

***Zooplankton/Food Web Monitoring for Adaptive
Multi-Species Management
Near-term Recommendations***

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Executive Summary

The regional interest in multi-species fisheries management as well as indicators of the Bay's health has rekindled interest in routine zooplankton monitoring for the tidal waters of the Chesapeake Bay and its tributaries. The Chesapeake Bay Program issued a Request for Proposals (RFP) and from an open competition, selected a project for initiation in spring 2005, with the understanding that the project team would request expert opinion of the proposed work. The new project's material was to be assessed relative to the previously collected zooplankton data and developed indices as well as new issues concerning relevance of the collected information to refining the indices and serving as the foundation for multi-species fisheries management modeling activities in the region. The Chesapeake Research Consortium was requested to convene regional interested parties and a small expert team from other estuaries to discuss the project and its potential contributions for extending the historical database, expanding zooplankton indicators of Bay health, and providing critical data for new multi-species models being considered in fisheries management.

A workshop was held at the Smithsonian Environmental Research Center in January, 2005. Project team members, agency personnel, and experts openly discussed agency needs for the collected information, merits of the expected deliverables, location of sampling stations, field techniques, and sampling schedule, and possible modifications for the 2005 sampling season and future sampling considerations.

Zooplankton were recognized as integral members of the ecosystem, reflecting top-down and bottom up processes. Hence, collection of zooplankton data is important to identifying chronic as well as acute changes to the system, but only if long term data collection is a commitment. Within the limits of the funding provided and guidance given in the RFP, the selected project was identified as relevant and focused, providing requested information pertinent to summer fish populations and potential indicators of Bay health that are in preliminary development for mesohaline and polyhaline reaches of the tidal Bay.

There are important considerations for the agencies sponsoring future zooplankton monitoring in tidal waters.

- A long-term commitment to data collection must be assured; it is only long term data records that ensure sufficient information for detecting ecosystem change, whether through restoration efforts, fisheries management, or natural controls (e.g., climate change, variable river discharges, hurricanes).
- All monitoring, including zooplankton, should be coordinated with on-going monitoring efforts, insuring co-location of water quality, phytoplankton, and zooplankton sampling in space and time. Coordination should also extend to historical fishery sampling activities (e.g., MD DNR seine survey) as well as future ichthyoplankton surveys being considered by NOAA's Chesapeake Bay Office and Oxford Laboratory and invasive/exotic species analyses (partnering with the national effort housed at SERC).
- Monitoring and analysis should include measures of size structure, as shifts in size may be as important in detecting change as total numbers of individuals.
- In the future, adequate resources for Bay-wide and year-round monitoring should be considered particularly with the current model demands for annual estimates of

zooplankton biomass. One means to accommodate this need is that samples could be collected as part of the on-going water quality monitoring program and archived for future analyses.

- A greater investment in analysis and interpretation must be assured, providing resources for extramural interpretation and review and
- The development of indices, whether IBIs or zooplankton-fish measures, should be used to form specific hypotheses to test the validity of the relationships 'detected' by the indicators.

The selected zooplankton monitoring program is highly specific and RFP-focused and more than adequately addresses the needs of the agency's request. However, the new demands in the system, for both indices of restoration success (Bay health) and multi-species fisheries management, should result in much greater coverage in space and time of this under-sampled trophic group. Continued dialog between the agency and the research community is encouraged, to enlarge sampling opportunities and very importantly, increase data analysis and interpretation.

Zooplankton/Food Web Monitoring for Adaptive Multi-Species Management

Near-term Recommendations

Introduction

Zooplankton are integral to aquatic productivity, serving as primary consumers of nutrient-driven primary producers, and as prey for fish. Microzooplankton are also important members of the microbial loop, recycling production from the bacterioplankton and picoplankton to regenerate nitrogen and phosphorus pools for the system.

This diverse group of protozoa and metazoans has been a centerpiece for the plankton monitoring program of the Water Quality Monitoring program since 1984, and curtailed in 2002. Recent interest in zooplankton as critical prey for fisheries ecosystem modeling efforts in the region as well as for using this group as potential indicators of Bay health has led to reinstatement of a modified zooplankton monitoring effort, scheduled to begin in spring-summer 2005. The Chesapeake Bay Program requested a comprehensive review of the proposed project, to assess its potential similarities to the previous program as well as its ability to provide desired products such as Bay indicators of health and importance to future living resource modeling necessary for the coming regional commitment to multi-species fisheries management.

This is the second of two reports arising from the workshop dedicated to this assessment, *Zooplankton/Food Web Monitoring for Adaptive Multi-Species Management* held January 12-13, 2005. Products from the workshop include: 1) Report 1, a brief document with recommendations emerging from the workshop that identified needed changes sampling design, coordination with other programs, contingencies, etc.) to the proposed work. These changes were to be addressed quickly by the project team, funding agencies, and possibly others before sampling began. And 2) Report 2, which documents the substance of the workshop discussions and sets forth recommendations for the future.

Workshop objectives

The primary goal of the workshop was to ensure the project emerging from the Zooplankton/Food Web Monitoring competition has been designed to meet the goals of the Chesapeake Bay Program (CBP). However, the desired uses and applications of zooplankton monitoring information are many and diverse, and given the limited funding available at the time of the award, any zooplankton monitoring program to be conducted in 2005 must be narrowly focused with objectives scaled appropriately. Day 1 of the workshop was structured to 1) lay out the information and information products desired from a zooplankton monitoring program, 2) learn from invited experts whether, in their opinion, the proposed program can deliver the desired results and 3) review the achievements of the previous zooplankton program and finally, 4) consider the advice and recommendations from all participants for meeting a larger suite of objectives in the near and longer term. Day 2 was devoted to 1) gaining consensus on a list of achievable objectives for the immediate future, on the program design to support those objectives and on the products/deliverables to be expected and 2) developing recommendations

for future modifications and additions to the monitoring program to meet expanded monitoring objectives and more of the Bay Program's information needs. The agenda (appendix A) originally called for separate breakout sessions to address the new project from the perspectives of fisheries and water quality. In practice, the workshop participants (appendix B) remained together and addressed the issues as a group.

What CBP information needs are zooplankton studies expected to fulfill?

Richard Batiuk, CBP Associate Director for Science, and Robert (Bob) Wood, Workshop Chair and NOAA's Director at the Oxford Cooperative Laboratory, laid out the framework for the workshop.

Monitoring must inform management decisions

In his opening charge to workshop participants, Batiuk stressed that monitoring must inform management decisions. Monitoring data must yield products (e.g., indicators, indices of biological integrity (IBI), and other metrics) that link zooplankton back to land use and management practices, loadings, and habitat quality and forward to harvests and living resources, in short, make the 'Source to Resource' connection. Similar to other biological endpoints, he envisions a zooplankton IBI as the basis for zooplankton 'criteria' and an indicator of Bay health. Conversely, indicators and metrics should be developed that are diagnostic of change and impairment. Information should be spatially and seasonally explicit and packaged to fit directly into the management decision-making framework. Additionally, zooplankton data and data products must feed trophic and other ecosystem models under development that will be the future tools for managing the Bay's resources and, thus, the Bay itself (see appendix C for the details of his presentation.)

Examples of applications to management

Wood expanded on applications of zooplankton monitoring data in his presentation (appendix D), demonstrating, by example, from his own research, a hierarchy of data and data analysis products that leads from data collection (monitoring) to management decisions. In the zooplankton context, he presented the following flow of information product development:

- Collect zooplankton population data;
- Assess 'status' of zooplankton populations relative to some desirable endpoint;
- Identify and evaluate stressors that impact zooplankton, causing or influencing the status condition and distinguishing between
 - manageable stressors such as effects of eutrophication and
 - unmanageable stressors such as climate variability and disease;
- Define the consequences of zooplankton status, i.e., what does it mean
 - for fisheries,
 - for water quality; and
- Incorporate zooplankton status in an encompassing index of ecosystem health.

The value and range of potential applications up the information hierarchy depend largely on the data quality and quantity at the base: the spatial and temporal density of the data, the length of the time series, sampling design, and taxonomic specificity, among other things. Most of these are limited primarily by fiscal resources.

As with other components of a dynamically changing ecosystem, assessing zooplankton community status is not simple, since status definitions are not in place. Status implies a condition along a continuum of conditions (e.g., good, poor, marginal), or a position relative to a standard (meets, fails, borderline), or a rank within a set of contenders relative to a condition (e.g., best, worst). There is a lively difference of opinion in the scientific community, and expressed at the workshop, on the utility/validity of a qualitative, hierarchical valuation of zooplankton status conditions that implies one condition to be inherently better than another, not just different. However, Batiuk made clear that the Chesapeake Bay Program has specific restoration goals and is not neutral as far as ecological endpoints are concerned. Program managers must be able to evaluate conditions and evaluate status as either supporting the restoration goals as ‘good’ or ‘healthy’ or identify a condition some distance from the goal as ‘bad’ or ‘impaired’.

Wood offered empirical examples from his research of linkages between zooplankton (as prey) and a valued resource (predator), showing the relationship between zooplankton distribution and abundance and bay anchovy recruitment. The work illustrates differences between wet and dry years, indicating climate-dependent variability in the relationship. Further, another analytical exercise revealed climate-related configurations of conditions that benefit coastal and anadromous spawners differentially. Such relationships, to the extent they are identified and understood, can be modeled mathematically to predict recruitment success as well as the impact on recruitment levels of changing prey levels, climate effects, or other forcing functions.

The zooplankton-bay anchovy-rainfall example is a relatively simple interaction to describe and model. The Bay ecosystem is complex and multi-tiered, however, and Wood offered schematic representations of much more complicated models that attempt to quantify and simulate the relationships and energetic interactions among and between food web members at the ecosystem level: the conceptual linkage between the CBP water quality model, the CASM model for lower trophic levels, and Ecopath-Ecosim predator-prey fisheries model. These models are the future tools for managing the Bay, for they represent the complicated real-world habitat and trophic interdependencies, albeit over-simplistically. The zooplankton-anchovy example and the trophic models illustrate zooplankton’s critical position in the system (appendix D). At present, data density for the various model components is uneven; many of the higher trophic level components of the models are data poor.

In this context, what contributions have zooplankton studies made here and elsewhere?
The invited external experts provided examples from their research in other estuaries.

Zooplankton as indicators of expected and unexpected ecosystem change

All three scientists (W. Kimmerer, San Francisco State University; M. Pace, Intitute of Ecosystem Studies; B. Sullivan, University of Rhode Island) emphasized the value of long term data sets to detecting change and understanding causes and consequences of change in the ecosystem, particularly in a period of strong ecosystem change, characteristic of the Chesapeake currently. The signs of ecosystem change may be subtle and manifested in many different ways. The causes of change, both direct and indirect, may not be diagnosable if the appropriate data are not available.

Pace (appendix E) described the effects of zebra mussel invasion in the Hudson River, where mussels depressed smaller zooplankton forms (rotifers and cladocerans) but left larger forms (copepods, the preferred fish prey) unaffected. The changes in the zooplankton community were associated with changes in fish distribution with declines in species or age classes dependent on open water relative to species dependent on littoral areas. In addition, “littoral species” were generally more abundant upriver in the zone of high zebra mussel density while “pelagic fish” shifted downriver to areas of low zebra mussel density.

Kimmerer (appendix F) summarized the effects of Asian clam invasion in San Francisco Bay. First indications of an impact had been the relocation of fish populations. Zooplankton data revealed that clams had eliminated the prey populations for smelts and anchovies; fish then relocated downstream of the clam-grazing influence. Pre- and post-clam zooplankton data indicated that zooplankton were numerous in both periods but in the post-invasion period, zooplankton species composition and size structure had shifted to smaller forms not eaten by the two fish taxa.

Sullivan (appendix G) described changes in Narragansett Bay effected by the ctenophore *Mnemiopsis*. Weekly monitoring of zooplankton and chlorophyll revealed a change in the timing of *Mnemiopsis*' first appearance in the spring. The temporal shift has been attributed to warming winter water temperatures. The early ctenophores eliminate the summer copepod population, followed by elevated chlorophyll (a surrogate for phytoplankton) and a 2- to 4-fold decrease in fish larvae. The elevated chlorophyll is attributed to decreased grazing by copepods; the decrease in fish larvae is attributed to lower food availability (decreased copepods) and/or to lower dissolved oxygen from decomposition of the excess phytoplankton.

Zooplankton as link between primary production and higher trophic levels, with strong influence on abundance and distribution of species 'above' and 'below' them in the food web.

The three case studies illustrate zooplankton's pivotal position in the food web and suggest the myriad species-specific interactions that, taken together, move production through the food web. They also illustrate how disruptions or changes to those interactions can lead to altered use of habitat and movement of production through the complex array of prey and predators in any system.

The case studies emphasize the importance of integrated biological monitoring as well as the particular utility of zooplankton as a critical system component. The guest experts noted that in each of these case studies, zooplankton were key to detecting and diagnosing the causes of major ecosystem shifts when they occurred. As predictors of future change, zooplankton can serve as alarm bells signaling or foreshadowing likely changes in the system, but the experts cautioned that predicting the specificity of such shifts on other components of the ecosystem would be difficult, as zooplankton impact a suite of predators 'above' them and identifying specific predator responses might be impossible.

What did the previous CBP zooplankton program contribute in this context?

The previous CBP-funded zooplankton survey was conducted from mid 1984 through 2002 as part of the integrated Water Quality Monitoring Program. The Program included zooplankton, phytoplankton, and benthos components as representative 'first responders' to anticipated water quality improvements. They were included in order to demonstrate the benefits of improvements cascading through the food web, beginning with the primary and secondary producers and, theoretically, continuing through to oysters, crabs, and fish. There was some progress toward these objectives, but the zooplankton component was eliminated from the Program in 2002 because of budget restrictions, methodological inconsistencies between data collection organizations, and perceived lack of usefulness to management.

The project team, in their presentations, offered their view of the previous zooplankton survey (appendices H-N). They acknowledged problems with some of the historic data and the still incompletely developed tools for management. However, they countered that they believed that the data are widely used by the scientific community and that the geographic density and length of record are highly valued. Findings and products derived from those data were presented including:

- A demonstrated link between gelatinous zooplankton and reduction (20-40%) of oyster larvae and anchovy eggs; a proposed link between the demise of oysters, loss of shell, and sea nettle numbers;
- Demonstration that microzooplankton in some places and certain times constitute the bulk of zooplankton biomass in the Chesapeake system;
- Development of a striped bass habitat index that incorporates food availability and habitat quality to derive a characterization index (spawning criteria from salinity and temperature and larval survival criteria from temperature and food availability); and
- Development of zooplankton IBIs for summer mesohaline and polyhaline regions with highly predictive validation results (work in progress).

Zooplankton as indicators of ecosystem health

As noted earlier, there are mixed opinions concerning use of zooplankton as indicators of ecosystem health. The guest experts were generally in agreement that because zooplankton communities are the net result of both bottom-up and top-down pressures, community status does not track to a particular level of ecosystem functioning. Sullivan cited examples where shifts in taxonomic-, life stage-, or size-structure or localized differences in these structures *do* indicate differences in water quality. For instance, rotifers are abundant and copepods are generally depressed in shallow areas that experience frequent hypoxia. But it is also true that that same community structure can arise from other causes as well, not all of which are 'bad' or indicative of specific, unhealthy transitions in the ecosystem.

In fact, the critical suite of metrics for ecosystems is still not known, according to Kimmerer. Kimmerer questioned whether IBIs could be robust indicators of ecosystem integrity as systems experience ecosystem change. While the multi-parameter IBIs shown in the presentations may be highly predictive of water quality and habitat condition in the current ecosystem construct, he expressed doubt that they would remain robust if there were a major shift. He commented further that if the IBI's value is to provide information on zooplankton community health itself, then the characteristics of good or bad (healthy or unhealthy) are based on unfounded value

judgments. If the zooplankton IBI's value in assessing ecosystem health is as a measure of food adequacy for fish, then would not fish-based measures be more appropriate?

The proposed 2005 monitoring project

<i>What</i>	<i>How</i>	<i>When</i>	<i>Where</i>
Mesozooplankton Abundance/biomass/ Species composition	202 um-mesh oblique tow thru water column	Mar/Apr –May 3 cruises	TF-OH region: 13 stations fish spawning areas in the main stem and 6 tribs
Microzooplankton Abundance/biomass/ Species composition	whole water and 44 um-mesh net	“	“
Mesozooplankton Abundance/biomass/ Species composition	202 um-mesh oblique tow thru water column	May-September 3 cruises	MH-PH region: 13 stations juvenile nursery and adult habitats in the main stem and 6 tribs
Microzooplankton Abundance/biomass/ Species composition	whole water and 44 um-mesh net	“	“
Gelatinous zooplankton Abundance/biomass/ Species composition Size distribution	1-m diameter net, 500 um-mesh	May-September	MH-PH reion: 13 stations in main stem and 6 tribs

The 2005 monitoring project is described in more detail in the workshop background document (CRC 2005). Since the project design preceded the workshop and funds are fixed and limited for the year, participants' comments/recommendations focused on immediate refinements and near-term modest expansions that might improve the project's prospects for fulfilling the anticipated objectives and expectations.

Recommendations for the 2005 program and beyond

1) Project objectives

Given the limited funding at present and the many potential intended uses for zooplankton information, there is a need to clearly articulate the limited objectives of the monitoring program at this juncture and the objectives that can be reasonably incorporated in the future. The objectives will define the deliverables and guide sample methodology as well as data analysis.

The 2005 monitoring objectives are geared primarily to water quality management applications. The CBP has indicated that it needs biological indicators of water quality. Previous work on zooplankton IBIs indicate that zooplankton communities are different in the least impaired versus most impaired waters, but the empirical IBIs need additional development, validation and review. Therefore, it is unclear whether the current metrics and IBIs meet management needs.

What is missing in the IBI for the zooplankton-water quality connection is WHY and HOW do zooplankton respond to water quality? How do individual community members respond to different types of water quality degradation, i.e., what are the likely zooplankton responses to different environmental stressors? What are the likely responses to phytoplankton population shifts, to anticipated changes as the Bay moves toward a more restored state? From this knowledge, we can move to zooplankton IBI's with more holistic underpinnings and, likely, with better translatability to water and habitat quality. Similarly, IBIs for the zooplankton-fish connection must be developed based on determining what about zooplankton (quality, composition) is 'good' for their dependent consumers (fish).

If the objectives are expanded to include assessments of the quality and quantity of zooplankton as food for the major planktivores and planktivorous life stages in the Bay food web and quantification of other trophic interactions and impacts such as jellyfish grazing of fish eggs and larvae, then sampling needs to be much more comprehensive in time and space and integrated with sampling of the related trophic groups as well, including other zooplankton forms such as epibenthic species, e.g., mysids, and other larger zooplankton. Ichthyoplankton and meroplanktonic life stages of other ecologically important species should also be considered.

In lieu of establishing truly integrated surveys, the zooplankton data from the 2005 project should be able to provide useful information on food quality and quantity for fish within the stated constraints and should be useful 'ballpark estimates' for modeling efforts underway and planned.

Another objective of the zooplankton monitoring program is simply and very importantly to continue the long-term record. The various modeling efforts are attempting to mimic the dynamic interactions of species and habitats, but much is still unknown. There was consensus among the participants that to understand the consequences of events, whether climatic or other natural events or management interventions, the data record must precede and follow the events. Since 'events' are often unforeseen and can manifest themselves in subtle and cataclysmic ways, the record needs to be ongoing and unbiased.

2) Sampling design: Temporal and spatial coverage

Workshop participants were generally satisfied with station selections and sampling frequency for the 2005 survey. However, there were some general recommendations that should be addressed for the short- and longer term.

- The zooplankton program should coordinate with water quality and phytoplankton monitoring programs to be sure correlative data are collected at zooplankton stations. If new stations are added or established stations moved, then a plan to ensure continuity of the long-term data record for zooplankton and phytoplankton in the regions of loss or gain needs to be developed and implemented.
- The workshop participants generally agreed with the limited resource-dependent sampling schedule for 2005: the trigger for initiating the spring sampling is water temperature of 12°C, typically attained in March-April. At present, the schedule calls for 3 cruises in spring

(March-May) to sample spawning areas in the tidal fresh-oligohaline portions of the upper Bay and tributaries and 5 cruises over the summer (May-September) to sample the meso- and polyhaline regions of the Bay and tributaries (the 'nursery' for juvenile fish and the summer feeding grounds for many adults). There was some discussion of the relative merits of 3:5 or 4:4 cruise distributions over the two seasons. Sampling frequency could be tuned to water temperature or the spawning status of the fish. The sampling scheme is currently designed within the time-space theater of the plankton-menhaden-striped bass interaction. There may be progress benchmarks in this interaction from this project and others to guide sampling frequency.

This schedule leaves three-quarters of the annual cycle uncharacterized for various resident micro- and mesozooplankton communities in selected salinity zones and no information on the over-wintering and early spring populations of the gelatinous forms. This is a major loss for the management-required and dependent ecosystem models. At present, the Ecosim with Ecopath (EwE) trophic model (also known as the Fisheries Ecosystem Model (FEM)) uses annual biomass estimates as input parameters and is not spatially explicit but the hope and intention is to add more seasonal and regional specificity in the future (there are other spatially explicit models like EwE available and should EwE not provide the spatial resolution needed, these other models should be explored). The current sampling program cannot provide good annual estimates nor will seasonal detail be possible without the additional data.

- A suggestion was made to sample one or more stations year-round. If funds are not available in the 2005 project, then the suggestion is to collect samples but archive them for future analysis should funds become available. A plan to 'hitchhike' on the once/twice-monthly water quality cruises should be considered.
- Participants emphasized the importance of identifying and sampling the estuarine turbidity maximum (ETM) in each tributary and in the mainstem Bay. The ETM is typically a critical nursery area for fishes. The ETM is non-stationary and easily could be missed with the current fixed-station design. It is recommended that a plan and budget be developed for adding an adaptive sampling station so that the ETM is sampled consistently under different flow regimes. This should be done as early in the program as possible.
- It is also necessary to account for direct and indirect effects of a salinity gradient on zooplankton communities in the sampling design. The participants expressed concern about the ability to fully interpret the 2005 project information for lack of contemporaneous data over a larger portion of the salinity gradients in each sampling region. In the current design, spring samples are collected at upstream fixed stations, presumably in tidal fresh-oligohaline waters; summer samples are collected at downstream fixed stations, presumably representative of meso- and polyhaline waters.
- The proposed zooplankton monitoring project focuses on pelagic zooplankton at mostly open water, mid-channel stations. The 'nursery' areas for juvenile fish are typically in shallower waters. The difference between the mid-channel and near-shore shallow water zooplankton communities is not known and not addressed by this proposed monitoring project. A CBP

shallow-water monitoring program for water quality is currently in place that could provide a platform and context for some comparison studies. Funds for formal studies are not available at present but it was recommended that the 'interested community' be vigilant for opportunities to undertake this contemporaneous sampling.

In addition, epibenthic zooplankton and macroplankton species (such as mysids and amphipods among others) are known to be important in the diets of many fish species and these are not representatively sampled in the proposed survey. The CBP partners are encouraged to expand a monitoring program (nocturnal) to sample this primary prey in order to numerically support the upper trophic level modeling in the region, critical to the multi-species fisheries management commitments regionally.

- The primary sample collection method is currently an oblique tow through the water column. This is a concession to funding limitations and is consistent with the collection strategy in the historical monitoring program (1985-2002). However, there are reasons to encourage depth-stratified sampling if possible: 1) The tidal portions of the Bay and tributaries are partially mixed (density-stratified) estuaries, and organisms utilize the different layers for up- and down-stream transport, refuge, and physiological necessity, to name just a few factors. 2) For assessment and regulatory purposes, the Bay and tributaries are broken up into 'designated uses' for which uniquely defined water quality criteria have been established. The designated uses have seasonal and spatial (including depth) components in their definitions that are biologically based, either directly or indirectly. The sampling design of the long-running CBP water quality monitoring program takes the water column structure into account and collects samples above and below the pycnocline when the water column is stratified.

3) *Sample collection and analysis*

- In the previous zooplankton monitoring program, population data for gelatinous zooplankton were obtained from the counts in mesozooplankton net tows. The new program includes a separate gelatinous component with sampling gear more appropriate for these animals. Ctenophore abundance/biomass estimates are sensitive to length of tow and the characteristics of the sampling nets. Thus, studies to quantify differences between past and proposed ctenophore and jellyfish sample collection and analysis methods are recommended so that the old and new data can be comparative.
- Sample enumeration methods depend on objectives. Because the program objectives may change or be expanded at a later date, it was suggested that archival samples be collected and stored for future analysis. There was also the suggestion that an archive-sample plan be developed that would cover unforeseen (and unfunded) sample collection opportunities and purposes (such as special habitat or environmental conditions or the year-round collections mentioned earlier).
- Size should be included as a data parameter. Size is an important feature of species-specific interaction: Two of the case studies cited by the outside experts included examples of the effect of an ecosystem change on zooplankton size distribution and the effect of a change in

zooplankton size distribution on predators. In recognition of that fact, the EwE (FEM) model uses predator and prey biomass levels by size class.

- Because of the multiple objectives mentioned at the workshop, the project team should clearly describe in the project documentation or Scope of Work the sample enumeration methods and the rationale in terms of the specific objectives to be addressed. For example, is the method focusing on an assessment of fish-food abundance, zooplankton community diversity, or detection of invasive species? If not these or there are other, they should be described.
- With no intended criticism of the proposed biomass estimation method (biomass estimated by carbon conversion factors found in literature), it was suggested the project team review the literature for additional current methods and modify proposed methods if better techniques are available and to conduct method comparability analyses as needed. (Biomass is a primary parameter in the ecosystem models.)
- Invasive and exotic species are a growing concern in the Bay and nationally and could themselves be the main subject of a monitoring program. However, because invasives are not the priority objective of the current program, any information from this program can be only anecdotal. Failure to detect any particular species does not mean that it is not present at some significant level. The project team is advised to determine the Bay Program's requirements for Invasives information: What are priority species? Which of these are likely to be captured in the proposed sampling design and which warrant additional effort, if necessary, to detect their presence? Additional resources will be required for exploring special sample analysis and species identification. Collaboration with local Invasives experts, such as G. Ruiz, Smithsonian Environmental Research Center will be required.

4) *Data analysis, products, deliverables*

Because of funding limitations, the 2005 monitoring project is obligated only to provide CIMS-compliant observational data, no secondary data or interpretative reports will be drafted at this point. Data analysis, interpretation and further development of management tools and applications will have to be covered by other funding mechanisms. In support of this, workshop participants were unanimous in recommending more data exploration and analysis of the long-term data set, including data from the new project. They emphasized the unique value of the data set for its length of record and spatial coverage.

- **IBIs and other indices**
Given the foregoing comments about IBIs, it will be important to see if the current IBIs stand up with additional data from the new monitoring program. For the water quality-zooplankton index to have relevance to management, it will be necessary to postulate and test (through research and/or data analysis) hypotheses that explain the response of zooplankton to water quality as evidenced in the empirical IBI findings. That is, hypotheses to explain how low nutrient /sediment concentrations, adequate dissolved oxygen, improved water clarity and particular phytoplankton community composition (and the opposite conditions) influence zooplankton communities to get the observed IBI results.

The same is true for the zooplankton-fish indices. It will be necessary to identify species individually or feeding groups for which the zooplankton-as-food index are relevant. It is also necessary to include other aspects of habitat quality, and the zooplankton-as-food index can serve as one element in a more comprehensive index of habitat condition. The project team has already developed some portion of these in the Striped Bass Food Availability Index and Striped Bass Habitat Suitability Index. These indexes need to be extended to other species and, as suggested above, be grounded by explanatory underpinnings.

- Trend/time-series information

The ecosystem models require historical time-series data for calibration and validation. They need contemporary data and time-series data into the future to run the models in present day, track the success of the model forecasts, and alert modelers and management when the old system relationships show signs of change.

Ecosystem changes are not always obvious. They can be slow and subtle or they can be masked by large seasonal and inter-annual variation. Tests for linear and nonlinear trends in selected community elements/characteristics should be conducted at some regular interval to detect significant changes.

- Other data analysis needs – These needs are numerous. Needs for more/better ‘process-rate’ information: production rates from the literature, as well as empirically derived from observational data, e.g, adult-juvenile ratios; growth rate (biomass accumulation) differential based on temperature and/or other dependent factors. The modeling community needs to better identify what data are required to improve seasonal and spatial definition and where data analysis and new data can fill this need.

Summary and Concluding Comments

- The previous zooplankton monitoring program provided useful, if imperfect, data, and those data have been under-analyzed and under-utilized.
- Zooplankton are an important link in the Chesapeake Bay food-web, but as intermediate players, i.e., subject to bottom-up pressures as well as top-down demand; zooplankton information is most useful within the framework of a broader, multi-trophic-level monitoring program.
- Managing the Bay’s living resources requires an understanding of the relationships of the species to their habitat and each other, as well as their response to harvest and other removal. Our understanding of the multi-tiered trophic relationships in the Bay is incomplete and we lack even basic information about many important food-web and habitat components. We still lack sensitive, directly measured indicators of food-web stability and ‘ecosystem health’. The resources of Bay Program partners should be enlisted to the cause, and monitoring and research efforts of the various Bay partner agencies and institutions should be better integrated.
 - Integrated trophic/ecosystem monitoring must be initiated. This is likely to be an iterative process and can begin with smaller projects in collaboration with others (e.g., NCBO) and taking advantage of strategic ‘samples of opportunity’.

- There needs to be a focused effort to educate and market internally the concept of and need for an integrated trophic level monitoring program (that would include zooplankton)
- The over-arching questions around which such a monitoring program would be designed must be formulated. Many, if not most of those questions have been articulated in this workshop.
- From these questions, lists of related modeling and research needs would follow.
- The existing analytical capability of Bay partners should be harnessed and directed toward these information needs;
- Bay partners should contribute increased funding in order to attract academics and others to apply their talents toward these information needs.
- Zooplankton monitoring program design is critical and very much dependent on funding level.
- It is not enough to demonstrate the linkages from ‘source to resource’, but sampling and analysis must be geared toward management applications.

Executive Summary

The regional interest in multi-species fisheries management as well as indicators of the Bay's health has rekindled interest in routine zooplankton monitoring for the tidal waters of the Chesapeake Bay and its tributaries. The Chesapeake Bay Program issued a Request for Proposals (RFP) and from an open competition, selected a project for initiation in spring 2005, with the understanding that the project team would request expert opinion of the proposed work. The new project's material was to be assessed relative to the previously collected zooplankton data and developed indices as well as new issues concerning relevance of the collected information to refining the indices and serving as the foundation for multi-species fisheries management modeling activities in the region. The Chesapeake Research Consortium was requested to convene regional interested parties and a small expert team from other estuaries to discuss the project and its potential contributions for extending the historical database, expanding zooplankton indicators of Bay health, and providing critical data for new multi-species models being considered in fisheries management.

A workshop was held at the Smithsonian Environmental Research Center in January, 2005. Project team members, agency personnel, and experts openly discussed agency needs for the collected information, merits of the expected deliverables, location of sampling stations, field techniques, and sampling schedule, and possible modifications for the 2005 sampling season and future sampling considerations.

Zooplankton were recognized as integral members of the ecosystem, reflecting top-down and bottom up processes. Hence, collection of zooplankton data is important to identifying chronic as well as acute changes to the system, but only if long term data collection is a commitment. Within the limits of the funding provided and guidance given in the RFP, the selected project was identified as relevant and focused, providing requested information pertinent to summer fish populations and potential indicators of Bay health that are in preliminary development for mesohaline and polyhaline reaches of the tidal Bay.

There are important considerations for the agencies sponsoring future zooplankton monitoring in tidal waters.

- A long-term commitment to data collection must be assured; it is only long term data records that ensure sufficient information for detecting ecosystem change, whether through restoration efforts, fisheries management, or natural controls (e.g., climate change, variable river discharges, hurricanes).
- All monitoring, including zooplankton, should be coordinated with on-going monitoring efforts, insuring co-location of water quality, phytoplankton, and zooplankton sampling in space and time. Coordination should also extend to historical fishery sampling activities (e.g., MD DNR seine survey) as well as future ichthyoplankton surveys being considered by NOAA's Chesapeake Bay Office and Oxford Laboratory and invasive/exotic species analyses (partnering with the national effort housed at SERC).
- Monitoring and analysis should include measures of size structure, as shifts in size may be as important in detecting change as total numbers of individuals.
- In the future, adequate resources for Bay-wide and year-round monitoring should be considered particularly with the current model demands for annual estimates of

zooplankton biomass. One means to accommodate this need is that samples could be collected as part of the on-going water quality monitoring program and archived for future analyses.

- A greater investment in analysis and interpretation must be assured, providing resources for extramural interpretation and review and
- The development of indices, whether IBIs or zooplankton-fish measures, should be used to form specific hypotheses to test the validity of the relationships 'detected' by the indicators.

The selected zooplankton monitoring program is highly specific and RFP-focused and more than adequately addresses the needs of the agency's request. However, the new demands in the system, for both indices of restoration success (Bay health) and multi-species fisheries management, should result in much greater coverage in space and time of this under-sampled trophic group. Continued dialog between the agency and the research community is encouraged, to enlarge sampling opportunities and very importantly, increase data analysis and interpretation.

Zooplankton/Food Web Monitoring for Adaptive Multi-Species Management

Near-term Recommendations

Introduction

Zooplankton are integral to aquatic productivity, serving as primary consumers of nutrient-driven primary producers, and as prey for fish. Microzooplankton are also important members of the microbial loop, recycling production from the bacterioplankton and picoplankton to regenerate nitrogen and phosphorus pools for the system.

This diverse group of protozoa and metazoans has been a centerpiece for the plankton monitoring program of the Water Quality Monitoring program since 1984, and curtailed in 2002. Recent interest in zooplankton as critical prey for fisheries ecosystem modeling efforts in the region as well as for using this group as potential indicators of Bay health has led to reinstatement of a modified zooplankton monitoring effort, scheduled to begin in spring-summer 2005. The Chesapeake Bay Program requested a comprehensive review of the proposed project, to assess its potential similarities to the previous program as well as its ability to provide desired products such as Bay indicators of health and importance to future living resource modeling necessary for the coming regional commitment to multi-species fisheries management.

This is the second of two reports arising from the workshop dedicated to this assessment, *Zooplankton/Food Web Monitoring for Adaptive Multi-Species Management* held January 12-13, 2005. Products from the workshop include: 1) Report 1, a brief document with recommendations emerging from the workshop that identified needed changes sampling design, coordination with other programs, contingencies, etc.) to the proposed work. These changes were to be addressed quickly by the project team, funding agencies, and possibly others before sampling began. And 2) Report 2, which documents the substance of the workshop discussions and sets forth recommendations for the future.

Workshop objectives

The primary goal of the workshop was to ensure the project emerging from the Zooplankton/Food Web Monitoring competition has been designed to meet the goals of the Chesapeake Bay Program (CBP). However, the desired uses and applications of zooplankton monitoring information are many and diverse, and given the limited funding available at the time of the award, any zooplankton monitoring program to be conducted in 2005 must be narrowly focused with objectives scaled appropriately. Day 1 of the workshop was structured to 1) lay out the information and information products desired from a zooplankton monitoring program, 2) learn from invited experts whether, in their opinion, the proposed program can deliver the desired results and 3) review the achievements of the previous zooplankton program and finally, 4) consider the advice and recommendations from all participants for meeting a larger suite of objectives in the near and longer term. Day 2 was devoted to 1) gaining consensus on a list of achievable objectives for the immediate future, on the program design to support those objectives and on the products/deliverables to be expected and 2) developing recommendations

for future modifications and additions to the monitoring program to meet expanded monitoring objectives and more of the Bay Program's information needs. The agenda (appendix A) originally called for separate breakout sessions to address the new project from the perspectives of fisheries and water quality. In practice, the workshop participants (appendix B) remained together and addressed the issues as a group.

What CBP information needs are zooplankton studies expected to fulfill?

Richard Batiuk, CBP Associate Director for Science, and Robert (Bob) Wood, Workshop Chair and NOAA's Director at the Oxford Cooperative Laboratory, laid out the framework for the workshop.

Monitoring must inform management decisions

In his opening charge to workshop participants, Batiuk stressed that monitoring must inform management decisions. Monitoring data must yield products (e.g., indicators, indices of biological integrity (IBI), and other metrics) that link zooplankton back to land use and management practices, loadings, and habitat quality and forward to harvests and living resources, in short, make the 'Source to Resource' connection. Similar to other biological endpoints, he envisions a zooplankton IBI as the basis for zooplankton 'criteria' and an indicator of Bay health. Conversely, indicators and metrics should be developed that are diagnostic of change and impairment. Information should be spatially and seasonally explicit and packaged to fit directly into the management decision-making framework. Additionally, zooplankton data and data products must feed trophic and other ecosystem models under development that will be the future tools for managing the Bay's resources and, thus, the Bay itself (see appendix C for the details of his presentation.)

Examples of applications to management

Wood expanded on applications of zooplankton monitoring data in his presentation (appendix D), demonstrating, by example, from his own research, a hierarchy of data and data analysis products that leads from data collection (monitoring) to management decisions. In the zooplankton context, he presented the following flow of information product development:

- Collect zooplankton population data;
- Assess 'status' of zooplankton populations relative to some desirable endpoint;
- Identify and evaluate stressors that impact zooplankton, causing or influencing the status condition and distinguishing between
 - manageable stressors such as effects of eutrophication and
 - unmanageable stressors such as climate variability and disease;
- Define the consequences of zooplankton status, i.e., what does it mean
 - for fisheries,
 - for water quality; and
- Incorporate zooplankton status in an encompassing index of ecosystem health.

The value and range of potential applications up the information hierarchy depend largely on the data quality and quantity at the base: the spatial and temporal density of the data, the length of the time series, sampling design, and taxonomic specificity, among other things. Most of these are limited primarily by fiscal resources.

As with other components of a dynamically changing ecosystem, assessing zooplankton community status is not simple, since status definitions are not in place. Status implies a condition along a continuum of conditions (e.g., good, poor, marginal), or a position relative to a standard (meets, fails, borderline), or a rank within a set of contenders relative to a condition (e.g., best, worst). There is a lively difference of opinion in the scientific community, and expressed at the workshop, on the utility/validity of a qualitative, hierarchical valuation of zooplankton status conditions that implies one condition to be inherently better than another, not just different. However, Batiuk made clear that the Chesapeake Bay Program has specific restoration goals and is not neutral as far as ecological endpoints are concerned. Program managers must be able to evaluate conditions and evaluate status as either supporting the restoration goals as ‘good’ or ‘healthy’ or identify a condition some distance from the goal as ‘bad’ or ‘impaired’.

Wood offered empirical examples from his research of linkages between zooplankton (as prey) and a valued resource (predator), showing the relationship between zooplankton distribution and abundance and bay anchovy recruitment. The work illustrates differences between wet and dry years, indicating climate-dependent variability in the relationship. Further, another analytical exercise revealed climate-related configurations of conditions that benefit coastal and anadromous spawners differentially. Such relationships, to the extent they are identified and understood, can be modeled mathematically to predict recruitment success as well as the impact on recruitment levels of changing prey levels, climate effects, or other forcing functions.

The zooplankton-bay anchovy-rainfall example is a relatively simple interaction to describe and model. The Bay ecosystem is complex and multi-tiered, however, and Wood offered schematic representations of much more complicated models that attempt to quantify and simulate the relationships and energetic interactions among and between food web members at the ecosystem level: the conceptual linkage between the CBP water quality model, the CASM model for lower trophic levels, and Ecopath-Ecosim predator-prey fisheries model. These models are the future tools for managing the Bay, for they represent the complicated real-world habitat and trophic interdependencies, albeit over-simplistically. The zooplankton-anchovy example and the trophic models illustrate zooplankton’s critical position in the system (appendix D). At present, data density for the various model components is uneven; many of the higher trophic level components of the models are data poor.

In this context, what contributions have zooplankton studies made here and elsewhere?
The invited external experts provided examples from their research in other estuaries.

Zooplankton as indicators of expected and unexpected ecosystem change

All three scientists (W. Kimmerer, San Francisco State University; M. Pace, Intitute of Ecosystem Studies; B. Sullivan, University of Rhode Island) emphasized the value of long term data sets to detecting change and understanding causes and consequences of change in the ecosystem, particularly in a period of strong ecosystem change, characteristic of the Chesapeake currently. The signs of ecosystem change may be subtle and manifested in many different ways. The causes of change, both direct and indirect, may not be diagnosable if the appropriate data are not available.

Pace (appendix E) described the effects of zebra mussel invasion in the Hudson River, where mussels depressed smaller zooplankton forms (rotifers and cladocerans) but left larger forms (copepods, the preferred fish prey) unaffected. The changes in the zooplankton community were associated with changes in fish distribution with declines in species or age classes dependent on open water relative to species dependent on littoral areas. In addition, “littoral species” were generally more abundant upriver in the zone of high zebra mussel density while “pelagic fish” shifted downriver to areas of low zebra mussel density.

Kimmerer (appendix F) summarized the effects of Asian clam invasion in San Francisco Bay. First indications of an impact had been the relocation of fish populations. Zooplankton data revealed that clams had eliminated the prey populations for smelts and anchovies; fish then relocated downstream of the clam-grazing influence. Pre- and post-clam zooplankton data indicated that zooplankton were numerous in both periods but in the post-invasion period, zooplankton species composition and size structure had shifted to smaller forms not eaten by the two fish taxa.

Sullivan (appendix G) described changes in Narragansett Bay effected by the ctenophore *Mnemiopsis*. Weekly monitoring of zooplankton and chlorophyll revealed a change in the timing of *Mnemiopsis*' first appearance in the spring. The temporal shift has been attributed to warming winter water temperatures. The early ctenophores eliminate the summer copepod population, followed by elevated chlorophyll (a surrogate for phytoplankton) and a 2- to 4-fold decrease in fish larvae. The elevated chlorophyll is attributed to decreased grazing by copepods; the decrease in fish larvae is attributed to lower food availability (decreased copepods) and/or to lower dissolved oxygen from decomposition of the excess phytoplankton.

Zooplankton as link between primary production and higher trophic levels, with strong influence on abundance and distribution of species 'above' and 'below' them in the food web.

The three case studies illustrate zooplankton's pivotal position in the food web and suggest the myriad species-specific interactions that, taken together, move production through the food web. They also illustrate how disruptions or changes to those interactions can lead to altered use of habitat and movement of production through the complex array of prey and predators in any system.

The case studies emphasize the importance of integrated biological monitoring as well as the particular utility of zooplankton as a critical system component. The guest experts noted that in each of these case studies, zooplankton were key to detecting and diagnosing the causes of major ecosystem shifts when they occurred. As predictors of future change, zooplankton can serve as alarm bells signaling or foreshadowing likely changes in the system, but the experts cautioned that predicting the specificity of such shifts on other components of the ecosystem would be difficult, as zooplankton impact a suite of predators 'above' them and identifying specific predator responses might be impossible.

What did the previous CBP zooplankton program contribute in this context?

The previous CBP-funded zooplankton survey was conducted from mid 1984 through 2002 as part of the integrated Water Quality Monitoring Program. The Program included zooplankton, phytoplankton, and benthos components as representative 'first responders' to anticipated water quality improvements. They were included in order to demonstrate the benefits of improvements cascading through the food web, beginning with the primary and secondary producers and, theoretically, continuing through to oysters, crabs, and fish. There was some progress toward these objectives, but the zooplankton component was eliminated from the Program in 2002 because of budget restrictions, methodological inconsistencies between data collection organizations, and perceived lack of usefulness to management.

The project team, in their presentations, offered their view of the previous zooplankton survey (appendices H-N). They acknowledged problems with some of the historic data and the still incompletely developed tools for management. However, they countered that they believed that the data are widely used by the scientific community and that the geographic density and length of record are highly valued. Findings and products derived from those data were presented including:

- A demonstrated link between gelatinous zooplankton and reduction (20-40%) of oyster larvae and anchovy eggs; a proposed link between the demise of oysters, loss of shell, and sea nettle numbers;
- Demonstration that microzooplankton in some places and certain times constitute the bulk of zooplankton biomass in the Chesapeake system;
- Development of a striped bass habitat index that incorporates food availability and habitat quality to derive a characterization index (spawning criteria from salinity and temperature and larval survival criteria from temperature and food availability); and
- Development of zooplankton IBIs for summer mesohaline and polyhaline regions with highly predictive validation results (work in progress).

Zooplankton as indicators of ecosystem health

As noted earlier, there are mixed opinions concerning use of zooplankton as indicators of ecosystem health. The guest experts were generally in agreement that because zooplankton communities are the net result of both bottom-up and top-down pressures, community status does not track to a particular level of ecosystem functioning. Sullivan cited examples where shifts in taxonomic-, life stage-, or size-structure or localized differences in these structures *do* indicate differences in water quality. For instance, rotifers are abundant and copepods are generally depressed in shallow areas that experience frequent hypoxia. But it is also true that that same community structure can arise from other causes as well, not all of which are 'bad' or indicative of specific, unhealthy transitions in the ecosystem.

In fact, the critical suite of metrics for ecosystems is still not known, according to Kimmerer. Kimmerer questioned whether IBIs could be robust indicators of ecosystem integrity as systems experience ecosystem change. While the multi-parameter IBIs shown in the presentations may be highly predictive of water quality and habitat condition in the current ecosystem construct, he expressed doubt that they would remain robust if there were a major shift. He commented further that if the IBI's value is to provide information on zooplankton community health itself, then the characteristics of good or bad (healthy or unhealthy) are based on unfounded value

judgments. If the zooplankton IBI's value in assessing ecosystem health is as a measure of food adequacy for fish, then would not fish-based measures be more appropriate?

The proposed 2005 monitoring project

<i>What</i>	<i>How</i>	<i>When</i>	<i>Where</i>
Mesozooplankton Abundance/biomass/ Species composition	202 um-mesh oblique tow thru water column	Mar/Apr –May 3 cruises	TF-OH region: 13 stations fish spawning areas in the main stem and 6 tribs
Microzooplankton Abundance/biomass/ Species composition	whole water and 44 um-mesh net	“	“
Mesozooplankton Abundance/biomass/ Species composition	202 um-mesh oblique tow thru water column	May-September 3 cruises	MH-PH region: 13 stations juvenile nursery and adult habitats in the main stem and 6 tribs
Microzooplankton Abundance/biomass/ Species composition	whole water and 44 um-mesh net	“	“
Gelatinous zooplankton Abundance/biomass/ Species composition Size distribution	1-m diameter net, 500 um-mesh	May-September	MH-PH reion: 13 stations in main stem and 6 tribs

The 2005 monitoring project is described in more detail in the workshop background document (CRC 2005). Since the project design preceded the workshop and funds are fixed and limited for the year, participants' comments/recommendations focused on immediate refinements and near-term modest expansions that might improve the project's prospects for fulfilling the anticipated objectives and expectations.

Recommendations for the 2005 program and beyond

1) Project objectives

Given the limited funding at present and the many potential intended uses for zooplankton information, there is a need to clearly articulate the limited objectives of the monitoring program at this juncture and the objectives that can be reasonably incorporated in the future. The objectives will define the deliverables and guide sample methodology as well as data analysis.

The 2005 monitoring objectives are geared primarily to water quality management applications. The CBP has indicated that it needs biological indicators of water quality. Previous work on zooplankton IBIs indicate that zooplankton communities are different in the least impaired versus most impaired waters, but the empirical IBIs need additional development, validation and review. Therefore, it is unclear whether the current metrics and IBIs meet management needs.

What is missing in the IBI for the zooplankton-water quality connection is WHY and HOW do zooplankton respond to water quality? How do individual community members respond to different types of water quality degradation, i.e., what are the likely zooplankton responses to different environmental stressors? What are the likely responses to phytoplankton population shifts, to anticipated changes as the Bay moves toward a more restored state? From this knowledge, we can move to zooplankton IBI's with more holistic underpinnings and, likely, with better translatability to water and habitat quality. Similarly, IBIs for the zooplankton-fish connection must be developed based on determining what about zooplankton (quality, composition) is 'good' for their dependent consumers (fish).

If the objectives are expanded to include assessments of the quality and quantity of zooplankton as food for the major planktivores and planktivorous life stages in the Bay food web and quantification of other trophic interactions and impacts such as jellyfish grazing of fish eggs and larvae, then sampling needs to be much more comprehensive in time and space and integrated with sampling of the related trophic groups as well, including other zooplankton forms such as epibenthic species, e.g., mysids, and other larger zooplankton. Ichthyoplankton and meroplanktonic life stages of other ecologically important species should also be considered.

In lieu of establishing truly integrated surveys, the zooplankton data from the 2005 project should be able to provide useful information on food quality and quantity for fish within the stated constraints and should be useful 'ballpark estimates' for modeling efforts underway and planned.

Another objective of the zooplankton monitoring program is simply and very importantly to continue the long-term record. The various modeling efforts are attempting to mimic the dynamic interactions of species and habitats, but much is still unknown. There was consensus among the participants that to understand the consequences of events, whether climatic or other natural events or management interventions, the data record must precede and follow the events. Since 'events' are often unforeseen and can manifest themselves in subtle and cataclysmic ways, the record needs to be ongoing and unbiased.

2) Sampling design: Temporal and spatial coverage

Workshop participants were generally satisfied with station selections and sampling frequency for the 2005 survey. However, there were some general recommendations that should be addressed for the short- and longer term.

- The zooplankton program should coordinate with water quality and phytoplankton monitoring programs to be sure correlative data are collected at zooplankton stations. If new stations are added or established stations moved, then a plan to ensure continuity of the long-term data record for zooplankton and phytoplankton in the regions of loss or gain needs to be developed and implemented.
- The workshop participants generally agreed with the limited resource-dependent sampling schedule for 2005: the trigger for initiating the spring sampling is water temperature of 12°C, typically attained in March-April. At present, the schedule calls for 3 cruises in spring

(March-May) to sample spawning areas in the tidal fresh-oligohaline portions of the upper Bay and tributaries and 5 cruises over the summer (May-September) to sample the meso- and polyhaline regions of the Bay and tributaries (the 'nursery' for juvenile fish and the summer feeding grounds for many adults). There was some discussion of the relative merits of 3:5 or 4:4 cruise distributions over the two seasons. Sampling frequency could be tuned to water temperature or the spawning status of the fish. The sampling scheme is currently designed within the time-space theater of the plankton-menhaden-striped bass interaction. There may be progress benchmarks in this interaction from this project and others to guide sampling frequency.

This schedule leaves three-quarters of the annual cycle uncharacterized for various resident micro- and mesozooplankton communities in selected salinity zones and no information on the over-wintering and early spring populations of the gelatinous forms. This is a major loss for the management-required and dependent ecosystem models. At present, the Ecosim with Ecopath (EwE) trophic model (also known as the Fisheries Ecosystem Model (FEM)) uses annual biomass estimates as input parameters and is not spatially explicit but the hope and intention is to add more seasonal and regional specificity in the future (there are other spatially explicit models like EwE available and should EwE not provide the spatial resolution needed, these other models should be explored). The current sampling program cannot provide good annual estimates nor will seasonal detail be possible without the additional data.

- A suggestion was made to sample one or more stations year-round. If funds are not available in the 2005 project, then the suggestion is to collect samples but archive them for future analysis should funds become available. A plan to 'hitchhike' on the once/twice-monthly water quality cruises should be considered.
- Participants emphasized the importance of identifying and sampling the estuarine turbidity maximum (ETM) in each tributary and in the mainstem Bay. The ETM is typically a critical nursery area for fishes. The ETM is non-stationary and easily could be missed with the current fixed-station design. It is recommended that a plan and budget be developed for adding an adaptive sampling station so that the ETM is sampled consistently under different flow regimes. This should be done as early in the program as possible.
- It is also necessary to account for direct and indirect effects of a salinity gradient on zooplankton communities in the sampling design. The participants expressed concern about the ability to fully interpret the 2005 project information for lack of contemporaneous data over a larger portion of the salinity gradients in each sampling region. In the current design, spring samples are collected at upstream fixed stations, presumably in tidal fresh-oligohaline waters; summer samples are collected at downstream fixed stations, presumably representative of meso- and polyhaline waters.
- The proposed zooplankton monitoring project focuses on pelagic zooplankton at mostly open water, mid-channel stations. The 'nursery' areas for juvenile fish are typically in shallower waters. The difference between the mid-channel and near-shore shallow water zooplankton communities is not known and not addressed by this proposed monitoring project. A CBP

shallow-water monitoring program for water quality is currently in place that could provide a platform and context for some comparison studies. Funds for formal studies are not available at present but it was recommended that the 'interested community' be vigilant for opportunities to undertake this contemporaneous sampling.

In addition, epibenthic zooplankton and macroplankton species (such as mysids and amphipods among others) are known to be important in the diets of many fish species and these are not representatively sampled in the proposed survey. The CBP partners are encouraged to expand a monitoring program (nocturnal) to sample this primary prey in order to numerically support the upper trophic level modeling in the region, critical to the multi-species fisheries management commitments regionally.

- The primary sample collection method is currently an oblique tow through the water column. This is a concession to funding limitations and is consistent with the collection strategy in the historical monitoring program (1985-2002). However, there are reasons to encourage depth-stratified sampling if possible: 1) The tidal portions of the Bay and tributaries are partially mixed (density-stratified) estuaries, and organisms utilize the different layers for up- and down-stream transport, refuge, and physiological necessity, to name just a few factors. 2) For assessment and regulatory purposes, the Bay and tributaries are broken up into 'designated uses' for which uniquely defined water quality criteria have been established. The designated uses have seasonal and spatial (including depth) components in their definitions that are biologically based, either directly or indirectly. The sampling design of the long-running CBP water quality monitoring program takes the water column structure into account and collects samples above and below the pycnocline when the water column is stratified.

3) *Sample collection and analysis*

- In the previous zooplankton monitoring program, population data for gelatinous zooplankton were obtained from the counts in mesozooplankton net tows. The new program includes a separate gelatinous component with sampling gear more appropriate for these animals. Ctenophore abundance/biomass estimates are sensitive to length of tow and the characteristics of the sampling nets. Thus, studies to quantify differences between past and proposed ctenophore and jellyfish sample collection and analysis methods are recommended so that the old and new data can be comparative.
- Sample enumeration methods depend on objectives. Because the program objectives may change or be expanded at a later date, it was suggested that archival samples be collected and stored for future analysis. There was also the suggestion that an archive-sample plan be developed that would cover unforeseen (and unfunded) sample collection opportunities and purposes (such as special habitat or environmental conditions or the year-round collections mentioned earlier).
- Size should be included as a data parameter. Size is an important feature of species-specific interaction: Two of the case studies cited by the outside experts included examples of the effect of an ecosystem change on zooplankton size distribution and the effect of a change in

zooplankton size distribution on predators. In recognition of that fact, the EwE (FEM) model uses predator and prey biomass levels by size class.

- Because of the multiple objectives mentioned at the workshop, the project team should clearly describe in the project documentation or Scope of Work the sample enumeration methods and the rationale in terms of the specific objectives to be addressed. For example, is the method focusing on an assessment of fish-food abundance, zooplankton community diversity, or detection of invasive species? If not these or there are other, they should be described.
- With no intended criticism of the proposed biomass estimation method (biomass estimated by carbon conversion factors found in literature), it was suggested the project team review the literature for additional current methods and modify proposed methods if better techniques are available and to conduct method comparability analyses as needed. (Biomass is a primary parameter in the ecosystem models.)
- Invasive and exotic species are a growing concern in the Bay and nationally and could themselves be the main subject of a monitoring program. However, because invasives are not the priority objective of the current program, any information from this program can be only anecdotal. Failure to detect any particular species does not mean that it is not present at some significant level. The project team is advised to determine the Bay Program's requirements for Invasives information: What are priority species? Which of these are likely to be captured in the proposed sampling design and which warrant additional effort, if necessary, to detect their presence? Additional resources will be required for exploring special sample analysis and species identification. Collaboration with local Invasives experts, such as G. Ruiz, Smithsonian Environmental Research Center will be required.

4) *Data analysis, products, deliverables*

Because of funding limitations, the 2005 monitoring project is obligated only to provide CIMS-compliant observational data, no secondary data or interpretative reports will be drafted at this point. Data analysis, interpretation and further development of management tools and applications will have to be covered by other funding mechanisms. In support of this, workshop participants were unanimous in recommending more data exploration and analysis of the long-term data set, including data from the new project. They emphasized the unique value of the data set for its length of record and spatial coverage.

- **IBIs and other indices**
Given the foregoing comments about IBIs, it will be important to see if the current IBIs stand up with additional data from the new monitoring program. For the water quality-zooplankton index to have relevance to management, it will be necessary to postulate and test (through research and/or data analysis) hypotheses that explain the response of zooplankton to water quality as evidenced in the empirical IBI findings. That is, hypotheses to explain how low nutrient /sediment concentrations, adequate dissolved oxygen, improved water clarity and particular phytoplankton community composition (and the opposite conditions) influence zooplankton communities to get the observed IBI results.

The same is true for the zooplankton-fish indices. It will be necessary to identify species individually or feeding groups for which the zooplankton-as-food index are relevant. It is also necessary to include other aspects of habitat quality, and the zooplankton-as-food index can serve as one element in a more comprehensive index of habitat condition. The project team has already developed some portion of these in the Striped Bass Food Availability Index and Striped Bass Habitat Suitability Index. These indexes need to be extended to other species and, as suggested above, be grounded by explanatory underpinnings.

- Trend/time-series information

The ecosystem models require historical time-series data for calibration and validation. They need contemporary data and time-series data into the future to run the models in present day, track the success of the model forecasts, and alert modelers and management when the old system relationships show signs of change.

Ecosystem changes are not always obvious. They can be slow and subtle or they can be masked by large seasonal and inter-annual variation. Tests for linear and nonlinear trends in selected community elements/characteristics should be conducted at some regular interval to detect significant changes.

- Other data analysis needs – These needs are numerous. Needs for more/better ‘process-rate’ information: production rates from the literature, as well as empirically derived from observational data, e.g, adult-juvenile ratios; growth rate (biomass accumulation) differential based on temperature and/or other dependent factors. The modeling community needs to better identify what data are required to improve seasonal and spatial definition and where data analysis and new data can fill this need.

Summary and Concluding Comments

- The previous zooplankton monitoring program provided useful, if imperfect, data, and those data have been under-analyzed and under-utilized.
- Zooplankton are an important link in the Chesapeake Bay food-web, but as intermediate players, i.e., subject to bottom-up pressures as well as top-down demand; zooplankton information is most useful within the framework of a broader, multi-trophic-level monitoring program.
- Managing the Bay’s living resources requires an understanding of the relationships of the species to their habitat and each other, as well as their response to harvest and other removal. Our understanding of the multi-tiered trophic relationships in the Bay is incomplete and we lack even basic information about many important food-web and habitat components. We still lack sensitive, directly measured indicators of food-web stability and ‘ecosystem health’. The resources of Bay Program partners should be enlisted to the cause, and monitoring and research efforts of the various Bay partner agencies and institutions should be better integrated.
 - Integrated trophic/ecosystem monitoring must be initiated. This is likely to be an iterative process and can begin with smaller projects in collaboration with others (e.g., NCBO) and taking advantage of strategic ‘samples of opportunity’.

- There needs to be a focused effort to educate and market internally the concept of and need for an integrated trophic level monitoring program (that would include zooplankton)
- The over-arching questions around which such a monitoring program would be designed must be formulated. Many, if not most of those questions have been articulated in this workshop.
- From these questions, lists of related modeling and research needs would follow.
- The existing analytical capability of Bay partners should be harnessed and directed toward these information needs;
- Bay partners should contribute increased funding in order to attract academics and others to apply their talents toward these information needs.
- Zooplankton monitoring program design is critical and very much dependent on funding level.
- It is not enough to demonstrate the linkages from ‘source to resource’, but sampling and analysis must be geared toward management applications.

Appendix A

Workshop Agenda

Chesapeake Bay Zooplankton/Food Web Monitoring Workshop
January 12-13, 2005

DAY 1 January 12, 2005

- 08:30-08:45 Welcome.....Sellner
- 08:45-09:15 Management applications of zooplankton/foodweb indicators and metrics.....Batiuk, Wood
- 09:15-10:30 External Experts' presentations: Management indicators and metrics for other systems:
Wim Kimmerer, Tiburon Laboratory, San Francisco State University
Mike Pace, Institute of Ecosystem Studies, New York
Barbara Sullivan, Graduate School of Oceanography, University of Rhode Island
- 10:45-12:00 Project Team presentations of metrics/indicators in new project for fisheries/ecosystem management.....Lacouture et al.
- 01:30-02:15 Project Team presentations of metrics/indicators in new project for water quality management.....Lacouture et al.
- 02:30-04:45 Discussion of new project from the Fisheries and Water Quality Management Perspectives..... Wood
- 04:45-05:00 Plenary: Where do we stand, homework assignments, logistics update.....Sellner

DAY 2 January 13, 2005

- 08:30-08:45 Plenary: Re-energize groups and outline day's program.....Sellner
- 08:45-12:00 Participants discuss new food web project from the fisheries and water quality management perspectives.....Wood
- 01:30-03:00 Plenary: Decision summary and recommendations.....Wood
- 03:00 Adjourn
- 03:15-04:30 Steering Committee and external experts to discuss recommendations

Appendix B

Participant List

Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Workshop Chair:

Robert (Bob) Wood, NOAA's director of the Oxford Cooperative Laboratory, Oxford, MD

Steering Committee:

Kevin Sellner, Director, CRC
Richard Batiuk, Chesapeake Bay Program, Associate Director for Science
Denise Breitburg, SERC
Mike Fritz, Chesapeake Bay Program, Living Resources Subcommittee Coordinator
Richard Lacouture, Morgan State University Environmental research Center

Steering Committee Data Manager & Historian

Jackie Johnson, ICPRB

Project and Project Support Team:

Richard Lacouture, Morgan State University Environmental Research Center
Stella Sellner, Morgan State University Environmental Research Center
Denise Breitburg, Smithsonian Environmental Research Center
William Burton, Versar, Inc
Christine Sillett, Versar, Inc
Claire Buchanan, ICPRB
Jackie Johnson, ICPRB

Invited External Reviewers

Will Kimmerer, Tiburon Laboratory, San Francisco State University
Mike Pace, Institute of Ecosystem Studies
Barbara Sullivan, Graduate School of Oceanography, University of Rhode Island

Rappoteurs

Meghan Leavey, CRC
Kenna Osgood, CRC

Participants

Steve Giordano, NCBO
Dave Kimmel, HPL-UMCES
Mary Ellen Ley, USGS
Roberto Llanso, Versar, Inc.
Bruce Michael, MD DNR
Marcia Olson, NCBO
Mike Roman, HPL-UMCES

Peter Tango, MD DNR
Howard Townsend, NCBO
Jim Uphoff, MD DNR

Appendix C

Reconstruction of the PowerPoint presentation
by
Richard Batiuk, Associate Director for Science
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Management Applications of Zooplankton/Food Web Indicators and Metrics

Workshop Charge:

- Review of the proposed zooplankton community indices and metrics;
- Identification of other additional and/or alternative indices, metric, diagnostic tools;
- Consensus on the specific measures of zooplankton community speciation, abundance, biomass, and related ecosystem/rate;
- Recommendations for refinements/changes to the design of the zooplankton monitoring program.

Management Application:

- Provide interpreted information for the purpose of informing and influencing decisions having a direct effect on restoration of the Chesapeake Bay ecosystem.

Key to Management Application:

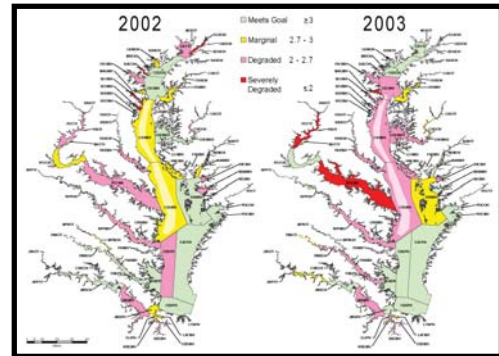
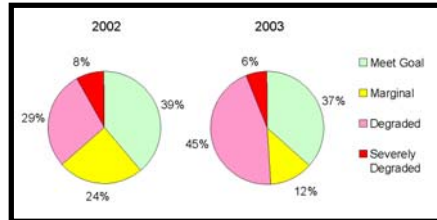
- Index it – no Latin names to deal with
- Map it—make it have geographic relevance
- Relate it to the Bay ‘holy trinity’ (oysters, crabs, striped bass)
- Provide for diagnostics to connect with manageable entity (e.g., loadings, harvest, habitat)
- Place it directly into a management decision-making framework

Opportunities for Influencing Management Decisions:

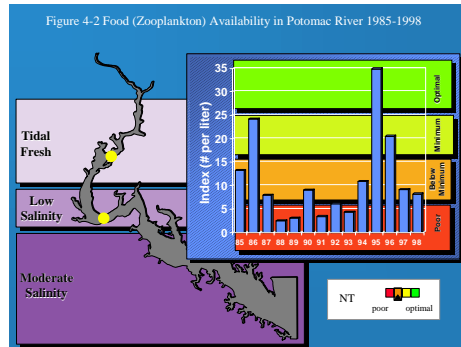
- Assessing contributions for fisheries production
 - Zooplankton as quality food index
 - Larval fish food availability
 - Gelatinous zooplankton predation potential
- Understanding effects on fisheries production through zooplankton community responses to external stressors
 - Zooplankton habitat quality index
 - Zooplankton as quality food index (species-specific)
 - Larval fish food availability
- Determining attainment of Open designated use habitat
 - Zooplankton community Index of Biotic Integrity
 - Zooplankton habitat quality index
 - Larval fish food availability
 - Zooplankton as quality food index

- Great opportunity for becoming part of the decision-making process for ‘listing’ and ‘delisting’ tidal waters – the benthic folks have done it!
- Calibration, verification and management application of water quality models linked to lower trophic levels
 - Zooplankton community abundance and composition measures
 - Zooplankton community rate process measures (e.g., filtration, predation rates)
- Development of new/refinement of existing Chesapeake Bay water quality criteria
 - Zooplankton habitat quality requirements
 - Zooplankton habitat quality index
 - Factoring in zooplankton oxygen requirements to the oxygen minima needed by critical Bay species
- Communicating the ‘State of the Bay’
 - Zooplankton community index of biotic integrity
 - Zooplankton habitat quality index
 - Larval fish food availability index
 - Zooplankton community index components of an encompassing “state of the Chesapeake Bay Ecosystem” report system

Example of the benthic status report



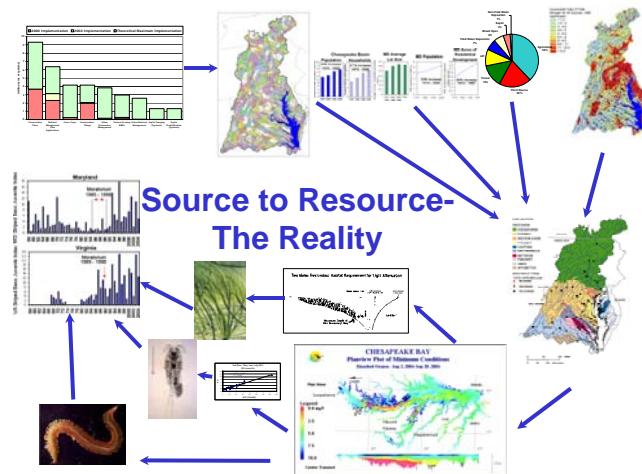
Example of Food Availability



- Understanding current and projecting future ecosystem responses to restoration efforts
 - Zooplankton community abundance and composition diagnostics (detecting and explaining community/abundance shifts)
- Detecting exotic species
 - Zooplankton species identification and enumeration

Immediate opportunities for influence

- Communicating “How the Bay’s doing” through the redesigned Chesapeake Bay Program indicators
- State decision-making on ‘303(d)’ lists for tidal waters: ‘to list or de-list’
- Providing real “how’s the Bay ecosystem faring” feedback to Tributary Strategy implementation



- Framing how we are going to manage multiple species using ecosystem-based principles

Appendix D

Reconstruction of the PowerPoint presentation
by
Bob Wood, NOAA's director for the Cooperative Oxford Laboratory
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Potential for management application of a zooplankton monitoring survey

Key to Management Application:

- Index it – no Latin names to deal with
- Map it—make it have geographic relevance
- Relate it to the Bay 'holy trinity'
- Provide for diagnostics to connect with manageable entity (e.g., loadings, harvest, habitat)
- Place directly into a management decision-making framework

Data Application Goals:

- Assess zooplankton population status
- Evaluate stressors on zooplankton populations
 - Manageable (e.g., eutrophication)
 - Unmanageable (e.g., climate variability, disease)
- Define consequences of poor zooplankton condition...why does it matter/
 - for fisheries
 - for water quality
- Provide scientifically-based index of ecosystem 'health'

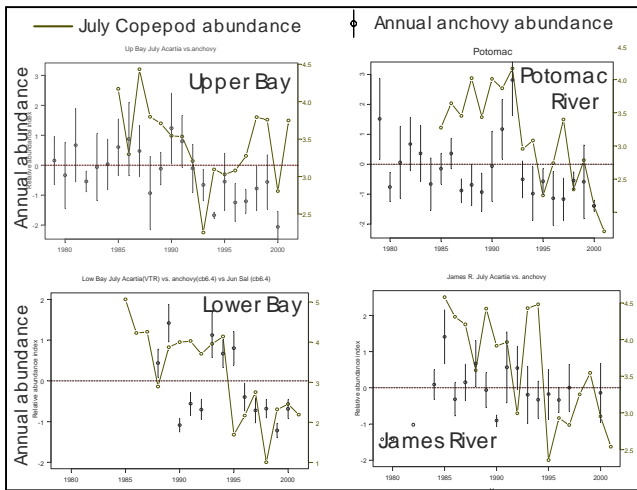
The Key:

- The value of the monitoring data will be limited by
 - spatial resolution and extent
 - temporal frequency and time series length
- These are limited by money and design!

Exploiting an opportunity:

- The value of recent or ongoing efforts

- Statistical modeling
Sampling design: (old survey data)



- Anchovy example, using bioenergetic approach

Patterns in anchovy consumption: Are climate-zooplankton linkages impacting fisheries through the forage base?

$$\text{Consumption} = \text{Metabolic loss} + \text{Waste} + \text{Growth}$$

$$C = C_{\max} \times P\text{-value} \times f(T)$$

$$C_{\max} = a \times (\text{Weight of fish})^b$$

where

C_{\max} = maximum feeding rate standardized to grams of fish ($\text{g} \cdot \text{g}^{-1} \cdot \text{d}^{-1}$),

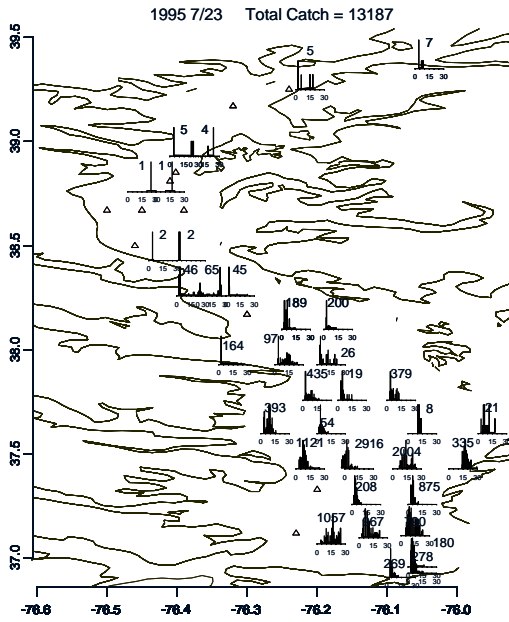
a = intercept of the weight dependence function,

b = weight dependence coefficient, and

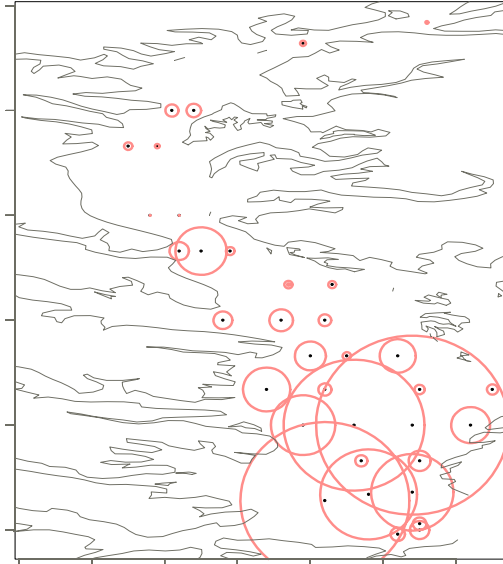
$f(T)$ = water temperature dependence function for warm water fishes.

Example 1995- dry & poor anchovy recruitment

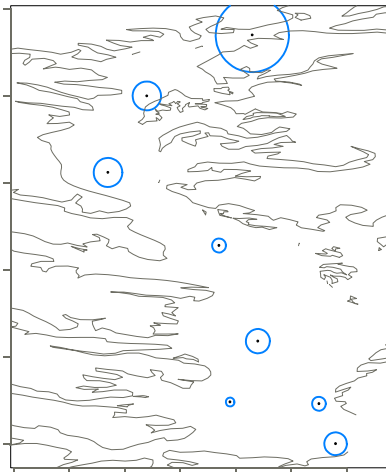
Larval anchovy sampling



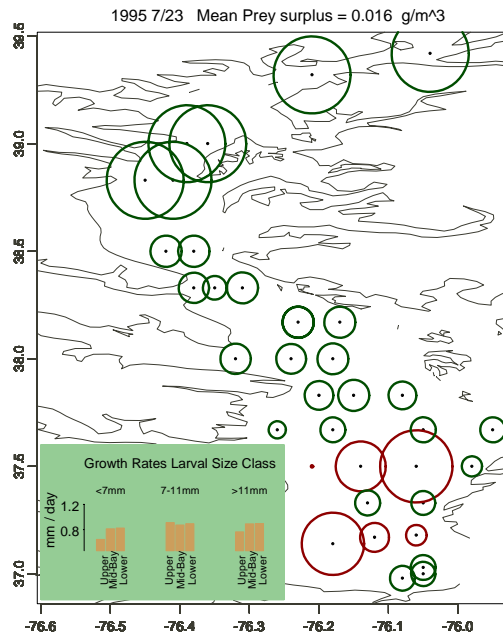
Larval anchovy consumption



Prey (zooplankton) density

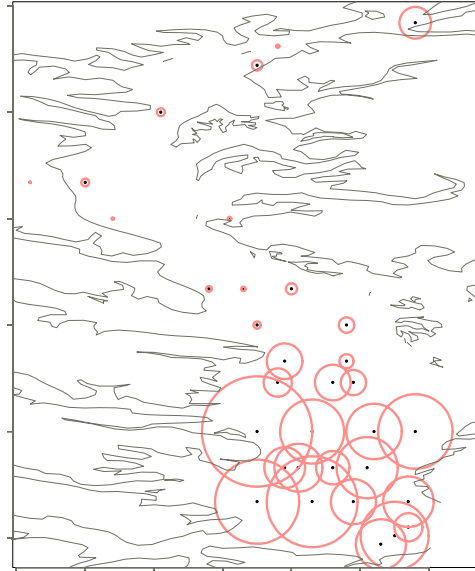


Anchovy Growth rates

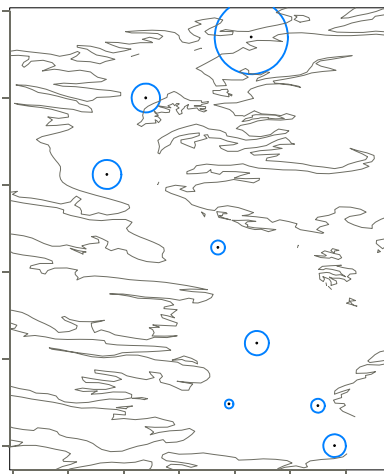


Example 1998-wet & good anchovy recruitment

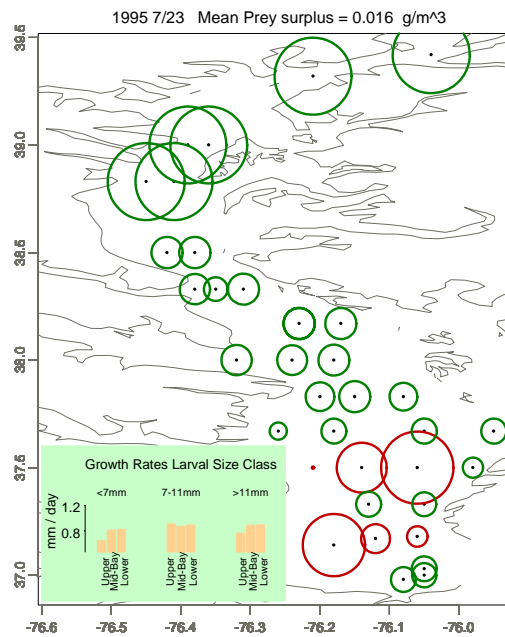
Larval anchovy consumption



Prey (zooplankton) density



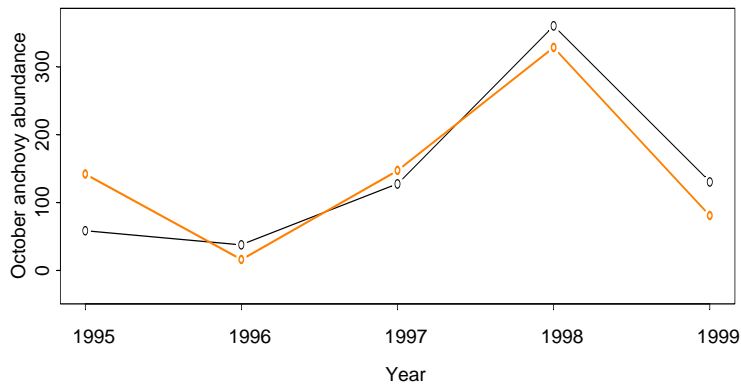
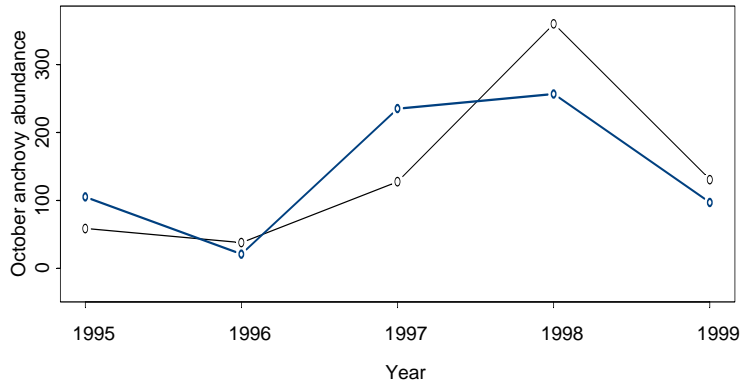
Anchovy Growth rates



Example: Predicting October recruitment from July larval abundance and consumption surplus

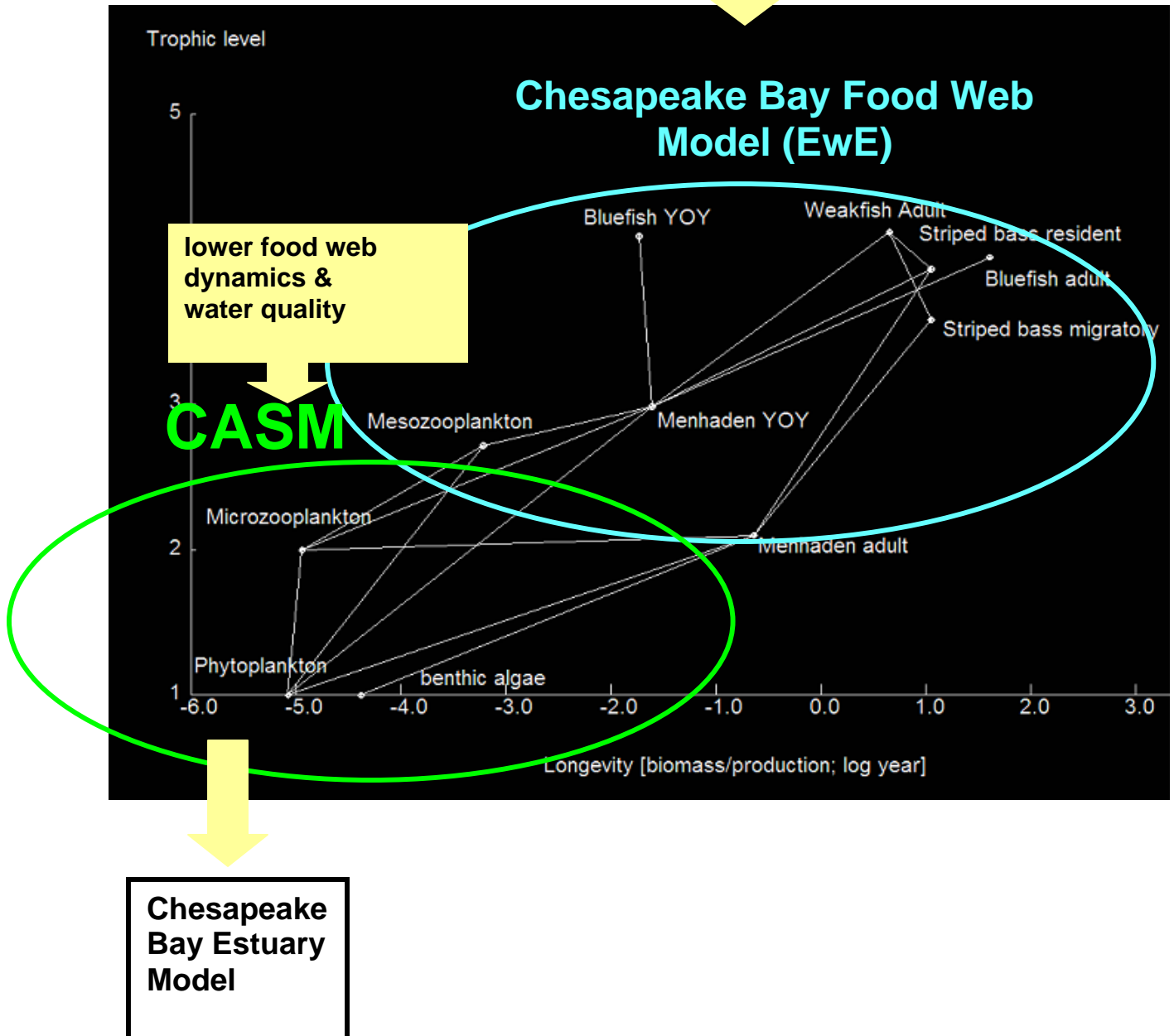
Top figure: with larval abundance only, explains 61% of variance

Bottom figure: larval abundance plus consumption surplus explains 83% of variance



- Process modeling (an example)
 - Integrates models across scales
 - Likely relies heavily on multi-species survey information
 - Provides full view of *source-to-resource* or air & watersheds to fisheries yield

Response of commercially important species fisheries exploitation forcing

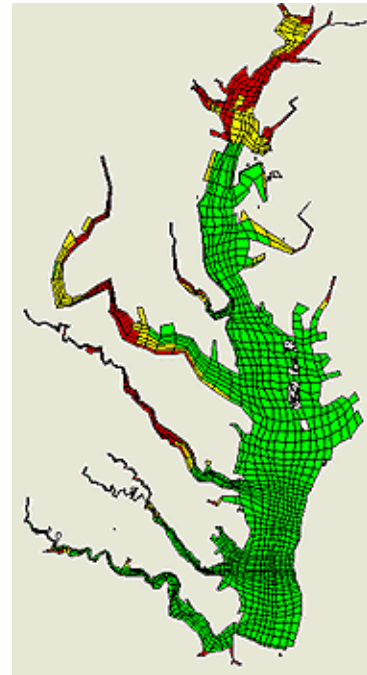
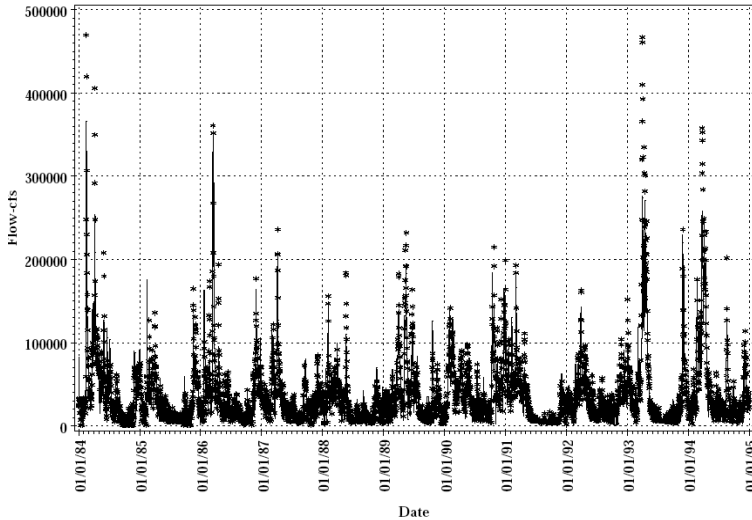


Bay Program's estuarine model or water quality model.

10,000 computational cells; average cell size = 6 m x 5 m x 5 ft
 up to 15 depth layers
 time steps as short as 5 minutes

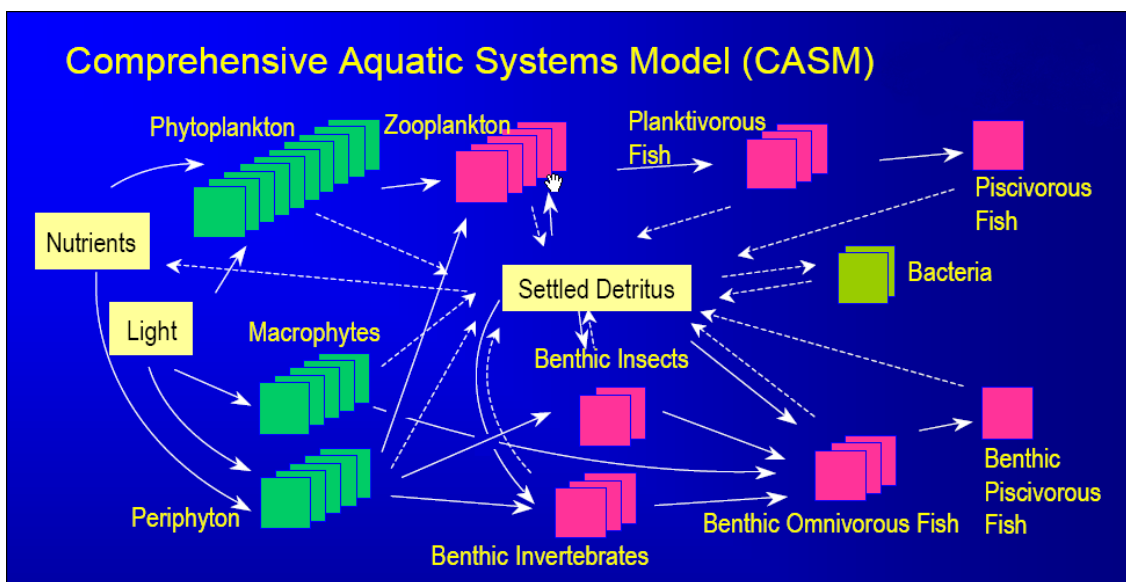
Sediment, Nutrients, Water Quality

FIG. 14a. Susquehanna River at Conowingo Dam Observed and Simulated Flow
 (*=Observed, -=Simulated)

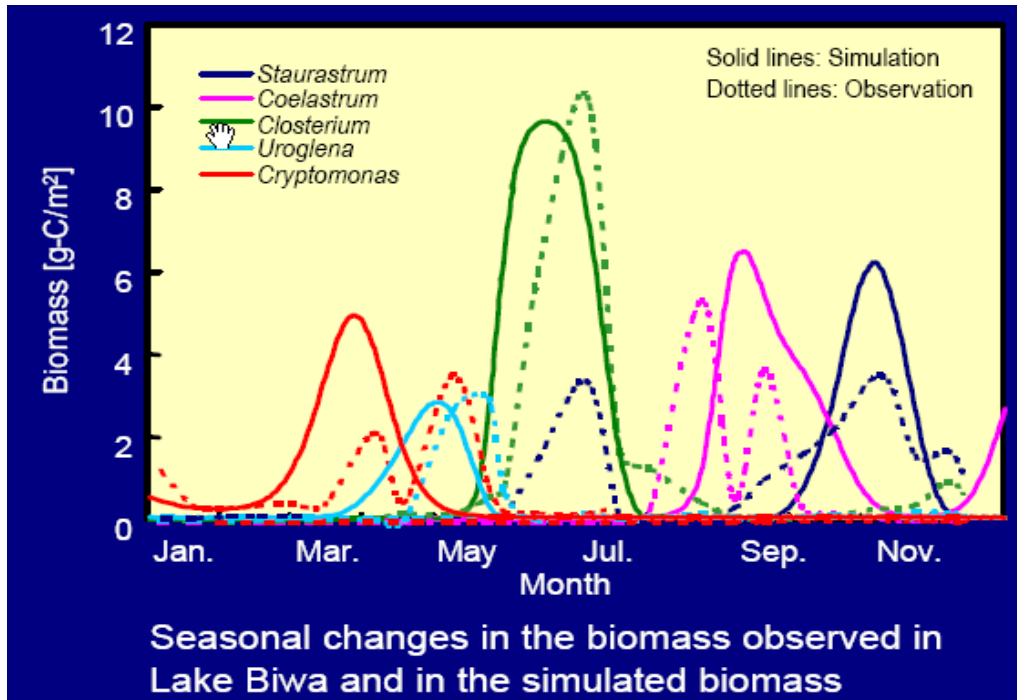


CASM model estimates changes in biomass based upon bioenergetics

- Requires diet information
- Time steps of days
- Best used on lower trophic levels

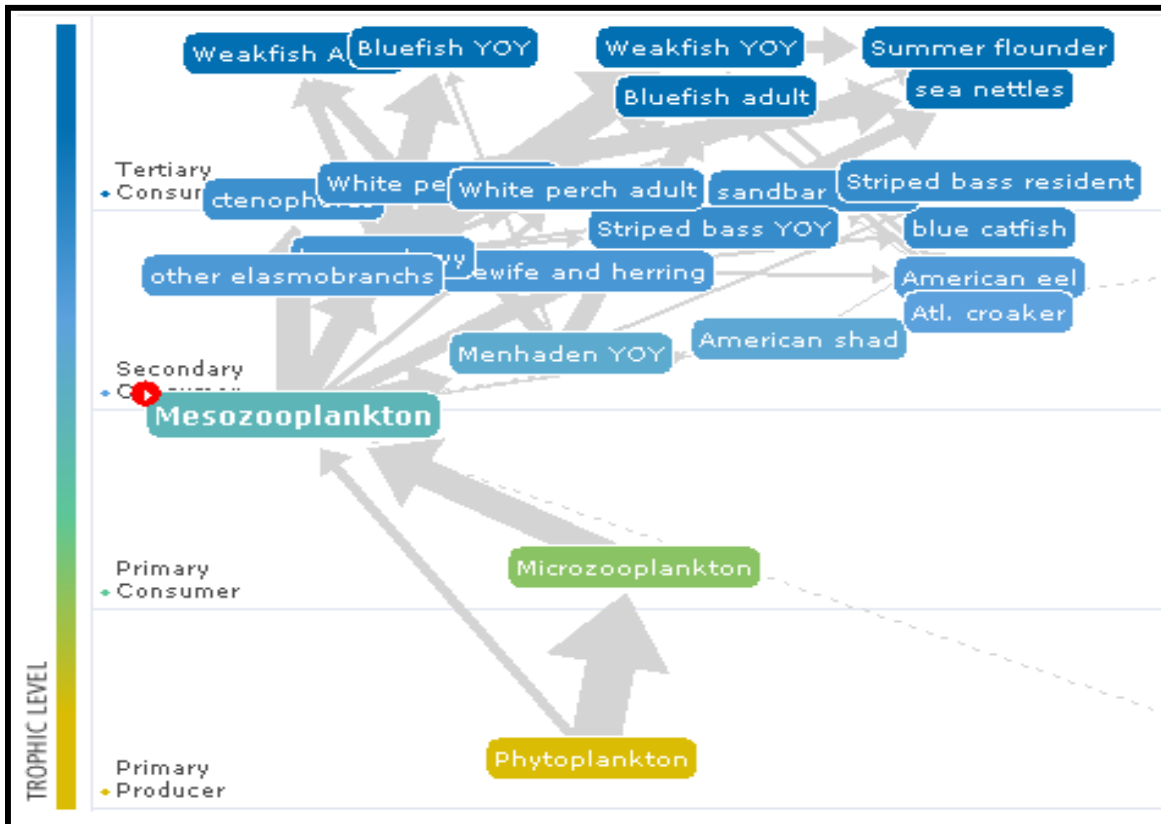


CASM's temporal resolution



Chesapeake Bay Fisheries Ecosystem Model (aka Ecopath with Ecosim, EWE)

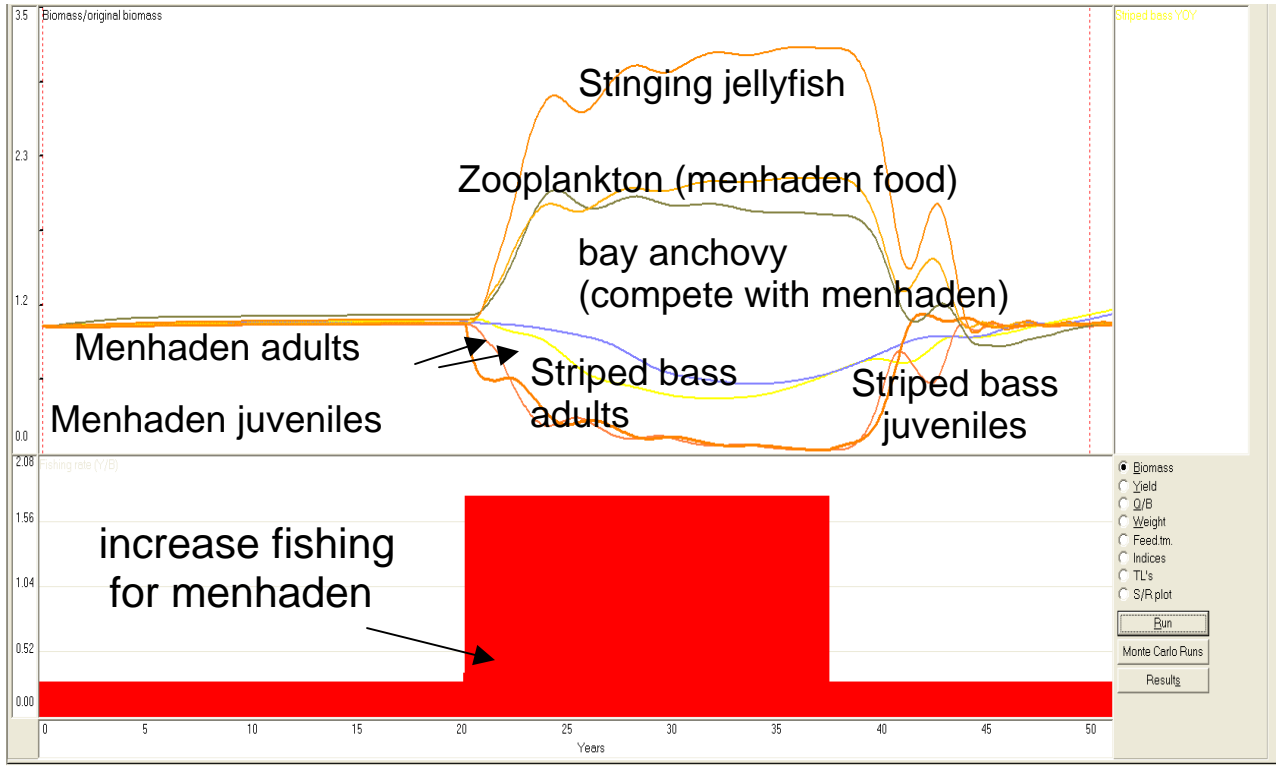
- EWE is a network analysis food web model
- Fishery ecosystem orientation
- Fisheries explicitly included in order to test management scenarios
- Various other forcing functions available



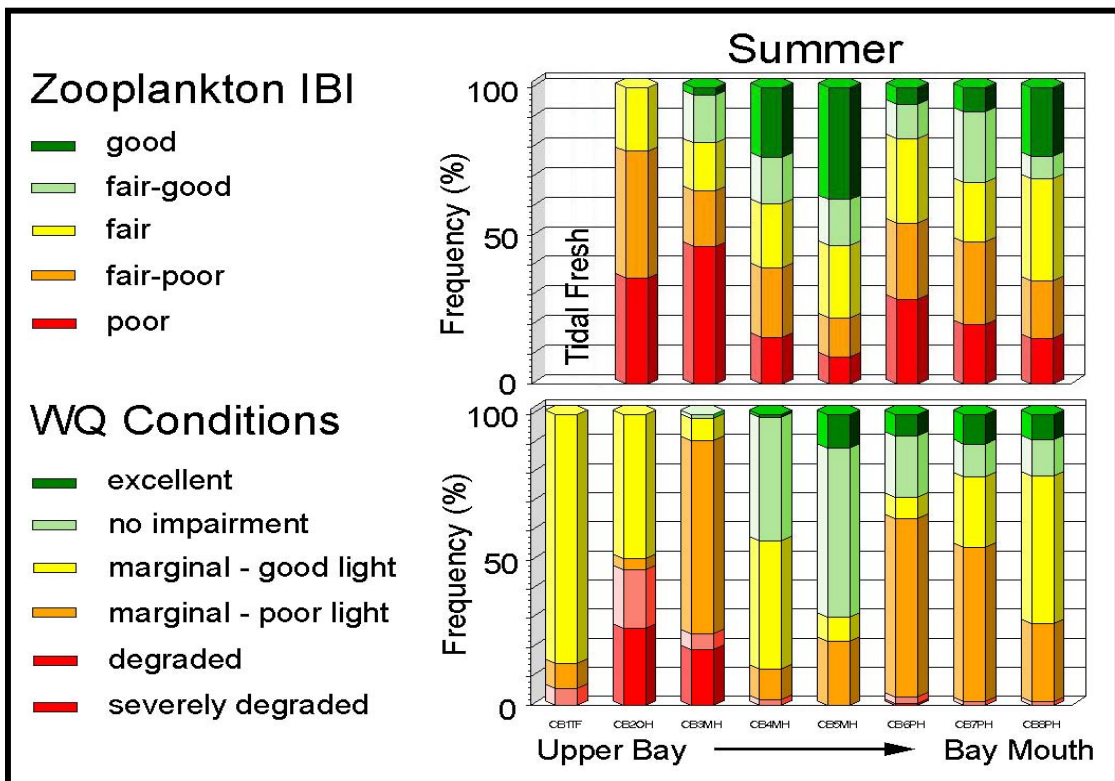
Required information

- B Biomass (tons per km²)
- P/B Production/biomass (tons per km² per year)
- Q/B Consumption/biomass (tons per km² per year)
- EE Ectrophic efficiency (proportion)
- DC Diet composition (proportion)
- Time series data are useful when available

EWE Simulation scales



Zooplankton Metrics / Indices



Remarks

Zooplankton monitoring...

- Design is critical but limited by realities (\$);
- Old monitoring survey provided a very useful (not perfect), yet Underutilized, data set;
- Source to resource, but also sampling to management application;
- Must attract Bay Program Partner resources
 - Better harness and coordinate existing analyst power
 - Tap into partner \$ to attract broad interest of academics

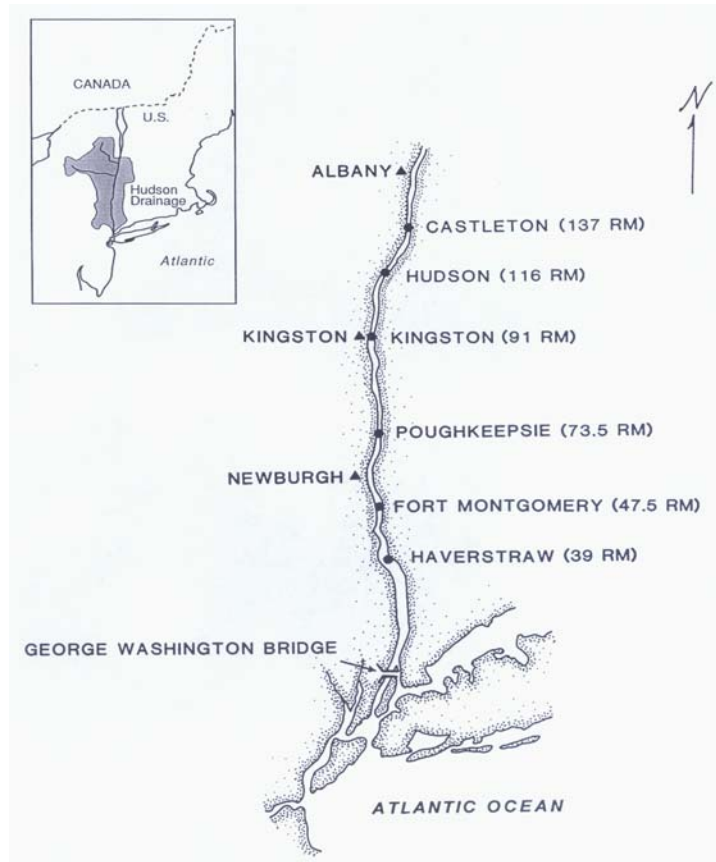
Appendix E

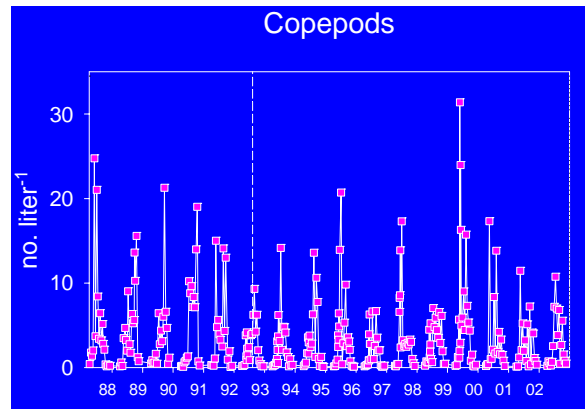
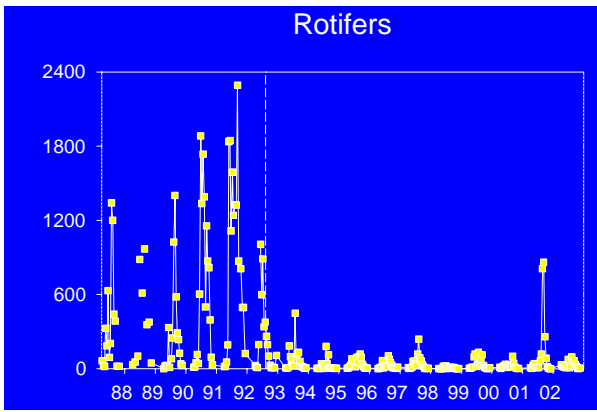
Reconstruction of the PowerPoint presentation
by
Mike Pace, Institute of Ecosystem Studies
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Two Examples from Zooplankton Time Series

- Zebra mussel (*Dreissena polymorpha*) invasion of the Hudson River
 - Differential impact on small zooplankton
 - Fast dynamics (sampling problem)
 - Long term data reveal flow/grazer interactions
- Experimental lakes
 - Importance of large zooplankton in determining responses to increased nutrient loading

Hudson River Estuary





→

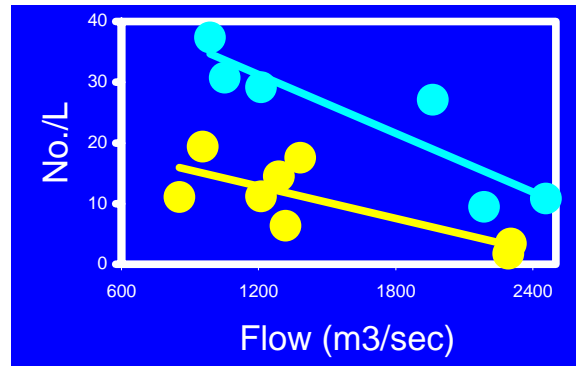
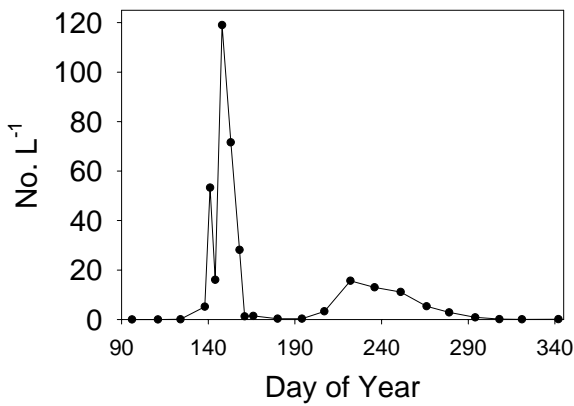
Zebra mussels

→

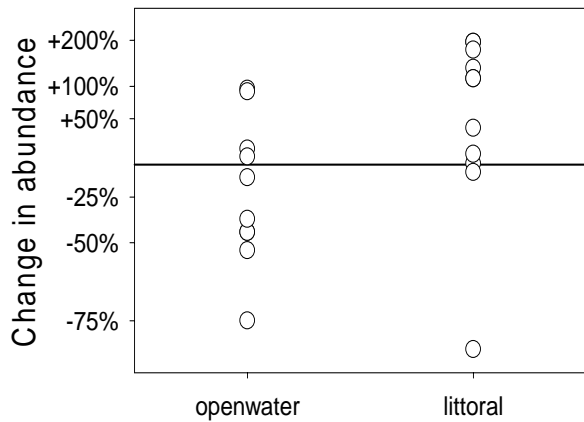
Zebra mussel invasion caused top down depression of rotifers and cladocerans, but copepods seemed unaffected. Shift in spatial distributions of fishes was observed: pre-invasion, open-water dominated; post-invasion, littoral zone dominated.

Cladoceran Abundance

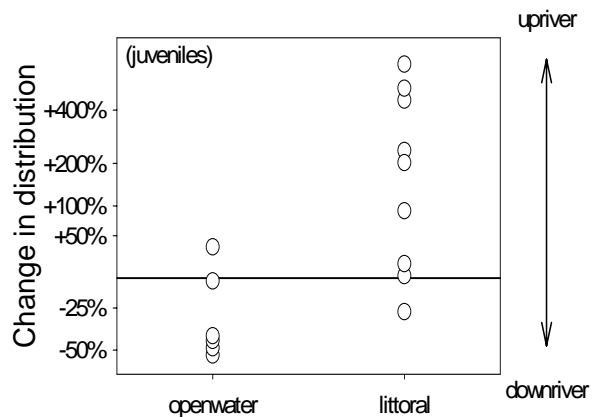
Hudson River *Bosmina* (1999)



Early life history stages of fish that are “open water” have declined

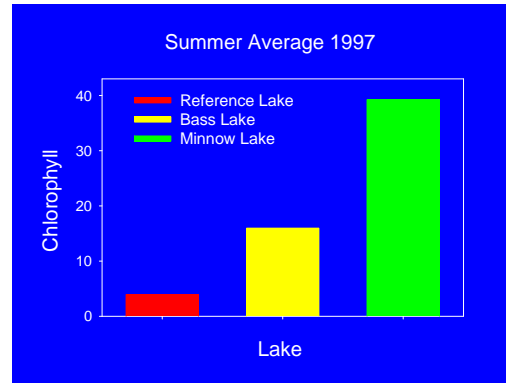
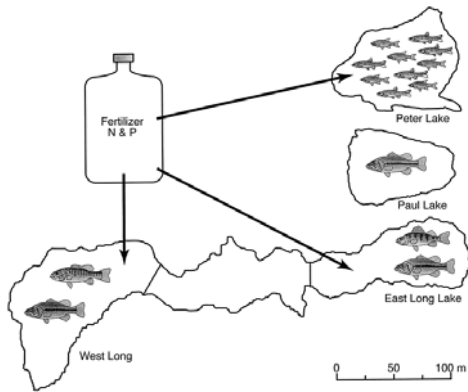


Populations have shifted in the river



Lake Studies

Peter and Paul Lakes, University of Notre Dame Environmental Research Center (UNDERC)



Bass and Minnow Lakes fertilized with N and P. Fish community contrasts (bass vs. minnow dominance) create contrasts in zooplankton size and grazing.

Lessons and Thoughts

- Size structure key feature of zooplankton communities
 - Microzooplankton reveal zebra mussel impacts in the Hudson
 - Large-bodied *Daphnia* critical for limiting phytoplankton in enriched lakes
- Problem of fast dynamics
- Some interactions likely only revealed by long-term observations
- Monitoring programs need to expect the unexpected

Appendix F

Reconstruction of the PowerPoint presentation
by
Wim Kimmerer
Romberg Tiburon Center for Environmental Studies
San Francisco State University
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Some thoughts on assessment and indicators based on work in the San Francisco Estuary

- Assessment in CALFED Program
- Zooplankton analyses and patterns

A few facts about the CALFED program

- Ended the California water wars in 1994
- Big program (similar scale to Chesapeake)
- Presentation focus: Ecosystem Restoration Program

About the estuary

- Low productivity
- Amur river clam invaded in 1986-87
- Strongest effect on phytoplankton in summer
- Muted response of fish and zooplankton

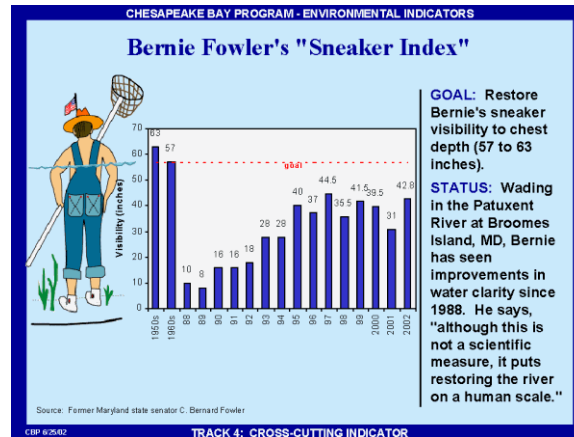
Some fundamental problems for assessment

- Multiple goals for different subsystems
 - Tidal, riverine, riparian, floodplain, ...
- Complex web of interactions
 - Causal relationships numerous and subtle
 - System is drastically altered
 - Only one state, but it's a big one!
- Impetus for action outstrips knowledge
 - Actions got ahead of planning
 - Still trying to catch up

What we want: Simple metrics related to key ecosystem response

Chesapeake Bay:

watershed land use →
nutrient loading →
high primary production →
high turbidity →
low oxygen →
loss of benthos



What we get: Numerous metrics

Multiple (conflicting) goals
Numerous target variables
Many ecosystem responses
Multiple forcing factors

...and we have not yet figured out what these metrics should be.

Goals of the San Francisco Bay's Ecosystem Restoration Program

- Rehabilitate natural processes
- Sustain populations for harvest
- Recover at-risk native species
- Protect functional habitats
- Reduce impacts of introduced species
- Reduce impacts of toxic substances
- Recover at-risk native species
 - 8 fish, 1 mammal, 2 birds, 2 insects, 6 plants
 - Contribute to recovery of 25 additional species
- Rehabilitate natural processes
 - Freshwater flow, geomorphic & riparian processes,....
- Sustain populations for harvest
 - Salmon, sturgeon, striped bass, black bass, shad,...
- Protect functional habitats
 - Floodplain, gravel-bedded river, tidal marsh, mudflat, open water, ...
- Reduce impacts of introduced species
 - Most plants, benthos, freshwater fish,
- Reduce impacts of toxic substances
 - Many agricultural chemicals, selenium, mercury,...

What are the leading Indicators?

The urbanized estuary – some key issues

- Loss of marshes
- Reduced variability
- Altered sediment budget
- Altered flow regimes
- Diversions from tidal freshwater
- Harvest
- Land use
- Toxic inputs
- Introduced species

The nature of the zooplankton data

- Long-term monitoring
 - Interagency Ecological Program
 - 1972 to present
 - Upper estuary only
 - 3 size classes
 - Abundance by species, genus
 - Limited taxonomic range
- Shorter-term projects
 - USGS (1978-1981)
 - Kimmerer and Bollens (1997-1999), lower estuary
- Biomass calculations
- First observation: Copepod densities have remained the same; however, size spectra of the taxa has changed tremendously.

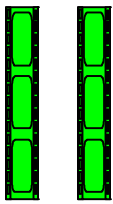
Summary

- Diatoms virtually gone from the northern estuary
- Change in copepods offset by new species, new size distribution
- Anchovies left this region, probably because of low food
- Copepods may have been released from predation
- A new environment for copepods = different species!

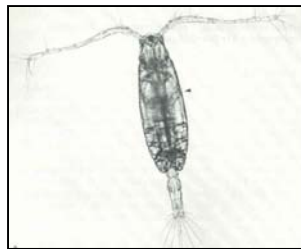
Appendix G

Reconstruction of the PowerPoint presentation
by
Barbara Sullivan
University of Rhode Island
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Climate Change, Nutrients, and Food Web Dynamics in Narragansett Bay-- Applications to Chesapeake Bay



Phytoplankton

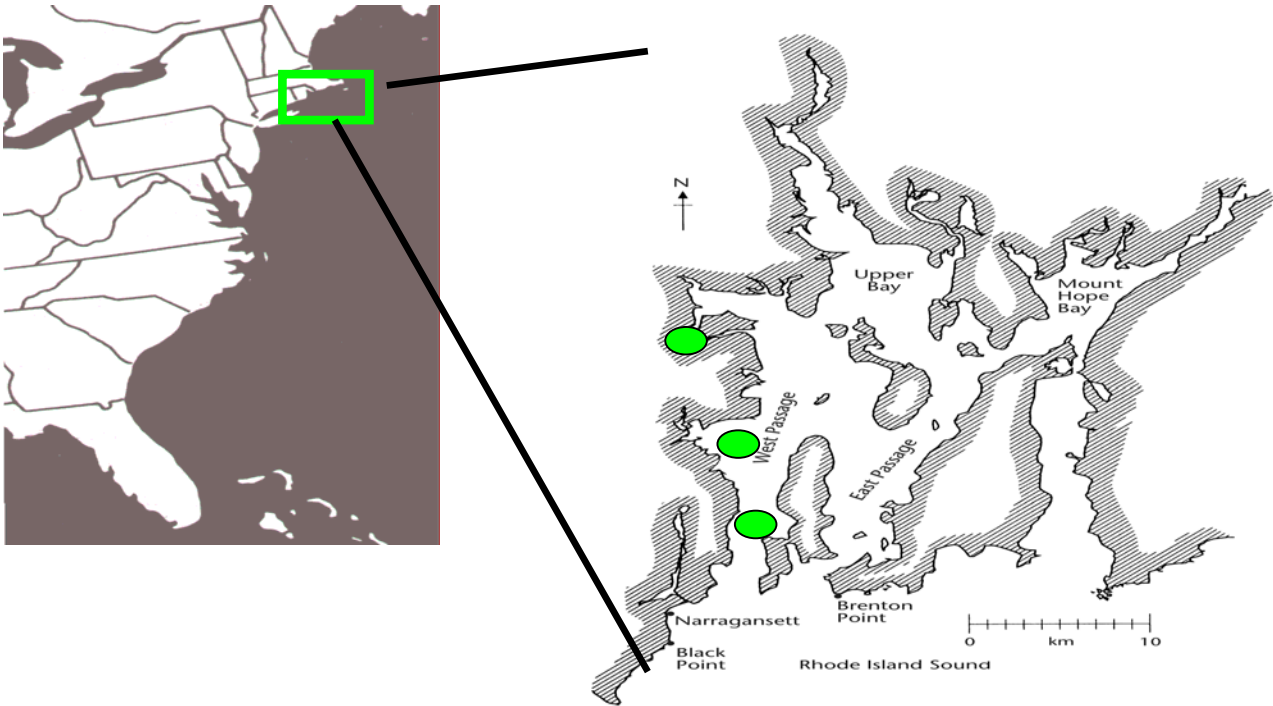


Copepods



Comb jellies

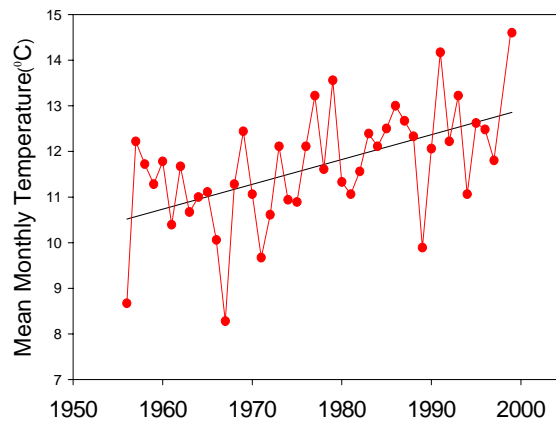
Narragansett Bay, Rhode Island USA



Weekly – all year
 Chlorophyll a
 Microzooplankton
 Mesozooplankton
 Jellies (ctenophores)

Station 1 (lower-most) low nutrient, 8 m
 Station 2 (middle station), med nutrient, 5 m
 Station 3 (upper-most), high nutrient, 4 m

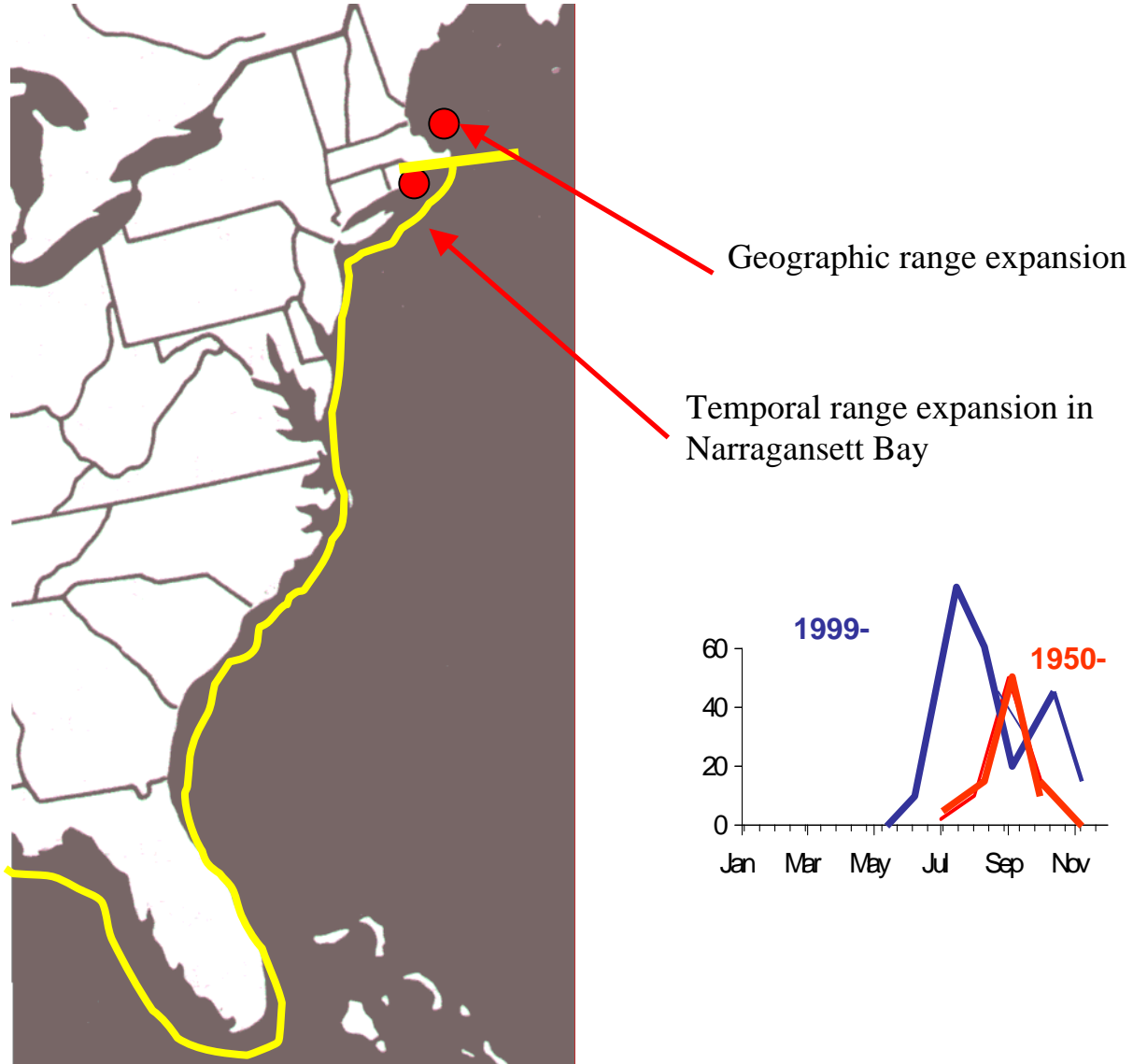
Temperatures in May 1955-2000



Temperature increases in Narragansett Bay are evident

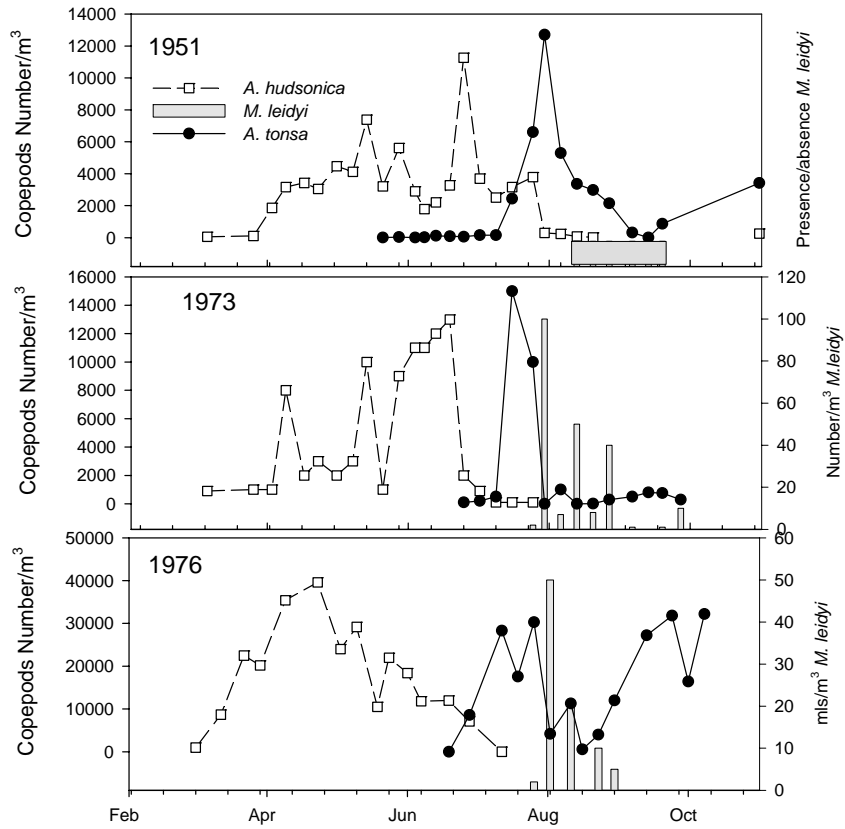
Changes in *Mnemiopsis* spp. Distribution in North America

1950-1979 vs 1999-2004

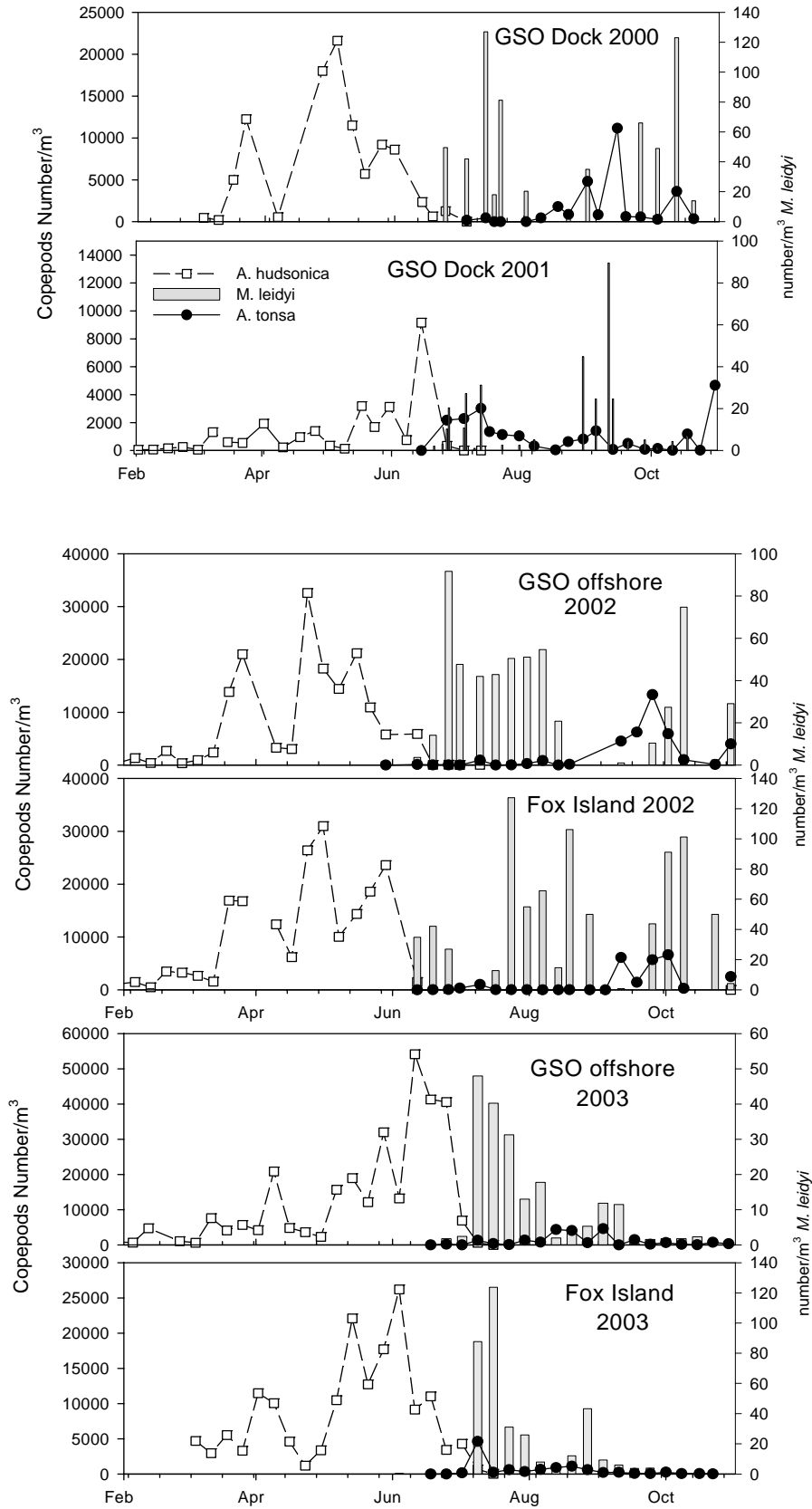


Detection of shift only possible with long-term data sets!

PAST: Significant summer copepod production



PRESENT: Summer copepods severely reduced



Appendix H

Reconstruction of the PowerPoint presentation
by
Richard Lacouture,
Morgan State Estuarine Research Center
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Overview

- **Goals of the workshop**
- **Historical CBP Zooplankton Monitoring Program**
- **The New Zooplankton Monitoring Program**

Goals of the workshop

- PI Goals – to clearly describe the program’s metrics, analytical tools, deliverables and goals, and to interact with the participants to attain the workshop’s goals;
- Workshop Goals – to assess the proposed new zooplankton monitoring program and produce a document which describes the consensus of the participants relative to the new program’s proposed work;
- Participant Goals – to share their knowledge and expertise and constructively assist in formulating the best zooplankton monitoring program for science and management of Chesapeake Bay

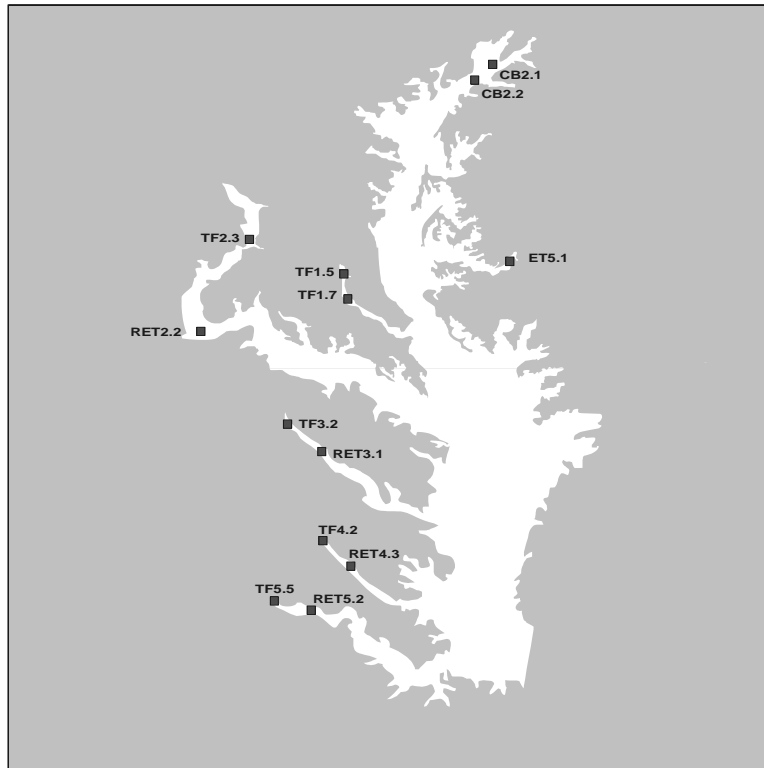
Historical CBP Zooplankton Monitoring Program

- Zooplankton monitoring was a component of the Chesapeake Bay Water Quality Monitoring Program from 1984-2002
- Sampling included 36 fixed sites in the Bay and its tributaries
- Mesozooplankton, microzooplankton and gelatinous zooplankton (MD only) were collected monthly (meso and microzooplankton were collected bi-weekly in April-May 1992-2002)
- Monitoring and analysis were conducted by different organizations in MD & VA with a total budget of \$358K.

The New Zooplankton Monitoring Program

- The focus of the new program was shaped by the management needs specified in CBP’s RFP and resulted in a project with two primary aims:
 - Spring sampling in tidal fresh/oligohaline waters in order to collect relevant information for spawning of anadromous fish.

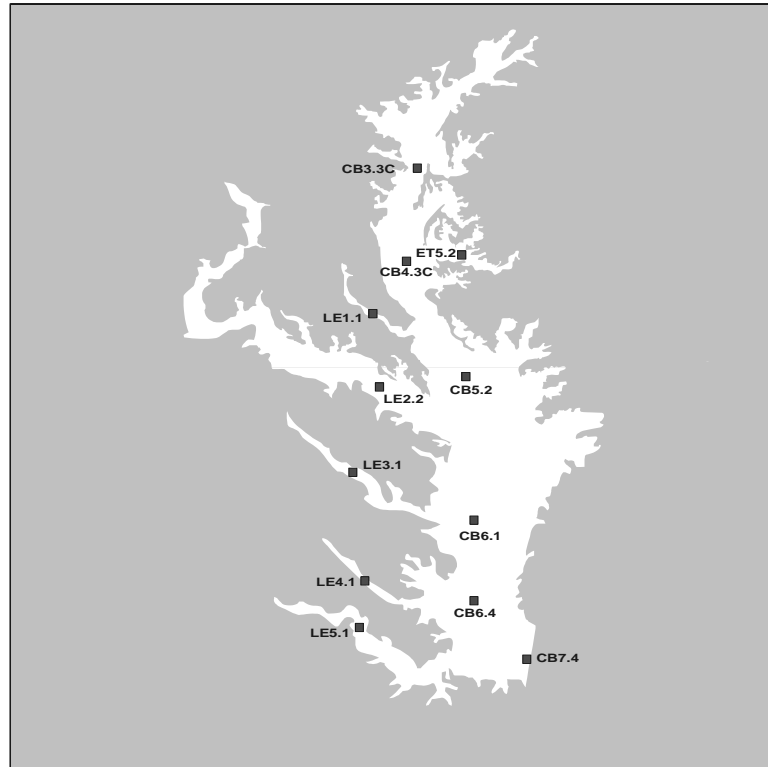
- Summer sampling in mesohaline/polyhaline waters to describe prey available for planktivorous forage fish, etc. and to characterize gelatinous zooplankton to assess potential impacts on the food web.
- Other considerations include: 1) historical continuity, 2) synoptic collections with other monitoring parameters, and 3) cost effectiveness for the available funds (\$217K).
- **Spring component**
 - *When* – 3 sampling events evenly spaced between early-April and mid-June (temperature as cue to begin).
 - *What* – mesozooplankton, net microzooplankton, and whole water microzooplankton.
 - *Where* – 13 sites in tidal fresh/oligohaline reaches of mainstem Bay and 6 tributaries.



- *How* – will be described for each metric in ensuing presentations (other appendices).

- **Summer component**

- When – 5 monthly cruises May-September.
- What – gelatinous zooplankton, mesozooplankton, net microzooplankton, and whole water microzooplankton.
- Where – 13 sites in mesohaline/polyhaline areas of the mainstem Bay and 6 tributaries.



- How – methods will be described for each metric in presentations to follow.

- **Data and QAQC**

- A comprehensive data dictionary will be compiled in CBP-specified format to document all data elements, Standard Operating Procedures (SOPs) of field and lab techniques, and analytical tools that are used routinely in the project.
- Data will be delivered electronically in a CBP-approved format to be available on CIMS.
- 10 % of all meso- and microzooplankton samples will be recounted for QA/QC purposes and these data will be part of the annual data deliverable.

- **Deliverables**
 - Taxonomic abundance and biomass data for zooplankton.
 - Annual interpretive report containing:
 - Trend analysis of all zooplankton data in context with the historical program
 - Results of the zooplankton IBI
 - Results from the Food Availability Index
 - Results from the Larval Striped Bass Habitat Index
 - Interpretation of the impacts of gelatinous zooplankton on the Bay food web

- **Program Objectives**
 - Characterize communities in tidal fresh and oligohaline waters during spring to estimate prey available to early life stages of spawning anadromous fish.
 - Characterize zooplankton communities in mesohaline/polyhaline areas in late spring and summer to describe prey available to summer breeding fishes, juvenile fish, and planktivorous forage fish.
 - Characterize gelatinous zooplankton in mesohaline/polyhaline regions during late spring and summer to assess their relationship and potential impact to the food web as predators of and competitors to fish.
 - Provide a database that is consistent with historical zooplankton data and other existing CB monitoring program components in order to examine relationships between zooplankton, other trophic levels, and water quality parameters.
 - Provide a database that is useful to the various existing modeling efforts (water quality, trophic dynamics, and fisheries-oriented) and to those to be formulated in the future.

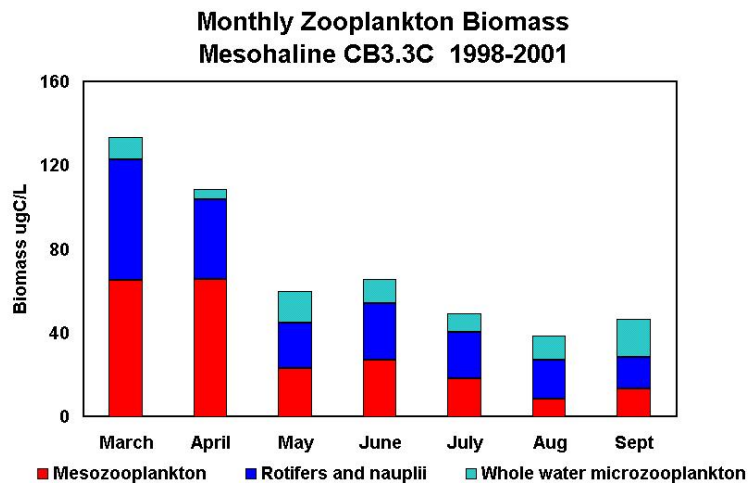
Appendix I

Reconstruction of the PowerPoint presentation
by
Stella Sellner
Morgan State Estuarine Research Center
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Microzooplankton Component

How Do We Define Microzooplankton?

- Classically, zooplankton from 20-200 μm
- Predominantly ciliated protozoans, copepod nauplii, rotifers, and various planktonic larvae. Some of these organisms are larger (e.g., large rotifers) than the upper range of classical microzooplankton and are included.
- $<20 \mu\text{m}$ protozoans can make up an important part of the biomass and density of the entire microzooplankton community and are included.
- In summary, microzooplankton includes classical microzooplankton taxa, some in an intermediate group of organisms that overlap micro- and mesozooplankton, and the $<20 \mu\text{m}$ group.

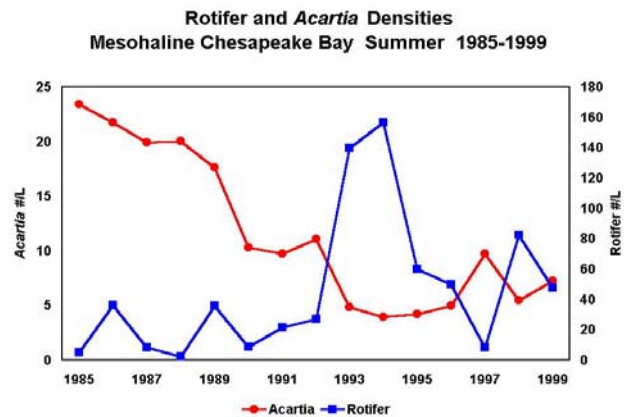
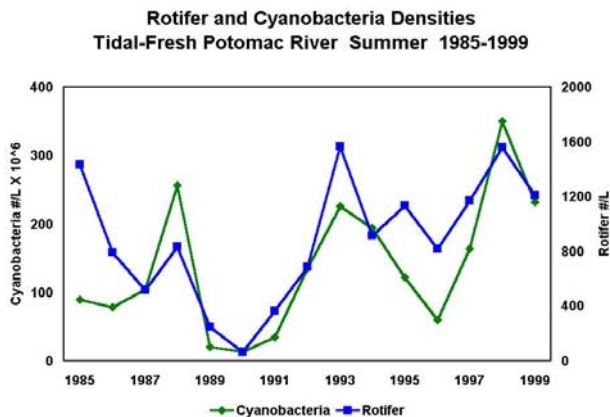


- In spring, microzooplankton make up 40-50% of zooplankton biomass.
- In summer, microzooplankton comprise 60-75% of total zooplankton biomass, with the smallest animals (from the whole water counts) contributing 0-40% to total biomass in August and September.

Overview of the Microzooplankton Component of the CBP Water Quality Monitoring Program (1984-2002)

- Maryland data – 1984-2002; Virginia data – 1993-2002.
- Abundance data are available at <http://www.chesapeakebay.net>.
- Maryland collected samples with a 44 µm mesh net, 1984 through 2002, and whole water samples at mesohaline stations 1998-2001.
- Split samples between states revealed that comparable metrics were rotifer and copepod nauplii abundance and biomass.
- Trends were run for densities of major groups, rotifer and nauplii abundances were used in Larval Striped Bass Habitat Index, rotifer abundance was used in development of ZIBI, and simple trophic interactions were explored.

Some Findings: Trophic interactions



New Project Field Sampling Methods

- Locations – 26 stations throughout Bay and tributaries.
- Frequency – tidal fresh and oligohaline in spring (3 cruises, April-June) and mesohaline and polyhaline in summer (5 cruises, May-September).
- Two distinct methods for sample collection and enumeration are used in order to quantify ‘classic’ microzooplankton, those organisms that are not efficiently captured with a 202 µm net and smallest protozoans and fragile ciliates that are lost on the net.

Sample collection – Net Samples

- Larger, ‘hard’ bodied organisms will be collected using a diaphragm pump to pump water from each of 10 depths spread evenly over the entire water column into a submerged 44 µm mesh net and decanted into a jar containing buffered formalin (final concentration 2%).

Sample collection – Whole Water Samples

- Smaller and soft-bodied ciliated protozoans will be collected from 2 composite samples pumped from each of 10 depths (into a carboy) and decanted into a 500-ml bottle containing acid Lugol's solution (final concentration 2%).

Counting procedures

– Net Samples

- Overnight settling will be employed if a sample needs to be concentrated.
- 1-ml aliquot will be removed with a Hensen-Stempel pipet, transferred to a Sedgwick-Rafter cell, and counted at 100 x with a compound microscope.
- At least one chamber will be counted for each sample, and if the total does not reach 250 organisms, subsequent 1-ml aliquots enumerated until a count of 250 organisms is obtained or 3 ml examined. If a certain organism is abundant (more than 60 per chamber), it will not be counted in subsequent aliquots.
- From net samples, larger 'hard' bodied organisms are counted.

- Whole Water Samples

- A 5 to 25-ml subsample will be removed from the sample jar, put into a settling chamber, and allowed to settle.
- The entire chamber will be examined and organisms counted at 250 X with an inverted microscope to obtain a minimum count of 100 organisms. If this number is not reached, another subsample will be counted. If an organism is abundant (>60), it will not be counted in the second subsample.
- From whole water samples, smaller organisms and all soft-bodied ciliates will be counted.

Data to be generated

- Density – (number L⁻¹) for species or groups and total community.
- Biomass – (ugC L⁻¹) for species or groups and total community.
- Species composition or size groups –
 - Needed for biomass calculations
 - Important to create “composite zooplankton” used in models
 - Potential for long-term shifts in functional groups or species

Significance of Microzooplankton

- Chesapeake Bay is a plankton-based system whose trophic structure is regulated by a combination of top-down (predation) and bottom-up control.
- Microzooplankton typically feed on bacteria, nanoflagellates, phytoplankton, and smaller microzooplankton and are prey for mesozooplankton, gelatinous zooplankton, and early stages of larval fish, making them important links in the food web of the Bay.

- Groups, e.g., rotifers, within the microzooplankton are known to be indicators of eutrophication and changes in their numbers and composition may reflect changes in the system.

Potential Uses for Microzooplankton Data

- Tropho-dynamic models
 - Ecopath with Ecosim – trophic mass balance model - uses total microzooplankton biomass.
 - Zooplankton Suspension Feeder Model- spreadsheet model to provide estimates of zooplankton grazing impacts on phytoplankton – uses abundances and clearance rates of major groups within microzooplankton community.
 - CASM (part of zooplankton and benthic suspension-feeder modeling project) – model to provide predictions of the impacts of changes in zooplankton and benthic assemblages on phytoplankton – will use abundances and clearance rates of microzooplankton.
 - Chesapeake Bay Water Quality Model – uses microzooplankton biomass.
- Trophic Indicators
 - Larval Striped Bass Habitat Index - developed to assess environmental conditions for striped bass recruitment – uses spring copepod nauplii and rotifer biomass at spawning stations as part of food for larval striped bass.
 - Zooplankton Index of Biotic Integrity (ZIBI) – characterizes environmental conditions in summer mesohaline and polyhaline Bay and tributary sites - rotifer abundance is one of the metrics used.
 - Trophic interactions – establishment of simple trophic linkages that can be an evaluation tool for water quality changes in the system.
 - Early detection of invasive species.

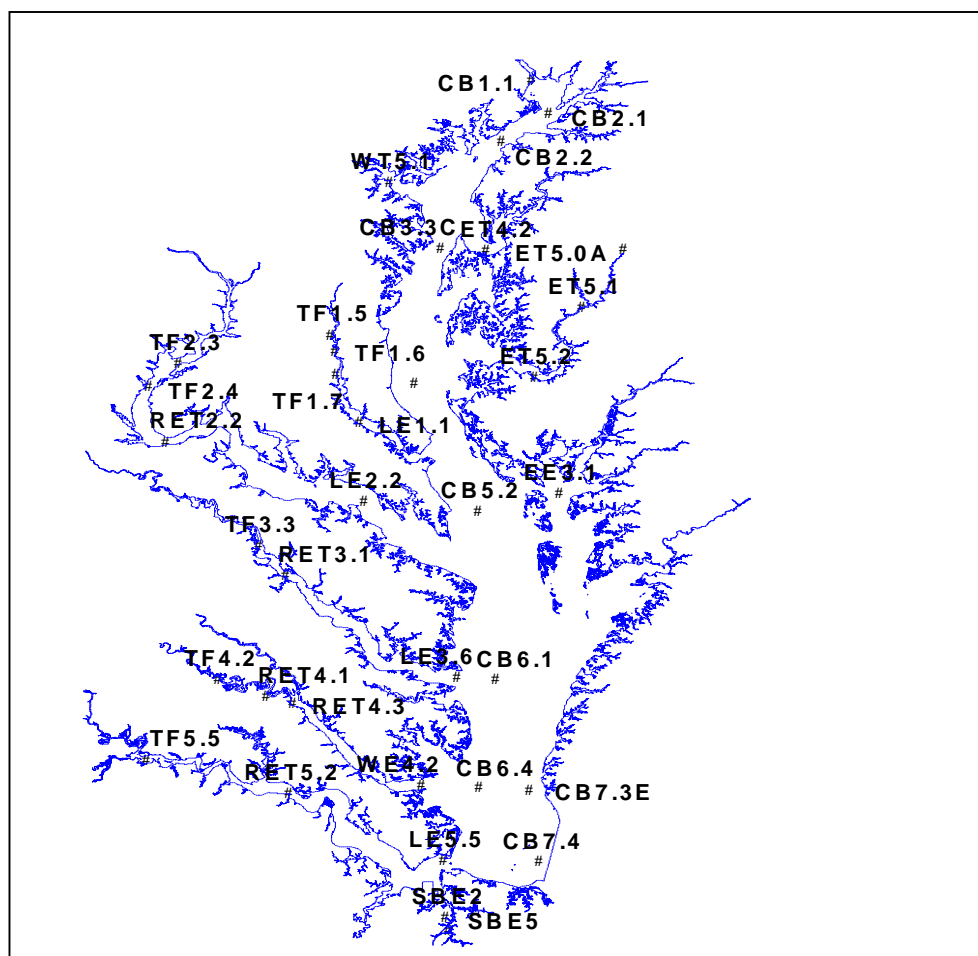
Appendix J

Reconstruction of the PowerPoint presentation
by
William Burton
Versar, Inc
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Mesozooplankton Component

Estimates of mesozooplankton species composition (organisms $\geq 202 \mu\text{m}$): species and life-stage identification (adult or copepodite for calanoid copepods; abundance (number m^{-3}); and biomass ($\mu\text{gC m}^{-3}$, estimated from count data).

Chesapeake Bay mesozooplankton monitoring began in Maryland in 1985, in Virginia in 1986. In Maryland, 14 stations, and in Virginia, 16 stations, were sampled continuously for 17 years, through 2002 (see map below). Over this time, there were some shifts in stations and changes in lab and field methods. Replicates were composited in 1996 and thereafter.



Data Analysis

Data analysis in early years focused on

- Describing season and yearly patterns in species composition and abundance;

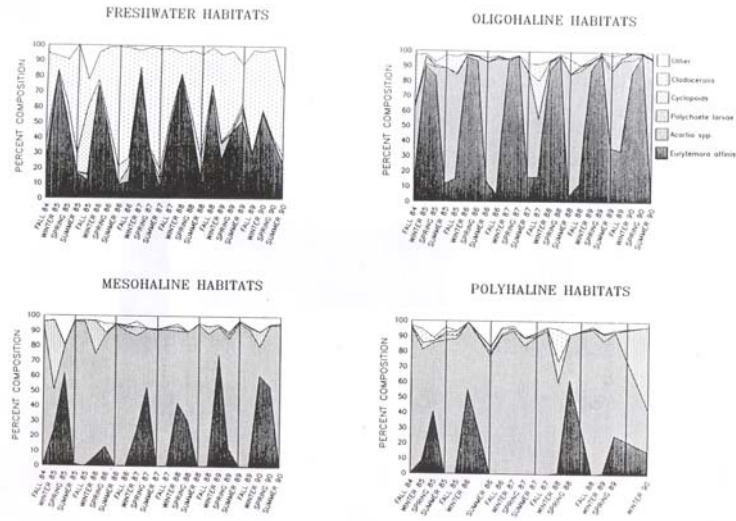


Figure 3-3. Percent composition of zooplankton species groups in freshwater, oligohaline, mesohaline, and polyhaline habitats for the August 1984-September 1990 sampling period

- Links between water quality changes and mesozooplankton (e.g., Patuxent River).

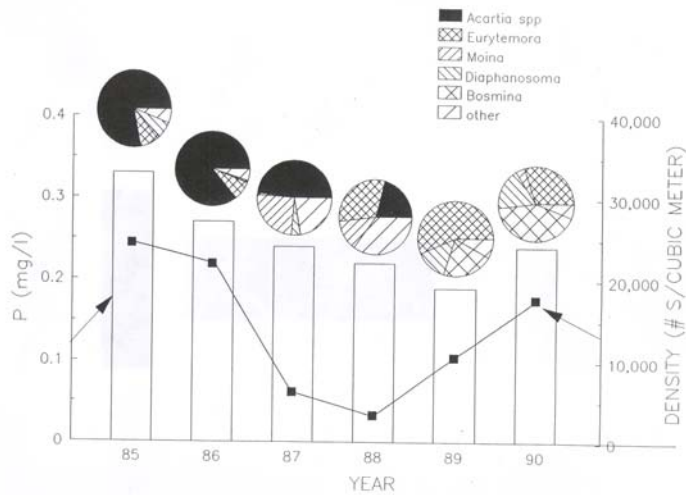


Figure 3-14. Relationship between phosphorus (histograms) and zooplankton density (boxes) at the upper Patuxent River station PXT0402 for the summer 1985-1990 period

The data base grew in the 1990s, yielding:

- Identification of the relationship between spring zooplankton densities to fish spawning success.

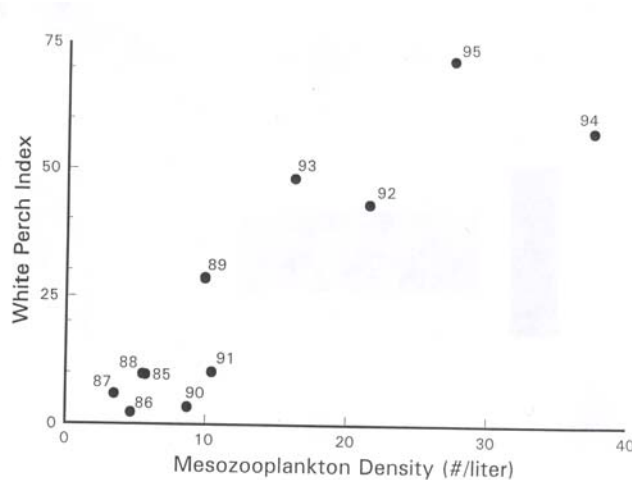


Figure 4-7. Relationship between spring mesozooplankton densities and the white perch juvenile index for the Patuxent River from 1985 through 1995.

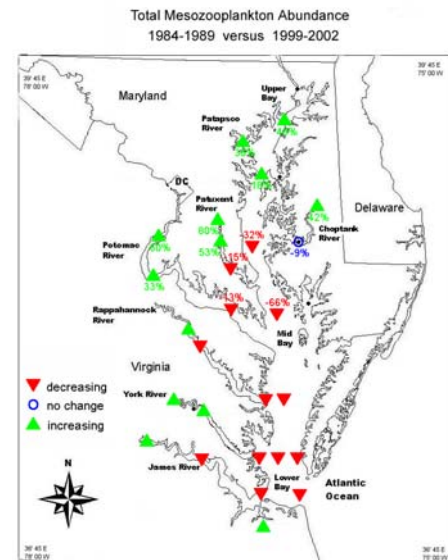
- Potential zooplankton indicators were investigated such as ratios between calanoid copepods and the sum of cladocerans and cyclopoid copepods

Assessing trends in the ratio of calanoid densities to the sum of cladoceran and cyclopoid densities between 1985 and 1999

<u>Region</u>	<u>Spring</u>	<u>Summer</u>	<u>Annual</u>
Choptank	-0.43 (p=0.03)	NT	-0.37 (p=0.05)
Patuxent	-0.46 (p=0.02)	-0.42 (p=0.02)	-0.50 (p=0.01)
Potomac	NT	-0.43 (p=0.02)	-0.33 (p=0.07)
Upper Bay	NT	NT	NT

- Relationships between blue-green algae blooms and *Bosmina* were examined, and

- By the mid-1990's, the data were used to investigate status and trends for Tributary strategies.
- Then, later focus shifted to the development of indices
 - Z-IBI polyhaline, summer
 - Z-IBI mesohaline, summer
 - Food availability index
 - Habitat suitability index



Major Findings of the 1984-2002 CBP Zooplankton Monitoring Program

- Zooplankton status in Chesapeake Bay is generally not good.
- Sharp declines in mesooplankton have occurred in mid Bay.
- The overall zooplankton food base is declining and shifting to smaller sizes.
- Ctenophore ('comb') jellyfish have gradually increased in the middle Bay while populations of the forage fish species that eat zooplankton have been declining.
- Despite improving trends in some tributaries, zooplankton food levels for migratory fish larvae are currently inadequate in most major spawning/nursery areas.

The New Food Web Monitoring Program

- Spring anadromous spawning area sampling in tidal fresh and oligohaline waters (3 events).
- Summer high salinity sampling in meso- and polyhaline waters (5 events).
- MD and VA stations.
- Consistent laboratory techniques for all collections.

Field methods

- Towed nets: 0.2 m, 202 μ m mesh bongo nets
- Water column partitioned into 5 depth-steps
- Two stepped oblique tows through the entire water column at each station
- 5- to 10-minute tows
- Replicate tows composited into 1 sample
- Filtered volume approximately 25 m³

Lab methods

- Aliquots removed using Hensen-Stempel pipettes
- Hierarchical counting technique employed

- Sample concentrated or diluted to facilitate counting
- At least 60 individuals of the most dominant forms in a small subsample (usually 1-2 mls) will be enumerated
- An additional count will follow where all species that had counts less than 60 in the previous subsample are counted in a 5- to 10-ml subsample
- Another sample count will enumerate species retained on an 850 um-mesh sieve not previously identified in the pipette samples
- Individuals will be identified to species and life-stage

Data Usefulness

- Estimate prey densities available to finfish species in spring and summer. Fish species that are dependent on zooplankton at some stage of their life include:
 - American shad
 - Hickory shad
 - Striped anchovy
 - Atlantic menhaden
 - Atlantic croaker
 - Atlantic herring
 - Atlantic silverside
 - Alewife
 - Bay anchovy
 - Black drum
 - Blueback herring
 - Red drum
 - Spot
 - Striped bass
 - Weakfish
 - White perch
 - Yellow perch
- Possible relationships between changes in zooplankton abundance and composition in relation to water quality conditions will be explored
- Species-specific counts will provide a means to bin data into various ecological groups for modeling
- Refine current zooplankton indicators
- Provide data for uses in water quality and ecosystem models
- Detect invasive species of zooplankton

Appendix K

Reconstruction of the PowerPoint presentation
by
Denise Breitburg
Smithsonian Environmental Research Center
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Gelatinous Zooplankton Component

2 dominant species:

Chrysaora quinquecirrha (scyphomedusa) and *Mnemiopsis leidyi* (lobate ctenophore)

Common gelatinous zooplankton in Chesapeake Bay are:

Scyphomedusae:

- Cyrosapra quinqucirrha* (sea nettle)
- Stomalaphus meleagris* (cannonball jelly)
- Cyanea capillata* (lion's mane)
- Aurelia aurita* (moon jelly)
- Rhpilema verrilli* (mushroom cap jelly)

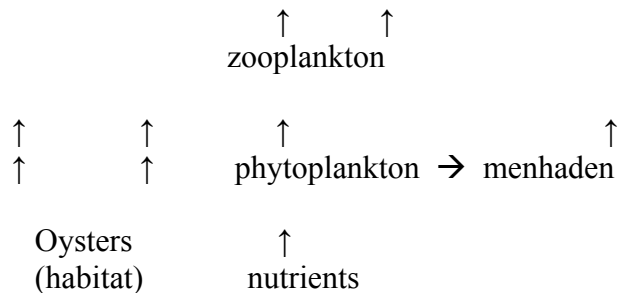
Hydromedusae:

Ctenophores:

- Mnemiopsis leidyi*
- Beroe ovata*

Players in the trophic scheme:

Sea nettles ← Ctenophores ← bay anchovy → Piccivores



Sea nettles and ctenophores

- Are dominant consumers in the system
- Predictions of abundances of their prey are not feasible without including them in analysis and models

- They may be affected differently than their prey by changing water quality

Gelatinous zooplankton metrics

Scyphomedusae: # m⁻³, biovolume m⁻³, bell diameter, identified to species
 Hydromedusae: # m⁻³, biovolume m⁻³
 Ctenophores: # m⁻³, biovolume m⁻³, length for *Mnemiopsis*
 # m⁻³, biovolume m⁻³ for *Beroe*

Field sampling:

- Towed net: 1 m-diameter, 0.5 mm mesh netting
- Whole water column – stepped oblique tows
- May-September mesohaline and polyhaline sites

Sample processing (all in the field)

- Total volume for each species (hydromedusae lumped); sample drained in 2 mm sieve
- Total count, if ≤100 individuals; subsample of at least 100 individuals if total >100
- Up to 30 of each scyphomedusa spp. measured (bell diameter to nearest 0.5 cm)
- Lengths of 30 ctenophores and >3 vs <3 cm for remainder in 100 individual subsample
- Photos or preserved specimens for those with questionable ID

Data Uses

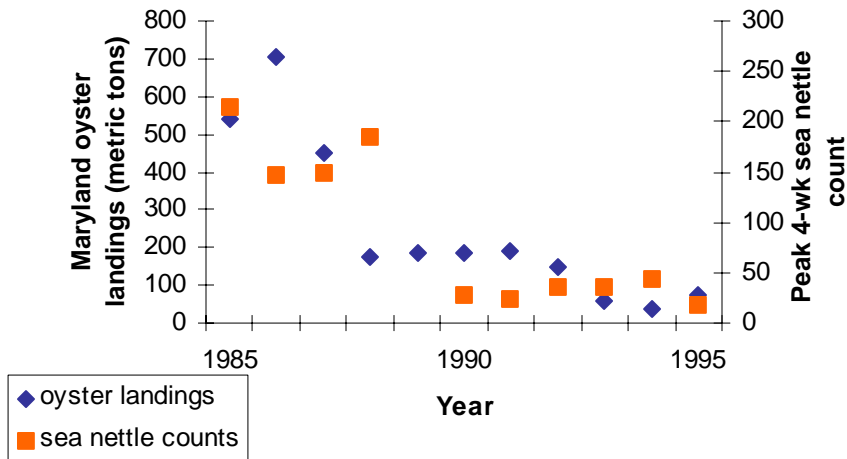
- Multispecies fisheries and food web modeling: Ecopath, CASM, mesohaline IBI linking zooplankton to water quality
- Research models and statistical analyses aimed at understanding Chesapeake Bay system

Why aren't previous measurements sufficient?

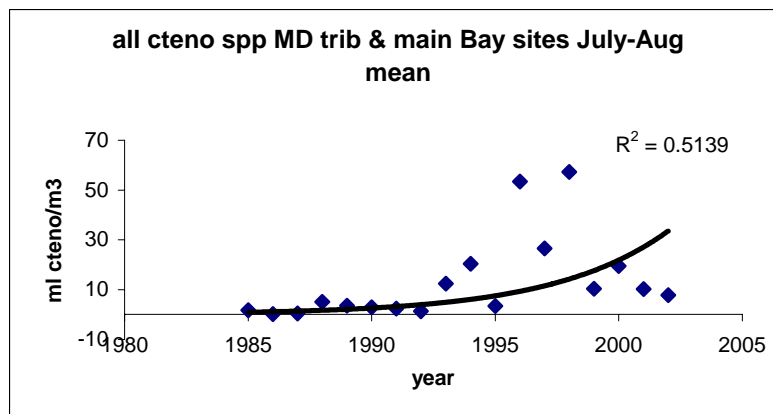
- Nets used in old zooplankton program too small for sea nettles (but good data on ctenophores)

- Bay is changing and abundances of gelatinous zooplankton are as well

Temporal pattern of oyster landings and sea nettle abundances



Oysters provide habitat for sea nettles; sea nettles consume ctenophores; ctenophores consume planktonic oyster larvae. As oyster abundance declines, so also do sea nettles, which reduces predation on ctenophores. Ctenophores increase and consume more oyster larvae as well as bay anchovy larvae.



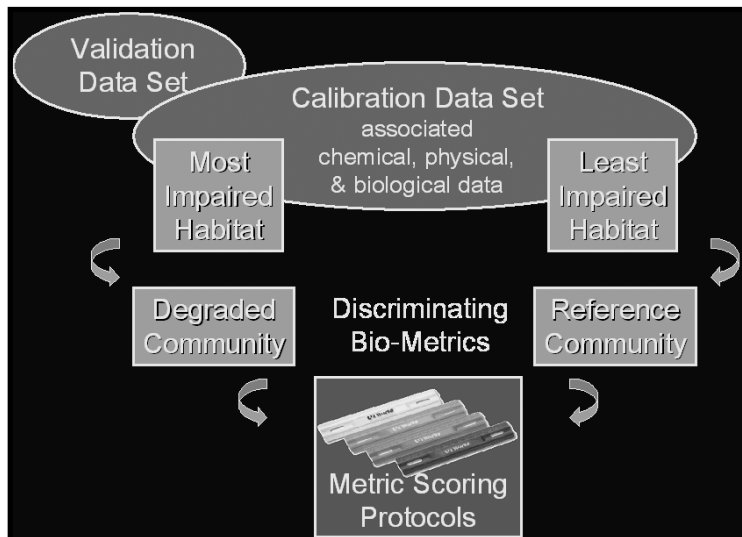
Appendix L

Reconstruction of the PowerPoint presentation
by
Claire Buchanan
Interstate Commission for the Potomac River Basin
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

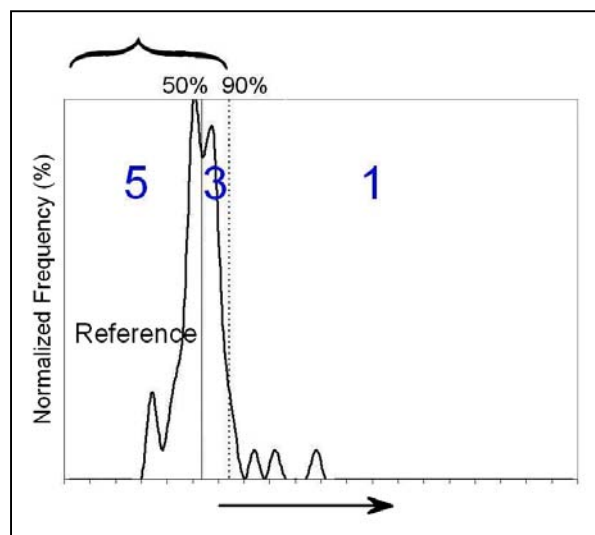
A Zooplankton IBI for Summer Polyhaline (>18 psu) Chesapeake Bay

Definition of a zooplankton index of biotic integrity (IBI): an index that is sensitive to summer polyhaline water quality conditions, using community indicators, or metrics.

IBI Terminology



Scoring criteria or thresholds



IBI terminology, continued

- The IBI is the average of a number of metric scores (e.g., from 1 through 5)
- Metric Discrimination Efficiency (DE)
 - % of metric scores ≥ 3 in Least-Impaired events
 - % of metric scores < 3 in Impaired events
- IBI Classification Efficiency (CE)
 - % IBIs ≥ 3 in Least-Impaired events
 - % IBIs < 3 Impaired events

Classifying Summer Polyhaline Habitat Conditions

- Habitat classification criteria have been developed for PHYTOPLANKTON

Least-Impaired Habitat

$\leq 0.07 \text{ mg DIN L}^{-1}$
 $\leq 0.007 \text{ mg PO}_4 \text{ L}^{-1}$
 $> 1.85 \text{ m Secchi depth}$

Impaired Habitat

$> 0.07 \text{ mg DIN L}^{-1}$
 $> 0.007 \text{ mg PO}_4 \text{ L}^{-1}$
 $\leq 1.85 \text{ m Secchi depth}$

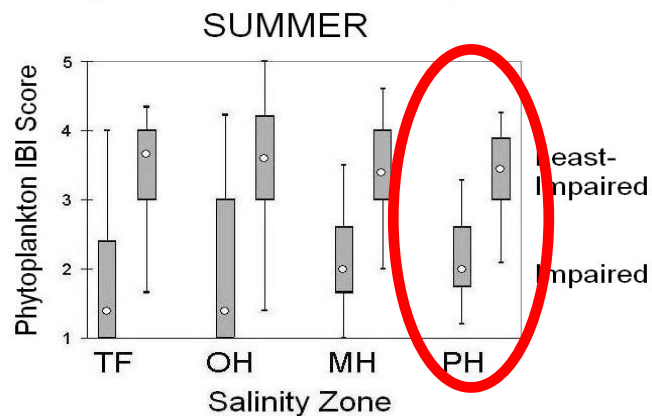
*Achieves CBP 2003 criteria for chlorophyll *a*, DO, and water clarity.

Secchi criteria vary with salinity and season: Tidal Fresh (TF)=0.8 m, oligohaline (OH)=0.7 m, mesohaline (MH)=1.45 m, polyhaline (PH)=1.85 m.

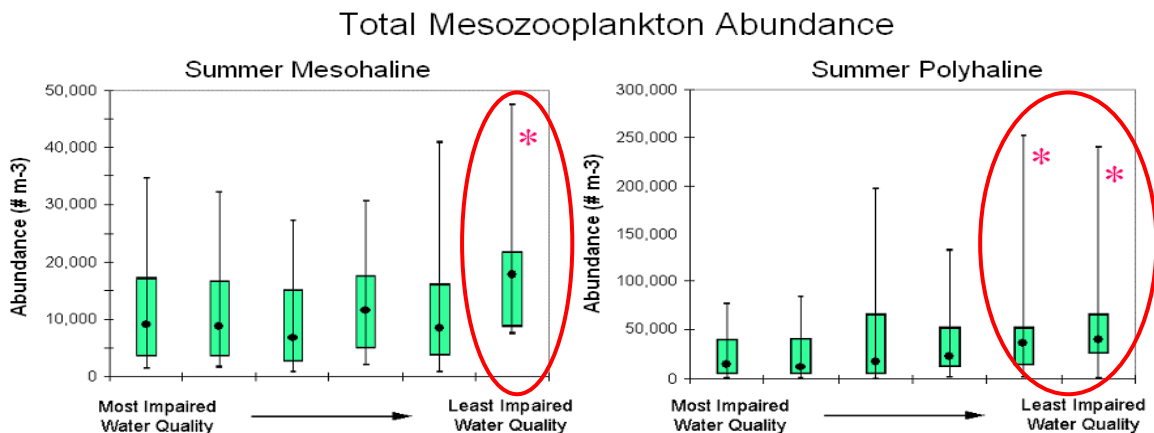
[see: Nutrient bioassays, T. Fisher & A. Gustafson, 2003; Relative Status method, M. Olson, 2003]

- Polyhaline phytoplankton were classified using 9 metrics, with 80% Classification Efficiency

- Chlorophyll *a*
- chl:C
- pheophytin
- % crypto biomass
- diatom biomass
- dino biomass
- pico-phytoplankton abundance
- total biomass



- Zooplankton in Phytoplankton in Habitat Conditions – Characterizing Zooplankton Reference and Degraded Communities

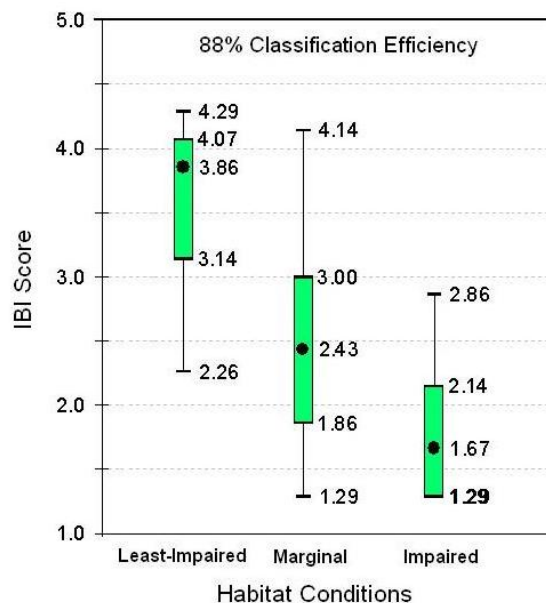


- Polyhaline stations with most frequent Least-Impaired events: CB6.1, CB6.4, CB7.3E, CB7.4.
- Polyhaline stations with most frequent Impaired events: CB6.1, WE4.2, SBE2, SBE5.
- Calibration data set: Least-Impaired n=11; Marginal n=116; Impaired n=31.
- Metric selection: 21 taxa abundance metrics and 4 diversity metrics evaluated for ability to discriminate.
- Metric scoring: 7 metrics selected and metric scoring criteria, or thresholds, identified from distributions.

	<u>Score=1</u>	<u>Score=5</u>
Barnacle larvae (# m ⁻³)	> 45.6	= 0
Total rotifer (# L ⁻¹)	> 14	≤ 1
Total cladocerans	< 50.3	≥ 1,034
Total copepods	< 4,796	≥ 10,194
Predatory mesozooplankton	< 134	≥ 1,707
Simpson diversity	< 0.417	≥ 0.723
Total mesozooplankton	< 8,265	≥ 13,994

Metric Discrimination Efficiency / IBI Classification Efficiency

	Impaired %correct ID (n=31)	L-impaired %correct ID (n=11)	Average %
Barnacle larvae (# m ⁻³)	61	82	72
Total rotifer (# L ⁻¹)	70	78	71
Total cladocerans (# m ⁻³)	61	91	76
Total copepods (# m ⁻³)	65	73	69
Predatory mesozooplankton (# m ⁻³)	84	82	83
Simpson diversity	77	73	70
Total mesozooplankton (# m ⁻³)	61	82	72
IBI	94	82	88



- Validation of the IBI: Jackknife with Replacement

Metric	% Total Error
Barnacle larvae (# m ⁻³)	37.9
Total rotifer (# L ⁻¹)	14.5
Total cladocerans (# m ⁻³)	40.1
Total copepods (# m ⁻³)	17.8
Predatory mesozooplankton (# m ⁻³)	15.6
Simpson diversity	34.7
Total mesozooplankton (# m ⁻³)	18.5
IBI Score	11.5%

- Robust index (11.5% estimated total error)
- Sensitive to water quality (88% classification efficiency)
- No individual metric ‘drives’ the IBI
 - Removing any metrics one at a time does not substantially change the IBI classification efficiency nor its distributions in impaired/least-impaired groups
- Needs refinement and true validation in future (Problem: only low number of Least-impaired sites, n=11)
- Proving useful in Index of Ecosystem Health for open water habitats, e.g., Forage fish-zooplankton-phytoplankton-water quality parameters

Sources

Phytoplankton habitat criteria and reference communities:

C. Buchanan, R.V. Lacouture, H.G. Marshall, M. Olson, and J.M. Johnson. 2005. Phytoplankton reference communities for Chesapeake Bay and its tidal tributaries. *Estuaries* 28: 138-159.

Fisher, T. R. and A. B. Gustafson. 2003. Nutrient-addition bioassays in Chesapeake Bay to assess resources limiting algal growth. Progress report: August 1990-December 2002. Prepared for Maryland Department of Natural Resources, Chesapeake Bay Water Quality Monitoring Program, by University of Maryland Horn Point Laboratory, Cambridge, Maryland.

Olson, M. 2002. Benchmarks for nitrogen, phosphorus, chlorophyll, and suspended solids in Chesapeake Bay. Chesapeake Bay Program Technical Report Series, Chesapeake Bay Program, Annapolis, Maryland.

Summer polyhaline zooplankton IBI

K. E. Carpenter, C. Buchanan, and J.M. Johnson. (Submitted.) An index of biotic integrity based on the summer polyhaline zooplankton community of the Chesapeake Bay.

Appendix M

Reconstruction of the PowerPoint presentation
by
Kristine Sillett
Versar, Inc
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

A Zooplankton IBI for Summer Mesohaline (5-18 psu) Chesapeake Bay

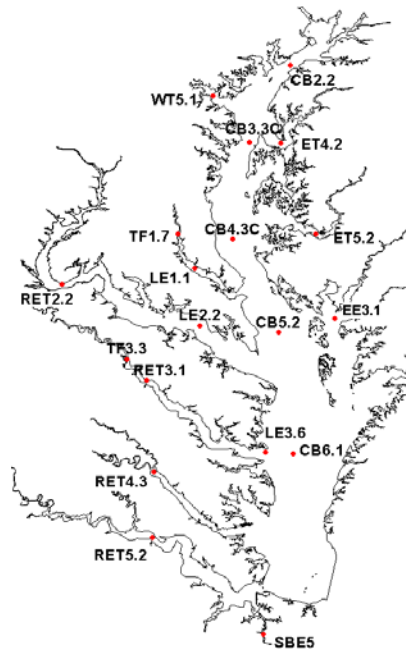
Definition of a zooplankton index of biotic integrity (IBI): an index that is sensitive to summer mesohaline water quality conditions, using community indicators, or metrics.

- Calibration data set

CBP Monitoring Program, 19 stations,
salinity >5 – 18 psu
July-September
1984-2002 (Maryland data)
2000-2002 (Virginia data)

Primarily characterized by:
Calanoid copepod *Acartia tonsa*
Ctenophore *Mnemiopsis*
Rotifer genus *Synchaeta*

Also important: cyclopoid copepods,
cladocera, barnacle nauplii, and
polychaete larvae in the mesozooplankton,
and protozoans and copepod nauplii in the
microzooplankton

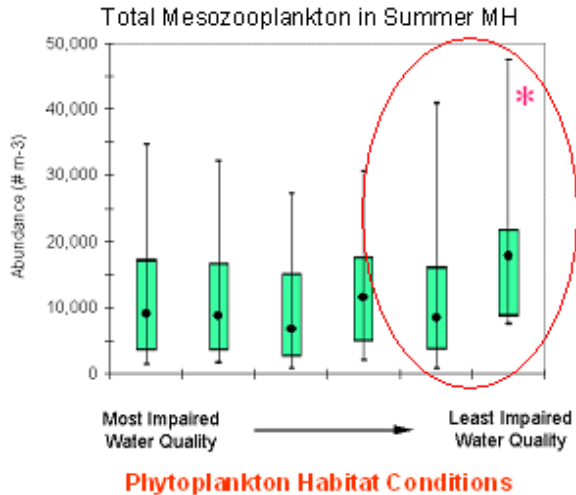


- Characterizing Zooplankton Habitats

Nutrient and light criteria used to characterize regions

Mesohaline phytoplankton-zooplankton habitat conditions did not clearly define mesohaline zooplankton habitat conditions.

Significantly higher median total mesozooplankton abundance in least-impaired phytoplankton habitat conditions (usable zooplankton samples associated with these conditions low [n=6] due to program methodology differences).



High abundances also found in more impaired phytoplankton habitat conditions

CART analysis, using *Acartia* as the response variable, was done to determine key physical, chemical, and phytoplankton parameters needed to characterize least-impaired (reference) and impaired conditions.

- Classifying Summer Mesohaline Habitat Conditions

Least-impaired (all criteria must be met)	Impaired (Secchi depth <1.45 m, and one or more criteria below)
PO4 < 0.0035 mg L ⁻¹	PO4 > 0.0073 mg L ⁻¹
DIN < 0.007 mg L ⁻¹	DIN > 0.542 mg L ⁻¹
CHLa 4.5 – 26.3 ug L ⁻¹	CHLa <4.5 ug L ⁻¹ or >26.3 ug L ⁻¹
Dino biomass < 350 ugC L ⁻¹	Dino biomass > 350 ugC L ⁻¹
Diatom biomass 26-510 ugC L ⁻¹	Diatom biomass <26 or >510 ugC L ⁻¹

Calibration data set Least-impaired n=25, Marginal n=206, Impaired n=144

- Distribution of Least-impaired and Impaired Habitat Conditions
Most frequent Least-Impaired events observed at: CB4.3C, CB5.2 (limited VA data)
Most frequent Impaired events: WT5.1, CB2.2, CB3.3C, TF1.7, LE1.1, LE2.2, ET5.2
- Metric selection
22 candidate metrics were evaluated for inclusion in the IBI (species abundance, species diversity, and trophic composition)

Only metrics with statistically different median values (Mann Whitney U test, p<0.05) were considered for the IBI.

- Zooplankton IBI Summer Mesohaline Component Metrics and Scoring Thresholds

Metric	Scoring		
	1	3	5
Acartia abundance (no. m-3)	< 7837	7837 - 13861	> 13861
Balanid larvae abundance (no. m-3)	> 49.1	15.9 - 49.1	< 15.9
Ctenophore biovolume (ml m-3)	> 6.7	0.68 - 6.7	< 0.68
Cyclopoid abundance (no. m-3)	< 10.8	10.8 - 24.0	> 24.0
Rotifer abundance (no. liter -1)	> 94.7	26.6 - 94.7	< 26.6
Total meso. abundance (no. m-3)	< 8435	8435 - 14141	> 14141

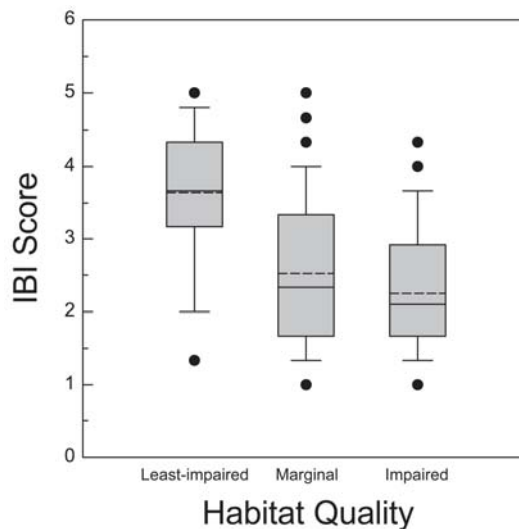
Higher abundances of total mesozooplankton, *Acartia*, and cyclopoids associated with least-impaired conditions.

Higher abundances of rotifers and balanid larvae and higher ctenophore biovolume associated with impaired conditions.

- Zooplankton IBI Summer Mesohaline Classification Efficiencies

Metric	Percent samples correctly classified		
	Least-impaired (n = 25)	Impaired (n = 144)	Total
Acartia abundance	76%	58%	67%
Barnacle abundance	68%	58%	63%
Ctenophore	79%	61%	70%
Cyclopoid	76%	68%	72%
Rotifer abundance	80%	58%	69%
Total abundance	76%	58%	67%
Overall IBI Score	80%	75%	78%

- Zooplankton IBI Summer Mesohaline Index Scores



- Validation of the IBI: Jackknife with Replacement

Metric	% Total Error
<i>Acartia</i> abundance	15.7
Barnacle abundance	18.6
Ctenophore biovolume	10.8
Cyclopoid abundance	19.4
Rotifer abundance	17.8
Total abundance	16.7
IBI Score	7.4 %

- **Summary**

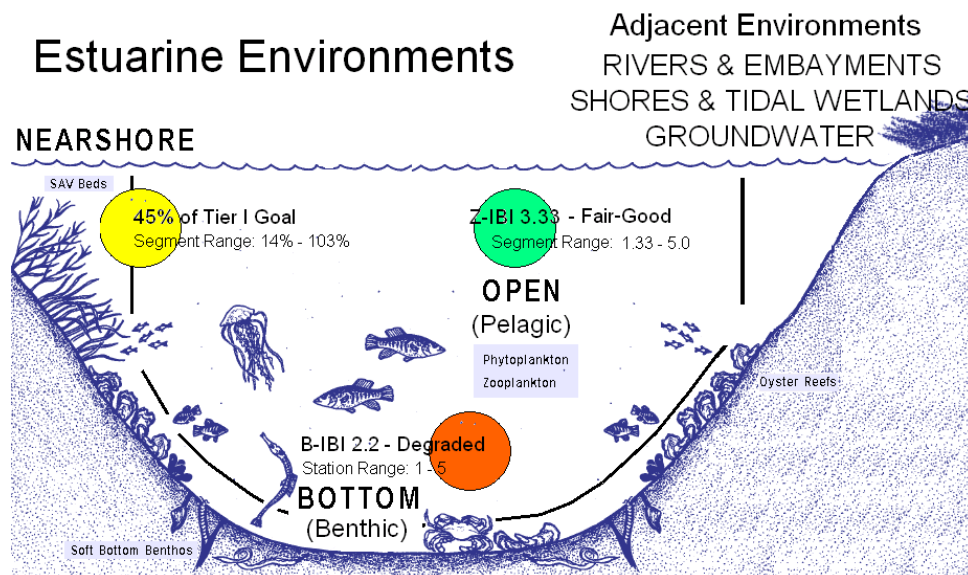
The Z-IBI appears to be a useful tool in discriminating between least-impaired and impaired conditions

Work in progress

- Refine criteria for identifying habitat conditions'
- Incorporate more data from lower Bay (Virginia stations)
- Validate the IBI with independent data

Management implications

- Provide beneficial information for assessing ecosystem integrity of the Bay



Z-IBI values – median and range of all summer mesohaline Z-IBI scores at Station CB5.2 between 1984-2002

Appendix N

Reconstruction of the PowerPoint presentation
given by
Richard Lacouture
for
Jacobs and Heimbock et al.
AKRF, Inc.
Chesapeake Bay Zooplankton/ Food Web Workshop
January 12-13, 2005

Food Availability Index and Larval Striped Bass Habitat Index

Food Availability Index

- An index that was developed to describe the condition of available zooplankton prey for larval striped bass
- This was accomplished by utilizing the results of a number of studies which focused on this predator-prey relationship
- Four food categories were formulated to reflect the condition of food available to larval striped bass
- These categories use the geometric mean mesozooplankton density during spawning season (April – June)

Food categories for the Food Availability Index:

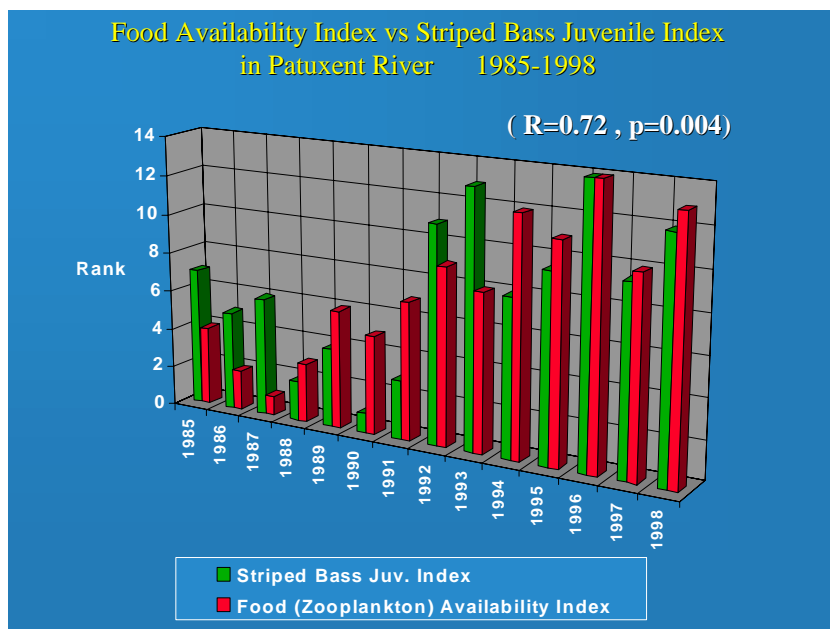
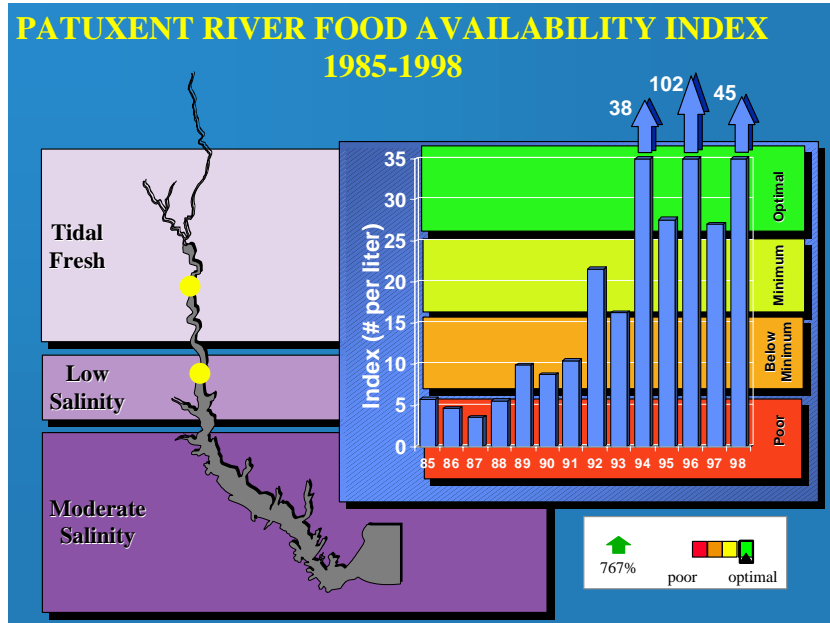
Category	Geometric mean density (# L ⁻¹)
Optimal	>25
Minimum	>15-25
Below-minimum	5-15
Poor	<5

Testing the Food Availability Index

- The geometric mean density of mesozooplankton for April-June was calculated for tidal fresh/oligohaline sampling sites
- These values were compared to the MDDNR Striped Bass Juvenile Index
- This correlation was analyzed with the Spearman's rank correlation test

Success of Food Availability Index versus Larval Striped Bass Juvenile Index

- Patuxent River – highly significant for striped bass ($p < 0.001$) and white perch ($p < 0.003$)
- Potomac River – no significant relationship for either fish species
- Choptank – no significant relationship for striped bass and marginally significant for white perch ($p = 0.08$)
- Upper Bay – no significant relationship for striped bass; significant relationship for white perch ($p = 0.01$)



Larval Striped Bass Habitat Index

- The correlation results of the Food Availability Index and Juvenile Striped Bass Index and results from other studies indicate that other environmental conditions play an important role in larval survival.
- An individual-based model (Rose and Cowan, 1993) was used as a template for the Larval Striped Bass Habitat Index.
- Water temperature, salinity, water clarity and a new zooplankton index (uses micro- and mesozooplankton densities) were incorporated into the Larval Striped Bass Habitat Index.

Larval Striped Bass Habitat Index Sub-Indices

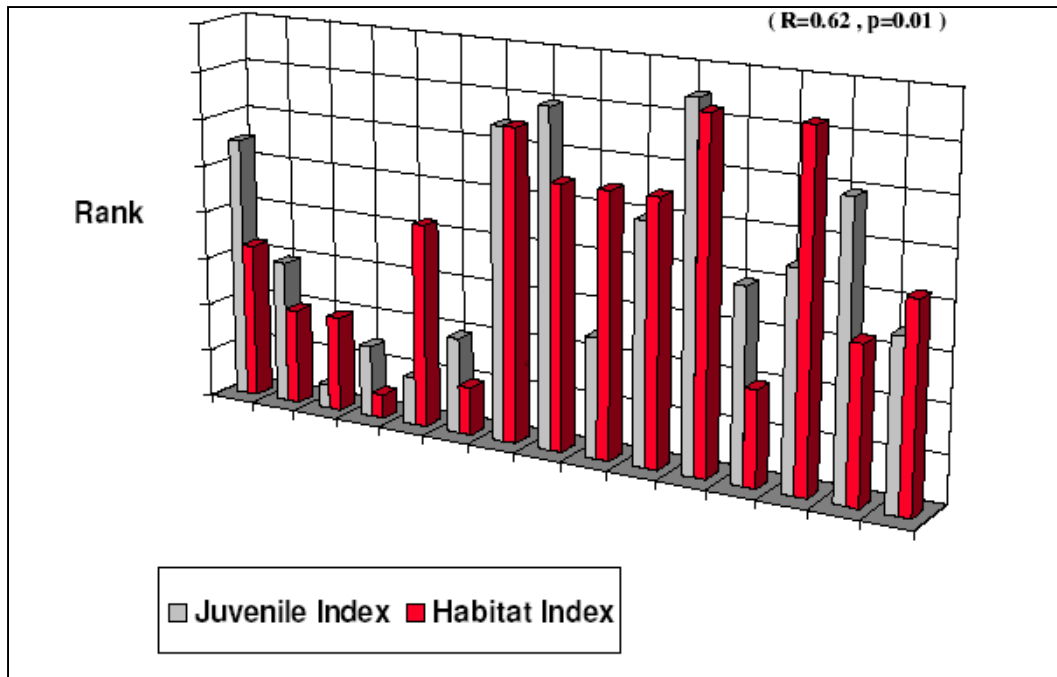
- Spawning Sub-Index
 - Associated with spawning conditions
 - Average salinity < 0.5 psu
 - Average water temperature is no less than the temperature in the preceding period
 - Average water temperature is 11.4° – 22.3°C
- Early Survival Sub-Index
 - Calculated as the product of the survival rates of egg and yolk-sac larvae – both are a function of average water temperature
- Zooplankton Availability Sub-Index based on
 - Estimation of the minimum food requirement
 - Estimation of the maximum consumption rate
 - Estimation of available zooplankton biomass (rotifer, copepod nauplii, mesozooplankton)

Scoring of the Larval Striped Bass Habitat Index

- Cohort Score – based on all 3 sub-indices, a cohort is scored with the value of the lowest of the 3 index scores (if a score of 0 occurs for any of the sub-indices, a cohort score of 0 results)
- Annual Larval Striped Bass Habitat Index Score – the sum of the Cohort Scores

Validation of the Larval Striped Bass Habitat Index

- The annual Larval Striped Bass Habitat Index scores were ranked for the time series and compared with the rankings from the MDDNR Juvenile Striped Bass Index for the same period
- The correlation of these rankings was quantified by a Spearman's rank correlation test.



Refinement of the Larval Striped Bass Habitat Index

- The poor fit between the Larval Striped Bass Habitat Index and the Juvenile Striped Bass Index in the Choptank River indicates that further refinements are necessary and that these types of refinements may be tributary-specific.
- Analysis of the sub-indices indicates that flow and the size of the spawning stock may be factors in improving the index in the Choptank
- An additional factor, which other studies have suggested may be important, is pH (Choptank is poorly buffered)