
cbmjb
cbmip
cbmoc
cbmpr
delsl
delll
delds
delbl
mulba
mulne
mulb6
mulb9
hudsk
hudts
hudtn
hudsc


DO
(vertical lines denote Apr 1 - Oct 31)
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Sep-04
Dec-04
cbvgi
cbvcb
cbvtc
cbvsh
cbmrr
cbmmc
cbmjb
cbmip
cbmoc
cbmpr
delsl
della
delds
delbl
mulba
mulne
mulb6
mulb9
hudsk
hudts
hudtn
hudsc



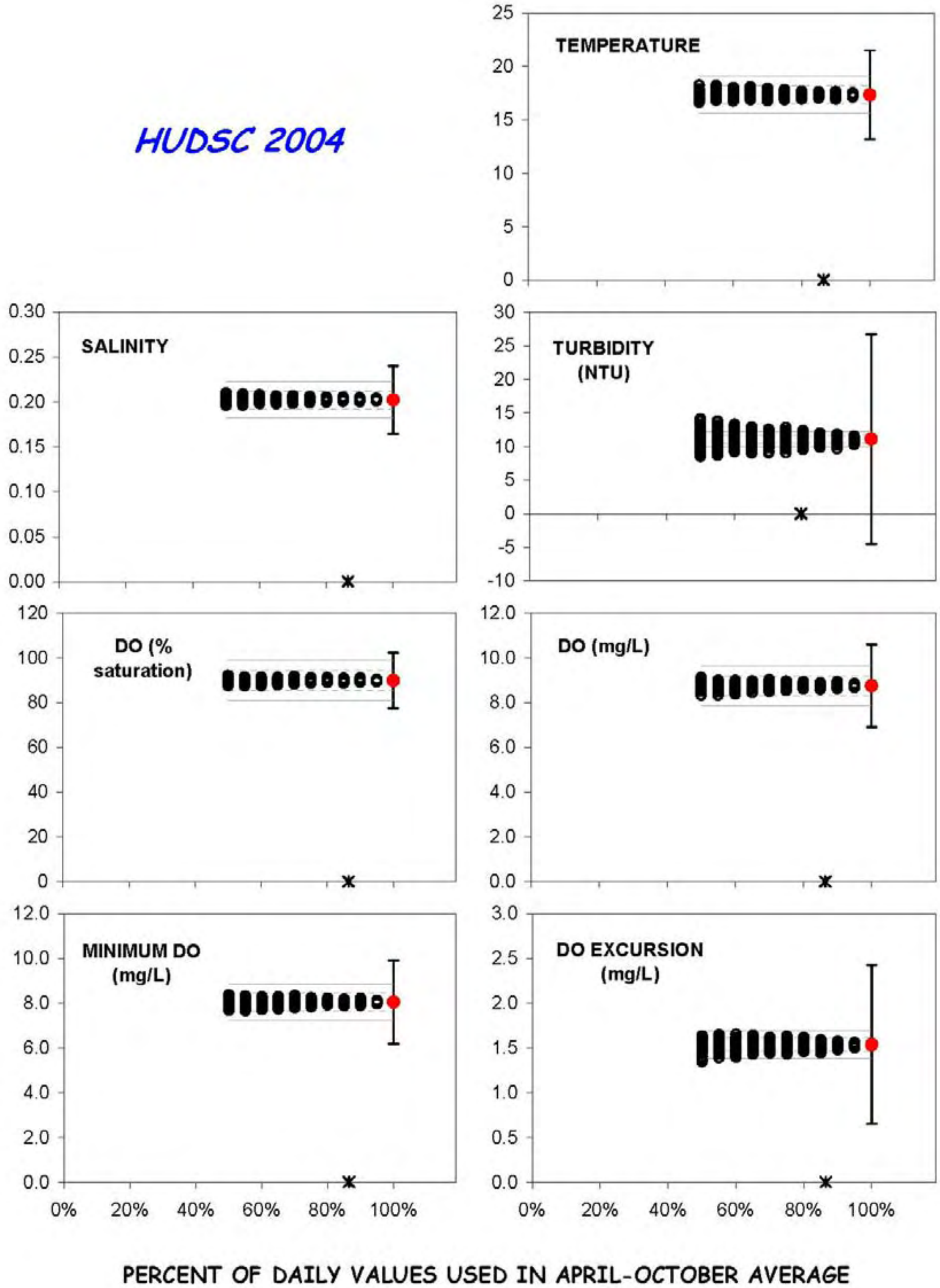
Chlorophyll-a
(vertical lines denote Apr 1 - Oct 31)
0
5
10
15
20
25
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Sep-04
Dec-04
cbvgi
cbvcb
cbvtc
cbvsh
cbmrr
cbmmc
cbmjb
cbmip
cbmoc
cbmpr
delsl
delll
delds
delbl
mulba
mulne
mulb6
mulb9
hudsk
hudts
hudtn
hudsc

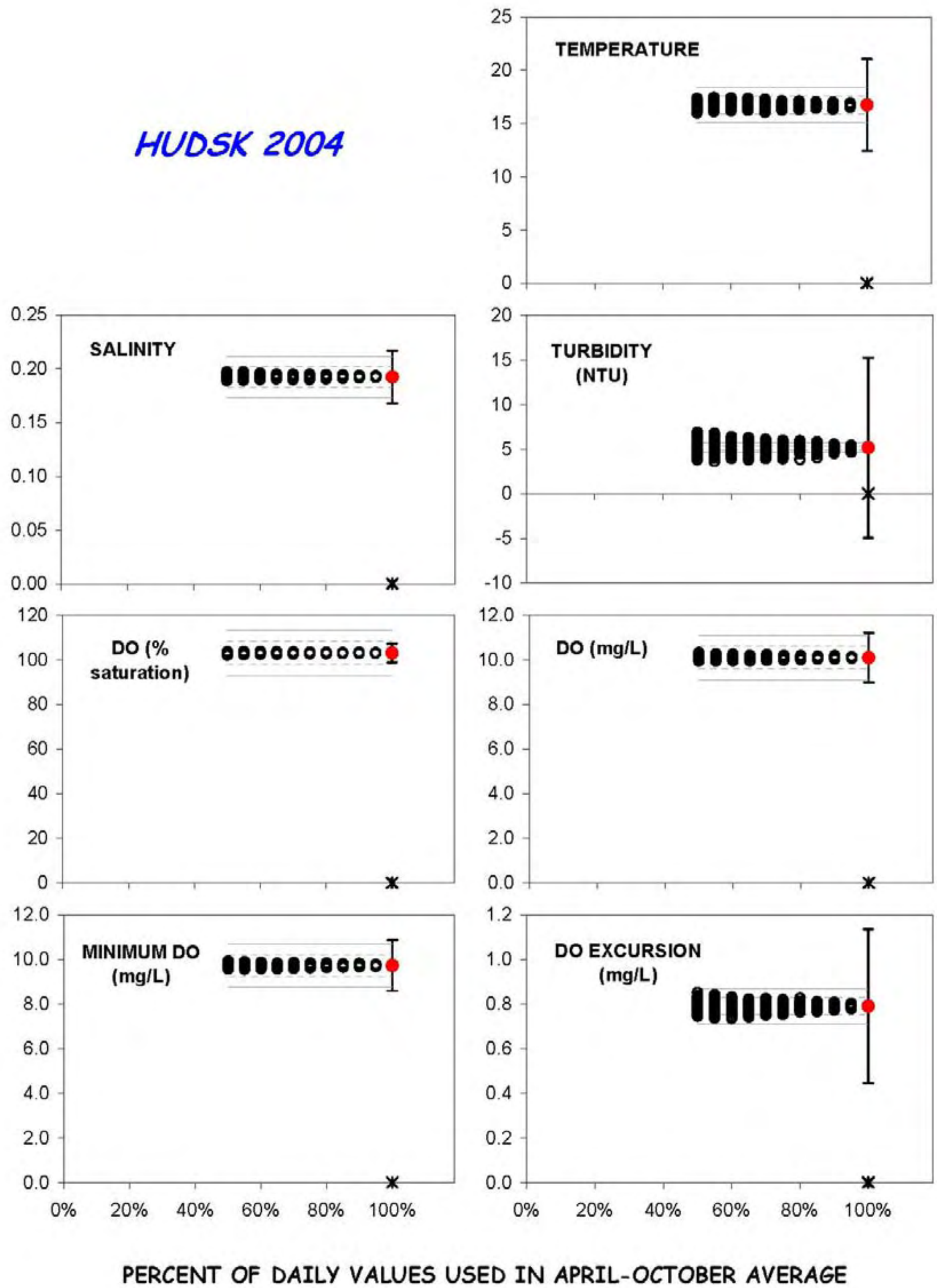

DIN
(vertical lines denote Apr 1 - Oct 31)
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Sep-04
Dec-04
cbvgi
cbvcb
cbvtc
cbvsh
cbmrr
cbmmc
cbmjb
cbmip
cbmoc
cbmpr
delsl
delll
delds
delbl
mulba
mulne
mulb6
mulb9
hudsk
hudts
hudtn
hudsc

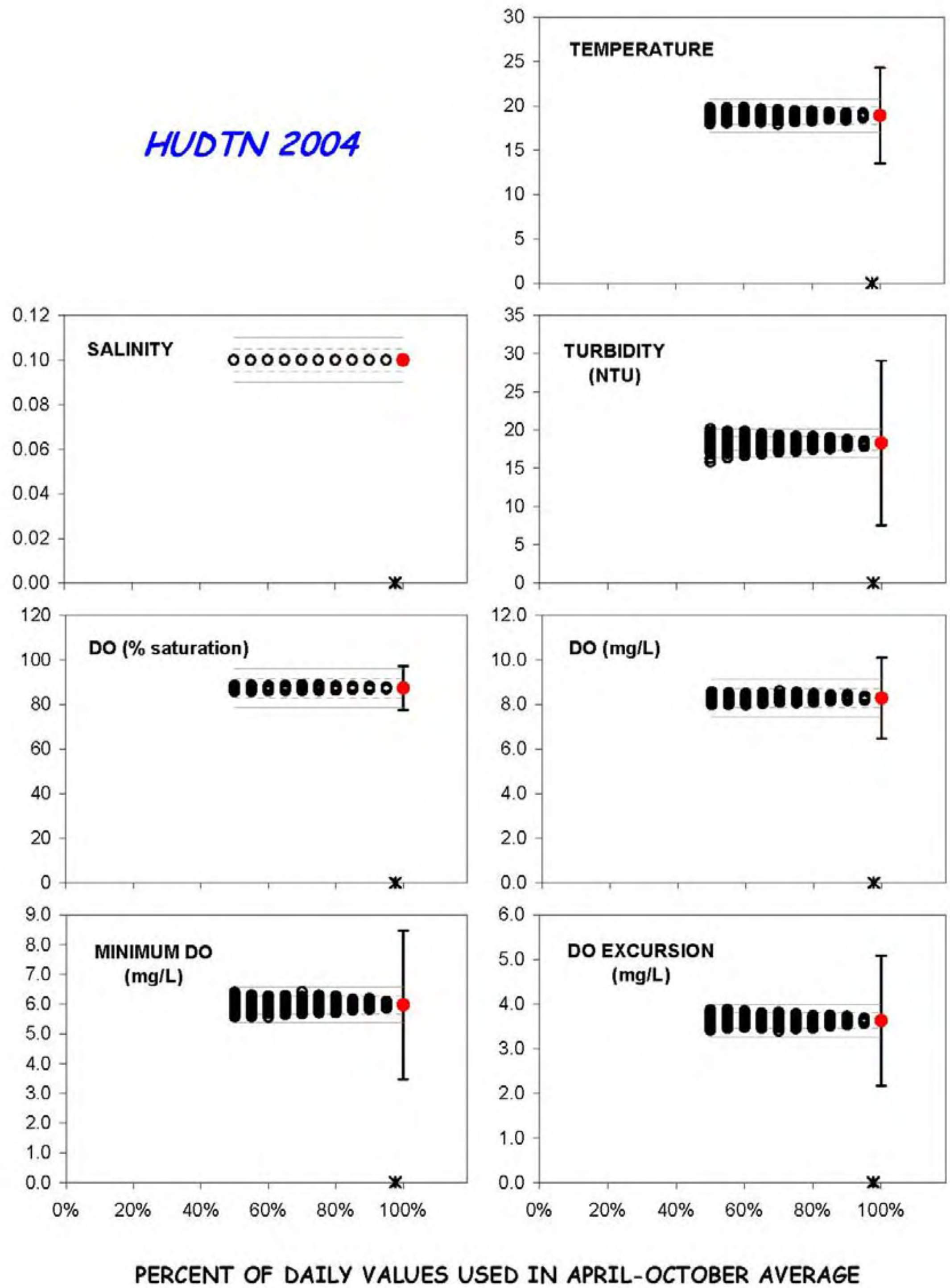


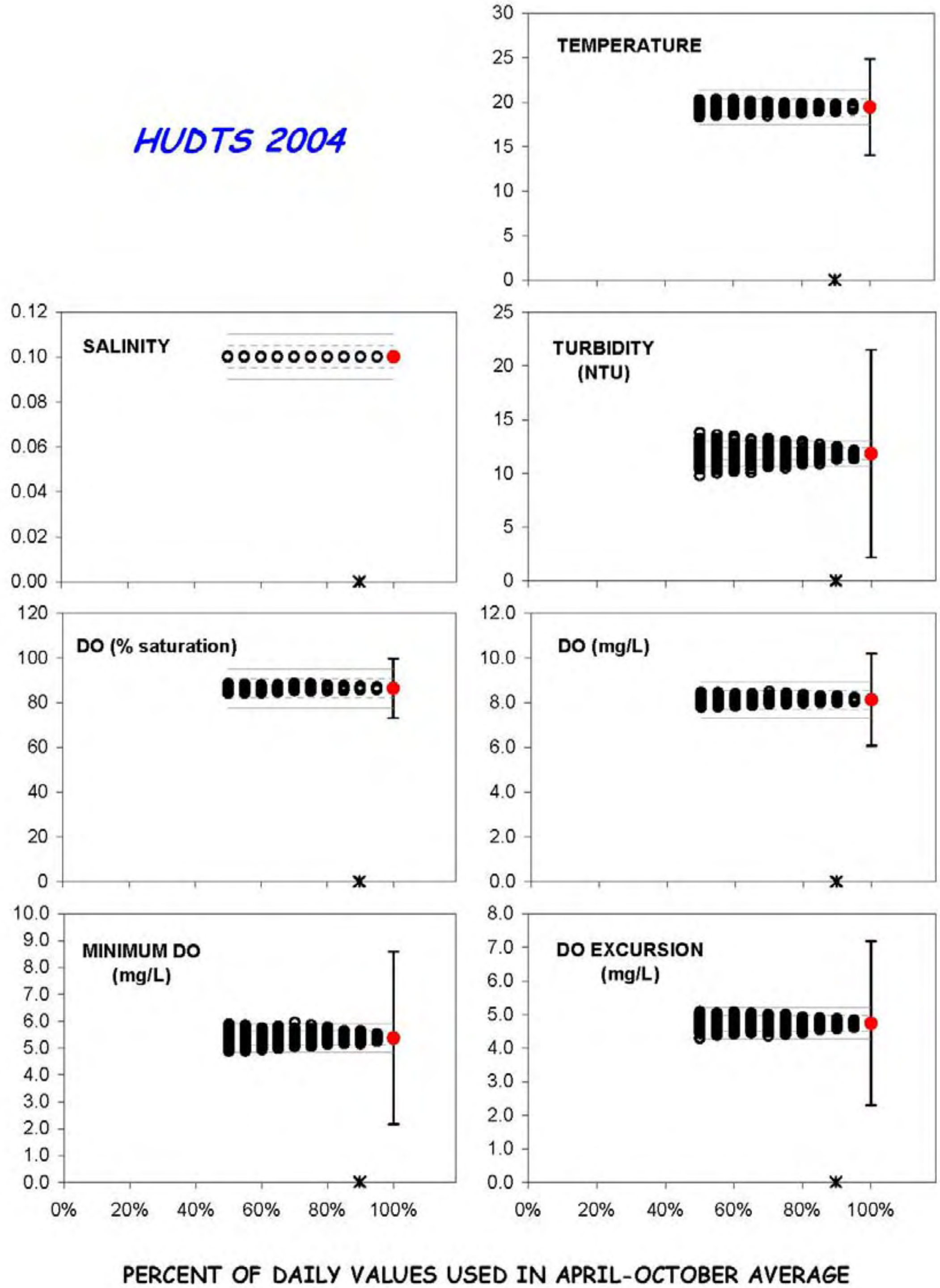
DIP
(vertical lines denote Apr 1 - Oct 31)
Jan-02
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Sep-04
Dec-04
cbvgi
cbvcb
cbvtc
cbvsh
cbmrr
cbmmc
cbmjb
cbmip
cbmoc
cbmpr
delsl
delll
delds
delbl
mulba
mulne
mulb6
mulb9
hudsk
hudts
hudtn
hudsc

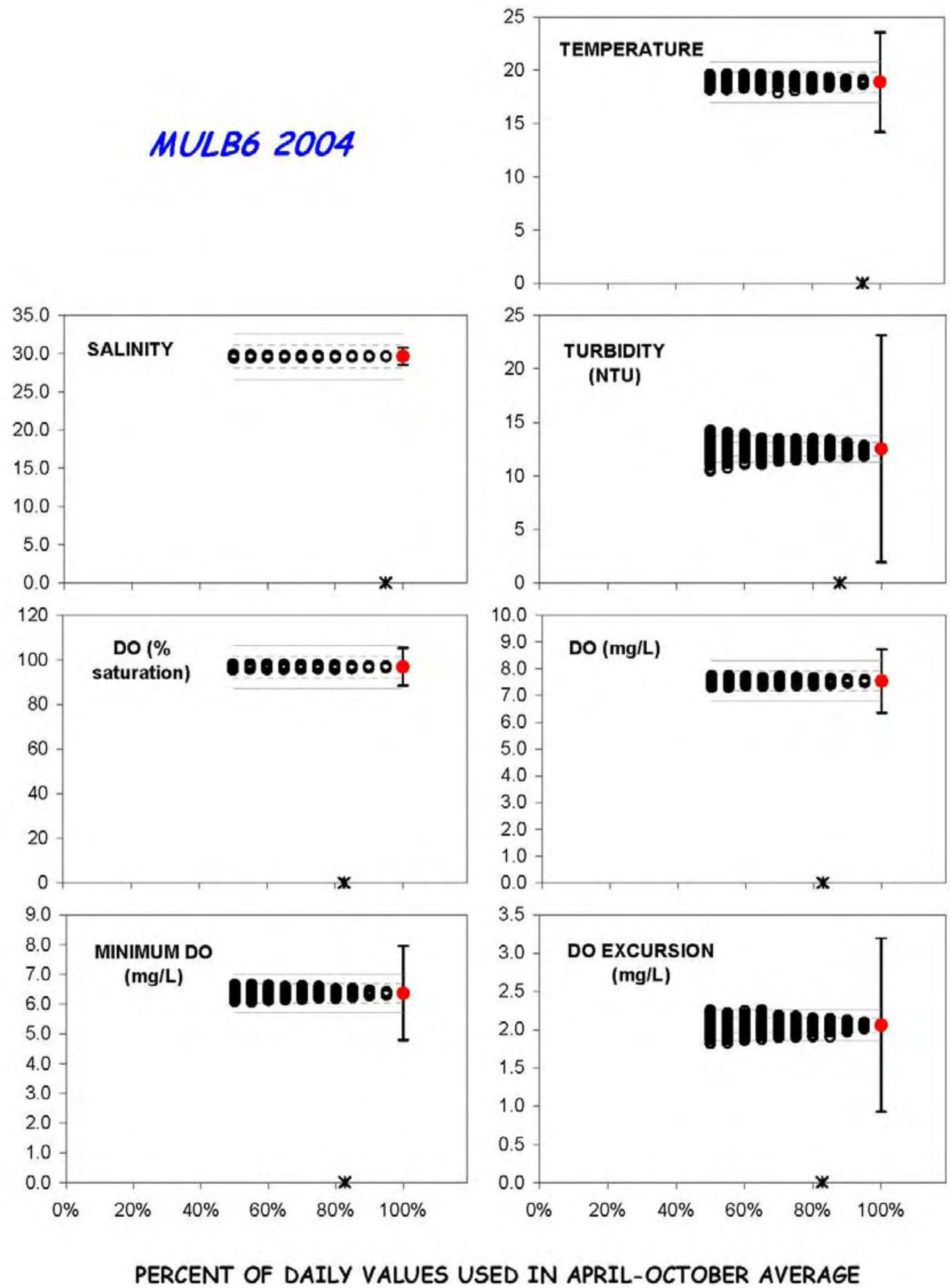
Appendix E. Effect of missing water quality (YSI) data on April-October averages. Subsets of Apr-Oct daily averages consisting of 50-95% of all values were randomly selected in 5% increments. A total of 100 independent sets were selected at each increment and averages were computed. Red point indicates the mean using all Apr-Oct data; error bars denote standard deviations of all Apr-Oct values. Asterisk indicates the overall percent of available data from April-October (out of 214 days). Gray dashed lines enclose the region within 5% of the overall mean; gray solid lines enclose the region within 10% of the overall mean.

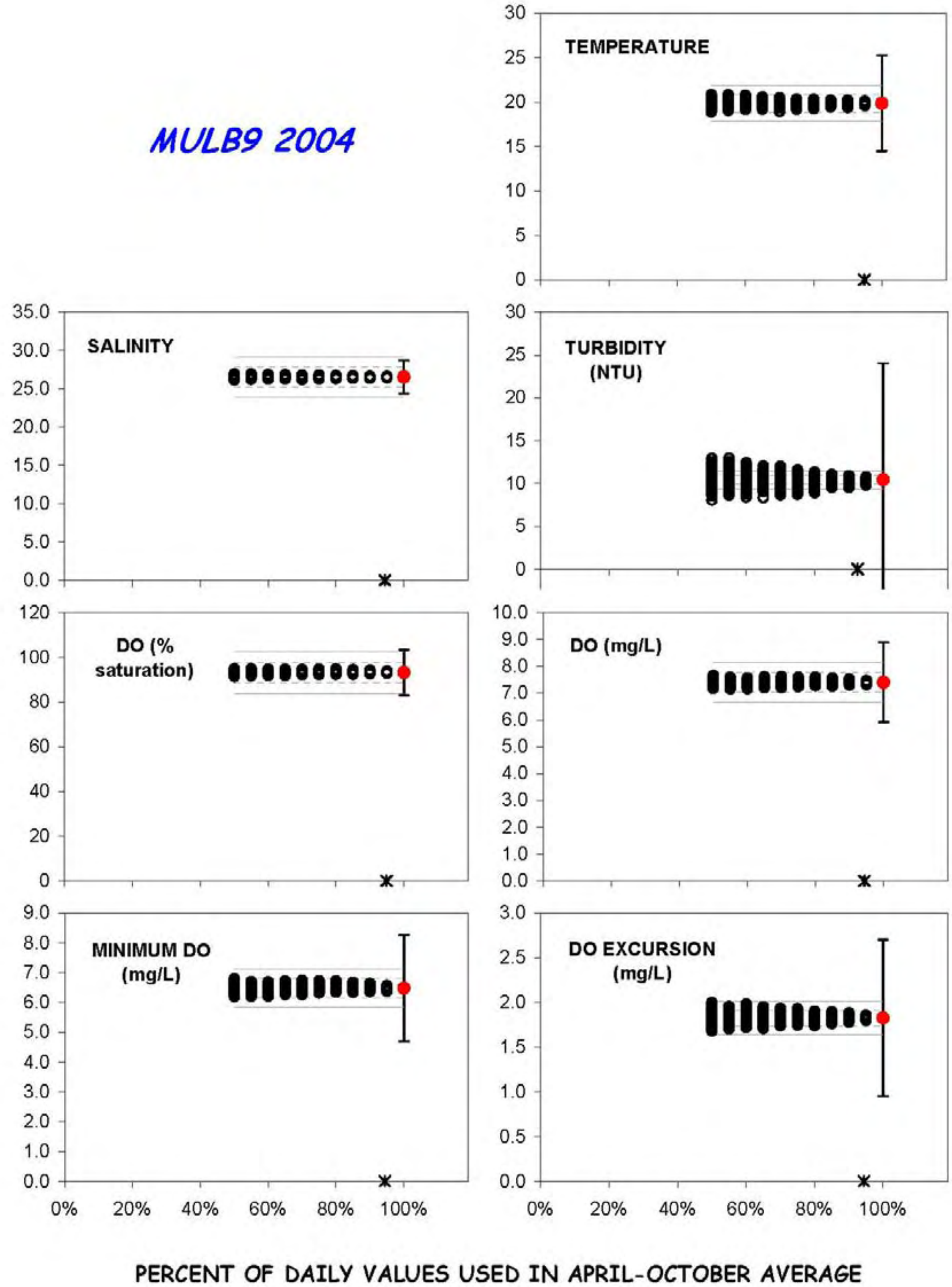

HUDSC 2004
TEMPERATURE
SALINITY
TURBIDITY (NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO (mg/L)
DO EXCURSION (mg/L)
0% 20% 40% 60% 80% 100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

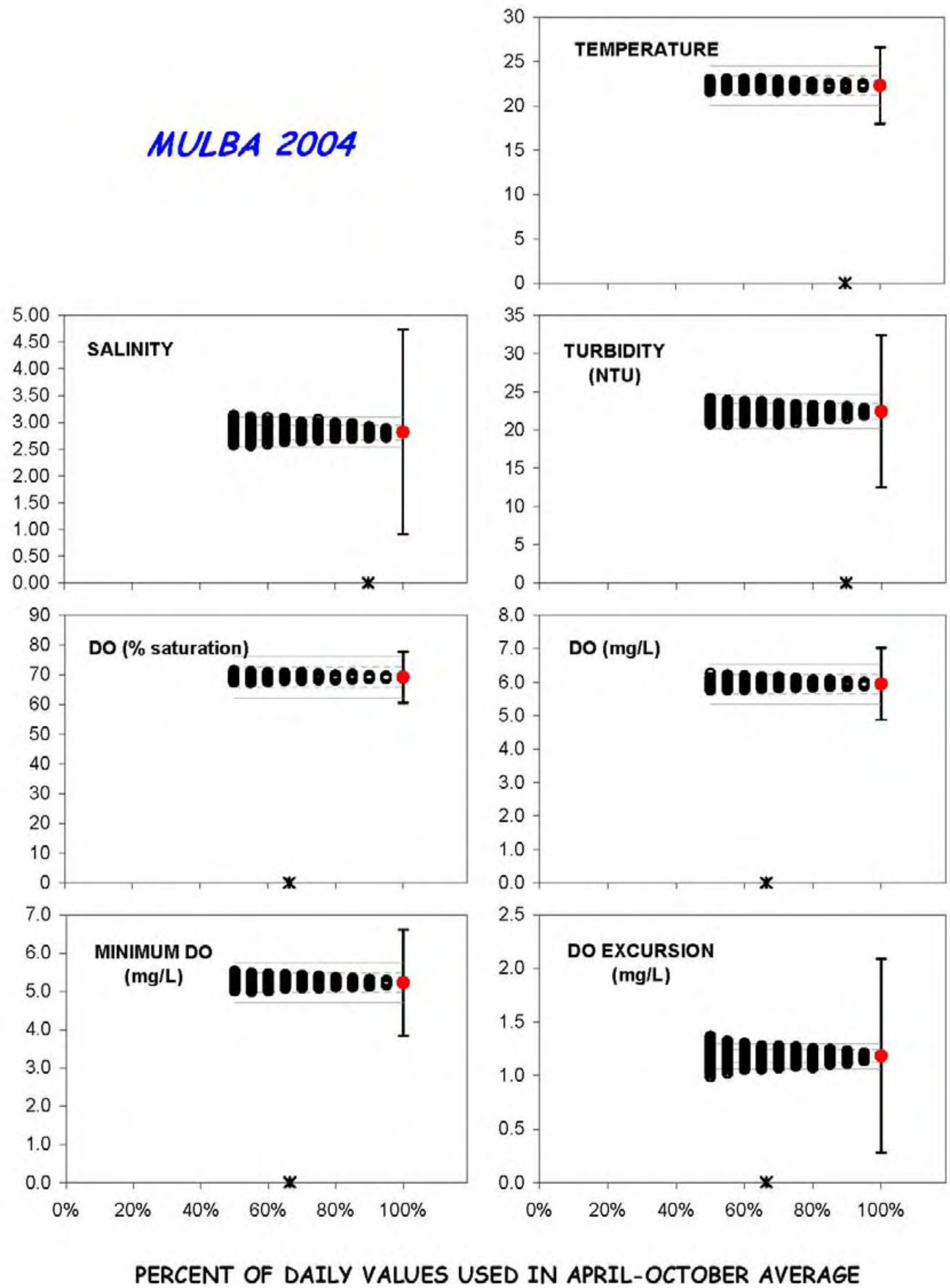

HUDSK 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (%
saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

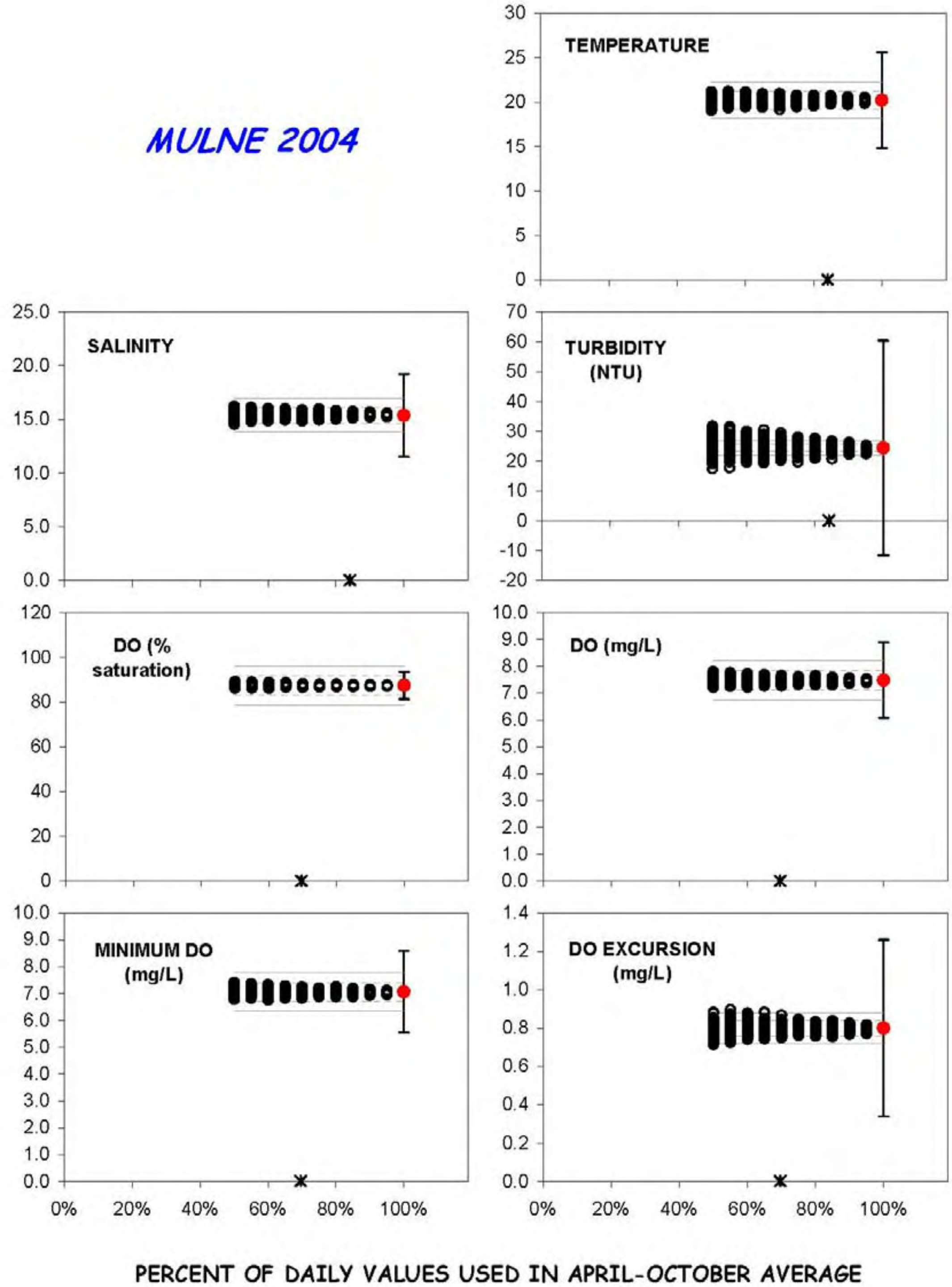

HUDTN 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

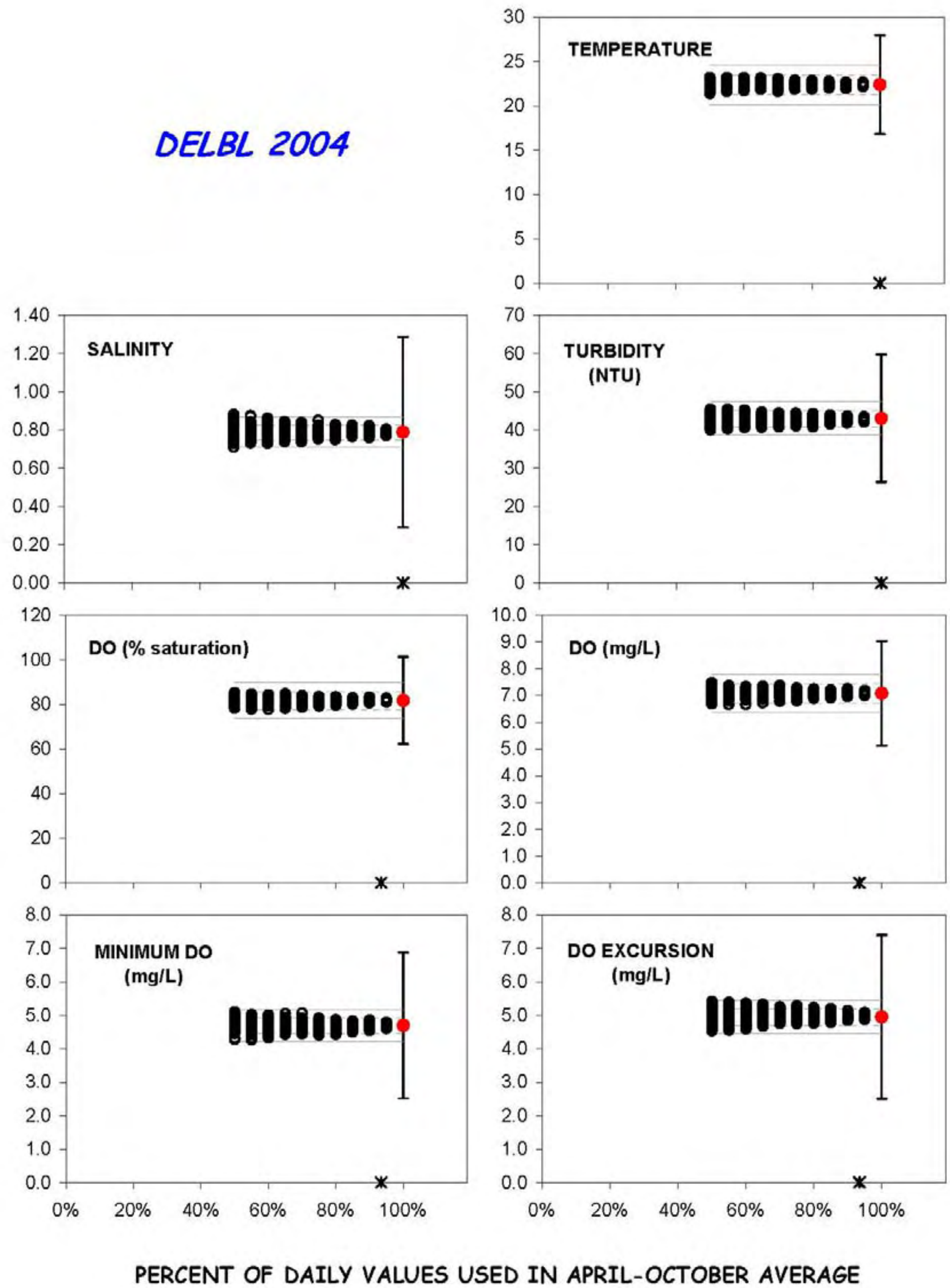

HUDTS 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

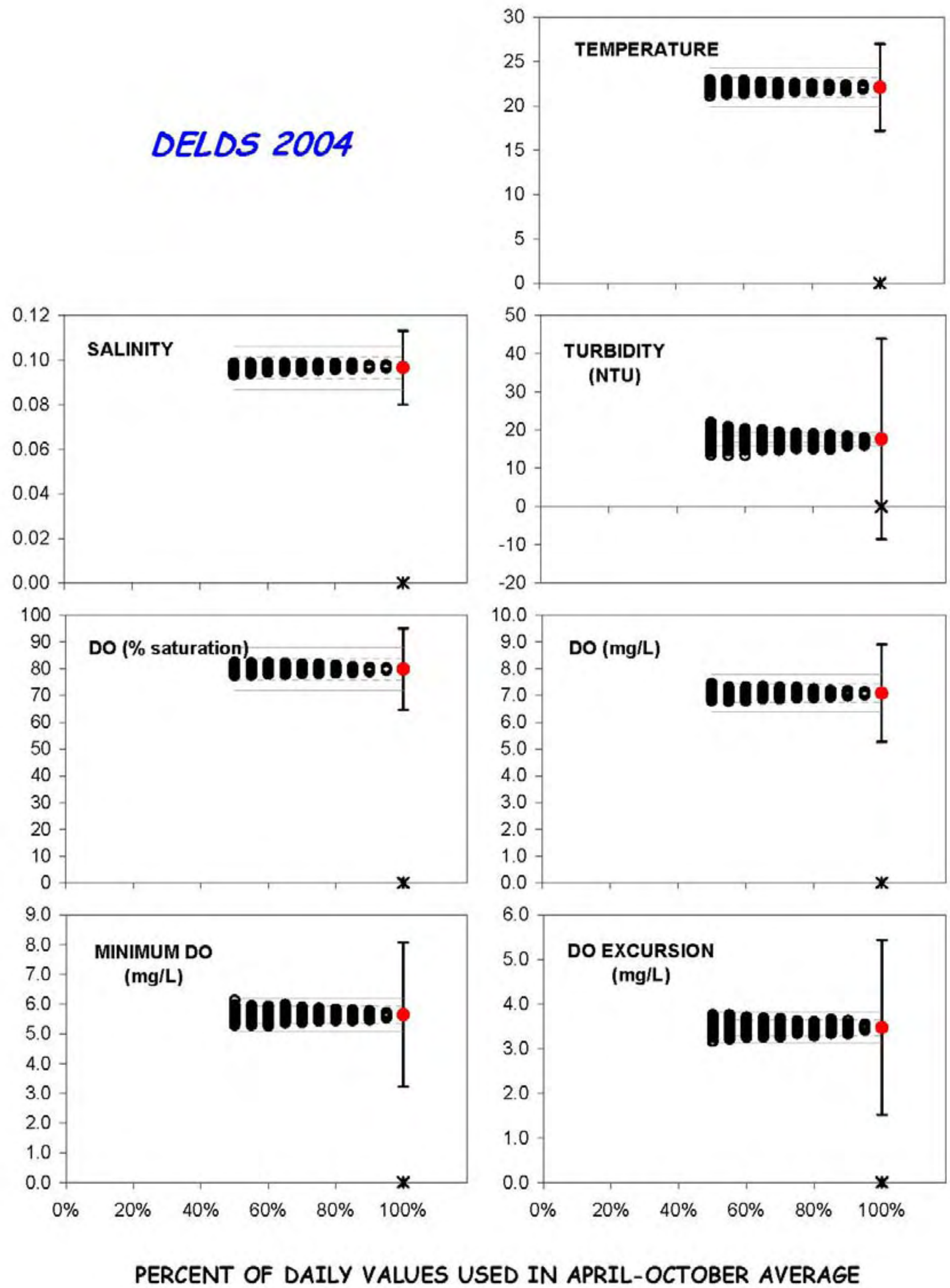

MULB6 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (%
saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

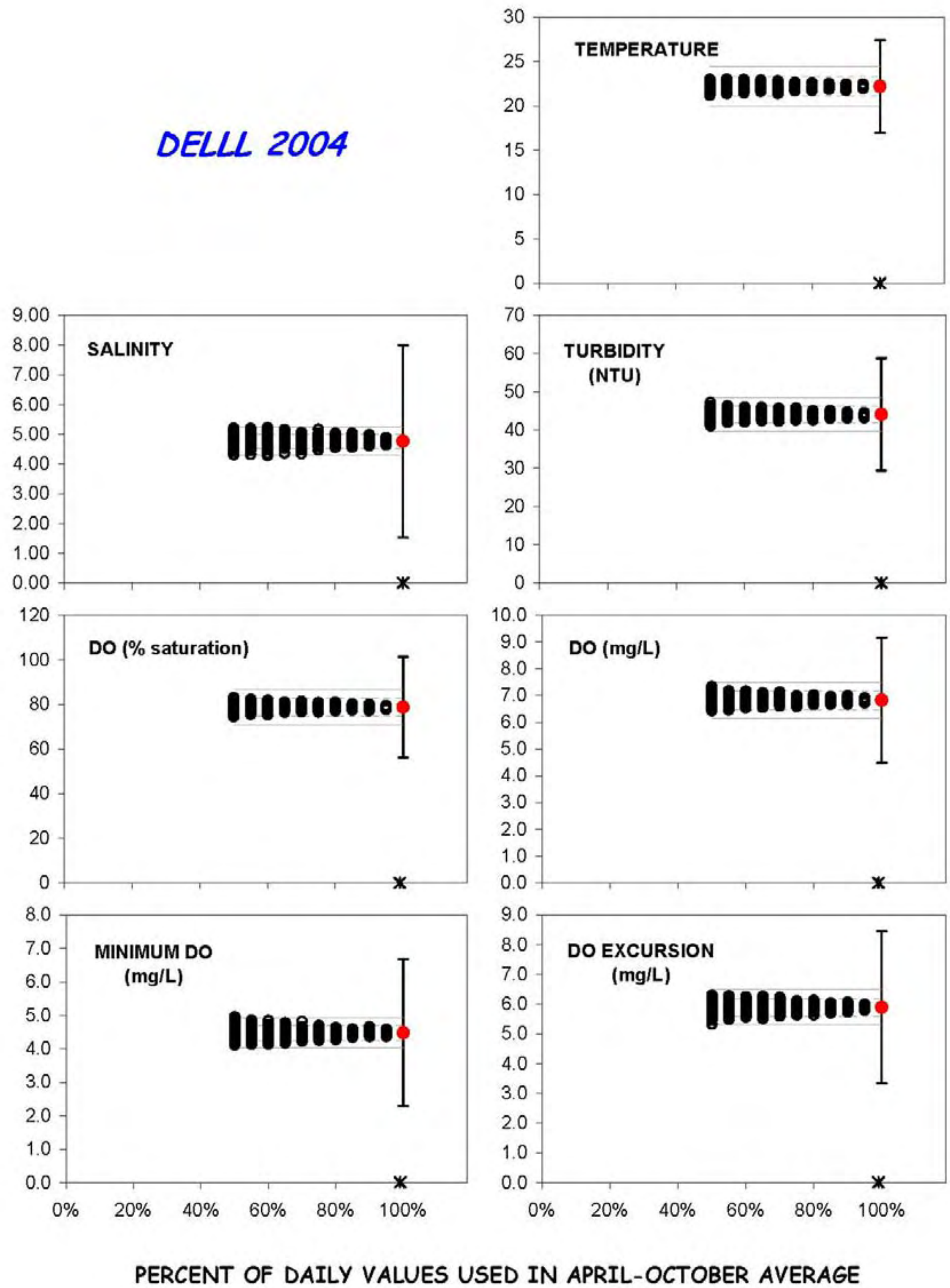

MULB9 2004
TEMPERATURE
SALINITY
TURBIDITY (NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO (mg/L)
DO EXCURSION (mg/L)
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

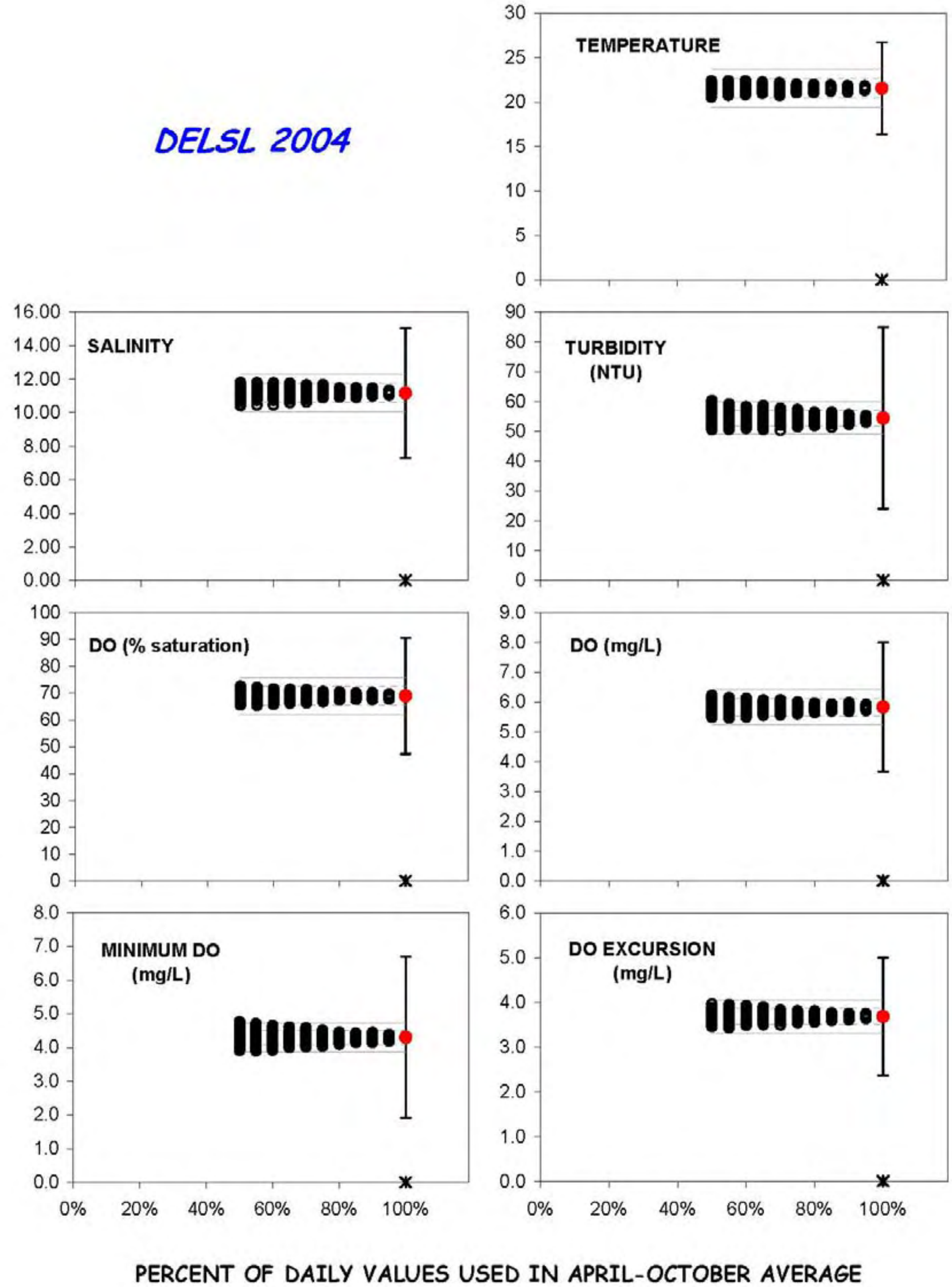

MULBA 2004
TEMPERATURE
SALINITY
TURBIDITY (NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO (mg/L)
DO EXCURSION (mg/L)
0% 20% 40% 60% 80% 100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

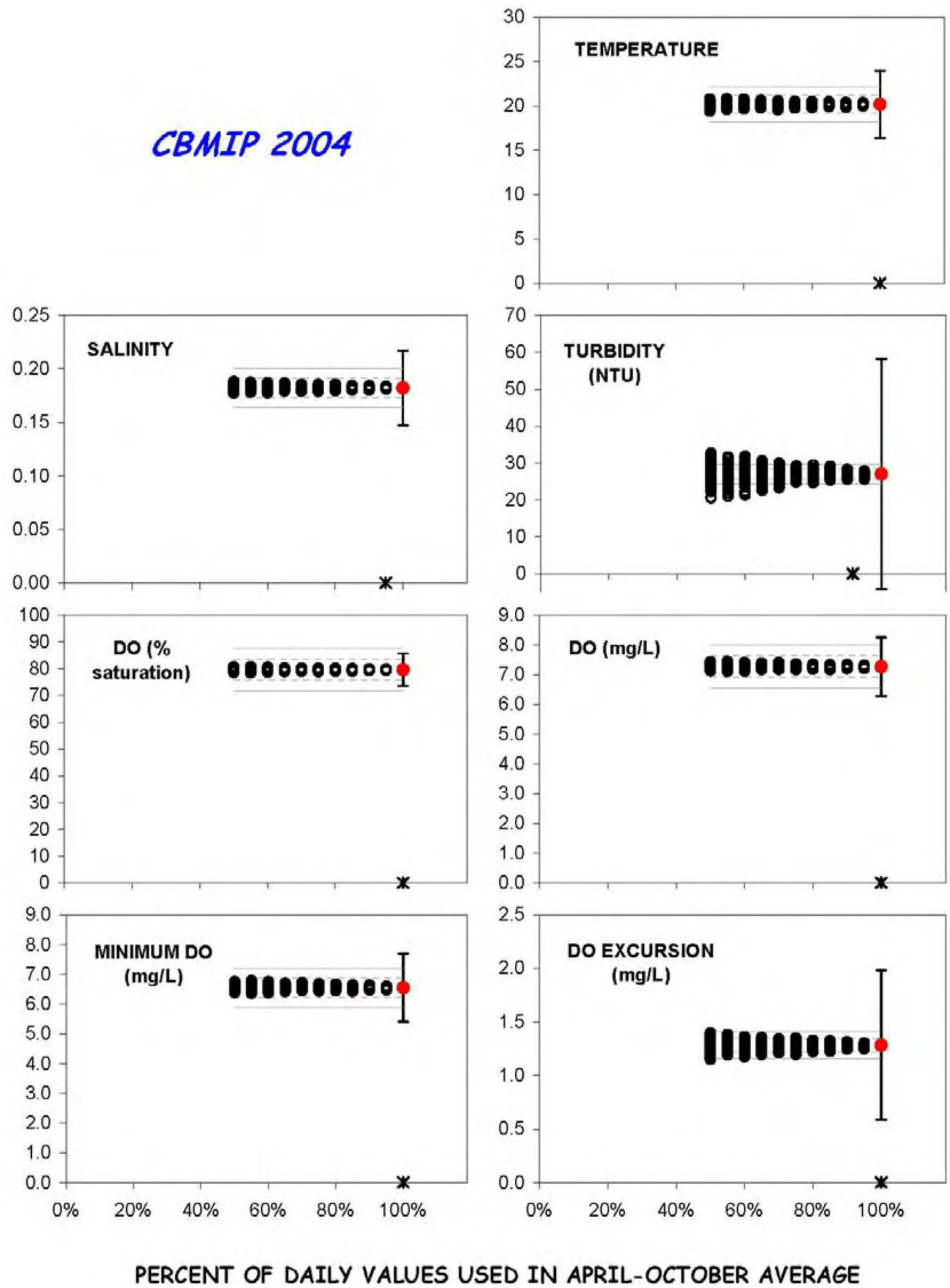

MULNE 2004
TEMPERATURE
SALINITY
TURBIDITY (NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO (mg/L)
DO EXCURSION (mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE


DELBL 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

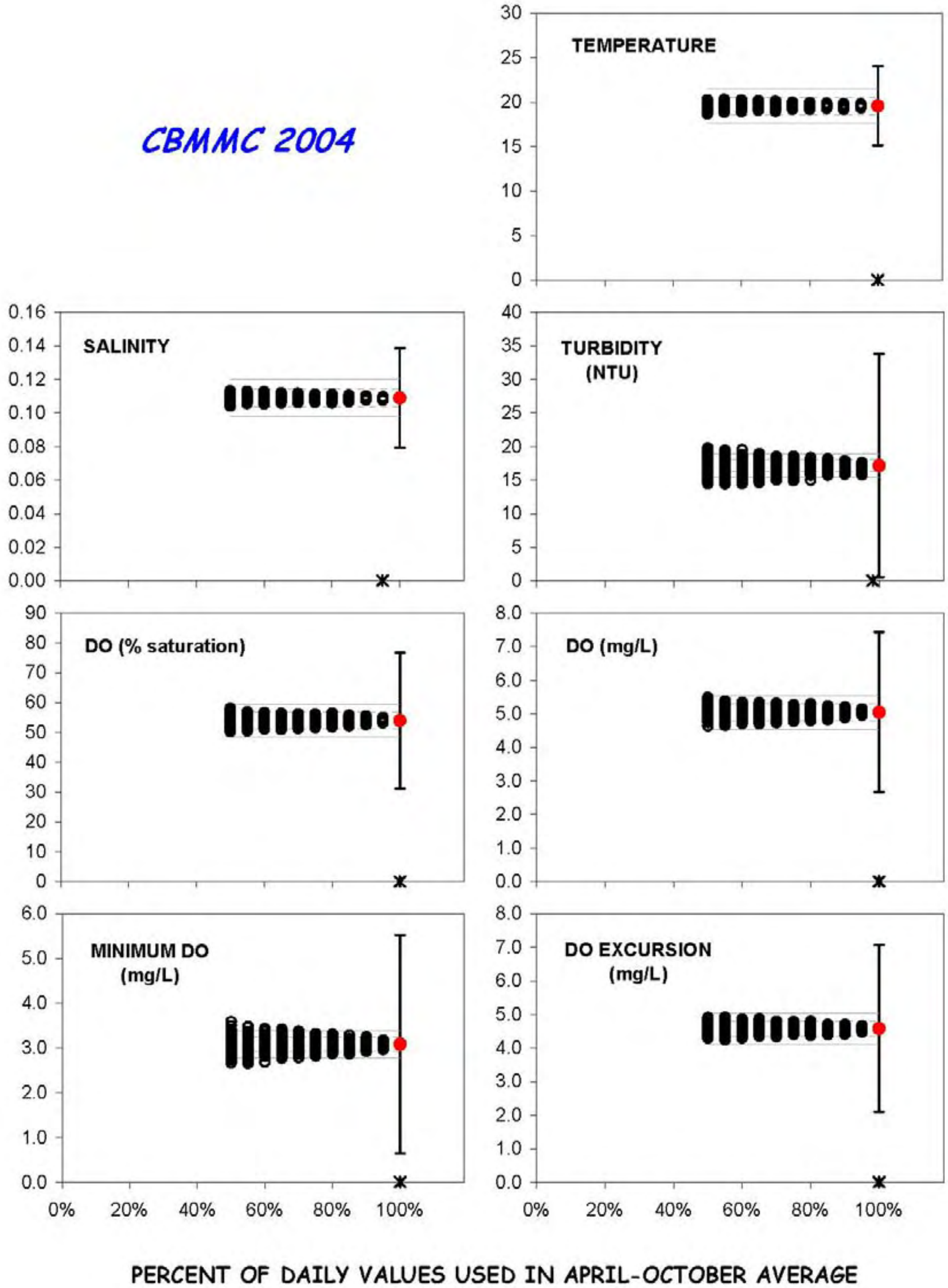

DELDS 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE


DELLL 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

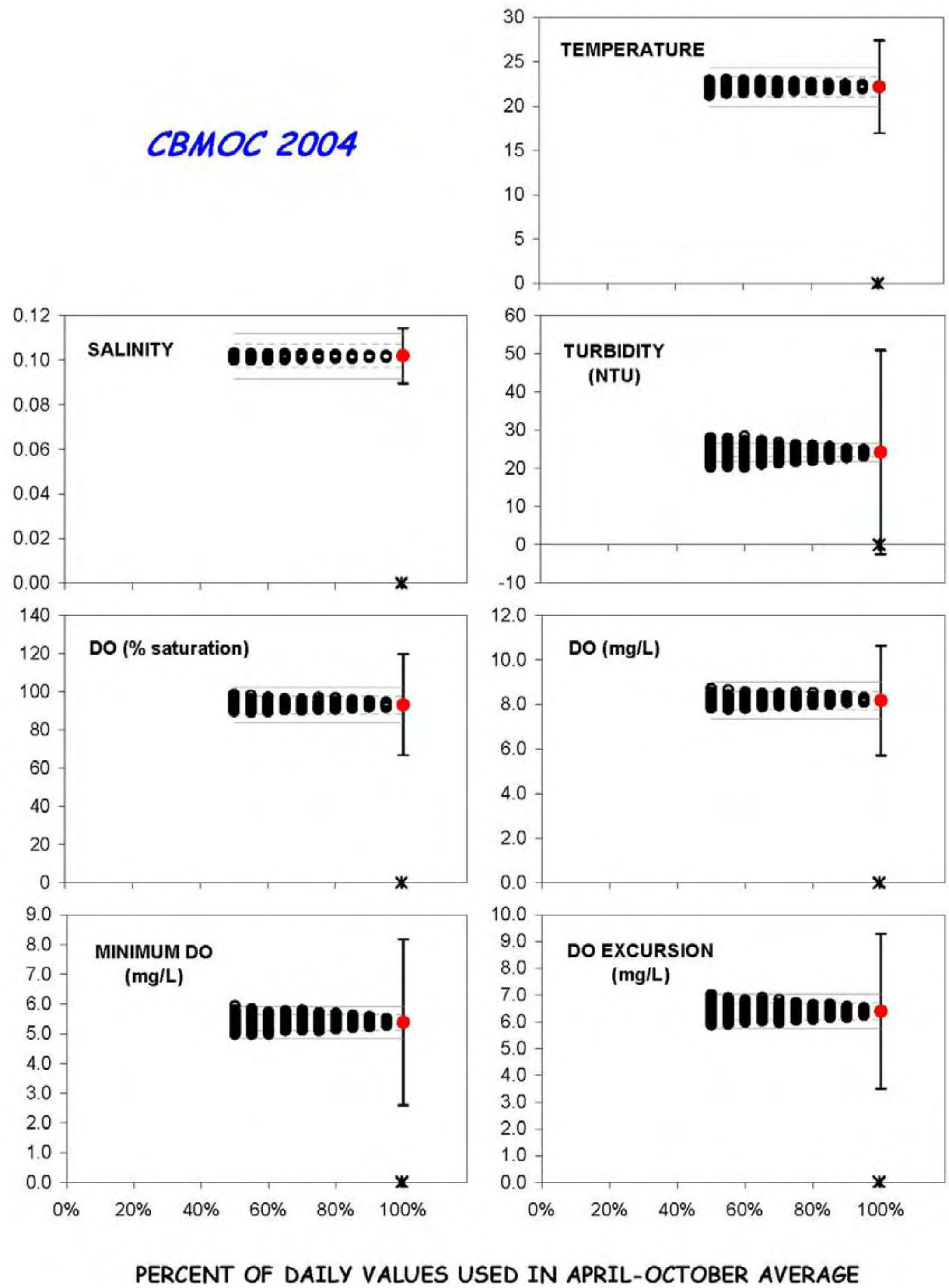

DELSL 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

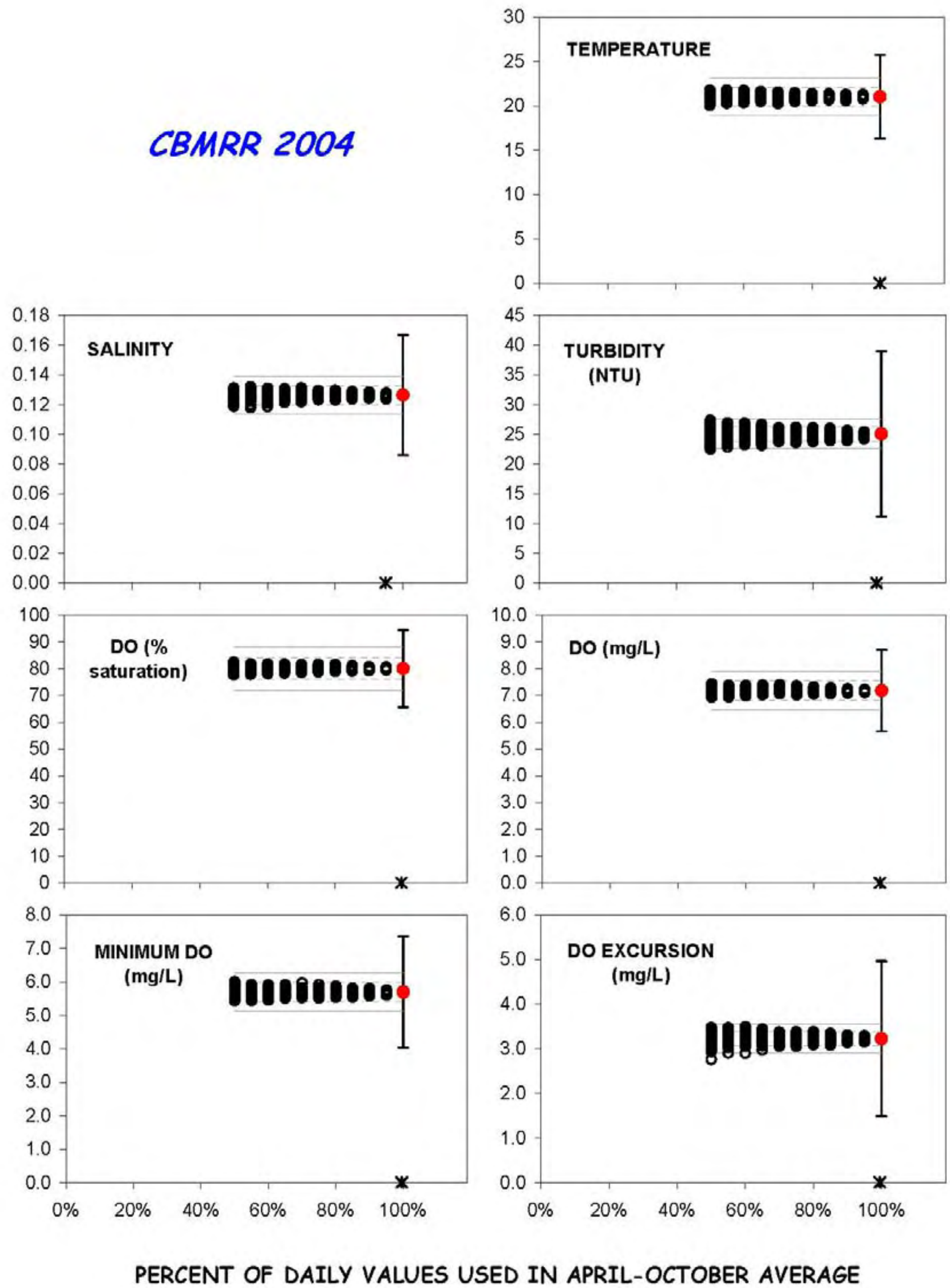


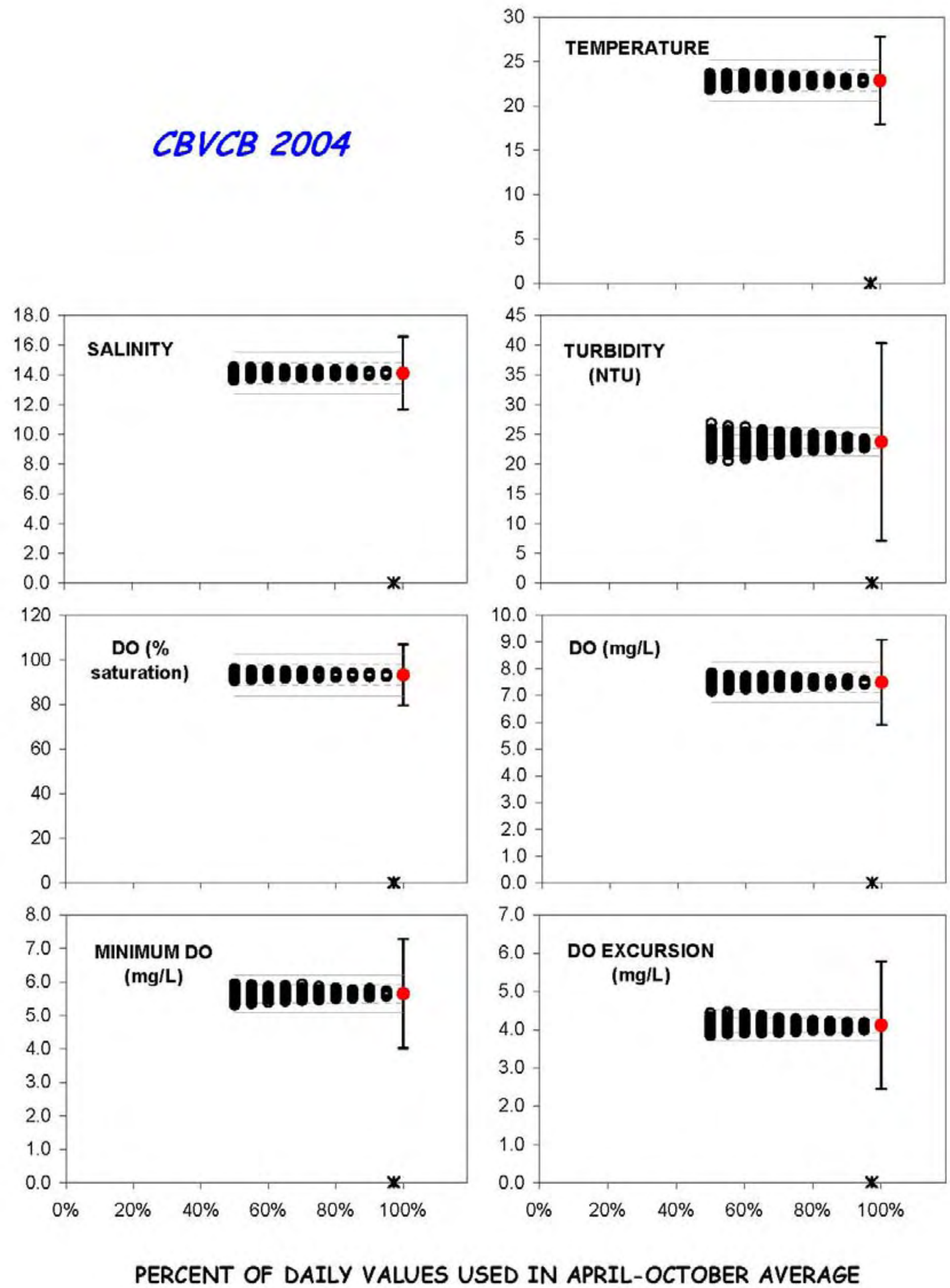
CBMIP 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (%
saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE



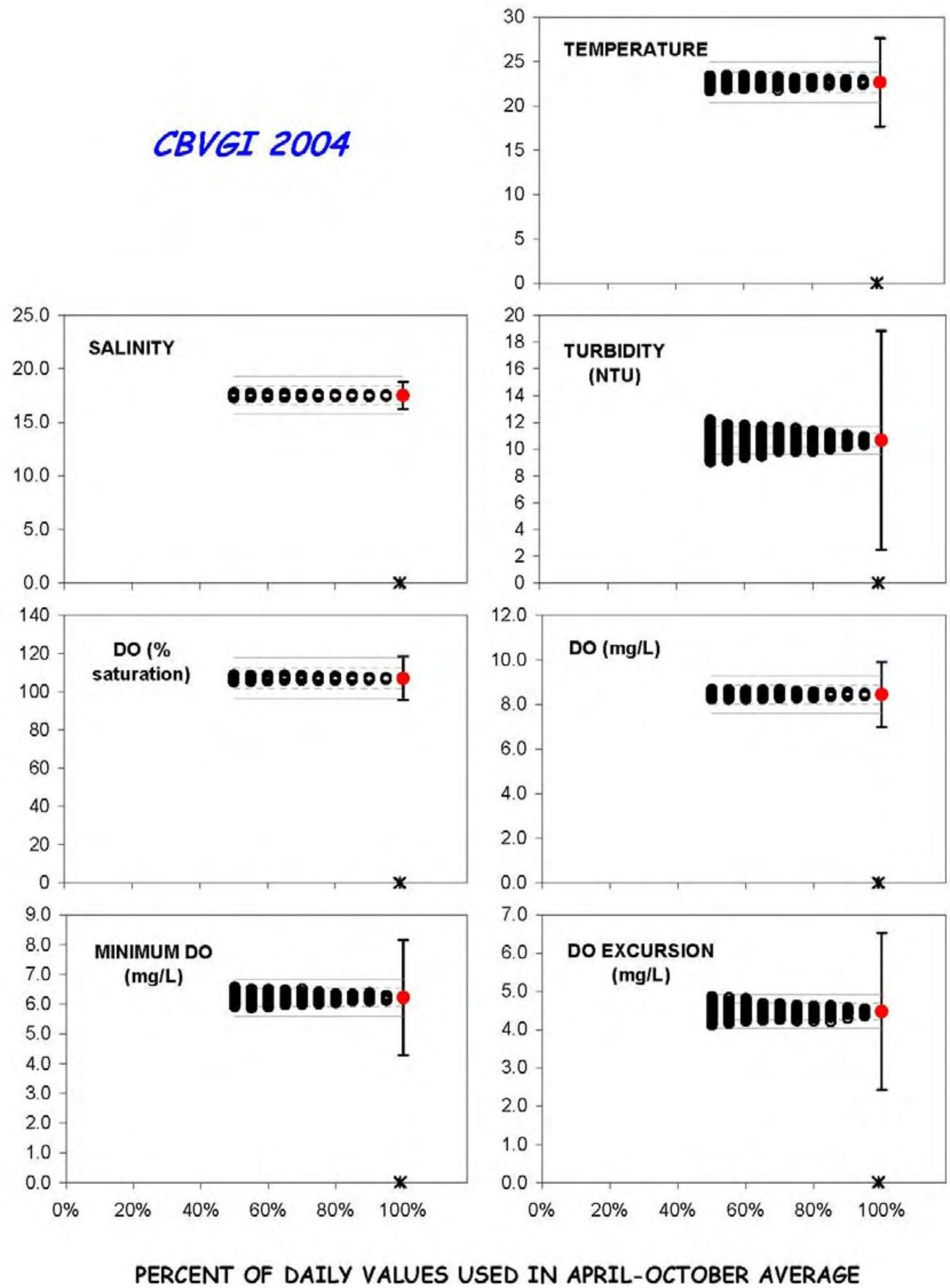
CBMMC 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE


CBMOC 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

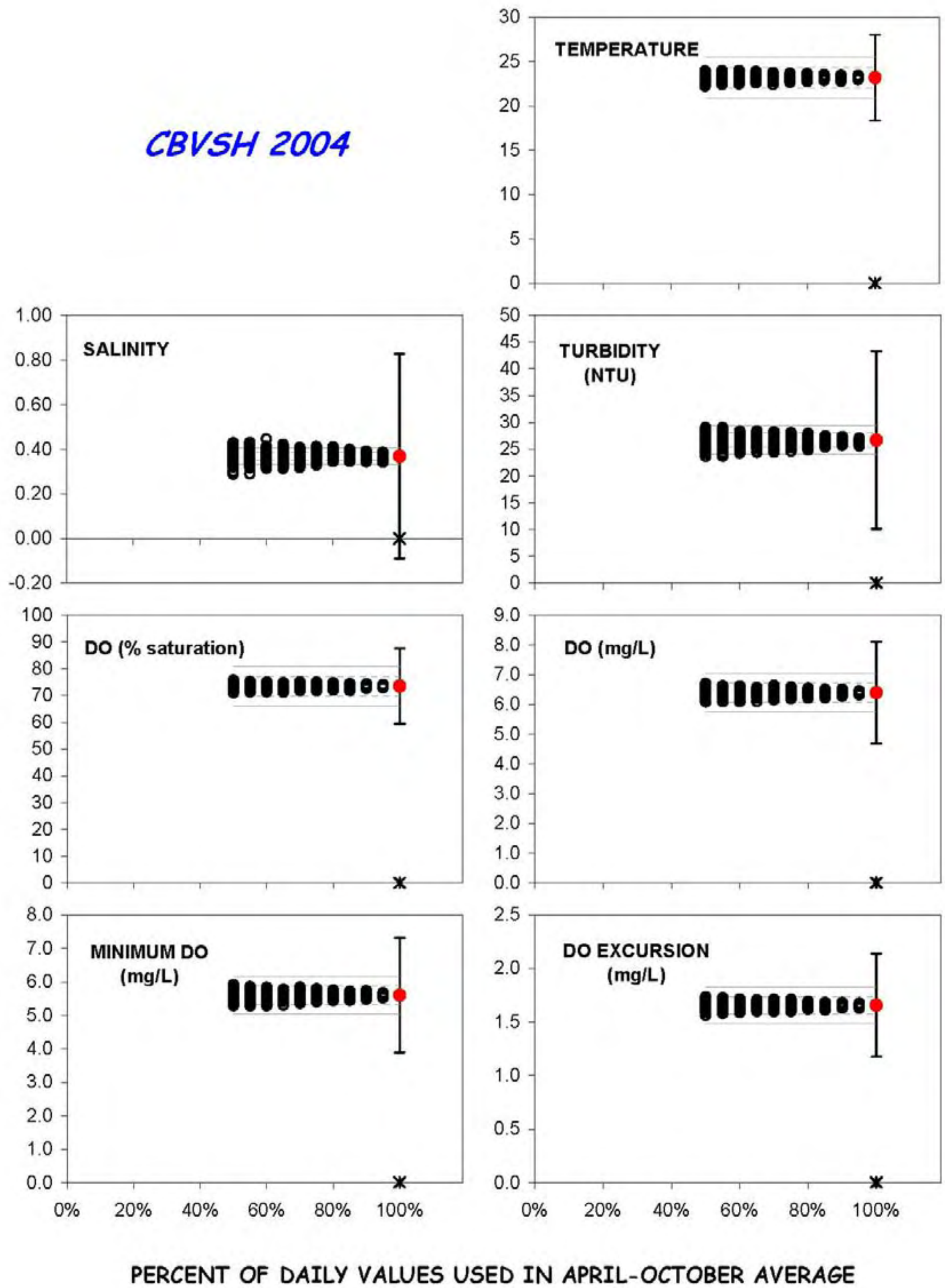

CBMRR 2004
TEMPERATURE
SALINITY
TURBIDITY (NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO (mg/L)
DO EXCURSION (mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

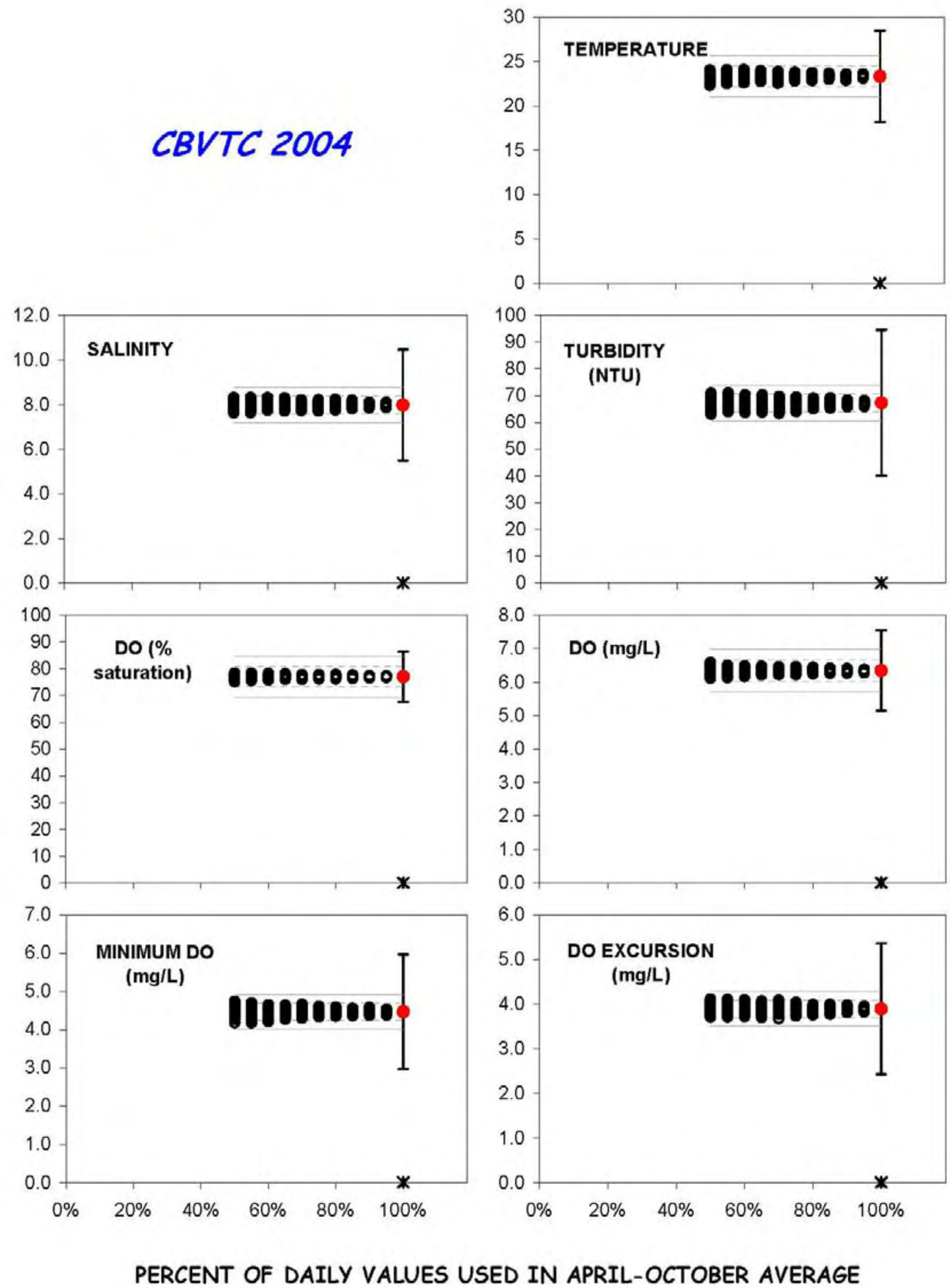


CBVCB 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (%
saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

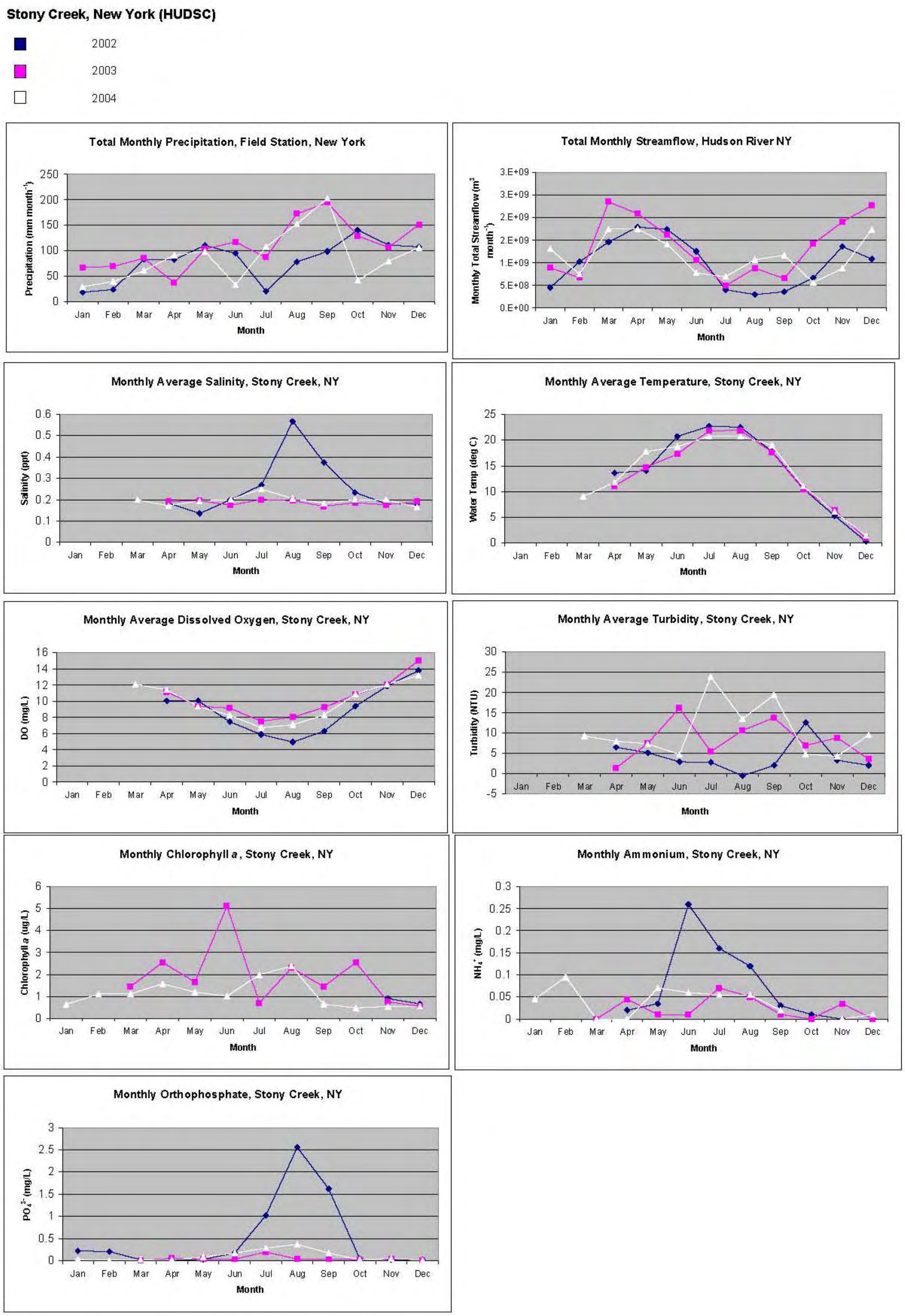


CBVGI 2004
TEMPERATURE
SALINITY
TURBIDITY (NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO (mg/L)
DO EXCURSION (mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE


CBVSH 2004
TEMPERATURE
SALINITY
TURBIDITY
(NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO
(mg/L)
DO EXCURSION
(mg/L)
0%
20%
40%
60%
80%
100%
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE


CBVTC 2004
TEMPERATURE
SALINITY
TURBIDITY (NTU)
DO (% saturation)
DO (mg/L)
MINIMUM DO (mg/L)
DO EXCURSION (mg/L)
PERCENT OF DAILY VALUES USED IN APRIL-OCTOBER AVERAGE

Appendix F. Monthly average time series by site, 2002-2004.

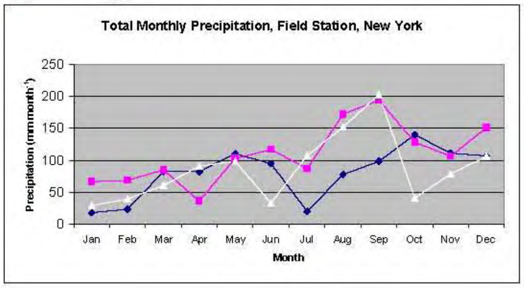


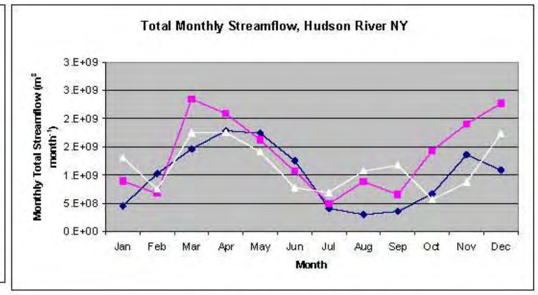
Saw Kill, New York (HUDSK)

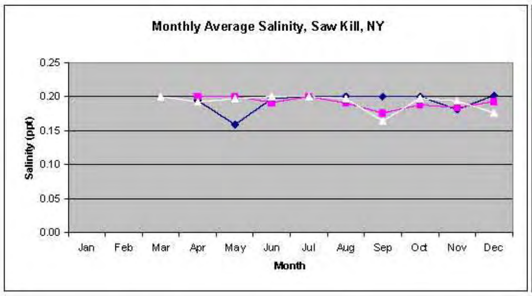
2002

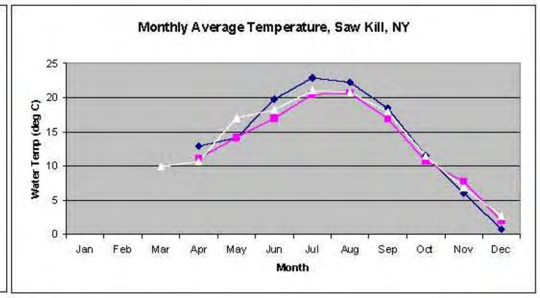
2003

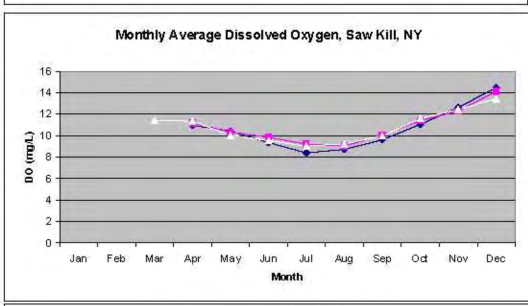
2004

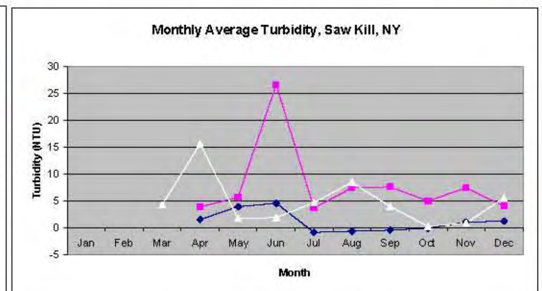


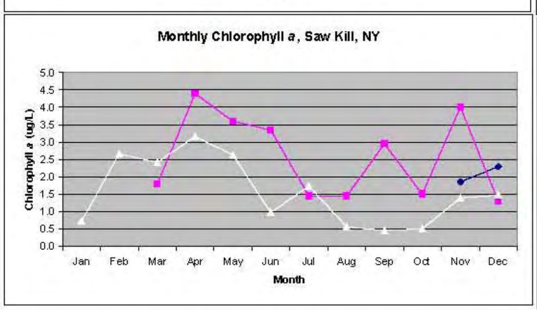


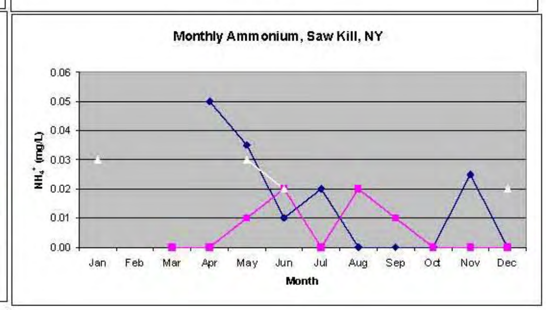


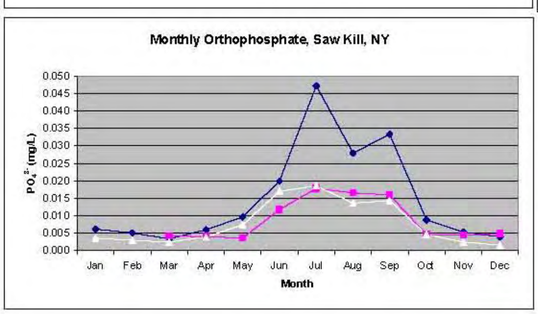






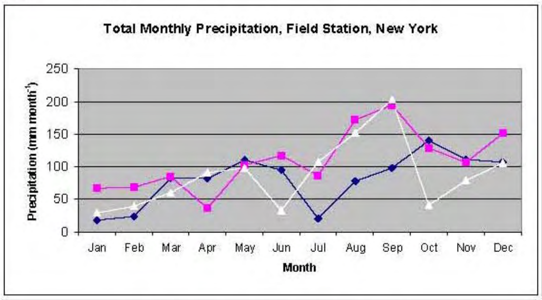


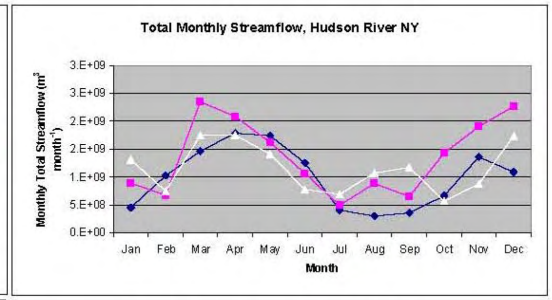


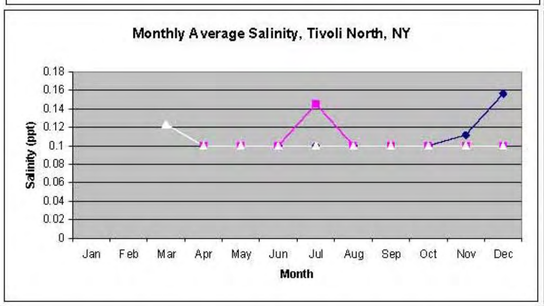


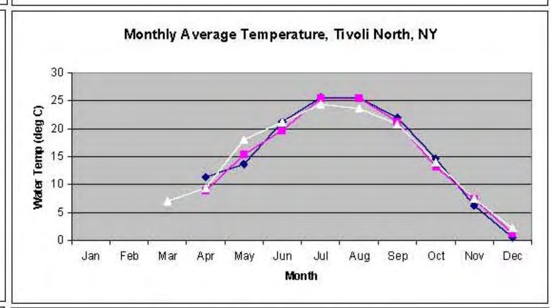
Tivoli North, New York (HUDTN)

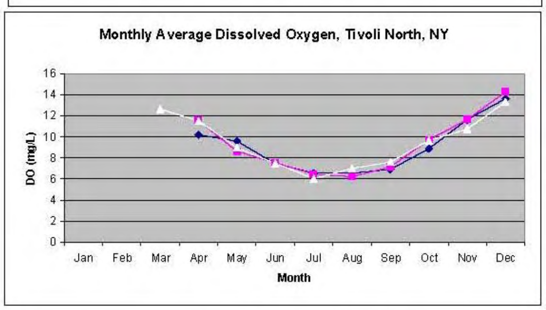
- 2002
- 2003
- 2004

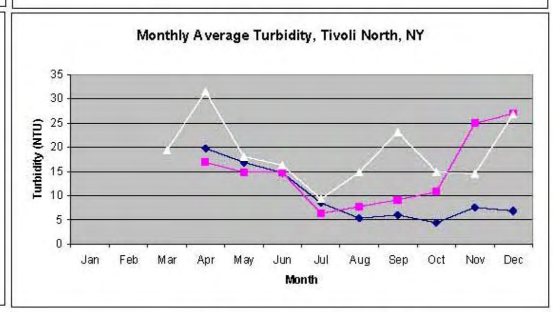


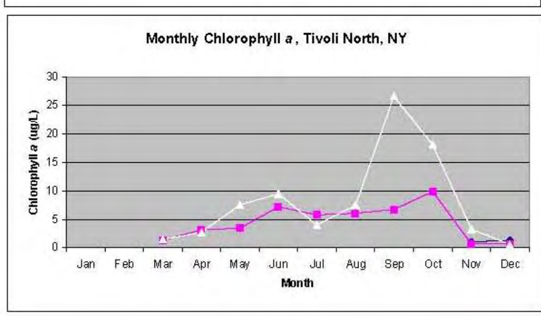


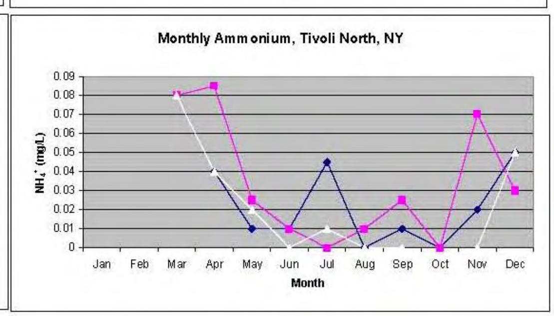


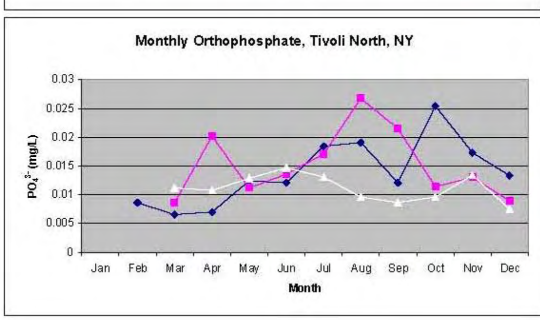






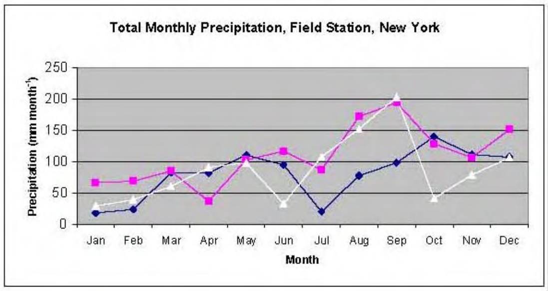


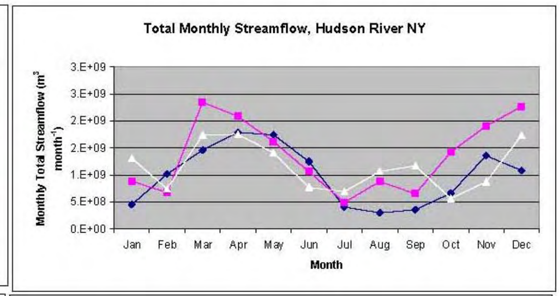


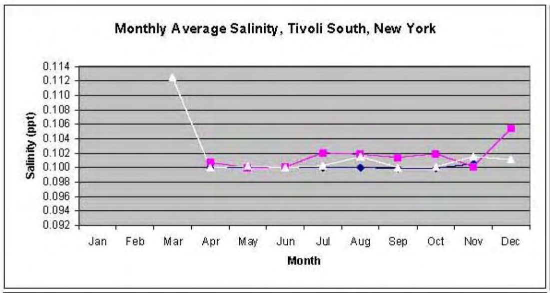


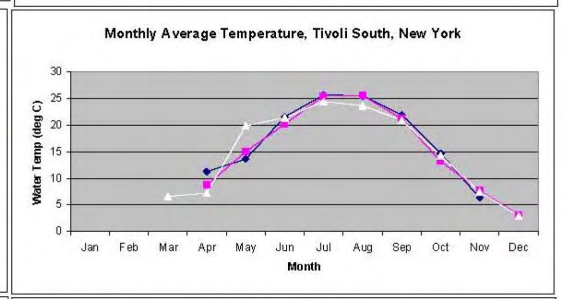
Tivoli South, New York (HUDTS)

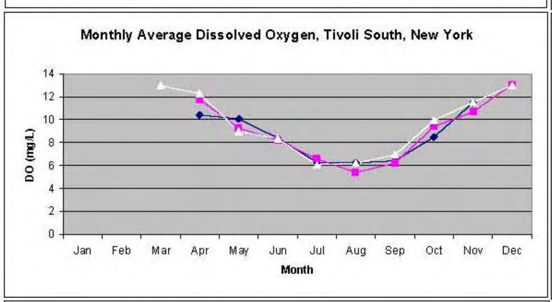
■ (dark blue)	2002
■ (pink)	2003
□	2004

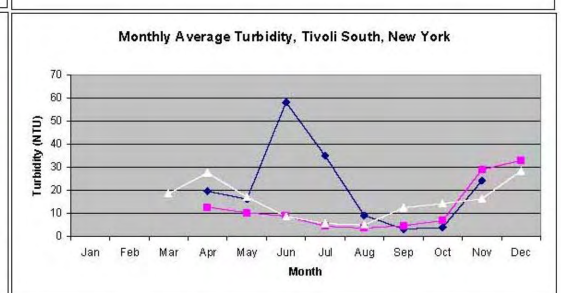


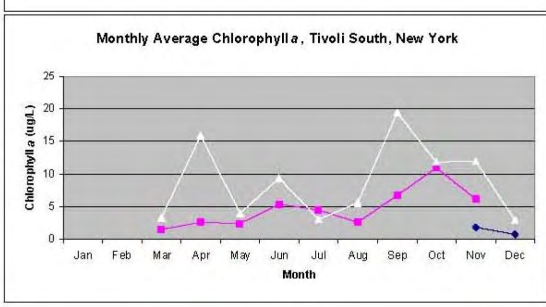


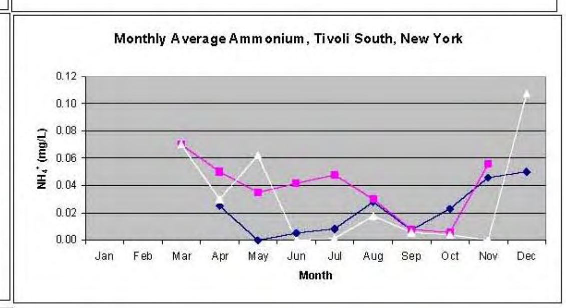


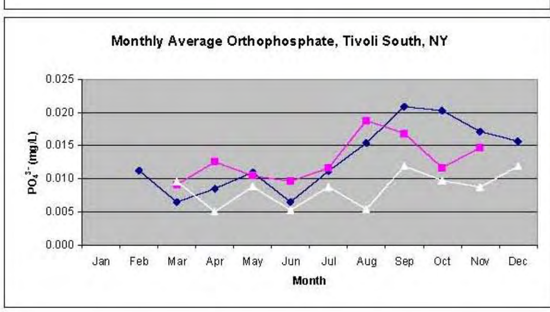






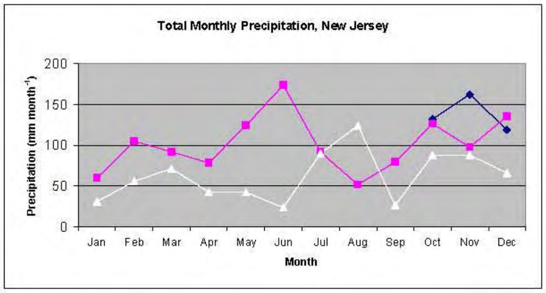


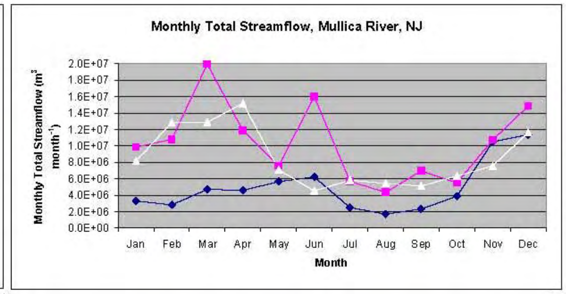


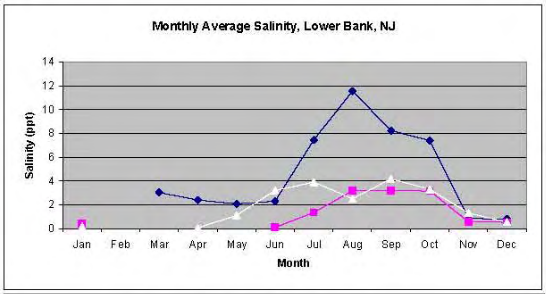


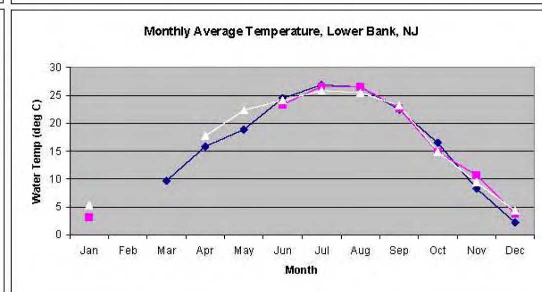
Lower Bank, New Jersey (MULBA)

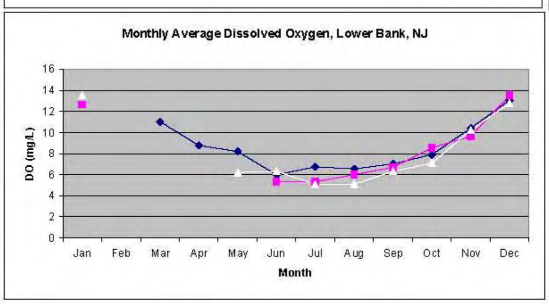
- 2002
- 2003
- 2004

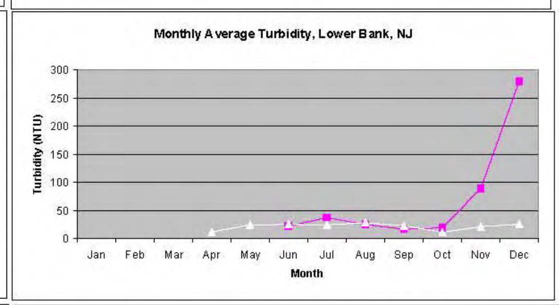


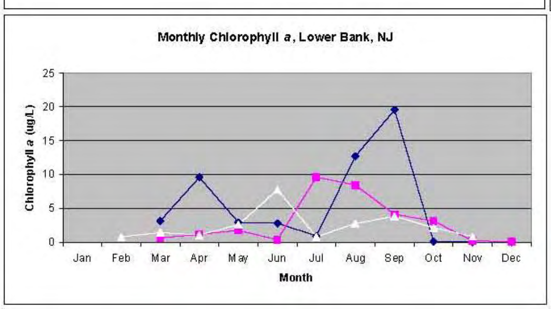


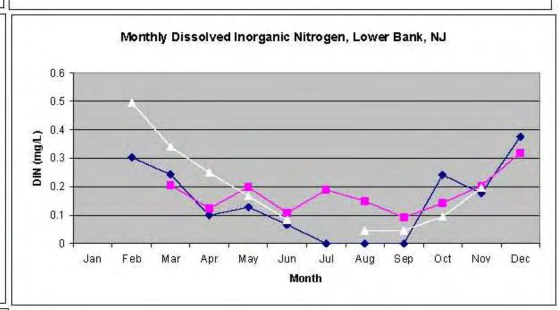


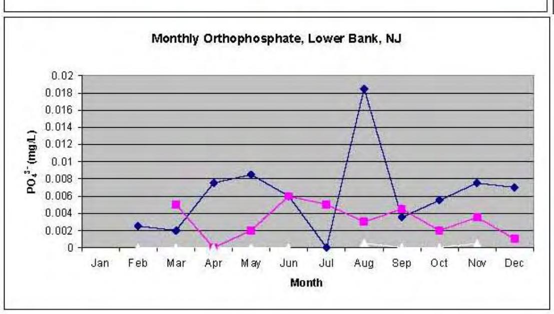










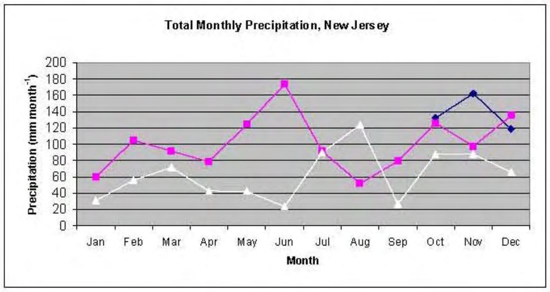


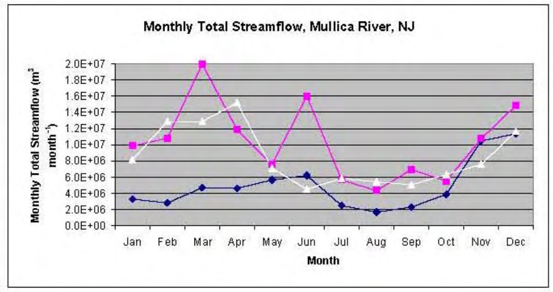
Chestnut Neck, New Jersey (MULNE)

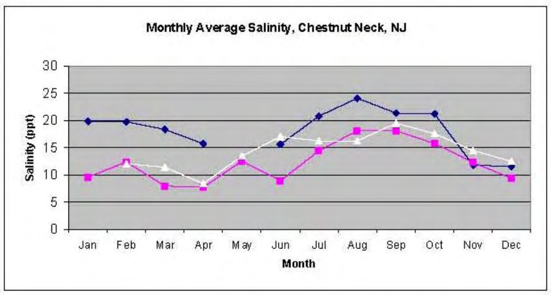
2002

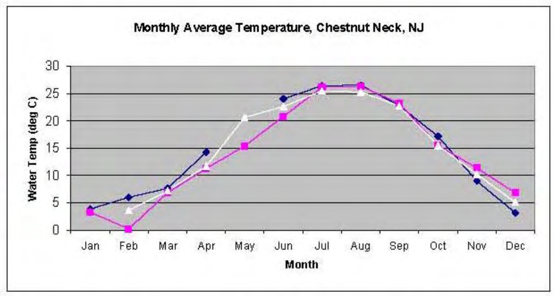
2003

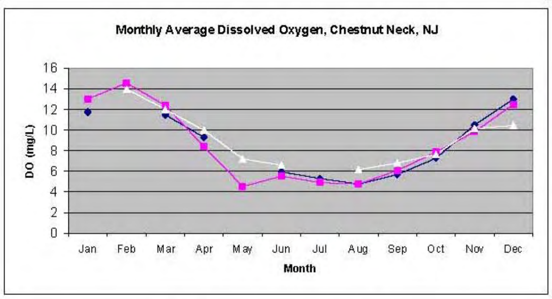
2004

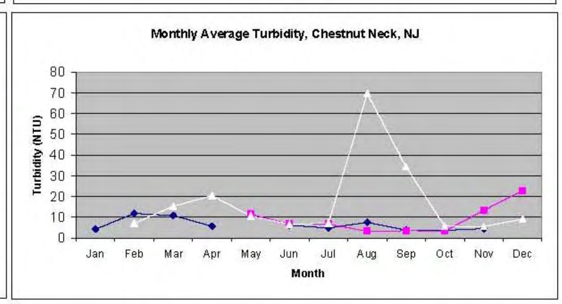


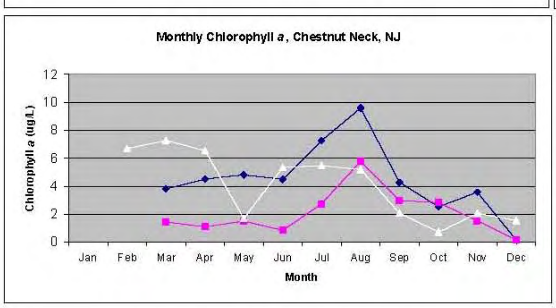


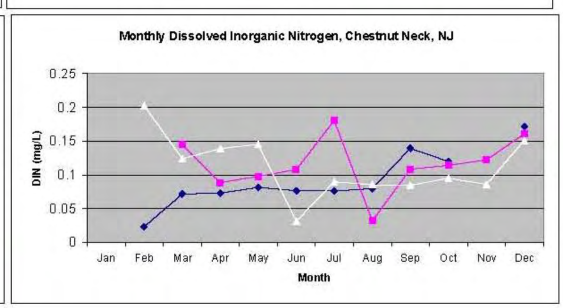


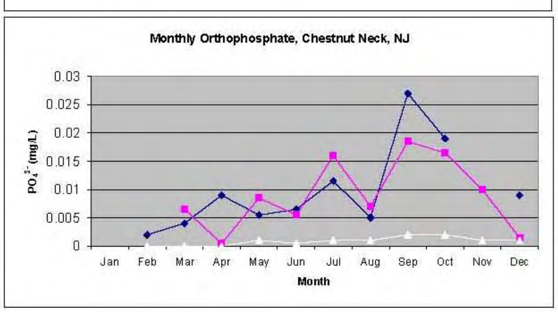










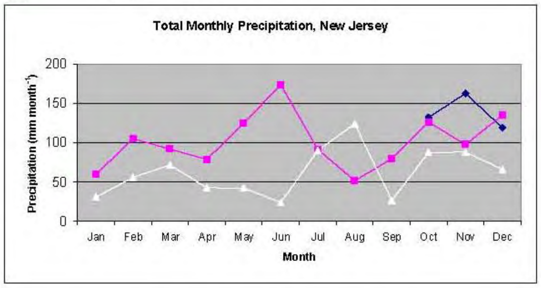


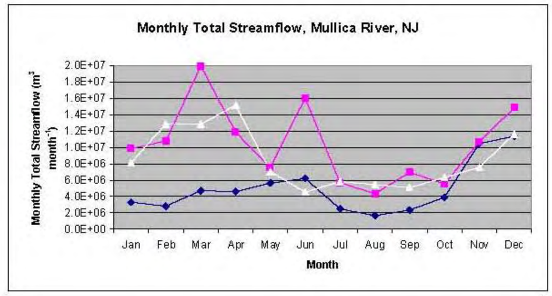
Buoy 126, New Jersey (MULB6)

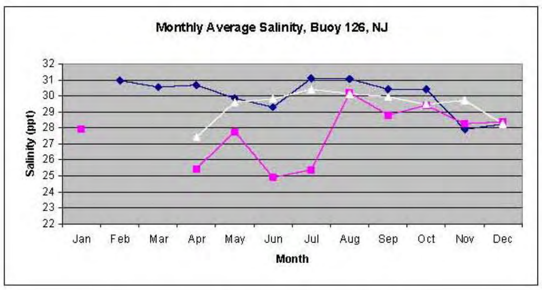
2002

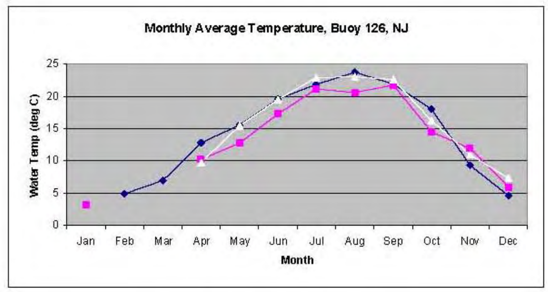
2003

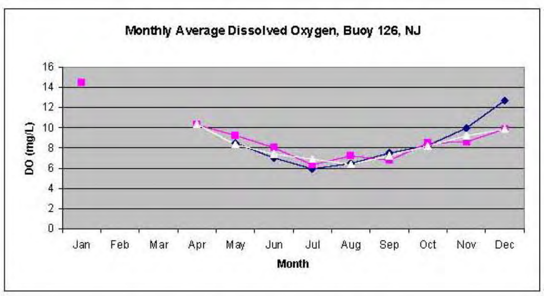
2004

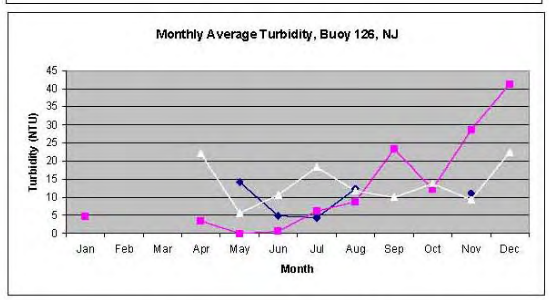


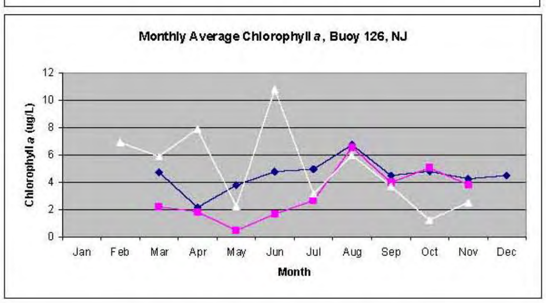


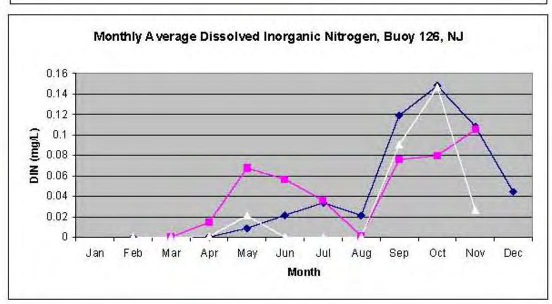


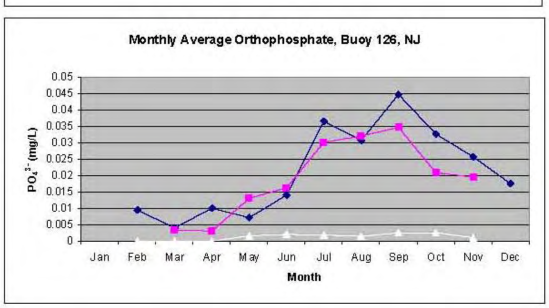










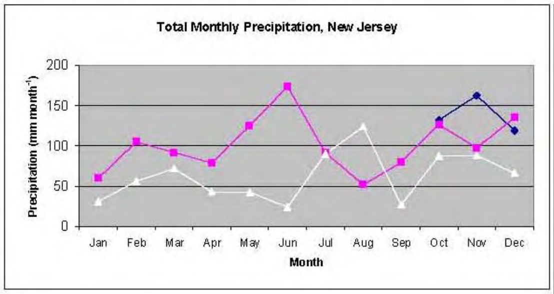


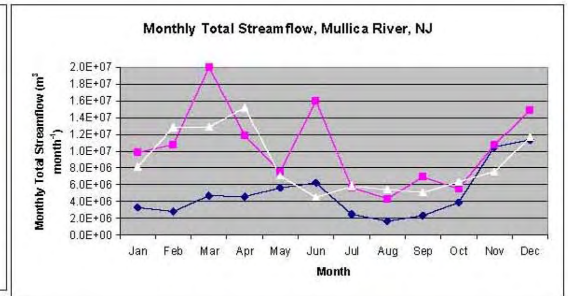
Buoy 139, New Jersey (MULB9)

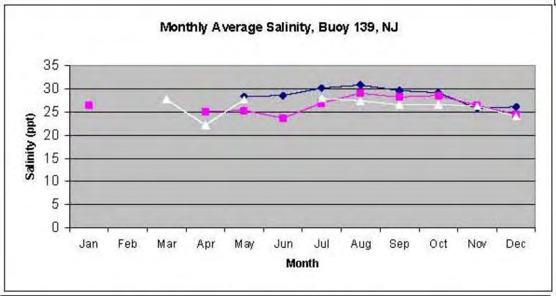
2002

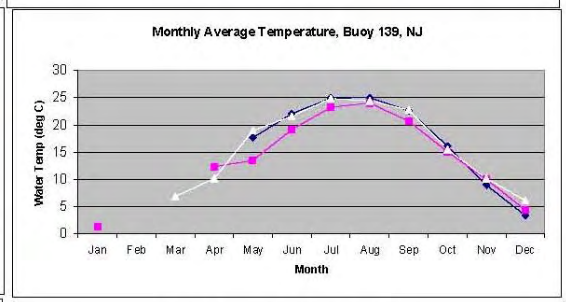
2003

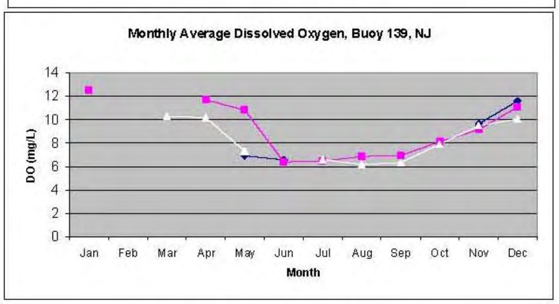
2004

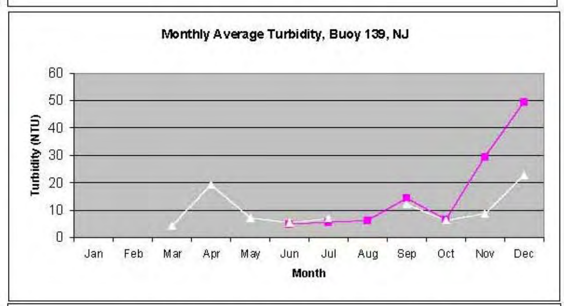


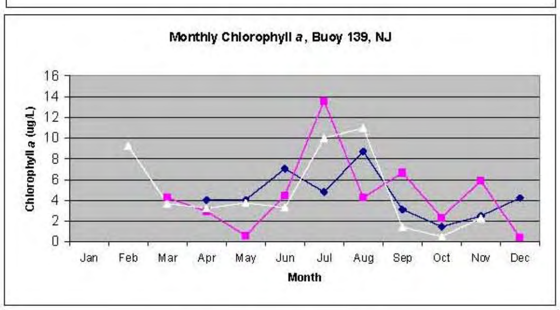


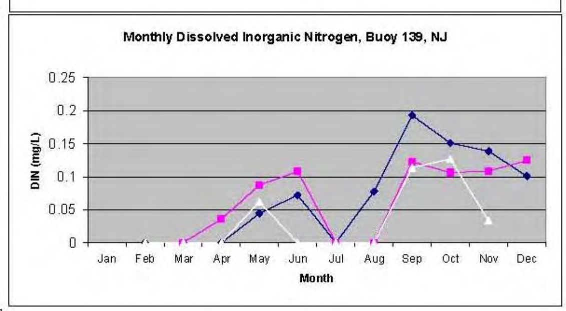


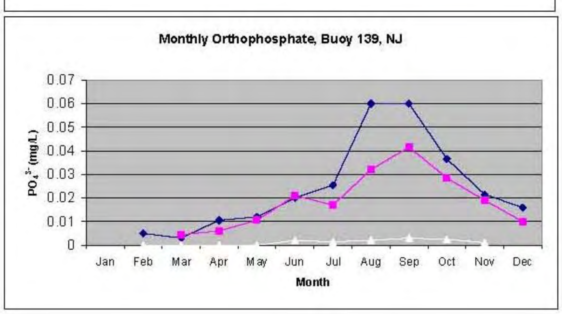






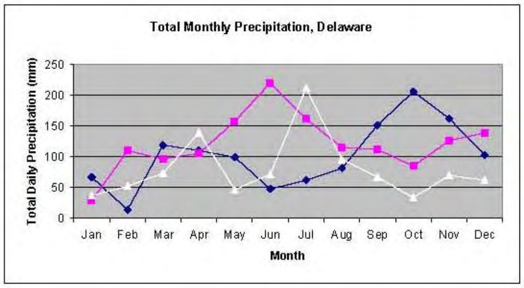


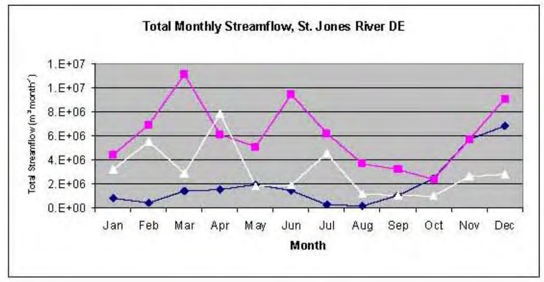


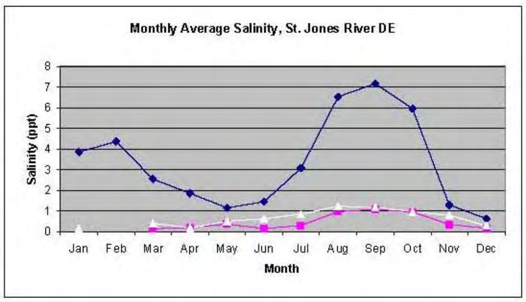


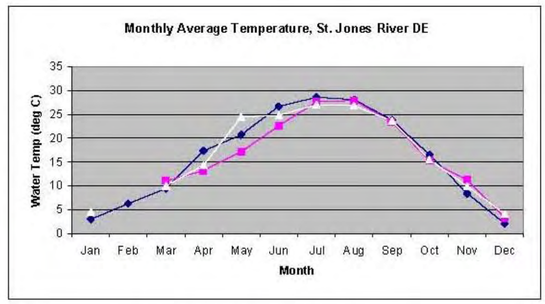
Blackbird Landing, DE

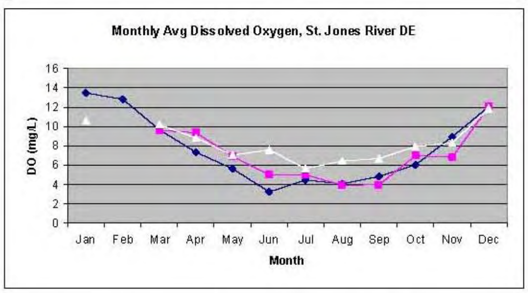
- 2002
- 2003
- 2004

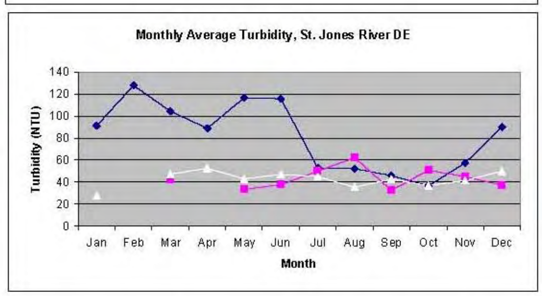


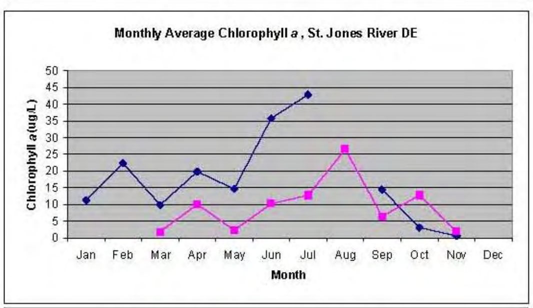


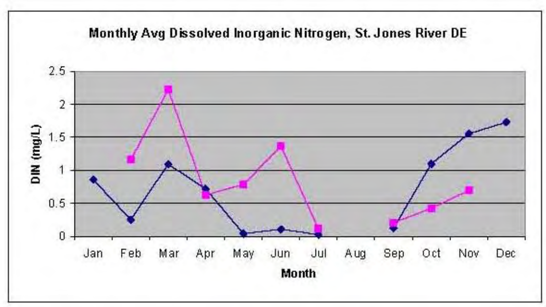


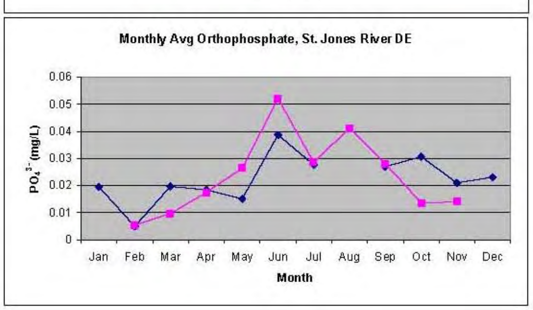










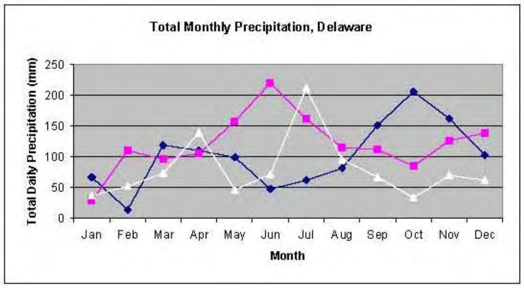


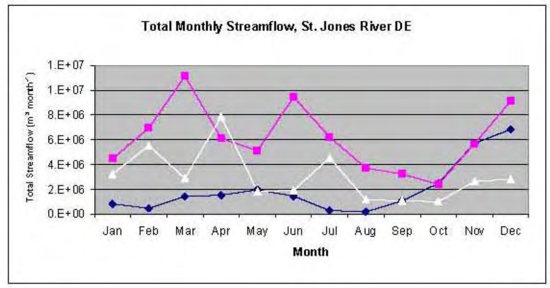
Division Street, DE (DELDS)

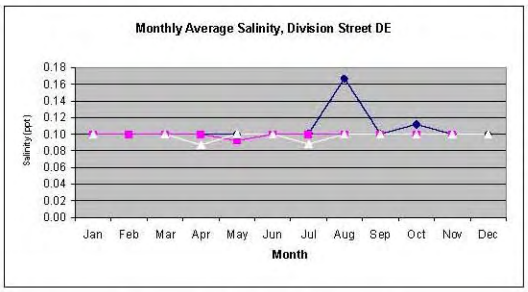
2002

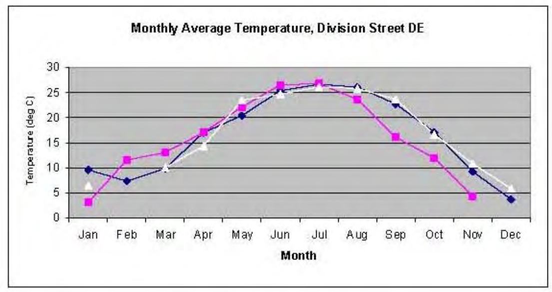
2003

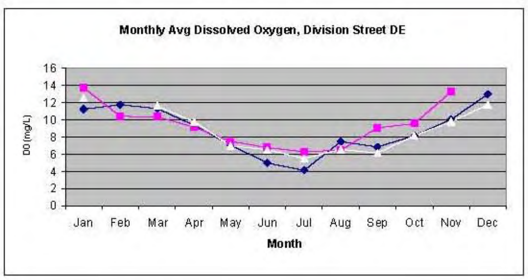
2004

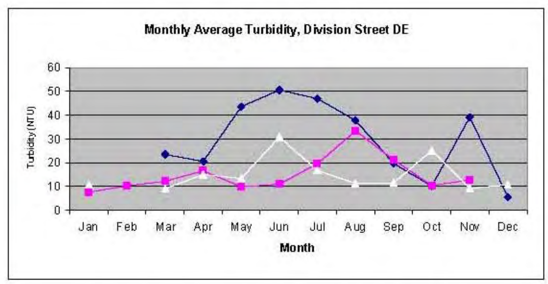


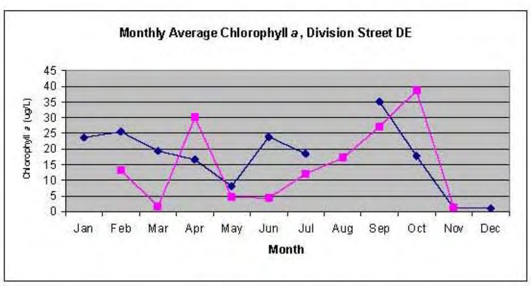


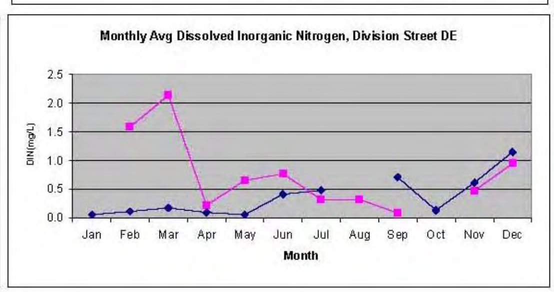


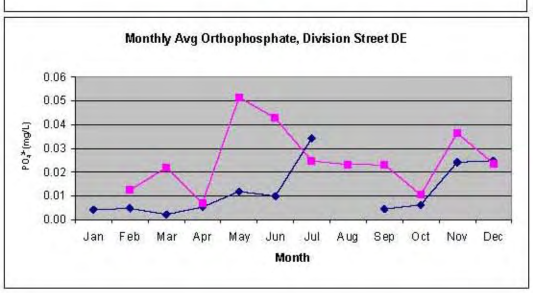










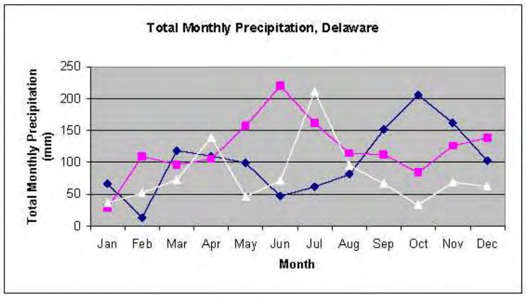


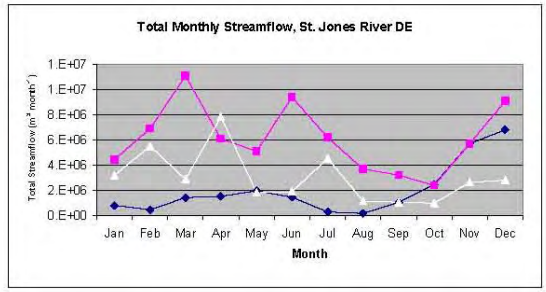
Lebanon Landing, DE (DELLL)

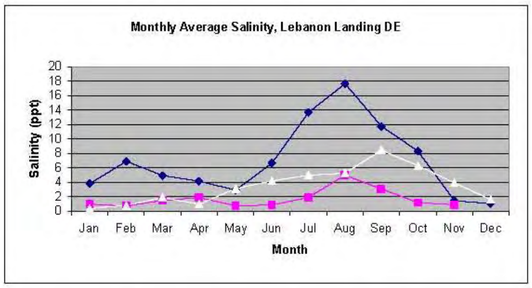
2002

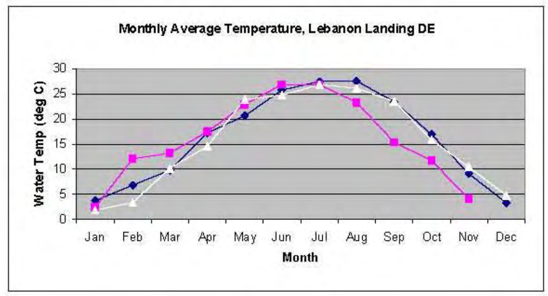
2003

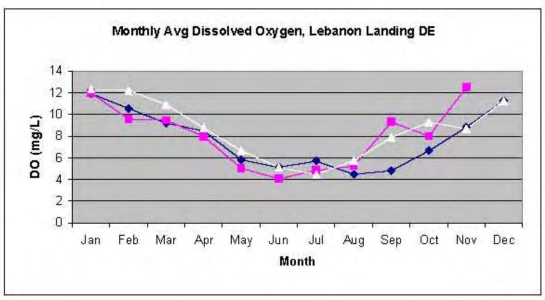
2004

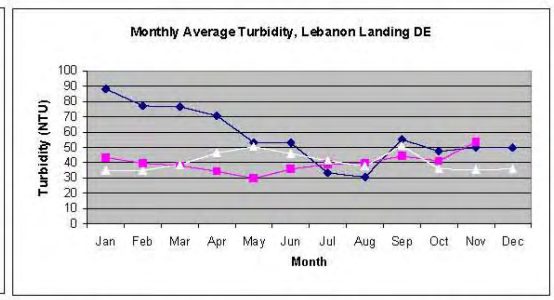


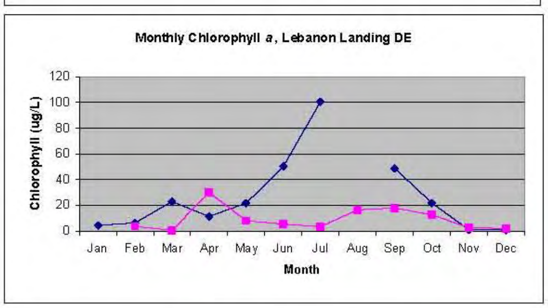


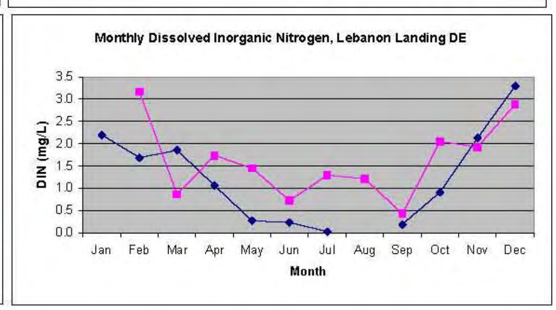


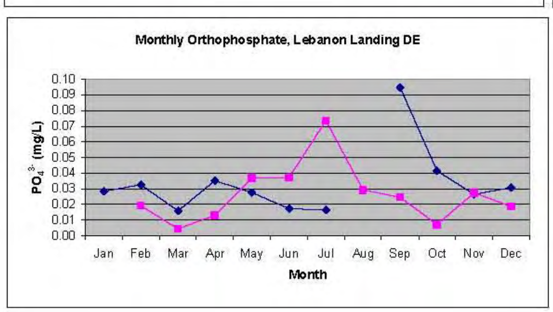










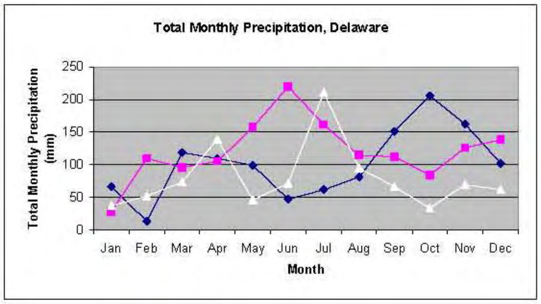


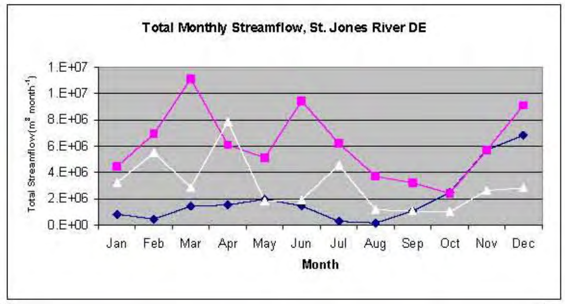
Scotton Landing, DE (DELSL)

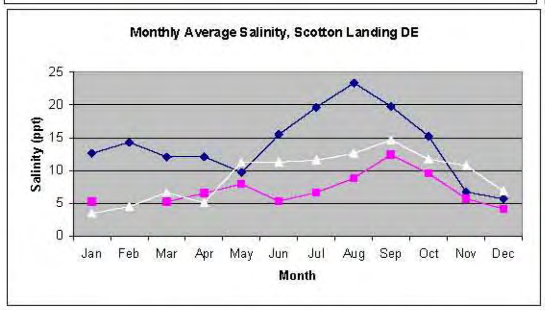
■ 2002

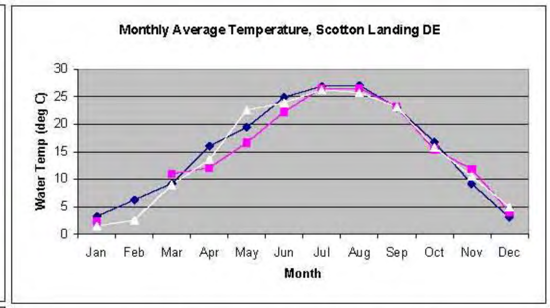
■ 2003

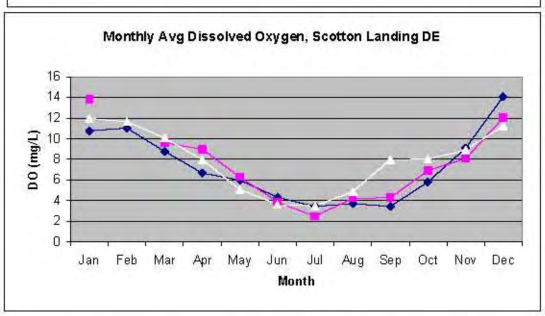
□ 2004

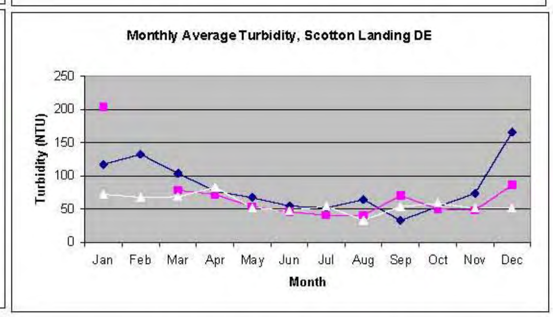


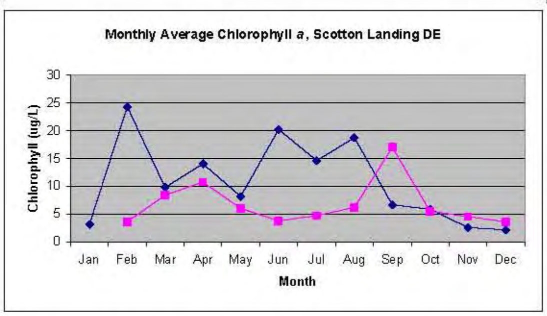


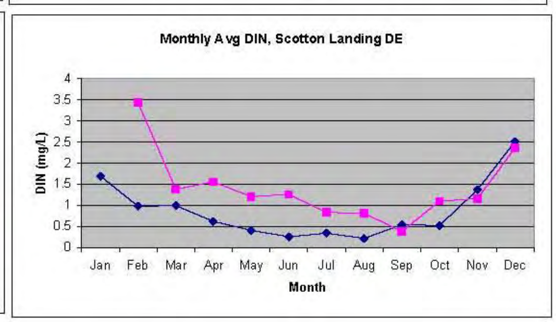


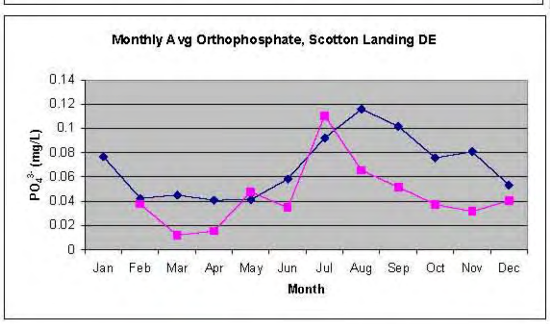










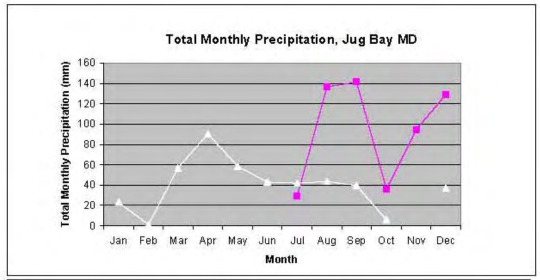


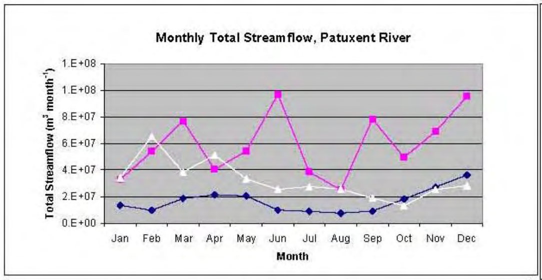
Otter Point Creek, Maryland (CBMOC)

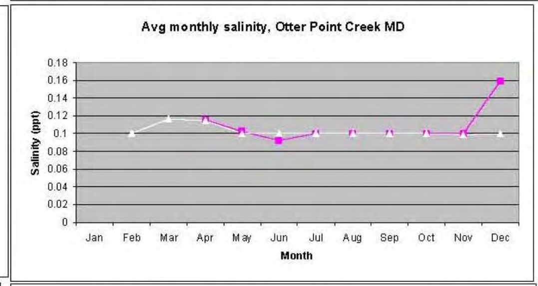
■ 2002

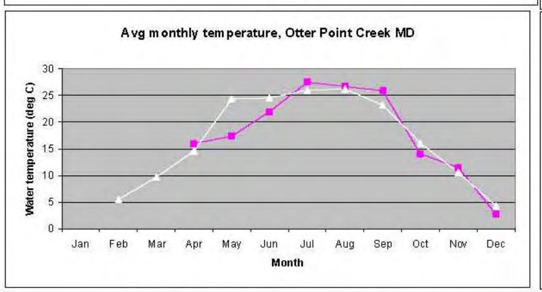
■ 2003

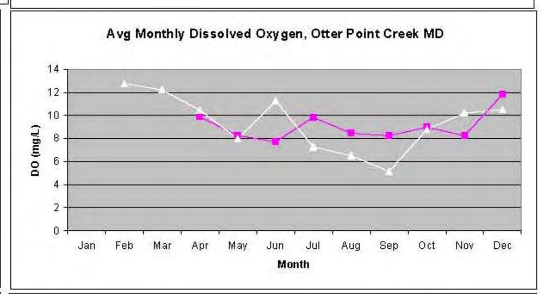
□ 2004

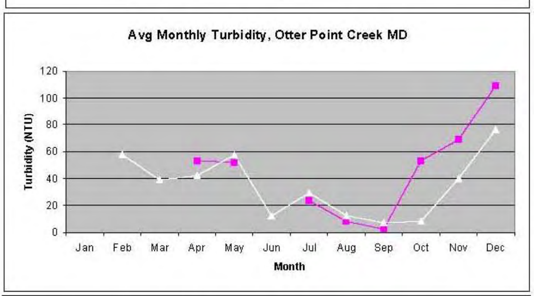


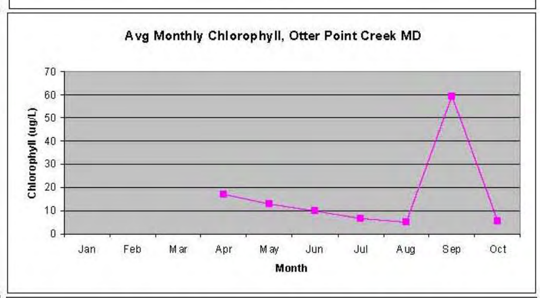


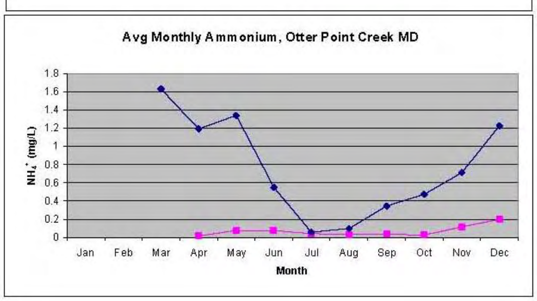


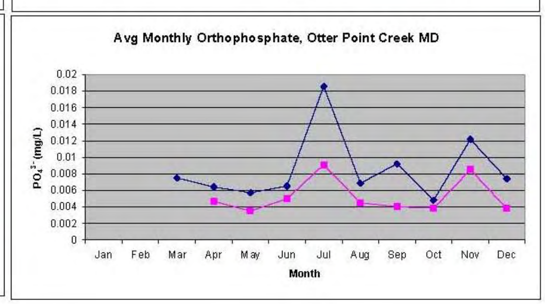






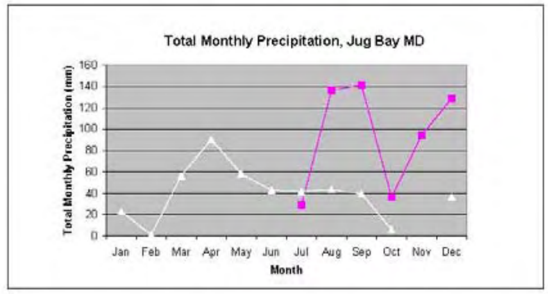


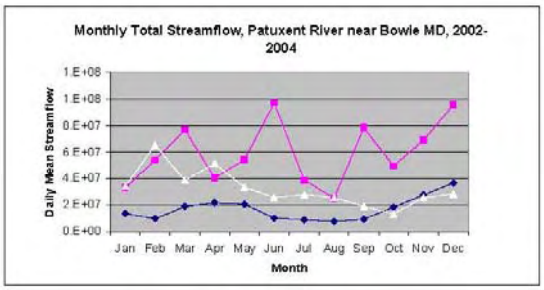


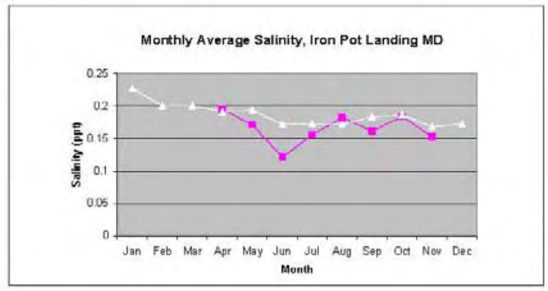


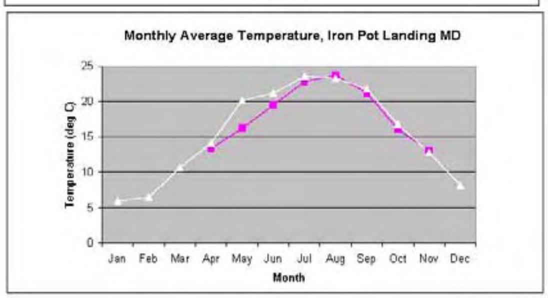
Iron Pot Landing, MD (CBMIP)

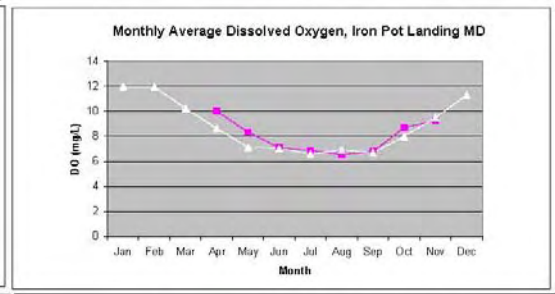
- 2002
- 2003
- 2004

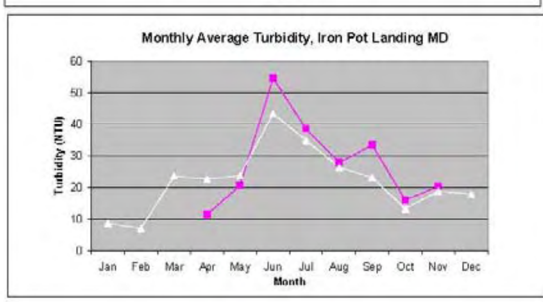


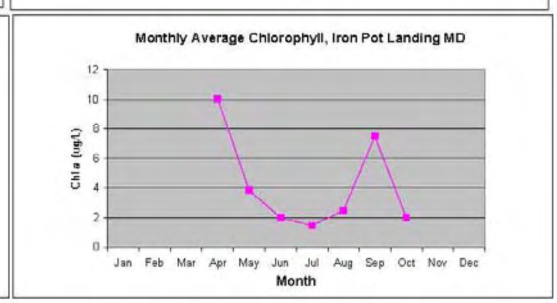


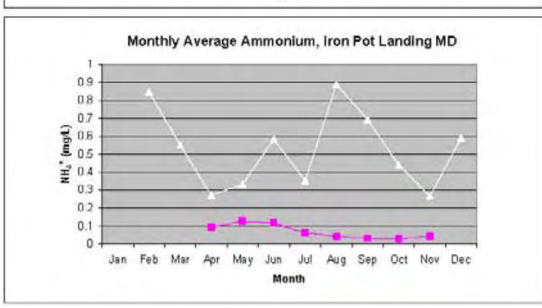


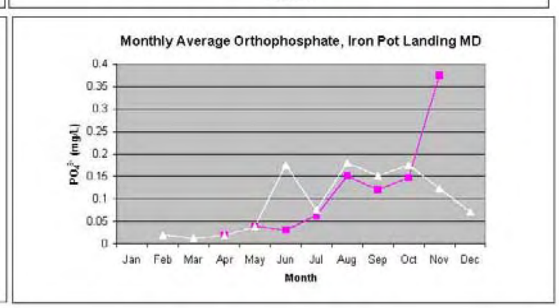




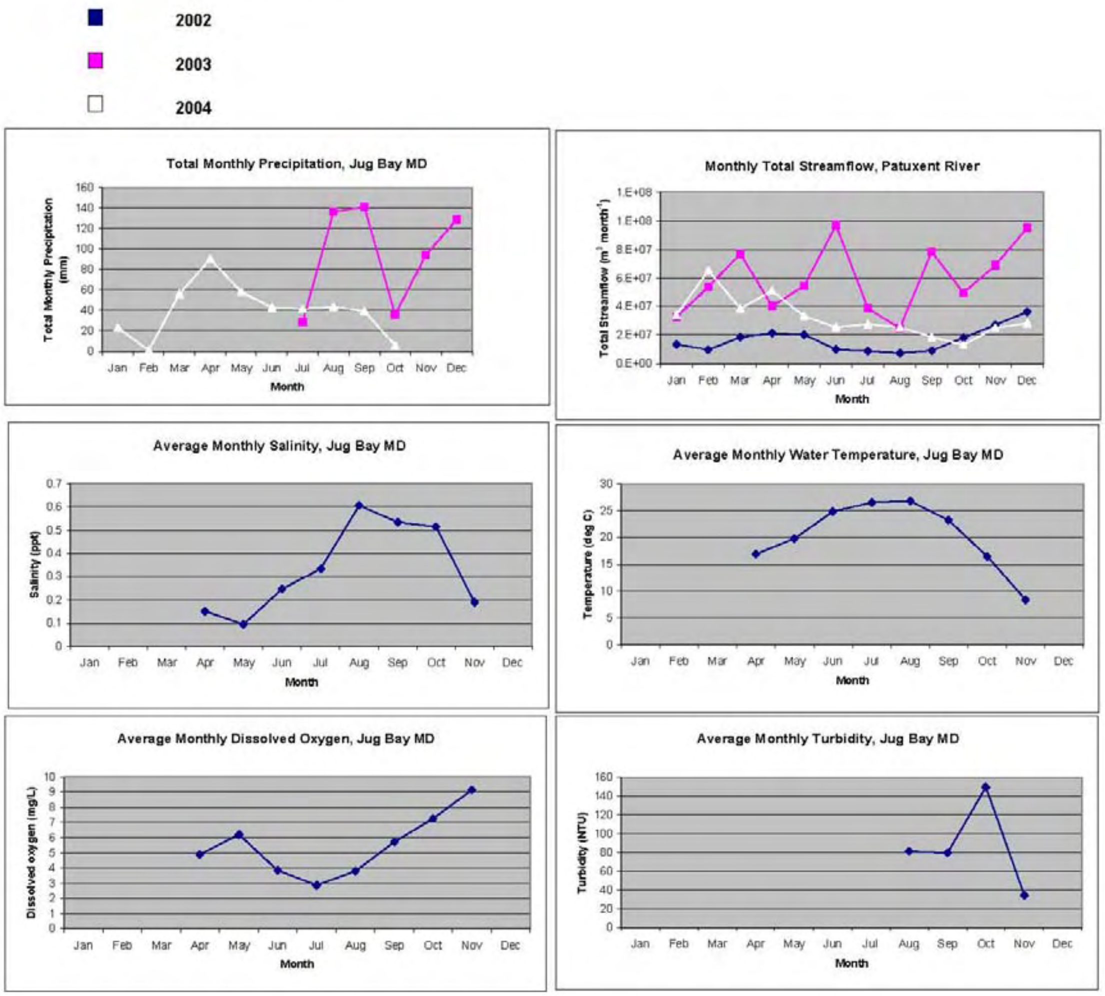






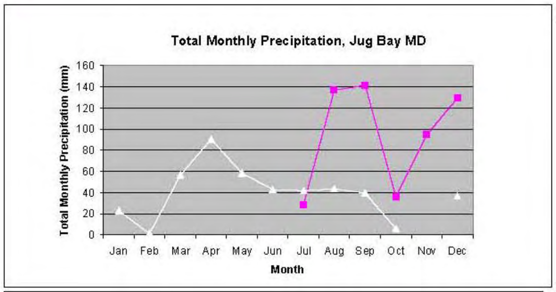


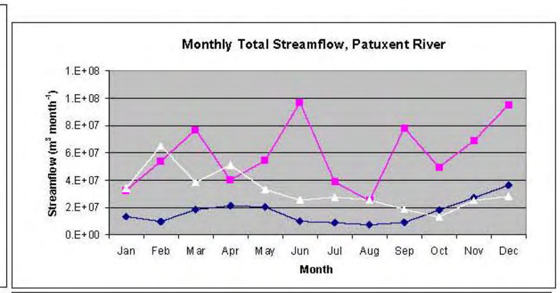
Jug Bay, Maryland (CBMJB)

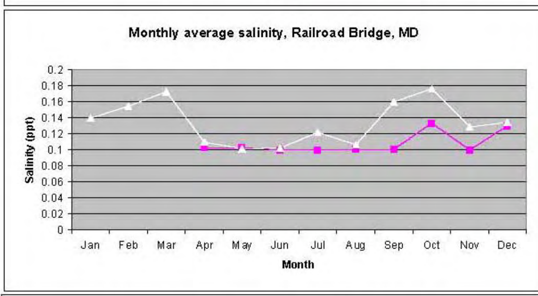


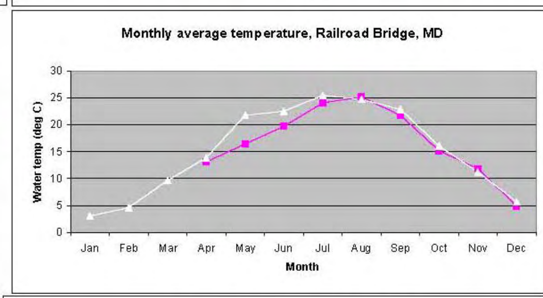
Railroad Bridge, Maryland (CBMRR)

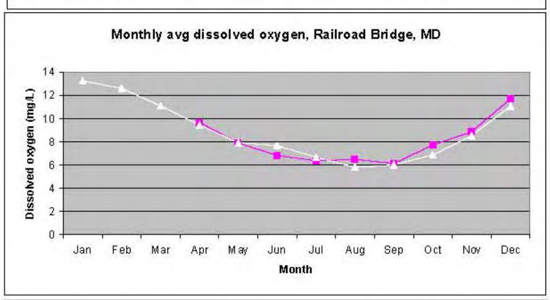
- 2002
- 2003
- 2004

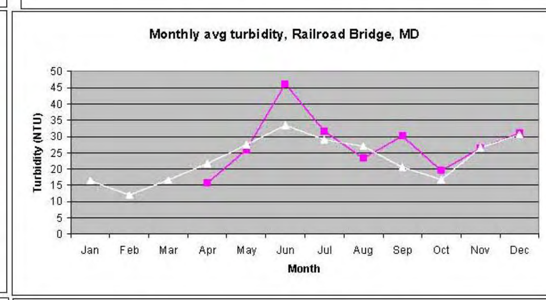


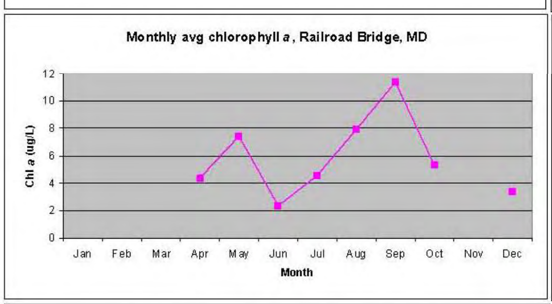


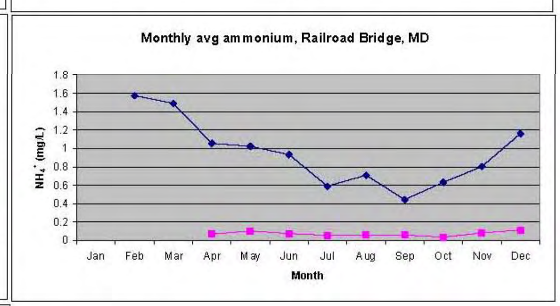


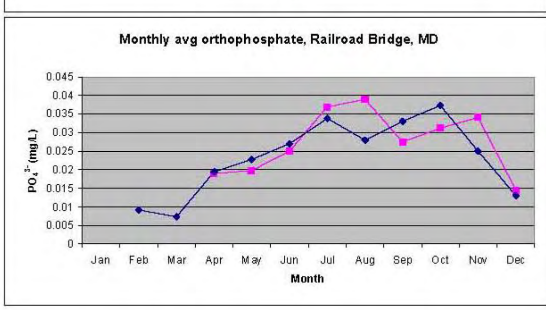






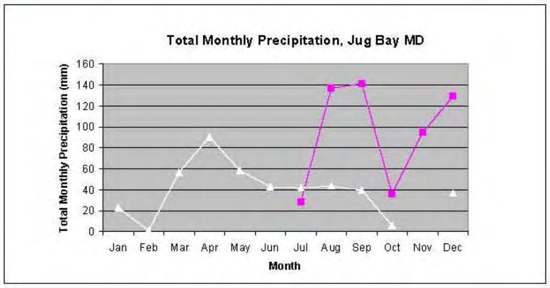


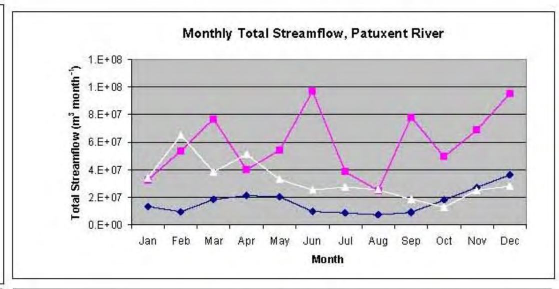


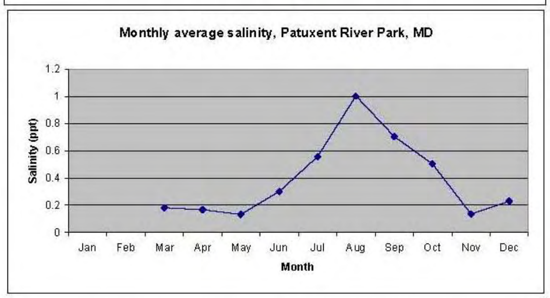


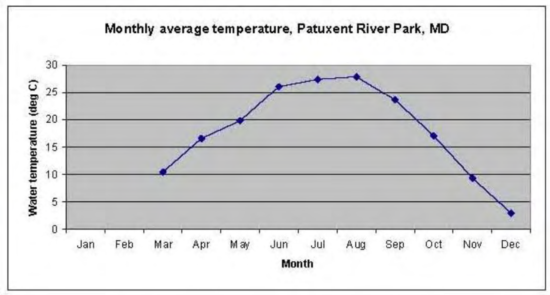
Patuxent River Park, Maryland (CBMPR)

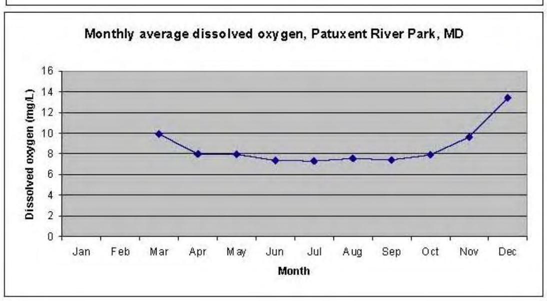
- ■ 2002
- ■ 2003
- □ 2004

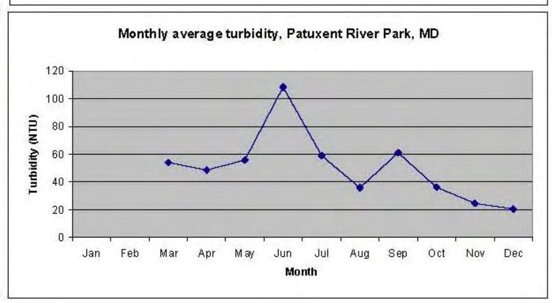






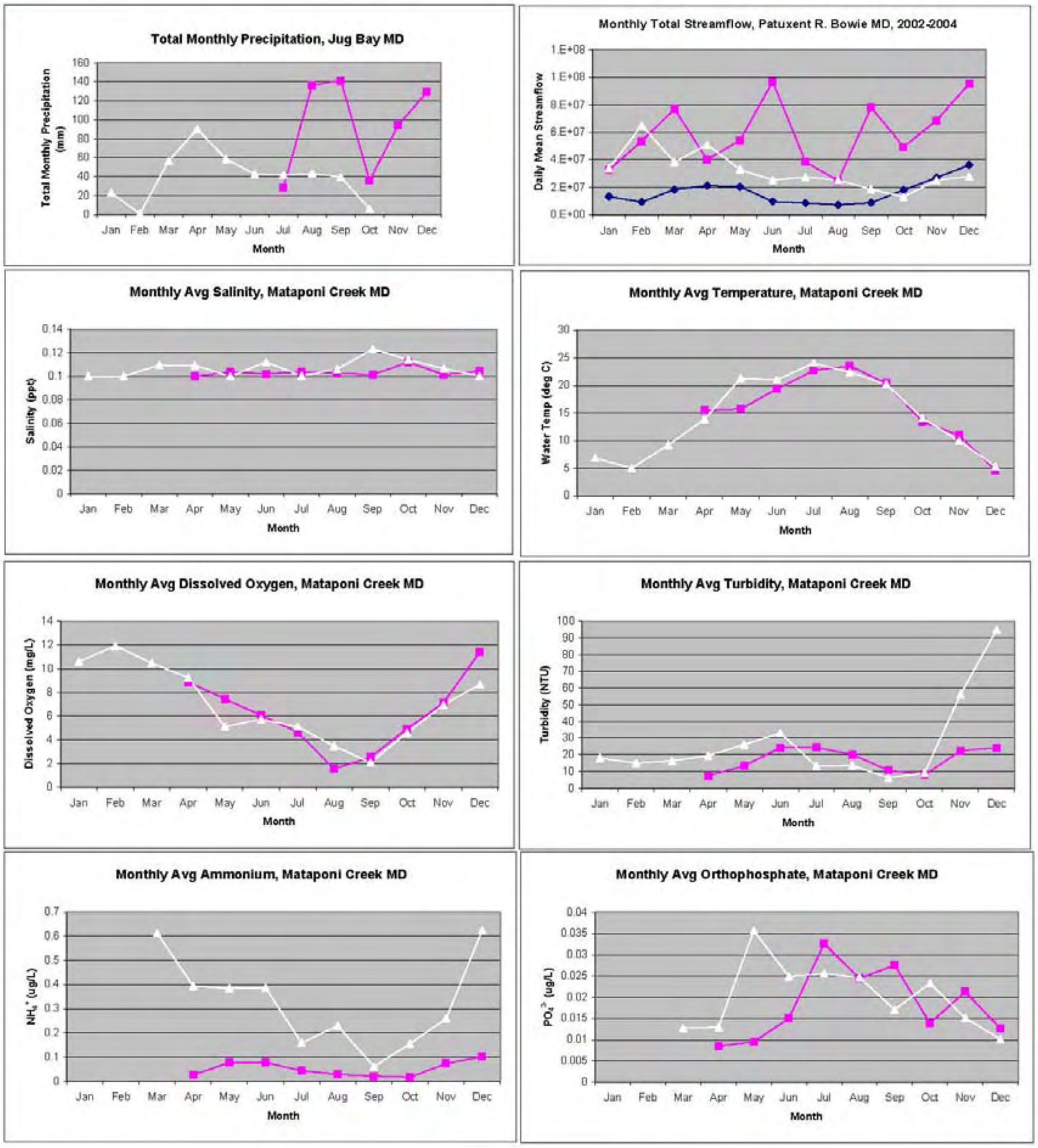






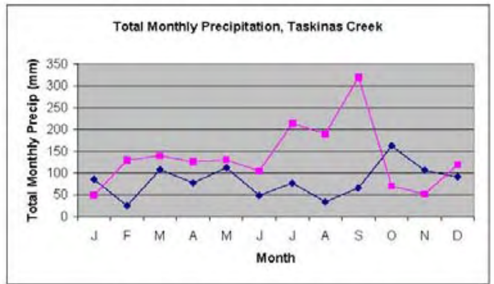
Mataponi Creek, MD (CBMMC)

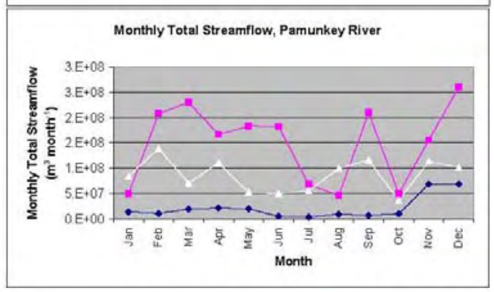
- 2002
- 2003
- 2004

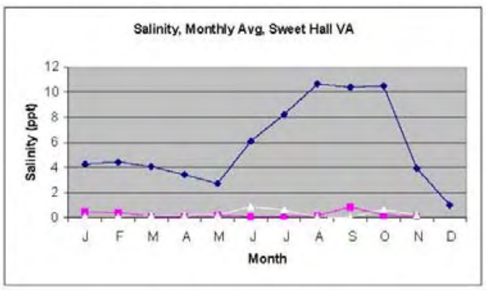


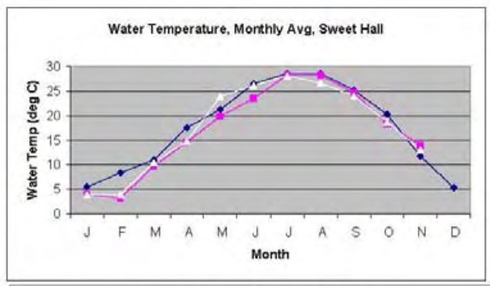
Sweet Hall, Virginia (CBVSH)

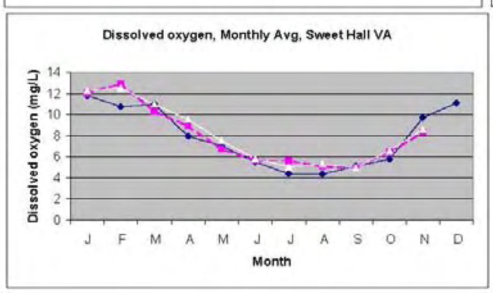
- 2002
- 2003
- 2004

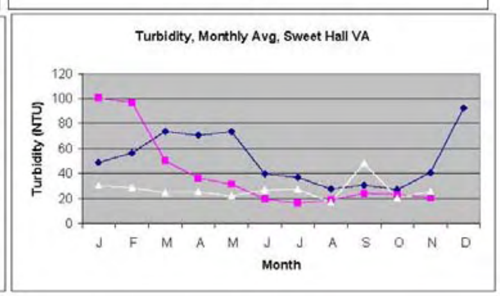


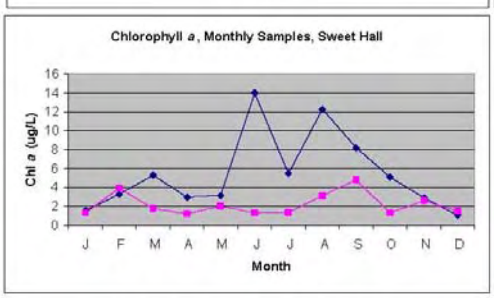


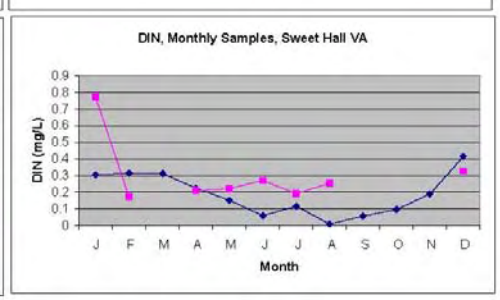


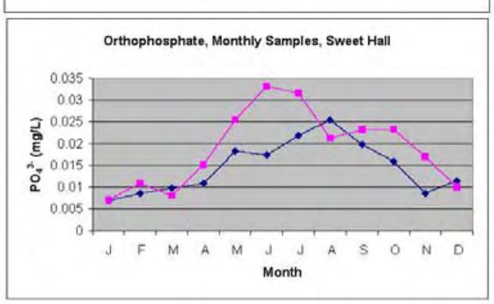






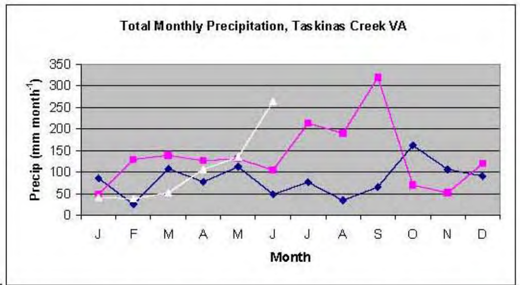


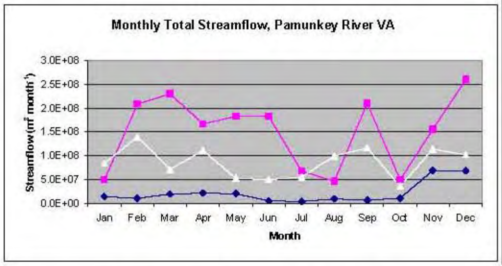


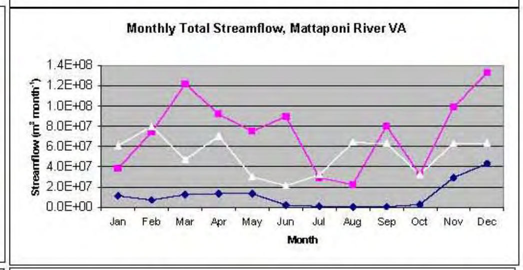


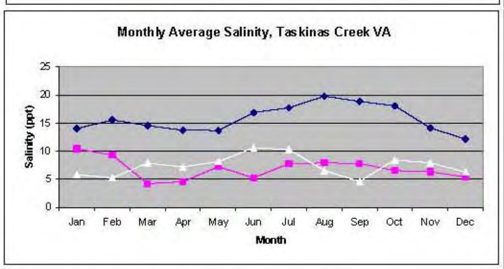
Taskinas Creek, Virginia (CBVTC)

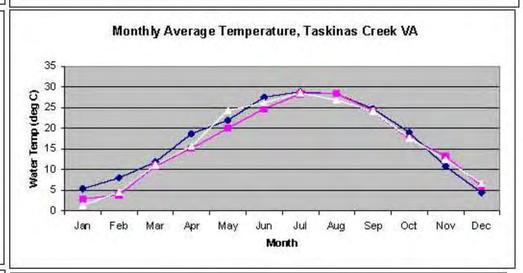
- 2002
- 2003
- 2004

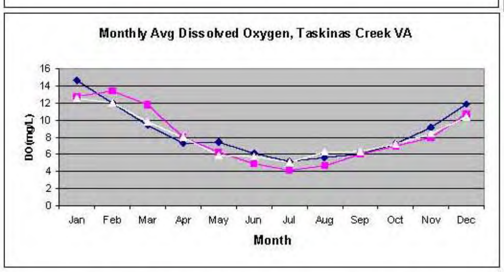


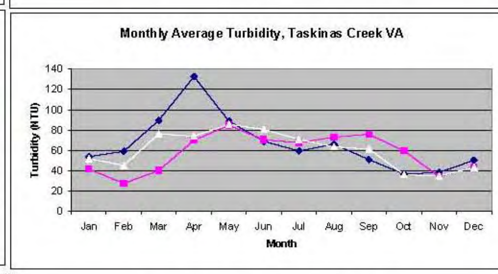


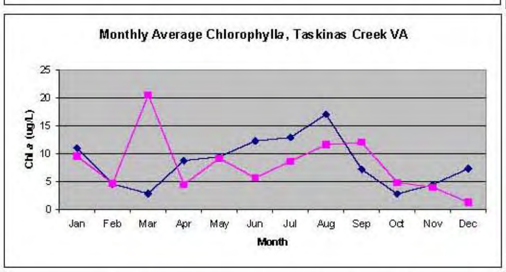


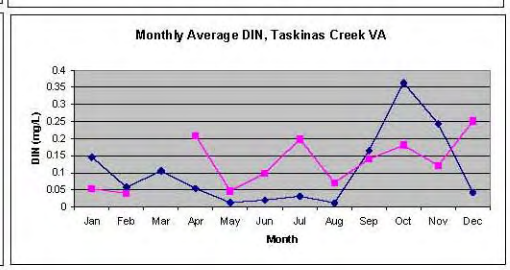


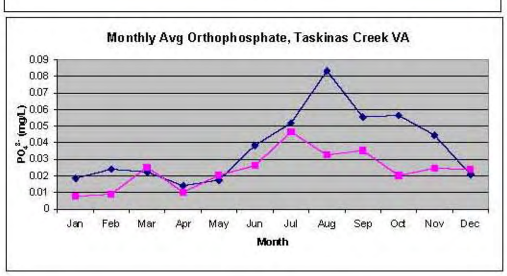






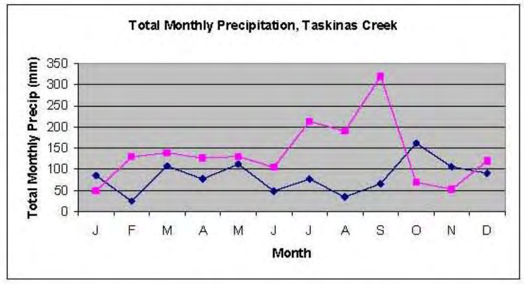


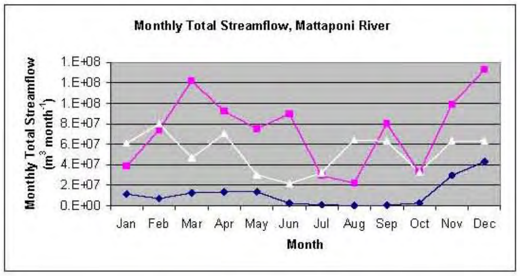


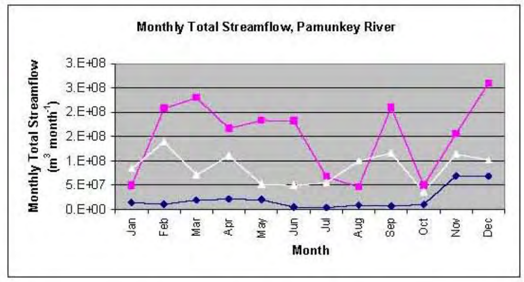


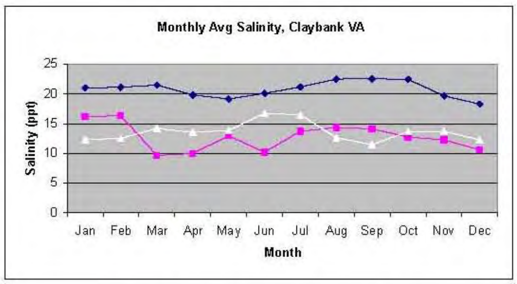
Claybank, Virginia (CBVCB)

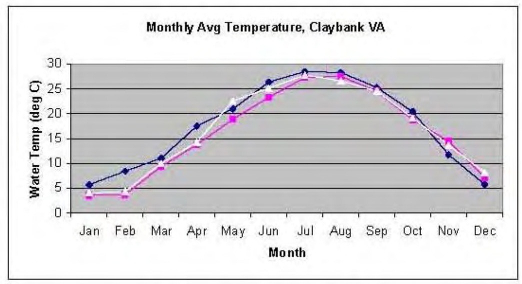
- 2002
- 2003
- 2004

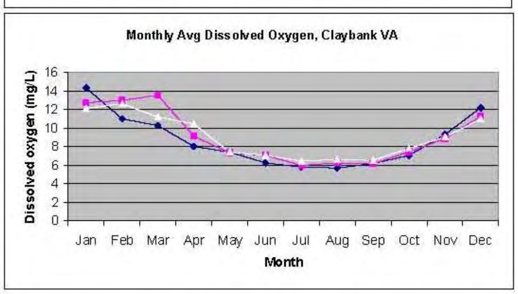


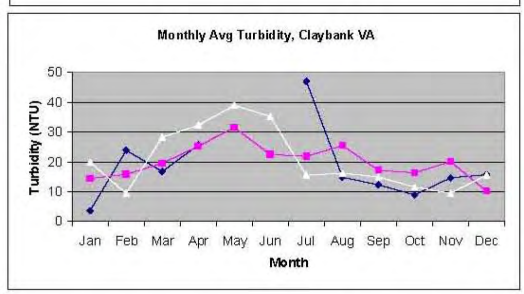


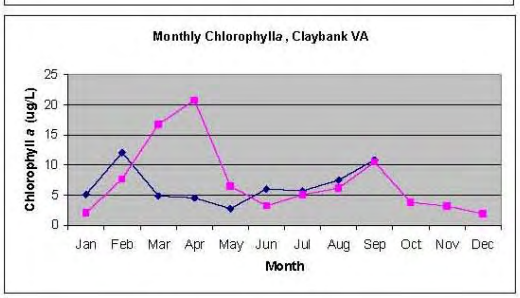


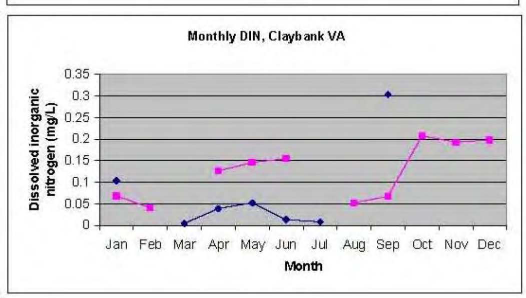


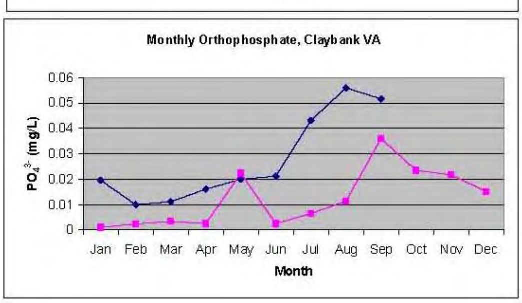






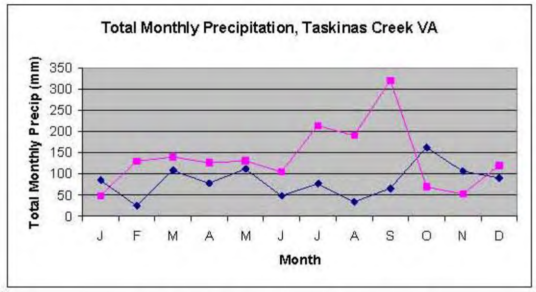


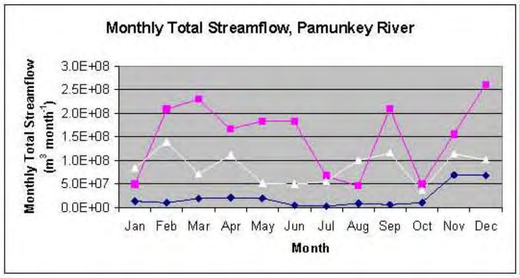


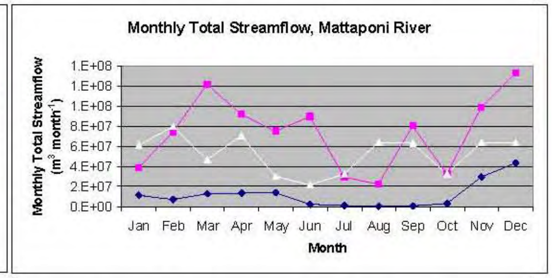


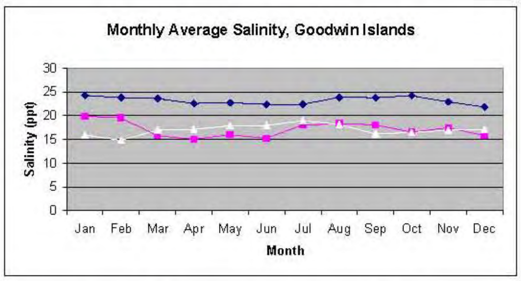
Goodwin Islands, VA (CBVGI)

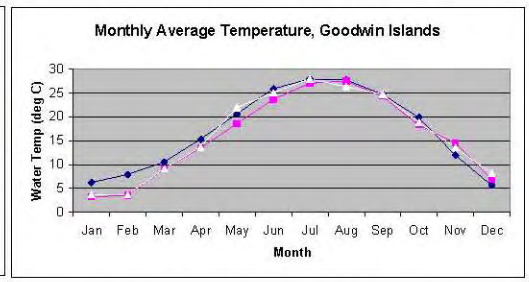
- 2002
- 2003
- 2004

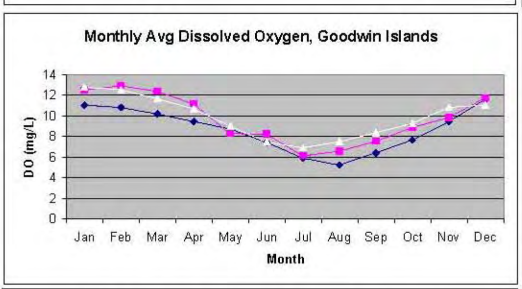


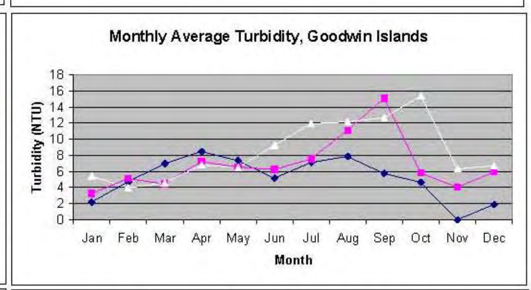


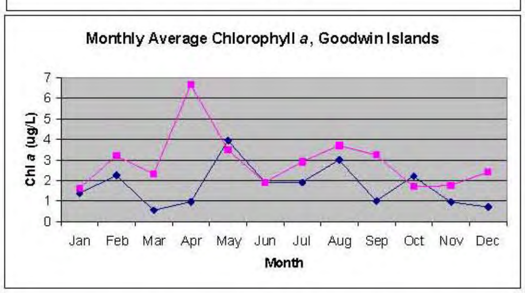


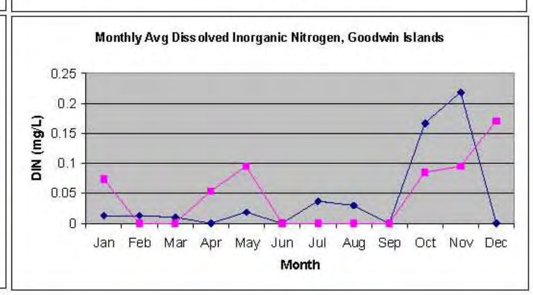


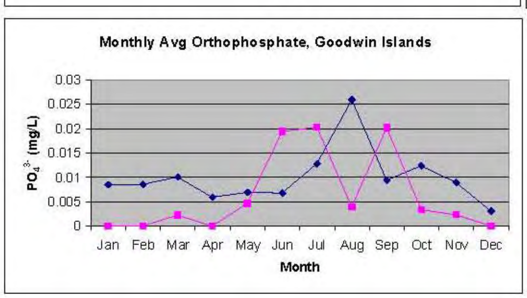




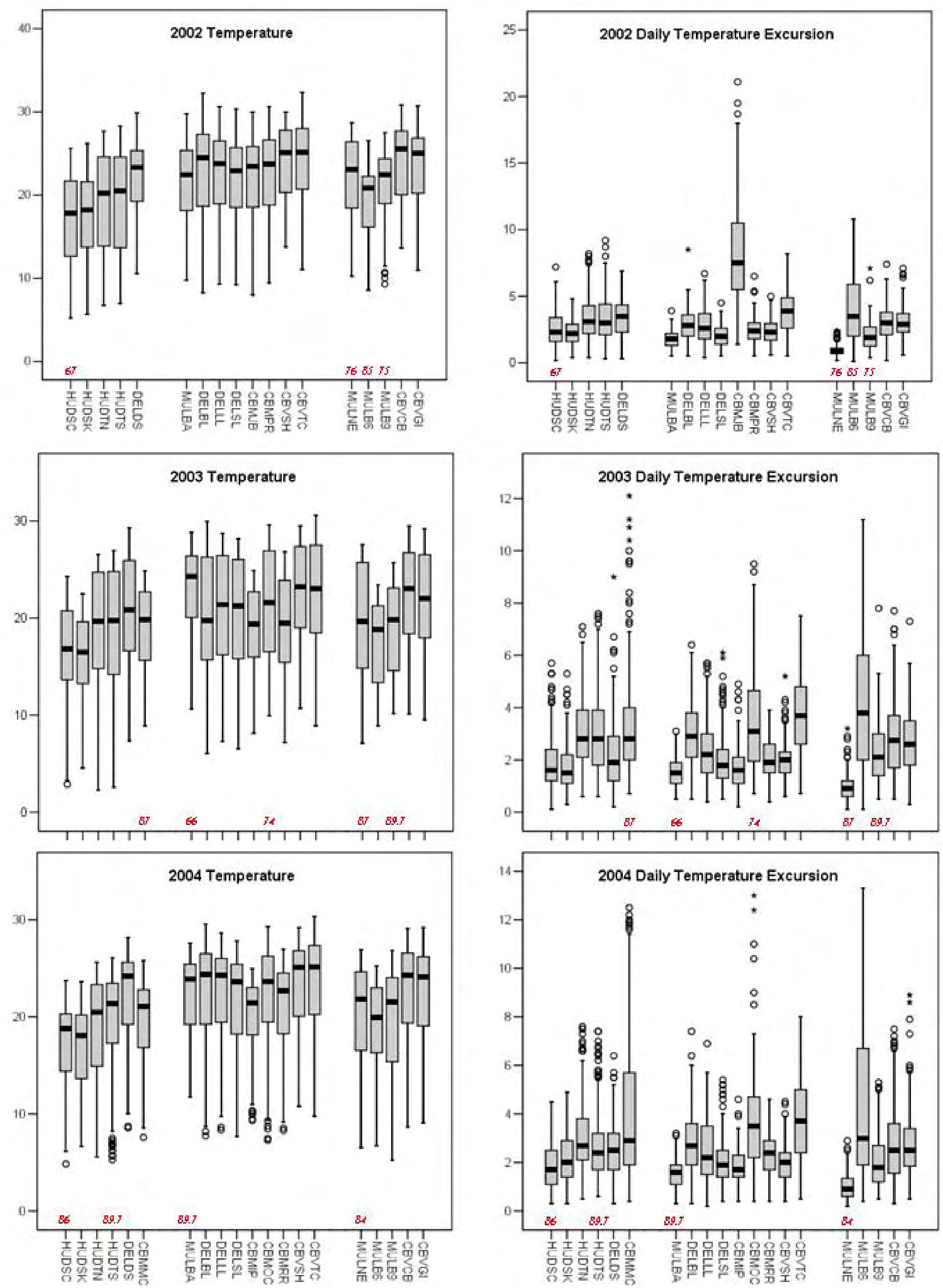


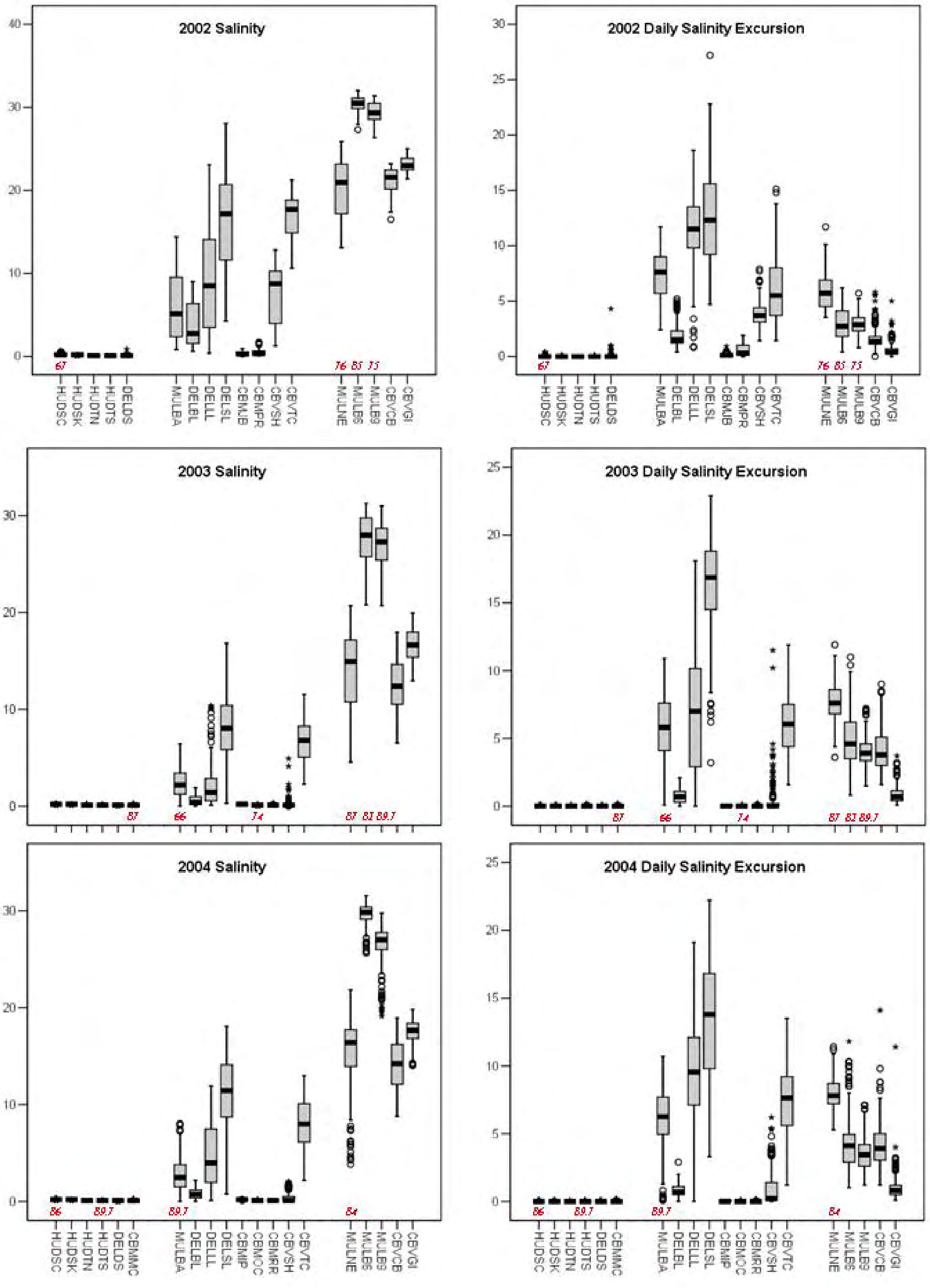


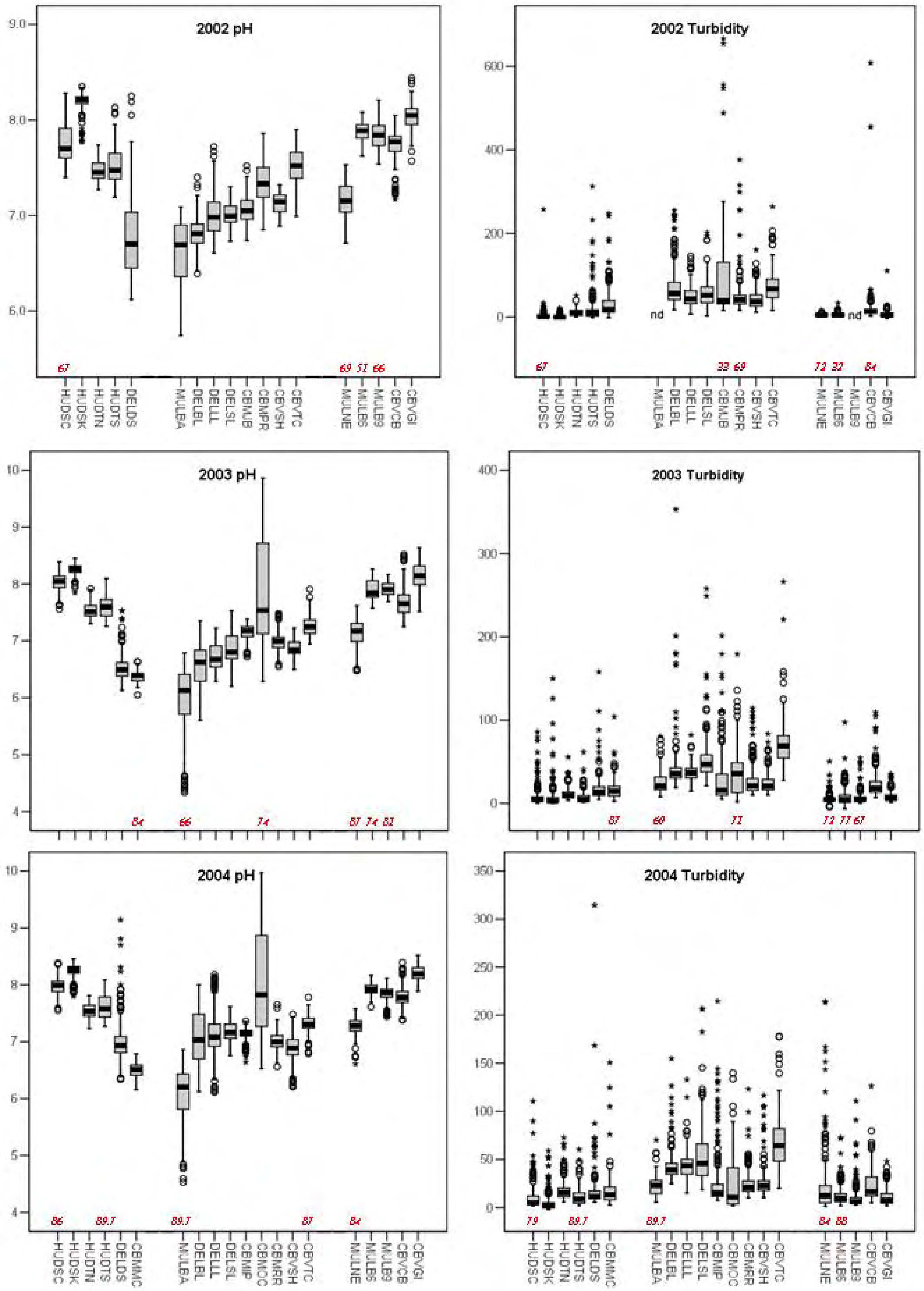


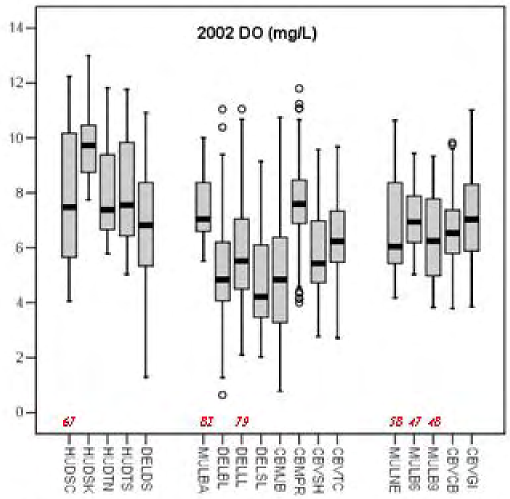


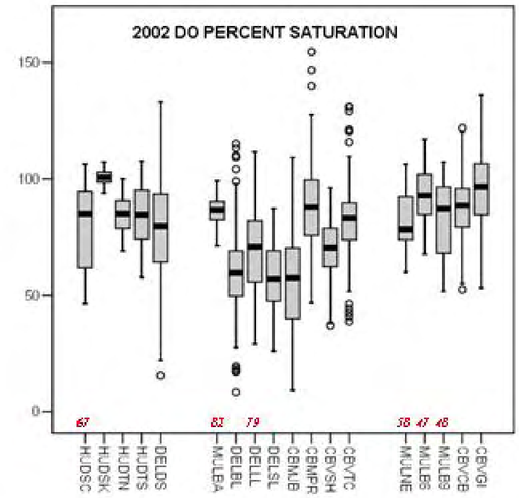
Appendix G. Box plots of April-October water quality and nutrient data by cluster for the period 2002-04. See Figure 14 for an explanation of symbols. Numbers in red under water quality (YSI) data are the percent of available data for the period Apr-Oct. Red text under chlorophyll/nutrient data indicates the number of months of missing data for the period Apr-Oct.

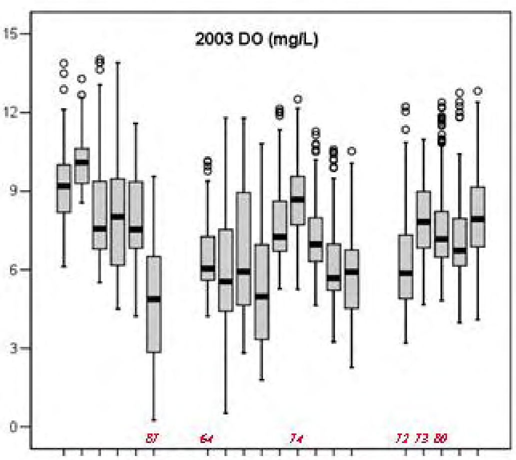


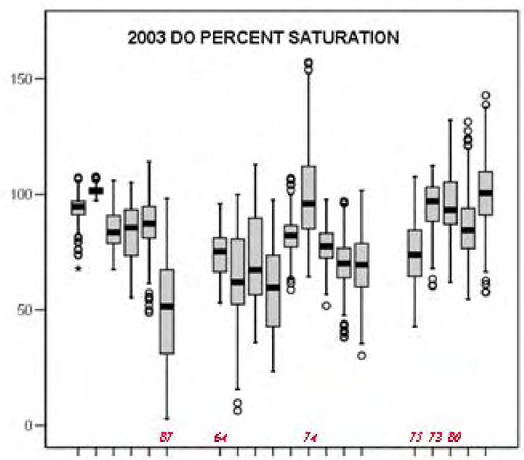

2002 Salinity
2002 Daily Salinity Excursion
HUDSC HUDSK HUDTN HUDTS DELDS MULBA DELBL DELLL DELSL CBMJB CBMPR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI
2003 Salinity
2003 Daily Salinity Excursion
2004 Salinity
2004 Daily Salinity Excursion
HUDSC HUDSK HUDTN HUDTS DELDS CBMMC MULBA DELBL DELLL DELSL CBMIP CBMOC CBMRR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI

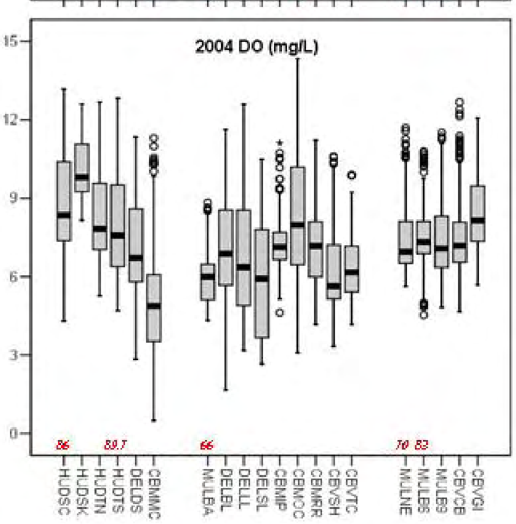

2002 pH
2002 Turbidity
2003 pH
2003 Turbidity
2004 pH
2004 Turbidity
HUDSC HUDSK HUDTN HUDTS DELDS MULBA DELBL DELLL DELSL CBMJB CBMPR CBVSH CBVTC MULNE MULB5 MULB9 CBVCB CBVGI
HUDSC HUDSK HUDTN HUDTS DELDS CBMMC MULBA DELBL DELLL DELSL CBMIP CBMOC CBMRR CBVSH CBVTC MULNE MULB5 MULB9 CBVCB CBVGI
nd

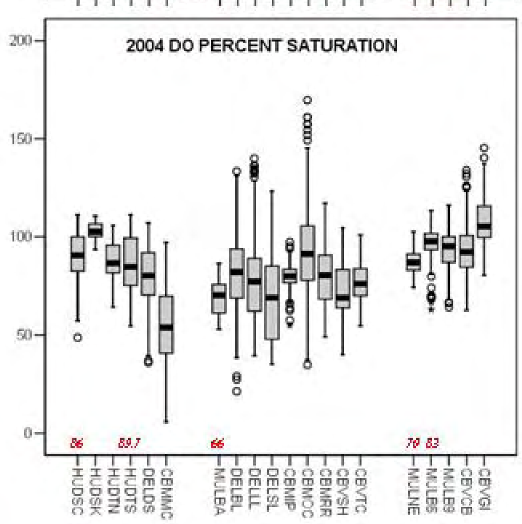

2002 DO (mg/L)
HUDSC HUDSK HUDTN HUDTS DELDS MULBA DELBL DELLL DELSL CBMJB CBMPR CBVSH CBVTC MULNE MULB5 MULB9 CBVCB CBVGI

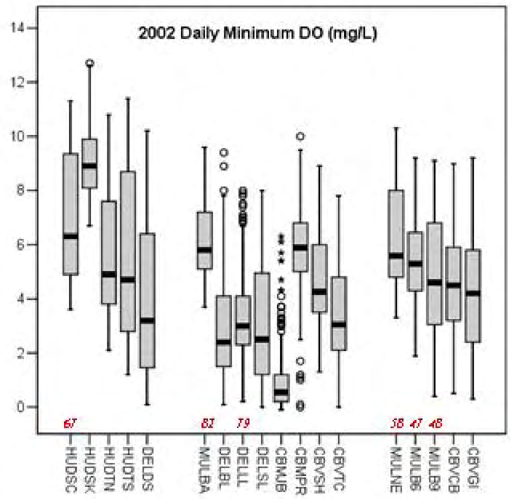

2002 DO PERCENT SATURATION
HUDSC HUDSK HUDTN HUDTS DELDS MULBA DELBL DELLL DELSL CBMJB CBMPR CBVSH CBVTC MULNE MULB5 MULB9 CBVCB CBVGI

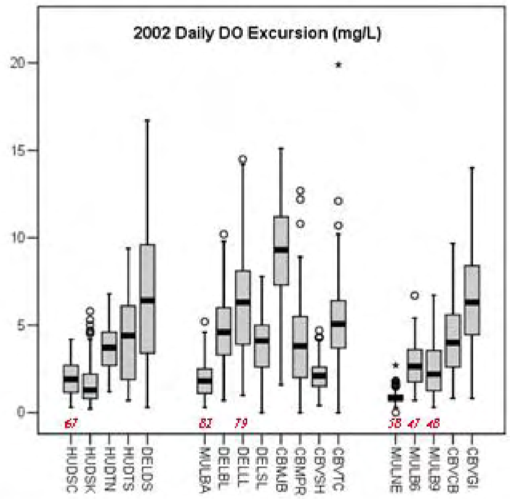

2003 DO (mg/L)

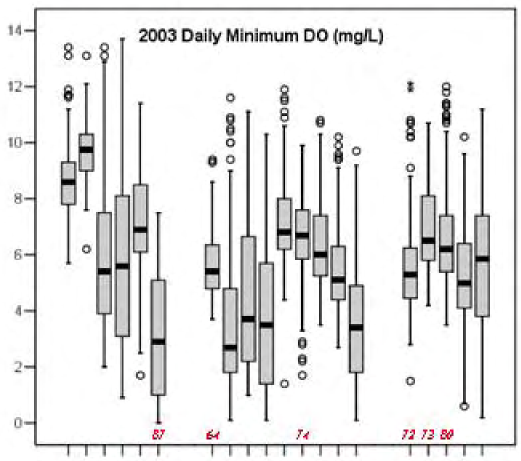

2003 DO PERCENT SATURATION

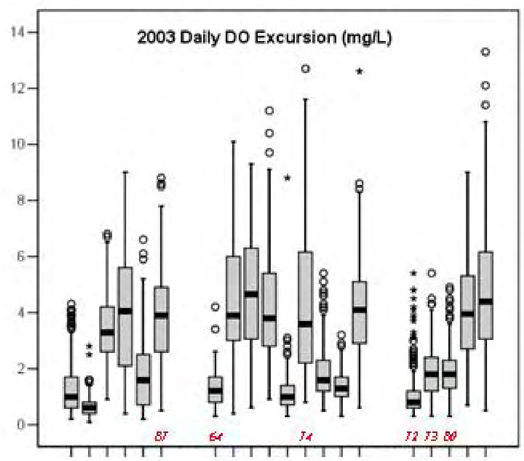

2004 DO (mg/L)
HUDSC HUDSK HUDTN HUDTS DELDS CBMMC MULBA DELBL DELLL DELSL CBMIP CBMOC CBMRR CBVSH CBVTC MULNE MULB5 MULB9 CBVCB CBVGI

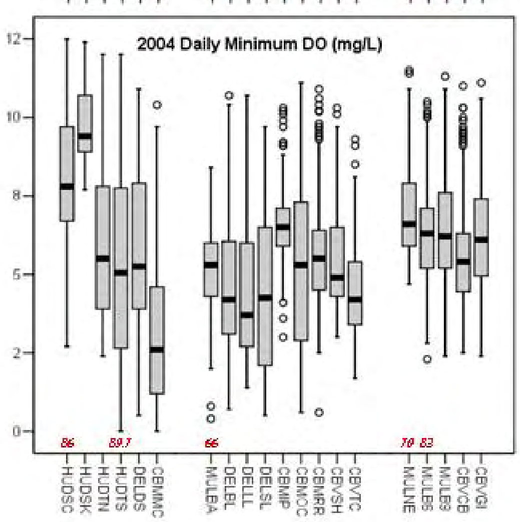

2004 DO PERCENT SATURATION
HUDSC HUDSK HUDTN HUDTS DELDS CBMMC MULBA DELBL DELLL DELSL CBMIP CBMOC CBMRR CBVSH CBVTC MULNE MULB5 MULB9 CBVCB CBVGI

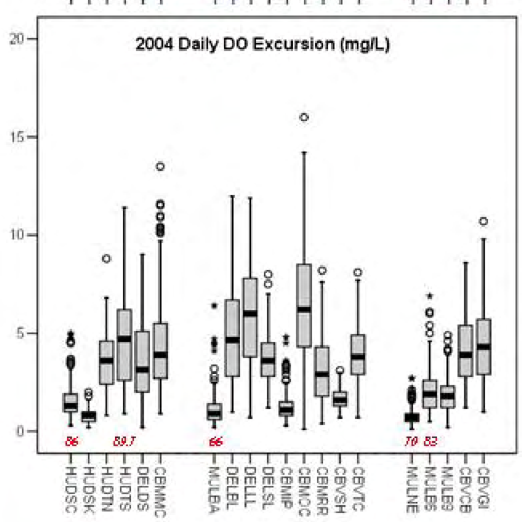

2002 Daily Minimum DO (mg/L)
HUDSC HUDSK HUDTN HUDTS DELDS MULBA DELBL DELLL DELSL CBMJB CBMPR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI

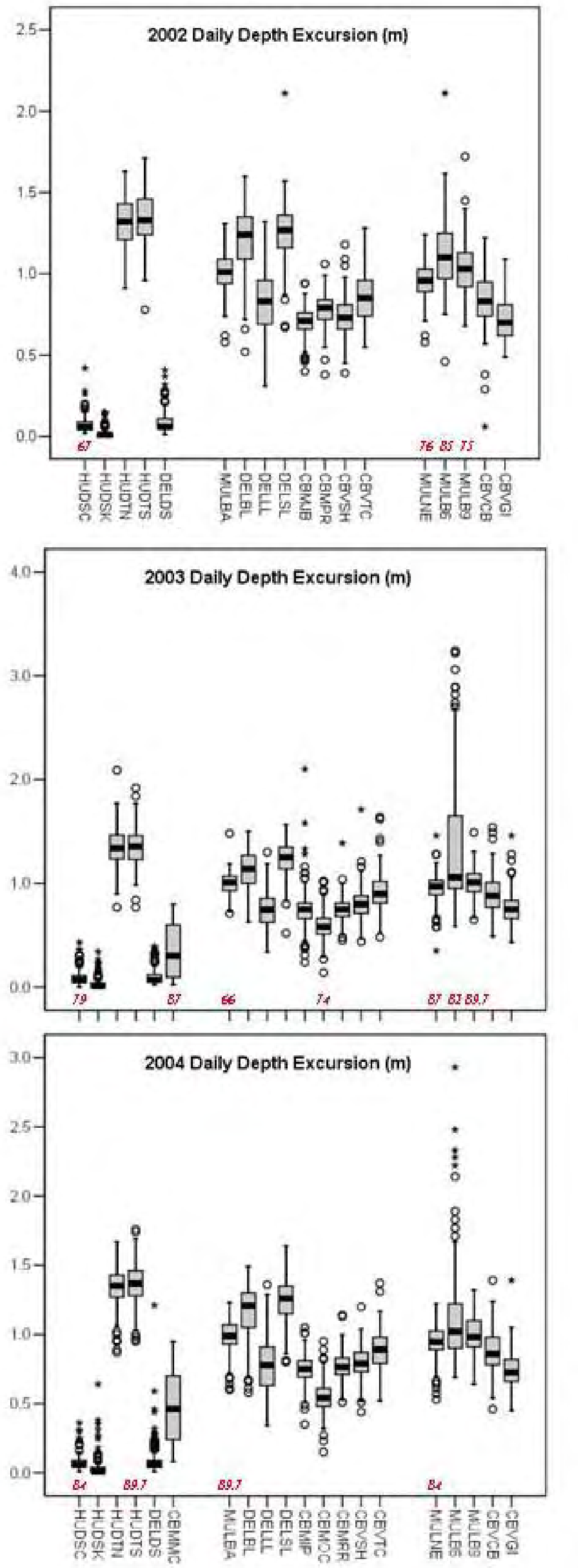

2002 Daily DO Excursion (mg/L)
HUDSC HUDSK HUDTN HUDTS DELDS MULBA DELBL DELLL DELSL CBMJB CBMPR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI

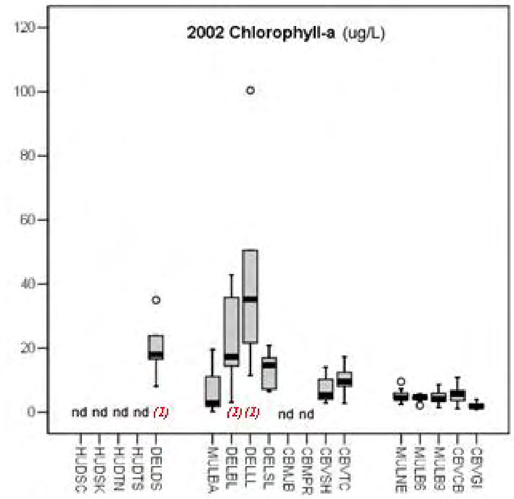

2003 Daily Minimum DO (mg/L)

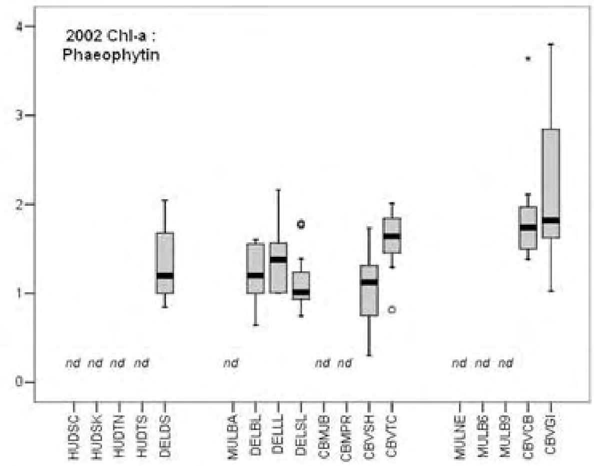

2003 Daily DO Excursion (mg/L)

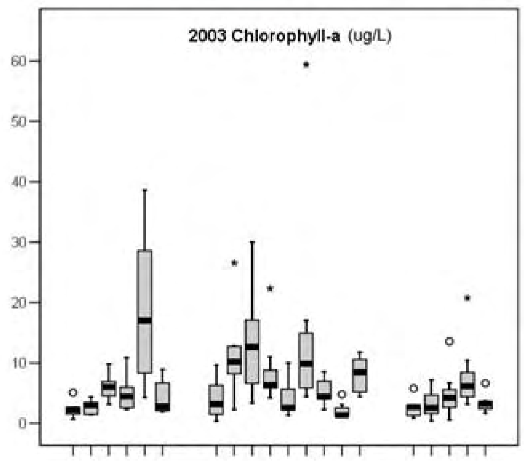

2004 Daily Minimum DO (mg/L)
HUDSC HUDSK HUDTN HUDTS DELDS CBMMC MULBA DELBL DELLL DELSL CBMIP CBMOC CBMRR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI

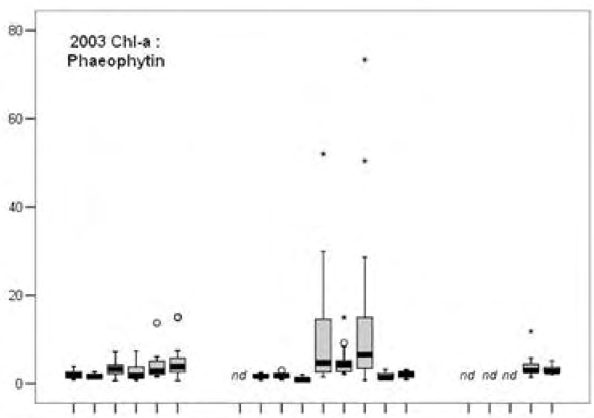

2004 Daily DO Excursion (mg/L)
HUDSC HUDSK HUDTN HUDTS DELDS CBMMC MULBA DELBL DELLL DELSL CBMIP CBMOC CBMRR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI

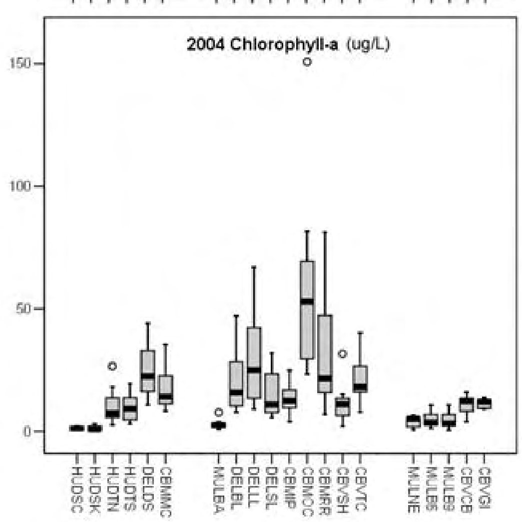

2002 Daily Depth Excursion (m)
HUDSC HUDSK HUDTN HUDTS DELDS MULBA DELBL DELLL DELSL CBMJB CBMPR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI
2003 Daily Depth Excursion (m)
2004 Daily Depth Excursion (m)
HUDSC HUDSK HUDTN HUDTS DELDS CBMMC MULBA DELBL DELLL DELSL CBMJP CBMCC CBMPR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI

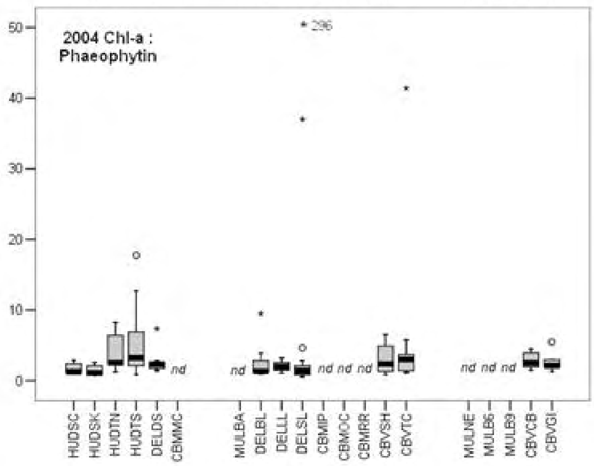

2002 Chlorophyll-a (ug/L)
nd nd nd nd (1) (1) (1) nd nd
HUDSC HUDSK HUDTN HUDTS DELDS MULBA DELBL DELLL DELSL CBMJB CBMPR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI

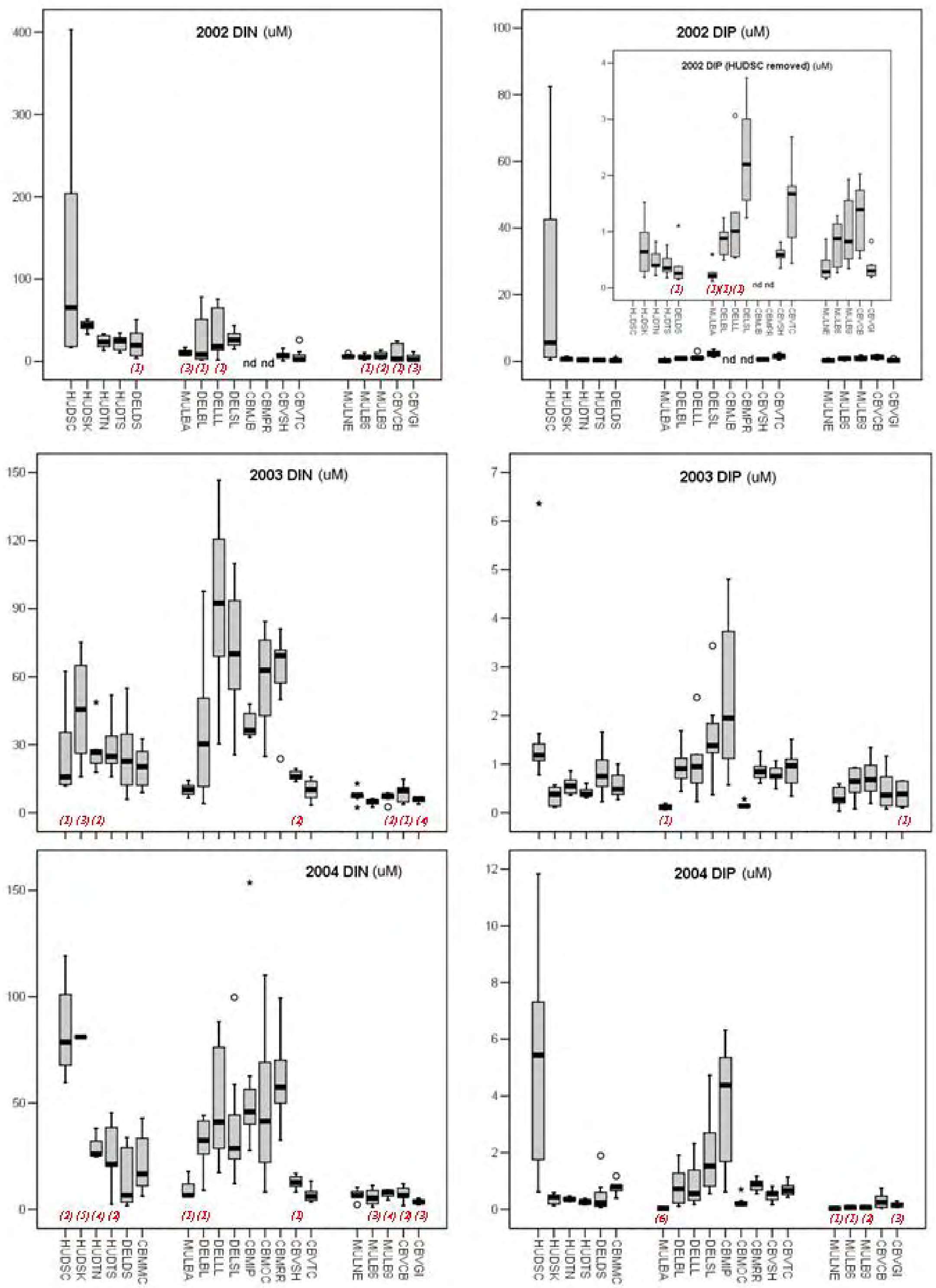

2002 Chl-a : Phaeophytin
nd nd nd nd nd nd nd nd nd nd
HUDSC HUDSK HUDTN HUDTS DELDS MULBA DELBL DELLL DELSL CBMJB CBMPR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI

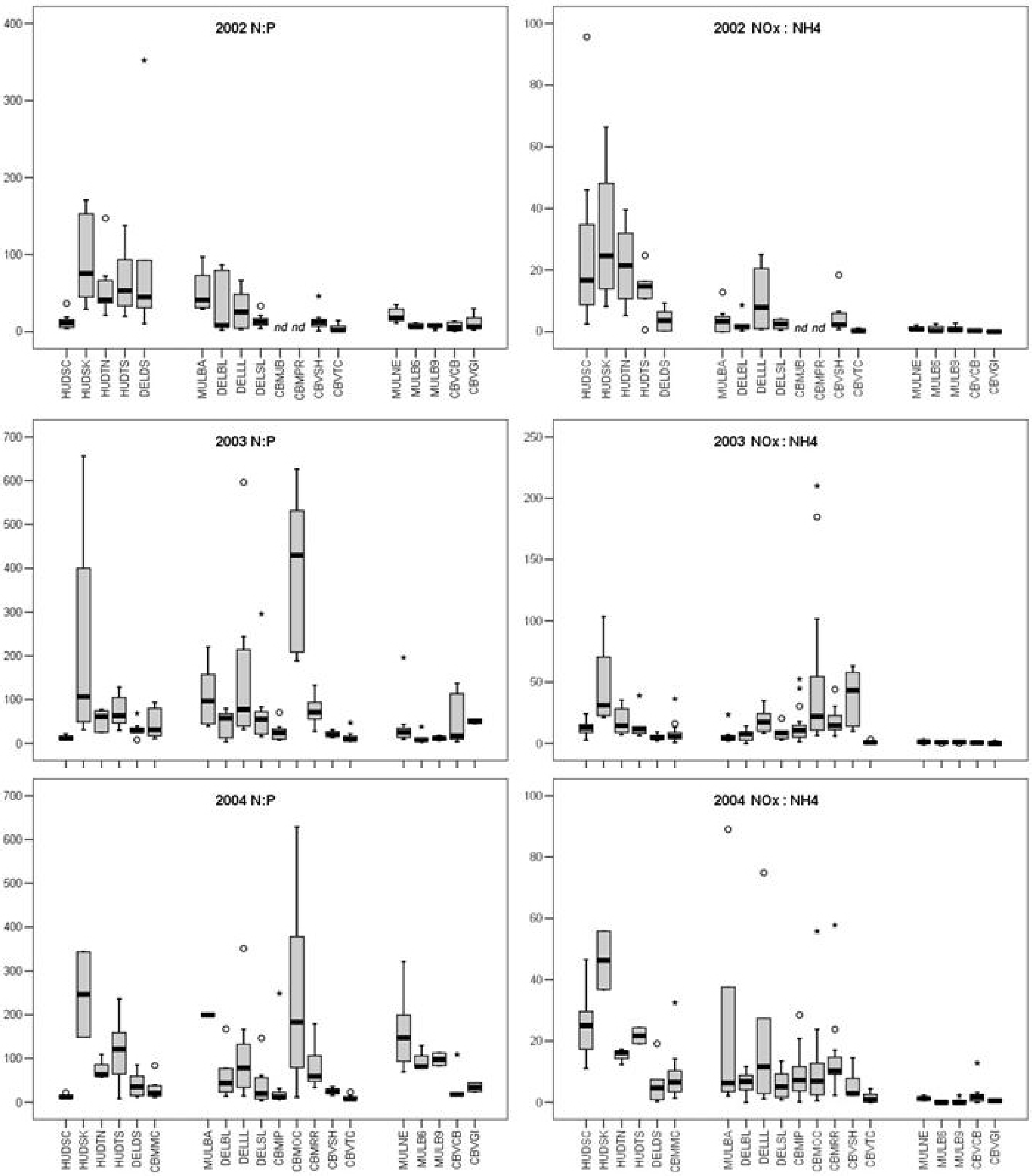

2003 Chlorophyll-a (ug/L)


2003 Chl-a : Phaeophytin
nd nd nd nd

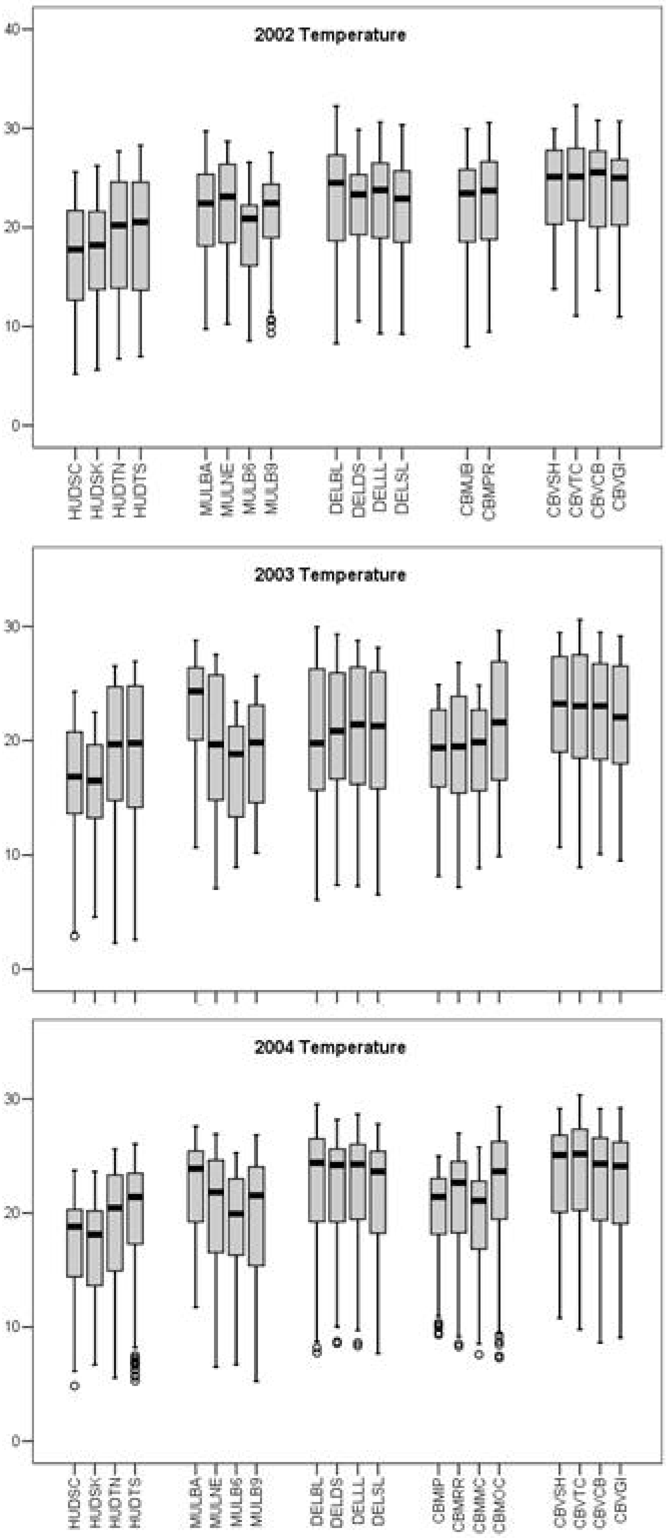

2004 Chlorophyll-a (ug/L)
HUDSC HUDSK HUDTN HUDTS DELDS CBMMC MULBA DELBL DELLL DELSL CBMIP CBMOC CBMRR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI

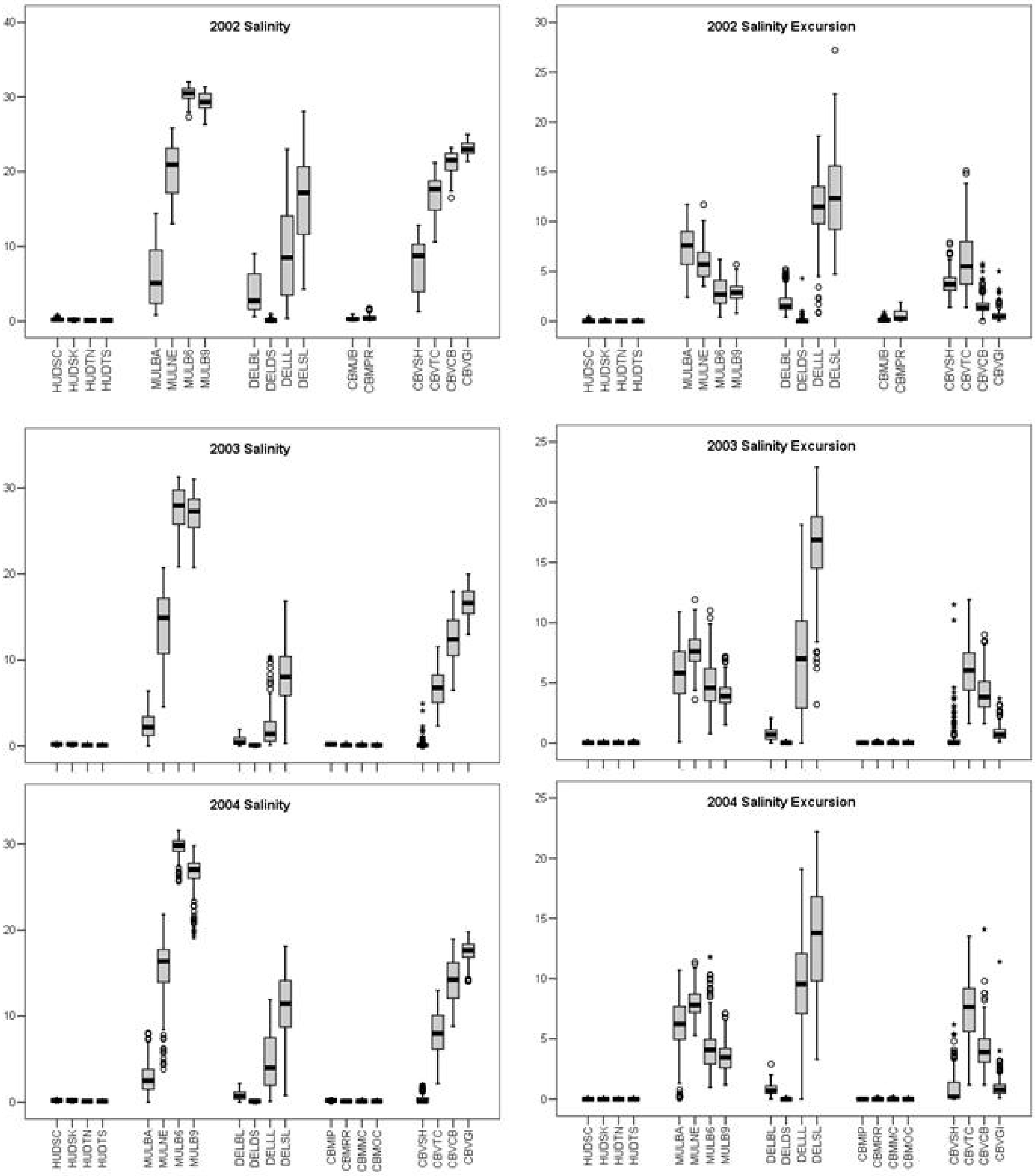

2004 Chl-a : Phaeophytin
296
nd nd nd nd nd nd nd nd
HUDSC HUDSK HUDTN HUDTS DELDS CBMMC MULBA DELBL DELLL DELSL CBMIP CBMOC CBMRR CBVSH CBVTC MULNE MULB6 MULB9 CBVCB CBVGI

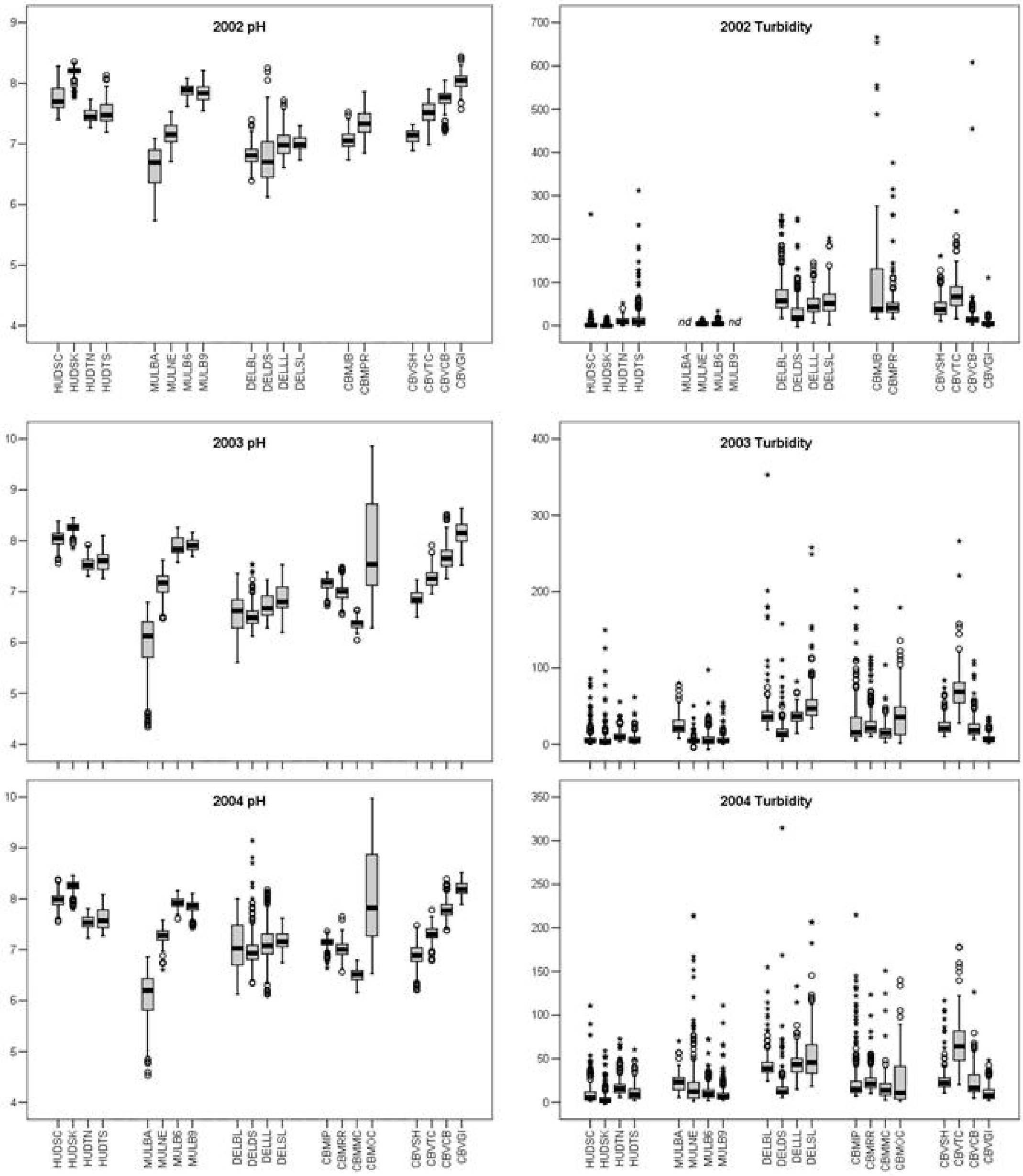

2002 DIN (uM)
2002 DIP (uM)
2002 DIP (HUDSC removed) (uM)
2003 DIN (uM)
2003 DIP (uM)
2004 DIN (uM)
2004 DIP (uM)
nd nd
HUDSC HUDSK HUDTN HUDTS DELDS MULBA DELBL DELLL DELSL CBNJB CBMPR CBVSH CBVTC MULNE MULB5 MULB9 CBVCB CBVGI
HUDSC HUDSK HUDTN HUDTS DELDS CBNMC MULBA DELBL DELLL DELSL CBMIP CBMOC CBMRR CBVSH CBVTC MULNE MULB5 MULB9 CBVCB CBVGI

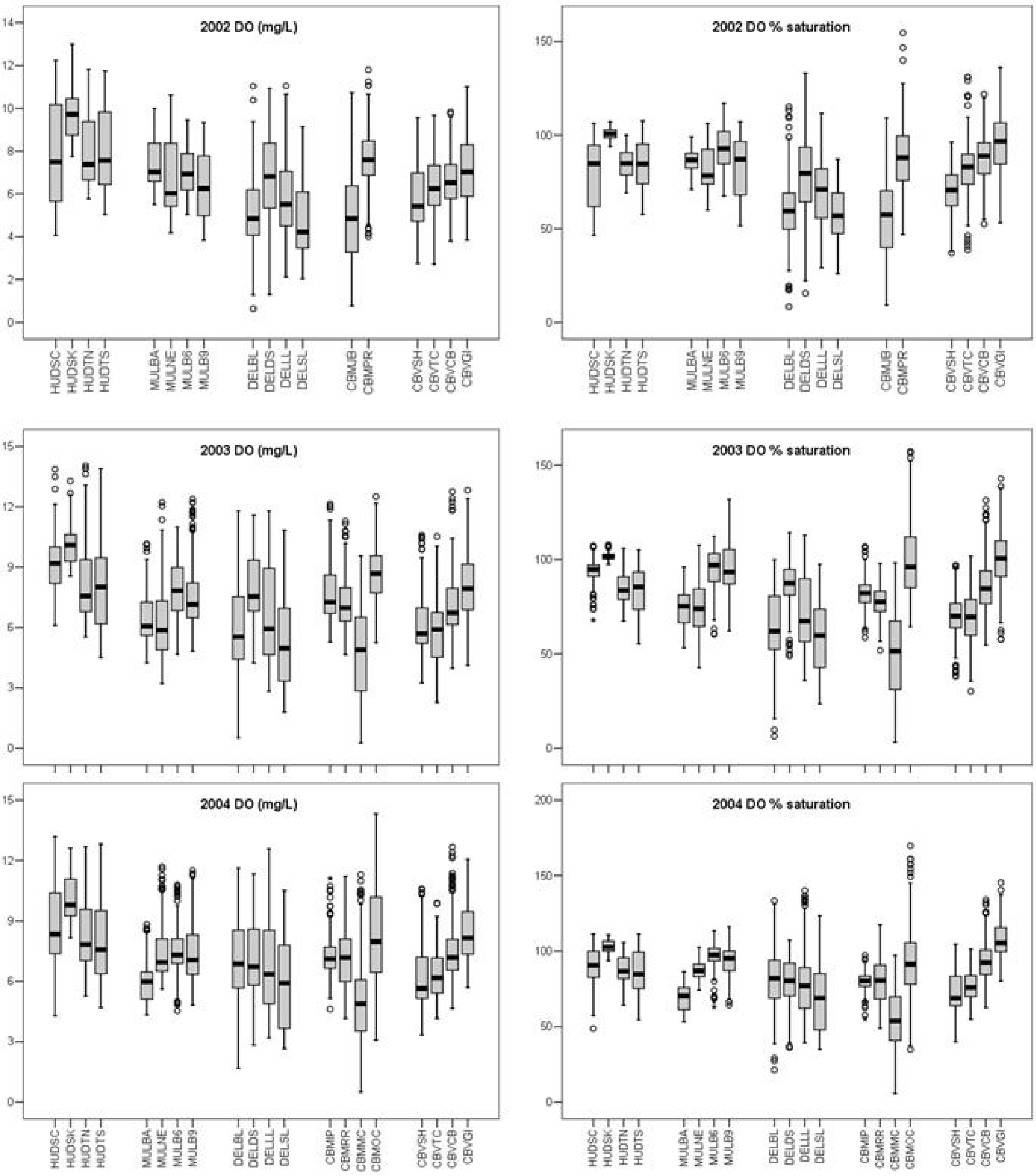

2002 N:P
2002 NOx : NH4
2003 N:P
2003 NOx : NH4
2004 N:P
2004 NOx : NH4
nd
HUDSC
HUDSK
HUDTN
HUDTS
DELDS
CBMMC
MULBA
DELBL
DELLL
DELSL
CBMJB
CBMPR
CBMIP
CBMOC
CBMRR
CBVSH
CBVTC
MULNE
MULB6
MULB9
CBVCB
CBVGI

Appendix H. Box plots of April-October water quality and nutrient data by reserve for the period 2002-04. See Figure 14 for an explanation of symbols.

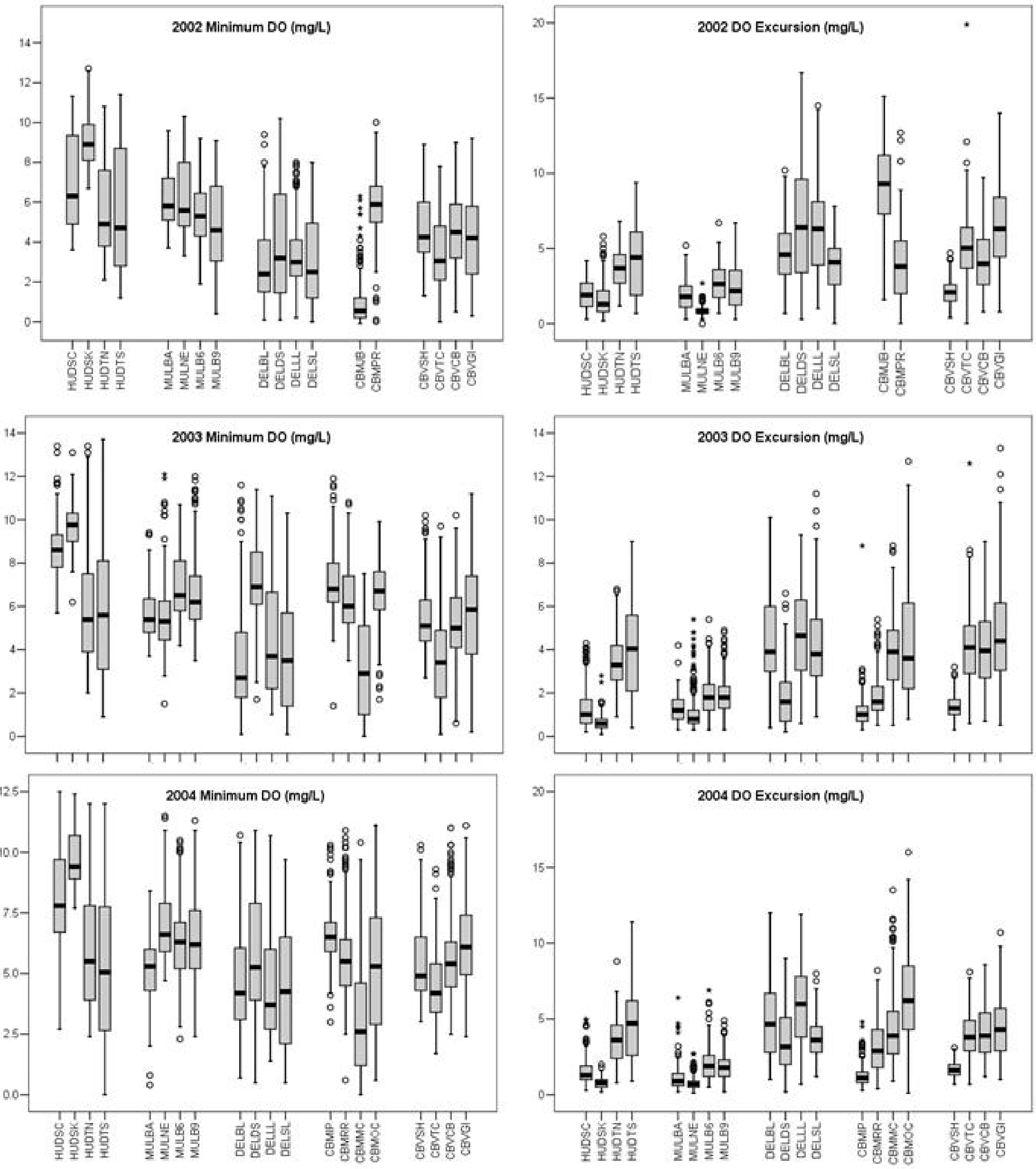


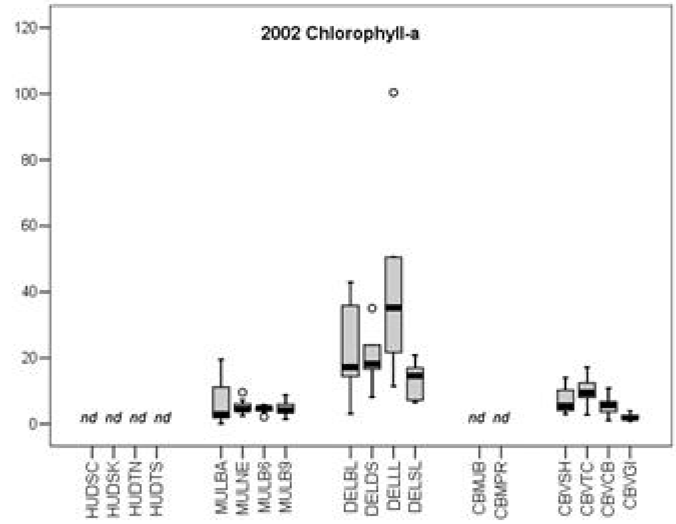

2002 Salinity
2002 Salinity Excursion
HUDSC HUDSK HUDTN HUDTS MULBA MULNE MULB6 MULB9 DELBL DELDS DELLL DELSL CBMJB CBMPR CBVSH CBVTC CBVCB CBVGI
2003 Salinity
2003 Salinity Excursion
2004 Salinity
2004 Salinity Excursion
HUDSC HUDSK HUDTN HUDTS MULBA MULNE MULB6 MULB9 DELBL DELDS DELLL DELSL CBMIP CBMRR CBMMC CBMOC CBVSH CBVTC CBVCB CBVGI

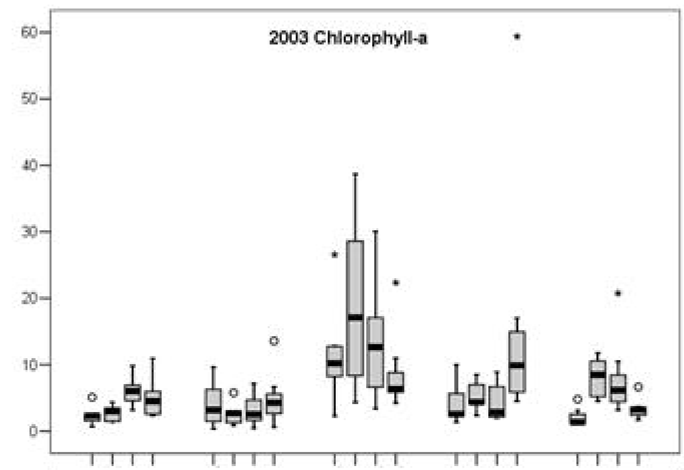

2002 pH
2002 Turbidity
2003 pH
2003 Turbidity
2004 pH
2004 Turbidity
HUDSC HUDSK HUDTN HUDTS
MULBA MULNE MULB6 MULB9
DELBL DELDS DELLL DELSL
CBMJB CBMPR
CBMIP CBMRR CBMMC CBMOC
CBVSH CBVTC CBVCB CBVGI
nd

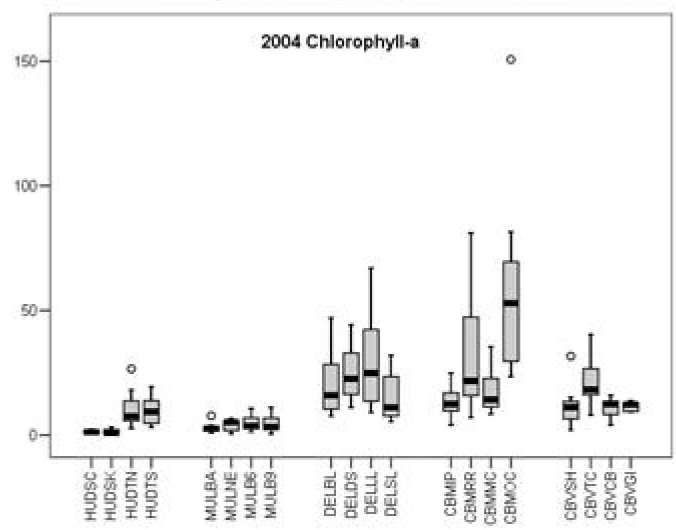


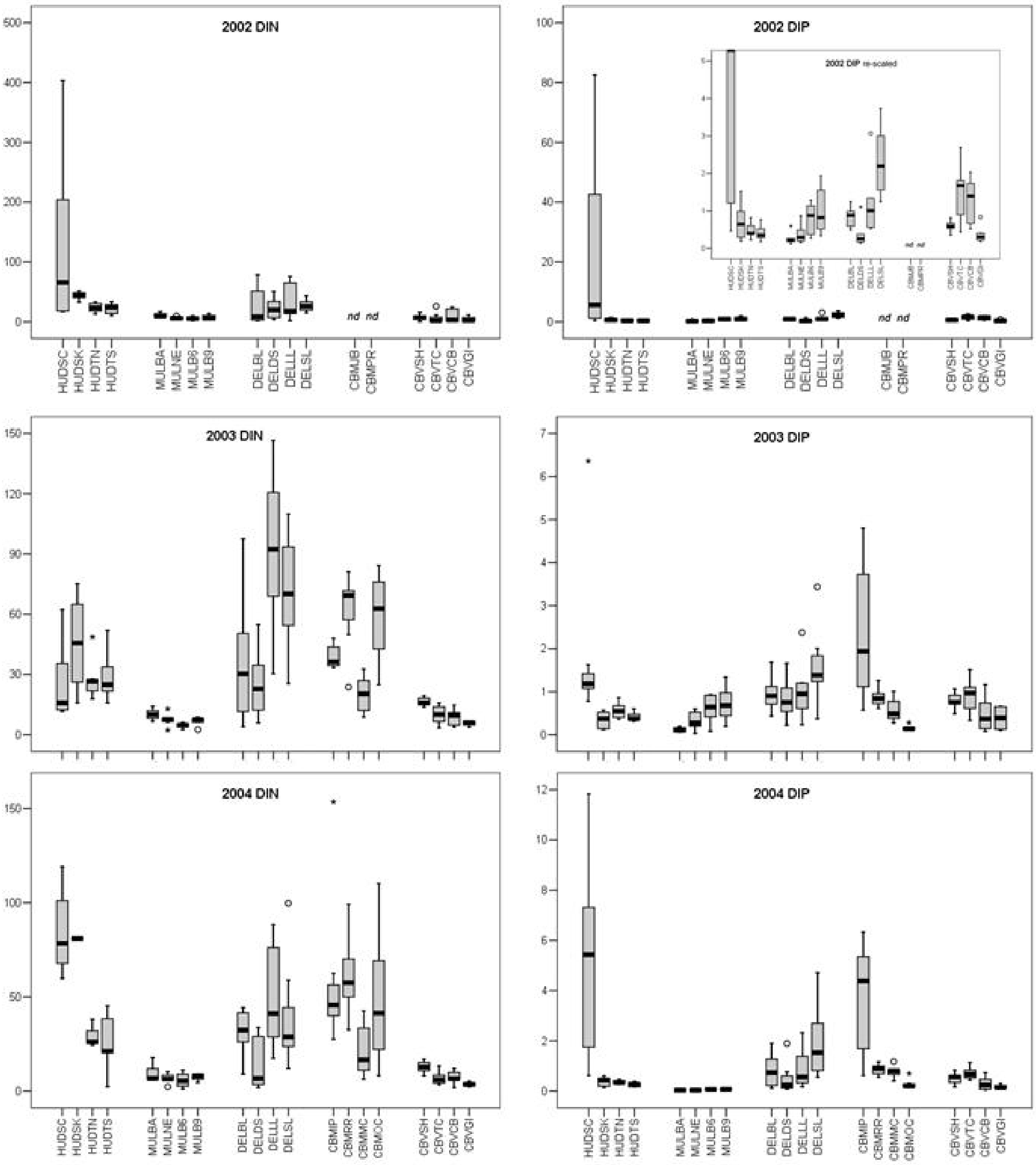
2002 DO (mg/L)
2002 DO % saturation
2003 DO (mg/L)
2003 DO % saturation
2004 DO (mg/L)
2004 DO % saturation
HUDSC
HUDSK
HUDTN
HUDTS
MULBA
MULNE
MULB6
MULB9
DELBL
DELDS
DELLL
DELSL
CBMJB
CBMPR
CBMIP
CBMRR
CBMMC
CBMOC
CBVSH
CBVTC
CBVCB
CBVGI

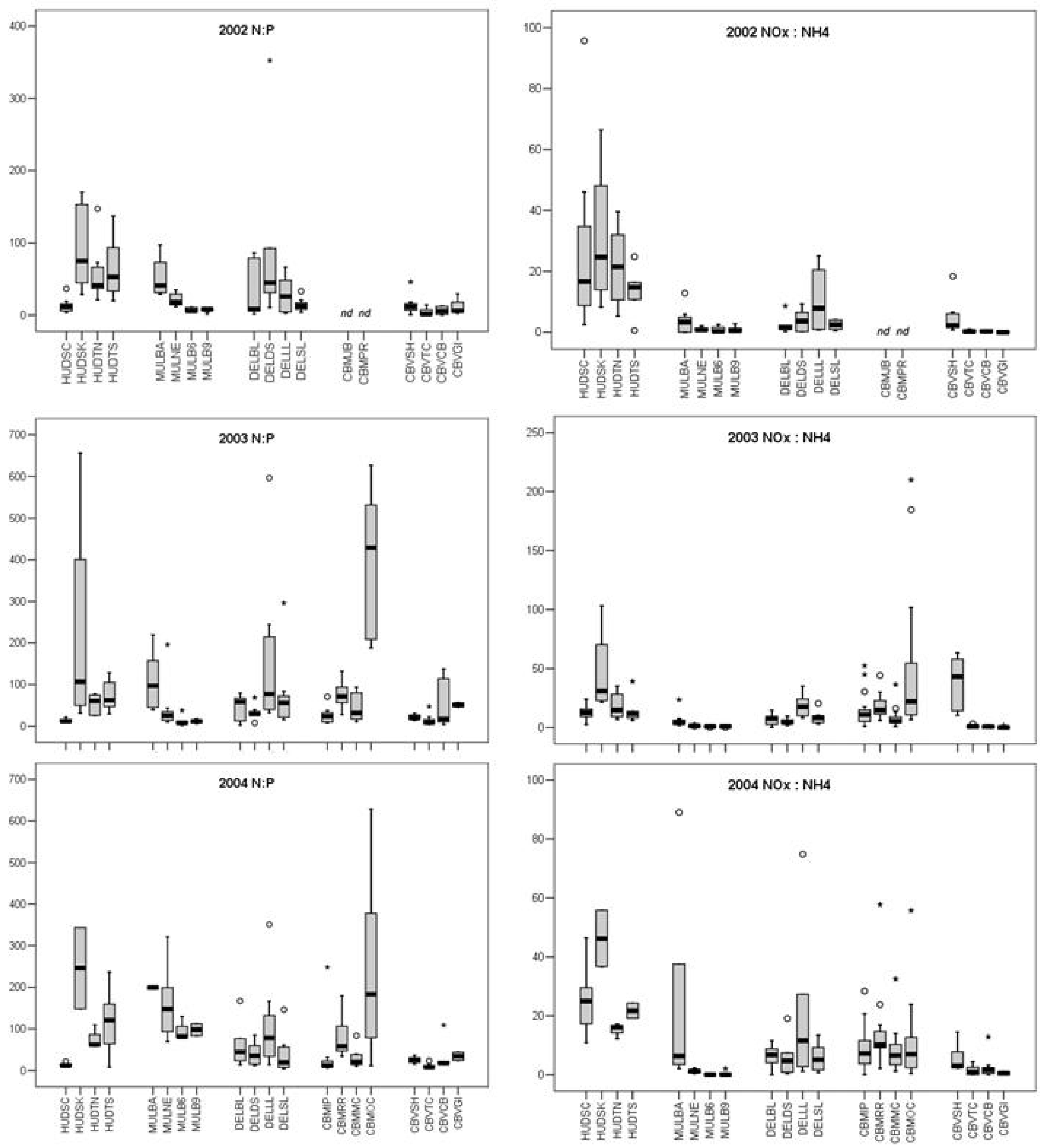

2002 Minimum DO (mg/L)
2002 DO Excursion (mg/L)
HUDSC HUDSK HUDTN HUDTS MULBA MULNE MULB6 MULB9 DELBL DELDS DELLL DELSL CBMJB CBMPR CBVSH CBVTC CBVCB CBVGI
2003 Minimum DO (mg/L)
2003 DO Excursion (mg/L)
2004 Minimum DO (mg/L)
2004 DO Excursion (mg/L)
HUDSC HUDSK HUDTN HUDTS MULBA MULNE MULB6 MULB9 DELBL DELDS DELLL DELSL CBMIP CBMRR CBMMC CBMOC CBVSH CBVTC CBVCB CBVGI


2002 Chlorophyll-a
120
100
80
60
40
20
0
nd nd nd nd
nd nd
HUDSC
HUDSK
HUDTN
HUDTS
MULBA
MULNE
MULB6
MULB9
DELBL
DELDS
DELLL
DELSL
CBMJB
CBMPR
CBVSH
CBVTC
CBVCB
CBVGI


2003 Chlorophyll-a
60
50
40
30
20
10
0


2004 Chlorophyll-a
150
100
50
0
HUDSC
HUDSK
HUDTN
HUDTS
MULBA
MULNE
MULB6
MULB9
DELBL
DELDS
DELLL
DELSL
CBMIP
CBMRR
CBMMC
CBMOC
CBVSH
CBVTC
CBVCB
CBVGI


2002 DIN
2002 DIP
2002 DIP re-scaled
2003 DIN
2003 DIP
2004 DIN
2004 DIP
nd nd
HUDSC HUDSK HUDTN HUDTS
MULBA MULNE MULB6 MULB9
DELBL DELDS DELLL DELSL
CBMJB CBMPR
CBMIP CBMRR CBMMC CBMOC
CBVSH CBVTC CBVCB CBVGI


2002 N:P
2002 NOx : NH4
2003 N:P
2003 NOx : NH4
2004 N:P
2004 NOx : NH4
nd nd
HUDSC HUDSK HUDTN HUDTS
MULBA MULNE MULB6 MULB9
DELBL DELDS DELLL DELSL
CBMJB CBMPR
CBMMP CBMRR CBMMC CBMOC
CBVSH CBVTC CBVCB CBVGI