1999 MWRA Annual Technical Workshop
Summary

for

Meetings and Public Presentations Task 34

Submitted to

Massachusetts Water Resources Authority
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Key Points and Conclusions

Benthic Monitoring

Benthic Monitoring Thresholds Approach/Rationale (Mr. Ken Keay, MWRA)
- Benthic thresholds are not done and completing them is a priority
- No changes to the benthic community are expected as a result of outfall discharges
- Focus on local or nearfield areas where any change is most likely to first be seen.
- Thresholds must be easy to apply and evaluate ecologically significant parameters.

1998 Sediment Profile Imaging (Dr. Robert Diaz, VIMS)
- Distribution of sediment textures at nearfield study area appeared to be dominated by physical processes, as indicted by the organisms sediment index (OSI)
- Surface features were dominated by biogenic activity.
  - Mounds and tubes were the dominant surface biogenic structures, and subsurface structures and organisms were common and widely distributed.
  - Well-developed fauna characterized as intermediate to advanced in successional stage.
- Sediments over much of the nearfield did not exhibit within-station variability with the silty-sand as the modal sediment type
- Three SPI images per station not enough to consistently estimate a 50% change in the RPD layer at all nearfield stations.

1998 Hardbottom Community (Dr. Barbara Hecker, Hecker Environmental)
- The structure of the hardbottom benthic community is controlled by location on the drumlins (concurrent depth), substratum type, local relief, and sediment drape.
- Most areas appear to be temporally stable.
- A number of areas are spatially heterogeneous.
- Differences between temporal and spatial variance are difficult to dissect.
- Some variability exists in the data. Hardbottom habitats are patchy in nature.
- Current program highly unlikely to be able to detect small shifts or changes in the composition of the hardbottom communities.
- The most likely “keystone” species would be Lithothamnion because it is very abundant, widely distributed, less patchy than Asparagopsis, and appears to be sensitive to sediment loading.

Infaunal Community Overview (Dr. Roy Kropp, Battelle)
The presentation focused on the findings of Blake et al. (1998) because 1998 data analysis was incomplete.
- Traditional ecological metrics (density, species numbers, diversity) were very similar among Nearfield and Midfield stations and, with the possible exception of species numbers, showed little or no apparent temporal trend. Species numbers may have showed an increasing trend with time.
- However, cluster analysis of the Nearfield and Midfield stations revealed two primary infaunal communities. One was typically associated with sandy substrates near the outfall and has been a relatively consistent feature for several years. The other was typically associated with siltier substrates located farther from the outfall.
- Cluster analysis of Fairfield stations revealed two main types of infaunal community. One was comprised of stations in Cape Cod Bay. The second consisted of all the remaining Fairfield stations. The geographic location and depth of the stations may offer a better explanation of the station groupings than measured sedimentary features.
Benthic Community Threshold Assessment (Dr. Gene Gallagher, UMass – Boston)
- At the community- and functional-group levels, thresholds will be based on significant changes in a “pooled” population of nearfield stations with respect to
  - Species diversity (richness and evenness
  - Change in indicator species
  - Change in frequency of functional groups
- This threshold assessment can be made quickly (within 1 week).
- A full assessment of change in species composition will be made at the end of each year. This requires a longer QA/QC process for species composition.

1998 Sediment Chemistry (Dr. Carlton Hunt, Battelle)
- Contaminant concentrations consistent with previous sampling years.
- Changes due to shifts in grain size and TOC
- Lower concentrations at some stations than values found in the early 1990s.

Fish and Shellfish Monitoring

Introduction to Fish and Shellfish Threshold (Dr. Carlton Hunt, Battelle)
- This area of the HOM program is mature and has been executed consistently since 1994.
- Thresholds are well established.

1998 Caged Mussel Studies
- Contaminant concentrations were consistent with or slightly lower than previous years.
- A site in Quincy Bay was added to the monitoring program in 1998. This site was added to evaluate the effects of the diversion of Nut Island discharges.
- A site in eastern Cape Cod Bay was added to the monitoring program in 1998. This site was added as an offshore reference site.

1998 Flounder and Lobster Chemistry Studies (Ms. Lisa Lefkovitz, Battelle)
- 1998 results are consistent with previous years
- Organic contaminant concentrations
  - Generally highest at the Discovery (Boston Inner Harbor) site and lowest at the eastern Cape Cod Bay site.
  - Generally decreased since 1992, particularly at the Discovery and Deer Island sites.
- Metals concentrations
  - More variable than organic contaminant concentrations and relatively constant between years
  - Mercury concentrations in flounder livers have decreased since 1992.

1998 Flounder Histopathology (Dr. Michael Moore, WHOI)
- Catch per unit effort of winter flounder generally higher than in recent years, particularly at Broad Sound and the outfall.
- Histopathology findings were consistent with previous years at all sites.
Water Column Monitoring and Nutrient Cycling

Modeling Results for 1993 and 1994 (Mr. Jim Fitzpatrick, HydroQual)

- When compared to observed data, the model appears to capture the major temporal and spatial features of phytoplankton biomass, as indicated by chlorophyll a, and dissolved inorganic nutrients in Massachusetts and Cape Cod Bays.
- The model also appears to capture the major temporal and spatial features observed in the dissolved oxygen data.
- Computed rates of bottom water dissolved oxygen are consistent with those estimated from the harbor outfall monitoring program data.
- The model approximately reproduces the seasonal and spatial features of sediment nutrient processes are indicated by comparing model computations against observed data for sediment oxygen demand, ammonia flux, nitrate flux, and phosphate flux.
- However, the model underestimates dissolved silica fluxes in Massachusetts Bay.
- Model computations of DIN:DIP and DIN:Si ratios are consistent with the observed data and suggest that during the summer months primary productivity is limited by the availability of dissolved inorganic nitrogen.
- While the model appears to reproduce the major temporal trends in the observed data, particularly when viewed using seasonal averaging periods, the model does not reproduce species-specific algal blooms, such as were observed in the spring of 1992 and the fall of 1993.
- While the model partially reproduced the differences in bottom water minimum dissolved oxygen between 1992, 1993, and 1994, the model was unable to reproduce the minimum dissolved oxygen values observed in 1994.

1998 Physical Regime (Dr. Rocky Geyer, WHOI)

- Forcing conditions
  - warm winter,
  - very wet spring (particularly May and June)
  - persistent southerly (upwelling) winds in summer
- Oceanographic conditions
  - warm bottom water (early)
  - very low salinity at surface and bottom
  - high stratification
  - less warming of bottom water than normal
- 1998 may have seen some upwelling events that affect biological conditions

1998 Water Quality Overview (Mr. Scott Libby, Battelle)

- Lack of a Winter/Spring Bloom – The winter/spring period in Massachusetts and Cape Cod Bays is often characterized by the occurrence of a bloom in phytoplankton and chlorophyll. The presence of elevated nutrient concentrations, increasing light availability and water temperatures, and the onset of seasonal stratification establish conditions that are conducive for a bloom to occur in the bays. Other factors may play a role in the realization of a winter/spring bloom – zooplankton grazing, resident phytoplankton assemblage, and many other physical, chemical, and/or biological factors that have not been resolved. In the winter/spring period in 1998, no bloom was observed and elevated nutrient concentrations persisted in the surface waters until May. Nutrient and production data indicate that bloom conditions existed and that the phytoplankton community had started to bloom (nutrient drawdown between February and March and high productivity), but an increase in biomass was not achieved and a winter/spring bloom did not occur in Massachusetts Bay. In Cape Cod Bay, however, the data suggest that a bloom may have occurred prior to the first survey in February.
• July/August Upwelling – Physical and chemical data suggest that significant upwelling events occurred in July and August of 1998 and that these events input nutrients into the coastal surface waters. Evidence of this was observed at coastal stations along the south shore and in the western nearfield. The upwelling conditions, along with tidal transport from Boston Harbor, supplied nutrients to the nearfield that supported the high phytoplankton concentrations that were observed in August.

• September/October Fall Bloom – As with the winter/spring bloom, the fall bloom is not a consistent annual characteristic in the Bays. The intensity of the fall bloom and the phytoplankton species that bloom have varied from year to year during the baseline-monitoring period. In 1998, the fall bloom was not single species bloom, but rather a general increase in the numbers of a variety of chain-forming diatoms. The bloom was more clearly observed in the increased chlorophyll concentrations and productivity data that were collected.

• Extended Period of Stratification and DO decline – The onset of seasonal stratification was slightly delayed in 1998 compared to previous baseline monitoring years as was the overturn of the water column and the return to winter conditions. The water column was stratified until November throughout much of the nearfield and a deep halocline was present in December at the deeper eastern nearfield stations. The strength and duration of stratification are important factors in the decline of bottom water dissolved oxygen concentrations. Due to the persistence of stratified conditions in 1998, bottom water DO concentrations decreased over the entire June to December time period in the nearfield area. The delay in mixing, combined with a pulse of organic material from the atypical November/December bloom, led to the annual minimum in bottom water DO concentration (7 mg L$^{-1}$) observed in December. The DO minimum concentration was not extremely low in comparison to data collected during previous baseline monitoring years. Due to major storm events and the lack of an input of organic material from a winter/spring bloom, the bottom water DO concentrations observed in June were very high (11.2 mg L$^{-1}$), which subsequently lessened the effect of the delay in returning to well-mixed winter conditions.

• November/December Elevated Ammonia and Phosphate Concentrations – In November and December 1998, anomalously high concentrations of ammonium and phosphate were observed in the western nearfield that correlated with high concentrations observed by the MWRA in Boston Harbor. The source of these nutrients was not determined, but may have been due to the transfer of south system sewage flows from Nut Island to the Deer Island facility, increased dredging operations in the harbor, an ecological change in biological utilization of nutrients in the Harbor, or other factors. It is suspected that the anomalously high NH$_4$ and PO$_4$ concentrations triggered a localized bloom that was observed in the nearfield in December.

1998 Plankton Overview (Dr. Jefferson Turner, UMass – Dartmouth)

• Whole-Water Phytoplankton Assemblage
  • Microflagellates and small cryptomonads were the numerical dominants.
  • Sustained increase in total phytoplankton abundance, from low levels in February through April to high levels in May through October, followed by declines in November and December.
  • No major winter/spring bloom or fall bloom
  • No confirmed nuisance algae blooms, although the fall Pseudo-nitzschia pungens records could have included some P. multiseries. Maximum abundance of P. pungens did not exceed 83 x 10$^3$ cells/L.

• Screened Water Phytoplankton
  • Distephanous speculatum (silicoflagellate) was dominant in February, followed by Ceratium longipes and C. tripos.
  • C. longipes and C. tripos dominant from March onward, followed by other dinoflagellates.
  • Sustained bloom of C. longipes and C. tripos was the major event
• Zooplankton
  • Dominated by copepod nauplii, adults, and copepodites of the small copepods *Oithona similis* and *Pseudocalanus* spp., with seasonal subdominant contributions from gastropod and bivalve veligers and a mixture of other normally occurring taxa.
  • Additional Cape Cod Bay stations samples during WF981, WF982, and WF984 extended total abundance recorded for F01 and F02.
  • Once outfall on line, expect the copepod abundance in the nearfield and farfield outside Boston Harbor will be dominated by *Oithona similis*, *Pseudocalanus* spp., and, to a lesser extent, *Paracalanus parvus*, *Centropages typicus*, *C. hamatus*, and *Calanus finmarchicus*.
  • Meroplankton abundance are “spikey” and more likely related to reproductive cycles of the macrobenthic parents than to processes in the plankton.
• Zooplankton Threshold. Suggest abundance of *Acartia tonsa/A. hudsonica* > 50% of the total non-naupliar copepods (adults and copepodites)

**1998 Productivity Overview** *(Dr. Aimee Keller, URI)*
• Annual production at N04, N18, and F23 lower than in prior years
• Seasonal productivity pattern dominated by fall bloom
• No winter-spring bloom despite increased chlorophyll-specific production during typical bloom period
• Bloom failure not correlated with nutrient availability or light limitation
• Bloom failure may be related to warm winter temperatures and increased grazing by zooplankton
• Productivity significantly correlated with composite parameter (but variable across years)

**1998 Nutrient Cycling in the Harbor** *(Dr. Anne Giblin, Marine Biological Laboratory)*
• Sediment trends in the highly impacted sites in the northern Harbor may be showing some decrease in fluxes even with the amphipods present.
• Denitrification rates have gone up and down a bit with amphipod colonization but still not a major factor in removing anthropogenic nitrogen.
• DIN/DIP ratio may have shifted up but the majority of 1998 data still shows benthic fluxes still less than 16 (i.e., would contribute to nitrogen limitation).

**Statistical Approach to Threshold Testing and Rule Setting** *(Dr. Jeff Rosen, TPMC)*
• Currently evaluating ways to aggregate data and conduct statistical tests
• Must define rules for aggregating the data.
Introduction and Program Overview

The goals of the 1999 MWRA Annual Technical Review Workshop were to:

- Present, review, and discuss 1998 data in the context of historical understanding of the system,
- Provide a forum for discussing the 1998 results in the context of previous monitoring years and potential or predicted affects of the new outfall effluent to the Massachusetts Bay system,
- Debate the monitoring thresholds as appropriate,
- Develop themes and key presentations for the upcoming public OMSAP science meeting,
- Provide technical discussions that would enhance data interpretation in the annual reports,
- Convey progress toward outfall startup, post-discharge monitoring plan development, and reporting issues.

HOM Program Update

Many facility improvements have been made over the last 10 years, resulting in improvements in solids discharges. The improvements include the cessation of sludge discharges in December 1991, the new primary treatment facility startup in 1995, the new secondary treatment facility startup in 1997, and the diversion of Nut Island flows to the Deer Island facility in 1998. Each improvement was followed generally by a decrease in effluent solids and contaminants loadings. Since 1992 the total effluent nitrogen loading has remained at approximately 10,000-12,000 tons per year. Modeled average dilution of sewage effluent under winter conditions shows that, historically, the effluent from existing harbor outfalls entered the system, and that the effluent will enter the system from the new Massachusetts Bay outfall but will be diluted much more quickly than effluent from existing outfalls.

MWRA's discharge permit is the most environmentally protective permit ever issued. The Outfall Monitoring Plan and the Contingency Plan have been incorporated into the permit. With the effluent discharge from the Massachusetts Bay outfall scheduled to begin in the fall of 1999, plans are being finalized for meeting and responding to the permit requirements. Section 8.a.of Draft NPDES Permit #MA0103284 essentially requires the on-time delivery of data products:

> the results of any monitoring required by the contingency plan shall be reported ...(annually)...except that if any parameter exceeds the corresponding early "caution level" or "warning level" the monitoring results shall be reported within ten (10) days after the results becomes available. The MWRA shall make all reasonable efforts to provide results within ninety (90) days after the sampling event, and MWRA shall obtain approval from EPA and the MADEP if the results will take longer than one hundred and fifty (150) days.

To date, HOM3 has submitted data reports within the 90-day reporting requirement, with one exception (histology), and beaten the 1992-1997 average by two or more months for each report type. This performance confirms MWRA's ability to meet the permit-imposed deadlines.

In Section 8.b. of the draft permit describes the warning-level-reporting process.

Section 8.a. Draft NPDES Permit #MA0103284: If any parameter exceeds the "warning level" listed above in Section 8.a., the MWRA shall (1) determine whether there are any adverse environmental impacts from such exceedance, (2) evaluate the extent to which MWRA discharge contributes to such impacts, and (3) unless MWRA demonstrates by convincing evidence, to the satisfaction of EPA and the MADEP, that the MWRA discharge does not contribute to such adverse environmental impacts, develop a plan and schedule to address such impacts...

Toward this end, the following activities are in the process of being completed.
Outfall Monitoring Plan Status and Thresholds

- Revised draft of the OMP in development
- Focusing on completing threshold statements
- Threshold testing will be one theme for the June (Tentative) 1998 OMSAP Public Science Meeting
- Automation of the threshold and monitoring comparison process pending completion of thresholds (Task 30). Will reside within the database. Review data on upload and acceptance
- Requires strict protocols for the data aggregation and defined statistical testing protocols

Workshop Summary Organization

A list of workshop participants immediately follows this introduction. Key points are summarized and presented by speaker. A complete compendium of presentation materials is included at the end of the document.
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- Traditional ecological metrics (density, species numbers, diversity) were very similar among Nearfield and Midfield stations and, with the possible exception of species numbers, showed little or no apparent temporal trend. Species numbers may have showed an increasing trend with time.
- However, cluster analysis of the Nearfield and Midfield stations revealed two primary infaunal communities. One was typically associated with sandy substrates near the outfall and has been a relatively consistent feature for several years. The other was typically associated with siltier substrates located farther from the outfall.
- Cluster analysis of Farfield stations revealed two main types of infaunal community. One was comprised of stations in Cape Cod Bay. The second consisted of all the remaining Farfield stations. The geographic location and depth of the stations may offer a better explanation of the station groupings than measured sedimentary features.
Benthic Community Threshold Assessment (Dr. Gene Gallagher, UMass – Boston)
- At the community- and functional-group levels, thresholds will be based on significant changes in a “pooled” population of nearfield stations with respect to
  - Species diversity (richness and evenness
  - Change in indicator species
  - Change in frequency of functional groups
- This threshold assessment can be made quickly (within 1 week).
- A full assessment of change in species composition will be made at the end of each year. This requires a longer QA/QC process for species composition.

1998 Sediment Chemistry (Dr. Carlton Hunt, Battelle)
- Contaminant concentrations consistent with previous sampling years.
- Changes due to shifts in grain size and TOC
- Lower concentrations at some stations than values found in the early 1990s.

Fish and Shellfish Monitoring

Introduction to Fish and Shellfish Threshold (Dr. Carlton Hunt, Battelle)
- This area of the HOM program is mature and has been executed consistently since 1994.
- Thresholds are well established.

1998 Caged Mussel Studies
- Contaminant concentrations were consistent with or slightly lower than previous years.
- A site in Quincy Bay was added to the monitoring program in 1998. This site was added to evaluate the effects of the diversion of Nut Island discharges.
- A site in eastern Cape Cod Bay was added to the monitoring program in 1998. This site was added as an offshore reference site.

1998 Flounder and Lobster Chemistry Studies (Ms. Lisa Lefkovitz, Battelle)
- 1998 results are consistent with previous years
- Organic contaminant concentrations
  - Generally highest at the Discovery (Boston Inner Harbor) site and lowest at the eastern Cape Cod Bay site.
  - Generally decreased since 1992, particularly at the Discovery and Deer Island sites.
- Metals concentrations
  - More variable than organic contaminant concentrations and relatively constant between years
  - Mercury concentrations in flounder livers have decreased since 1992.

1998 Flounder Histopathology (Dr. Michael Moore, WHOI)
- Catch per unit effort of winter flounder generally higher than in recent years, particularly at Broad Sound and the outfall.
- Histopatholgoy findings were consistent with previous years at all sites.

Water Column Monitoring and Nutrient Cycling

Modeling Results for 1993 and 1994 (Mr. Jim Fitzpatrick, HydroQual)
• When compared to observed data, the model appears to capture the major temporal and spatial features of phytoplankton biomass, as indicated by chlorophyll a, and dissolved inorganic nutrients in Massachusetts and Cape Cod Bays.
• The model also appears to capture the major temporal and spatial features observed in the dissolved oxygen data.
• Computed rates of bottom water dissolved oxygen are consistent with those estimated from the harbor outfall monitoring program data.
• The model approximately reproduces the seasonal and spatial features of sediment nutrient processes are indicated by comparing model computations against observed data for sediment oxygen demand, ammonia flux, nitrate flux, and phosphate flux.
• However, the model under-estimates dissolved silica fluxes in Massachusetts Bay.
• Model computation of DIN:DIP and DIN:Si ratios are consistent with the observed data and suggest that during the summer months primary productivity is limited by the availability of dissolved inorganic nitrogen.
• While the model appears to reproduce the major temporal trends in the observed data, particularly when viewed using seasonal averaging periods, the model does not reproduce species-specific algal blooms, such as were observed in the spring of 1992 and the fall of 1993.
• While the model partially reproduced the differences in bottom water minimum dissolved oxygen between 1992, 1993, and 1994, the model was unable to reproduce the minimum dissolved oxygen values observed in 1994.

1998 Physical Regime (Dr. Rocky Geyer, WHOI)
• Forcing conditions
  • warm winter,
  • very wet spring (particularly May and June)
  • persistent southerly (upwelling) winds in summer
• Oceanographic conditions
  • warm bottom water (early)
  • very low salinity at surface and bottom
  • high stratification
  • less warming of bottom water than normal
• 1998 may have seen some upwelling events that affect biological conditions

1998 Water Quality Overview (Mr. Scott Libby, Battelle)
• Lack of a Winter/Spring Bloom – The winter/spring period in Massachusetts and Cape Cod Bays is often characterized by the occurrence of a bloom in phytoplankton and chlorophyll. The presence of elevated nutrient concentrations, increasing light availability and water temperatures, and the onset of seasonal stratification establish conditions that are conducive for a bloom to occur in the bays. Other factors may play a role in the realization of a winter/spring bloom – zooplankton grazing, resident phytoplankton assemblage, and many other physical, chemical, and/or biological factors that have not been resolved. In the winter/spring period in 1998, no bloom was observed and elevated nutrient concentrations persisted in the surface waters until May. Nutrient and production data indicate that bloom conditions existed and that the phytoplankton community had started to bloom (nutrient drawdown between February and March and high productivity), but an increase in biomass was not achieved and a winter/spring bloom did not occur in Massachusetts Bay. In Cape Cod Bay, however, the data suggest that a bloom may have occurred prior to the first survey in February.
• July/August Upwelling – Physical and chemical data suggest that significant upwelling events occurred in July and August of 1998 and that these events input nutrients into the coastal surface waters. Evidence of this was observed at coastal stations along the south shore and in the western
nearfield. The upwelling conditions, along with tidal transport from Boston Harbor, supplied nutrients to the nearfield that supported the high phytoplankton concentrations that were observed in August.

- **September/October Fall Bloom** – As with the winter/spring bloom, the fall bloom is not a consistent annual characteristic in the Bays. The intensity of the fall bloom and the phytoplankton species that bloom have varied from year to year during the baseline-monitoring period. In 1998, the fall bloom was not a single species bloom, but rather a general increase in the numbers of a variety of chain-forming diatoms. The bloom was more clearly observed in the increased chlorophyll concentrations and productivity data that were collected.

- **Extended Period of Stratification and DO decline** – The onset of seasonal stratification was slightly delayed in 1998 compared to previous baseline monitoring years as was the overturn of the water column and the return to winter conditions. The water column was stratified until November throughout much of the nearfield and a deep halocline was present in December at the deeper eastern nearfield stations. The strength and duration of stratification are important factors in the decline of bottom water dissolved oxygen concentrations. Due to the persistence of stratified conditions in 1998, bottom water DO concentrations decreased over the entire June to December time period in the nearfield area. The delay in mixing, combined with a pulse of organic material from the atypical November/December bloom, led to the annual minimum in bottom water DO concentration (7 mg L\(^{-1}\)) observed in December. The DO minimum concentration was not extremely low in comparison to data collected during previous baseline monitoring years. Due to major storm events and the lack of an input of organic material from a winter/spring bloom, the bottom water DO concentrations observed in June were very high (11.2 mg L\(^{-1}\)), which subsequently lessened the effect of the delay in returning to well-mixed winter conditions.

- **November/December Elevated Ammonia and Phosphate Concentrations** – In November and December 1998, anomalously high concentrations of ammonium and phosphate were observed in the western nearfield that correlated with high concentrations observed by the MWRA in Boston Harbor. The source of these nutrients was not determined, but may have been due to the transfer of south system sewage flows from Nut Island to the Deer Island facility, increased dredging operations in the harbor, an ecological change in biological utilization of nutrients in the Harbor, or other factors. It is suspected that the anomalously high NH\(_4\) and PO\(_4\) concentrations triggered a localized bloom that was observed in the nearfield in December.

### 1998 Plankton Overview (Dr. Jefferson Turner, UMass – Dartmouth)

- **Whole-Water Phytoplankton Assemblage**
  - Microflagellates and small cryptomonads were the numerical dominants.
  - Sustained increase in total phytoplankton abundance, from low levels in February through April to high levels in May through October, followed by declines in November and December.
  - No major winter/spring bloom or fall bloom
  - No confirmed nuisance algae blooms, although the fall *Pseudo-nitzschia pungens* records could have included some *P. multiseries*. Maximum abundance of *P. pungens* did not exceed 83 \(\times\) 10\(^3\) cells/L.

- **Screened Water Phytoplankton**
  - *Dinophysis* (silicoflagellate) was dominant in February, followed by *Ceratium longipes* and *C. tripos*.
  - *C. longipes* and *C. tripos* dominant from March onward, followed by other dinoflagellates.
  - Sustained bloom of *C. longipes* and *C. tripos* was the major event

- **Zooplankton**
• Dominated by copepod nauplii, adults, and copepodites of the small copepods *Oithona similis* and *Pseudocalanus* spp., with seasonal subdominant contributions from gastropod and bivalve veligers and a mixture of other normally occurring taxa.
• Additional Cape Cod Bay stations samples during WF981, WF982, and WF984 extended total abundance recorded for F01 and F02.
• Once outfall on line, expect the copepod abundance in the nearfield and farfield outside Boston Harbor will be dominated by *Oithona similis*, *Pseudocalanus* spp., and, to a lesser extent, *Paracalanus parvus*, *Centropages typicus*, *C. hamatus*, and *Calanus finmarchicus*.
• Meroplankton abundance are “spikey” and more likely related to reproductive cycles of the macrobenthic parents than to processes in the plankton.
• Zooplankton Threshold. Suggest abundance of *Acartia tonsa/A. hudsonica* > 50% of the total non-naupliar copepods (adults and copepodites)

1998 Productivity Overview *(Dr. Aimee Keller, URI)*
• Annual production at N04, N18, and F23 lower than in prior years
• Seasonal productivity pattern dominated by fall bloom
• No winter-spring bloom despite increased chlorophyll-specific production during typical bloom period
• Bloom failure not correlated with nutrient availability or light limitation
• Bloom failure may be related to warm winter temperatures and increased grazing by zooplankton
• Productivity significantly correlated with composite parameter (but variable across years)

1998 Nutrient Cycling in the Harbor *(Dr. Anne Giblin, Marine Biological Laboratory)*
• Sediment trends in the highly impacted sites in the northern Harbor may be showing some decrease in fluxes even with the amphipods present.
• Denitrification rates have gone up and down a bit with amphipod colonization but still not a major factor in removing anthropogenic nitrogen.
• DIN/DIP ratio may have shifted up but the majority of 1998 data still shows benthic fluxes still less than 16 (i.e., would contribute to nitrogen limitation).

**Statistical Approach to Threshold Testing and Rule Setting** *(Dr. Jeff Rosen, TPMC)*
• Currently evaluating ways to aggregate data and conduct statistical tests
• Must define rules for aggregating the data.
Effluent Solids loading

Dec. 1991
Sludge discharge stopped

1995
New Primary

1997
Secondary startup
1998
Nut I. flow to Deer Island

Tons per day

Year

Overview – Benthic Monitoring (Day 1) (Mr. Ken Keay, MWRA)
Effluent metals loading

Year

Pounds per day
0 200 400 600 800 1000

Sum of Chromium, Copper, Nickel, Lead, and Zinc
Average Modeled Dilution of Sewage Effluent, Winter Conditions

Existing Harbor Outfalls

New Bay Outfall
Draft NPDES permit #MA0103284, Section 8.a.

"The results of any monitoring required by the contingency plan shall be reported ..." (annually) "except that if any parameter exceeds the corresponding early "caution level" or "warning level" the monitoring result shall be reported within ten (10) days after the result becomes available. The MWRA shall make all reasonable efforts to provide results within ninety (90) days after the sampling event, and MWRA shall obtain approval from EPA and the MADEP if the results will take longer than one hundred and fifty (150) days."
Delivery Performance, 1992-1998
Threshold-related Data reports

Months after collection

- Average, 1992-1997
- 1998 Average (range)

Data Reports:
- Nutrients
- Plankton
- Infauna
- Sed. Chem.
- SPI
- Histology
- Tissue Chem.

Require
Goal
Contingency Plan Process

DO 100 i=1,many
   i = years, j = Different thresholds
   C
   C RDM = Routine Discharge Monitoring Data
   C CAUTN = Contingency Plan Caution level
   C WARN = Contingency Plan Warning level

   Do 200 j = 1,~50
   TRIGGR(i,j) = f(RDM(i))

   IF(TRIGGR(i,j) .lt. CAUTN(j)) THEN
       write (everywhere,*) ' NO PROBLEM'
       OUTPUT = 'No Problem'

   ELSE IF(TRIGGR(i,j) >= CAUTN(j)) THEN
       CALL EVALUATE(TRIGGR,CAUTN,i,j,OUTPUT)
       CALL RESPONSE(MORE, CAUSAL, OUTPUT, etc.)

       IF(OUTPUT = 'No Problem') THEN
           write (everywhere,*) ' NO PROBLEM'
           GO TO 200

   ELSE IF(TRIGGR(i,j) > WARN(j)) THEN
       CALL PROBLEM(OMTF, DEP, EPA, PUBLIC, etc.)

   ENDIF

200   CONTINUE
100   CONTINUE

DON'T STOP
DON'T END
Draft NPDES permit #MA0103284, Section 8.b.

"If any parameter exceeds the "warning level" listed above in Section 8.a, the MWRA shall: (1) determine whether there are any adverse environmental impacts from such exceedance, (2) evaluate the extent to which MWRA discharge contributes to such impacts, and (3) unless MWRA demonstrates by convincing evidence, to the satisfaction of EPA and the MADEP, that the MWRA discharge does not contribute to such adverse environmental impacts, develop a plan and schedule to address such impacts . . . ."
Overview – Water Column Monitoring (Day 2) (Dr. Mike Mickelson, MWRA)
Environmental and man-made perturbations which affect valued ecosystem components

Those effects which are of
- local scale,
- understandable interaction, and
- conceivable relevance to outfall
are the basis of the Outfall Monitoring Plan.

Outfall monitoring Plan.

The Contingency Plan identifies selected measurements to be used as thresholds for action.

The other measurements are just as important because they
- Explain impact of exceedance
- Explain cause of exceedance
- Demonstrate ability to detect changes that do occur
- Further understanding of the ecosystem
Delivery Performance, 1992-1998
Threshold-related Data reports

Average, 1992-1997
1998 Average (range)

Months after collection

Data Reports

Nutrients  Plankton  Infauna  Sed. Chem.  SPI  Histology  Tissue Chem.
Draft NPDES permit #MA0103284, Section 8.b.

"If any parameter exceeds the "warning level" listed above in Section 8.a, the MWRA shall: (1) determine whether there are any adverse environmental impacts from such exceedance, (2) evaluate the extent to which MWRA discharge contributes to such impacts, and (3) unless MWRA demonstrates by convincing evidence, to the satisfaction of EPA and the MADEP, that the MWRA discharge does not contribute to such adverse environmental impacts, develop a plan and schedule to address such impacts . . .".
Action list from EPA/MADEP permit for MWRA outfall T01

Monitor effluent

Ambient monitoring
   Plan and modify design
   Report results
   Model eutrophication
   Model the whale-prey food web
   Test diffuser dilution

Contingency Plan
   Report exceedances
   Simulate a problem

Monitor pathogen exposure of shellfish

Maintain and operate the treatment plant

Implement Best Management Practices

Pollution prevention
   Limit industrial discharges

Monitor sludge quality for agricultural use

Monitor CSO facilities and storm spills

Impose water conservation
Outfall Monitoring Plan: Development Status (Dr. Carlton Hunt, Battelle)
MWRA Outfall Monitoring Plan: Development Status

1998 Science Review Meetings

April 9 and 12, 1999

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**Development status**

- Revised draft of the OMP in development
- Focusing on completing threshold statements
- Threshold testing will be one theme for the June (Tentative) 1998 OMSAP Public Science Meeting
- Automation of the threshold and monitoring comparison process pending completion of thresholds (Task 30)
  - Will reside within the database
  - Review data on upload and acceptance
- Requires
  - Strict protocols for the data aggregation
  - Defined statistical testing protocols
Threshold Changes in the Last Year

- Effluent
  - Removed floatable threshold (not in permit)
- Water
  - Oxygen
    - Depletion rate threshold removed
  - Chlorophyll
    - No changes
  - Nuisance species
    - Modified Psuedonitzchia threshold
  - Zooplankton
    - Modified threshold statement
- Fish and Shellfish
  - Contaminants
    - Removed lipid based thresholds, clarify if do caution thresholds on dry or wet weight
  - Histopathology
    - No changes
- Seafloor
  - Benthos
    - Identified 5 candidate thresholds
  - Contaminants
    - No changes
  - Organic loading
    - No changes

Threshold Testing Cycle

1. Data Generation
2. Data Reconciliation
3. Threshold Statement
4. Data aggregation protocol
5. Notification
6. Comparison to threshold
7. Decision Rule
Where are we in the process?

- Effluent
- Water
  - Oxygen
  - Chlorophyll
  - Nuisance species
  - Zooplankton
- Fish and Shellfish
  - Contaminants
  - Histopathology
- Seafloor
  - Benthos
  - Contaminants
  - Organic loading

Data Reconciliation; Threshold Statement; Test protocol; Decision Rule

Threshold Work in Progress

- Water
  - Evaluating statistical approach to means testing and the development of 95th percentile testing
  - Evaluating the data aggregation protocols and statistical test (Decision rules)
  - Evaluating incorporation zero values that dominate the database into the testing
- Fish and Shellfish
  - Decision on wet versus dry weight for caution thresholds
- Seafloor
  - Working on decisions rules on the diversity thresholds and threshold statements
  - Evaluating the compositional and functional thresholds
Activities and Schedules

- Complete draft synthesis reports for 1998: May - June time frame
- Complete threshold statements, data aggregation and decision rules - early June
- Develop rapid threshold review protocols - June - July
- Complete draft Outfall Monitoring Plan - June
- Develop presentations for the OMSAP public science meeting: May - June

Meeting goals

- Review and discuss 1998 data
- Debate the thresholds as appropriate
- Develop themes and key presentations for the June OMSAP public science meeting
Table. Summary of thresholds against which monitoring data will be compared to evaluate whether significant environmental change occurs in Massachusetts and Cape Cod Bays.

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<tr>
<th>Area/Location</th>
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</thead>
<tbody>
<tr>
<td>Effluent (prior to entrance into the outfall tunnel)</td>
<td>Total nitrogen</td>
<td>E-1</td>
<td>Total nitrogen loading &gt;12,500 tons/year</td>
<td>Total nitrogen loading &gt;14,000 tons/year</td>
<td></td>
</tr>
<tr>
<td>Chlorine, residual</td>
<td>E-2</td>
<td>None</td>
<td></td>
<td>631 μg/L average daily</td>
<td></td>
</tr>
<tr>
<td>PCBs</td>
<td>E-3</td>
<td>None</td>
<td></td>
<td>PCB (as Arochlor) limit =0.0045 mg/L monthly</td>
<td></td>
</tr>
<tr>
<td>Toxicity</td>
<td>E-4</td>
<td>None</td>
<td></td>
<td>Acute: effluent LC50 &lt; 50% for shrimp; Chronic: effluent NOEC for fish growth and sea urchin fertilization &lt; 1.5% effluent</td>
<td></td>
</tr>
<tr>
<td>CBOD</td>
<td>E-5</td>
<td>None</td>
<td></td>
<td>&gt;40 mg/L weekly &gt;25 mg/L monthly</td>
<td></td>
</tr>
<tr>
<td>Fecal coliform Bacteria</td>
<td>E-6</td>
<td>None</td>
<td></td>
<td>14,000 fecal coliforms/100 ml at point of dechlorination (weekly mean, monthly 90th percentile, and 24 consecutive hours)</td>
<td></td>
</tr>
<tr>
<td>Total Suspended Solids</td>
<td>E-7</td>
<td>None</td>
<td></td>
<td>45 mg/L weekly 30 mg/L monthly</td>
<td></td>
</tr>
<tr>
<td>Treatment plant performance</td>
<td>Non trigger parameters listed in Part one of the permit e.g., pH, Flow; selected contaminants; selected nitrogen species; settleable solids; cyanide; Volatile organic compounds; etc</td>
<td>E-8</td>
<td>More than 5 violations of permit requirements/year. Note: Specific conditions for each of these non trigger parameters can be found in Part I of the MWRA Discharge Permit</td>
<td>Operating in violation of the expected permit requirements more than 5% of the time per year. e.g., pH &lt;6 or &gt;9 at any time, flow &gt;436 MGD for dry day</td>
<td></td>
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<tbody>
<tr>
<td>Bottom water</td>
<td>Dissolved oxygen concentration</td>
<td>W-1</td>
<td>Survey mean DO is less than 6.5 mg/L for any one survey during stratification (June-Oct.)</td>
<td>Survey mean DO is less than 6 mg/L for any one survey during stratification (June-Oct.)</td>
<td>No exceedances during baseline period. Range in monthly means is across baseline period (1992 – 1998) is xx – xx mg/L</td>
</tr>
<tr>
<td>Nearfield</td>
<td>Chlorophyll level</td>
<td>W-2</td>
<td>Annual mean Nearfield concentration greater than 1.5x baseline annual mean</td>
<td>Annual mean Nearfield concentration greater than 2x baseline annual mean.</td>
<td>Baseline through 1997: Gong (1998) Mean = 1.95 ± 0.47 mg/L, Caution = 2.92 mg/L, Warning = 3.89 mg/L</td>
</tr>
<tr>
<td>Nearfield</td>
<td>Chlorophyll level</td>
<td>W-3</td>
<td>Seasonal (Spring, Summer, Fall) Nearfield mean concentration exceeds 95th percentile of the baseline seasonal distribution</td>
<td>None</td>
<td>Baseline through 1997: Gong (1998) Mean Spring: 6.61±0.63 mg/L, Summer: 1.30±0.5 mg/L, Fall: 2.45±1.11 mg/L. Threshold (caution/warning) Spring: 2.68/3.35 mg/L, Summer: 2.61/2.83 mg/L, Fall: 4.93/5.66 mg/L</td>
</tr>
<tr>
<td>Nearfield</td>
<td>Nuisance algae abundance</td>
<td>W-4</td>
<td>Seasonal (Spring, Summer, Fall) mean concentration of <em>Alexandrium tamarense</em> or <em>Phaeocystis poucheti</em> exceeds 95th percentile of the baseline seasonal mean. Seasonal (Spring, Summer, Fall) mean concentration of confirmed <em>Pseudo-nitzschia multiseries</em> exceed 500,000 cells per liter.</td>
<td>None</td>
<td>Under development</td>
</tr>
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<tr>
<td>Nearfield</td>
<td>Zooplankton abundance</td>
<td>W-5</td>
<td>The abundance of <em>Acartia tonsa</em>/<em>A. hudsonica</em> becomes greater than 50% of the copepodite plus adult copepod abundance in a Nearfield sample. Alternative: Nearfield abundance of copepodites and adult stages of <em>Calanus, Pseudocalanus, Centropages typicus, Oithona</em> does not decrease by more than 50% of the baseline mean and the abundance of copepodites and adult stages of <em>Acartia, Eurytemora, Centropages hamatus</em> does not increase by more than 50% of the baseline mean.</td>
<td>None</td>
<td>Under development</td>
</tr>
<tr>
<td>Farfield</td>
<td>PSP extent in the Farfield</td>
<td>W-6</td>
<td>Any new incidence at a state PPS monitoring station having no previously reported incidence</td>
<td>None</td>
<td>PPS has never been observed at 3 of 18 monitoring stations</td>
</tr>
<tr>
<td>Plume</td>
<td>Initial dilution</td>
<td>W-7</td>
<td>None</td>
<td>Effluent dilution under stratified and unstratified conditions less than predicted by EPA as basis for NPDES permit</td>
<td>Dilution is expected to be 70:1 at a distance of 60m from the diffusers. Plume tracking studies in December 1999 and June 2000 will confirm dilution</td>
</tr>
<tr>
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<td>-------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Fish and Shellfish</td>
<td>Mercury</td>
<td>FS-1</td>
<td>Annual mean mercury dry-weight concentration in flounder, lobster, and caged mussel meat greater than twice the baseline mean.</td>
<td>Annual mean mercury concentration in flounder, lobster, and caged mussel meat greater than 0.8 μg/g wet weight</td>
<td>Baseline Mean through 1998 (wet weight): Flounder = 0.085 ppm Lobster = 0.154 ppm Caged Mussel = 0.022 ppm</td>
</tr>
<tr>
<td>Outfall site</td>
<td>PCB</td>
<td>FS-2</td>
<td>Annual mean PCB dry-weight concentration in flounder and meat greater than twice the baseline mean.</td>
<td>Annual mean PCB concentration in flounder, lobster, and caged mussel meat greater than 1.6 μg/g wet</td>
<td>Baseline Mean through 1998 (wet weight): Flounder = 38.1 ppb Lobster = 17.1 ppb</td>
</tr>
<tr>
<td>Outfall site</td>
<td>Lead</td>
<td>FS-3</td>
<td>Annual mean dry-weight lead concentration in caged mussel meat greater than greater than twice the baseline mean.</td>
<td>Annual mean lead concentration in caged mussel meat greater than 3 μg/g wet weight</td>
<td>Baseline Mean through 1998 (wet weight): Caged Mussel = 0.43 ppm</td>
</tr>
<tr>
<td>Flounder Outfall Site</td>
<td>Liver disease incidence</td>
<td>FS-4</td>
<td>Flounder liver disease (CHV) greater than harbor baseline prevalence (1991-1998)</td>
<td>None</td>
<td>Baseline Mean Through 1997 = 24.9</td>
</tr>
<tr>
<td>Area/Loc.</td>
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</tr>
</tbody>
</table>
| Nearfield | Depth of Redox potential discontinuity | B-1 Depth in the nearfield | Redox potential discontinuity declines to less than 0.5 x baseline | None | Baseline mean
|           |           |           |                |               | Approximately 3.5 cm |
| Nearfield | Toxics | B-2 Nearfield mean surface sediment contaminant concentrations greater than 90% of the EPA’s Equilibrium Partitioning Sediment Guideline (formerly sediment quality criteria) | Nearfield mean surface sediment contaminant concentrations greater than EPA’s Equilibrium Partitioning Sediment Guideline or NOAA Effects range Median (ERM-M) value | Under development | OMP will include a table of the most recent marine ERM-M values |
| Nearfield | Benthic diversity | B-3 Diversity threshold Diversity does not decrease more than n... of the baseline J’ (Evenness) Log α (Richness) E(S10) (Evenness & Richness) Exploring: the pooling versus separation of the sand and mud communities | | Under development | |
| Nearfield | Benthic Compositional | B-4 The sum of n (n = 4 to 6?) indicator species becomes more than x % of a community. Should x be percent of community OR an increase relative to baseline? | The sum of n (n = 4 to 6?) indicator species becomes more than 50 % of a community? | Under development | |
| Nearfield | Benthic Functional group (Ecologically significant measure) | B-5 Exploring: | | Under development | |
| Nearfield | Benthic Families approach (Ecologically significant measure) | B-6 Exploring: | | Under development | |
Benthic Monitoring
Benthic Monitoring Thresholds Approach/Rationale (Mr. Ken Keay, MWRA)

1999 MWRA Annual Technical Workshop
April 9 and 12, 1999
FIGURE 5.1.3.b. AREAS OF PREDICTED CHANGED AND DEGRADED BENTHIC COMMUNITIES DUE TO ORGANIC ENRICHMENT UNDER STRATIFIED CONDITIONS WITH SECONDARY TREATMENT FOR ALL SITES.
Figure 4. Location of near and farfield stations at midfield distances from the diffuser. The shaded area is the locus of points at a 2 km distance from the outfall. The inset shows the midfield study area location within Massachusetts and Cape Cod Bays.
Modeled deposition of particulate organic carbon (August)

- Harbor Outfall with Primary Treatment
  - 1000
  - (mg C/m²-d)
  - < 125

- Bay Outfall with Secondary Treatment
  - 1000
  - (mg C/m²-d)
  - < 125
Figure 39. Sediment composition at nearfield and midfield stations for the period 1992-1996.
Figure 42. Total organic carbon concentrations at the nearfield and midfield stations for the period 1992-1996.
Implications for sediment thresholds

- No expectation of substantial change.

- Change, if any, should be small, possibly not localized to the immediate vicinity of the outfall.

- Schedule leaves little or no time for detailed interpretation of the data prior to reporting on thresholds.

- Strong push from regulators & oversight committee for a KISS approach to threshold testing that's nonetheless ecologically and statistically valid.
Figure 20. Adjusted DPCA-H coordinates. Equivalent to the residuals from the regression shown in Figures 18 and 19. The three ellipses delineate regions within which new mean values, computed with one of three sample sizes ($n$), would not be significantly different from that of the baseline sentinel stations at $\alpha = 0.05$ and $\beta = 0.5$. Replicate labeling is as described in Figure 12.
Benthic Monitoring
1998 Sediment Profile Imaging (Dr. Robert Diaz, VIMS)
Nearfield summary.dbf
# 0.5 - 0.9 cm
# 1 - 1.9
# 2 - 3

Nearfield SPI 1998

0 2 4 6 Kilometers
• Biological processes (bioturbation)
• Surface sediments were dominated by processes
• Dominated by broad-scale physical

Sediment Textures
• 38 station-replicate images that had measured RPD depths only one exceeded a difference of 50% (NF14-3).
• Indicates that Quick Look analysis has sufficient resolution to estimate RPD depths given the 50% change criteria.
• Test sensitivity of the Quick Look analysis for estimating RPD depths within 50% of the actual RPD value

• Quick Look value was expressed as a percentage of the computer analysis value
For 3 station-replicates that had >1 cm difference in RPD:

- Quick Look analysis values were ≥3 cm.
- Detailed analyses were 0.9, 1.0, and 1.8 cm for NF14-2, NF14-3, and NF18-3.
- Overestimated RPD depth related to light color and low contrast of sediment.
- Subsequently accounted for in the computer image analysis.
Quick Look vs. Detailed Analyses

- Correspondence was very good.
- Prism penetration 1 in 69 station-replicates (NF23-1) differed by >1 cm.
- Surface relief 4 in 69 differed by >1 cm.
- RPD depth 3 in 69 differed by >1 cm.
## OSI (Rhoads and Germano 1986)

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Apparent Color
RPD Layer Depth (cm)

Nearfield SPI 1998

0  2  4  6 Kilometers
Sediment Types

Nearfield SPI 1998
Benthic Monitoring

1998 Hardbottom Community (Dr. Barbara Hecker, Hecker Environmental)
From Butman et al., 1992
Asparagopsis hamifera
1995-1998

Low relief

n=421

Moderately-low relief

n=436

Moderate relief

n=334

Moderately-high relief

n=534

High relief

n=293

Abundance category

None  Rare  Few  Common  Abundant
Cluster group designations
1996-1998

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1 dominated by upright algae
2 dominated by Lithothamnion spp.
3 very low Lithothamnion spp.
4 diffusers - Metridium senile
### Lithothamnion spp. (percent cover)
#### 1996-1998

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**Diff**

44
Conclusions

Structure of benthic community controlled by location on drumlin - concurrent depth substratum type local relief sediment drape

1) most areas appear to be temporally stable

2) but a number of areas are spatially heterogeneous

3) hard to dissect differences between temporal and spatial variance

4) some variability in data - patchy nature of hardbottoms

5) highly unlikely to be able to detect small shifts or changes in the composition of the hardbottom communities

6) probably the most likely "key-stone" species would be

Lithothamnion
- it is very abundant
- it is widely distributed
- less patchy than Asparagopsis
- appears to be sensitive to sediment loading
Benthic Monitoring
Infaunal Community Overview (Dr. Roy Kropp, Battelle)
Benthic Nearfield Stations
Figure 70. Intraannual density at nearfield and midfield stations for the period 1992-1997. Top diagram shows the mean and standard error for each station; bottom diagram shows abundances for each year.
Figure 71. Number of species at nearfield and midfield stations for the period 1992-1997. Top diagram shows the mean and standard error for each station; bottom diagram shows values for each year.
Figure 12: Shannon-Wiener diversity at nearfield and midfield stations for the period 1992-1997. Top diagram shows H' for each station; bottom diagram shows H' for each year.
Benthic Farfield Stations
Benthic Monitoring
Benthic Community Threshold Assessment (Dr. Gene Gallagher, UMass – Boston)
MA Bay Benthic Community Threshold Assessment

1999 MWRA Technical Workshop
Battelle New England
April 9, 1999
Eugene D. Gallagher
Jim Blake, ENSR
Peg Pelletier

Methods for assessing change
Species & functional groups
- Changes in diversity
  - Log-series alpha
  - $E(S_{17})$
  - Pielou’s $J'$
    - These diversity indices are sensitive to both species richness and species evenness
- Changes in functional group representation
  - MA Bay benthos has been classified into 8 functional groups
  - Chi-square tests
- Changes in indicator species

Benthic thresholds
Issues to be resolved
- The after effects will be determined using the 1992-1999 benthic baseline data
- What is the statistical population for Nearfield sites?
  - Are there significant differences among sand and silt-clay habitats in species richness or evenness
  - Do these groups need to be split for establishing a baseline
- So far, no major differences in sand vs. Mud in species diversity

$E(S_{17})$ and $H'$ are highly correlated
All 1992-1997 MA Bay data

Log-series alpha
Alpha (species richness) has been increasing in MA Bay

May’s Log-series
May (1975): Log series fits Sanders’ rarefaction curves

![Graph showing log-series alpha over years with a trend indicating an increase in MA Bay.](image)
Species diversity

Evenness may be more informative than richness
- Sanders-Hurlbert rarefaction curves reveal both richness & evenness
- Caswell (1972) used log series as a null model
- May (1975): Benthic communities tend to fit the log series
- Gray argued that benthic communities are not log-series, but were lognormally distributed
- Hughes & Lambshead showed that benthic communities are not log-normally distributed; Hughes modeled the dynamics

Non-dimensional diversity

Calculates evenness relative to a log-series null.
- Steps in analysis
  - Generate a rarefaction curve
  - Generate the log-series expectation
  - Divide the observed diversity by the log-series expectation
  - Non-dimensionalize by dividing numbers by the species total and expected species by observed total species
  - A deeply dipping curve indicates less evenness than log series.

West Falmouth Oilspill

Heaviest impacts 1 year after spill at Station 25

1992-1996 MA Bay

Departures from log series

Pielou’s J’ correlated with ND-Div

Pielou’s J will be used in the index development

PCA-H analysis

Ordination based on CNESS
- Steps in analysis
  - Convert species data to probabilities
  - Cluster samples and species
  - Order samples and species in space
- Results
  - Cluster analysis
    - Two major species & sample groups
    - Sand assemblage: Corophium
    - Three mud assemblages
  - Ordination analysis
    - Sand vs. mud the key environmental gradient
    - Interannual variability less important than space
Functional groups

**1992-1997 Near and Far**

- Warwick, Clarke, Gray & Underwood argue that species id’s not necessary
  - Major changes in community structure evident at phyla, class & family level
  - Tested on European pollution gradients
  - Not an explanations of dynamics

**Dynamic explanation**
- It is the diversity of functional groups that counts!
- Seems to apply from deep sea to shallow water

**Diversity of functional groups**

Even the deep-sea has high evenness of feeding groups

**Functional groups**

50 most abundant species classified

- Suspension feeders
- Interface feeders
- Surface deposit feeders
- Reverse conveyor-belt feeders
- Subsurface deposit feeders
- Top-down conveyor-belt species
- Omnivores/scavengers
- Predators
**Reverse conveyor-belt feeding**

*Food caching*

**Ordination of functional groups**

*1992-1996 data*

**Ordination based on functional groups**

**Associations of functional groups**

**Species vs. Functional Evenness**

**Conclusions**

At the levels of communities and functional groups:
- Thresholds will be based on significant changes in a "pooled" population of nearfield stations with respect to:
  - Species diversity (richness and evenness)
  - Change in indicator species
  - Change in frequency of functional groups
- This threshold assessment can be made quickly (approximately 1 week)
- At the end of each year, a full assessment of change in species composition will be made. This requires a longer QA/QC process for species composition
Benthic Monitoring
1998 Sediment Chemistry (Dr. Carlton Hunt, Battelle)
Sediment Contaminant Special Studies - 1998

MWRA Benthic Science Review Meeting

April 9, 1999

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Sampling rationale

- **Goal:** Collect additional sediment collections and testing to address possible short-term transport and impact
  - Focus on high TOC/depositional areas
- **Four locations** were chosen based on the following criteria:
  - Historical fine grained material (>50% sand/silt);
  - Relatively stable area (grain size composition >50% sand/silt over the period monitored)
  - High TOC, relative to other locations nearby (at least 1% TOC)
  - Within the zone of particle deposition from the BEM
  - Expand areas sampled quarterly by USGS (avoid samples from near USGS stations (NF12 and NF17)
Sampling rationale

- Recommended sites: FF10, NF8, NF24, and NF 22.
  - The first three stations lie on a line extending to the northwest from the west end of the diffuser and provide spatial gradient extending from the diffuser. This gradient extends towards the high deposition area predicted by the model.
- NF 22 lies to the southwest of the west end of the diffuser and is along the projected long-term transport path from the diffuser.
- FF10 was selected over NF12 because it
  - Extends the area of impact sampled under the contaminant special study Taek
  - Represents a Fairfield location near the center of the high deposition location predicted by the BEM model
- It is also a slightly more sandy location.
## Results - FF10

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Reasonably stable GB, TOC, and contaminants.

## Results - NF08

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Silt in contaminant levels between 2952 and 98508.
Likely grain size and TOC driven in 98 94 and 95 appear to be "real" silt.

Sediment Contaminant Special Studies - 1998
### Results - NF22

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- Coating of sediments in 98, TOC down a bit
- Relatively static concentrations 1994 to 1998

### Results - NF24

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*Note: one of the three 1998 samples had high pyrogenic PAH content in Finer; high TOC in '95

- Contaminant levels 1994 and 1998

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Sediment Contaminant Special Studies - 1998

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Battelle
Fish and Shellfish Monitoring
1998 Caged Mussel Studies (Ms. Lisa Lefkowitz, Battelle)
## MUSSELS COLLECTION

![Map of MUSSEL COLLECTION](image)

### Summary of Arrays Deployed and Recovered at 40- and 60-Days

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<td>1 Array</td>
<td>0 Array</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 Gloucester</td>
<td>0 Gloucester</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 Sandwich</td>
<td>0 Sandwich</td>
</tr>
<tr>
<td>Cape Cod</td>
<td>4</td>
<td>1 Array</td>
<td>1 Array</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 Gloucester</td>
<td>2 Gloucester</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 Sandwich</td>
<td>1 Sandwich</td>
</tr>
</tbody>
</table>

(1) Each "Array" consisted of 2 Gloucester Cages and 1 Sandwich Cage
MUSSEL MEASUREMENTS

SUMMARY OF BIOLOGICAL CONDITION PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell Length</td>
</tr>
<tr>
<td>Shell Volume</td>
</tr>
<tr>
<td>Shell Weight</td>
</tr>
<tr>
<td>Total Organism Weight</td>
</tr>
<tr>
<td>Total Soft Tissue Weight</td>
</tr>
<tr>
<td>Gonad-Mantle Weight</td>
</tr>
<tr>
<td>Non-Gonadal Tissue Weight</td>
</tr>
</tbody>
</table>

SUMMARY OF CHEMICAL PARAMETERS

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Number of Samples</th>
<th>Hg</th>
<th>Pb</th>
<th>PCBs</th>
<th>PAHs</th>
<th>Pests</th>
<th>Lipids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gloucester</td>
<td>36</td>
<td></td>
<td></td>
<td>!</td>
<td>!</td>
<td>!</td>
<td>!</td>
</tr>
<tr>
<td>Sandwich</td>
<td>36</td>
<td>!</td>
<td>!</td>
<td>(1)</td>
<td>(1)</td>
<td>(1)</td>
<td>(1)</td>
</tr>
</tbody>
</table>

(1) Sandwich Predeployment mussels were analyzed for organics in order to compare to Quincy 60-day Sandwich mussels which were also analyzed for organics due to loss of Gloucester mussels.
MUSSEL GROWTH AND CONDITION

- No acute mortality of deployed mussels at any of the locations.

- Shell length, volume and biomass increased during Discovery deployment.

- Did not assess biological condition at other stations due to lack of 60-day recoveries.
1998 MUSSEL RESULTS - METALS

1998 Mercury in Mussel Tissue

1998 Lead in Mussel Tissue
1998 MUSSEL RESULTS – Chlorinated Organics
(ng/g dry weight)

Total PCB

Pesticides

+ DIE LDRIN
+ Total CHLOR
+ Total DDT
# SUMMARY OF PAH LISTS OF ANALYTES

## 1997/1998 Complete PAH List

**Low Molecular Weight PAHs**
- 1-METHYLNAPHTHALENE
- 1-METHYLPHENANTHRENE
- 2,3,5-TRIMETHYLNAPHTHALENE
- 2,6-DIMETHYLNAPHTHALENE
- 2-METHYLNAPHTHALENE
- ACENAPHTHENE
- ACENAPHTHYLENE
- ANTHRACENE
- BENZOTHIAZOLE
- BIPHENYL
- C1-DIBENZOTHIOPHENES
- C1-FLUORENES
- C1-NAPHTHALENES
- C1-PHENANTHRENES/ANTHRACENES
- C2-DIBENZOTHIOPHENES
- C2-FLUORENES
- C2-NAPHTHALENES
- C2-PHENANTHRENES/ANTHRACENES
- C3-DIBENZOTHIOPHENES
- C3-FLUORENES
- C3-NAPHTHALENES
- C3-PHENANTHRENES/ANTHRACENES
- C4-NAPHTHALENES
- C4-PHENANTHRENES/ANTHRACENES
- DIBENZOFURAN
- DIBENZOTHIOPHENE
- FLUORENE
- NAPHTHALENE
- PHENANTHRENE

**High Molecular Weight PAHs**
- BENZ(A)ANTHRACENE
- BENZO(A)PYRENE
- BENZO(B)FLUORANTHENE
- BENZO(E)PYRENE
- BENZO(G,H,I)PERYLENE
- BENZO(K)FLUORANTHENE
- C1-CHRYSENE
- C1-FLUORANTHRENES/PYRENES
- C2-CHRYSENE
- C2-FLUORANTHRENES/PYRENES
- C3-CHRYSENE
- C3-FLUORANTHRENES/PYRENES
- C4-CHRYSENE
- CHRYSENE
- DIBENZO(A,H)ANTHRACENE
- FLUORANTHENE
- INDENO(1,2,3-C,D)PYRENE
- PERYLENE
- PYRENE

## NOAA "Historic" PAH List

**Low Molecular Weight PAHs**
- 1-METHYLNAPHTHALENE
- 1-METHYLPHENANTHRENE
- 2,3,5-TRIMETHYLNAPHTHALENE
- 2,6-DIMETHYLNAPHTHALENE
- 2-METHYLNAPHTHALENE
- ACENAPHTHENE
- ACENAPHTHYLENE
- ANTHRACENE
- BENZOTHIAZOLE
- BIPHENYL
- DIBENZOFURAN
- DIBENZOTHIOPHENE
- FLUORENE
- NAPHTHALENE
- PHENANTHRENE

**High Molecular Weight PAHs**
- BENZ(A)ANTHRACENE
- BENZO(A)PYRENE
- BENZO(B)FLUORANTHENE
- BENZO(E)PYRENE
- BENZO(G,H,I)PERYLENE
- BENZO(K)FLUORANTHENE
- CHRYSENE
- DIBENZO(A,H)ANTHRACENE
- FLUORANTHENE
- INDENO(1,2,3-C,D)PYRENE
- PERYLENE
- PYRENE
1998 MUSSEL RESULTS - PAHs
(ng/g dry weight)

97'98' List - Total LMW/HMW PAHs
1998 Mussels

NOAA Historic List - Total LMW/HMW PAHs
1998 Mussels
**TEST FOR SIGNIFICANT DIFFERENCE FROM PRE-DEPLOYMENT CONCENTRATIONS**
*(using 2-tailed student t-test)*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Discovery</th>
<th>DI</th>
<th>FOS</th>
<th>Cape Cod Bay</th>
<th>Quincy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Lead</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Total PCBs</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Total DDTs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Total Chlordanes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Dieldrin</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Lindane</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>PAHs - 97'/98' List</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total LMWPAH</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Total HMWPAH</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Total PAH</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

(1) Assume random sampling, normal distribution and equal variances
TEST FOR SIGNIFICANT DIFFERENCE FROM PRE-DEPLOYMENT CONCENTRATIONS
(using 2-tailed student t-test)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Discovery</th>
<th>DI</th>
<th>FOS</th>
<th>Cape Cod Bay</th>
<th>Quincy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PAHs - 97'/98' List</strong></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Total LMWPAH</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Total HMWPAH</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Total PAH</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>PAHS - NOAA Historic List</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total LMWPAH</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Total HMWPAH</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Total PAH</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

(1) Assume random sampling, normal distribution and equal variances
## COMPARISON BETWEEN GLOUCESTER AND SANDWICH PREDEPLOYMENT MUSSELS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SANDWICH</th>
<th></th>
<th>GLOUCESTER</th>
<th></th>
<th>Significantly Different (P=0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>s.d.</td>
<td>mean</td>
<td>s.d.</td>
<td></td>
</tr>
<tr>
<td>Total PCB</td>
<td>79.1</td>
<td>7.8</td>
<td>63.2</td>
<td>2.6</td>
<td>YES</td>
</tr>
<tr>
<td>Total Chlordane</td>
<td>14.2</td>
<td>1.4</td>
<td>6.8</td>
<td>0.5</td>
<td>YES</td>
</tr>
<tr>
<td>Total DDT</td>
<td>55.8</td>
<td>5.7</td>
<td>34.1</td>
<td>2.9</td>
<td>YES</td>
</tr>
<tr>
<td>DIELDRIN</td>
<td>5.7</td>
<td>0.5</td>
<td>2.8</td>
<td>0.3</td>
<td>YES</td>
</tr>
</tbody>
</table>

### 97'/98' PAHs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total LMW PAH</td>
<td>146.0</td>
<td>37.9</td>
<td>207.3</td>
<td>28.1</td>
<td>NO</td>
</tr>
<tr>
<td>HMW PAH</td>
<td>65.1</td>
<td>8.2</td>
<td>166.3</td>
<td>17.5</td>
<td>YES</td>
</tr>
<tr>
<td>Total PAH</td>
<td>211.1</td>
<td>22.8</td>
<td>373.6</td>
<td>39.7</td>
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</tbody>
</table>

### NOAA Historic List PAHs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1998</th>
<th></th>
<th>2007</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total LMW</td>
<td>65.8</td>
<td>17.3</td>
<td>104.3</td>
<td>27.7</td>
<td>YES</td>
</tr>
<tr>
<td>Total HMW</td>
<td>58.1</td>
<td>8.3</td>
<td>138.6</td>
<td>14.4</td>
<td>YES</td>
</tr>
<tr>
<td>TOTAL PAH</td>
<td>123.9</td>
<td>21.7</td>
<td>242.8</td>
<td>33.4</td>
<td>YES</td>
</tr>
</tbody>
</table>
ANNUAL AVERAGE PAHS FOR 1992 – 1998 MUSSELS

(ng/g dry weight)
ANNUAL AVERAGE Total PCBs FOR 1992 – 1998 MUSSELS

(ng/g dry weight)

Total PCB - Gloucester

Total PCB - Discovery

Total PCB - Deer Island

Total PCB in Mussels at Outfall Site
ANNUAL AVERAGE METALS FOR 1992 - 1998 MUSSELS

* Indicates pre-deployment mussels were collected from Gloucester. All other years used Sandwich Mussels.
## Comparison of 1998 Mussel Results with Thresholds

<table>
<thead>
<tr>
<th>STATION</th>
<th>N</th>
<th>% Dry Wt</th>
<th>Total PCB (ng/g wet wt.)</th>
<th>Total DDTs (ng/g DRY wt.)</th>
<th>Total Chlordane (ng/g wet wt.)</th>
<th>Total Dieldrin (ng/g DRY wt.)</th>
<th>Total PAH (ng/g DRY wt.)</th>
<th>Mercury (Hg) (ug/g wet wt.)</th>
<th>Lead (Pb) (ug/g wet wt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deer Island(1)</td>
<td>5</td>
<td>14.75</td>
<td>23.7 ± 1.7</td>
<td>38.0 ± 0.6</td>
<td>3.7 ± 0.14</td>
<td>0.60 ± 0.02</td>
<td>217.7 ± 3.9</td>
<td>0.016 ± 0.001</td>
<td>0.57 ± 0.13</td>
</tr>
<tr>
<td>Aquarium(6)</td>
<td>5</td>
<td>11.92</td>
<td>55.6 ± 6.9</td>
<td>81.9 ± 5.1</td>
<td>3.1 ± 0.40</td>
<td>0.92 ± 0.10</td>
<td>2047.0 ± 127.4</td>
<td>0.016 ± 0.001</td>
<td>0.58 ± 0.04</td>
</tr>
<tr>
<td>Gloucester(7)</td>
<td>5</td>
<td>11.15</td>
<td>7.0 ± 0.3</td>
<td>34.1 ± 1.3</td>
<td>0.8 ± 0.04</td>
<td>0.32 ± 0.02</td>
<td>242.7 ± 14.9</td>
<td>NA ± 0.000</td>
<td>NA ± 0.000</td>
</tr>
<tr>
<td>Sandwich(8)</td>
<td>5</td>
<td>13.29</td>
<td>78.7 ± 0.4</td>
<td>55.8 ± 2.5</td>
<td>14.2 ± 0.08</td>
<td>5.67 ± 0.03</td>
<td>150.4 ± 9.7</td>
<td>0.015 ± 0.001</td>
<td>0.44 ± 0.05</td>
</tr>
<tr>
<td>Cape Cod(9)</td>
<td>8</td>
<td>18.32</td>
<td>8.9 ± 0.4</td>
<td>15.8 ± 1.1</td>
<td>1.5 ± 0.12</td>
<td>0.52 ± 0.03</td>
<td>37.1 ± 5.2</td>
<td>0.014 ± 0.001</td>
<td>0.40 ± 0.03</td>
</tr>
<tr>
<td>Outfall(4)</td>
<td>8</td>
<td>15.77</td>
<td>9.2 ± 0.4</td>
<td>19.8 ± 1.3</td>
<td>1.6 ± 0.09</td>
<td>0.35 ± 0.01</td>
<td>36.1 ± 3.7</td>
<td>0.015 ± 0.001</td>
<td>0.36 ± 0.03</td>
</tr>
<tr>
<td>Quincy(M7)</td>
<td>5</td>
<td>15.35</td>
<td>41.7 ± 1.5</td>
<td>50.8 ± 2.2</td>
<td>3.5 ± 0.12</td>
<td>0.86 ± 0.03</td>
<td>191.4 ± 8.9</td>
<td>0.016 ± 0.001</td>
<td>0.52 ± 0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FDA Limit</th>
<th>2000</th>
<th>5000</th>
<th>300</th>
<th>300</th>
<th>1000</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>MWRA Caution Level (2 x Baseline, 1992-1997)</th>
<th>28.4</th>
<th>45.3</th>
<th>2.4</th>
<th>0.57</th>
<th>258.8</th>
<th>0.044</th>
<th>1.1</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>MWRA Warning Level (80% FDA)</th>
<th>1600</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>0.800</th>
</tr>
</thead>
</table>
Fish and Shellfish Monitoring
1998 Flounder and Lobster Chemistry Studies (Ms. Lisa Lefkowitz, Battelle)
FISH AND SHELLFISH 1998
FLOUNDER AND LOBSTER STUDY
CONCLUSIONS

- 1998 Results are consistent with previous study

- Organic contaminant concentrations are generally highest at Discovery (Boston Inner Harbor) and lowest at ECCB with DI levels somewhere in between.

- Concentrations of organic contaminants have generally decreased since 1992, especially at Discovery and DI locations.

- Metals concentrations are more variable and most concentrations have been relatively constant during the study period.

- Mercury concentrations in flounder livers appear to have decreased since 1992.
FLOUNDER COLLECTION - 1998

- Broad Sound
- Mass Bay outfall
- Deer Island Flats
- Off Nantasket Beach

Eastern Cape Cod

0 10 20 30 Kilometers
# FLOUNDER MEASUREMENTS

## Physical/Biological Measurements

<table>
<thead>
<tr>
<th>Morphological Measurements</th>
<th>Histological Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Length (mm)</td>
<td>Neoplasm</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>Focal HV</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>Tubular HV</td>
</tr>
<tr>
<td>Fin erosion</td>
<td>Centrotubular HV</td>
</tr>
<tr>
<td>Gross score/Lesions</td>
<td>Macrophage Aggregation</td>
</tr>
<tr>
<td></td>
<td>Biliary proliferation</td>
</tr>
</tbody>
</table>

## Chemical Measurements

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Number of Samples</th>
<th>Metals (Ag, Cu, Cr, Cd, Pb, Ni, Zn)</th>
<th>Hg</th>
<th>Pb</th>
<th>PCBs</th>
<th>PAHs</th>
<th>Pests</th>
<th>Lipids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flounder Meat</td>
<td>9*</td>
<td>!</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flounder Liver</td>
<td>9*</td>
<td>!</td>
<td>!</td>
<td>!</td>
<td>!</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 1998 – 3 stations (3 composites each) analyzed for chemistry (DI, FOS, ECCB).
1992 - 1998 FLOUNDER RESULTS
TOTAL PCBs (ng/g dry weight)

- Total PCB concentrations in 1998 are lower than in recent years;
- The trend shows highest concentrations at DIF and lowest at ECCB, consistent with previous study years.
• Pesticide concentrations in 1998 are within the range of previous years, t-DDTs are lowest since 1992 (except Mirex in livers)
• The trend shows highest concentrations at DIF and lowest at ECCB, consistent with previous study years
• No clear response to major infrastructure changes (91/92’ DI sludge removal; 96 secondary treatment on-line)
1992 - 1998 FLOUNDER RESULTS
TOTAL PAHS IN LIVER
(ng/g dry weight)

- Total PAH concentrations in 1998 are among the lowest measured during study at all locations;
- The trend shows highest concentrations at DIF and lowest at ECCB, consistent with previous study years;
- Gradual decline in concentrations corresponds to 1992 sludge removal at DI.
1992 - 1998 FLOUNDER RESULTS
SELECTED METALS (ug/g dry weight)

- 1998 fillet Hg, lowest at ECCB, highest at Outfall.
  1998 Hg patterns in livers, similar to fillets.
- Liver Hg concentrations are generally similar at DIF and FOS and lowest at (except Hg at DIF in '92', '93').
- 1998 levels are generally consistent since 1995.
1992 - 1998 FLOUNDER RESULTS
SELECTED METALS (ug/g dry)

- Generally, metals concentrations in livers are highest at the FOS and lowest at DI, unlike organic contaminant patterns.
- 1998 levels are within the range of previous measurements and are generally lower; except Cu, Ni, Pb at ECCB, Cu, Ni at FOS and Ni at DIF.
- Overall, the trend is for similar or decreasing metals concentrations at all sites since 1992.
Comparison of Selected Flounder Parameters to FDA and MWRA Thresholds

<table>
<thead>
<tr>
<th>STATION</th>
<th>Total PCB (ng/g wet wt)</th>
<th>Total DDTs (ng/g DRY wt)</th>
<th>Total Chlordanes (ng/g wet wt)</th>
<th>Dieldrin (ng/g wet wt)</th>
<th>Mercury (Hg) (ug/g wet wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean s.d.</td>
<td>Mean s.d.</td>
<td>Mean s.d.</td>
<td>Mean s.d.</td>
<td>Mean s.d.</td>
</tr>
<tr>
<td>DIF(1)</td>
<td>52.4 8.0</td>
<td>29.9 4.7</td>
<td>3.0 0.4</td>
<td>0.55 0.05</td>
<td>0.05 0.01</td>
</tr>
<tr>
<td>OUTFALL(4)</td>
<td>19.7 11.0</td>
<td>11.9 7.14</td>
<td>1.0 0.6</td>
<td>0.22 0.11</td>
<td>0.06 0.02</td>
</tr>
<tr>
<td>ECCB(5)</td>
<td>8.10 0.6</td>
<td>5.74 0.67</td>
<td>0.3 0.0</td>
<td>0.14 0.01</td>
<td>0.03 0.01</td>
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<td>2000 (5000 ng/g wet)</td>
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<td>79.5 47.55</td>
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</table>
1992 - 1998 FLOUNDER RESULTS
Additional SELECTED METALS (ug/g dry)

Zinc in Flounder Liver

Chromium in Flounder Liver
LOBSTER COLLECTION
September 1998

[Map showing locations: Mass Bay outfall, Deer Island Flats, Eastern Cape Cod]
LOBSTER MEASUREMENTS

Physical/Biological Measurements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Deer Island</th>
<th>Outfall</th>
<th>Cape Cod</th>
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<tr>
<td>CARAPAPICE LENGTH (mm)</td>
<td>N</td>
<td>S.E.</td>
<td>S.E.</td>
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<td>WEIGHT (g)</td>
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<td>SHELL_EROS</td>
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* A sex ratio of 0 indicates that all 15 lobsters were male.

CHEMICAL MEASUREMENTS

<table>
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<tr>
<th>Sample Type</th>
<th>Number of Samples</th>
<th>Metals (Ag, Cd, Cr, Cu, Ni, Zn)</th>
<th>Hg</th>
<th>Pb</th>
<th>PCBs</th>
<th>PAHs</th>
<th>Pests</th>
<th>Lipids</th>
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<td>Lobster Hepatopancreas</td>
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1992 - 1998 LOBSTER RESULTS
TOTAL PCBs (ng/g dry weight)

- 1998 Total PCB concentrations in lobster meat are lower than in recent years.
- 1998 Total PCB concentrations in lobster hepatopancreas are consistent with recent years.
- Highest concentrations at DIF and lowest at ECCB, consistent with previous study years.
1992 - 1998 LOBSTER RESULTS
SELECTED PESTICIDES (ng/g dry weight)
- Total PAH concentrations in 1998 are consistent with previous years.
- The trend shows highest concentrations at DIF and lowest at ECCB.
- Decline in concentrations at DIF after 1992; corresponds to sludge removal at DI.
1992 - 1998 FLOUNDER RESULTS
SELECTED METALS (ug/g dry)

- 1998 lobster meat and hepatopancreas Hg concentrations are lower than 1997; within range of previous years.
- No discernable trends between stations or years.
1992 - 1998 LOBSTER RESULTS
SELECTED METALS (ug/g dry)

- 1998 levels are within the range of previous measurements; except for Ag.
- Generally, metals concentrations in lobster hepatopancreas have been constant over the study period; except for Ag and Cr.
Comparison of Selected Lobster Parameters to FDA and MWRA Thresholds

<table>
<thead>
<tr>
<th>STATION</th>
<th>Total PCB (ng/g wet wt)</th>
<th>Total DDTs (ng/g DRY wt)</th>
<th>Total Chlordanes (ng/g wet wt)</th>
<th>Dieldrin (ng/g wet wt)</th>
<th>Mercury (Hg) (ug/g wet wt)</th>
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<td>Mean s.d.</td>
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<td>Mean s.d.</td>
<td>Mean s.d.</td>
<td>Mean s.d.</td>
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<td>16.73 3.42</td>
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<td>0.60 0.09</td>
<td>0.56 0.09</td>
<td>0.11 0.01</td>
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<td>OUTFALL(4)</td>
<td>9.69 2.63</td>
<td>8.46 2.6</td>
<td>0.39 0.16</td>
<td>0.52 0.02</td>
<td>0.13 0.02</td>
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<tr>
<td>ECCB(5)</td>
<td>7.79 1.76</td>
<td>9.46 2.2</td>
<td>0.24 0.02</td>
<td>0.34 0.01</td>
<td>0.09 0.01</td>
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<tr>
<td>FDA Limit</td>
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<td>0.84 1.9</td>
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</table>
1992 - 1998 LOBSTER RESULTS
ADDITIONAL SELECTED METALS (ug/g dry)
Fish and Shellfish Monitoring
1998 Flounder Histopathology (Dr. Michael Moore, WHOI)
WINTER FLOUNDER MILESTONES

1975 Howe and Coates - migration south of the Cape (10's of miles) vs. North (~1 mile.) Hence a better station marker north of Cape.

1975 Murchelano describes finrot in NY Bight and associates with pollution.

1985 Murchelano and Wolke - tumors and vacuolated cells from Boston Harbor winter flounder.


Gardner et al (1989), Myers et al (1994) and HOM - linkage of tumors and vacuolated cells to contaminants - PAH and pesticides especially

1990 NOAA Reproductive Success study - no linkage to contaminants in Boston samples

1991 to present Moore, Hillman et al. - 5 station survey.
Figure 1. Flounder Sampling Stations.
Table 1 - Catch per unit effort (# of fish per min. of bottom time) for winter flounder trawled in April/May

<table>
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<td>Nantasket Beach</td>
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<td>1.52</td>
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<td>0.88</td>
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<td>Future Outfall</td>
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<td>0.24</td>
<td>0.60</td>
<td>0.31</td>
<td>0.81</td>
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<tr>
<td>Eastern Cape Cod Bay</td>
<td>0.67</td>
<td>0.49</td>
<td>0.77</td>
<td>0.42</td>
<td>0.21</td>
<td>1.38</td>
<td>0.32</td>
<td>0.23</td>
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</table>

The same vessel and net was used at all times
Centrotubular Hydropic Vacuolation Severity Compared Between Sites and Years

Year

Mean severity of centrotubular hydropic vacuolation for each station (0-4)

- Deer Island
- Nantasket Beach
- Broad Sound
- Future Outfall Site
- Eastern Cape Cod Bay
Liver slices examined per fish: 1 for 1987 to 1990, 3 thereafter
Water Column Monitoring and Nutrient Cycling
Modeling Results for 1993 and 1994 (Mr. Jim Fitzpatrick, HydroQual)
Figure 3-11. Seasonal and Annual Probability Distributions of Surface Chlorophyll-a
Surface Chla 1992-1994

- 1992
- 1993
- 1994

Nearfield - Seasonal

Nearfield, Farfield - Tunal

Different years dominated different seasons

Winter 1992
Spring 1994
Fall 1993 - high Conc in 1997

Asterionellopsis
Figure 3-13. Seasonal and Annual Probability Distributions of Surface Fluorescence
- a little more obvious in the fluorescence data
Figure 3-14. Seasonal and Annual Probability Distributions of Mid-Depth Fluorescence
- Again you can see it in the mid-depth fluorescence

- So there is evidence that blooms occur at different times during the three years
Figure 3-18. Seasonal and Annual Probability Distributions of Surface DSi
- Differences in Surface OSi
- Appear to be associated with Slooms
- Probably dealing with diatom Slooms
Figure 3-15. Seasonal and Annual Probability Distributions of Surface POC
loc data are more sparse but the evidence of different amount of biomass are not as clear possibly different species with different C : O2L
Figure 3-21. Seasonal and Annual Probability Distributions of Bottom DO
- Observed differences in bottom DO
- Especially summer and fall 1994
- The gap increase from summer to fall so the rate of decline is not the same from year to year

- Standard never < 6.0 mg/L

- MWRP could potentially have been blamed

- Data show natural variability such as the does occur without the reflected outfall

- Low DO's observed more often in the nearfield location

- Why lower DO in 1994?
Figure 2-1. Loading Comparison of Sources for 1992 through 1994
- Loading similar between the 3 years
  - 1992
  - 1993
  - 1994

- Similar River Flows
- Similar meteorological forcings
Figure 3-10. Seasonal and Annual Probability Distributions of Density Stratification
- Lower DO trapped in bottom water for a longer period of time
- Higher temps at the same time as higher salinity
- Less stratification
- Higher sal could be indicative of ocean water from boundary
Figure 3-5. Seasonal and Annual Probability Distributions of Bottom Temperature
- Temperature?
- Higher bottom Temp
- Surface Temp similar
- More mixing?
- Warm Temp from boundary?
- Could contribute to higher oxidation rate
Figure 3-22. Stations Used for Boundary Condition Data
- How will the model reproduce different conditions if the forcings are the same?

- Boundary Conditions?

- Large Open Boundary

- Limited Data
1994 Temporal Calibration Results for Grid Cell (19,17) Vs Data Station F27
1994 Temporal Calibration Results for Grid Cell (18,18) Vs Data Station F26
Figure 3-2. Water Quality Sampling Stations in Massachusetts and Cape Cod Bays 1994
- 1994 Station locations modified to improve boundary conditions

- With improved BC and new Hydro WE decided to rerun 1992 as we modeled 1993 and 1994
Figure A-3. C/Chlorophyll-a Ratio vs. _A. glacialis_ concentration for October 1993
Figure 4-30. Gross Primary Productivity 1993
Figure 4-31. Gross Primary Productivity 1994
Figure 4-37. Model vs. Data Probability Comparisons for Bottom DO 1992
Figure 4-40. Model vs. Data Probability Comparisons for Bottom DO 1993
Figure 4-43. Model vs. Data Probability Comparisons for Bottom DO 1994
<table>
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Figure 4.44: Model vs. Data Temporal Comparison for SOD 1992-1994
Figure 4-46. Model vs. Data Temporal Comparison for Nitrate Flux 1992-1994
Figure 4-48. Model vs. Data Temporal Comparison for Phosphate Flux 1992-1994
Figure 4-50. Massachusetts Bay Nitrogen Mass Balance
- Not asked for projections
- Other tests of calibration, primary productivity
  - Respiration by decline in DO
  - Nitrogen
  - Mass balance
    - In Cape Ann
    - Out Cape Cod
  - Sources
  - Sink Sediment
  - MWRA 3% TN

49% in 1991, reaches sediment denitrified

Model put MWRA in perspective
  - Threshold evaluation
Water Column Monitoring and Nutrient Cycling
1998 Physical Regime (Dr. Rocky Geyer, WHOI)
Summary of Physical Oceanography  
MWRA Outfall Site  
1998  

1. Forcing Conditions  
   • Warm winter  
   • Very wet spring (particularly June)  
   • Persistent southerly (upwelling) winds in summer  

2. Oceanographic Conditions  
   • Warm bottom water (early)  
   • Very low salinity, surface and bottom  
   • High stratification  
   • Less warming of bottom water than normal
### Charles River Discharge

<table>
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<tr>
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<th>apr-jun</th>
<th>jul-sep</th>
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### Merrimack River Discharge

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<td><strong>401</strong></td>
<td><strong>451</strong></td>
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### Southerly (upwelling) Wind Stress
**\( \text{Pa} \times 10^3 \)**

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### Wind Speed
**\( \text{m/s} \)**

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<th>Jul-Sep</th>
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Boston Buoy and N21 temperature
Near-surface and near-bottom temperature, N-21
Water Column Monitoring and Nutrient Cycling
1998 Water Quality Overview (Mr. Scott Libby, Battelle)
1998 Nutrient Overview

- General Trends - Nutrients, Chla and DO
- 1998 "Events"
- Interannual Comparisons
Inner Nearfield: N10, N11

Outer Nearfield: N04, N07, N16, N20
1996 Annual Mean = 1.54 μg/L
Spring Average = 2.43 μg/L
Summer Average = 0.78 μg/L
Fall Average = 1.47 μg/L

1997 Annual Mean = 1.23 μg/L
Spring Average = 1.29 μg/L
Summer Average = 1.14 μg/L
Fall Average = 1.29 μg/L

1998 Annual Mean = 2.65 μg/L
Spring Average = 0.83 μg/L
Summer Average = 2.46 μg/L
Fall Average = 4.05 μg/L
Station F23

Station N18

Interannual In-situ Fluorescence

Circles = Surface (A); Squares = Mid-Depth (C)
Nitrate + Nitrite (Nearfield Stations)

Surface and Bottom are offset by 3 days

Concentration (µM)

Jan   Feb   Mar   Apr   May   Jun   Jul   Aug   Sep   Oct   Nov   Dec

- Surface Average  -  Mid-Depth Average  -  Bottom Average
Phosphate (Nearfield Stations)

Surface and Bottom are offset by 3 days

[Graph showing concentration (µM) over months from January to December, with lines for Surface Average, Mid-Depth Average, and Bottom Average.]
Parameter: AMMONIUM
Sampling Depth: Surface
Last Survey Day: 11/25/98
Sampling Event: WN98G
Minimum Value 1.32 µM at N04
Maximum Value 8.57 µM at N10
Contour Interval = 1 µM
Parameter: In situ Dissolved Oxygen
Sampling Depth: Bottom
Last Survey Day: 10/17/88
Sampling Event: WF98E
Minimum Value: 6.09 mg/L at F01
Maximum Value: 9.38 mg/L at N01
Contour Interval = 1 mg/L

kilometers
Parameter: In situ Dissolved Oxygen
Sampling Depth: Bottom
Last Survey Day: 12/16/98
Sampling Event: WN98H
Minimum Value 4.54 mg/L at N04
Maximum Value 9.93 mg/L at F03
Contour Interval =1 mg/L
Nearfield Dissolved Oxygen Concentrations in Bottom Waters
Mean of all nearfield stations.
Interannual Stellwagen Basin Dissolved Oxygen Cycle
Surface and Bottom Waters
Stellwagen Basin Dissolved Oxygen Concentrations in Bottom Waters
Symbols indicate the mean of 4 Stellwagen stations (F12, F17, F19, F22)
Annual Oxygen Minimum:
Nearfield & Stellwagen, 1992-98

$SB = (0.777 \times NF) + 1.745 \quad R^2 = 0.96$
Water Column Monitoring and Nutrient Cycling
1998 Plankton Overview (Dr. Jefferson Turner, UMass – Dartmouth)
Farfield Whole Water Phytoplankton

High/Low Range

Mean

10^6 cells/L

WF98E
10/5

WF98B
8/18

WF987
6/16-19, 6/22

WF984
3/31-4/3

WF982
2/27-3/2

WF981
2/3-2/10

247
Farfield Screened Phytoplankton

<table>
<thead>
<tr>
<th>Sample Code</th>
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<tr>
<td>WF981</td>
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- **High/Low Range**
- **Mean**
Nearfield Screened Phytoplankton

- High/Low Range
- Mean

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<th>Date</th>
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<td>11/25</td>
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Seasonal Whole-water Phytoplankton Assemblages

Microflagellates are usual numerical-dominants throughout the year, and their abundance generally tracks water temperature, being most abundant in summer and least abundant in winter.

In addition to microflagellates, the following are dominant in different periods:

**Winter (primarily February)** – diatoms abundant

*Chaetoceros debilis, C. socialis, Thalassiosira nordenskioldii, T. rotula*

**Spring (March, April, May)** – usually diatoms, except during *Phaeocystis* years

*assorted species of Thalassiosira, Chaetoceros, Heterocapsa rotundatum, and (especially nearshore) cryptomonads*

**Summer (June, July, August)** – microflagellates at peak abundance, with cryptomonads, *Skeletonema costatum* (especially nearshore), *Leptocylindrus danicus, Rhizosolenia delicatula, Ceratulina pelagica*, and various small-sized species of *Chaetoceros*.

**Fall (September through December)** – diatoms abundant

*Asterionellopsis glacialis, Rhizosolenia delicatula, Skeletonema costatum, Leptocylindrus minimus, L. danicus, cryptomonads, and assorted gymnodinoid dinoflagellates*
Plankton Summary - 1998

Whole-Water Phytoplankton:

There was a sustained increase in total phytoplankton abundance from low levels in February through April (means of 0.3-0.8 x 10^6 cells/liter) to high levels in May through October (means of 0.7-3.5 x 10^6 cells/liter), followed by declines in November and December (Nearfield means of 0.4-0.7 x 10^6 cells/liter).

Unlike other years, there was not a major winter/spring bloom or fall bloom.

Phytoplankton assemblages were numerically dominated by microflagellates and cryptomonads (< 10 μm), with subdominant contributions by various chain-forming diatoms such as Chaetoceros socialis and Skeletonema costatum (winter and spring), Leptocylindrus minimus, L. danicus, Rhizosolenia fragilissima, Proboscia alata, and S. costatum (summer), and Chaetoceros spp., Leptocylindrus spp., S. costatum, and Pseudo-nitzschia spp. in the fall.

There were no confirmed blooms of nuisance algae in 1998, although the fall Pseudo-nitzschia records for P. “pungens” could have included some of the domoic-acid-producing species P. multiseries. However, total abundances of Pseudo-nitzschia “pungens” did not exceed 82 x 10^3 cells/liter.

Screened Water Phytoplankton (> 20 μm):

The silicoflagellate Distephanus speculum was dominant in February, with subdominant contributions by the dinoflagellates Ceratium longipes and C. tripos.

From March onward, C. longipes and C. tripos were dominant, with subdominant contributions by other dinoflagellates such as C. furca, C. fusus, C. lineatum, Dinophysis norvegica and Protoperidinium trochoidium.

The sustained bloom of Ceratium longipes and C. tripos was the major event for screened-water taxa.
Plankton Summary – 1998

Zooplankton:

The zooplankton were dominated, as usual, by copepod nauplii, adults and copepodites of the small copepods *Oithona similis* and *Pseudocalanus* spp., with seasonal subdominant contributions from gastropod and bivalve veligers, and a mixture of other normally-occurring taxa.

Addition of stations F32 and F33 in Cape Cod Bay during WF981, WF982, and WF984 extended the range of total abundance recorded for F01 and F02 from 12-24 to 25-56 x 10^3 animals m^-3 during WF981, from 15-24 to 27-29 x 10^3 animals m^-3 during WF982, and from 13 to 19-28 x 10^3 animals m^-3 during WF984.

During WF984, abundance of *Calanus finmarchicus* copepodites comprised only 3-4% of the catch at F01 and F02, but 7-11% at F32 and F33. Thus, for this important forage item of right whales that feed in Cape Cod Bay at this time of the year, addition of the two new stations captured a three-fold increase in patchiness of this copepod that would have been missed by sampling only Stations F01 and F02.
Nearfield Zooplankton

- **High/Low Range**
- **Mean**
Why is *Acartia tonsa* (Copepoda: Calanoida) restricted to nearshore environments?

Gustav-Adolf Paffenhöfer¹, Donald E. Stearns²

¹Skidaway Institute of Oceanography, PO Box 13687, Savannah, Georgia 31416, USA  
²Dauphin Island Sea Lab., PO Box 369–370, Dauphin Island, Alabama 36528, USA

**ABSTRACT:** The copepod *Acartia tonsa* is adapted to high food concentrations which it encounters in estuaries and upwelled waters. It cannot obtain sufficient food for reproduction on the middle and outer shelf, where food concentrations are usually low, because it decreases clearance rates when concentrations of *Thalassiosira weissflogii* fall below 0.25 mm³ l⁻¹. In comparison, the offshore copepod *Paracalanus* sp. continues to increase its clearance rate when food levels are below the above-mentioned concentration. Several factors are thought to be responsible for this reduction of clearance rates of *A. tonsa* feeding on *T. weissflogii*: (1) The proportion of time during which water is transported towards the copepod decreases with decreasing food concentration. (2) The efficiency of capturing food particles decreases below 22 μg C l⁻¹ (= 0.28 mm³ l⁻¹ of *T. weissflogii*). (3) *A. tonsa* does not seem to route phytoplankton cells individually towards its median, and therefore cannot use a, hypothesized, increased sensitivity of its chemoreceptors at low chlorophyll concentrations to increase clearance rate.

**INTRODUCTION**

The genus *Acartia* (Copepoda: Calanoida) occurs mostly in estuaries and nearshore environments although several representatives of the genus are found offshore (i.e. *A. danae*, *A. negligens*; Bowman 1971). *A. tonsa* is found throughout the year in the estuaries of Georgia and South Carolina, USA, when water temperatures range from 9 to 30 °C (Lonsdale & Coull 1977, Paffenhöfer unpubl.). In terms of biomass it is the most abundant zooplankton species in the estuaries of North and South Carolina (Lonsdale & Coull 1977, Fulton 1984). It is the most frequently occurring zooplankton species in Georgia estuaries (Jacobs 1968, Stuckey & Knowles 1975). However, *A. tonsa* is rarely abundant (> 100 ind m⁻³) on the middle and outer shelf (Paffenhöfer unpubl.). There, throughout most of the year, representatives of the genus *Paracalanus* are among the most abundant copepods. In estuaries, their close relative *Parvocalanus crassirostris* is often as abundant as *A. tonsa* (Lonsdale & Coull 1977).

Why is *Acartia tonsa* abundant in estuaries but not on the shelf? In order to answer this question, we considered 4 variables: temperature, salinity, predation and food. Temperature is not considered a limiting factor since it is higher during winter and slightly lower during summer on the shelf than in the estuaries. Thus, *A. tonsa* would experience less temperature stress offshore than in the estuary. Also, *A. tonsa* is able to adapt to temperatures ranging from −1 to 32 °C (Gonzalez 1974). Neither is salinity limiting: at 17 °C, *A. tonsa* females survived about equally well at salinities ranging from 11 to 36% (Lance 1964). Predation does not appear to be the decisive variable in restricting *A. tonsa* offshore distribution, since the species maintains its high abundance near- and inshore, partly because of its superior ability (as compared to *Paracalanus* and others) to avoid predation by planktivorous fish (Kimmerer 1986, for *A. tranteri*). This leaves only food with all the components of animal-algae interactions as a possible controlling variable.
Fig. 30  CERATIUM
A. C. tripous ventral view to show the plates (after Wall & Evitt 1975)
B. C. tripous dorsal view to show the plates (after Wall & Evitt 1975)
C. I and II recently divided C. tripous to show development of new parts
D. C. tripous telophase to show plane of cell division  E. C. arietinum
F. C. gibb  G. C. symmetricum  H. C. hexacanthum dorsal view
I. C. hexa.  rim side view to show twisting

Fig. 31  CERATIUM
A. C. macroceros  B. C. horridum  C. C. longipes  D. C. longipes f. arcticum
To half scale
E. C. multispinulose  F. C. trochoceros  G. C. carriense  H. C. horridum copulation
between a macroswarmer and microswarmer (after Von Stosch, 1964)
- *Calanus finmarchicus* Gunnar,

- L. ♀ 2,7-5,5 mm.; ♂ 2,35-3,6 mm.

- *Centropages typicus* Kröyer,

- L. ♀ 1,6-2 mm.; ♂ 1,4-1,9 mm.

- *Othona similis*: ♂, Male, dorsal; ♀, female, dorsal; Total length, 0.7-0.95 mm.

- *Paracalanus porcupus*: ♂, Male, dorsal; Total length, 0.75-1 mm.
Why Is *Acartia tonsa* Restricted to Estuarine Habitats?\(^1\)

Patricia A. Tester\(^2\) and Jefferson T. Turner\(^3\)

\(^2\) National Marine Fisheries Service, NOAA  
Southeast Fisheries Research Center, Beaufort Laboratory  
Beaufort, North Carolina 28516, USA  
\(^3\) Southeastern Massachusetts University  
North Dartmouth, Massachusetts 02747, USA

Abstract

The salinity tolerance of naupliar stages is a major factor in restricting the abundant calanoid copepod *Acartia tonsa* to estuarine and nearshore waters. There is significantly greater naupliar survival at salinities less than full-strength seawater, and salinity-temperature interaction experiments indicate optimal conditions for *A. tonsa* nauplii are < 25 ppt and > 15°C. The early naupliar stages do exhibit some osmoregulatory ability, however. Demonstrations using fluorescein dye show that even the non-feeding, N1 stage can drink. While adult *A. tonsa* are good osmoregulators and, consequently tolerate a wide range of salinities, the restriction of this species to estuarine and coastal habitats may be a function of the physiology of the nauplii rather than the adult.

![Graph](image.png)

Fig. 1. Percent survival of *Acartia tonsa* nauplii as a function of salinity and temperature. Observed % naupliar survival included in Table 1.
Fig. 1. *Paracalanus* sp. and *Acartia tonsa*. Clearance rate (F) of adult females feeding on the diatom *Thalassiosira weissflogii*. Clearance rates of *Paracalanus* sp. are the geometric means of the following ranges of food concentration: 0.05 to 0.20, 0.20 to 0.35, 0.80 to 1.10 mm$^3$ l$^{-1}$. For *A. tonsa* geometric means were calculated for the following ranges: 0.05 to 0.20, 0.20 to 0.30, 0.30 to 0.45, 0.80 to 1.40 mm$^3$ l$^{-1}$. Bars: 95% confidence limits. Lines drawn by hand.

Fig. 3. Comparison of the clearance rates for *Acartia tonsa* fed on *Thalassiosira weissflogii* cultures (Paffenhöfer & Stearns 1988) and natural phytoplankton in the Mississippi River plume (Turner & Tester 1989a), and on *Gymnodinium breve* during a red tide (Turner & Tester 1989b).
Fig. 4. *Nitzschia pungens* f. *multiseries* from Cardigan Bay: (A) light photomicrograph showing chains of *N. pungens*; (B) scanning electron micrograph of a single valve showing the costae; and (C) same valve at higher magnification, showing the rows of poroids between the costae.
Suggested Zooplankton Threshold:

If the Acartia tonsa/A. hudsonica abundance at the nearfield stations in any given sample ever exceeded 50% of total non-naupliar copepods (i.e. adults plus copepodites), then we would know there had been a big change. Whether such a change was due to eutrophication or salinity would not be known based on that, but if Acartia’s ever exceed 50% of the copepod abundance, then we would know that something had happened.

The reason that I suggest >50% Acartia abundance in the nearfield, is that I suspect that it will never happen, and that anything else would be within the very broad quantitative envelope of variability for abundances of a few repeatedly and perennially dominant taxa.

Presently, and I fully expect after the outfall goes on line, the copepod abundance in the nearfield, and farfield outside Boston Harbor will be dominated by Oithona similis, Pseudocalanus spp., and to a much lesser extent Paracalanus parvus, Centropages typicus and C. hamatus, Calanus finmarchicus and other typically "offshore" copepods. Since these "non-Acartia's" often co-occur at varying, and for all but Oithona and Pseudocalanus copepodites, low numbers throughout the nearfield and farfield, any thresholds based upon their numbers would not be clear-cut. However, if we see Acartia spp. ever comprising over half the copepods anywhere but inside the harbor, then we know that, for whatever reason, there had been a big change (for example a runoff pulse due to a hurricane).

In terms of meroplankton (planktonic larvae of benthic invertebrates), while they often dominate the numbers in many zooplankton samples, their periods of abundance are “spikey,” and likely more related to reproductive cycles of the macrobenthic parents, than to processes in the plankton.
Pennate Diatom *Nitzschia pungens* as the Primary Source of Domoic Acid, a Toxin in Shellfish from Eastern Prince Edward Island, Canada


Atlantic Research Laboratory, National Research Council of Canada, 1411 Oxford St., Halifax, N.S. B3H 3Z1


An outbreak of food poisoning in Canada during autumn 1987 was traced to cultured blue mussels (*Mytilus edulis*) from the Cardigan Bay region of eastern Prince Edward Island (P.E.I.). The toxin, identified as domoic acid, had not previously been found in any shellfish and this outbreak represents the first known occurrence of human poisoning by this neurotoxin. A plankton bloom at the time of the outbreak consisted almost entirely of the pennate diatom, *Nitzschia pungens* f. *multiseries*, and a positive correlation was found between the number of *N. pungens* cells and the concentration of domoic acid in the plankton. *Nitzschia pungens* f. *multiseries* isolated from Cardigan Bay produced domoic acid in culture at levels (1 to 20 pg-cell$^{-1}$) comparable with values estimated for *N. pungens* in the plankton samples. Isolates of several Cardigan Bay phytoplankton, including the closely related species *Nitzschia seriata*, failed to produce domoic acid. Other *Nitzschia* spp. and two *Amphora* coflea*formis* isolates also failed to produce domoic acid. We conclude that *N. pungens* was the major source of the domoic acid in toxic mussels in eastern P.E.I. The recurrence, in November 1988, of a monospecific bloom of *N. pungens* and the presence of domoic acid in plankton and mussels reinforced this conclusion.
Water Column Monitoring and Nutrient Cycling
1998 Productivity Overview (Dr. Aimee Keller, URI)
ACKNOWLEDGEMENTS:

Candace Oviatt
Laura Reed
Gwynne Holcombe
Tarquin Dorrington
Scott Sauchuk
Andy Parrella
Liz Bruce

Funding: MWRA
Introduction
C-14 Production

Changes in Methodology

Results
  Model Parameters
  Daily Production
  Annual Production

Bloom Failure

Modeling
Volume incubated reduced to 5 ml

Samples not filtered

Incubated at 16 light levels (2 dark)

Range of light: 0 to 2000 uE m$^{-2}$ s$^{-1}$

Incubation period: 1-2 h
Sampling Primary Productivity

Stations: N04, N18 - Nearfield
         F23 - Harbor

Depths:  S, MS, M, MB, B

Surveys:
         N04-N18 (17 total, Feb.-Dec. 1998)
         F23 (6 total, Feb.-Oct. 1998)
<table>
<thead>
<tr>
<th>Changes in Methodology</th>
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<tbody>
<tr>
<td>Results</td>
</tr>
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<td>Model Parameters</td>
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<td>Daily Production</td>
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<tr>
<td>Bloom Failure</td>
</tr>
<tr>
<td>Modeling</td>
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</tbody>
</table>
P-I Curves

1. Webb et al. 1974 - No Photoinhibition

\[ P(I) = P_{\text{max}} \left(1 - e^{-\alpha I/P_{\text{max}}}\right) \]

with: \( P(I) \) = primary production at irradiance \( I \)
\( P_{\text{max}} \) = light saturated maximum production
\( \alpha \) = initial slope of P-I curve

2. Platt et al. 1980 - Photoinhibition

\[ P(I) = P_{sb} \left(1 - e^{-\alpha I/P_{sb}}\right) e^{-\beta I/P_{sb}} \]

with: \( P(I) \) = primary production at irradiance \( I \)
\( P_{sb} \) = theoretical maximum production
without photoinhibition
\( \alpha \) = initial slope of P-I curve
\( \beta \) = term indicating degree of inhibition

note: \( P_{\text{max}} = P_{sb} \left[\alpha/(\alpha + \beta)\right] \left[\beta/(\alpha + \beta)\right]^{\beta/\alpha} \)
Figure 5.1 An Example Photosynthesis-Irradiance Curve From Station N04 Collected in August
Alpha vs $P_{\text{max}}$ (1995 - 1997)

- $y = 0.005x + 0.01$
- $R^2 = 0.73$

$\alpha^B$ vs $P^B_{\text{max}}$ (1995 - 1997)

- $y = 0.010x - 0.02$
- $R^2 = 0.64$
MODEL PARAMETERS - SUMMARY

- Seasonal pattern for N04 and N18 different from F23

- Parameters generally decreased with increased depth

- Chl-specific parameters increased during the spring and fall bloom periods (but no spring bloom materialized)

- Increased photosynthetic efficiency related to:
  1-elevated light in spring
  2-improved nutrient availability in fall

- Parameters significantly correlated (as in prior years)

- Frequency distributions skewed to the left relative to 1995-97
Chlorophyll-specific Production (mg C/mg chl/d)
Daily Production (mg C m\(^{-3}\) d\(^{-1}\))

Depth (m)

Cruise

N18
Chlorophyll-specific Production (mg C/mg chl/d)
Daily Production (mg C/m³/d)
Areal Production

Chlorophyll-Specific Areal Production

Survey Date

Survey Date
C14 Production

mg C m\(^{-2}\) d\(^{-1}\)

Date

C14 Production

mg C m\(^{-2}\) d\(^{-1}\)

Date
PRODUCTION - SUMMARY

- N04 and N18 exhibited peak productivity during the fall bloom (surface samples)

- Production at F23 increased through June then declined during the fall

- Subsurface chlorophyll maxima above 15 m characterized by elevated productivity (but not below 15 m)

- Chl-specific production increased during the spring bloom period (N04-18) but no bloom materialized

- Annual productivity low relative to prior years (since no spring bloom)

- Productivity decreasing at F23 over time, bloom peaks declining at N04
Potential Factors Influencing Size of Spring Bloom

$I_0$ - Daily Incident Radiation

Limiting Nutrients

Photic Depth

Temperature - Direct and Indirect

Predation - Zooplankton, Benthos
<table>
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<th>Year</th>
<th>F23</th>
<th>N04</th>
<th>N16-18</th>
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<td>33.6</td>
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<td>1996</td>
<td>14.5</td>
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<td>1997</td>
<td>15.3</td>
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<tr>
<td>1998</td>
<td>12.2</td>
<td>40.4</td>
<td>21.0</td>
</tr>
</tbody>
</table>
Temperature (NOAA) Narragansett Bay

\[ y = -146 + 0.075x \quad R = 0.69 \]

Year

Chlorophyll a (\(\mu g\) liter\(^{-1}\))

\[ y = 20.4 - 2.89x \quad R = 0.78 \]

1977-1997 Narragansett Bay

Temperature (\(^\circ C\))

-1 0 1 2 3 4 5 6
Peak Bloom Production vs Biomass
1995-1998

\[ y = 610x + 337 \]

\[ R^2 = 0.61 \]

Peak Bloom Chl vs Temp
1995-1998

\[ y = -2.84x + 12.4 \]

\[ R^2 = 0.88 \]

Peak Bloom Chl vs Mean Zooplankton

\[ y = -6.5x + 45.9 \]

\[ R^2 = 0.54 \]
Modeling Production

\[ P(14C) = m \cdot \text{BLOZ}_p + b \]

\( P(14C) \) = primary production (mg C m\(^{-2}\) d\(^{-1}\))
\( B \) = biomass (mg Chl a m\(^{-3}\))
\( I_0 \) = incident irradiance (E m\(^{-2}\) d\(^{-1}\))
\( Z_p \) = photic depth (m)
\( b \) = intercept
\( m \) = slope
**F23**

\[ y = 0.22x + 71.3 \]
\[ R^2 = 0.96 \]

**N04**

\[ y = 0.28x + 30.5 \]
\[ R^2 = 0.33 \]

**N18**

\[ y = 0.31x + 17.7 \]
\[ R^2 = 0.68 \]
Slope of equation $P = m\text{BIOZ}_p + b$

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<tr>
<td>N16-18</td>
<td>0.56</td>
<td>0.64</td>
<td>0.56</td>
<td>0.31</td>
</tr>
</tbody>
</table>
1995-1997

\[ y = 0.31x + 767.74 \]

\[ R^2 = 0.29 \]
**P_{\text{max}} vs Chl a**

\[ y = 1.24x + 0.75 \]

\[ R^2 = 0.57 \]

**Alpha vs Chl a**

\[ y = 0.0093x + 0.018 \]

\[ R^2 = 0.53 \]
CONCLUSIONS
1998

- Annual production at NO4, N18 and F23 lower than in prior years

- Seasonal productivity pattern dominated by fall bloom

- No winter-spring bloom despite increased chlorophyll-specific production during typical bloom period

- Bloom failure not correlated with nutrient availability or light limitation

- Bloom failure may be related to warm winter temperatures and increased grazing by zooplankton

- Productivity significantly correlated with composite parameter (but variable across years)
E nthetic Fluxes

...ing in Harbor only

diment nutrient recycling to production

gaffect nutrient ratios

he sediment in nutrient nitrification and burial
delling – calibration and

and sediment-water nutrient
grain size
Conclusions

1) Long term trends – It's a bit early (and stations have changed) but sediments in the highly impacted sites in the Northern Harbor may be showing some decrease in fluxes even with the amphipods present.

2) Denitrification rates have gone up and down a bit with amphipod colonization but still not a major factor in removing anthropogenic N.

3) DIN/DIP ratio may have shifted up but majority of 1998 data still shows benthic fluxes still less than 16 (i.e. would contribute to N limitation)

4)
Water Column Monitoring and Nutrient Cycling
Statistical Approach to Threshold Testing and Rule Setting (Dr. Jeff Rosen, TPMC)
Developing Protocols to apply the Thresholds
Automating the evaluation of the Outfall Monitoring Data

What are the issues?
- Should the variability in the monitoring results (or the baseline) be considered in the evaluation relative to the threshold?
- If the variability is considered how should the results be aggregated before calculating the confidence intervals?
- Should all parameters be handled the same way?

Proposed Approach
- Calculate one sided confidence intervals (the relevant direction).
- Evaluate if threshold is within the one sided confidence interval
- If it is within the confidence interval then threshold is not exceeded

Should the variability in the monitoring results (or the baseline) be considered in the evaluation relative to the threshold?

As an example: Should these two results both trigger the same response?

Propose that variability be considered in some of the response parameters.
- Establish thresholds based on baseline data or levels which have demonstrated ecological or resource management foundations. e.g. State action levels, ER-L, ER-M values, etc.
- Decide on direction of comparison, DO < threshold, Arochlor>threshold
- Calculate a one sided 95% confidence interval (t distribution)

Comparison
- Trigger ≤ lower confidence limit (e.g. for DO)
- Trigger ≥ upper confidence limit (e.g. for Arochlor)
- Yes ➔ Trigger Response
- No ➔ No response
Example

- Fabricated Data - seventeen stations sampled on one day.
- If the warning threshold is set at 6.0 then these results would trigger a warning when it is probably not appropriate.
- Detectable difference for these results is .96 mg/liter. Any value between 5.52 < DO < 6.48 are not distinguishable from the threshold
- Do you want this to trigger a response?

Aggregation Issues

- Data collection for each parameter will occur over a wide range of spatial and temporal scales
- The monitoring plan needs to specify how the data will be evaluated relative to each established threshold
- The method of aggregation and comparison to the threshold can have significant effects on the actions required

Example

<table>
<thead>
<tr>
<th>Detectable Differences Using</th>
<th>All Means of Depths</th>
<th>Means of Depths</th>
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<tbody>
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</tr>
<tr>
<td>Standard Deviation</td>
<td>2.12</td>
<td>1.12</td>
</tr>
<tr>
<td>count</td>
<td>85</td>
<td>17</td>
</tr>
<tr>
<td>Detectable Difference</td>
<td>0.81</td>
<td>0.96</td>
</tr>
</tbody>
</table>

\[ \delta = \sqrt{\frac{6.2 + (2\sigma^2)}{n}} \]

Conclusion

- The way we aggregate the results will have an effect on the comparison between monitoring results and the thresholds.
- We need to decide on how to aggregate the results to do the comparison with the thresholds.
- These steps need to be defined in great detail
- Ultimately these comparisons should be automated.

Progress Made

- Detailed descriptions of the approaches have been proposed for many parameters.
  - Total Nitrogen, Toxics, Effluent Toxicity, cBOD, Fecal Coliform, Total Suspended Solids, Floatables, Dissolved Oxygen, DO depletion rate, fish and shellfish tissue concentrations, RPD depth
- More work is required to define detailed approaches for Chlorophyll a, Zooplankton, Nuisance algae, Benthic Communities

Evaluating approaches for Chlorophyll a Data

- Two Thresholds to evaluate -
  - Annual mean < 1.5 (2.0) + baseline Mean
  - Seasonal Mean < 95th%ile baseline Seasonal mean
- Evaluating approaches of aggregation
  - Pooling Depths at a station
  - Pooling stations for a survey
  - Pooling surveys over seasons
Evaluating Detectable Differences

- Will vary depending on variance estimates included in calculations?
- What are the intended Sampling units?
  - Each depth at a station for each survey?
  - The overall station for each survey (over all depths)?
  - The Near Field (over all stations and depths) for a survey?

Power

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Accepted</th>
<th>Rejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>True Correct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>False Type I Error</td>
<td>Trigger</td>
<td>No Trigger</td>
</tr>
</tbody>
</table>

$H_0$: Measured Value = Threshold - Trigger a response

$H_a$: Measured Value is > (or <) Threshold - No Response

$\alpha = .05$ Probability of rejecting null hypothesis when it is True. We would not trigger a response when it should be triggered.

Power = $1 - \beta = .80$. The probability of rejecting the null hypothesis when it is false. The probability of not prompting a response when in fact there is no need for a response. (Prevents false alarms 80% of the time)

Detectable Difference

What is the difference which can be detected with a given sample size ($n$), Variance ($\sigma^2$), $\alpha = 0.5$, $\beta = .20$?

For one tailed test calculated from:

$$n = \frac{(Z_{\alpha} + Z_{\beta})^2 \times 2\sigma^2}{\delta^2}$$

where $\delta = \mu_1 - \mu_2$

Solve for $\delta$

$$\delta = \sqrt{(Z_{\alpha} + Z_{\beta})^2 \times 2\sigma^2/n}$$

$\delta$ is the detectable difference. The difference which can be detected with the probabilities of $\alpha$ and $\beta$ specified

Products

- Summary of distributional properties for different aggregation strategies
- Detectable differences with $\alpha = .05$ and $\beta = .20$ for each aggregation strategy (assumes that variance estimates for the baseline are representative of the variances that will be observed post outfit validation)
- Recommendations for the logistics of evaluating the Chlorophyll a Thresholds.