Assessment and Interpretation of District of Columbia Plankton Monitoring Program Data

October 1999

DRAFT

Prepared by

Claire Buchanan, Michelle Fox and Jan Ducnuigeen
Interstate Commission on the Potomac River Basin
Suite 300, 6110 Executive Blvd
Rockville, MD 20852

for

District of Columbia
Water Resources Division
51 N Street NE
Washington, DC 20002

ICRPB Report 99-8

Acknowledgments
The authors would like to thank Peter May (District of Columbia, WRMD) and R. Christian Jones (George Mason University) for their help in assembling information and data sets. Figures 2, 3, and 12 were provided by Cherie Schultz (ICPRB).

Assessment and Interpretation of District of Columbia Plankton Monitoring Program

October 1999

Introduction

The purpose of this project was to analyze the available District of Columbia plankton data and evaluate of the plankton monitoring programs. In 1993 and 1994, the Interstate Commission on the Potomac River Basin (ICPRB) computerized phytoplankton and zooplankton monitoring data collected by the District of Columbia Department of Regulatory Affairs, Environmental Regulation Administration, Water Resources Management Division (WRMD) between 1979 and June 1990. These data were computerized to facilitate data evaluation and interpretation. Subsequent to the District of Columbia data entry project, ICPRB staff participated in a Chesapeake Bay Program effort to develop a suite of zooplankton and phytoplankton bioindicators for the bay and its tidal tributaries. The bioindicators are calculated from the monitoring data and used to evaluate the "health" of tidal waters. In this project, ICPRB reviewed and QA/QC'ed the available 1990 - 1994 plankton monitoring data, added these data to the original databases, and restructured the databases slightly to better accommodate bioindicator calculations. The CBP bioindicator metrics were calculated where possible from the District of Columbia plankton monitoring data and evaluated. Large gaps in the post-1990 plankton monitoring data precluded a thorough evaluation of the data. The gaps existed primarily because sample counts have not yet been submitted to the District by its contractors. Attempts were made by ICPRB to compare the plankton results with results of other District monitoring programs where the data sets overlapped. Monitoring data from the fish survey, water quality monitoring program and submerged aquatic vegetation program were obtained and analyzed to varying extents. Finally, ICPRB made several observations on the usefulness of the plankton monitoring program, to begin to determine if information yield could be improved and the programs better coordinated with other District water monitoring programs.

Data Preparation

Original Tasks

- Update the 1979-1990 plankton data NODC codes
- Review and update if necessary the 1990-1997 plankton data files that were entered by District of Columbia contractors, and modify the database structure slightly to accommodate the bioindicator calculations.

Summary

The January 1979 - June 1990 phytoplankton data set and the 1983 - June 1990 zooplankton data set computerized by ICPRB in 1993-1994 (Buchanan and Gibbons 1994) were combined with the partially completed data sets for 1990 - 1994 counted by George Mason University (GMU). Still missing are data for some 1993 and 1994 samples and all the post-1994 samples. These are

currently being counted by George Washington University (GWU) and are not expected to be finished until early 2000. The GMU data were checked against the District of Columbia Chain of Custody paperwork and QA/QC'ed by ICPRB. Approximately 1.4% of the phytoplankton count records were missing date information and 0.9% were missing species names, therefore 2.4% of the data records were not useable. Approximately 8.9% of Anacostia and Potomac zooplankton records were found to contain gaps in information needed to normalize the data (i.e. no information on volume pumped, sample total volume, and/or percentage of sample counted under the microscope) or lacked date information, and therefore were not useable. All but one of these gaps were in 1990 and 1991. Plankton records containing all information were prepared for incorporation into the Chesapeake Bay Program (CBP) database structure and analyzed for zooplankton indicators.

1979 - 1990 Phytoplankton Data

The 1979 - 1982 District of Columbia phytoplankton samples were counted by Wapora, Inc. and the 1983 - June 1990 samples were counted by Cove Corporation (see Buchanan and Gibbons 1994 for details). These data were part of the District's established database and readily available for analyses. The time series has occasional gaps because of sample decomposition due to delays in counting the samples after they were collected. Buchanan and Gibbons (1994) found a high degree of variability in rarer species that was apparently introduced by the Cove Corporation counting method, and specifically by the low numbers of microscope grid fields counted for many samples. Laboratory split sample counts done for QA/QC purposes suggest that bluegreen densities may be underestimated in the phytoplankton database. Finally, common filamentous and colonial species were enumerated as # filaments and # colonies rather than as # cells between August 1983 and July 1987, hence total counts calculated for samples from this time period are not comparable to those before and after this time period.

Several steps were taken to prepare the data for analysis. 1) The NODC species codes were updated. 2) The colony and filament count vs cell count designation, and the cell size information was broken out into separate columns. 3) Results of another, nearby monitoring program were used to estimate # cells from # colonies and # filaments for three bluegreen species. The average number of cells per *Microcystis aeruginosa* colony and *Anabaena* and *Aphanizominon flos-aquae* filaments observed at a Potomac River survey station near Piscataway Creek, MD, just south of the District of Columbia, during summer were obtained from Walter Butler, MDDNR (personal communication).

1990 - 1994 (Partial) Phytoplankton Data

ICPRB received a partially complete 1990 - 1994 phytoplankton data set from GMU in the form of a dBase database. No documentation on the counting process, species list, data handling, or other documentation was received, although most of the details were confirmed verbally with Dr. Chris Jones, George Mason University, or through email with Dr. Kay Baker in Hawaii who did the actual counts. The table consisted of several fields: Station, Date, Factor, Species Name, and Count. The Species Name field contained a numerical code in front of the species name. This code had to be extracted out of this field in order to make NODC taxon code matching possible. The Date field also had to be converted to a long international date form. Factor referred to the

correction factor used to calculated number of cells per milliliter from raw counts of each species. Taxon matching was conducted to correct spelling errors, a size field was established to account for various species size differences, and the NODC codes were inserted. Count was given in number of cells per milliliter. A total of 2.35% of the 18739 data records could not be used: 1.4% (266 records) were determined to have missing dates, and 0.9% (175 records) had blank species names.

1979 - 1990 Zooplankton Data

The 1982 - 1983 District of Columbia zooplankton samples were counted by Dr. Don Aurand and the 1983 - 1990 samples were counted by Cove Corporation (see Buchanan and Gibbons 1994 for details). These data were part of the District's established database. The time series contains few gaps, however between November 1988 and June 1990 the Clarke-Bumpus net flow meter did not work and counts for this time period are not quantitative. Hence, they were not directly useful for calculating zooplankton indicators.

1990 - 1994 (Partial) Zooplankton Data

ICPRB received the available1990 - 1994 zooplankton data from Mr. Peter May on a diskette. The files were copies of data files delivered to the District of Columbia by GMU. There were several seemingly related files on the diskette, however only one of the files could be opened by the Commission. After consultation with Dr. R. Christian Jones at GMU, it was determined that the set of files on the disk were part of a Paradox export. The large file that could be opened contained species count data whereas the others were much smaller and contained supporting information. Neither DCRA nor ICPRB are able to use Paradox export files, however much of the supporting information was provided verbally by Mr. May or in the District's Chain of Custody papers for each station-date event, i.e. number of tows, tow length, net diameters, net mesh. The lack of complete documentation on the collection and counting procedures and the data handling made processing the data difficult but not impossible.

The original species count file obtained from the diskette consisted of a table of species counts for each sampling event. Field names across the top of the table were Sampling Date, Size (refers to mesh size of plankton net used), Station, Counter (initials of GMU staff person counting the sample), Counting Date (date sample was counted), Volume Pumped (volume pumped was really volume sampled since nets were used to collect the samples rather than a pump), Sample Volume (total volume of final sample), and Volume Counted (the subsample volume that was counted), followed by abbreviations of each species name. Species counts were located in the columns headed by species name. In order to facilitate data analysis, this "horizontal" database structure was laboriously reorganized and made "vertical" so that each record contained all the sampling information and a count for an individual species.

The original data had a number of problems:

- Some records contained blanks in the date, volume pumped, sample volume and volume counted fields, making it impossible to analyze the data quantitatively;
- The abbreviated species names were difficult to decipher;
- No information on units of measure were included; and

- Many of the volume pumped values contained odd values for which there was no documentation.

Several steps were taken to check the accuracy and completeness of data files:

1) Sample dates, mesh sizes, and stations listed on the Chain of Custody papers were compared to those found in the GMU data file to identify any discrepancies. Six discrepancies were found, all in July and August of 1993:

- 7/12/93 at PMS 37
- 7/12/93 at PMS 10
- 7/13/93 at ANA 14
- 8/9/93 at PMS 37
- 8/9/93 at PMS 10
- 8/10/93 at ANA 14

The data files indicated these samples were collected with the 48 micron mesh net whereas the Chain of Custody papers indicated they were collected with the 80 micron mesh net. During this period of time, the District was acquiring two nets (48 micron and 202 micron) to replace its single net (80 micron) in order to better sample the different zooplankton size fractions and make their collection methods comparable to Maryland and Virginia Chesapeake Bay Monitoring Program collection methods. After consulting with Mr. May, ICPRB decided to use the 80 micron mesh net size as the proper mesh size for these dates.

2. Data entry errors in station names (e.g. AAGO1 instead of AAG01) and dates (e.g. 3/12/63) were identified and corrected.

3. Information on net diameters was obtained from the District and incorporated into the data set to independently calculate the volume sampled. The 48 micron, 80 micron, and 202 micron nets used through the summer of 1994 were 30 cm diameter nets with a net area of 0.07068583 m^2. Sometime in September/fall of 1994, the District nets were stolen. Two nets were borrowed from the Academy of Natural Sciences Benedict Laboratory and used through July 1995 when the District was able to replace its stolen nets. The 48 micron mesh net from the Academy had a 12 cm diameter and the 202 micron mesh net had a 50 cm diameter. Exactly when the District began using the borrowed nets is not documented. The exact date of the switch between the two types of nets in 1994 is not clear. To be on the safe side, a net diameter of 30 cm was used for samples through the end of July 1994. Since the chain of command papers that ICPRB possessed indicate only Kenilworth stations (AAG stations) were sampled after July of 94, we assume all the stations for the database as it now stands were using the 30 cm diameter nets.

4. There were species names in the database which did not match precisely those found in known EPA/Chesapeake Bay Program species lists. Efforts were made to establish corrected names and include a field for life stage for those species requiring such information. A sampling gear method code also had to be created to fit the data into the Chesapeake Bay Program format.
5. Species counts per cubic meter were calculated from the raw count, tow distance, tow length, sample volume, count volume, and volume pumped, as well as net area. Many of these variables

within the calculation were either zero or blank, and therefore many of the calculated counts per cubic meter are invalid, and a placeholder of -999 was used in these instances.

ICPRB intends to ask Dr. Chris Jones to review the final database to determine if all relevant and available information has been included in the database and species abundances were calculated correctly from the available information.

Data Evaluation

Original Tasks

- Calculate as many of the phytoplankton and zooplankton bioindicators as possible, given the constraints and limitations of the data.
- Assess and report the status and trends in the indicators
- Obtain other District of Columbia data sets and,
- where possible, relate the zooplankton and phytoplankton indicator results to water quality, benthos, fish, and ichythyoplankton monitoring programs

Phytoplankton Indicators Applied to District of Columbia Data

The Chesapeake Bay Program (CBP) Phytoplankton Indicators Project report is unfortunately still pending from Old Dominion University (ODU), the project lead, and a final list of phytoplankton indicators and the methods used to calculate them is not available. The District of Columbia presently collects monitoring data that can be used to produce all of the *candidate* phytoplankton indicators currently being tested, except one (Primary Production). The candidate tidal freshwater phytoplankton indicators include seasonal calculations of Cyanobacteria Biomass, Diatom Biomass, Cryptophyte Biomass, Chlorophyte Biomass, a count-derived estimate of Total Phytoplankton Biomass, the ratio of Total Cell Number to Total Biomass, Surface Chl *a*, Primary Productivity, and Indicators of Nutrient and Light Limitation derived from water quality parameters. Old Dominion University is evaluating these and other indices to determine if they can be combined into a single Phytoplankton Index of Biotic Integrity (IBI).

Taxon Biomass Indicators Five of the candidate indicators are calculated by multiplying species cell counts by a species-specific biomass conversion factors to obtain species-specific biomasses. The biomasses of all species within individual taxa or for all species are then summed. This method essentially weights the cell counts for a given species according to its average biomass. Biomass is considered more representative of the phytoplankton community than numbers since phytoplankton species can vary in size from less than 1 micron to more than 100 microns. Biomass conversion tables are still being compiled from tables generated by George Mason University's Gunston Cove Ecosystem Study (R. Christian Jones), the Academy of Natural Sciences Estuarine Research Center (Richard Lacouture) and Old Dominion University (Harold Marshall). Appendix A, for example, is a table of the biomass conversion factors presently used by Old Dominion University for phytoplankton species. The District of Columbia phytoplankton database is ready to have biomass conversion factors applied when a final list is compiled and become available. The resulting indicators will effectively document phytoplankton species composition by biomass, identify species shifts, and determine trends in important taxa in

District of Columbia waters. Cyanobacteria, or bluegreen algae, are pollution tolerant, non-nutritional for most consumers, and can produce toxins (although this aspect has not been conclusively documented in the Potomac River). Diatoms, chlorophytes and cryptophytes are important seasonal foods for invertebrate consumers.

Ratio of Total Biomass to Total Cell Number This indicator is calculated by dividing total phytoplankton biomass per milliliter by the total number of cells per milliliter. Since it relies on *taxon biomass* estimates, it could not be calculated at this time (see above). This indicator provides a measure of average cell biomass which can be a good indicator of shifts in food quality as well as of the impacts of low light and/or low nutrient conditions. Small average cell biomass is considered indicative of poor environmental conditions, and a decrease in average cell biomass generally signals a degrading phytoplankton community from a mesozooplankton or benthic invertebrate grazer's perspective. The CBP phytoplankton monitoring program has documented long-term declines in average cell size in the Potomac mainstem since 1985 (Lacouture et al 1999).

Surface Chl a Chlorophyll a is a surrogate measure of total phytoplankton biomass and is collected with the water quality monitoring data. The District collects chlorophyll a at most of its water quality monitoring stations. Chlorophyll a data were obtained from the Chesapeake Bay Program. The available data are currently very limited (1984-1987).

Indicators of Nutrient and Light Limitation Using bioassay results, Fisher and Gustafson (1998) have developed criteria with which to evaluate nitrogen and phosphorus monitoring data for phytoplankton nutrient limitation in Chesapeake tidal waters. Values of dissolved inorganic nitrogen (DIN) that are less than 0.07 milligrams per liter indicate the combined concentrations of nitrate, nitrite and ammonium are low enough to limit phytoplankton growth. Values of the ratio of DIN to orthophosphate (DIN:PO_4) that fall below 150 indicate no phosphorus limitation is occurring. Ratio values between 150 and 450 are associated with a 25-50% probability of phosphorus limitation. Ratio values above 450 are associated with a greater than 50% probability of phosphorus limitation. Fisher and Gustafson are presently preparing criteria with which to evaluate water clarity data (e.g. secchi depth) for light limitation of phytoplankton growth. This will be analogous to the light requirement for submerged aquatic vegetation developed earlier by the Chesapeake Bay Program.

Preliminary Analyses of Available Phytoplankton Indicators

- Chlorophyll a. Interesting geographic patterns are emerging in the limited District chlorophyll data that are available:

  1) As expected, chlorophyll concentrations show seasonal fluctuations (high in summer, low in winter), and are higher in the slower moving Anacostia River than in the faster moving Potomac River mainstem (Figure 1).

  2) Anacostia River chlorophyll concentrations peak approximately midway along the length of that river, 6-8 kilometers from the confluence with the Potomac River (Figure 2), where water clarity is the poorest (Figure 3) and phytoplankton growth should be most

light-limited. This is an interesting anomaly that might be explained after closer examination of the water column thermal stratification and the taxonomic composition of the Anacostia phytoplankton community. Chlorophyll concentrations at the mouth of the Anacostia are similar to those in the Potomac mainstem, probably reflecting the cyclic, tidally-driven intrusion of Potomac mainstem waters into the lower Anacostia.

3) In the Potomac mainstem, chlorophyll concentrations are lowest at the upper-most stations (e.g. PMS 01, PMS10), as could be expected given the river's rapid flushing time in this stretch. However, chlorophyll concentrations do not increase downriver, below Roosevelt Memorial Bridge, where the river slows and widens (Figure 1). Although nutrient concentrations increase in this lower portion (Figure 4), water clarity decreases (Figure 5) suggesting that light may be limiting algal growth and accumulation.

- Nitrogen and Phosphorus Limitation. The nutrient data available from the CBP were analyzed to determine nitrogen and phosphorus limitation of phytoplankton growth using the criteria developed by Fisher and Gustafson (1998). Data gaps were avoided, i.e. station-dates with values for only one or two dissolved inorganic nitrogen species (NH_4, NO_2, NO_3) were excluded.

1) Dissolved inorganic nitrogen concentrations appear to be rarely, if ever, low enough to limit phytoplankton growth (i.e. less than 0.07 milligrams per liter) at any of the District stations, at any time of year, between 1984 and 1994. Post 1994 data were not available. Nitrogen concentrations at the uppermost District mainstem stations, located upstream of the metropolitan area wastewater treatment plants, are already higher than the nitrogen limitation threshold. Nitrogen concentrations increased with distance downstream (Figure 4), further diminishing the possibility of nitrogen limitation. The lack of nitrogen limitation suggests that nutrient reduction efforts above the fall-line have not reduced ambient nitrogen concentrations sufficiently to limit phytoplankton growth, and that some other parameter limits phytoplankton growth.

2) Phosphate concentrations were occasionally low enough to limit phytoplankton growth, i.e. the value of the ratio DIN:PO_4 was greater than 150 and hence associated with a 25% - 50% probability of phosphorus limitation (Figure 6). The possibility of phosphorus limitation occurred most frequently in winter and spring which are normal algal blooms periods. The rarity of phosphorus limitation indicates that nutrient reduction efforts above the fall-line have not reduced ambient phosphorus concentrations sufficiently to limit phytoplankton growth for a prolonged length of time, and that some other parameter limits phytoplankton growth.

- Water Clarity and Light Limitation. Poor water clarity, and specifically the attenuation of light in the water column, is thought to be the factor most limiting to phytoplankton growth in the upper Potomac near Indian Head and Gunston Cove (Fisher and Gustafson 1998, Lacouture et al 1999, Jones et al 1999). Secchi depth, the measure of water clarity used by the District, is lowest in the Anacostia River, averaging around 0.5 meters between 1984 and 1994. Secchi depth was slightly higher in the lower Potomac, with annual averages ranging from 0.5 to 0.8 meters between 1984 and 1994. Secchi depth

was highest in the upper Potomac, above Haines Point, averaging approximately 1 meter (Figure 7). Criteria will be available in January 2000 for evaluating the District's water clarity data and determining the likelihood of phytoplankton light limitation. Poor water clarity probably limits growth of other plants in the District. Secchi levels below 1 meter in unsheltered areas of the river and below 0.8 meters in sheltered areas are considered limiting to the growth of most species of submerged vascular plants (Hurley et al 1991).

Possible Future Analyses of Phytoplankton Indicators

The indicators described above could be used in the following analyses. This list is not inclusive, however the proposed analyses address known areas of concern in the Potomac River.

- Trend analysis of taxa biomasses. District results are expected to complement and perhaps parallel, to some extent, the monitoring results from the Chesapeake Bay Program tidal fresh Potomac stations and the Gunston Cove Ecosystem Study stations. These other programs have found that, after a downward trend in summer and annual cyanobacteria biomass during the 1980s, upward trends occurred in these indicators during the 1990s. The upward trends are possibly due to the large nutrient loads introduced by frequent high flow years since 1993 and the continued decreasing trends in light (secchi depth), both of which favor bluegreen algal dominance. Other taxa biomass indicators showed no seasonal trends. The District results are expected to demonstrate more clearly the impacts of the present decade's extreme flow conditions on the phytoplankton community since their Potomac mainstem stations are closer to the fall-line. These stations will also demonstrate to a better degree the immediate benefits of Biological Nitrogen Removal which was implemented in September 1996 at the Blue Plains Wastewater Treatment Plant. There has been some concern that reducing nitrogen will alter the ambient nitrogen to phosphorus ratio (Redfield ratio) in such a way that bluegreen algae growth will be encouraged.

- Taxa biomass status analysis. A general conclusion of a recently draft Chesapeake Bay Program report, "Tidal Potomac Integrated Analysis Project: A Series of Reports on the Water Quality and Living Resources Responses to Management Actions to Reduce Nutrients in the Potomac River Estuary" (ICPRB report 99-4), was that the intensity and magnitude of Potomac summer bluegreen algal blooms has declined since the 1970s and early 1980s. This is based on a comparison of phytoplankton monitoring results for Maryland Department of Natural Resources and the George Mason University Gunston Cove Ecosystem Study for the1985 and 1999 summers. During these two periods, environmental conditions were comparable and extremely favorable for bluegreen algal bloom development--calm, hot, sunny, low flows–however *Microcystis aeruginosa* blooms were not as dense or as prolonged in Maryland and Virginia waters during 1999. Combined estimates of total bluegreen algae biomass for Maryland, Virginia and District waters would whether the centroid of the population was simply shifted upriver by the 1999 low flow conditions, or whether the intensity and magnitude of the bluegreen blooms are indeed declining.

- Analysis of phytoplankton species composition for food quality. The food quality of the

District phytoplankton could be evaluated with respect to both the zooplankton and phytoplankton consumers. Fulton (1991, 1988a, 1988b, 1987) has demonstrated the negative impact of bluegreen algae on zooplankton growth and survival in the Potomac River. Lacouture (personal communication) and others have developed criteria with which to evaluate the food value of the phytoplankton community to its consumers. These criteria can be applied to the District data after taxa biomasses are calculated.

- More sophisticated analysis of water quality data for nitrogen and phosphorus limitation. Gaps *seem* to exist in the District water quality data, i.e. some station-dates have values for only one or two of the three nitrogen species which comprise dissolved inorganic nitrogen (NH_4, NO_2, NO_3). However, the lack of data could also signify that one or more of the nitrogen species was below detection limits and hence not included in the database. Closer examination of the District's water quality sampling record and monitoring data is required before the absence of nitrogen limitation and phosphorus limitation can be confirmed for all District monitoring stations.

- Evaluation of water quality data for phytoplankton light limitation. As mention above, Fisher and Gustafson (University of Maryland) will be publishing criteria in January 2000 for evaluating water clarity monitoring data and determining phytoplankton light limitation. These criteria should be applied to the District's secchi depth monitoring data. The analysis will confirm the role of poor water clarity in limiting phytoplankton growth in the District, and help to set expectations as management efforts continue to reduce nutrients. For example, nutrient reductions will have no long-term effect on phytoplankton growth until light is above threshold levels.

Zooplankton Indicators Applied to District of Columbia Data

The Chesapeake Bay Program zooplankton indicators include seasonal calculations of Total Mesozooplankton Abundance, Copepod Abundance, Cladocera Abundance, Total Rotifer Abundance, Diversity and the Food Availability Index for Larval Striped Bass. Mesozooplankton include copepods and cladocerans which are distinct taxonomic groups. Rotifers are part of the microzooplankton which includes protozoans and the copepod nauplii life stage as well as rotifers. These indicators effectively document zooplankton taxon composition by abundance, identify shifts in the major taxa, and determine taxa trends in District of Columbia waters. There is accumulating evidence in other Potomac monitoring data that mesozooplankton are strongly influenced by, and hence closely linked to, fish abundances whereas microzooplankton dynamics are closely correlated to chlorophyll and nutrient concentrations trends (Buchanan and Jones 1999, Buchanan and Vaas 1994, Jacobs and Burton 1996, Sellner et al 1999, Lacouture et al 1999)

Spring Mesozooplankton Abundance (Food Availability Index)
Jacobs and Burton (1996) demonstrated a positive correlation between spring abundances of mesozooplankton and the summer juvenile indexes of striped bass and white perch. The larvae of striped bass, white perch and other anadromous fish feed on zooplankton after they hatch in spring in tidal fresh waters. Sufficient spring zooplankton food for anadromous fish larval stages correlated with good year class strength the following summer.

Summer Mesozooplankton Abundance
Summer populations American shad, blueback herring, alewife, gizzard shad, bay anchovy, Atlantic menhaden, banded killifish and spottail shiner depend on mesozooplankton for food since they are "obligate" planktivores. Buchanan and Vaas (1994) and Buchanan and Jones (1999) found inverse correlations between fish predator abundance and mesozooplankton prey abundance in the lower tidal freshwater zone of the Potomac, below Washington DC, with high summer predator abundance corresponding to low prey abundance, and vice versa ("top-down control") under the 1973-1991 open-water habitat conditions (Figure 8).

Copepod Abundance Copepods are a major taxonomic group of the mesozooplankton. As a whole, they tend to be less tolerant of eutrophic waters. *Eurytemora affinis* is the dominant copepod in the tidal freshwater Potomac River.

Cladocera Abundance Cladocera are another major taxonomic group of the mesozooplankton. They tend to be more tolerant of eutrophic waters than copepods but are adversely affected by hypereutrophic waters.

Total Rotifer Abundance Rotifers are a major taxonomic group of the microzooplankton and as such are considered part of the "microbial loop" or food chain that links phytoplankton and smaller consumer organisms with bacteria. They have very rapid life cycles (sometimes less than a day) and their numbers correlate closely with chlorophyll concentrations in many regions of the Chesapeake.

Preliminary Analyses of Available Zooplankton Indicators

As mentioned earlier, only intermittent zooplankton data are available at this time. Therefore, a thorough analysis of the zooplankton monitoring results was not possible. We did a few exploratory analyses to begin to determine the usefulness of the data and to identify some general patterns.

- Overall abundances of copepods and cladocera, the two major taxonomic groups in the mesozooplankton, were low relative to those in the tidal freshwater reach below Washington, DC and in other Chesapeake tributaries. Abundance were similar in the Anacostia (ANA14) and the lower Potomac mainstem (PMS37) and lowest in the upper Potomac mainstem (Figure 9). Previous analyses of CBP zooplankton monitoring data suggest the relatively low numbers in the Potomac mainstem are a consequence of the high flushing time in this reach of the river (Buchanan, in prep). They should not be expected to reach the high levels found in the freshwater zones of smaller, slower moving tributaries to the Chesapeake such as the Choptank and Patuxent rivers. The low numbers in the Anacostia River, however, are likely caused by another factor since residence times in this tributary are very long–comparable, in fact, to the Choptank and Patuxent rivers.

- Copepods, cladocera and rotifers show seasonal fluctuations (high in summer, low in winter), as expected (Figure 10).

- The limited data suggest that both cladocera and copepods abundances may be increasing (Figure 9). This could indicate improvement in the District zooplankton communities or it could be an artifact of the high flow years in the 1990s. High winter and spring flows create a large tidal freshwater zone in the Potomac estuary, and if flows drop in late spring and early summer the growing mesozooplankton populations at that time are not washed out of the system as rapidly and can accumulate to high densities.

- The limited data available on mesozooplankton abundances suggest mesozooplankton food abundances available for larval anadromous fish in spring are "below minimum" and "poor" in the Potomac mainstem. Food availability elsewhere in the Potomac has generally been depressed, too. The food availability index below Washington, DC, at the Indian Head CBP monitoring station and the Gunston Cove Ecosystem Study monitoring stations has been "below minimum" and "minimum."

- Rotifers abundances in Potomac mainstem are low to moderate relative to other freshwater areas in the Chesapeake. Rotifers are also affected by the high flushing times and this seems to be evident in the District's Potomac River, i.e. rotifer abundances increase from PMS10 in the upper reach to PMS37 in the lower reach.

- Dissolved oxygen is not a cause of low zooplankton abundances in the mainstem but probably is, in some way, a cause of the low abundances in the Anacostia River. Dissolved oxygen concentrations in the mainstem of the Potomac River adjacent to the District rarely fall below 5 milligrams per liter, the minimum acceptable dissolved oxygen concentration to support aquatic life (Jordan et al. 1992). Dissolved oxygen concentrations reach their lowest levels in summer, as expected, but climb to near saturation levels during the other seasons (Figure 11). Dissolved oxygen in the Anacostia River drops below 5 milligrams per liter along most of its length, from June to October (Figure 12a, 12b).

Possible Future Analyses of Zooplankton Indicators

The indicators described above could be used in the following analyses. This list is not inclusive, however the proposed analyses address known areas of concern in the Potomac River.

- Trend analysis of taxa abundances and the ratio of copepods to cladocerans. Increases in species abundances and shifts in the zooplankton taxonomic composition can be expected in the upper tidal Potomac as water quality improves.

- Food availability index for larval anadromous fish (spring mesozooplankton abundance). This is an important indicator to monitor as shad and other fish restoration efforts are implemented. Survival of the larval stage is believed to determine much of a species recruitment each year.

- Correlations between summer mesozooplankton and planktivorous finfish. Top-down control of the mesozooplankton population by (at least) planktivorous fish seems to predominate in the mainstem and embayment below Washington, DC. There are direct

management implications if this correlation is found in the District. The results suggest that the upper Potomac may be a good candidate for attempting top-down control of eutrophication to complement and enhance bottom-up controls (nutrient reductions). The partially recovered SAV beds are capable of supporting sizable populations of largemouth bass and other top-predators. If top-predators are protected from overfishing, their populations may regulate planktivorous (and other forage) fish species sufficiently to allow mesozooplankton to develop larger summer populations and remove more phytoplankton, blue-greens included.

- Analysis of NH_4 data for ammonium toxicity. Levels of ammonium in the Anacostia River are high, especially in the cental region of the river, and could be impacting the zooplankton populations. This possible relationship can be investigated with District monitoring data.

- Analysis of dissolved oxygen. More evaluation of the dissolved oxygen levels in the Anacostia River is needed to determine "anoxic-volume days" (an oxygen indicator used by the CBP for the Bay mainstem) and other measures of anoxic/hypoxic stress to fish, zooplankton and benthos.

- Further analyze the food quality of phytoplankton. The work of several investigators suggests the productivity of summer mesozooplankton populations is below potential under current Potomac conditions (see above), in part because of poor food quality. Heinle et al (1979) observed that production of Eurytemora affinis, the dominant copepod in the tidal fresh and oligohaline Potomac, was well below its experimentally determined potential in a 1977 study and hypothesized poor phytoplankton food quality as the cause. Fulton (1988a, 1988b, 1991) quantified the impact of the frequently found bluegreen, Microcystis, on feeding and survival of zooplankton in the Gunston Cove area. Zooplankton species that presently dominate the Potomac tidal freshwater have behaviors or mechanisms that allow them to somewhat avoid or minimize the impacts of abundant toxic or non-nutritious bluegreen algal cells in their food, i.e. Eurytemora (copepod), Bosmina, Diaphanosoma and Moina (cladocera) and Brachionus (rotifer). Bluegreen algae are still an major component of Potomac phytoplankton assemblages in summer. Present conditions in the tidal fresh--low light levels (high turbidity), excess nutrients and toxic pollutants--all favor bluegreen algae dominance. Another indicator to evaluate would be the ratio of dissolved organic carbon to phosphate ($DOC:PO_4$). It has been successfully used to evaluate the food value of phytoplankton for cladocera which require relatively high levels of phosphorus in their diets.

Monitoring Program Evaluation

Original Tasks

- Reviewing District of Columbia phytoplankton and zooplankton monitoring programs to 1) determine their relevancy to the District's overall monitoring goals and objectives and 2) determine the validity and applicability of the data
- Evaluating station locations, sampling frequency, and collection and counting methods.

- Determining if the plankton monitoring programs can be modified to provide more useful data for assessments.
- Determining if the plankton programs can be better coordinated with other monitoring programs, tidal and non-tidal, to improve information yield and more clearly document ecosystem responses to management actions.
- Make specific recommendations to the District of Columbia

Much of this section's tasks could not be accomplished because monitoring data were not available, i.e. not submitted by District contractors. Several statements can be made based on the data that have been evaluated:

- The plankton monitoring results can be related and compared to other District monitoring programs. They appear to be meeting their original goals and objectives as stated in the District of Columbia monitoring plans.

  Phytoplankton Monitoring Program Objectives: establish baseline qualitative and quantitative data for the characterization of community structure especially as it pertains to the detection of short and long-term trends in species abundance, distribution, and composition. Additional measures are taken to allow for the prediction and investigation of prokaryotic (bluegreen) algal blooms.

  Zooplankton Monitoring Program Objectives: establish baseline qualitative and quantitative data for the characterization of community structure especially as it pertains to the detection of short and long-term trends in species abundance, distribution and composition.

- Station locations are well positioned for plankton monitoring. The number of phytoplankton samples collected for species counts could be reduced somewhat since the data of some adjacent station appear to be very similar.

- The District could consider reducing the sampling frequency in winter and reallocated these monitoring "slots" to other times of the year. Production is usually lowest in winter, and although winter blooms of dinoflagellates and Eurytemora affinis are important to the system, a less frequent sampling regime combined with chlorophyll measurements (collected during the water quality monitoring) could probably detect these events.

- The collection methodology has improved. "Micro"zooplankton and "meso"zooplankton methods provide better estimates of total abundance and biomass of these components. The District zooplankton data are now comparable to those of Versar and ANS for CBP monitoring, with the exception that the Academy of Natural Sciences now samples for protozoa in its microzooplankton component.

- Poor preservation and the lengthy time between collection and counting are still problems for the District plankton phytoplankton monitoring program. District staff are well aware of this problem., but are apparently stymied by bureaucratic delays in getting the samples subcontracted for processing.

- Phytoplankton count methods have varied in the past, but the present count methodology has improved and is comparable to the Academy of Natural Sciences methods, e.g. cells of "filaments" and "colonies" are now counted so analysts can estimate species biomasses.

Literature Cited

Buchanan, C. and S. Gibbons. 1994. Establishment of a Computerized Database for the Plankton Data Collected by the District of Columbia through June 1990, Final Report and Technical Report (Volume I and II). ICPRB Report 94-5, prepared for the District of Columbia Department of Consumer and Regulatory Affairs.

Buchanan, C. and R. C. Jones. 1999. Further Analysis of Predator-Prey Relationships in Potomac Estuary Monitoring Data. Presentation at the BiAnnual Meeting of the Estuarine Research Federation.

Buchanan, C. and P. Vaas. 1994. Associations between Chesapeake Bay Program zooplankton monitoring data and Maryland and Virginia juvenile finfish survey data. In Hill, P. and S. Nelson (eds) Towards a sustainable coastal watershed: the Chesapeake experiment. Proceedings of a conference, 1-3 June 1994. Norfolk, VA. Chesapeake Research Consortium publication 149.

Fisher, T.R. and A.B. Gustafson, 1998. Level 1 Report Maryland Department of Natural Resources Chesapeake Bay Water Quality Monitoring Program - Nutrient Bioassay Component. 14 pp.

Fulton, R. S. III. 1991. Interactions of cyanobacteria with herbivorous zooplankton. Adv. in Ecology 1:107-120.

Fulton, R. S. III. 1988a. Grazing on filamentous algae by herbivorous zooplankton. Freshw. Biol. 20:263-271.

Fulton, R. S. III. 1988b. Resistance to blue-green algal toxins by *Bosmina longirostris*. J. Plank. Res. 10(4):771-778.

Fulton, R. S. III. and H. W. Paerl. 1987. Toxic and inhibitory effects of the blue-green alga *Microcystis aeruginosa* on herbivorous zooplankton.

Heinle, D. R., P. Pulles and H. S. Millsaps. 1979. Population dynamics of zooplankton in the upper Potomac Estuary, March through May 1977. Final report to the State of Maryland, Power Plant Siting Program. U. Maryland Center for Environmental and Estuarine Studies, Reference No. 79-82

Hurley, L. 1991. "Submerged Aquatic Vegetation" in Funderburk et al [eds], *Habitat Requirements for Chesapeake Bay Living Resources* (second edition). Chesapeake Research Consortium, Inc. Solomons, Maryland.

Jacobs, F. and W. Burton. 1996. Chesapeake Bay Water Quality Monitoring Program 1995 Mesozooplankton Component. Report prepared for Maryland Department of Natural Resources by Versar, Inc.

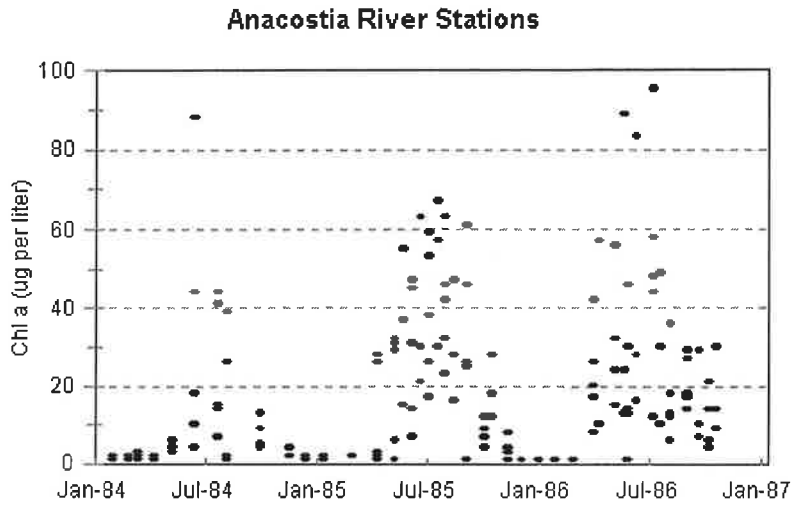
Jones, R.C., 1999. Long-term Trends in Summer Phytoplankton Chlorophyll a in the Tidal Fresh Potomac River, USA: Relationship to Climatic and Manangement Factors. In Press.

Jordan, S., C. Stenger, M. Olson, R. Batiuk, and K. Mountford. 1992. Chesapeake Bay Dissolved Oxygen Goal for Restoration of Living Resources Habitats. A synthesis of living resource habitat requirements with guidelines for their use in evaluating model results and monitoring information. CBP/TRS 88/93. Annapolis, MD.

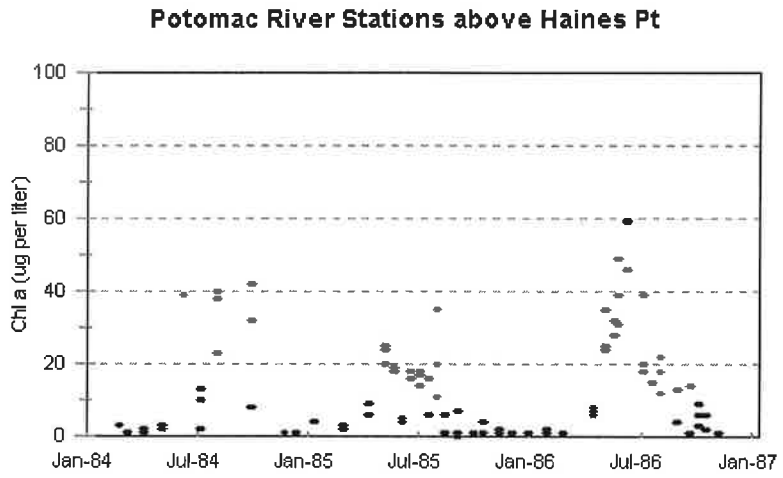
Lacouture, R.V., S. Sellner, A. Hartsig and A. Imirie. 1999. Long term trends and current status of phytoplankton and microzooplankton - Chesapeake Bay and Potomac, Patuxent and Choptank Rivers. Level 1 Report for Phytoplankton and Microzooplankton Component of the Chesapeake Bay Water Quality Monitoring Program. 40 pp.

Sellner, K.G., R.V. Lacouture, S.G. Sellner, W. Burton, R.E. Magnien. 1999. Bottom-up, Top-down, and Physical Constraints on Summer Mesohaline Chesapeake Bay Dinoflagellates. Presentation at the BiAnnual Meeting of the Estuarine Research Federation.

A



B



C

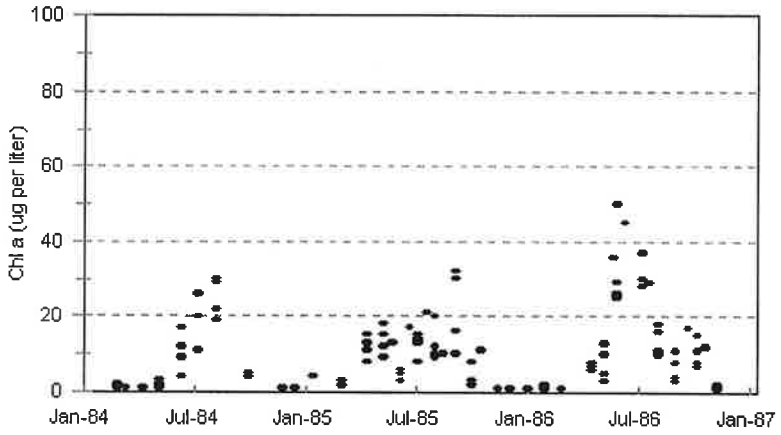


Figure 1. District of Columbia chlorophyll a data, 1984 - 1986. A: all sampled Anacostia River stations; B: all sampled Potomac River mainstem stations above Hains Point; C: all sampled Potomac River mainstem stations below Hains Point. Data obtained from the Chesapeake Bay Program Data Center.

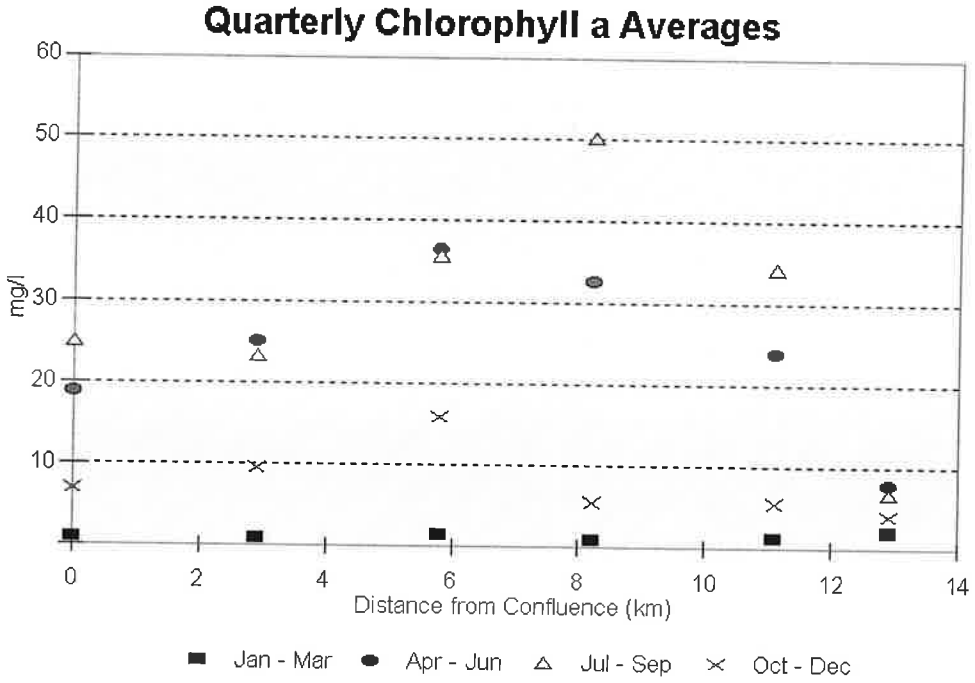


Figure 2. Seasonal (quarterly) averages of surface chlorophyll *a* in the Anacostia River. X-axis is the distance from the confluence of the Anacostia and Potomac rivers. Y-axis is the concentrations of chlorophyll in milligrams per liter.

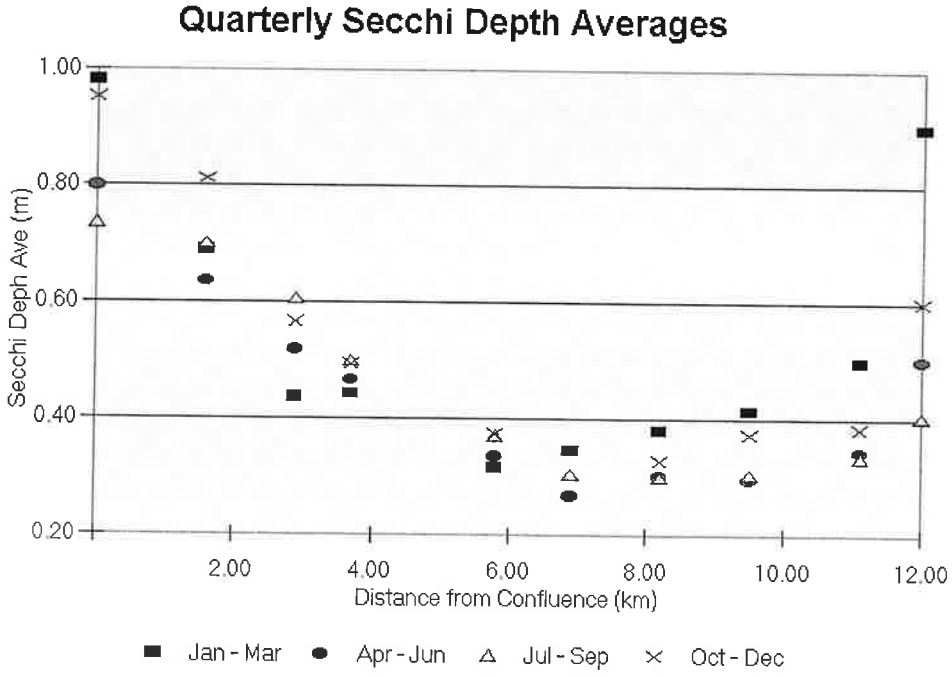


Figure 3. Seasonal (quarterly) averages of secchi depth in the Anacostia River. X-axis is the distance from the confluence of the Anacostia and Potomac rivers. Y-axis is the average secchi depth (meters).

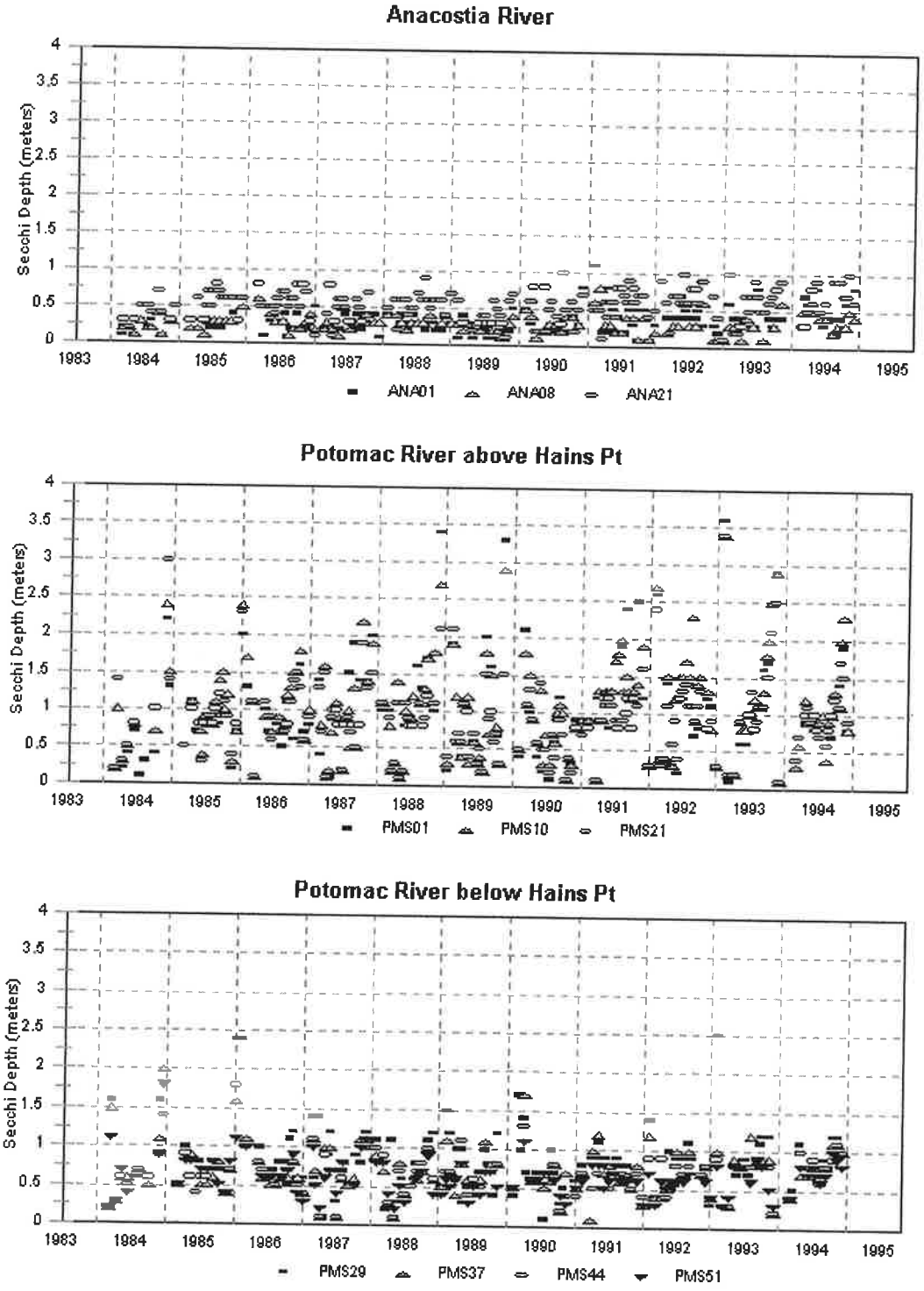
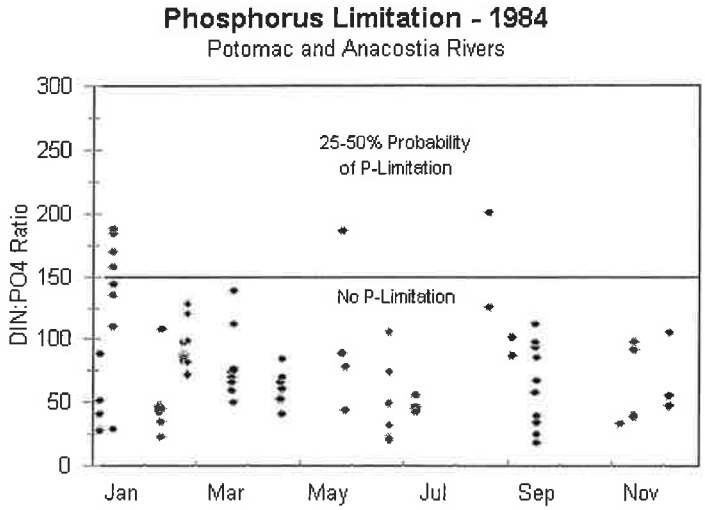


Figure 5. Secchi depth (meters) measured at three Anacostia stations, three upper Potomac mainstem stations (above Haines Point) and three lower Potomac mainstem stations (below Haines Point), for all available sampling dates (1984 - 1994). ANA01 and PMS01 are the farthest upstream stations in their respective rivers; PMS29 is at the confluence of the Anacostia and Potomac rivers.



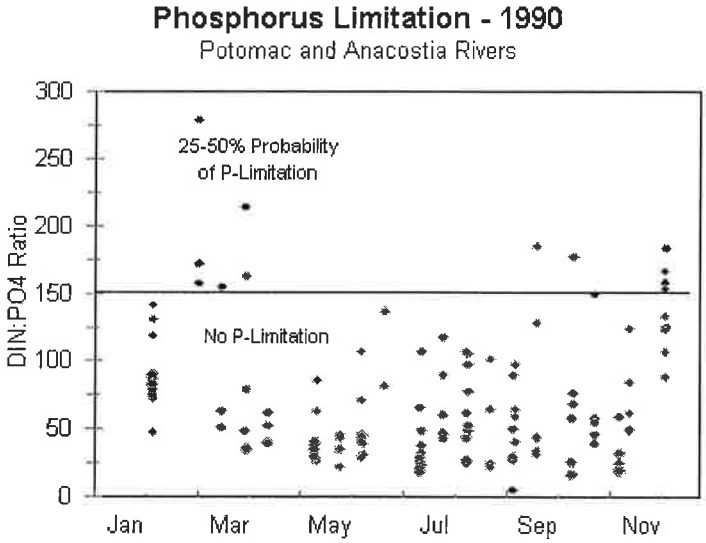
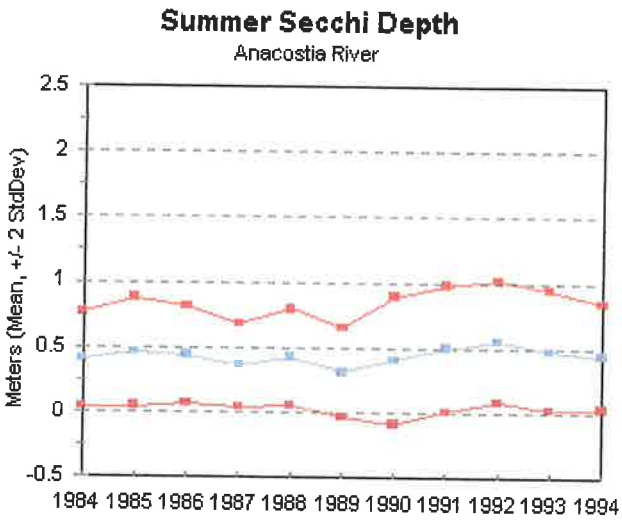
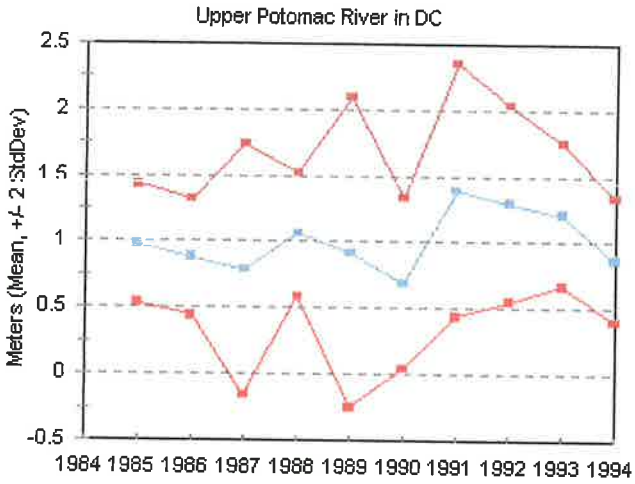


Figure 6. Analysis of District of Columbia water quality data for phosphorus limitation of phytoplankton growth, 1984 and 1990. Values of the dissolved inorganic nitrogen to ortho-phosphate ratio (DIN:PO_4) that are less than 150 are associated with little or no phosphorus limitation of phytoplankton growth. Values of DIN:PO_4 between 150 and 450 are associated with a 25-50% probability of phosphorus limitation. Values of DIN:PO_4 greater than 450 are associated with a >50% probability of phosphorus limitation. (From Fisher and Gustafson, 1998).

A



B



C

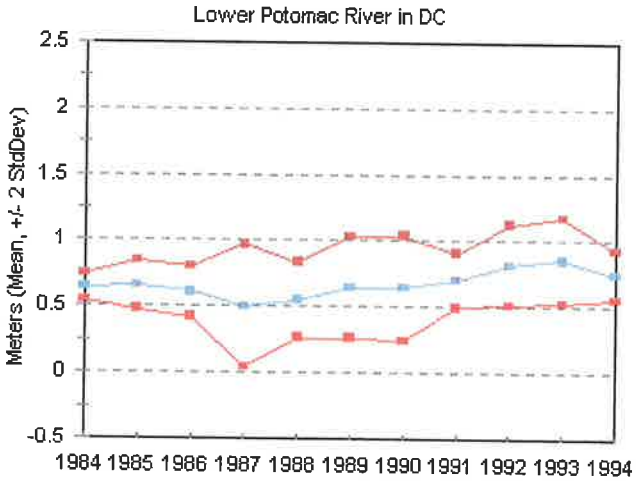


Figure 7. Mean summer secchi depth ± 2 standard deviations, 1984-1994. Summer is July - August. A = all Anacostia stations; B = all Potomac mainstem stations above Hains Point; C = all Potomac mainstem stations below Hains Point.

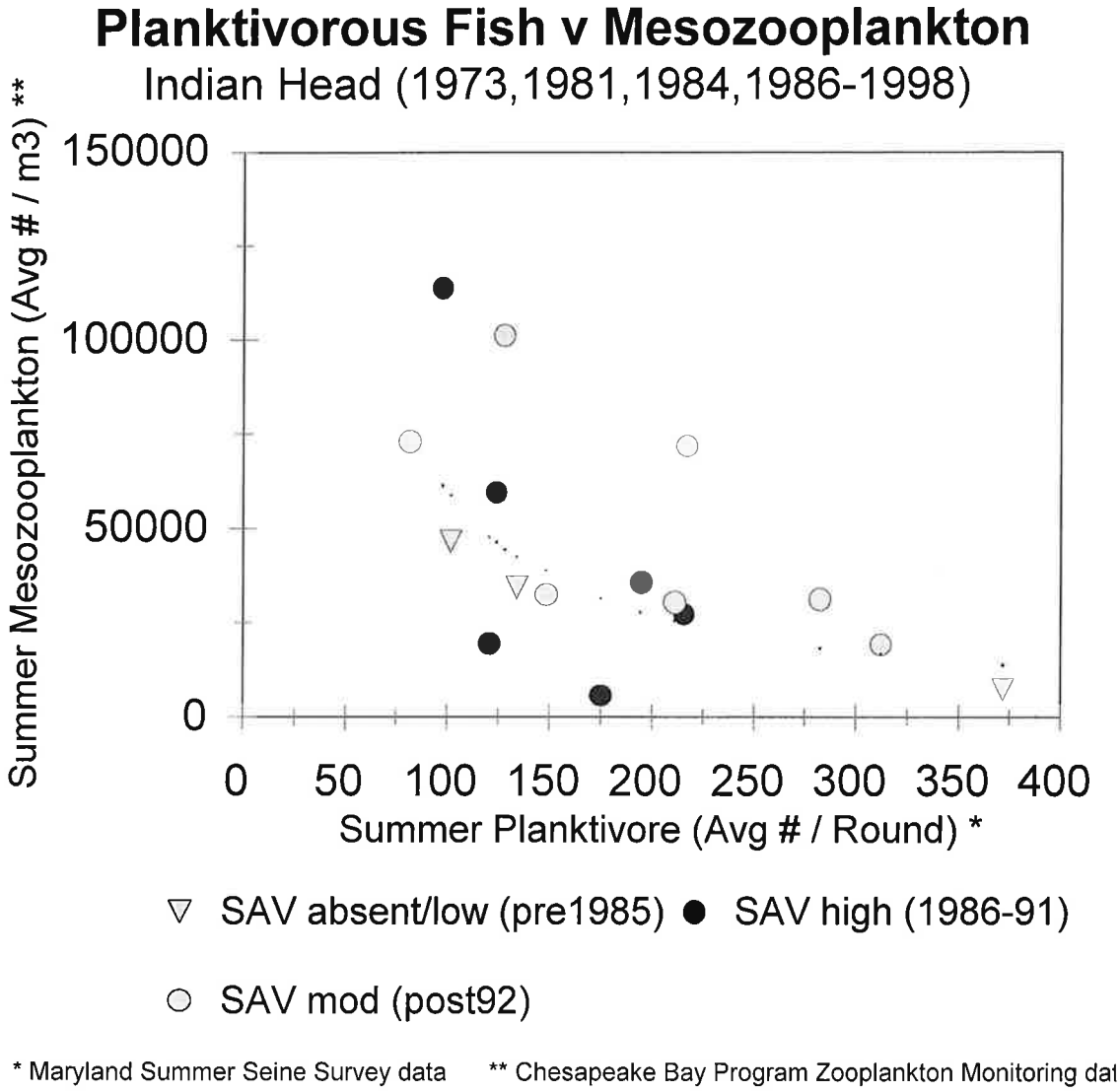


Figure 8. Inverse relationship between planktivorous fish (blueback herring, alewife, American shad, bay anchovy, Atlantic menhaden, gizzard shad, banded killifish, golden shiner, spottail shiner) and mesozooplankton (from Buchanan and Vaas 1994, Buchanan and Jones 1999). Summer = July - September. Summer planktivore = average number per round of the Maryland summer seine survey. Summer mesozooplankton = average number per cubic meter, Chesapeake Bay Program Zooplankton Monitoring Program monthly samples.

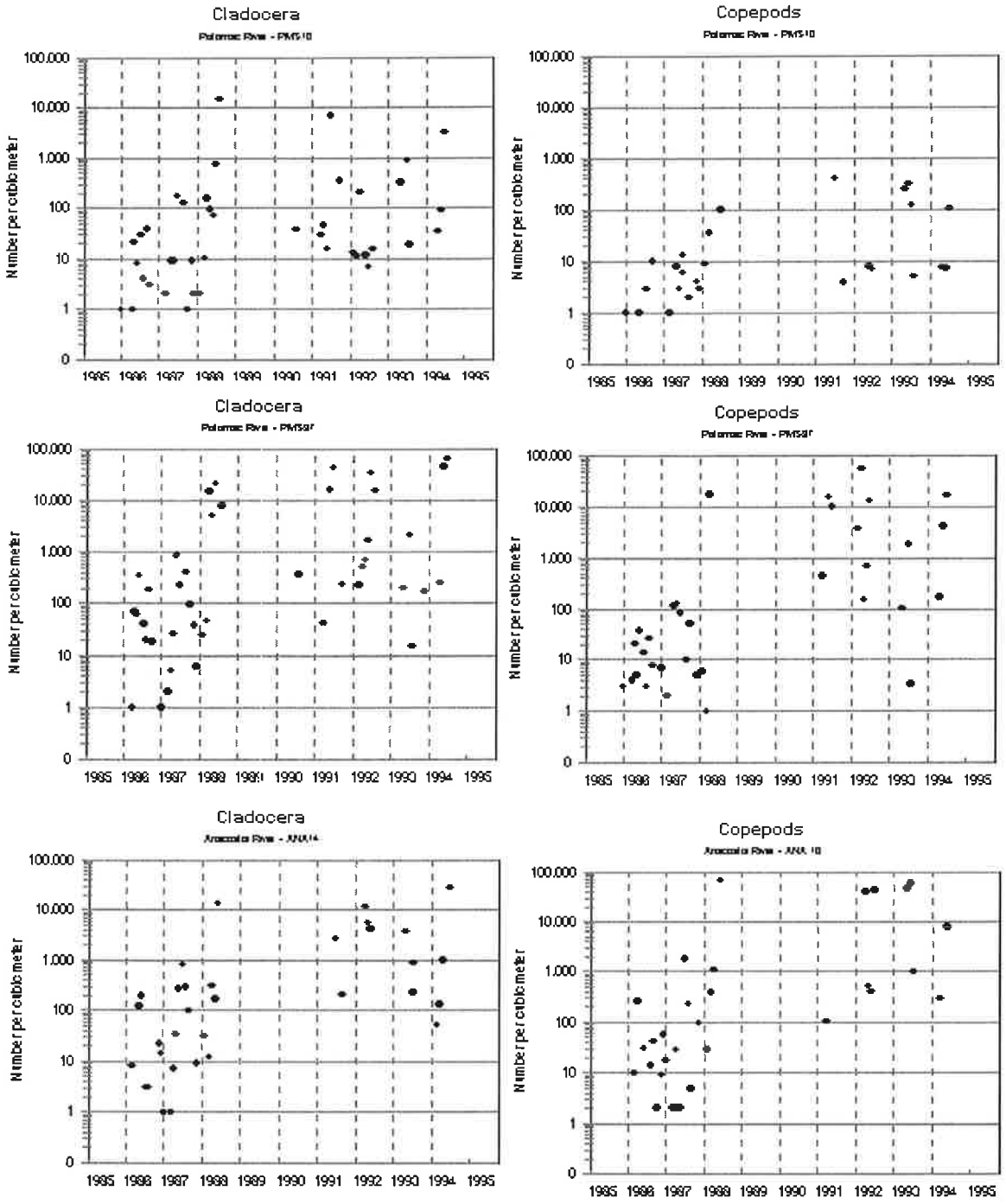


Figure 9. Abundances of the two major mesozooplankton taxa, cladocera and copepod, at the upper Potomac mainstem station (PMS10), the lower Potomac mainstem station (PMS37), and the Anacostia station (ANA10). Not all counts for 1990-1994 are available. Counts between mid 1988 and mid 1990 are qualitative and not shown.

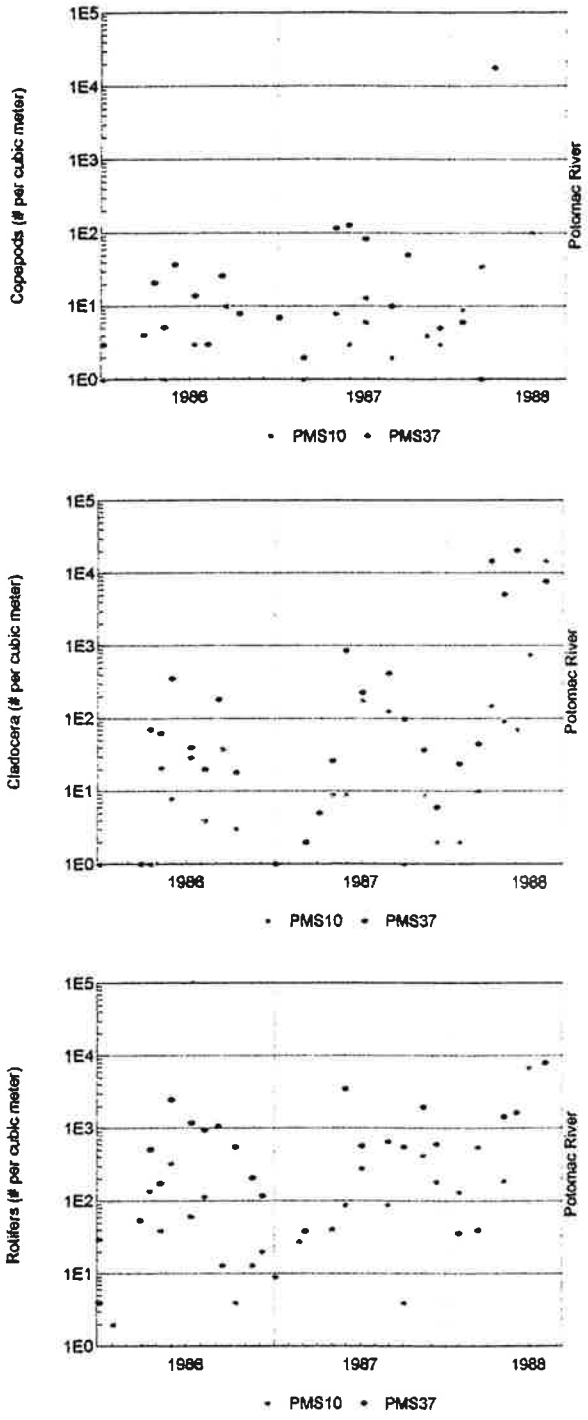


Figure 10. Abundances of the major zooplankton taxa in the Potomac River near the District of Columbia, 1986-1988. Station PMS10 is above Hains Point, Station PMS37 is below Hains Point and the confluence of the Anacostia River. As expected, zooplankton populations decline in winter and are highest in summer.

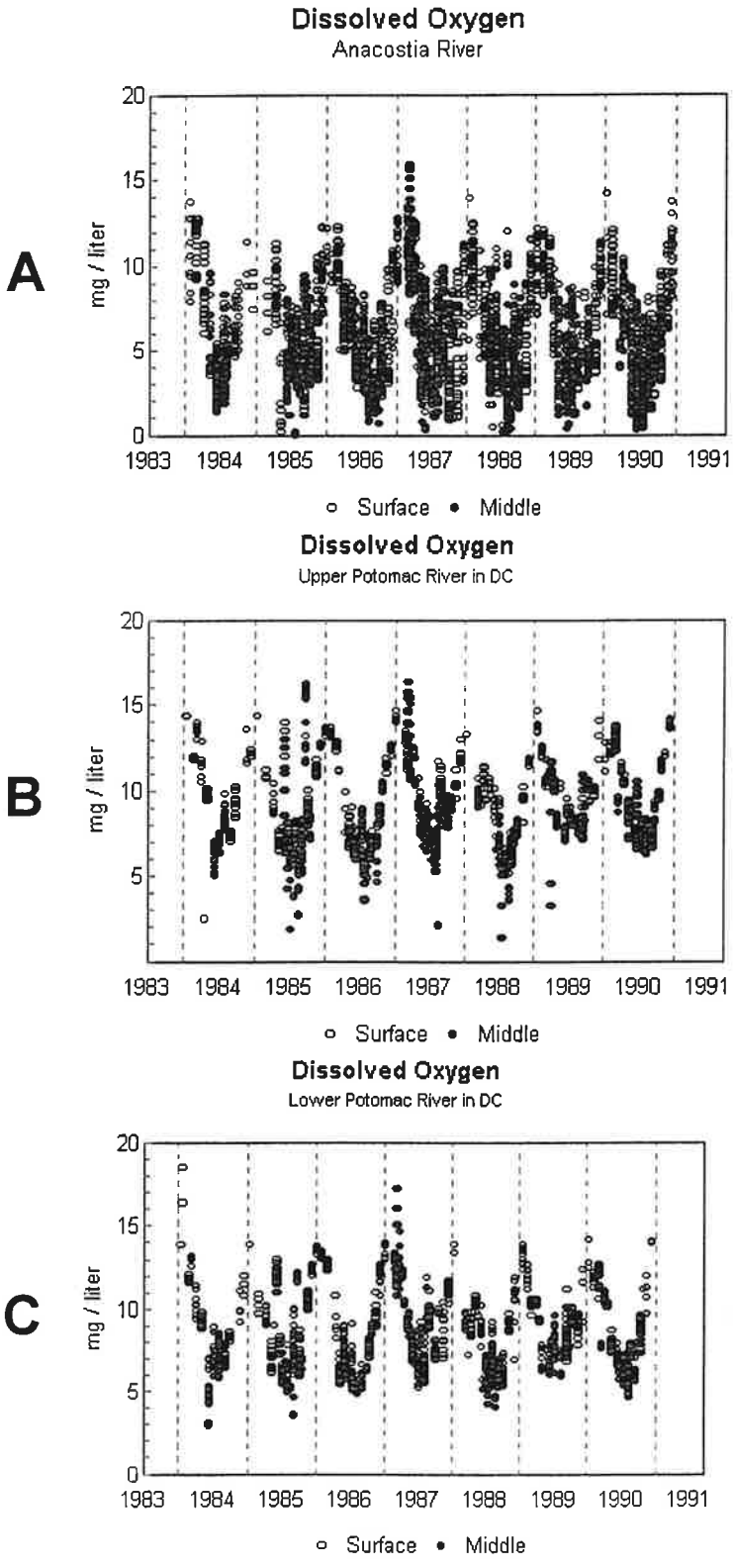
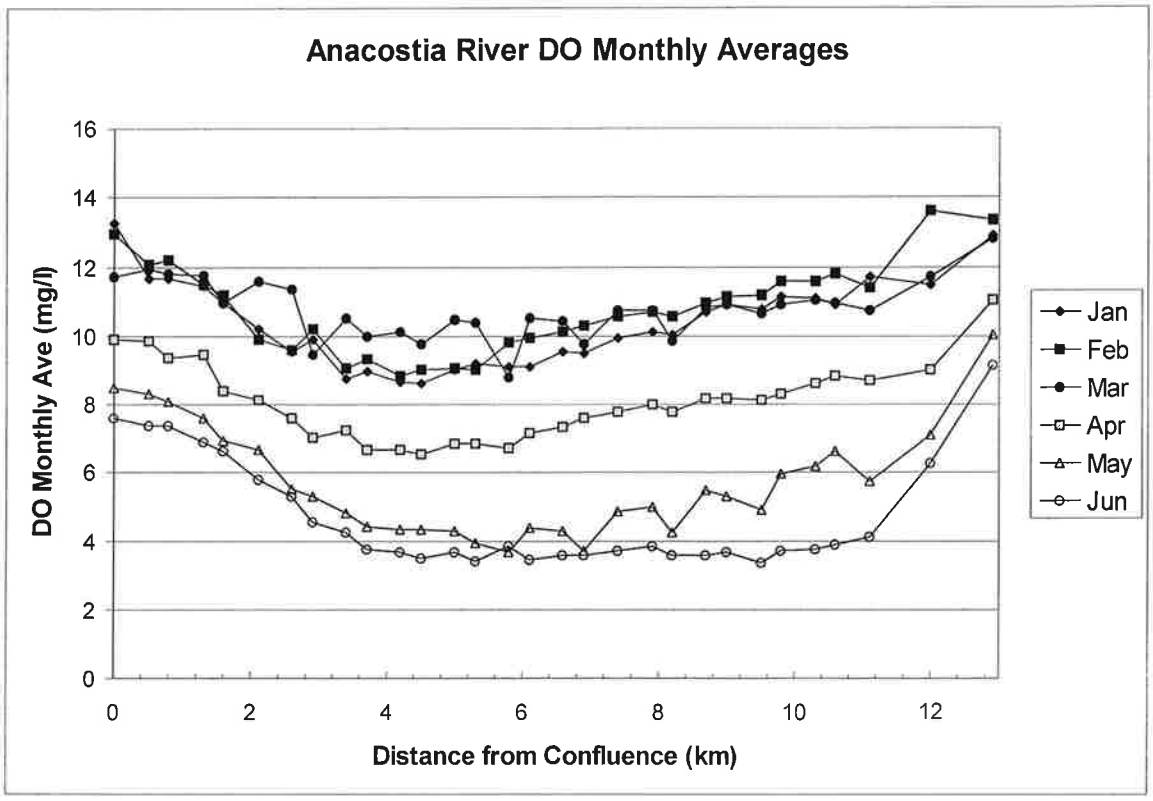


Figure 11. Dissolved oxygen for 1984 - 1990 in the Anacostia River (A), Upper Potomac River above Hains Point (B), and Lower Potomac River below Hains Point (C).



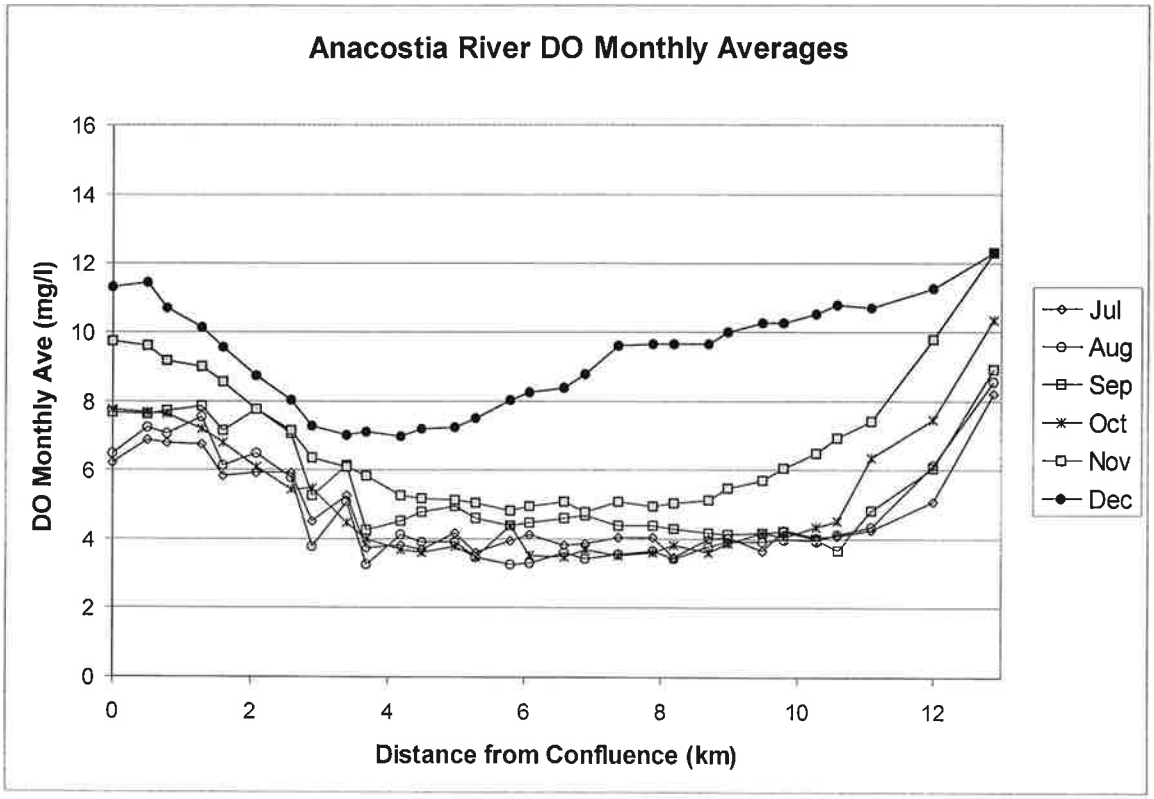


Figure 12 a, b. Average monthly dissolved oxygen for all Anacostia River stations (1984 - 1998). Lowest levels occur temporally between May and November, and spatially between 3 and 12 kilometers above the confluence with the Potomac River.