Development of Zooplankton Community Environmental Indicators for Chesapeake Bay:

A report on the project's results for June 1993 - June 1994

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Prepared for

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MEMORANDUM

June 1994

To: Robert E. Magnien
Steven E. Bieber

From: Claire Buchanan

Subject: Final report for the period June 15, 1993 to June 1, 1994 (Round 2) for the project "Development of Zooplankton Community Environmental Indicators for Chesapeake Bay", Interagency Agreement **420-C-MDE93**.

The objectives of Round 2 were to a) further analyze the data, especially the effects of estuarine flow on the indicators, b) incorporate these analyses into the chapters of last year's final report, and c) integrate the chapters and produce a comprehensive document which identifies useful indicators, explains the scientific support for them, and demonstrates how the indicators are calculated from the existing zooplankton monitoring data and interpreted. These objectives were agreed upon at a 11 August 1993 meeting of the zooplankton indicators team in Richmond, Virginia, and are reflected in the deliverables for interagency contract 420-C-MDE93.

Dr. Raymond Alden, a Virginia PI on the project, and his staff at the Applied Marine Research Laboratory of Old Dominion University were responsible for further analyzing the data. This step was a prerequisite to accomplishing most of the other objectives. Contract delays in Virginia prevented Dr. Alden from performing these analyses in the first and second quarters of Round 2 of this project.[1] During the project's third and fourth quarters, the zooplankton indicator team debated how the zooplankton data should be corrected for flow effects. Discussions took place during a January 13th conference call, a February 18th meeting of the closely related Phytoplankton Indicators Project, and through individual phone calls and FAXes. Drs. Alden, Birdsong and Buchanan also worked independently to test some of the suggested methods. Preliminary results of the efforts of Drs. Birdsong and Alden to correct zooplankton data for flow effects were included in a talk presented at the Chesapeake Research Consortium conference in Norfolk, VA, on June 1, 1994 (see Attachment A) and are being published in the conference proceedings. In a June 13, 1994 meeting of the Data Analysis Workgroup (DAWG) of the Monitoring Subcommittee, a number of researchers who had been

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[1] Funding for Round 2 was split, with $25,000 routed through Virginia Department of Environmental Quality to the Virginia principal investigators at Old Dominion University, and $12,500 routed through the Maryland Department of the Environment to the Interstate Commission and Maryland principal investigators. A contract between VADEQ and Old Dominion University was not finalized until late December 1993, effectively preventing work on the project from starting until January 1994.

working independently to identify flow correction protocols for Chesapeake Bay water quality and biological data presented and compared their results. It was agreed at the meeting that a consistent protocol was needed to avoid future confusion and mistaken interpretations of the data. To reach a concensus on which protocol to use, the DAWG workgroup proposed that Dr. Alden compare the different possible protocols using the same data sets. Although this decision further delayed accomplishing the objectives of this project, it will benefit the project's long-term goals because the same protocol will be followed by CBP researchers to correct for water quality and biological monitoring data. Errors in interpretation and time-consuming re-corrections of the data for flow will be avoided in the future.

Progress has been made in other areas of the project. Specifically, Dr. Jacobs chapter ("Food Limitation of Striped Bass Larvae in Spring") has been reworked using the log-transformed mean of mesozooplankton spring densities found in Striped bass spawning reaches. Still lacking are reanalyses and graphs of the James, York and Rappahannock data. The chapter by Claire Buchanan and Pauline Vaas ("Preliminary Investigations of Associations...") has been reworked with data through 1991 for all tributaries. The results were presented at the Chesapeake Research Consortium conference in Norfolk, VA. and are being published in the conference proceedings (see Attachment B). An overview of the entire project was presented in a session of the Estuarine Research Federation/International Association for Great Lakes Research joint meeting in Windsor, Ontario in June, 1994 (see Attachment C).

In a tangential effort which will have relevance later on to the zooplankton indicator project, the principal investigators, data analysts and managers of the CBP zooplankton monitoring programs made specific recommendations for improving the coverage and information yield of the programs and tentatively proposed an "ideal" sampling regime (see Attachment D). This effort was in response to requests by the adhoc Refinement Workgroup of the Monitoring Subcommittee to re-evaluate the existing sampling regimes. The zooplankton group also recommended that the adhoc Refinement Workgroup consider the impact of their decisions (to modify the CBP water quality monitoring programs) on the "ideal" sampling regime for zooplankton rather than on the existing one. The recommendations made to the adhoc Refinement Workgroup will be included in the final report for this project.

The delays imposed on the project by the stalled contract process in Virginia and by the lengthy debates and investigations on how to flow-correct the zooplankton data have prevented any of the original objectives of Round 2 from being accomplished. These objectives have now been transferred to Round 3 of the project (Interagency Agreement 669-C-MDE94; June 15, 1994 through June 15, 1995). Unused funds from Round 2 will be used during Round 3 (see Attachment E).

Attachments:

(A) *Long-term trends in the Lower Chesapeake Bay (1985-1992):III. The Hydraulic Effects of Flow on Zooplankton Populations.* R. S. Birdsong and R. W. Alden III. (Abstract)

(B) *Zooplankton Indicators of Estuarine Ecosystem Health.* C. Buchanan, R. W. Alden III, R. S. Birdsong, F. Jacobs and K. G. Sellner. (Abstract)

(C) *Association between Chesapeake Bay Program Zooplankton Monitoring Data and Maryland and Virginia Summer Seine Survey Data.* C. Buchanan and P. Vaas. (Manuscript)

(D) *A summary of Recent Attempts to Draft "Ideal" Sampling Regimes for Chesapeake Bay Program Plankton Monitoring Components to Improve Coverage and Information Yield, January 1994.* (Report)

(E) Financial statement of funds (Round 2 and Round 3 only)

Long Term Trends I: Water Quality

Long-term Trends in the Lower Chesapeake Bay (1985-1992): I. Water Quality

Raymond W. Alden III, R. Michael Ewing, Steven W. Sokolowski, and Michael F. Lane, Applied Marine Research Laboratory, Old Dominion University, Norfolk, VA 23529-0456

A long-term water quality monitoring program has been established in the Virginian waters of the Chesapeake Bay. To date, over eight years of data have been collected and analyzed to characterize spatio-temporal patterns and long-term trends in water quality. Complementary multivariate statistical procedures were employed to define spatial and seasonal patterns, while a series of non-parametric trend analyses were used for determining overall, site-specific, and season-specific long-term trends for water quality variables in the tributaries and main stem of the Bay. Particular attention was focused on determining the effect of river flow on the trends, because flow rates in some of the tributaries have changed dramatically since the beginning of the monitoring program. The results of these analyses and the ecological/management implications of major findings will be discussed. In addition, confirmatory analyses will be presented to demonstrate the relative power, robustness, and defensibility of the statistical approaches that have been employed.

Long-Term Trends in the Lower Chesapeake Bay (1985-1992): II. Phytoplankton

Harold G. Marshall and Raymond W. Alden III, Dept. of Biological Sciences and the Applied Marine Research Laboratory, Old Dominion University, Norfolk, VA 23529

Results of a seven year monitoring program provided the basis to determine the long-term trends of the phytoplankton community in the lower Chesapeake Bay. Data sets were analyzed by a series of powerful nonparametric trends tests. The overall trends in the data were then analyzed by the seasonal intrablock sign test based on the Kendall Tau statistic and the aligned rank test. Those trends unique to certain seasons, or stations, or to interaction of stations and seasons were analyzed by a chi-square protocol. In addition, since there were distinct differences in the three rivers and the bay flow patterns, an equation was utilized for the station data analysis to correct for flow within the system, and allow for more realistic comparisons of the station data. Spatial grouping of assemblages characteristic to the eastern, western and northern portions of the lower Bay were identified. There were 6-8 successful groupings of the species, with maximum productivity and highest nutrient concentrations associated with the western section of the Bay. There were overall trends for increased seasonal abundance of total phytoplankton and for increased concentrations of phytoflagellates during the summer and early fall months. This phytoflagellates pattern was displayed in major blooms of a series (5) of dinoflagellates that occurred from July through September in 1992. Likely areas of concern would be any increased nutrient loadings in the watersheds of the James, York and Rappahannock Rivers that would support bloom development. Future blooms (and possible fish kills) would be more apt to occur along the western region of the Bay and near the entrances, or in the plumes, of these rivers, or in restricted harbor sites along the southwest margin of the Bay.

Long-term Trends in the Lower Chesapeake Bay (1985-1992): III. The Hydraulic Effects of Flow on Zooplankton Populations

Ray S. Birdsong and Raymond W. Alden III, Dept. of Biological Sciences and The Applied Marine Research Laboratory, Old Dominion University, Norfolk, VA 23529

Plankton populations at most tidal freshwater monitoring stations and some downstream stations in the Chesapeake Bay tributaries are periodically subjected to hydraulic impact, as high flow events cause the rapid downstream transport of planktonic organisms. Hydraulic impact events occur regularly in some tributaries, usually at the time of the spring freshet, and vary in magnitude with flow rate, cross-sectional configuration at the station location, and the degree of upstream salt-wedge intrusion. Both temporal and spatial comparisons of plankton community metrics require that hydraulic effects be taken into account. Using the James and York Rivers as a case study, we here report on an approach to removing the effect of flow (or, conversely, flushing time) on plankton monitoring data.

Topic Number: 11,c,o

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ZOOPLANKTON INDICATORS OF ESTUARINE ECOSYSTEM HEALTH.

Estuarine monitoring data were used to explore linkages between zooplankton, water quality and other biotic groups, and develop community-based zooplankton indicators of ecosystem health. Data were collected from the Chesapeake Bay mainstem and eight diverse subestuaries: the Choptank, Patapsco, Patuxent, Potomac, Rappahannock, York, James and Elizabeth rivers. Anthopogenic impacts are evident despite the controlling influences of flow, salinity and temperature. Microzooplankton, an integral part of the "microbial loop", correlate well ($r^2 > 60$) with chlorophyll and are excellent metazoan indicators of eutrophication. One species, a hypotrich ciliate, seems a good indicator of recent low DO events. Mesozooplankton, larger-bodied zooplankton which are food for most larval fish, are at present *weakly* linked to phytoplankton throughout, but are *strongly* linked to finfish planktivores during summer in most tidal fresh and oligohaline reaches. Food web management strategies developed for freshwater lakes can probably be applied to tidal fresh reaches with relatively long residence times, to bolster mesozooplankton populations and reduce algal blooms. Linkages between mesozooplankton and finfish planktivores are not clearcut in mesohaline and polyhaline waters, possibly because of invertebrate planktivore abundances. None of the largest striped bass nursery areas in the Chesapeake system had "optimal" food levels for normal striped bass larval growth during Spring (April-June). Only one (Choptank) consistently met "minimum" requirements (15-25 mesozooplankton liter^{-1}). Toxic pollutants are the confirmed cause of low zooplankton abundance in the Elizabeth River. Efforts to develop an "index of biological integrity" for estuarine zooplankton are underway.

ASSOCIATIONS BETWEEN CHESAPEAKE BAY PROGRAM ZOOPLANKTON MONITORING DATA AND MARYLAND AND VIRGINIA SUMMER SEINE SURVEY DATA

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Abstract

Many of the dominant finfish species in Chesapeake Bay waters are obligate planktivores (e.g. bay anchovy, Atlantic silversides, Atlantic menhaden), suggesting strong links might be found between zooplankton and finfish communities. Correlations between the average summer abundances of mesozooplankton ($>202\mu$m) and finfish that are obligate planktivores are examined in this paper. Abundances were obtained from the Chesapeake Bay Program zooplankton monitoring data and the Virginia and Maryland juvenile finfish seine survey data. Planktivore - mesozooplankton relationships were found at five of ten Chesapeake Bay Program zooplankton monitoring stations in tidal fresh and oligohaline waters during the summer growing season. Abundances were inversely related in tidal fresh waters, suggesting top-down control of the mesozooplankton by finfish planktivores. Abundances were directly related in oligohaline stations, indicating bottom-up control of the finfish planktivores by mesozooplankton. Planktivore and/or mesozooplankton abundances were consistently low at tidal fresh and oligohaline stations where no relationships were evident. These stations have poor water quality, changing water quality, and/or rapid flushing rates. Straightforward relationships between mesozooplankton and finfish planktivores were not evident at the four mesohaline stations, where invertebrate predation (jellyfish, meroplankton) and hypoxia/anoxia become significant controllers of the mesozooplankton community during the summer. Further investigations will hopefully substantiate the plankton - fish linkages in all salinity regimes and quantify the factors that disrupt linkages. Predator - prey relationships can be the basis for developing zooplankton indicators of finfish community structure and trophic imbalances in Chesapeake Bay, as they are elsewhere.

Introduction

Zooplankton are the prey of many abundant fish species, several depleted fish species and most fish larvae in Chesapeake Bay. Bay anchovy and Atlantic silversides, currently the dominant resident species (Carmichael et al. 1992), are obligate planktivores their entire lives, feeding only on mesozooplankton. Atlantic menhaden, the dominant species, consume zooplankton during early life stages in coastal waters, then develop specialized brachial structures after entering the estuary that allow them to filter phytoplankton and detritus as well as zooplankton. American shad and the river herring, which were historically abundant and heavily exploited and are now habitat-impaired, feed principally on zooplankton during their growing periods in the estuary. Zooplankton are the obligate prey of larval stages of most finfish species, regardless of what prey the larvae switch to as they metamorphose. For example, striped bass feed on zooplankton in spring and early summer as larvae, become facultative predators of invertebrates near the end of their first summer, and are strict piscivores by one year. Finally, facultative predators on zooplankton (e.g. sunfish, minnows, killifish) are presently abundant in bay fish communities (Carmichael et al. 1992) and will consume mesozooplankton along with other prey.

The dominance of obligate and facultative planktivores in Chesapeake Bay finfish communities suggests strong trophic linkages exist between finfish and zooplankton. Such linkages are evident as close correlations between predator and prey. The discovery of similar relationships in freshwater systems has lead to the development of zooplankton indicators of finfish community structure, for the purpose of fisheries management. Galbraith (1975) used the abundance of *Daphnia* spp. to predict the survival and "fishing quality" of rainbow trout in Michigan lakes. Mills and Schiavone (1982) successfully correlated zooplankton size, growth of planktivorous fish, and the size structure of percid and centrarchid populations in New York lakes. Mills, Green and Schiavone (1987) further observed that zooplankton size in the New York lakes was a good indicator of the relative abundances of piscivores and "panfish" (planktivores). Resource management strategies in the Great Lakes have for some time recognized the value of zooplankton as indicators of fish community structure and ecosystem balance (Evans and Jude 1986, Johannsson 1987, Hartig et al. 1991). Considering the bay-wide coverage of the zooplankton monitoring program, zooplankton indicators could be useful to Chesapeake Bay management if finfish - zooplankton linkages are found.

Methods

In this paper, correlations between the average summer abundances of obligate planktivores and their prey, the mesozooplankton, in the upper mainstem and six Chesapeake Bay tributaries are calculated. Trophic linkages were expected to be strongest between obligate planktivores and their prey. Trophic linkages are also most evident in July, August and September when planktivorous species are actively feeding, growth rates are at their annual maxima, and young-of-the-year contribute substantially to the overall predation pressure on mesozooplankton. Tributary differences in water quality, hydrology and salinity were expected to help sort out the influences of other controlling factors and clarify the environmental limits within which strong trophic linkages are possible. For example, regressions with slopes nearly parallel to the graph's axes or with weak correlation coefficients indicate other controlling factors (eg. salinity, water quality, high flow, predation by another group) strongly influence the mesozooplankton or finfish planktivores.

Finfish planktivore data were obtained from the Maryland Estuarine Juvenile Finfish Survey and the Virginia Juvenile Striped Bass Survey. Both are long-term, shoreline seine surveys done in bay tributaries and the upper bay. Sampling sites are located in the spawning and nursery grounds of commercially important anadromous fish. Seine hauls are done in July, August and September and all species are at least identified and counted. Details of the programs and maps of the seine station locations are given in the Chesapeake Bay Monitoring Atlas (Heasly et al. 1989) and elsewhere. For this study, only seine stations located near a zooplankton monitoring station were used (Table 1).

Maryland and Virginia seine survey protocols are different, so the data sets were normalized to make them comparable. Maryland collects three rounds of seine hauls at each shore site, with two hauls per round, for a total of six hauls per summer. Virginia collects five rounds of two seine hauls per round for a total of ten hauls during the same time period. Occasionally sites in both states were not sampled. To prevent the gaps from biasing finfish estimates, site-year data were excluded if:

> *Maryland*: at least two hauls out of six total hauls were missing for a site in a particular year, *except* if a zooplankton monitoring station was paired with only one seine station, in which case all of the data were kept whether or not there were missing hauls. (There were nine site-year combinations that were deleted from the Maryland data.)
>
> *Virginia*: at least three hauls out of the ten total hauls were missing for a site in a particular year. (Only one site had at least three hauls missing. An additional 21 site-year combinations had two of the ten hauls missing, but these were not deleted.)

For each year, species counts from the seine sites adjacent to each zooplankton monitoring station were grouped and averaged to obtain the mean abundance of each species per round (two seine hauls) in both Virginia and Maryland. Means of species known to be obligate planktivores were then extracted and summed to obtain average planktivore abundance per round for each year. A list of these planktivore species is given in Table 2.

Mesozooplankton include copepodites and adult copepods, cladocera, meroplankton, and mysids. Mesozooplankton data were obtained from the ongoing Maryland and Virginia Zooplankton Monitoring Programs of the Chesapeake Bay Program (CBP), for the years 1984 - 1991 (Choptank, Patuxent and Potomac rivers, upper bay), 1986 - 1991 (James and Rappahannock rivers) and 1987 - 1991 (York River). At each zooplankton monitoring station, samples are collected with towed nets (202 micrometer mesh) from several depths and combined. Station locations are shown in Figure 1. Several lower tributary zooplankton stations and all of the bay mainstem stations south of CB2.2 could not be matched with seine sites and are therefore not included in this study.

Regressions were made between the average station abundance of mesozooplankton for July, August and September of each year and each year's average planktivore abundance for the matching seine station(s). Historical mesozooplankton data were available in the vicinity of the upper Potomac TF2.3 station for 1974 (unpublished data obtained from Versar, Inc. and described in Ecological Analysts, 1974) and 1981 (Buchanan and Schloss, 1983).

Results

Only stations that experienced similar salinities were directly compared because of the recognized impact of salinity on zooplankton community structure. The term "planktivore" refers to finfish planktivores in the following discussion, except when noted otherwise. Analysis results are summarized in Table 3.

Four zooplankton monitoring stations are entirely in tidal freshwater (0 - 0.5 ppt salinity): CB1.1 (upper bay), TF2.3 (Potomac), TF5.5 (James) and TF4.2 (York). The average planktivore abundances at seine sites near these four stations were low relative to brackish water sites during the study period. In contrast, summer zooplankton abundances were relatively high at the Potomac station, low at the James and York stations and exceptionally low at the upper bay station (Table 3). Summer zooplankton community structure in the tidal fresh was diverse compared to oligohaline and mesohaline communities. The upper bay and the Potomac have the largest tidal freshwater reaches in the Chesapeake Bay complex of waterways; the York has one of the smallest.

The upper bay and Potomac stations showed inverse relationships between mesozooplankton and planktivore abundance during the summer months (Figures 2a, 2b). Mesozooplankton abundance decreased when planktivore abundance, and presumably predation pressure, increased. The inverse relationship indicates mesozooplankton abundance is the dependent variable and varies in response to planktivore abundance. The upper bay data span a small range of mesozooplankton abundances and a large range of planktivore abundances. The 1991 datum was excluded because flows from the

Susquehanna River were exceptionally low that summer. Mean daily flows averaged 5847.5 cubic feet per second for 92 days (July - September), or near the 10th percentile of all mean daily flows for 1967 - 1992. Consequently, seine sites near CB1.1 were at times oligohaline. The ten Potomac data points span a wide range of both planktivore and mesozooplankton abundances, and they best fit a log-log curve (i.e. log [mesozooplankton] = 7.796 - 1.5321 log [planktivores]) when the 1985 datum is removed. In 1985, submerged aquatic vegetation (SAV) returned suddenly to the TF2.3 area between Marshall Hall and Quantico (Carter and Rybicki 1986) and dramatically affected the tidal fresh ecosystem (see below). The position of the 1985 datum as an outlier suggests there were short-term repercussions on the planktivore - mesozooplankton relationship.

Planktivore - mesozooplankton relationships were not found at the tidal fresh James (TF5.5) and York (TF4.2) stations (Table 3, Figures 2c, 2d). In the James, summer planktivore abundances were approximately 1/2 of those in the tidal fresh Potomac and upper bay. Summer mesozooplankton abundances were low, approximately 1/2 to 1/4 of those found in the tidal fresh Potomac and the smaller, freshwater/oligohaline reaches of the Choptank and Patuxent. The tidal fresh York had relatively low mesozooplankton abundances and populations frequently crashed below 1000 mesozooplankton per m^3 (R. Birdsong, personal communication). Planktivore abundances near the tidal fresh York station were often the lowest found in the Virginia and Maryland seine surveys combined.

The relatively diverse zooplankton community of the tidal fresh shifts quickly to an *Acartia* dominated, estuarine community as it enters the oligohaline (0.5 - 5.0 ppt salinity). However, there is no consistent pattern of change in summer mesozooplankton abundance moving downstream from tidal fresh to oligohaline stations[1] in Chesapeake tributaries (Table 3). Abundances dropped in the Potomac, rose in the upper bay, and remained low in the James. Abundances declined somewhat between the fresh/oligohaline and the oligohaline/low mesohaline stations in the Patuxent. Summer planktivore abundances increased moving downstream to the oligohaline reaches, except in the James and Patuxent.

Three of the six oligohaline stations exhibited *positive* correlations between summer planktivore and mesozooplankton abundances during the study period (Figures 3a, 3e, 3f). Specifically, planktivore abundance was high when mesozooplankton abundance was high. The positive correlations suggest that planktivores are the dependent variable and are responding to mesozooplankton abundance (food availability). Clear relationships were not found in the oligohaline/low mesohaline James (Figure 3c) or the tidal fresh/oligohaline Patuxent (Figure 3d). A weak *inverse* relationship was found in the oligohaline/low mesohaline Potomac (Figure 3b).

The mesohaline covers extensive stretches in the middle and lower tributaries of the Chesapeake Bay as well as approximately half the length of the Bay mainstem. The Maryland and Virginia juvenile finfish seine surveys, from which the planktivore estimates were derived for this study, extend only into the tributary mesohaline reaches because they focus on summer nursery areas of anadromous fish. Furthermore, the James and the York do not have zooplankton monitoring stations in true mesohaline waters. Therefore, mesozooplankton - planktivore linkages could only be examined at four tributary mesohaline stations: ET5.2 (Choptank), LE1.1 (Patuxent), LE2.2

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[1] Summer salinities at none of these stations were strictly oligohaline (0.5 - 5 ppt). Stations ET5.1 and TF1.5 typically experienced both fresh and oligohaline conditions during the summer. Stations RET5.2 and TF1.7 experienced both oligohaline and low mesohaline (5 - 10 ppt) conditions. And stations RET2.2 and CB2.2 experienced fresh, oligohaline and low mesohaline conditions. Data for summers with predominantly tidal fresh conditions have been removed from the RET2.2 and CB2.2 regressions. The Rappahannock station TF3.3 was not included in this paper because salinities there range from tidal fresh to mesohaline with no clear dominance of one salinity regime.

(Potomac) and RET3.1 (Rappahannock). No correlations were evident between mesozooplankton and planktivore abundance at these four stations (Table 3). Summer densities of mesozooplankton at the tributary mesohaline stations were variable, with a relatively high average at ET5.2 (Choptank), moderate averages at LE1.1 (Patuxent) and LE2.2 (Potomac), and a low average at RET3.1 (Rappahannock). Planktivore abundances near zooplankton monitoring stations were moderate, except in the Choptank where they were high (Table 3).

Discussion

Tidal fresh (0 - 0.5 ppt) and Oligohaline (0.5 - 5 ppt)

A planktivore - mesozooplankton relationship occurs at the upper bay station (CB1.1) despite the suspected impacts of high flow and eutrophication on mesozooplankton abundance (Table 3). The station is located in the high flow zone at the mouth of the Susquehanna River. Samples from this particular station underestimate average zooplankton densities for the upper bay area known as the Susquehanna Flats (K. Sellner and F. Jacobs, personal communication). However, they track zooplankton trends found downstream at CB2.2 and probably reflect actual trends and trophic relationships in the Flats. Zooplankton populations appear to be affected by the relatively high ambient nutrient concentrations in Susquehanna Flats, i.e. biomass ratios of microzooplankton to mesozooplankton are exceptionally high ($\text{average}_{'84-'90}$ = 85%) when compared to ratios from other tidal freshwater reaches of the bay. Nitrogen concentrations did not change significantly during the study period whereas phosphorus declined somewhat (Magnien and Boward in prep.).

Significant habitat changes at the tidal fresh Potomac station during the 1980's appeared to shift the mesozooplankton - planktivore relationship from one end of the regression curve towards the other. In 1985, biomass estimates of submerged aquatic vegetation in the TF2.3 area increased 16.5-fold (spring) to 1.7-fold (fall) over the previous year (Carter and Rybicki 1986), and acreage quadrupled (Chesapeake Bay aerial SAV surveys). The SAV improved water quality (Carter et al. 1988) and allowed a resurgence of largemouth bass (L. Fewlass, personal communication). Largemouth bass is a top predator that feeds primarily on smaller fish, including planktivores, and crayfish and relies heavily on submerged aquatic vegetation (SAV) for habitat. Largemouth bass surveys (1988, 1989, 1992, 1993) in various Maryland Chesapeake Bay tributaries show that the Potomac population is presently the largest in Maryland, has good - excellent recruitment, and provides "an outstanding fishery" with a relatively high catch per angler per hour rate (Fewlass et al. 1993). On the average, planktivores declined about 20% after 1985 and mesozooplankton increased more than 60%. Different regression slopes seem to be evident for pre-SAV and SAV-concurrent data. Data for the three pre-SAV years ('73,'81,'84) suggest a shallow negative regression slope whereas the five years after 1985, when SAV populations were fairly stable in the vicinity of TF2.3, reveal a steep negative slope (Table 3, Figure 2b). Changes in water quality did not correlate with changes in mesozooplankton abundance in the tidal fresh Potomac during the study period. Total phosphorous concentrations were relatively low and loads declined. Total nitrogen concentrations were high, and increased (Magnien and Boward in prep., MDE 1993).

In the tidal fresh James and York, planktivore and mesozooplankton were low and no relationship between the two variables was found. These findings suggest some factor, or combination of factors, has an impact large enough to depress both planktivore and mesozooplankton populations and disrupt linkages between the two. Ongoing analyses to determine the importance of flow and residence time to zooplankton populations in Chesapeake tributaries will help to clarify whether or not natural causes are responsible. Other possible causes could include ammonia and low dissolved oxygen. For 1986 - 1988, 22 violations of the EPA ammonia criteria were observed in the tidal fresh James, with most occurring in summer, and summer levels of dissolved oxygen went below 4.0 milligrams per liter in approximately 9% of the tidal fresh York measurements (Alden et al. 1992).

The positive correlations between summer planktivore and mesozooplankton abundances found at the oligohaline stations CB2.2, TF1.7 and ET5.2 can be interpreted either as evidence of a direct link between predator and prey or evidence of another factor causing predator and prey to vary in a similar fashion. The first interpretation seems correct because there do not appear to be any factors that can similarly control mesozooplankton and planktivore abundances in all the oligohaline reaches. Piscivores crop juvenile and adult planktivores but not mesozooplankton. Jellyfish predators influence both mesozooplankton and fish larvae, however they are rare in the oligohaline (Lippson et al. 1979). Similarly, most meroplankton predators of mesozooplankton and fish larvae have small, pulsed populations in the oligohaline and cannot exert a large, sustained predation pressure. A substantial population of facultative finfish planktivores in the oligohaline (e.g. striped bass Y-O-Y, mummichog, sticklebacks, sheepshead minnow, and the rainwater, striped, marsh, and spotfin killifishes) could conceivably regulate both planktivore larvae and mesozooplankton, and this possibility remains to be examined. A cursory look at the fish communities in Maryland (Carmichael et al. 1992) suggests this possibility is unlikely because these are not dominant species. Water quality at CB2.2, TF1.7 and ET5.2 were not similar. Overall conditions ranged from "fair" (CB2.2, TF1.7) to "generally good" (ET5.2). Total nitrogen concentrations were "severely impacted" at TF1.7, "stressed" at CB2.2 and "fair" at ET5.2. Chlorophyll and phosphorous concentrations varied between low (CB2.2) and high (TF1.7). Dissolved oxygen concentrations ranged from sufficient (CB2.2 and ET5.2) to fair-poor (TF1.7) (Magnien and Boward, in prep., MDE 1993). If one accepts the interpretation that predator and prey are directly linked and not similarly controlled by a third variable, then the regression coefficients imply a substantial degree of bottom up control by the mesozooplankton on the planktivores in the oligohaline reaches of Chesapeake Bay.

In comparison to the positive regression slopes above, the weak ($p = 0.08$) inverse relationship between planktivore and mesozooplankton abundances at the Potomac oligohaline station (RET2.2) is odd. Changing water quality conditions and significant concentrations of several chemical pollutants are characteristic of this portion of the Potomac. Ambient concentrations of nitrogen at RET2.2 are high and have increased since 1984. Total phosphorous concentrations are low and declining (Magnien and Boward in prep., MDE 1993). A pilot study done for the Chesapeake Bay Program (Hall et al. 1992) and earlier studies found water column and sediment toxicity in the general area RET2.3. Known stressors in the water column downstream at Morgantown and the Dahlgren Naval Weapons Laboratory include tributyltin (TBT), copper, and nickel, and possibly mercury and lead, in excess of EPA water quality criteria. *Acartia*, the dominant species during the summer, is known to be sensitive to trace metals and population crashes in the Elizabeth River (which empties into the lower James River) have been associated with elevated metal concentrations (Sunda et al. 1990). Further years of data are needed to resolve whether the inverse planktivore - mesozooplankton relationship at RET2.2 is a valid one or an artifact of other factors.

The absence of a mesozooplankton - planktivore relationship and the low abundances of both groups in the James (RET5.2) repeats the pattern found at the James tidal fresh station (Table 3). It reiterates the hypothesis that outside controlling factors may be decoupling trophic linkages at this station. Possible reasons for this pattern are still uncertain and information on toxic pollutants other than Kepone is scarce. Kepone, a chlorinated hydrocarbon, was found in high concentrations in the James in 1975 and resulted in a decade long restriction on fishing in the system. It is still an important contaminant in the lower James (Kennish 1992).

The Patuxent fresh/oligohaline station (TF1.5) is more transitional in nature than the other oligohaline stations, which may be one reason a planktivore - mesozooplankton relationship was not found here. Zooplankton species composition at this station is most like those in tidal fresh stations, except for frequent incursions by *Acartia*. Similarly, summer planktivore abundances are more comparable to those in the tidal fresh. Changing nutrient concentrations at this station due to improved wastewater treatment may be another factor modifying a planktivore - mesozooplankton relationship. For example, summer concentrations of ammonium, a compound whose ionic form (NH_3^+) is toxic to aquatic organisms when present in high concentrations, have declined over 80% and summer dissolved oxygen has increase 1.5 mg/liter during the study period (S. Bieber, personal communication). Phosphorous loadings are still high here, however - approximately three times the loadings in the larger Potomac River. When the system reaches a new dynamic equilibrium and improved water quality conditions are established, a mesozooplankton - planktivore relationship may become evident and the influence of salinity on the regression can be clarified.

The slopes of the significant, planktivore - mesozooplankton regressions differ markedly in the tidal fresh and oligohaline reaches, i.e. they are negative in tidal freshwater and positive (with one possible exception) in oligohaline water. The difference indicates a fundamental change takes place in the zooplankton - fish relationship at the leading edge of the salt wedge. It is believed that the relative dominance of predator and prey responses to each other and to their environment determines whether predator - prey correlations are positive, negative, or absent when predation pressure is strong (Williamson et al. 1989). Abundant planktivores occur in all reaches of the bay except the York (TF4.2) and the James (TF5.5, RET5.2), indicating predation pressure is strong. A comparison of the tidal fresh and oligohaline habitats and communities highlights some factors potentially causing shifts in prey vulnerability, predator - prey overlap, and predator efficiency as salinity changes. Zooplankton diel vertical migration, a versatile method of reducing predator - prey overlap in most aquatic systems, is regularly disrupted by strong vertical mixing in the tidal fresh (Buchanan and Schloss 1983) and oligohaline (Heinle et al. 1979) reaches of partially-mixed estuaries. The loss of this adaptive behavior is somewhat compensated for by higher turbidity in estuaries which shrinks the reactive zones of visual planktivores (although not of Atlantic menhaden, the dominant species in Chesapeake Bay). Prey vulnerability is further reduced in the oligohaline by a major, salinity-induced shift in zooplankton species composition from a diverse freshwater community frequently dominated by cladoceran species to an estuarine community dominated by one copepod species, *Acartia tonsa*, in the summer. *Acartia* tolerate a wide range of salinities. They are omnivores capable of selectively consuming detritus, net phytoplankton and even smaller zooplankton (Lonsdale 1981b, White and Roman 1992) and are therefore well adapted to utilizing the enormous amounts of organic material generated as freshwater species die out. They are also, as copepods, better adapted to escaping fish predators than the slower moving Cladocera which rely more on vertical migration and transparency to avoid predation. The shift towards an *Acartia* dominated community could be expected to reduce the influence of both the environment and predation as controlling factors on the overall mesozooplankton population and consequently change the zooplankton-fish relationship.

The different regression slopes in the tidal freshwater and oligohaline also suggest the following hypothesis: the dominant direction of trophic control is top-down in the tidal fresh and bottom-up in the oligohaline. As evidenced by inverse regression slopes, predators appear to have more control over the prey's abundance than the prey, as food, have on predator abundance in the tidal fresh. This echoes a pattern found repeatedly in freshwater lakes where manipulations of planktivore abundance bring about opposite changes in the abundance of lake zooplankton. If further analysis of the monitoring data and experimental work provide more evidence that top-down controls predominate in Chesapeake Bay tidal freshwater food chains, management actions that maintain moderate rather than excessive concentrations of planktivores will encourage vigorous populations of freshwater mesozooplankton species. Most of these zooplankton species are herbivorous on algae. Conversely, in Chesapeake Bay oligohaline waters during summer the prey appear to have more control over predator abundance than the predators, as consumers, have on prey abundance. Management actions that increase zooplankton abundance in oligohaline waters could be expected to enhance planktivore survival and abundances there.

Tributary mesohaline (5 - 18 ppt salinity)

No relationships were evident between mesozooplankton and planktivore abundance at the four mesohaline stations. The implication here is that the trophic linkage between obligate planktivores and their principal prey, the mesozooplankton, is either masked or uncoupled by other factors. A diverse, abundant collection of zooplankton predators and chronic summer hypoxia/anoxia are two known factors in mesohaline waters that exert strong controls on zooplankton populations. Predators of zooplankton during the summer include a variety of meroplankton larvae and epibenthic crustacea, *Neomysis americana* (mysid shrimp), the ctenophore *Mnemiopsis leidyi*, and the larvae of serially spawning finfish in addition to juvenile and adult finfish planktivores. All the stations stratify to some extent during the summer, the Choptank and Rappahannock sporadically and weakly and the Potomac and the Patuxent strongly and for long periods. Hypoxic, and sometimes anoxic, layers became established in the Potomac and Patuxent each summer and periodically intrude the Choptank station from the bay mainstem.

The diverse array of zooplankton predators in the mesohaline, in contrast to the tidal fresh and oligohaline, suggests in itself that planktivory is strong there and derives from numerous competing predators rather than one large group of similar predators (i.e. finfish planktivores). Many of the mesohaline predator species are thought to be capable of individually affecting zooplankton populations when they are abundant. For example, *Mnemiopsis leidyi*, the sea walnut, can consume 470 copepods per hour (Bishop 1967) and population maxima in mid-summer have been negatively associated with east coast estuarine copepod abundances (Mountford 1980). The impact of this invertebrate planktivore is reduced when *Chrysaora quinquecirrha*, a jellyfish predator of the sea walnut and zooplankton, reaches its annual maximum (Reigenbaum and Kelly 1984). Similarly, *Chrysaora* predation on ctenophores indirectly influences the predation potential of ctenophores on fish larvae in Chesapeake Bay by reducing ctenophore numbers (Cowan and Houde 1992). Regressions which account for the predation pressures of both invertebrate and finfish planktivores may show a clear relationship to mesozooplankton abundance in mesohaline reaches.

Analyses of historical monitoring data (1976 - 1980) from mesohaline waters of the Chesapeake Bay mainstem near Calvert Cliffs indicates the multiple regression method has promise. Olson (1987) used weekly and monthly data in step-wise regressions of mesozooplankton with water quality, food and predator abundance parameters monitored from 1976 to 1980. For the monthly data from May to September, biological variables that were significantly associated with *Acartia tonsa* abundance in single-year models included chlorophyll (1978), *Neomysis*, an invertebrate predator of zooplankton (1978, 1979), and bay anchovy biomass (1976). The one year that chlorophyll was significantly, and negatively, correlated with mesozooplankton coincided with many red-tide blooms which are unpalatable to zooplankton. The relationships with *Neomysis* were negative (inverse), whereas the relationship with bay anchovy was positive, suggesting top-down control of zooplankton by the mysid shrimp and bottom-up control of the bay anchovy by the zooplankton. When all the years were combined, Atlantic menhaden biomass was the second most significant variable after temperature. Again, the regression slope was positive. Olson used data from May through September which perhaps allowed temperature to dominate the combined-year model and many of the single-year models as the most significant variable. Reanalysis of the Calvert Cliffs data for the narrower time period of July through September - when temperatures do not span a wide range, finfish planktivory is typically at its annual maximum, and community composition is relatively stable - would be very helpful in documenting summer linkages between mesozooplankton and their predators, both invertebrate and finfish, in the Chesapeake Bay mainstem for the late 1970's, and whether these linkages have changed in the last 15 years of increasing eutrophication.

Food web management strategies

The inverse mesozooplankton - planktivore relationship described for the tidal fresh reaches indicate a "trophic cascade effect" in action. This concept was derived from recurring patterns of trophic interactions observed in freshwater lakes over many decades and recently synthesized into an overarching concept called the "trophic cascade effect." The concept states that substantial changes in the top predator population will have significant repercussions on all of the lower trophic levels in an otherwise balanced system[2] (Carpenter et al. 1987, Hartig et al. 1991). Studies have documented fundamental changes in planktivore, zooplankton and phytoplankton populations when piscivores have been reduced or overstocked (e.g. Lazzaro et al. 1992, Olrik et al. 1984, Gophen et al. 1990, Elser and Carpenter 1988, Mills and Green 1987, Hartig et al. 1991). An underlying assumption of the concept is that predators and prey at all trophic levels exert controls on each other in a balanced system but when drastic changes are made to the top of the food chain (top piscivore), controls at lower trophic levels either become excessive or very weak. When abundance of the top piscivore is brought back to pre-manipulation densities, the lower trophic levels come into balance again. In classic lake examples, overstocking the piscivores quickly results in very clear waters whereas overfishing the piscivore stocks results in a lake turbid with algal blooms. Food web management strategies for freshwater lakes that incorporate principles of the trophic cascade effect can probably be applied directly to tidal freshwater regions in the Bay area because their planktivore - mesozooplankton relationships appears to be identical to those found in lakes, i.e. an inverse relationship. Development and maintenance of a sizeable piscivore population (e.g. Largemouth bass) in tidal fresh reaches that are otherwise balanced (stable, relatively moderate nutrient loadings; acceptable dissolved oxygen levels; no toxicity) can be expected to bring planktivore abundances down, and thereby raise mesozooplankton - and ichthyoplankton - abundances, increase grazing pressure on the phytoplankton, and increase the transfer of organic material to higher trophic levels.

The *positive* regression slopes between planktivores and mesozooplankton in the oligohaline, and the apparently complex relationship between the mesozooplankton and a diverse array of vertebrate and invertebrate predators in the mesohaline, suggests that food web management strategies developed for freshwater lakes may not be directly transferable to oligohaline and mesohaline waters. Trophic relationships in these complex and much more dynamic salinity regimes need to be further explored and documented before legitimate food web management strategies can be proposed. These salinity regimes would probably benefit from increased mesozooplankton abundances in the tidal fresh, however. Larger zooplankton populations in the tidal fresh would generate a better food base in higher salinity regimes for larval and Y-O-Y fish, which use these areas as nursery grounds, as well as for planktivores.

Other avenues of investigation remain to be explored. First, only the juvenile summer seine surveys were used in this study. There are a number of trawl surveys, done throughout the bay

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[2] ecosystems that exhibit a dynamic equilibrium over the long-term, whose populations fluctuate seasonally or over longer cycles but maintain constant baseline abundances and whose production of organic material is in rough proportion to consumption (from *Chesapeake Bay Stategy for the Restoration and Protection of Ecologically Valuable Species*, 1993, Chesapeake Bay Program).

during different seasons, whose data would allow a better understanding of zooplankton linkages with more open water fish communities. Second, plankton - fish linkages during the summer are evident in ways other than straightforward regressions between planktivores and their prey, the mesozooplankton. For example, finfish planktivory elicits specific changes in zooplankton size frequency distributions, abundance of invertebrate planktivores, and prey vulnerability responses. Finfish and invertebrate planktivores have very different relationships with their prey in estuarine waters, and each can possibly obscure effects of the other in simple regressions such as was done for this paper. Further investigations will hopefully substantiate the plankton - fish linkages at some stations and identify environmental variables that are disrupting the linkages at other stations.

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Table 1. Station matches for zooplankton and juvenile finfish seine surveys in Maryland and Virginia. ( ) indicates previous station designation.

System	*State juvenile finfish seine station*	*CBP zooplankton monitoring station*
James	J56	TF5.5 (1J)
	J36, J29	RET5.2 (2J)
York	P51, P45 P42, P41	TF4.2 (1Y)
Rappahannock	R55, R50, R44	TF3.3 (1R)
	R37, R28	RET3.1 (2R)
Potomac	49, 50	TF2.3 (XEA6596)
	51, 62, 52	RET2.2(XDA1177)
	55, 64, 56	MLE2.2
Patuxent	85, 86	TF1.5 (PXT0402)
	92	TF1.7 (XED4892)
	106, 90	LE1.1 (XDE5339)
Upper Bay	68, 59, 3	CB1.1 (MCB1.1)
	10, 11, 88	CB2.2 (MCB2.2)
Choptank	002, 66	ET5.1 (MET5.1)
	67, 28, 29	ET5.2 (MET5.2)

Table 2. Obligate planktivore finfish species in Chesapeake Bay.

Alewife
American shad
Atlantic menhaden
Atlantic silverside
Atlantic thread herring
Banded killifish
Bay anchovy
Blueback herring
Bridle shiner
Comely shiner
Gizzard shad
Golden shiner
Spottail shiner
Striped anchovy
Pipefish

Table 3. Summary of regressions between summer (July - September) averages of finfish planktivore abundance and mesozooplankton abundance in Chespeake Bay tributaries and the upper bay. All the regression were linear with the exception of the Potomac (all data) which was a regression of the log of planktivore abundance and the log of mesozooplankton abundance. See Figure 1 for station locations. TF = tidal fresh (0 - 0.5 ppt), O = oligohaline (0.5 - 5 ppt), LM = low mesohaline (5 - 10 ppt), M = mesohaline (10 - 18 ppt). Mesozooplankton abundance is given as average number per cubic meter, planktivore abundance as average number per round. Within each salinity regime, tributaries are ranked from largest to smallest.

Station	Salinity	Years	n	Planktivore mean (SD)	Mesozoop. mean (SD)	r^2	p	slope	Yrs. excluded (reason)
Tidal Fresh									
Ches. Bay CB1.1	TF	84-90	7	193 (96)	1282 (694)	.47	.08	-4.962	91 (oligohaline in Susquehanna Flats)
Potomac TF2.3	TF	73,81,84, 86-91	9	179 (87)	38971 (33010)	.48	.03	logM=7.796-1.532logP	85 (year of submerged aquatic veg. return)
James TF5.5	TF	84-91	8	103 (67)	14873 (10883)	.34	ns		
York TF4.2	TF	87-91	5	45 (195)	12140 (16130)	.14	ns		
Potomac TF2.3	TF	86-90	5	162 (49)	48454 (41287)	.68	.06	-693.95	see explanation in text
Oligohaline									
Ches. Bay CB2.2	O/LM	85-89,91	6	585 (368)	21818 (17764)	.65	.04	+0.016	84,90 (freshwater)
Potomac RET2.2	O/LM	84-88,90-91	7	614 (305)	24058 (8927)	.47	.08	-0.023	89 (freshwater)
James RET5.2	O/LM	86-91	6	104 (81)	13651 (8195)	.07	ns		
Patuxent TF1.5	TF/O	84-91	8	133 (57)	27423 (20077)	.24	ns		
Patuxent TF1.7	O/LM	84-91	8	1198 (857)	17132 (10973)	.45	.06	+0.052	
Choptank ET5.1	TF/O	84-91	8	673 (421)	44440 (23620)	.55	.03	+0.013	
Mesohaline									
Potomac LE2.2	M	84-91	8	573 (305)	24033 (8266)	.11	ns		
Rappa. RET3.1	M	86-91	6	404 (145)	10575 (7421)	.10	ns		
Patuxent LE1.1	M	84-91	8	482 (177)	24404 (12147)	.08	ns		
Choptank ET5.2	LM/M	84-91	8	1451 (841)	30207 (15692)	.06	ns		

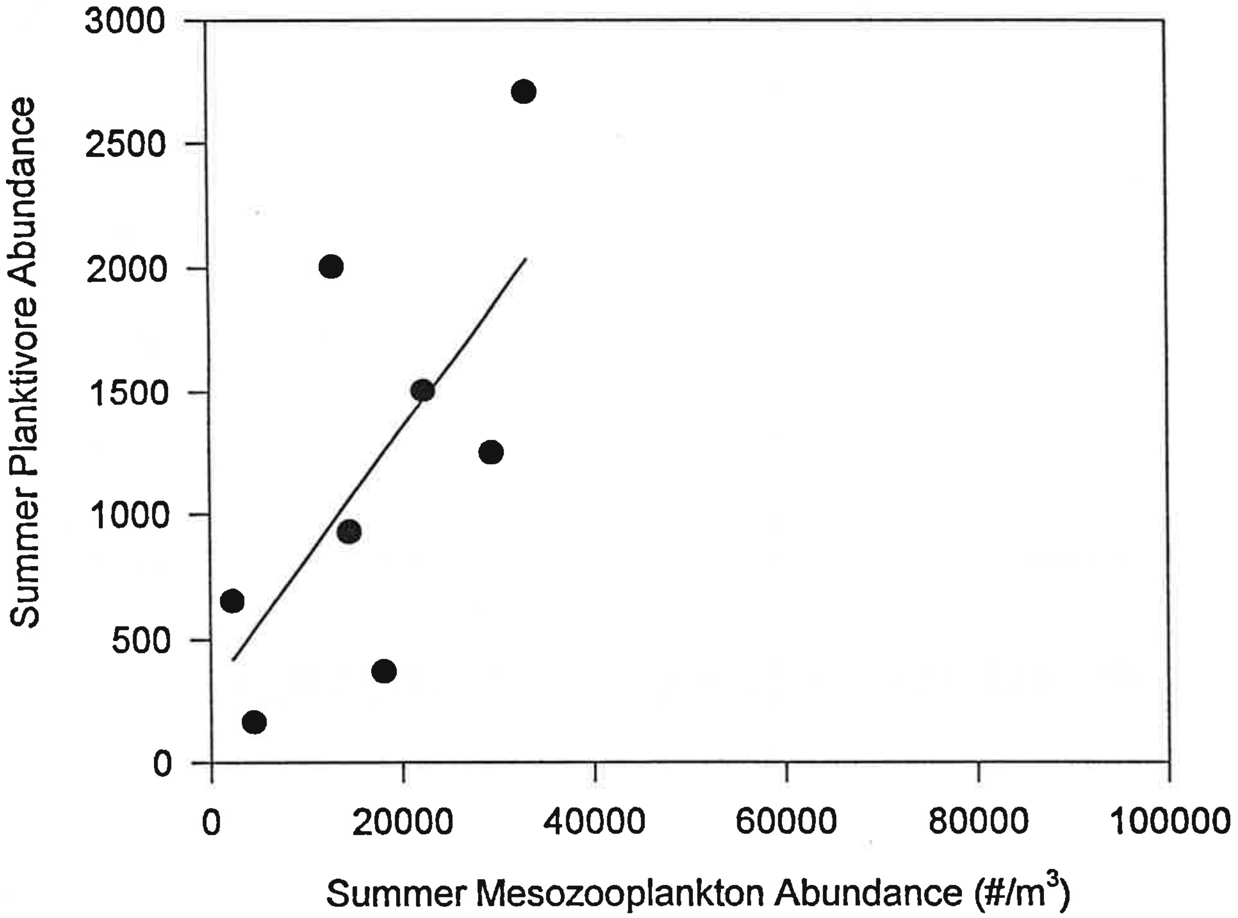
List of Figures

Figure 1. Chesapeake Bay Program zooplankton monitoring stations.

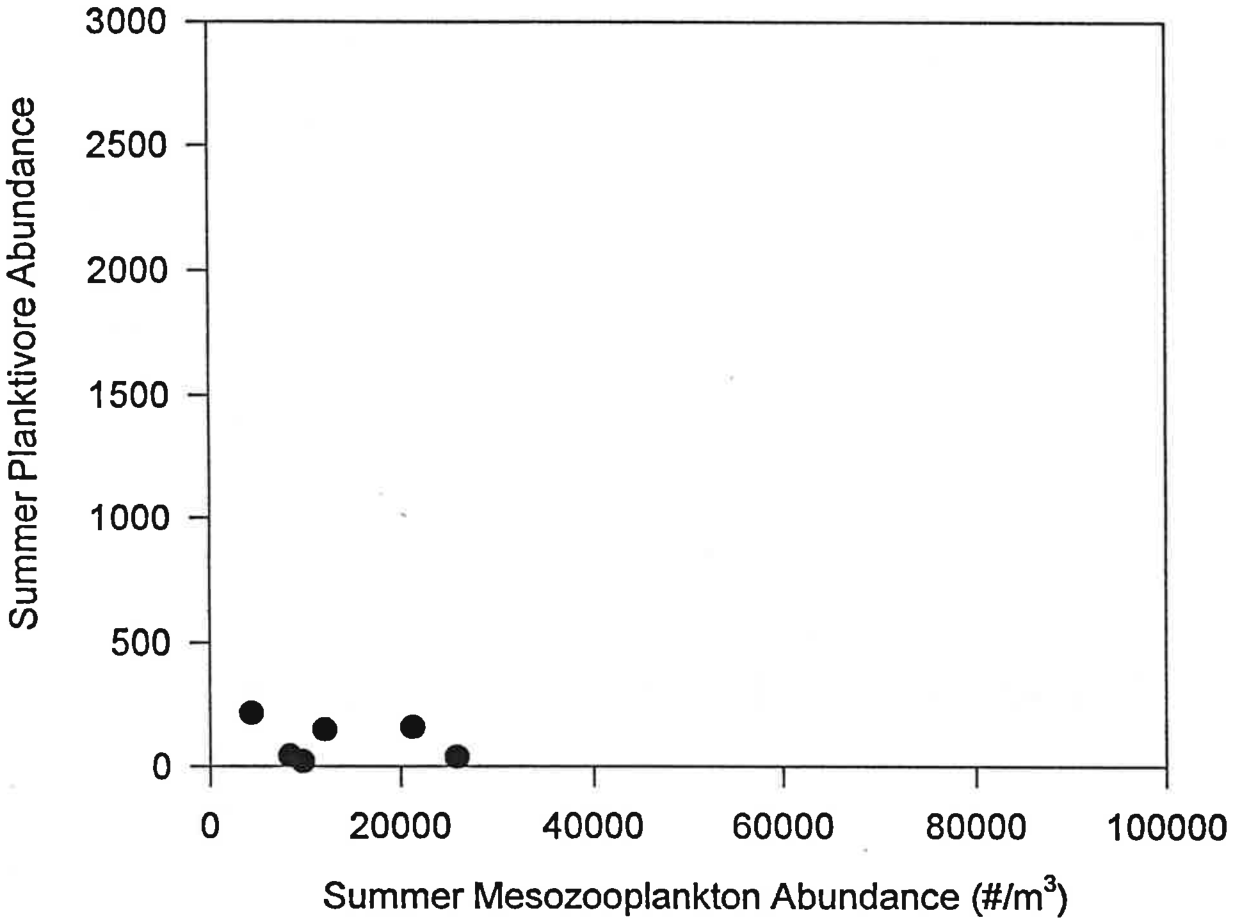
Figure 2. Average summer (July - September) mesozooplankton abundance (# m^{-3}) at tidal fresh zooplankton monitoring stations versus average planktivore abundance (# per round) at adjacent juvenile seine survey sites; a) CB1.1 (upper bay), b) TF2.3 (Potomac River), c) TF5.5 (James River), d) TF4.2 (York River). Solid lines are significant regressions ($p \leq 0.08$). In (a), the 1991 datum is excluded because seine sites near this freshwater station were oligohaline at times. In (b), the 1985 datum is excluded because of significant changes in the SAV population that year; dotted circles are 1986 - 1990. See Table 3 and text for discussion.

Figure 3. Average summer (July - September) mesozooplankton abundance (# m^{-3}) at oligohaline zooplankton monitoring stations versus average planktivore abundance (# per round) at adjacent juvenile seine survey sites; a) CB2.2 (upper bay), b) RET2.2 (Potomac River), c) RET5.2 (James River), d) TF1.5 (Patuxent River), e) TF1.7 (Patuxent River), f) ET5.1 (Choptank River). Solid lines are significant regressions ($p \leq 0.06$). Dashed line in (b) is a questionable regression ($p = 0.08$). Data for 1984 and 1990 in (a) and 1989 in (b) are excluded because salinities were below 0.5 ppt. See Table 3 and text for details. The positive regression slopes indicate mesozooplankton, the prey, are the independent variable, hence their abundances are put on the X axis. Correlation coefficients are the same regardless of which variable is placed on the X axis.

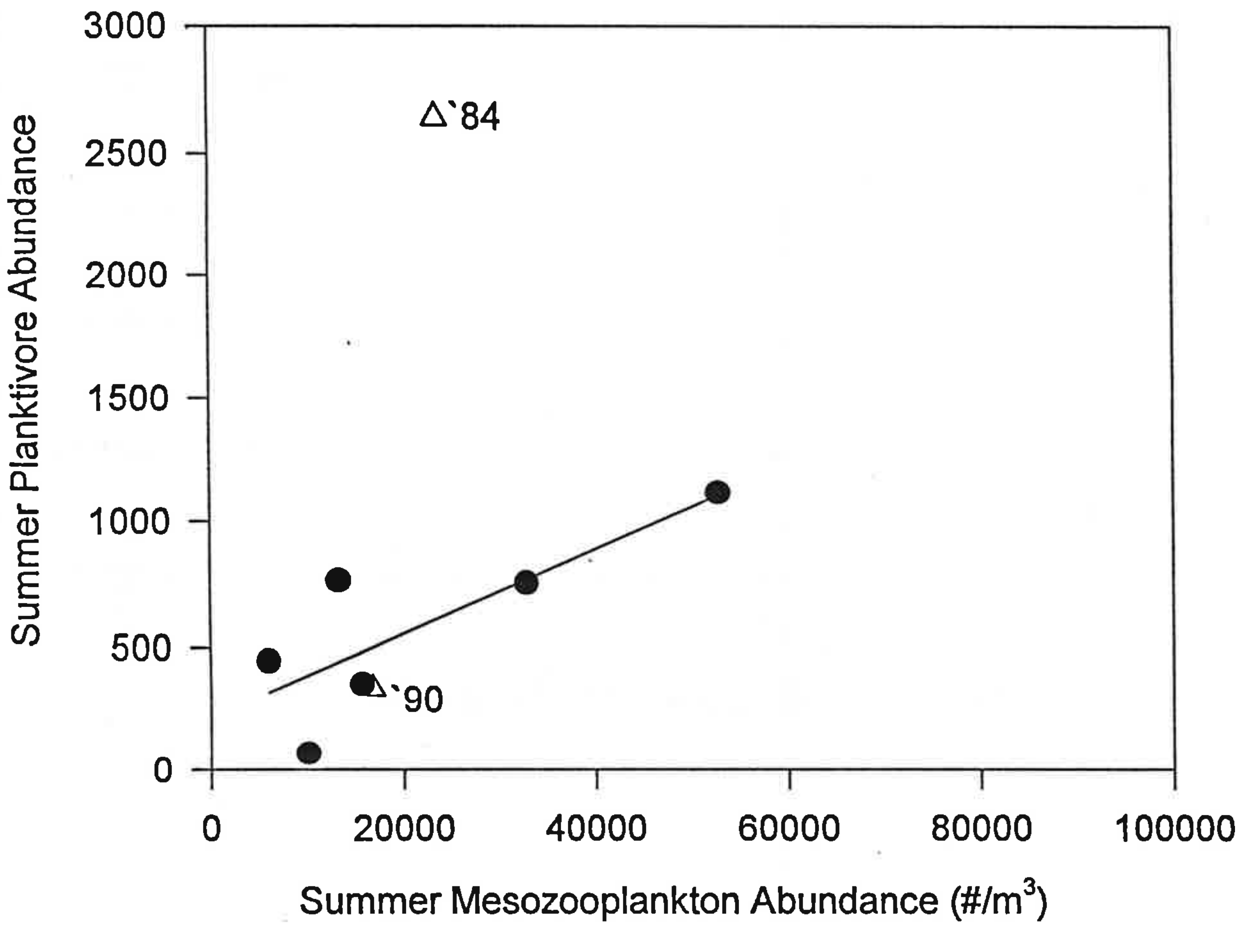
PATUXENT OLIGO/LOW MESOHALINE (TF 1.7)



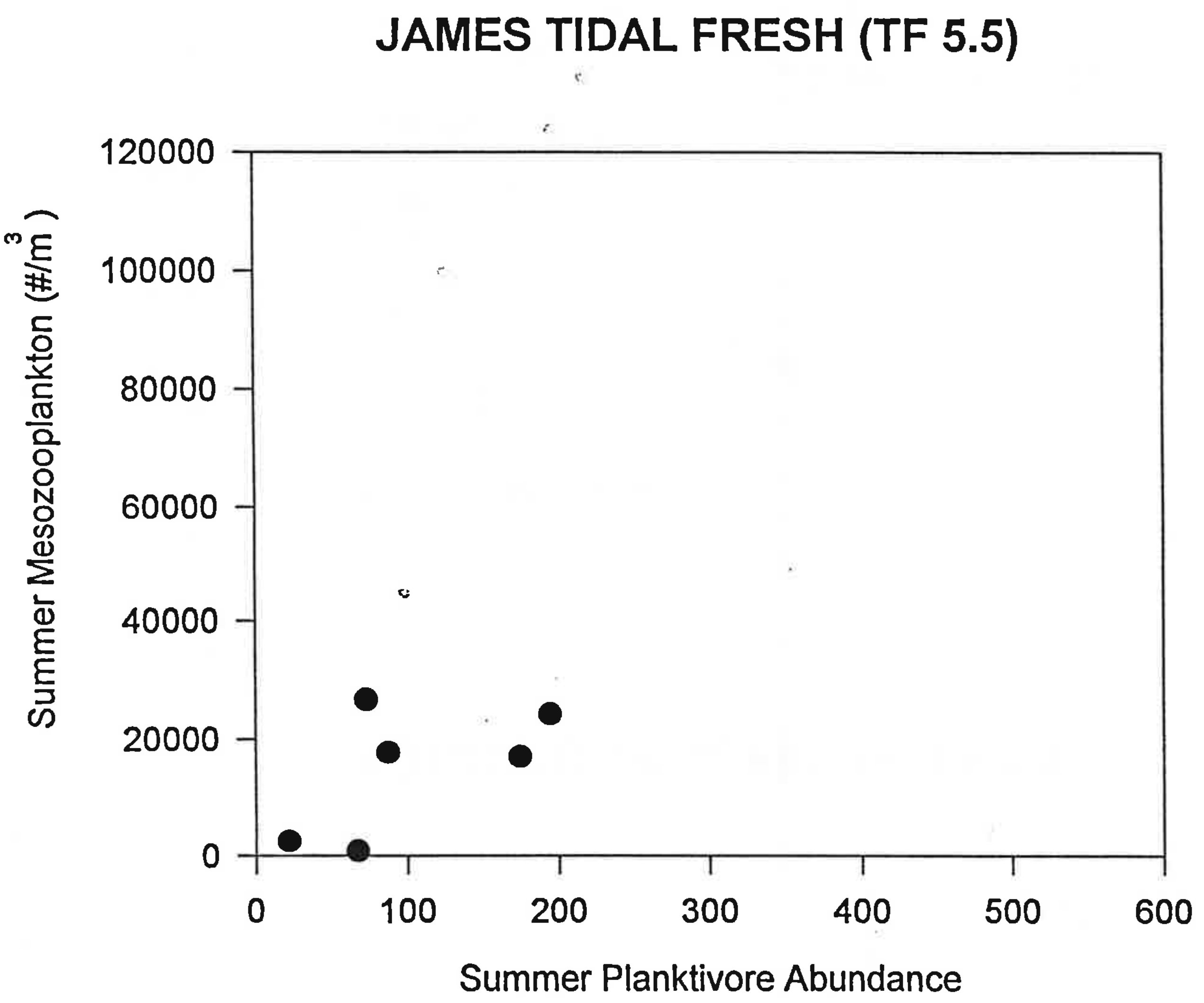
JAMES OLIGO/LOW MESOHALINE (RET 5.2)



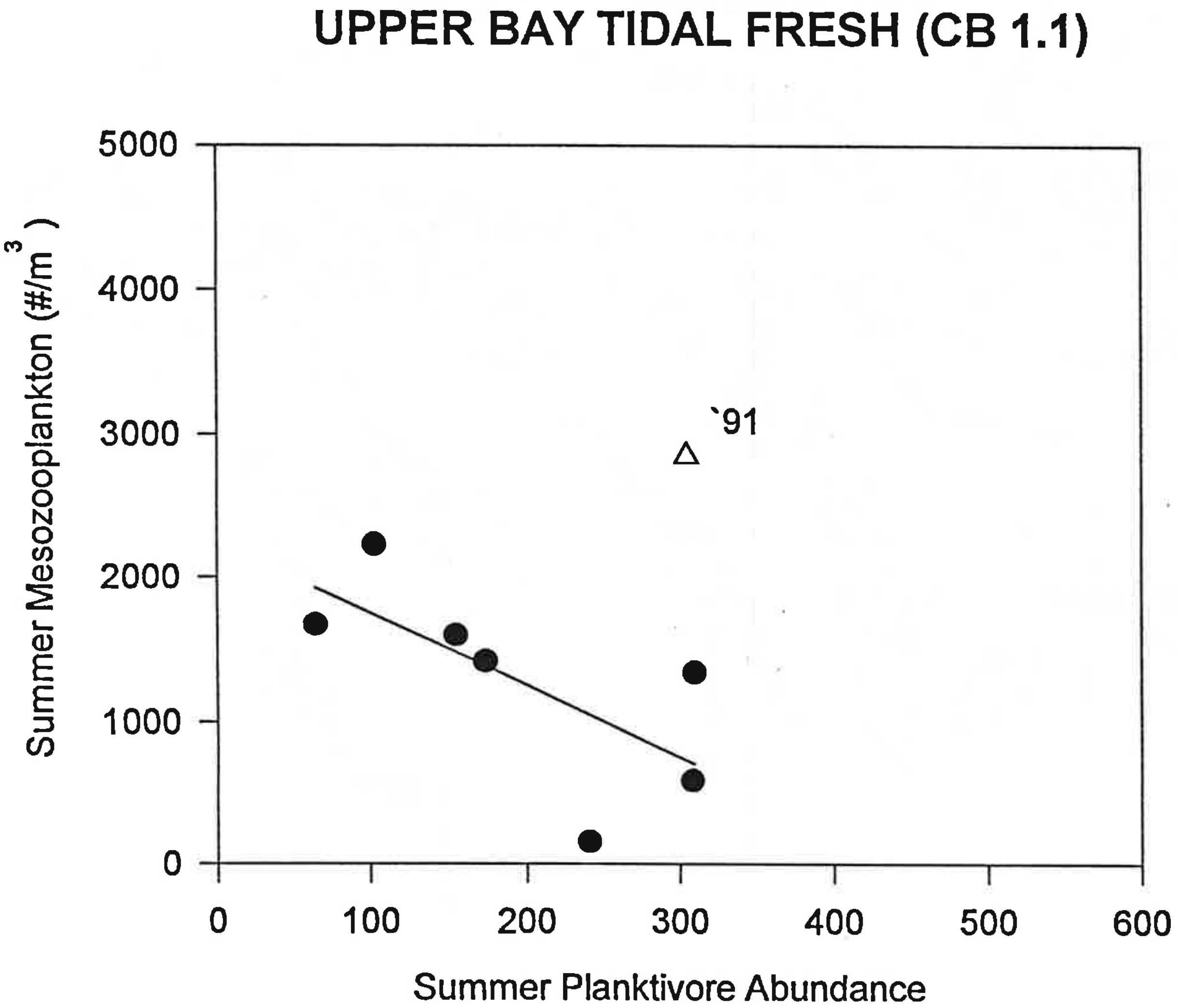
UPPER BAY OLIGO/LOW MESOHALINE (CB 2.2)



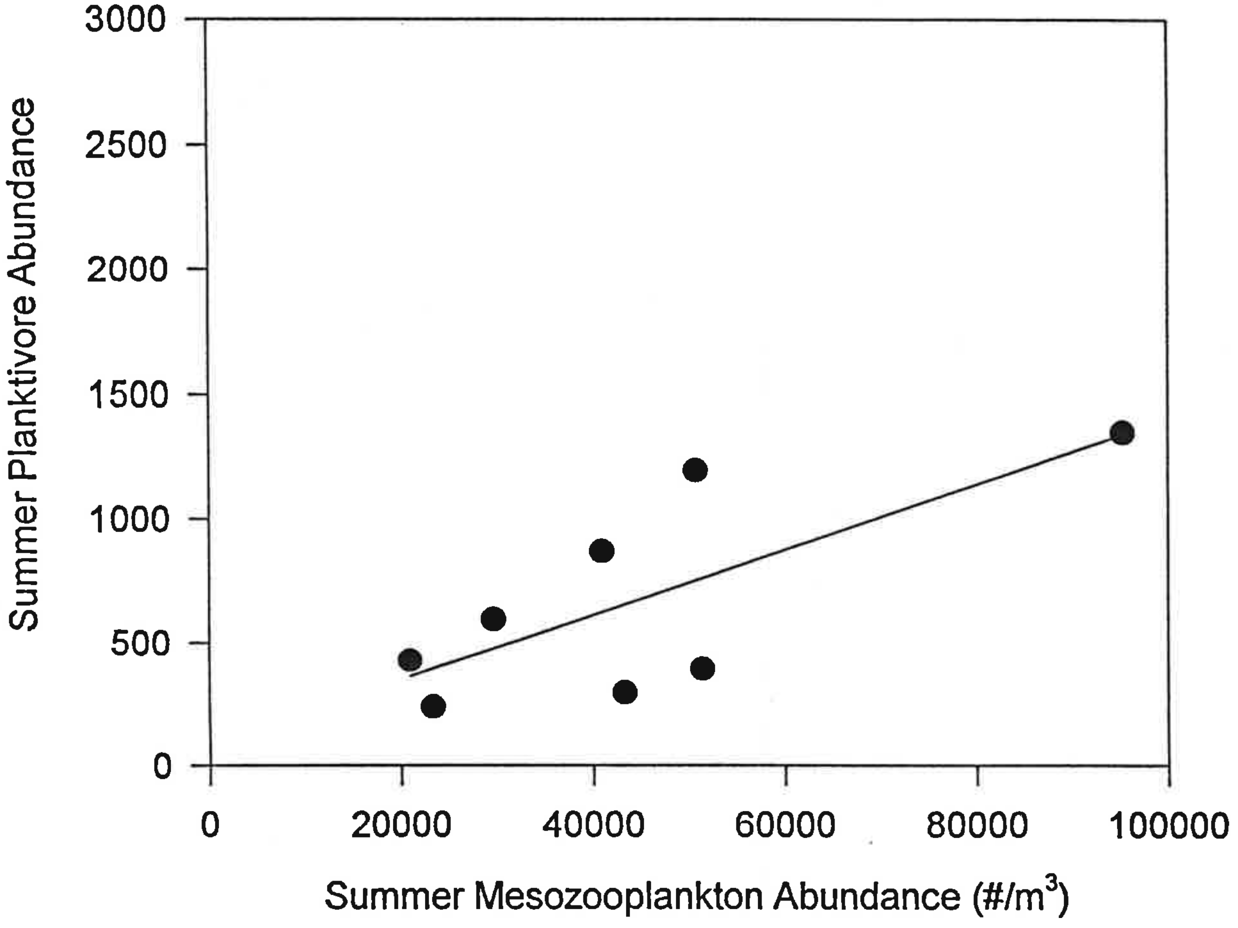
C


JAMES TIDAL FRESH (TF 5.5)
Summer Mesozooplankton (#/m^3)
120000
100000
80000
60000
40000
20000
0
0
100
200
300
400
500
600
Summer Planktivore Abundance

A


UPPER BAY TIDAL FRESH (CB 1.1)
Summer Mesozooplankton (#/m^3)
5000
4000
3000
2000
1000
0
`91
0
100
200
300
400
500
600
Summer Planktivore Abundance

CHOPTANK FRESH/OLIGOHALINE (MET 5.1)



A Summary of Recent Attempts to Draft "Ideal" Sampling Regimes for Chesapeake Bay Program Plankton Monitoring Components, to Improve Coverage and Information Yield

January 1994

Abstract

This summary attempts to combine the insights and opinions of the principal investigators, data analysts and managers of the nine-year-old Chesapeake Bay Program Zooplankton and Phytoplankton Monitoring Programs, and to articulate their recommendations for improving the coverage and information yield of the programs. Drafting an "ideal" sampling regime for phytoplankton is not possible at this time. Specific steps are recommended to so. An "ideal" sampling schedule is tentatively proposed for the zooplankton programs. It should cost-effectively collect the data required for evolving CBP information needs, although it may take several years to implement the changes and some of the recommendations may be modified in the interim.

Recent deliberations of an adhoc Refinement Workgroup of the Monitoring Subcommittee were the impetus for this effort to re-evaluate the existing sampling regimes. The workgroup is considering modifications to the CBP water quality programs to improve their information yield. The existing plankton programs are "piggybacked" onto the CBP water quality monitoring programs. The workgroup should consider the impact of their decisions on the "ideal" sampling regimes rather than on the existing ones.

Background

The Adhoc Refinement Workgroup of the Chesapeake Bay Program Monitoring Subcommittee is presently assessing whether existing water quality monitoring programs can continue to meet the evolving information needs of the CBP. Specifically, do the existing water quality monitoring programs give managers the ability to measure progress towards meeting CBP goals or determine when the goals have been met? Raymond Alden, a workgroup member, has applied statistical tests to 6 years of water quality data (1985 - 1990)

> "to determine the magnitude of trends that can be detected and are being compared to projected changes in water quality. The results of this analysis will be the basis for recommendations to the existing monitoring program. Contributions that alternative monitoring programs such as remote sensing, citizen monitoring, buoy deployment and the EMAP program can make towards meeting these information needs will be explored as part of the assessment. The product of the [adhoc workgroup's evaluation] will be a recommended monitoring approach for mainstem and tributary water quality with estimated costs to meet the information needs of a specified set of management objectives."

The Adhoc Refinement Workgroup is considering the consequences of reducing the CBP water quality monitoring programs from 20 to 12 annual cruises. Trends found in a 12-cruise subset of the data are almost as powerful and robust as trends found in the 20-cruise regime for many water quality parameters (Alden et al. 1992, 1993 draft). Such a cutback, however, would adversely impact some plankton monitoring programs because they are "piggybacked" onto the water quality cruises. Phytoplankton samples are presently taken on each of the 20 Maryland monitoring cruises. Although zooplankton samples are collected on only 12 cruises in Maryland, Virginia and the District of Columbia, twice-monthly zooplankton sampling has been recommended (and implemented in Maryland) for spring in spawning reaches of anadromous finfish (Zooplankton Workshop Report, Zooplankton Bioindicator Development Project - FY1992-1993). Program results are also suggesting that more frequent sampling during the summer may be desirable. Cutting the water quality monitoring programs to 12 monthly cruises will not allow the existing, "piggybacked" plankton programs to implement recommendations to sample more frequently and improve their information yield.

The Adhoc Refinement Workgroup requested the help of the plankton monitoring programs in answering the following questions:

- What physical and chemical parameters need to be measured when the plankton samples are collected in order to analyze and interpret the data?
- What are the critical sampling times and locations for zooplankton and phytoplankton? Specifically, what data is needed to calculate the plankton indicators being developed?

This request offered an opportunity to synthesize the insights and opinions of the program principal investigators, data analysts and managers, garnered during the programs' first nine years. A strawman "ideal" CBP plankton monitoring schedule was drafted, circulated, and discussed in a conference call on November 1, 1993. Station relocations and alternative sampling methods were also considered because they could improve the information yield of the programs. Effort was focused on those times and locations which yield plankton information most useful to management. In some cases, recommendations were based on anticipated data needs since neither the zooplankton nor the phytoplankton indicator projects are completed.

This summary presents an "ideal" CBP zooplankton sampling regime, assuming specific information needs, and proposes steps to draft an "ideal" CBP phytoplankton sampling regime. The "ideal" zooplankton sampling regime is the configuration the programs should take - in the opinions of the principal investigators, data analysts and managers - to improve coverage and cost effectively produce the data needed for specific information needs. Although it may take several years to implement the changes, and some of the recommendations may be modified in the interim, this "ideal" sampling regime should serve as a model of future zooplankton programs in the Adhoc Refinement Workgroup's present deliberations. The steps proposed to develop an "ideal" phytoplankton sampling regime closely parallel the objectives of the 2-year phytoplankton bioindicator project. Until this "ideal" sampling regime is developed, however, the consensus of the phytoplankton monitoring programs PI's and managers is to leave the programs as they are.

Water quality parameters important to measure simultaneously with plankton collections

Simultaneous measurement of several water quality parameters were initially deemed critical to the CBP living resources monitoring goal of identifying important linkages between living resources and their habitat and water quality. The following parameters are proximal controls of one or both of the plankton communities. The power and robustness of trends in the checked (✓) parameters were tested by the Adhoc Refinement Workgroup for the full 20-cruise data set and a 12-cruise subset (Alden et al. 1993). The ability of a 12-cruise regime to satisfactorily characterize ambient levels of these parameters during critical seasons is also presently being investigated by the EPA Chesapeake Bay Program and Region III. Until the consequences of a cutback to 12 cruises on correlations between these parameters and specific plankton indicators can be carefully investigated, we recommend continued measurement of at least the following parameters whenever plankton samples are collected.

Temperature
Salinity
pH
✓ Total suspended solids
✓ Chl *a*
✓ Secchi depth, or 1% light level
✓ Dissolved oxygen (above and below picnocline)
✓ TN, TP, DIN, DIP (at least during critical period - early spring to fall)
Dissolved available silica

"Ideal" zooplankton sampling regime

The original goals of the plankton monitoring programs were to characterize the plankton, document trends, and identify linkages between the plankton and water quality, habitat and other living resources. The previous 7-9 years of data on community composition have provided the coarse characterization of annual zooplankton cycles sought by CBP. Trend analyses of plankton data are planned for 1994 as part of the zooplankton indicator project. Linkages continue to be an important focal point of the programs. In particular:

- Zooplankton community responses to nutrient reductions;
- Impacts of toxic pollutants and anoxia/hypoxia on the zooplankton communities;
- Food available to larval and adult planktivorous finfish.

Information gains from slight program modifications could include:

- Zooplankton indicators of finfish community structure;
- Better quantification of critical zooplankton blooms and hence a better understanding of linkages to water quality, habitat and other living resources.

Recommended changes to zooplankton sampling locations:

The program principal investigators, data analysts and managers all recognized the value in keeping a station after data have been collected for eight years. However, data analyses indicate several existing stations are located near the interface of adjacent salinity zones and do not consistently represent the biota or biological responses expected for one salinity zone. So, although these "frontal" areas can be important habitat for estuarine fish, some of the key indicators we have developed for assessing stress are difficult to apply there. In some cases, the data can be presorted before they are analyzed. For instance, Patuxent data at TF1.5 (PXT0402) can be presorted into fresh (<0.5 ppt) and oligohaline (0.5 - 5 ppt) data, and the subsets analyzed separately. The usefulness of a station's data is enhanced by this procedure, and indicators such as Calanoids/(Cyclopoids + Cladocera) can be successfully applied. Stations that continue to be marginally useful in assessing the impact of control strategies, however, may not be worth keeping. Obvious gaps in station coverage also are apparent after 7-9 years of sampling. Many of the smaller tributaries do not have genuinely TF (tidal fresh) or LE (lower estuary) stations. Both these zones are expected to respond to nutrient reductions.

Station	**Reason**
Add:	
LE3.2 (Rappahannock) LE5.2 or LE5.4 (James) LE4.1 or LE4.3 (York)	No Virginia tributary presently has a lower estuary (LE) station that characterizes the tributary plankton. Rather, stations are located off the tributary mouths and are used to characterize mainstem plankton. We recommend initiating zooplankton sampling at LE 3.2 (Rappahannock), LE 4.1 or LE4.2 (York), and

LE5.2 or LE5.4 (James). These new plankton stations will give the program better coverage of the tributaries, and in particular a better understanding of summer hypoxia/anoxia's impact on plankton in the Rappahannock and York. The results can also be compared with those of the benthic monitoring already being done at these stations, as well as the long-term phytoplankton dataset collected by Dr. Haas off the US Coast Guard pier in Yorktown, Virginia.

Add spring/summer station in segment TF5 (James)

The James has historically been a significant spawning and nursery area for anadromous and resident fish species. Mesozooplankton densities measured at the sole TF plankton sampling station (TF5.5) are puzzlingly low in the spring. Flow characteristics at this station are being investigated (Zooplankton Indicator Project) as a possible cause. Low densities may also be related to the station's location. TF5.5 is typically well above the shifting tidal fresh/oligohaline boundary in the spring, and usually in the upper end of the striped bass spawning/nursery area. We recommend initiating a tidal fresh station below TF5.5, at TF5.6, to give us additional information about zooplankton abundance during the spring and summer spawning and nursery periods of larval fish. We can expect mesozooplankton abundances to be higher closer to the tidal fresh/oligohaline boundary if zooplankton densities along a longitudinal transect in the James mimic those in other large tidal fresh reaches of the bay.

Add spring/summer station at CB2.1 (upper mainstem)

The CB1.1 station located at the mouth of the Susquehanna River is affected by rapid flows (very short residence time) which dilute the local bay plankton. Consequently, the station produces unrealistic, low estimates of plankton abundance for this general area. Plankton sampling has began on a temporary basis at station CB2.1 opposite the Susquehanna's mouth. After another year or so of sampling, consistent differences between the two stations can be determined. We recommend keeping both CB1.1 and CB2.1, at least during the spring (spawning period of anadromous finfish, spring phytoplankton bloom period) and the summer (spawning period of critical resident finfish, period of maximum primary productivity). Sampling locations in this general area are critical because it is one of the two largest freshwater areas in the bay.

Add spring/summer station at XEA1840 (Potomac)

The Potomac and the upper Bay have the largest tidal fresh reaches in the bay. Plankton are monitored in the tidal fresh Potomac by the District of Columbia Environmental Control Division at two stations near the fall-line and by the Fairfax Co. Gunston Cove

Ecosystem Project at three stations (two deep, one shallow) adjacent to the cove. However, only two zooplankton stations (XEA6596 [TF2.3] and XDA1177 [RET2.2]) are presently monitored below Indian Head in the approximately 800 million m^3 of critical nursery areas for anadromous fish, especially larval striped bass in the spring and young-of-the-year herring in the summer. Historically, the spring mesozooplankton and larval striped bass maxima have been found between these two stations. Adding a third zooplankton monitoring station during spring and summer between the two stations, at WQ monitoring station XEA1840, would substantially improve our ability to estimate plankton abundance during critical nursery times and use zooplankton as indicators of the quality of larval fish habitat in the Potomac.

Add spring/summer station in segment TF2 (Patuxent)

PXT0402 straddles the tidal fresh/oligohaline boundary much of the time. Anticipated reductions in total suspended solids may allow cyanobacteria blooms to appear upstream of this station in this relatively nutrient-rich system. Initiating a spring/summer plankton sampling station above PXT0402, either at PXT0456 or at a "floating" station, could give us information on both cyanobacteria blooms and zooplankton densities in the upper portion of the spawning/nursery reach. We expect PXT0456 to have greater numbers of cyanobacteria, rotifers and cladocerans while the nutrient data might be very similar.

Drop XED4892 (TF1.7), add XED9490 (Patuxent)

XED4892 seems to straddle the oligohaline/mesohaline boundary and does not provide much useful data. Moving it upstream would give the Patuxent a truely oligohaline station which it presently does not have, and will give us more information about the Patuxent River than XED4892 presently does.

Consider adding 2 spring/summer stations in segment TF5 (Choptank)

Of the eight Chesapeake Bay finfish spawning/nursery areas presently being monitored for mesozooplankton, only the Choptank consistently meets "minimum" food level requirements (15 - 25 mesozooplankton $liter^{-1}$) for larval striped bass. Only one plankton station is currently monitored in the Choptank spawning/nursery reach. It straddles the freshwater/oligohaline boundary and is usually in the middle of the spawning/nursery area for striped bass, herring and other anadromous species. According to Mr. Jim Uphoff (MDNR), anadromous fish larvae are abundant upstream of MET5.1 in dry Springs and downstream of MET5.1 in wet Springs. In light of the importance of the Choptank to striped bass recruitment in the bay, the possibility of initiating zooplankton monitoring stations above and below MET5.1, to give us additional information during spring and summer, should be considered more closely. Currently, there are no MDE Chesapeake Bay Program monitoring sites above or below MET5.1. Mr. Uphoff indicated a station between 47.2 and 56.8 km and another near 79.0 km as the lower and upper ends of the anadromous fish spawning/nursery area.

The proposed station upstream of MET5.1 would be useful to the phytoplankton program as well, for the reason discussed above for PXT0402. MET5.1 is not a solidly freshwater station and the certainty of documenting cyanobacteria blooms, a useful indicator, at this station is low.

Possible changes to zooplankton sample collection and analyses methods

1. Both the Virginia and Maryland mesozooplankton monitoring programs currently collect two samples at each sampling location. Virginia's are collected with simultaneously towed nets whereas Maryland's are collected with sequential tows. In both programs, the samples are preserved and counted separately, and the final results averaged to generated estimates of the station zooplankton species abundances. The duplicates have been useful in documenting sampling variability and, in Maryland, zooplankton short-term variability at each station. However, this kind of information may not need to be documented endlessly. **Sampling protocol could be changed so that the replicates for each station are combined into one sample in the field.** This would yield a substantial cost savings, and the monies could be used to enhance spatial or temporal coverage where needed.

   The pros and cons of this suggestion need to be discussed in detail by the zooplankton PIs and biostatisticians before this can be put forward as a recommended change to the sampling programs. Eliminating replicates will weaken the Maryland program's ability to use ANOVA to document year-to-year differences in the mean annual density of *Acartia tonsa* and *Eurytemora affinis*. Some estimate of the variability could be kept by either 1) collecting replicates at 1 or 2 stations on each cruise, or 2) split sampling the replicates before they are combined, measuring biomass in one of the duplicates of each sample, and estimating variance from the two biomass measurements.

2. Summer hypoxia/anoxia and temperature stratification in the mesohaline strongly influence mesozooplankton vertical distribution (see attachment 1). The zooplankton monitoring programs collect depth-integrated samples for these areas and estimate zooplankton densities for the entire water column. **Collecting mesozooplankton samples above and below the oxycline or thermocline during summer, and calculating separate density estimates for those water bodies, may prove more useful in documenting linkages between the mesozooplankton and their major predators.** Again, the pros and cons of this suggestion need to be discussed by program managers

and PIs before it can be put forward as a recommendation.

Possible changes to the frequency of zooplankton sampling

Results of the Zooplankton Monitoring Workshop (Buchanan 1992) and the first year of the zooplankton bioindicator project strongly indicate the need for more frequent sampling during Spring at stations located in anadromous fish spawning reaches. Likewise, more frequent sampling at all stations appears to be needed during Summer, when primary productivity, zooplankton growth and grazing rates, and predation are at their annual highs. Twice monthly sampling in Spring and Summer would satisfy these needs.

Table 1. incorporates the recommended changes in station location and sampling frequency into the existing programs, and presents a first draft of an "ideal" zooplankton sampling schedule. When, and if, changes are made to the sample collection and analyses methods, an "ideal" sampling regime can be proposed.

Table 1. "Ideal" zooplankton sampling schedule (DRAFT)

Station			J	F		M		A		M		J		J		A		S		O	N	D
				1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd			
James	TF5.5	fresh	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	TF5.6	**new**						●	●	●	●	●		●	●	●	●	●				
	RET5.2	oligo	●	●		●		●		●		●		●	●	●	●	●		●		●
	LE5.4 or LE5.2	**new**	●	●		●		●		●		●		●	●	●	●	●		●		●
Elizabeth	SBE2	polyh	●	●		●		●		●		●		●	●	●	●	●		●		●
	SBE5	polyh	●	●		●		●		●		●		●	●	●	●	●		●		●
York	TF4.2	fresh	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	RET4.3	mesoh	●	●		●		●		●		●		●	●	●	●	●		●		●
	LE4.1 or LE4.3	**new**	●	●		●		●		●		●		●	●	●	●	●		●		●
Rappahannock	TF3.3	oligo	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	RET3.1	mesoh	●	●		●		●		●		●		●	●	●	●	●		●		●
	LE 3.2	**new**	●	●		●		●		●		●		●	●	●	●	●		●		●
Potomac	PMS10 (DC)	fresh	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	PMS37 (DC)	fresh	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	TF2.3 (XEA6596)	fresh	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	(XEA1840)	**new**						●	●	●	●	●		●	●	●	●	●				
	RET2.2 (XDA1177)	oligo	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	LE2.2	mesoh	●	●		●		●		●		●		●	●	●	●	●		●		●
Patuxent	(PXT0456)	**new**	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●

Zooplankton (cont.)

Station			J	F		M		A		M		J		J		A		S		O	N	D
				1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd			
Patuxent (cont.)	PXT0402	f/oligo	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	(XED9490)	**new**	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	LE1.1	mesoh	●	●		●		●		●		●		●	●	●	●	●		●		●
Patapsco	WT5.1	mesoh	●	●		●		●		●		●		●	●	●	●	●		●		●
Choptank	ET5.1	f/oligo	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	ET5.2	mesoh	●	●		●		●		●		●		●	●	●	●	●		●		●
Ches. mainstem	CB1.1	fresh	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	CB2.1	fresh						●	●	●	●	●		●	●	●	●	●				
	CB2.2	oligo	●	●		●		●	●	●	●	●		●	●	●	●	●		●		●
	CB3.3C	mesoh	●	●		●		●		●		●		●	●	●	●	●		●		●
	CB4.3C	mesoh	●	●		●		●		●		●		●	●	●	●	●		●		●
	CB5.2	m/p	●	●		●		●		●		●		●	●	●	●	●		●		●
	CB6.1	p/m	●	●		●		●		●		●		●	●	●	●	●		●		●
	CB6.4	polyh	●	●		●		●		●		●		●	●	●	●	●		●		●
	CB7.3E	polyh	●	●		●		●				●		●	●	●	●	●		●		●
	CB7.4	polyh	●	●		●		●		●		●		●	●	●	●	●		●		●
	LE3.6	p/m	●	●		●		●		●		●		●	●	●	●	●		●		●
	WE4.2	polyh	●	●		●		●		●		●		●	●	●	●	●		●		●
	LE5.5	polyh	●	●		●		●		●		●		●	●	●	●	●		●		●

"Ideal" sampling regime for phytoplankton

STILL IN PROGRESS
BUT
TENTATIVELY AS FOLLOWS:

Development of an "ideal" sampling regime for phytoplankton would be premature at this time. The following steps have been proposed as a means for producing such a regime:

Step 1. Clearly identify management expectations. What does the management community need from the phytoplankton monitoring programs to meet the stated CBP objectives of 1) characterize the phytoplankton, 2) document long-term trends, and 3) identify linkages to water quality, habitat and living resources.

- ☞ Frame these management needs as questions to be answered from the existing ten years of phytoplankton monitoring data.

Step 2. Identify the analytical and statistical methods to apply to the existing phytoplankton species data, productivity data and chlorophyll *a* data (continuous fluorometry and point sample) to answer these questions.

- ☞ Literature search
- ☞ Phytoplankton environmental indicators project (1st year) - begin to analyze data using common measures of the phytoplankton community
- ☞ Workshop (CRC sponsored?) including project PI's, program managers, statisticians and data analysts, outside scientific experts.
  - Present scope of phytoplankton monitoring programs, and results of states' analyses and of the bioindicator project's first year.
  - Focus agenda on questions listed in step 1 but ascertain how the monitoring data is of use to bay area researchers and modellers, as a tool in expanding our knowledge of basic plankton processes in the system.
- ☞ Meet with scientists and managers from other locations to share ideas and critique the CBP phytoplankton monitoring programs and their analytical approaches.
  - Possible forum: either an informal evening meeting or a series of formal talks within a session at an annual ERF or ASLO meeting. (For example, both 1994 ASLO and ERF June meetings have bioindicator sessions.)

Step 3. Test additional metrics on monitoring data, test power and robustness of metrics. (2nd year of phytoplankton indicator project).

- ☞ Identify a series of analytical methods to apply to the phytoplankton monitoring program, and a viable set of phytoplankton environmental indicators which will provide managers with answers to their original questions (objectives).

At the conclusion of the third step, managers and PI's of the phytoplankton monitoring programs should have good evidence of whether or not the existing sampling regime is able to produce the data necessary for the indicators. They will be better able to draft an "ideal" sampling regime for the programs at that time.

Possible changes to phytoplankton sample collection and analyses methods

1. Continuous, horizontal fluorescence is currently done in conjunction with taxonomic identifications and cell counts of phytoplankton samples for the Virginia mainstem and tributaries, the upper bay, and the upper Potomac. The taxon count data are interpreted to a much greater degree in state reports than the flouorometry data at this time. **Additional effort needs to be focused on interpreting and using the fluorometry data.** Fluorescences provide excellent information of the spatial distribution of chlorophyll biomass, an important phytoplankton indicator. Used in combination with the taxon count data, this gives the phytoplankton program much better information about the spatial and temporal extent of algal blooms.

2. **Both the Virginia and Maryland programs could enhance their abilities to track phytoplankton abundance and biomass in most of the bay with monthly phytoplankton collections coupled with twice-monthly fluorescence cruises during the winter, spring and summer bloom periods.** This sampling regime would improve both spatial and temporal coverage of the phytoplankton. The previous 7-9 years of data on community composition has provided the species "characterization" sought by the CBP; less intensive species composition analyses (12 cruises/year) in conjunction with occasional microscopic analyses of samples collected during fluorescence profiling would be sufficient for many areas now. The pros and cons of this suggestion need to be discussed in detail by the phytoplankton PI's and program managers before it can be put forward as a recommendation.

3. **Stratified sampling should continue at those Maryland and Virginia stations typified by strong pycnoclines overlying oxygen depleted bottom waters as well as at any station where sedimented nuisance algae might occur.** There is definitely an absence of plankton in hypoxic/anoxic waters.

Brief characterization of annual plankton cycles[1]

Month	Phytoplankton	Zooplankton (micro- & meso-)
Jan	Winter bloom period in oligohaline (Dinoflagellates) Bottom transport of diatom biomass into lower tribs and mainstem	Winter bloom period for *Eurytemora affinis*, *Synchaeta baltica*, which may be important to overwintering planktivores (eg. bay anchovy) in oligohaline and mesohaline in early spring
Feb	Winter bloom period... Bottom transport...	Winter bloom period...
Mar	Spring bloom period in poly- and mesohaline Winter bloom period in oligohaline ended	Spring baseline during high flow period which influences downriver extent of TF zone Anadromous fish larvae in VA nursery areas
Apr	Spring bloom reaching into oligohaline	Anadromous fish larvae in bay nursery areas
May	Spring bloom period ending	Anadromous fish larvae in bay nursery areas Resident fish spawning starts baywide
Jun	Summer baseline	Resident fish spawning baywide, young and many adults dependent upon zooplankton as food
Jul	Shift to summer spp. Primary productivity max.	Resident fish spawning... Jellyfish planktivores abundant
Aug	Primary productivity max.	Resident fish spawning... Jellyfish planktivores abundant
Sep	Primary productivity max.	Resident fish spawning

	ending	ending
Oct	Summer bloom declining Fall destratification	Summer bloom declining Fall destratification
Nov	-	-
Dec	Winter bloom period in tribs	Winter bloom possible

[1] CBP plankton monitoring programs should be able to rapidly respond to episodic events (e.g. very high flows, oil spills) or unusual blooms by increasing sampling frequency. This will allow us to track plankton responses more accurately.

ATTACHMENT E

ZOOPLANKTON BIOINDICATOR DEVELOPMENT (ICPRB FY93 Project 80 / FY94 Project 715)

ROUND 2 (June 15, 1993 - June 15, 1994)

BUDGET
6/15/94

	BUDGET:		EXPENDITURES:		REMAINING:
	Original Round 2 FY93 & 94	Revised 2/3/94 Round 2 FY93 & 94	Subtotal FY94 Rnd 2 (6/15/93 - 9/30/93)	Total Round 2 (6/15/93 - 6/15/94)	Carried over to Round 3 (6/15/94 - 6/15/95)
Contracts					
Fred et al.	$2250	$4886.74	$1186.74	$1186.74	$3700
Kevin et al.	$2250	$3953.00	$1933.00	$1933.00	$2020
subtotal	$4500	$8839.74	$3119.74	$3119.74	$5720
ICPRB Salaries, Fringe, Benefits					
	$7762	$3377.98	$1487.75	$3377.98	-0-
Travel	$190	$282.28	$93	$282.28	-0-
Meeting exp.	$48	-0-	-0-	-0-	-0-
	$12,500	$12,500	$4700.49	$6780	$5720