Bioaccumulation of selected metals and organic compounds in mussels deployed near Deer Island discharge, 1991

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EXECUTIVE SUMMARY

In order to assess the current potential for the bioaccumulation of selected chemical compounds resulting from the Deer Island Publicly-Owned Treatment Plant (POTW) discharges, a caged mussel study was conducted during the summer of 1991. The design of the study included two "control" stations, Gloucester and Discovery. The Discovery station (at the New England Aquarium) served as the "dirty" control while the Gloucester station (at Hodgkins Cove) served as the "clean" control. A third station was located near the Deer Island Light in order to expose mussels to the Deer Island discharge.

Mussels at the three stations were deployed on 20-21 June and retrieved on 22 August for a nominal 60-day exposure. During harvest, the mussels were randomly subsampled from each station and used to characterize the survival, growth, and condition indices of the mussels. The remainder of the mussels were submitted for tissue analysis. The soft tissue of the exposed mussels from each station was composited in the laboratory and analyzed for polynuclear aromatic hydrocarbons (PAH), selected pesticides, polychlorinated biphenyls (PCB), lead, copper, and zinc. This study was designed to be generally comparable to another study conducted by MWRA in 1987. However, the analytical methods used in this study were chosen in an effort to attain lower detection levels of the individual organic analytes than those reported in the 1987 study.

Mussel survival at the three stations was high, ranging from nearly 90 percent at the Discovery station to approximately 97 percent at Deer Island. Mussels deployed at the Discovery station were smaller than mussels from the other two stations (Gloucester and Deer Island). This observation suggested that smaller mussels may have been initially deployed at the Discovery station. Examination of mussels from the three stations did not detect any abnormalities, such as lesions or parasites, on the soft tissue from any animals.

The total PAH concentrations in the mussel tissues deployed at the Discovery station were the highest observed among the mussels from the three stations. Generally, the individual PAH compounds were the highest

at the Discovery station. However, the two- and three-ringed PAHs, particularly the methyl naphthalenes, were higher in the mussels deployed at the Deer Island station.

Mussel tissue concentrations of total pesticides and total PCBs were significantly higher in the Discovery mussels. The total concentrations of these compounds in mussel tissues retrieved from Deer Island were higher than the Gloucester mussel tissues but were generally less than concentrations reported for Discovery. Trans-nonachlor was found in Deer Island mussel tissues at significantly higher concentrations than mussels deployed at Discovery or Gloucester.

The Discovery mussels accumulated more copper and zinc compared to the Gloucester mussel concentrations. The increased zinc concentrations were believed to be, in part, a result of zinc anodes, which were in proximity to the deployment at this site. Deer Island mussels did not display any significant trend of increased accumulation of these three metals: lead, copper, and zinc.

The results of this study revealed a consistent trend of higher tissue concentrations of total PAHs, total pesticides, total PCBs, and several metals in the Discovery mussel tissue. Deer Island mussels also accumulated many of these compounds in tissue but at levels that were significantly less than the Discovery mussels. This trend suggests that the mussels located at the Discovery station may have been exposed to the highest ambient concentrations of many of the target analytes.

Mussel tissue concentrations from the shallow deployment at the Deer Island station were compared with those results reported in the 1987 MWRA study. Overall, the results of the comparisons suggested that the tissue concentrations in the 1991 study were lower than those previously reported. Although a difference in methods between the two studies may account for a portion of this decrease, the apparent trend of tissue concentration reductions most likely reflects decreased accumulation of many of the target analytes in the mussels analyzed from the Deer Island station in the 1991 study.

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ACKNOWLEDGMENTS

This project was conducted for Massachusetts Water Resources Authority (MWRA). Aquatec, Inc. was the primary consultant for this project. Field deployments and retrieval of mussels along with growth, condition and survival data on the mussels was generated by Marine Research, Inc. (MRI), Aquatec's subcontractor. Data and discussion from MRI's report (MRI 1991) were used in completion of this bioaccumulation report. Individual project responsibilities were:

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1.0 OVERVIEW

This bioaccumulation study for the Deer Island site was conducted for the Massachusetts Water Resources Authority (MWRA) as part of Aquatec, Inc.'s 1991 contract with MWRA. That contract provided for a bioaccumulation study of two sites, Deer Island and Nut Island, as required by the NPDES permits for facilities at those locations. In subsequent conversations between MWRA and the U.S. EPA, the NPDES requirement for a bioaccumulation study at the two sites was waived and no additional studies were required. The MWRA, however, chose to conduct a modified program at the Deer Island Light location.

The bioaccumulation study of mussels (Mytilus edulis) was conducted during the summer of 1991 to determine whether selected metals and organic compounds were being accumulated in test organisms in the vicinity of the Deer Island Light (DIL) discharge. As part of this study, mussels were also deployed at two "control" sites; the New England Aquarium (Discovery) served as a "dirty" control, and Hodgkins Cove (Gloucester) served as a "clean" control (Figure 1). The mussels were deployed for a nominal sixty-day period. The soft tissues of the exposed mussels were analyzed to measure body burdens of target analytes.

In 1987, an initial study was conducted by the MWRA (MWRA 1988) on the bioaccumulation of selected metals and organic compounds by mussels deployed at Deer Island Light and several other locations. The present study was designed to be generally comparable to the 1987 study. However, the 1991 study used different analytical methodologies to attain lower detection limits for organic compounds.

2.0 METHODS

2.1 Source of Mussels

On June 17, 1991, approximately fifteen hundred mussels were collected for testing purposes from the University of Massachusetts' marine station at Hodgkins Cove in Gloucester, Massachusetts. This area was chosen because mussels from this location had been used in previous bioaccumulation studies; one for the South Essex Sewage District (Camp, Dresser, and McKee, Inc. 1988) and a second for New Bedford, Massachusetts (MRI 1989). Subsamples of the collected mussels were deployed at the Gloucester station ("clean" control), off Deer Island, and at the Discovery station ("dirty" control) for the purpose of assessing contamination. Because the collected mussels had been exposed to fecal bacteria in Hodgkins Cove, their collection, transportation, and deployment were monitored by the Division of Marine Fisheries. The Commonwealth amended (Marine Research, Inc.) MRI's scientific permit No. 9004 for this study and specified that the shellfish officers in the locations involved be notified 24 hours before any activity took place.

One hundred and sixty-two of the mussels collected on 17 June in Hodgkins Cove were randomly selected and measured (average length = 61.1 mm). All mussels collected were then suspended in cages in the water from which they were taken. They were recovered on 20 June; 30 mussels were returned to MRI's laboratory for examination, 140 were delivered to Aquatec for chemical analysis, and the rest were prepared for deployment.

2.2 Deployment Moorings and Suspension System

Each mooring and suspension system at Deer Island consisted of two 50-lb mushroom anchors with an appropriate length of 8 mm polypropylene-encased steel cable attached to a 12-inch diameter inflatable buoy which suspended the system in the column of water. Depth of water at the Deer Island shallow test site was approximately 10 feet at mean low water and 15 feet at Deer Island deep test site. Mussels were suspended two feet from the buoy (and approximately 3-6 feet above the bottom) in 9"x9"x9" polypropylene test-tube baskets with lids. At Gloucester, the "control" station, mussels were suspended from the dock approximately 8

feet off bottom. At the Discovery station, mussels were suspended from the stern of the ship Discovery; at low tide they were approximately 8 feet off bottom and at high tide, 18 feet off bottom.

Fifty mussels were placed in each basket, which was then securely affixed with polypropylene ties to the encased cable. Four mooring systems or arrays containing a total of 800 mussels, 200 to each array, were utilized in the Deer Island test area. Two hundred and fifty mussels were suspended from one array off the Discovery. One array of three hundred mussels remained as controls at Gloucester.

2.3 Mussel Deployment and Retrieval

On 20 June 1991, the moorings were transported to an area off the light at Deer Island on a 34-foot vessel. The exact positioning of each array east of the Deer Island light was made from a 14-foot aluminum boat. A 100-foot length of polypropylene line tethered the anchor of each array to a stone in the riprap surrounding the light to facilitate later retrieval. The floats of all four arrays were visible from the surface and, therefore, were subject to possible vandalism. Seven days later, on 27 June, two arrays (400 mussels) were repositioned from the original site, Deer Island shallow deployment, to deeper water (~15 feet MLW) 200 feet east, designated Deer Island deep deployment. Floats were again tethered to riprap at the light but were now 5 to 7 feet below the surface at low water and only barely visible to an observer directly over the array in order to reduce potential vandalism.

On 21 June, one day after the initial deployment at Deer Island shallow, 250 mussels were suspended from the stern of Discovery (New England Aquarium). Three hundred mussels remained as controls at Gloucester (Hodgkins Cove).

On 19 July, 150 mussels each were removed from the arrays at Gloucester and the Discovery while one array of 200 mussels was removed from Deer Island deep deployment. Exposure time was as follows: Gloucester, 32 days; Discovery, 28; and Deer Island, 29. These mussels were frozen and kept for future analyses.

Mussels were harvested on 22 August from the three stations. At the deep deployment of Deer Island Light two of the four cages were lost during retrieval, limiting the number of mussels available for analysis to approximately 100 organisms. Approximately 200 mussels were recovered from the shallow deployment at Deer Island. Random subsamples of mussels were obtained for biological analyses and chemical analyses. Separate mussels for chemical analyses were stored in labeled plastic bags in coolers and kept cold during same-day transport to the laboratory where they were frozen until needed.

2.4 Examination of Mussels

In the laboratory, mussel length was measured to the nearest 0.1 mm with Vernier calipers and whole animals were wet-weighed on a Precision electronic balance to the nearest 0.1 g. Gonadal tissue was examined by microscope to determine the stage of gametogenesis at the beginning of the experiment (initial Gloucester) and after "thirty"-day and "sixty"-day exposures. Maturity was apparent if the eggs were 60 micron (u) or larger in diameter and if the sperm were motile. The degree of fouling on the outer shell was visually inspected and incidence of gross abnormalities on the soft tissue was noted using a magnifying glass.

The soft tissue from each mussel was transferred to aluminum baking cups, dried in a Blue M oven at 105°C (±1°C) for 24 hours, and then placed in a desiccator until weighed on a Mettler Balance H54 (±0.00001 g).

Based on the dry weight of the gonad-mantle tissue, non-gonadal soft tissue and the shell, two condition factors were calculated. The Condition Index I (CI I) was calculated as the weight of the gonad-mantle tissue divided by the weight of all the soft tissue (including gonad-mantle) and multiplied by 100. Condition Index II (CI II) was determined as the total weight of soft tissue (non-gonadal and gonad-mantle) divided by the shell dry weight and multiplied by 1000. The condition indices were calculated on thirty mussels collected before deployment, referred to as "Gloucester initial" and from thirty mussels each from the Gloucester, Deer Island shallow, and the Discovery stations after deployment. Sixteen

mussels from the Deer Island deep station were also used for condition indices after deployment. The after deployment indices were referred to as "sixty"-days in tables.

2.5 Chemical Analyses

In the laboratory, composite samples of 12 (Discovery) to 15 (Deer Island and Gloucester) mussels' soft tissue were obtained by dissection using disposable teflon-coated stainless steel blades. The tissues were then refrozen. Five composite samples were analyzed for the Gloucester and Discovery stations. Eight Deer Island station samples were analyzed, four from each of the shallow and deep deployments.

The extraction and analytical procedures generally followed National Status and Trends Methodologies (Figures 2 and 3). Tissues were analyzed for polynuclear aromatic hydrocarbons (PAH) using Gas Chromatography/Mass Spectrometry (GC/MS), while pesticides and polychlorinated biphenyls (PCB) were analyzed using Gas Chromatography/Electron Capture Detector (GC/ECD). Tissue extraction for metals was completed following procedures depicted in Figure 3. Analyses of digestate was completed using Inductively Coupled Plasma (ICP). Control compounds were spiked into each sample prior to extraction as part of the analysis for more representative quantification of the PAH, PCB, and pesticide target analytes. The spiked analytes were as follows:

PAH Internal Standards:

Naphthalene-d_8
Acenaphthene-d_{10}
Phenanthrene-d_{10}
Chrysene-d_{12}
Perylene-d_{12}

Pesticide/PCB Internal Standards:

Dibromooctafluorobiphenyl
Cl_5-PCB(121)
Cl_8-PCB(204)

The sample specific experimental recoveries (summarized in appendixes A, B, C, and D) were used for correction of the reported results for the target analytes in the mussels.

Blank analyses and sample duplicates were conducted routinely. Additional laboratory quality control included laboratory replicate samples and matrix spikes. For each analysis, laboratory replicates and matrix spike analyses were conducted for approximately 10 percent quality control sampling. Three samples of Standard Reference Material 1974 (Organics in Mussel Tissue) from the National Institute of Standards & Technology (NIST) containing certified concentrations of polynuclear aromatic hydrocarbons were analyzed as part of the quality control program. Non-certified concentrations of pesticides, PCBs, and metals were also reported for this standard reference tissue. Laboratory results and non-certified values are presented in the appendices. Lipid determinations were completed following the National Status and Trends Methodologies.

2.6 Statistical Analyses

Both parametric and non-parametric statistics were used for evaluation of the data. Biological measurements (i.e., condition indices) were statistically analyzed using the Analysis of Variance (ANOVA) since sample size at each station was large (generally N=30). Confidence intervals for each biological comparison of two stations were determined using the approach outlined by Snedecor and Cochran (1973) for ANOVA with unequal sample size.

Statistical analyses of individual chemical constituents on dry weight basis were completed using the Mann Whitney U test, a non-parametric test which provides a powerful alternative to the parametric t-test. This test was selected since the relatively small sample size (generally 8 or less) suggested that the data may not meet the assumptions of the t-test. The Mann Whitney U test is an excellent alternative to the t-test with its power-efficiency approximating 95.5 percent as sample size increases (Siegel 1956).

Since mussels deployed at two discrete depths were used for analyses of body burdens at the Deer Island Light station, chemical analyses conducted on individual composite samples were recorded separately by exposure depth. Statistical analyses (Mann Whitney U Test) of the two depths indicated that tissue concentrations of polynuclear aromatic hydrocarbons differed between the Deer Island deep and shallow mussel deployments ($P \leq 0.05$); therefore, the PAH data for each depth were treated separately. The pesticide, PCB, and metals sample analyses were not statistically different ($P > 0.05$) between the two deployment depths at Deer Island. These data were combined and used to compare this station with the other two stations, Discovery and Gloucester. Results were reported on a dry weight basis. Total PAHs, PCBs, and pesticides (i.e., sum of individual sample analytes) were calculated using the detection limit value for the analyte as an estimated concentration for those analytes not detected.

Lipid-corrected values for the PAHs, PCBs, and pesticides were determined by dividing the dry weight tissue concentration by the sample-specific lipid percentage (expressed as a decimal). These lipid-corrected values were plotted for comparison among the stations.

3.0 RESULTS

3.1 Biological

3.1.1 Survival

At 30 days (19 July), mussels at all locations appeared the same as when deployed. There was no growth attached to shells. No abnormalities, such as lesions or parasites, were observed on soft tissue. Based on 30 mussels from each location, survival rate was 100 percent at Gloucester, 96.7 percent at Deer Island deep, and 86.7 percent at the Discovery (Table 1).

Mussels were scheduled to be removed from the deployment areas on 19 August; however, due to the arrival of Hurricane Bob on that date, the retrieval was delayed until 22 August. In Gloucester, 154 mussels were retrieved for a 94.8 percent survival rate over a 67-day exposure time (Table 1). At the Discovery site, 101 were retrieved with survival of 89.1 percent over 62 days. At Deer Island shallow and deep deployments, after an exposure period of 63 days, 505 mussels were retrieved. Of these, 202 and 198 mussels were retrieved from two arrays at Deer Island shallow deployment, resulting in a survival rate of 97.5 percent and 95.5 percent, respectively. At Deer Island deep deployment, 105 mussels were retrieved with 100 percent survival; two cages of approximately 50 mussels each were lost in the process of winching the mooring system over the ship's gunnel.

Following the nominal 60-day exposure period, mussels at the Gloucester and Discovery locations were attached to each other within the cages by byssus threads, a normal condition. In both groups, growing in the cages with the adult mussels were about 15 small mussels (<5 mm in length) which were probably transferred unnoticed to the cages as very small juveniles hidden within the byssus threads of the adults. A few barnacles were attached to some of the mussel shells from both locations. An orange-colored bryozoan was observed on 10 percent of the Gloucester population while a brown-black bryozoan grew on the shells of most mussels in both populations as well as on the cages.

Deer Island deep deployment cages were covered with extensive growth of a coelenterate belonging to the family Tubularidae which, because of its pink-hearted hydranths, was believed to be Tubularia crocea. Bryozoans were growing on some shells and mussels were extensively covered with mud (possibly a result of Hurricane Bob, which passed about 50 miles to the east 3 days earlier). Mussels from Deer Island shallow deployment had less coverage by T. crocea and mud. Cages from both Deer Island sites had a high density of amphipods (Corophium spp., personal communication Mr. Hall, MWRA) and numerous small crabs throughout, which were not observed at the Gloucester or the Discovery locations. Fifty percent of mussels from Deer Island shallow deployment had barnacles attached. No abnormalities, such as lesions or parasites, were observed on soft tissue from any animals.

3.1.2 Sexual Maturity

Results of the initial examination of 30 mussels indicated that 9 were mature females, 2 immature females, 15 mature males, and 4 immature males (Table 2).

Gonadal tissue, muscles, gills, and viscera were checked for lesions or parasites at the time observations were made on gametogenesis. No abnormalities, lesions, or parasites were found. The female gonads were most often orange in color and the male was either yellow or a yellow-cream color.

Observations made on the stage of development of the gonads (Table 2) of 30-day retrieved mussels indicated that both Gloucester and Deer Island deep had the same number of mature females (14) and immature females (2); mature males for Gloucester were 7 and for Deer Island, 5. At Gloucester there were 7 immature males, at Deer Island deep, 8 immature males and 1 dead. At Discovery, 6 were mature females, 2 immature females, 11 mature males, 7 immature males, and 4 dead.

Thirty live mussels each from Gloucester and Discovery stations and 16 from Deer Island deep deployment were examined after the 60-day retrieval. Examination of Deer Island shallow deployment mussels was made on frozen animals sometime after retrieval and, because eggs lysed upon thawing, it

was difficult to distinguish mature eggs and sperm from immature; for that reason, data relating to gametogenesis are obscure in this one instance. Of the 30 mussels examined from both Gloucester and Discovery (Table 2), 17 from Gloucester and 10 from Discovery were mature females; 9 from Gloucester and 15 from Discovery were mature males; and 4 and 5, respectively, were immature. Of the 16 mussels examined at Deer Island deep, there were 8 mature females, 1 immature female, and 7 mature males.

3.1.3 Growth and Condition

The 30 mussels examined as part of the initial (June) evaluation had a mean shell length of 56.9 mm (Table 3). The mean wet weight was 18.9 g; mean shell dry weight, 10.0 g; mean gonad-mantle dry weight, 0.2 g; and mean non-gonadal soft tissue dry weight, 0.8 g. Most shells had barnacles attached, which were removed before the mussels were put in cages. In addition, 162 mussels were randomly selected and measured on 17 June. The mean length of this group was 61.1 mm.

Results of tissue and shell examination after 60 days indicated that mussels from the Discovery station averaged 53.6 mm in length, or 8.5 mm (0.33 in) smaller than the average length, 62.1 mm, of mussels from the Gloucester and Deer Island stations (Table 3). Furthermore, the Discovery mussels were smaller than those measured at the beginning of the study (61.1 mm). Although the original groups of mussels at each station were intended to represent an equal random mix of sizes, this difference suggests that smaller mussels were inadvertently placed in the Discovery cages. Because of the difference in length between mussels from the Discovery and the other stations, the Discovery mussels were not used in comparing wet and dry weights. Instead, mussels exposed to control conditions at Gloucester were contrasted to those exposed at Deer Island shallow and deep deployments. However, condition indices from all locations were utilized for comparative purposes.

Comparison of the wet weight of mussels from Gloucester, Deer Island shallow and Deer Island deep indicated that, after deployment, the Deer Island deep deployed mussels' weight of 28.1 g was greater than those of

Gloucester and Deer Island shallow, 26.4 and 25.2 g, respectively. The gonad-mantle dry weight of Deer Island deep, 0.5 g, was greater than Deer Island shallow, 0.4 g, and Gloucester, 0.3 g. Non-gonadal soft tissue weighed: Deer Island deep, 1.3 g; Deer Island shallow, 0.9 g; and Gloucester, 0.9 g.

With respect to shell dry weight, Deer Island shallow, 14.7 g, was larger than Gloucester and Deer Island deep; 13.1 and 13.0 g, respectively.

The ANOVA results for the gonad-mantle/total soft tissue condition index (CI I) indicated a significant difference in the indices ($P \leq 0.05$). The mean condition index showing a non-significant difference ($P > 0.05$) are underscored as follows:

Gloucester 0 days	Gloucester 60 days	Deer Island Deep 60 days	Discovery 60 days	Deer Island Shallow 60 days
19.2	22.3	27.6	29.1	30.0

The analyses of the relative gonad-mantle weight (CI I) did not increase substantially during the deployment at Gloucester while both Deer Island and Discovery mussel deployments were significantly higher than the June Gloucester mussel deployment ($P \leq 0.05$). Both Deer Island and the Discovery mussels' condition indexes were similar ($P > 0.05$). Although the Deer Island deep mussels were similar to Deer Island shallow and Discovery mussels, the Deer Island deep mussels were not statistically different from the Gloucester mussels retrieved in August. Even though the Deer Island deep condition index was more than 20 percent higher than August Gloucester condition index, the lack of significant difference was believe to be due, in part, to the reduced sample size ($N=16$) of Deer Island deep providing less statistical power than other locations (where $N=30$).

In reference to the condition index which measured the ratio of total soft tissue to shell (CI II), the data indicated a significant difference in indices ($P \leq 0.05$). The means, which were statistically non-significant, ($P > 0.05$) are underscored:

Deer Island Shallow 60 days	Gloucester 60 days	Gloucester 0 days	Deer Island Deep 60 days	Discovery 60 days
94.1	94.5	108.3	137.2	144.0

In this comparison, the test suggested that mussels from Deer Island shallow and Gloucester make up one group and those from Deer Island deep and Discovery make up a second.

The ratio of the weight of total soft tissue to shell weight of the Discovery and Deer Island deep was greater than that of the other group, there being more total soft tissue to shell. The relative weight of total soft tissue to shell weight of the Deer Island deep samples more resembled those of the Discovery population than Deer Island shallow's population only 200 feet distant. The two Deer Island station's mussels and Discovery station's mussels were similar in average gonad-mantle dry weight, while an apparent difference in non-gonadal soft tissue was noted. The Deer Island deep mussels average non-gonadal dry-weight (1.2607g) was about 35 percent higher than the Deer Island shallow mussels average non-gonadal soft weight tissue dry weight (0.9312g) and about 50 percent higher than the Discovery mussels average non-gonadal soft tissue dry weight (0.8462g).

3.2 Tissue Concentrations

The percent lipids in each tissue composite sample was determined from the samples used for chemical analysis. The average percentage and one standard deviation, in parenthesis, were as follows:

Gloucester June	Gloucester August	Discovery August	Deer Island Shallow	Deer Island Deep
4.6 (2.3)	4.3 (2.6)	5.8 (1.5)	3.5 (1.0)	3.1 (0.3)

Even through the Discovery mussels displayed the highest percentage of lipids, there were no statistical differences detected among the stations (based on combined Deer Island deployments) (Mann-Whitney U; $P>0.05$). The variability among stations in the mean lipid concentration was large, with the Discovery mean lipid concentration being nearly 75 percent larger than the combined Deer Island average lipid concentration. The correction of organic compound tissue concentrations (see below) was influenced by these

numerical (but not statistically different) variations. In effect, the higher lipid concentrations reported for the Discovery mussels resulted in lowered (relative to Gloucester and Deer Island) lipid adjusted tissue concentrations.

3.2.1 Polynuclear Aromatic Hydrocarbons

Matrix spike analyses were conducted on three samples obtained during this study (Table 4). The matrix spike analyses were conducted on samples that were analyzed in duplicate and recoveries were calculated twice for each matrix spike using both sets of results from the duplicate analysis of a sample. Overall, there was good agreement between the two duplicate determinations of recovery for the sample. Recoveries, however, were typically high between 100 and 120 percent. **These recoveries suggest that if a systematic reporting bias is occurring, the individual reported compound concentrations are conservative (i.e. higher values than actual).**

Percent differences between duplicate analyses of samples were calculated (Table 5) and indicated reasonably good agreement between the paired analyses. These differences were generally on the order of 20-30 percent when individual compounds were present in the tissue in appreciable concentrations.

Certified mussel tissue obtained from the National Institute of Standards and Technology (NIST) was analyzed in triplicate for polynuclear aromatic hydrocarbons (Table 6). These certified values reported by NIST are based upon results obtained from the NIST analysis of this material using two different analytical techniques. The uncertainty reported was obtained from a 95 percent prediction interval plus an allowance for systematic error between the methods used (NIST 1991).

There is generally good agreement between this study's reported average concentrations (N=3) and the average certified value. The Benzo(a)pyrene concentrations displayed a trend of higher values than those reported for the certified values. In general, the derived determinations for each of the compounds trended toward the upper range, further suggesting that the reported values for the individual compounds in tissue may be conservative.

The total PAH tissue concentrations in the Discovery site deployments were the highest observed among the three stations ($P \leq 0.05$) and reflected specific trends of individual compounds (Table 7; Figure 4). Body burdens of PAHs in the Deer Island mussels were significantly elevated above the Gloucester body burdens. The Deer Island shallow mussels generally displayed higher body burdens of each individual PAH compound than the body burdens observed for the Deer Island deep mussels. These differences were most noticeable in the two- and three-ringed PAHs (low molecular weight), which were highest in the Deer Island shallow mussels (Figure 5). Overall average tissue concentrations of two- and three-ringed PAHs in the Deer Island shallow mussels was approximately 714 ug/Kg compared to 240 ug/Kg and 74 ug/Kg observed for the Discovery and Gloucester mussels, respectively. The average concentration of the four-, five-, and six-ringed PAHs (high molecular weight) were significantly higher in the Discovery mussels (2330 ug/Kg) than in the Deer Island shallow mussels (829 ug/Kg) and the Gloucester (154 ug/Kg) mussels.

The concentration of target PAHs were corrected for lipid content in the composite mussel samples from the three stations (Figure 6). Lipid corrected PAH concentrations were similar to the trends observed for dry weight PAH concentrations; Deer Island shallow station displayed a higher concentration (per unit lipid) of two- and three-ringed PAHs while the total concentration of the four-, five-, and six- ringed PAHs was highest in the Discovery mussels.

3.2.2 Pesticides

Matrix spike recoveries were variable among the three samples analyzed (Table 8). The spike concentrations were chosen prior to analyses and varied in an effort to reflect anticipated tissue concentrations. A significant portion of this inter-sample variability may have been the result of different concentrations of pesticides used for matrix spike analyses. The sample, laboratory ID 143632MS, had pesticide matrix spike concentrations of 0.79 ug/Kg which were below detection levels in the tissues. Such low spike concentrations may have been one factor of the artificially high spike recoveries reported for this sample. The matrix spike pesticide concentrations of the other two samples (laboratory ID

143959MS and 143962MS) were higher for the Discovery and Deer Island samples than the Gloucester (143632MS). The recoveries for those two samples were comparable and generally within an acceptable range (80-120 percent). Two pesticides, Heptachlor and aldrin, displayed recoveries within the 140-150 percent range. In general, pesticide analysis results for individual parameters were consistent with non-certified values in NIST tissues (Appendix B). However, the DDE (2,4' and 4,4') analyses yielded variable results.

More than half of the target pesticides in the duplicate analyses were not present at detectable concentrations (Table 9). For those pesticides detected in the samples, the percent difference comparison of duplicate analyses typically ranged from 5 to 80 percent.

Hexachlorobenzene, lindane, mirex, aldrin, heptachlor, and heptachlor epoxide were generally at or below detection levels in the composite samples from all three stations (Figure 7; Table 10). Although no differences were observed between the dieldrin tissue concentrations in both Deer Island deployments and Gloucester, tissue concentrations of dieldrin in mussels from the Discovery site were significantly elevated ($P \leq 0.05$). Average alpha-chlordane concentration in mussels from Deer Island (10 ug/Kg) was significantly higher than the average Gloucester mussel tissue concentration (2.5 ug/Kg) but was significantly less than average Discovery mussel tissue concentration (19 ug/Kg). Total DDT (the sum of DDD, DDE, and DDT isomers) was significantly higher in the Discovery (94 ug/Kg) and Deer Island (48 ug/Kg) tissues than in the Gloucester tissues (28 ug/Kg). The concentrations of DDD (2,4' and 4,4') were higher in the Discovery tissue samples than in Deer Island tissues. Trans-nonachlor was found in statistically higher tissue concentrations in the Deer Island mussels ($P \leq 0.05$) than in mussels from the other two stations.

Lipid-corrected concentrations of pesticides in tissues displayed, in general, similar trends observed for dry weight concentrations (Figure 8). There were several individual lipid-corrected pesticide results which presented different trends than those noted for the dry weight values.

Total lipid-corrected DDDs were statistically highest in the Discovery samples. However, lipid-corrected 4,4' DDE was highest in the Deer Island samples (particularly the deep deployment). Lipid-corrected alpha-chlordane was higher in the Discovery tissues but these concentrations were not statistically different from the Deer Island tissue concentrations. Trans-nonachlor was significantly higher in Deer Island mussel tissue than in mussel tissues from Gloucester and Discovery.

3.2.3 Polychlorinated Biphenyls

The analyses of matrix spike recoveries were variable for the three PCB samples (Table 11). Recoveries were generally greater than 100 percent, with particularly high recoveries reported for the low spike concentrations of the Gloucester sample (laboratory ID 143632).

More than 40 percent of the individual PCBs were below detection level (Table 12). The percent differences between the paired PCB determinations ranged from 0 to 75 percent.

The lower chlorinated (C12) and higher chlorinated (C18, C19, and C110) PCBs were below detection level in the tissue composites (Table 13). For the remaining congeners which were detected, the highest concentrations of individual congeners were found in the Discovery samples (Figure 9). The five-chlorine (C15-PCB(101) and C15-PCB(118)) and the six-chlorine (C16-PCB(153) and C16-PCB(138)) PCB congeners were found in appreciable concentrations in both the Deer Island and the Discovery mussel tissues. These PCB concentrations were significantly higher in the Discovery tissues ($P \leq 0.05$) than both the Deer Island and Gloucester mussel tissue concentrations. Total PCB concentrations were statistically the highest in the Discovery tissues (477 ug/Kg) ($P \leq 0.05$). Deer Island mussel tissue average PCB body burden (200 ug/Kg) was also significantly ($P \leq 0.05$) higher than the Gloucester mussel average PCB body burden (77 ug/Kg).

Lipid-corrected PCB concentrations revealed similar trends to the dry weight analysis; highest individual congener and total PCB concentrations in the Discovery mussel tissue (Figure 10). The average of the seven chlorine PCB congeners (C17-PCB(170), C17-PCB(180), and C17-PCB(187)) was

the highest in the Discovery tissues on a dry weight basis, but lipid-corrected average concentrations of these congeners were numerically greater in the Deer Island tissues. Neither lipid-corrected analysis trend was statistically significant and may represent individual lipid sample variability.

3.2.4 Metals

The matrix spike recoveries for copper, lead, and zinc were within an 80-120 percent range with the exception of zinc for one sample: laboratory ID 143633MS (Table 14). Duplicate analyses averaged less than 15 percent difference with one maximum difference of nearly 19 percent for one lead determination (laboratory ID 143633) (Table 15).

Mussel tissue from the three stations were analyzed for copper, lead, and zinc (Table 16). Lead was found in low concentrations and no significant differences among the three stations were detected (Table 17).

The average copper concentration in the Discovery mussels (12.7 mg/Kg) was significantly higher than both Deer Island and Gloucester mussels. The average Deer Island copper concentration was significantly higher ($P \leq 0.05$) than the average Gloucester mussel copper concentration (7.4 mg/Kg) retrieved in August, but was not different ($P > 0.05$) than the 8.8 mg/Kg copper concentrations observed for Gloucester mussels retrieved in June.

The average zinc body burden in Discovery mussels was significantly elevated above the average Gloucester mussel body burden ($P \leq 0.05$). The average Deer Island zinc body burden was lower than the average Gloucester mussel body burden. One possible explanation for the high zinc levels in the Discovery mussels may have been their inadvertent deployment adjacent to zinc anodes (a fact which came to our attention during the completion of this report).

Metal tissue concentrations were adjusted for mussel non-gonadal dry weight to normalize bioaccumulated metals in non-gonadal tissue (Table 17). This normalization was judged to be representative of tissue concentrations since metals are generally believed to be bioconcentrated in the

non-gonadal tissue (Phillips 1976; Cain and Luoma 1986). The average percentage of non-gonadal dry weight for each location's samples was determined from the thirty mussels used for biological characteristics, not the mussels used to determine metal tissue concentrations. It was assumed that the percentage of non-gonadal tissue was consistent between mussels from the two groups (those used for biological analyses and for chemical analyses) of mussels from the same location.

Generally, trends in adjusted metal tissue concentrations among the locations were similar to non-adjusted trends. Adjusted lead tissue concentrations were not statistically different ($P>0.05$) among the Deer Island, Discovery, and the June Gloucester mussels. However, the August Gloucester adjusted lead tissue concentrations were significantly less than Deer Island and Discovery ($P\leq0.05$) but not significantly different from the June Gloucester mussels.

Adjusted copper tissue concentrations were significantly higher in the Discovery samples than in the Gloucester (both June and August) samples ($P\leq0.05$). The adjusted copper concentrations of Deer Island mussels were significantly less than the Discovery adjusted copper concentrations but were not statistically different from the Gloucester adjusted copper concentrations ($P>0.05$).

The adjusted zinc body burdens in the Discovery mussels was significantly higher than either the Deer Island or Gloucester body burdens ($P\leq0.05$). Adjusted Deer Island tissue concentrations were not elevated above the Gloucester adjusted tissue concentrations ($P>0.05$).

4.0 DISCUSSION

Biologically, there were differences noted for mussels deployed at the three stations. Average gonad-mantle dry-weights were similar among the Deer Island deployments (shallow and deep) and the Discovery deployment but were higher than the average for the Gloucester deployments (both the "initial" and "sixty"-day mussels). The average non-gonadal soft tissue was similar among all deployments (Gloucester, Deer Island shallow, and Discovery) with the exception of the Deer Island deep deployment. This average non-gonadal dry weight was more than 35 percent higher than the other deployments. It is unclear whether the smaller sample size (N=16) of mussels analyzed for the "sixty"-day Deer Island deep deployment and/or other factors may have contributed to the apparent high average non-gonadal soft tissue weight.

The smaller than average size of mussels at the Discovery station partially confounds the interpretation of results from the study. The methods of reporting tissue concentrations on a dry weight basis, the inspection of lipid-adjusted organic tissue concentrations, and normalization of metals tissue concentrations to non-gonadal tissue were utilized to ameliorate the possible effects of the size co-variable on station comparisons.

Statistical differences in PAH tissue concentrations between the shallow and deep deployed mussels at Deer Island may have reflected deployment conditions. As noted above, the higher degree of fouling may have affected the exposure of the deep mussels either by reduction of the exchange of water within the cages and/or by reducing the mussel exposure due to bioaccumulation of some of the contaminants by the fouling organisms. The lower tissue concentrations of mussels deployed at greater depths may also have been a result of non-homogeneous distribution of these contaminants in the water column, perhaps due to hydrographic factors occurring at this station.

As described previously, the 1991 bioaccumulation study was modeled after a study undertaken as part of the MWRA's Secondary Treatment Facilities Plan (MWRA 1988). The 1987 study analyzed mussel tissues after

30 days of deployment for organic compounds and 60 days of deployment for target metals, as compared to this study, which analyzed tissues from mussels deployed for a nominal "sixty"-day period for all target analytes. Although these variations existed, a generalized comparison of data was conducted to discern possible trends. The Deer Island shallow station was selected for comparison since it was the most comparable (in terms of deployment depths and hypothesized exposure) to the 1987 deployments. Also, the 1991 shallow deployment mussels were overall higher in tissue concentrations in the majority of the compounds when compared to the mussels from the 1991 deep deployment.

With the exception of copper, which showed no change, most of the contaminants were found in lower concentrations in the 1991 mussel tissues when compared with the 1987 tissue concentrations (Table 18). Lead, zinc and total DDTs were in the range of 10 - 20 percent less while other contaminants such as total PCBs, total PAHs and several pesticides were substantially lower -- 35 percent or more less in 1991.

Comparison of individual PAH compounds, which were found in detectable concentrations in the 1987 study, also indicated a general trend of reduced tissue concentrations in the 1991 samples when compared with the 1987 samples (Table 19). This was particularly true for the different methyl naphthalene compounds. Two compounds were found in comparable but arithmetic higher concentrations in 1991: Benzo(b,k)fluoranthene and Benzo(e)pyrene. The significance of the results of these two PAHs is not clear.

Overall, the results of these comparisons suggest that decreased tissue concentrations of mussels deployed at the Deer Island station in 1991 exist when compared with 1987. The statistical significance of this apparent trend was not evaluated formally since analytical and deployment method differences confound this comparison. However, even though differences in quantification of the total analyte concentrations and deployment methods

could have accounted for a portion of this observed decrease of tissue concentration between the two studies, the lower 1991 mussel tissue concentrations were believed to reflect, at least in part, decreased accumulation of most of the target analytes in tissues of deployed mussels.

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Table 1. Survival of mussels deployed at the dock in Hodgkins Cove, Gloucester, the Discovery at the New England Aquarium, and near the light off Deer Island. "Thirty"-day analyses were made on thirty animals taken from each location. "Sixty"-day analyses were made on all mussels found at the locations at the termination of the exposure period.

	Alive	Dead	Number	% Survival
"Thirty"-day				
Gloucester	30	0	30	100
Discovery	26	4	30	86.7
Deer Island	29	1	30	96.7
"Sixty"-day				
Gloucester	146	8	154	94.8
Discovery	90	11	101	89.1
Deer Island				
Shallow	197	5	202	97.5
Shallow	189	9	198	95.5
Deep	105	0	105[1]	100

[1]Two cages of 50 mussels each lost upon retrieval.

Table 2. Stage of gametogenesis of mussels determined before deployment for "initial" Gloucester, and at "thirty" and "sixty"-day intervals in mussels deployed at Gloucester, Discovery, and Deer Island.

	Sample size	Females		Males		
		Mature	Immature	Mature	Immature	Dead
"Initial"						
Gloucester	30	9	2	15	4	
"Thirty"-day						
Gloucester	30	14	2	7	7	
Discovery	30	6	2	11	7	4
Deer Island Deep	30	14	2	5	8	1
"Sixty"-day						
Gloucester	30	17		9	4	
Discovery	30	10		15	5	
Deer Island Deep	16	8	1	7		

Table 3. Summary of various parameters expressed as mean values for mussels. "Initial" Gloucester represents measurements on mussels at beginning of study and "sixty"-day represent values at end of study. Condition factors represent overall average of individual condition factor calculations. Sample size is listed in parentheses following the location.

Location	Mean Shell Length (mm)	Mean Total Wet Weight (g)	Mean Dry weight (g)			Mean Condition factor	
			Gonad-Mantle	Non-gonadal Soft Tissue	Shell	Gonad-Mantle/ Total Soft Tissue	Total Soft Tissue/ Shell
"Initial"							
Gloucester (30)	56.9	18.9	0.2119	0.8331	9.9825	19.2	108.3
"Sixty"-day							
Gloucester (30)	62.3	26.4	0.2709	0.9205	13.1436	22.3	94.5
Discovery (30)	53.6	16.7	0.3836	0.8462	8.7203	29.1	144.0
Deer Island Shallow (30)	62.9	25.2	0.4254	0.9312	14.7425	30.0	94.1
Deer Island Deep (16)	61.0	28.1	0.4985	1.2607	12.9958	27.6	137.2

Table 4. Percent recovery for matrix spike analyses conducted for polynuclear aromatic hydrocarbons.

Laboratory ID: Parameter	143632MS	143632MSD	143959MS	143959MSD	143962MS	143962MSD
Naphthalene	116	99	78	86	90	90
2Methylnaphthalene	132	125	111	115	153	141
1Methylnaphthalene	133	121	109	110	147	140
1,1Biphenyl	124	124	100	101	152	150
2,6Dimethylnaphthalene	102	99	171	114	109	81
Acenaphthylene	95	91	115	114	102	101
Acenaphthene	121	120	126	101	120	115
2,3,5Trimethylnaphthalene	124	119	206	133	167	130
Fluorene	113	113	132	118	120	113
Phenanthrene	106	101	120	99	118	101
Anthracene	110	104	107	106	107	102
1Methylphenanthrene	99	98	132	115	103	85
Fluoranthene	187	136	129	141	210	154
Pyrene	170	130	130	143	197	147
Benzo(a)anthracene	125	112	152	154	116	88
Chrysene	139	113	107	91	146	111
Benzo(b,k)fluoranthene	125	113	126	118	133	123
Benzo(e)pyrene	165	120	145	135	152	132
Benzo(a)pyrene	123	80	80	78	87	81
Perylene	92	91	100	98	98	95
Indeno(1,2,3-cd)pyrene	106	99	117	118	102	101
Dibenz(a,h)anthracene	102	101	122	124	100	99
Benzo(g,h,i)perylene	110	101	105	104	105	104

143632MS - The reported recoveries are based on the results from sample analyses 143632MS and 143632.
143632MSD - The reported recoveries are based on the results from sample analyses 143632MS and 143632D1.
143959MS - The reported recoveries are based on the results from sample analyses 143959MS and 143959.
143959MSD - The reported recoveries are based on the results from sample analyses 143959MS and 143959D1.
143962MS - The reported recoveries are based on the results from sample analyses 143962MS and 143962.
143962MSD - The reported recoveries are based on the results from sample analyses 143962MS and 143962D1.

Table 5. Duplicate analyses conducted for polynuclear aromatic hydrocarbons. When one sample was below detection level, percent differences were calculated assuming the concentration was at detection level.

Laboratory ID: Parameter	143632	143632D1	%	143959	143959D1	%	143962	143962D1	%
Naphthalene	9	16	56	32	25	25	12	13	8
2Methylnaphthalene	5	8	46	130	120	8	36	45	22
1Methylnaphthalene	<5	7	33	68	67	1	20	25	22
1,1Biphenyl	<5	<5	NA	17	16	6	7	8	13
2,6Dimethylnaphthalene	<5	<5	NA	130	180	32	67	89	28
Acenaphthylene	<5	<5	NA	<5	<5	NA	<5	<5	NA
Acenaphthene	<5	<5	NA	10	33	107	7	12	53
2,3,5Trimethylnaphthalene	<5	<5	NA	130	190	38	77	110	35
Fluorene	<5	<5	NA	23	37	47	17	23	30
Phenanthrene	<5	7	33	95	110	15	48	62	25
Anthracene	<5	<5	NA	19	19	0	9	14	43
1Methylphenanthrene	<5	<5	NA	83	98	17	47	62	28
Fluoranthene	19	39	69	240	230	4	160	200	22
Pyrene	18	33	59	240	230	4	160	200	22
Benzo(a)anthracene	<5	10	67	91	89	2	50	73	37
Chrysene	9	20	76	130	150	14	77	100	26
Benzo(b/k)fluoranthene	10	21	71	100	120	18	66	81	20
Benzo(e)pyrene	12	29	83	77	86	11	53	69	26
Benzo(a)pyrene	7	24	110	35	37	6	23	28	20
Perylene	<5	<5	NA	9	10	11	6	8	29
Indeno(1,2,3-cd)pyrene	<5	5	0	14	13	7	11	11	0
Dibenz(a,h)anthracene	<5	<5	NA	8	7	13	6	7	15
Benzo(g,h,i)perylene	<5	8	46	19	20	5	15	16	6

NA = Not applicable. Both results were below detection levels and percent difference could not be calculated.

Table 6. Triplicate analyses of NIST certified mussel tissue. All results are reported on a wet weight (ug/Kg) basis.

	Certified Values				
Parameter	Mean	95% Confidence Interval of Reported Values	Mean	Standard Deviation	Range
Phenanthrene	5.6	±1.4	5.5	0.6	(4.9-6.0)
Anthracene	0.75	±0.21	1.1	0.3	(0.9-1.4)
Fluoranthene	33.6	±5.8	37.8	3.6	(34.5-41.6)
Pyrene	34.1	±3.7	37.0	3.3	(33.4-39.8)
Perylene	1.05	±0.29	1.6	0.9	(1.1-2.7)
Benzo(b/k)fluoranthene*	6.5	±1.2	12.2	0.7	(11.4-12.8)
Benzo(a)pyrene	2.29	±0.47	3.2	0.6	(2.7-3.9)
Benzo(g,h,i)perylene	2.47	±0.28	2.6	0.2	(2.4-2.8)
Indeno(1,2,3-cd)pyrene	1.8	±0.33	1.5	0.5	(0.9-1.8)

*The reference value applies to the concentration of benzo(b)fluoranthene only. In the triplicate analyses, benzo(b/k)fluoranthene co-eluted.

Table 7. Polynuclear aromatic hydrocarbon (ug/Kg dry weight) concentrations in mussels exposed at the three stations.

	Gloucester										Discovery					Deer Island							
	June					August					August					Shallow				Deep			
LABORATORY ID:	143626	143627	143628	143629	143630	143631	143632	143633	143634	143635	143739	142740*	143741	143742	143743	143957	143958	143959	143960	143961	143962	143963	143964
Parameter																							
Naphthalene	36	35	77	14	37	10	9	13	21	15	19	79	24	15	34	13	20	32	24	10	12	13	11
2Methylnaphthalene	20	11	18	<5	13	6	5	7	12	7	14	66	16	10	18	55	95	130	120	31	36	37	35
1Methylnaphthalene	6	<5	8	<5	5	<5	<5	<5	7	<5	<10	36	11	<10	13	30	50	68	62	17	20	20	19
1,1'Biphenyl	<5	<5	5	<5	<5	<5	<5	<5	6	<5	<10	20	<10	<10	<10	7	11	17	15	5	7	7	5
2,6Dimethylnaphthalene	6	<5	7	<5	<5	<5	<5	<5	6	<5	16	42	12	<10	19	93	180	130	170	58	67	55	57
Acenaphthylene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<10	<10	<10	<10	<10	<5	<5	<5	<5	<5	<5	<5	<5
Acenaphthene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	26	31	22	25	26	7	13	10	18	6	7	6	6
2,3,5Trimethylnaphthalene	6	<5	9	<5	<5	<5	<5	<5	<5	<5	26	210	31	20	25	100	200	130	190	73	77	68	68
Fluorene	6	<5	<5	<5	<5	<5	<5	<5	<5	<5	17	100	18	<10	16	18	34	23	35	14	17	13	11
Phenanthrene	23	7	13	<5	8	<5	<5	6	12	8	35	520	43	29	30	54	100	95	90	39	48	41	37
Anthracene	7	<5	<5	<5	<5	<5	<5	<5	<5	<5	20	100	23	19	15	10	19	19	16	9	9	10	8
1Methylphenanthrene	6	<5	7	<5	<5	<5	<5	<5	<5	<5	39	290	45	30	35	55	110	83	84	35	47	44	39
Total of 2 & 3 ring groups	131	98	164	69	103	66	64	71	94	75	242	1504	265	198	251	447	837	742	829	302	352	319	301
Fluoranthene	20	12	22	<5	20	19	19	28	41	36	770	840	870	670	550	130	230	240	200	130	160	150	130
Pyrene	27	9	21	<5	18	18	18	26	38	42	710	910	810	620	520	130	230	240	200	130	160	160	130
Benzo(a)anthracene	17	<5	6	<5	7	<5	<5	8	10	9	130	110	160	110	100	49	100	91	78	36	50	51	39
Chrysene	21	7	14	<5	13	9	9	16	19	19	320	290	370	270	270	77	140	130	100	68	77	75	62
Benzo(b/k)fluoranthene	20	7	13	<5	9	10	12	18	24	20	210	220	270	180	190	62	120	100	83	46	66	59	44
Benzo(e)pyrene	17	8	13	<5	12	12	12	20	31	30	170	180	210	150	150	46	86	77	66	42	53	51	45
Benzo(a)pyrene	20	6	11	<5	10	7	7	13	25	27	45	59	65	48	45	21	37	35	29	15	23	19	17
Perylene	<5	<5	<5	<5	<5	<5	<5	<5	6	<5	16	20	17	12	15	7	21	9	8	<5	6	5	<5
Indeno(1,2,3-cd)pyrene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	19	26	26	20	22	9	14	14	12	7	11	8	6
Dibenz(a,h)anthracene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<10	12	12	10	<10	<5	7	8	7	<5	6	<5	<5
Benzo(g,h,i)perylene	6	<5	6	<5	<5	<5	<5	7	7	8	33	53	44	34	35	12	21	19	17	12	15	13	10
Total of 4, 5 & 6 ring groups	163	74	121	55	109	100	102	151	212	206	2433	2720	2854	2124	1907	548	1006	963	800	496	627	596	493
Total PAH's	294	172	285	124	212	166	166	222	306	281	2675	4224	3119	2322	2158	995	1843	1705	1629	798	979	915	794

* Sample was believed to be contaminated in the laboratory.

Table 8. Percent recovery for matrix spike analyses conducted for selected pesticides. Samples were spiked with pesticides at different concentrations. The matrix spike concentrations for samples 143632, 143959, and 143962 were 0.79 ug/Kg, 16 ug/Kg and 18 ug/Kg, respectively.

Laboratory ID: Parameter	143632MS	143632MSD	143959MS	143959MSD	143962MS	143962MSD
Hexachlorobenzene	230	0	117	117	137	137
Lindane (gamma-BHC)	142	142	118	118	111	111
Heptachlor	151	151	146	146	146	146
Aldrin	146	146	140	140	145	145
Heptachlor Epoxide	361	361	100	100	122	122
alpha-chlordane	314	196	54	78	116	146
trans-nonachlor	644	201	93	107	123	144
Dieldrin	590	216	80	73	87	89
2,4'-DDE	285	89	95	95	66	66
4,4'-DDE	1132	410	124	131	111	73
2,4'-DDD	662	101	79	91	123	140
4,4'-DDD	1346	674	89	88	140	185
2,4'-DDT	221	221	112	101	100	110
Mirex	127	127	107	107	107	107
4,4'-DDT	173	149	78	97	134	144

143632MS - The reported recoveries are based on the results from sample analyses 143632MS and 143632.
143632MSD - The reported recoveries are based on the results from sample analyses 143632MS and 143632D1.
143959MS - The reported recoveries are based on the results from sample analyses 143959MS and 143959.
143959MSD - The reported recoveries are based on the results from sample analyses 143959MS and 143959D1.
143962MS - The reported recoveries are based on the results from sample analyses 143962MS and 143962.
143962MSD - The reported recoveries are based on the results from sample analyses 143962MS and 143962D1.

Table 9. Duplicate analyses conducted for individual pesticides. When one sample was below detection level, percent differences were calculated assuming the concentration was at detection level.

Laboratory ID: Parameter	143632	143632D1	%	143959	143959D1	%	143962	143962D1	%
Hexachlorobenzene	<2.1	3.8	58	<6.0	<1.5	NA	<3.2	<2.6	NA
Lindane (gamma-BHC)	<2.1	<2.3	NA	<6.0	<1.5	NA	<3.2	<2.6	NA
Heptachlor	<2.1	<2.3	NA	<6.0	<1.5	NA	<3.2	<2.6	NA
Aldrin	<2.1	<2.3	NA	<6.0	<1.5	NA	<3.2	<2.6	NA
Heptachlor Epoxide	<1.9	<1.9	NA	<4.0	<1.1	NA	<2.6	<2.0	NA
alpha-chlordane	1.8	2.8	43	14	9.5	38	17	12	34
trans-nonachlor	<1.9	3.5	59	11	8.4	27	15	11	31
Dieldrin	<1.9	2.9	42	2.6	4	42	4.4	4.1	7
2,4'-DDE	<1.9	1.5	24	<4.0	<1.1	NA	<2.6	<2.0	NA
4,4'-DDE	5.4	11	68	20	19	5	20	26	26
2,4'-DDD	<1.9	4.4	79	7.8	5.6	33	9.8	7.2	31
4,4'-DDD	6.7	12	57	16	16	0	29	21	32
2,4'-DDT	<1.9	<1.9	NA	3	5.1	52	6	4.4	31
Mirex	<1.8	<1.9	NA	<3.7	<1.0	NA	<2.6	<2.0	NA
4,4'-DDT	1.9	2.1	5	8.4	4.8	55	6.7	5.0	29

NA = Not applicable. Both results were below detection levels and percent difference could not be calculated.

Table 10. Pesticide (ug/Kg dry weight) concentrations in mussels exposed at the three stations.

	Gloucester										Discovery					Deer Island							
	June					August					August					Shallow				Deep			
Laboratory ID:	143626	143627	143628	143629	143630	143631	143632	143633	143634	143635	143739	143740	143741	143742	143743	143957	143958	143959	143960	143961	143962	143963	143964
Parameter																							
Hexachlorobenzene	<1.2	<1.4	<2.5	<1.2	<1.3	<1.7	<2.1	2.0	<2.7	<2.5	<2.9	<3.1	<2.8	<2.1	<5.1	<1.6	<1.7	<6.0	<2.1	<2.0	<3.2	<1.5	<1.5
Lindane (gamma-BHC)	<1.2	<1.4	<2.5	<1.2	<1.3	<1.7	<2.1	<1.8	<2.7	<2.5	<2.9	<3.1	<2.8	<2.1	<5.1	<1.6	<1.7	<6.0	<2.1	<2.0	<3.2	<1.5	<1.5
Heptachlor	<1.2	<1.4	<2.5	<1.2	<1.3	<1.7	<2.1	<1.8	<2.7	<2.5	<2.9	3.3	<2.8	<2.1	<5.1	<1.6	<1.7	<6.0	<2.1	<2.0	<3.2	<1.5	<1.5
Aldrin	<1.2	<1.4	<2.5	<1.2	<1.3	<1.7	<2.1	<1.8	<2.7	<2.5	<2.9	<3.1	<2.8	<2.1	<5.1	<1.6	<1.7	<6.0	<2.1	<2.0	<3.2	<1.5	<1.5
Heptachlor Epoxide	3.7	<1.2	<2.1	<1.0	<1.3	<1.6	<1.9	<1.5	<2.1	<2.0	3.9	<2.1	2.1	<1.6	<4.1	<1.1	<1.2	<4.0	<1.5	<1.6	<2.6	<1.1	<1.2
alpha-chlordane	3.7	1.7	<2.1	<1.0	3.3	1.8	1.8	2.4	3.7	2.7	22	19	23	16	15	6.5	11	14	8.6	9.8	17	8.0	7.6
trans-nonachlor	<1.2	<1.2	<2.1	<1.0	<1.3	<1.6	<1.9	<1.5	<2.1	<2.0	<2.3	<2.1	<2.2	<1.6	<4.1	5.4	8.5	11	8.4	8.4	15	7.5	7.3
Dieldrin	<1.2	<1.2	<2.1	<1.0	<1.3	<1.6	<1.9	<1.5	4.3	2.1	11	7.1	10	6.9	10	1.7	3.0	2.6	2.8	2.7	4.4	2.8	2.8
2,4'-DDE	<1.2	<1.2	<2.1	<1.0	2.7	<1.6	<1.9	<1.5	<2.1	<2.0	<2.3	<2.1	<2.2	<1.6	<4.1	<1.1	<1.2	<4.0	<1.5	<1.6	<2.6	<1.1	<1.2
4,4'-DDE	11	6.6	<2.1	1.2	9.3	5.3	5.4	6.2	13	10	35	17	32	19	13	10	19	20	16	18	20	18	15
2,4'-DDD	7.0	4.1	5.6	<1.0	7.3	4.9	<1.9	3.7	5.8	4.2	17	12	18	13	11	3.6	6.6	7.8	4.8	5.5	9.8	4.4	5.5
4,4'-DDD	16	12	15	1.9	16	7.3	6.7	11	16	12	56	38	60	43	35	8.5	17	16	14	16	29	11	15
2,4'-DDT	<1.2	<1.2	<2.1	<1.0	<1.3	<1.6	<1.9	<1.5	<2.1	<2.0	1.9	<2.1	<2.2	<1.6	<4.1	2.1	3.2	3.0	3.2	2.8	6.0	2.9	2.7
Mirex	<1.4	<1.4	<2.4	<0.98	<1.3	<1.6	<1.8	4.5	<2.2	<1.9	<2.2	<2.4	<2.1	<1.6	<4.0	<1.0	<1.1	<3.7	<1.7	<1.5	<2.6	<1.1	<1.1
4,4'DDT	3.2	<1.4	2.2	<0.98	2.8	1.6	1.9	1.9	<3.0	1.5	5.4	9.8	4.0	2.8	3.0	3.8	4.3	8.4	4.4	2.9	6.7	1.4	3.1
Dieldrin/Aldrin group	2.4	2.6	4.6	2.2	2.6	3.3	4.0	3.3	7.0	4.6	13.9	10.2	12.8	9.0	15.1	3.3	4.8	8.6	4.9	4.7	7.6	4.3	4.3
Chlordane group	9.8	5.5	8.8	4.2	7.2	6.7	7.7	7.2	10.6	9.2	31.1	26.5	30.1	21.3	28.3	14.6	22.5	35.0	20.6	21.8	37.8	18.1	17.6
DDD/DDE/DDT	39.6	26.5	29.1	7.1	39.4	22.3	19.7	25.8	42.0	31.7	118	81.0	118	81.0	70.2	29.1	51.3	59.2	43.9	46.8	74.1	38.8	42.5

Table 11. Percent recovery for matrix spike analyses conducted for selected polychlorinated biphenyls. The matrix spike concentrations for samples 143632, 143959, and 143962 were 3.1 ug/Kg, 18 ug/Kg and 16 ug/Kg, respectively.

Laboratory ID: Parameter	143632MS	143632MSD	143959MS	143959MSD	143962MS	143962MSD
CL2-PCB(8)	168	168	125	125	128	128
CL3-PCB(18)	212	212	109	93	35	40
CL3-PCB(28)	228	205	174	154	179	144
CL4-PCB(44)	264	166	158	167	135	120
CL4-PCB(52)	333	212	181	157	217	152
CL4-PCB(66)	255	192	153	123	135	92
CL4-PCB(77)	98	98	123	123	92	92
CL5-PCB(101)	306	186	187	144	204	135
CL5-PCB(105)	236	199	148	132	139	110
CL5-PCB(118)	373	223	166	140	180	116
CL6-PCB(153)	571	276	131	94	187	105
CL5-PCB(126)	156	156	138	119	102	102
CL6-PCB(128)	206	206	120	117	103	83
CL6-PCB(138)	445	246	124	95	208	123
CL7-PCB(170)	124	124	144	131	123	107
CL7-PCB(180)	186	186	167	144	100	94
CL7-PCB(187)	235	170	162	129	139	108
CL8-PCB(195)	119	119	121	121	113	113
CL9-PCB(206)	116	116	102	102	93	93
CL10-PCB(209)	128	128	103	103	99	99

143632MS - The reported recoveries are based on the results from sample analyses 143632MS and 143632.
143632MSD - The reported recoveries are based on the results from sample analyses 143632MS and 143632D1.
143959MS - The reported recoveries are based on the results from sample analyses 143959MS and 143959.
143959MSD - The reported recoveries are based on the results from sample analyses 143959MS and 143959D1.
143962MS - The reported recoveries are based on the results from sample analyses 143962MS and 143962.
143962MSD - The reported recoveries are based on the results from sample analyses 143962MS and 143962D1.

Table 12. Duplicate analyses conducted for polychlorinated biphenyls. When one sample was below detection level, percent differences were calculated assuming the concentration was at detection level.

Laboratory ID: Parameter	143632	143632D1	Percent Difference	143959	143959D1	Percent Difference	143962	143962D1	Percent Difference
CL2-PCB(8)	<2.1	<2.3	NA	<6.5	<1.5	NA	<3.2	<2.6	NA
CL3-PCB(18)	<2.1	<2.3	NA	<6.5	3	74	3.5	2.8	22
CL3-PCB(28)	<2.0	2.7	25	9.9	13	27	8.2	14	52
CL4-PCB(44)	<2.1	3.1	38	10	8.6	75	9.4	12	24
CL4-PCB(52)	3.2	7	75	18	22	20	12	23	63
CL4-PCB(66)	2.9	4.9	51	7.4	13	55	9.9	17	53
CL4-PCB(77)	<1.8	<1.8	NA	<4.0	<1.0	NA	<2.5	<2.0	NA
CL5-PCB(101)	5.2	9	54	24	32	29	26	37	35
CL5-PCB(105)	1.7	2.9	52	5.1	8.1	45	7.0	12	53
CL5-PCB(118)	5.8	10	53	19	24	23	22	32	37
CL6-PCB(153)	8.4	17	68	40	47	16	35	48	31
CL5-PCB(126)	<1.8	<1.8	NA	<4.1	3.5	16	<2.5	<2.2	NA
CL6-PCB(128)	<1.8	<1.8	NA	5.6	6.2	10	4.2	7.5	56
CL6-PCB(138)	6.3	12	62	31	37	18	27	41	41
CL7-PCB(170)	<1.8	<1.8	NA	<4.1	2.4	52	<2.5	2.5	0
CL7-PCB(180)	<1.8	<1.8	NA	9.1	13	35	14	15	7
CL7-PCB(187)	3.1	5.1	49	10	16	46	9.3	14	40
CL8-PCB(195)	<1.8	<1.8	NA	<4.1	<1.0	NA	<2.5	<2.2	NA
CL9-PCB(206)	<1.8	<1.8	NA	<4.1	<1.0	NA	<2.5	<2.2	NA
CL10-PCB(209)	<1.8	<1.8	NA	<4.1	<1.0	NA	<2.5	<2.2	NA

NA = Not applicable. Both results were below detection levels and percent difference could not be calculated.

Table 13. Polychlorinated biphenyl (ug/Kg dry weight) concentrations in mussels exposed at the three stations.

	Gloucester										Discovery					Deer Island							
	June					August					August					Shallow				Deep			
Laboratory ID:	143626	143627	143628	143629	143630	143631	143632	143633	143634	143635	143739	143740	143741	143742	143743	143957	143958	143959	143960	143961	143962	143963	143964
Parameter																							
CL2-PCB(8)	<1.2	<1.4	<2.6	<1.2	<1.3	<1.8	<2.1	<1.9	<2.8	<2.5	<3.0	<3.1	<2.8	<2.1	<5.2	<1.6	<1.8	<6.5	<2.2	<2.0	<3.2	<1.5	<1.5
CL3-PCB(18)	<1.2	<1.4	<2.6	<1.2	<1.3	<1.8	<2.1	<1.9	<2.8	<2.5	10	12	5.6	6.9	5.5	<1.6	4.2	<6.5	<2.2	4.5	3.5	4.8	5.5
CL3-PCB(28)	2.6	2.1	4.2	<1.2	2.3	2.0	<2.0	2.9	4.2	2.6	27	22	27	21	19	3.9	11	9.9	10	8.9	8.2	11	10
CL4-PCB(44)	<1.2	3.0	4.6	<1.2	2.2	<1.8	<2.1	2.7	3.9	2.7	32	25	33	23	23	2.4	5.5	10	9.2	8.1	9.4	8.5	8.4
CL4-PCB(52)	<1.2	5.6	10	<1.2	6.2	<1.8	3.2	5.3	6.3	4.1	<3.0	54	65	48	35	11	22	18	15	14	12	16	14
CL4-PCB(66)	7.1	4.2	6.4	<1.0	5.8	2.9	2.9	4.1	6.3	4.2	29	23	32	22	21	7.0	14	7.4	10	11	9.9	<1.0	9.8
CL4-PCB(77)	1.3	<1.2	<2.1	<1.0	<1.2	<1.6	<1.8	<1.4	<2.1	<1.9	<2.1	<2.2	<2.1	<1.6	<4.1	<1.1	<1.2	<4.0	<1.5	<1.5	<2.5	<1.0	<1.2
CL5-PCB(101)	12	8.5	14	3.1	11	5.5	5.2	7.2	12	9.2	79	73	97	82	63	19	29	24	21	30	26	27	24
CL5-PCB(105)	3.1	2.7	4.4	<1.0	2.9	<1.6	1.7	3.1	4.0	2.5	21	16	26	14	15	3.8	9.7	5.1	6.7	8.2	7.0	7.9	7.5
CL5-PCB(118)	11	7.7	12	<1.0	5.3	5.2	5.8	8.1	13	9.4	63	52	79	65	46	12	22	19	19	23	22	22	19
CL6-PCB(153)	16	10	16	1.9	14	7.8	8.4	13	19	16	76	68	94	81	59	29	48	40	37	40	35	37	30
CL5-PCB(126)	<1.3	<1.3	<2.3	<1.0	<1.3	<1.6	<1.8	<1.5	<2.1	<1.8	4.0	4.2	<4.1	4.3	<3.9	<1.1	<1.2	<4.1	<1.7	<1.5	<2.5	<1.0	2.4
CL6-PCB(128)	<1.3	<1.3	<2.3	<1.0	<1.3	<1.6	<1.8	2.0	<2.1	<1.8	10	12	11	11	7.2	2.7	5.0	5.6	4.8	4.6	4.2	4.8	4.3
CL6-PCB(138)	16	9.3	14	1.3	12	6.0	6.3	10	15	11	62	56	77	66	45	17.0	32	31	29	30	27	28	22
CL7-PCB(170)	1.9	<1.3	<2.3	<1.0	<1.3	<1.6	<1.8	<1.5	<2.1	<1.8	2.6	3.2	3.6	2.7	2.7	1.4	2.8	<4.1	2.1	1.7	<2.5	1.4	1.2
CL7-PCB(180)	6.3	1.7	<2.3	<1.0	1.9	<1.6	<1.8	<1.5	<2.1	<1.8	10	11	13	11	9.7	5.9	14	9.1	11	8.2	14	9.8	7.1
CL7-PCB(187)	6.0	3.6	5.3	<1.0	4.8	2.3	3.1	4.1	5.6	4.8	16	18	17	17	13	6.5	13	10	14	10	9.3	9.6	8.4
CL8-PCB(195)	<1.3	<1.3	<2.3	<1.0	<1.3	<1.6	<1.8	<1.5	<2.1	<1.8	<2.1	<2.3	<2.0	<1.6	<3.9	<1.1	<1.2	<4.1	<1.7	<1.5	<2.5	<1.0	<1.1
CL9-PCB(206)	<1.3	<1.3	<2.3	<1.0	<1.3	<1.6	<1.8	<1.5	<2.1	<1.8	<2.1	<2.3	<2.0	<1.6	<3.9	<1.1	<1.2	<4.1	<1.7	<1.5	<2.5	<1.0	<1.1
CL10-PCB(209)	<1.3	<1.3	<2.3	<1.0	<1.3	<1.6	<1.8	<1.5	<2.1	<1.8	<2.1	<2.3	<2.0	<1.6	<3.9	<1.1	<1.2	<4.1	<1.7	<1.5	<2.5	<1.0	<1.1
Total PCB's	95	70	114	24	80	53	59	77	112	86	456	462	595	483	389	130	240	227	202	212	206	195	180

Table 14. Percent recovery for matrix spike analyses conducted for lead, copper, and zinc.

Laboratory ID Parameter	143633MS	143960MS	143964MS
Lead	90.9	97.0	87.0
Copper	97.1	108	110
Zinc	156	116.2	116.2

143632MS - The reported recoveries are based on the results from sample analyses 143633MS and 143633.
143960MS - The reported recoveries are based on the results from sample analyses 143960MS and 143960.
143964MS - The reported recoveries are based on the results from sample analyses 143964MS and 143964.

Table 15. Duplicate analyses conducted for lead, copper, and zinc. Analytical results are reported on a mg/Kg dry weight basis.

Laboratory ID: Parameter	143633	143633D1	%	143960	143960D1	%	143964	143964D1	%
Lead	5.5	4.5	18.7	6.3	5.8	3.3	5.6	5.0	11.9
Copper	7.5	7.5	<0.1	8.2	9.1	10.7	8.2	8.3	0.7
Zinc	168	164	2.1	154	160	3.8	139	122	12.9

Table 16. Lead, copper, and zinc (mg/Kg dry weight) concentrations in mussels exposed at the three stations.

	Gloucester										Discovery					Deer Island								
	June					August					August					Shallow				Deep				
Laboratory ID:	143626	143627	143628	143629	143630	143631	143632	143633	143634	143635	143739	143740	143741	143742	143743	143957	143958	143959	143960	143961	143962	143963	143964
Parameter																							
Lead, Total	5.2	4.5	8.9	7.1	6.9	4.4	5.0	5.5	5.5	4.7	4.6	6.8	7.6	4.4	8.6	6.3	4.5	7.4	6.0	6.2	5.5	5.3	5.6
Copper, Total	7.4	7.3	10.7	10.0	8.7	7.0	7.9	7.5	7.0	7.5	11.2	13.5	12.2	10.2	16.6	11.5	9.0	9.9	8.2	9.5	10.3	7.4	8.2
Zinc, Total	144.0	134.0	174.0	158.0	131.0	156.0	189.0	168.0	165.0	189.0	162.0	230.0	230.0	176.0	301.0	169.0	123.0	135.0	154.0	143.0	151.0	129.0	139.0

Table 17. Average lead, copper, and zinc tissue concentrations in mussels exposed at the three stations.

Uncorrected Tissue Concentrations (mg/Kg dry weight)

	Gloucester		Discovery	Deer Island
	June	August	August	August
	(N=5)	(N=5)	(N=5)	(N=8)
Parameter	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Lead, total	6.5 (1.7)	5.0 (0.5)	6.4 (1.8)	5.9 (0.9)
Copper, total	8.8 (1.5)	7.4 (0.4)	12.7 (2.5)	9.3 (1.3)
Zinc, total	148 (18)	173 (15)	220 (55)	143 (15)

Tissue Concentrations (mg/Kg of non-gonadal tissue dry weight)[1]

	Gloucester		Discovery	Deer Island
	June	August	August	August
	(N=5)	(N=5)	(N=5)	(N=8)
Parameter	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Lead, total	8.1 (2.1)	6.5 (0.6)	9.0 (2.8)	8.5 (2.0)
Copper, total	10.9 (1.9)	9.5 (0.5)	18.0 (3.5)	12.4 (2.0)
Zinc, total	184 (22)	223 (19)	310 (77)	206 (22)

[1]Tissue concentrations were determined by dividing uncorrected tissue concentrations (averaged above) by average dry weight percentage of non-gonadal soft tissue. Note that the average non-gonadal tissue weight percentage was determined from 30 mussels examined for biological characteristics (Table 3) and are not the same mussels used for tissue concentration analyses.

Table 18. Comparison of 1987 and 1991 mussel bioaccumulation results. The 1987 metal and organic means were based on 20 and 3 analyses, respectively. The 1991 means were based on 4 analyses.

Parameter	1987 Study Deer Island Deployment* Mean (SD)	1991 Study Deer Island Shallow Deployment Mean (SD)
Total PAHs (ug/Kg)	2363 (236)	1543 (376)
Total PCBs (ug/Kg)	630 (264)	200 (49)
Total DDTs (ug/Kg)	62.6 (33.7)	45.9 (12.8)
Dieldrin (ug/Kg)	11.4 (3.9)	2.5 (0.6)
Alpha-chlordane (ug/Kg)	21.5 (5.6)	10.0 (3.2)
Trans-nonachlor (ug/Kg)	18.0 (3.7)	8.3 (2.3)
Lead (mg/Kg)	7.2 (2.0)	6.1 (1.2)
Copper (mg/Kg)	9.6 (1.9)	9.7 (1.4)
Zinc (mg/Kg)	171 (68.6)	145 (20.3)

*1987 organics measured after 30 days, all other parameters measured after 60 days.

Table 19. Comparison of selected polynuclear aromatic hydrocarbon concentrations (ug/Kg dry weight) found in Deer Island mussel samples in 1987 and 1991. The 1987 means were based upon 3 analyses while the 1991 means were based on 4 analyses.

Parameter	1987 Deer Island Deployment Mean (SD)	1991 Deer Island Shallow Deployment Mean (SD)
2methylnaphthalene	120 (30.1)	100 (33.4)
1methylnaphthalene	81 (3.5)	53 (16.8)
2,6dimethylnaphthalene	291 (56.6)	143 (39.9)
2,3,5trimethylnaphthalene	383 (37.2)	155 (48.0)
Phenanthrene	151 (26.5)	85 (20.9)
Fluoranthene	315 (68.6)	200 (49.7)
Pyrene	356 (95.5)	200 (49.7)
Benzo(a)anthracene	81 (9.2)	80 (22.2)
Chrysene	152 (6.6)	112 (28.7)
Benzo(b,k)fluoranthene	72 (59.0)	91 (24.7)
Benzo(e)pyrene	58 (9.2)	69 (17.2)

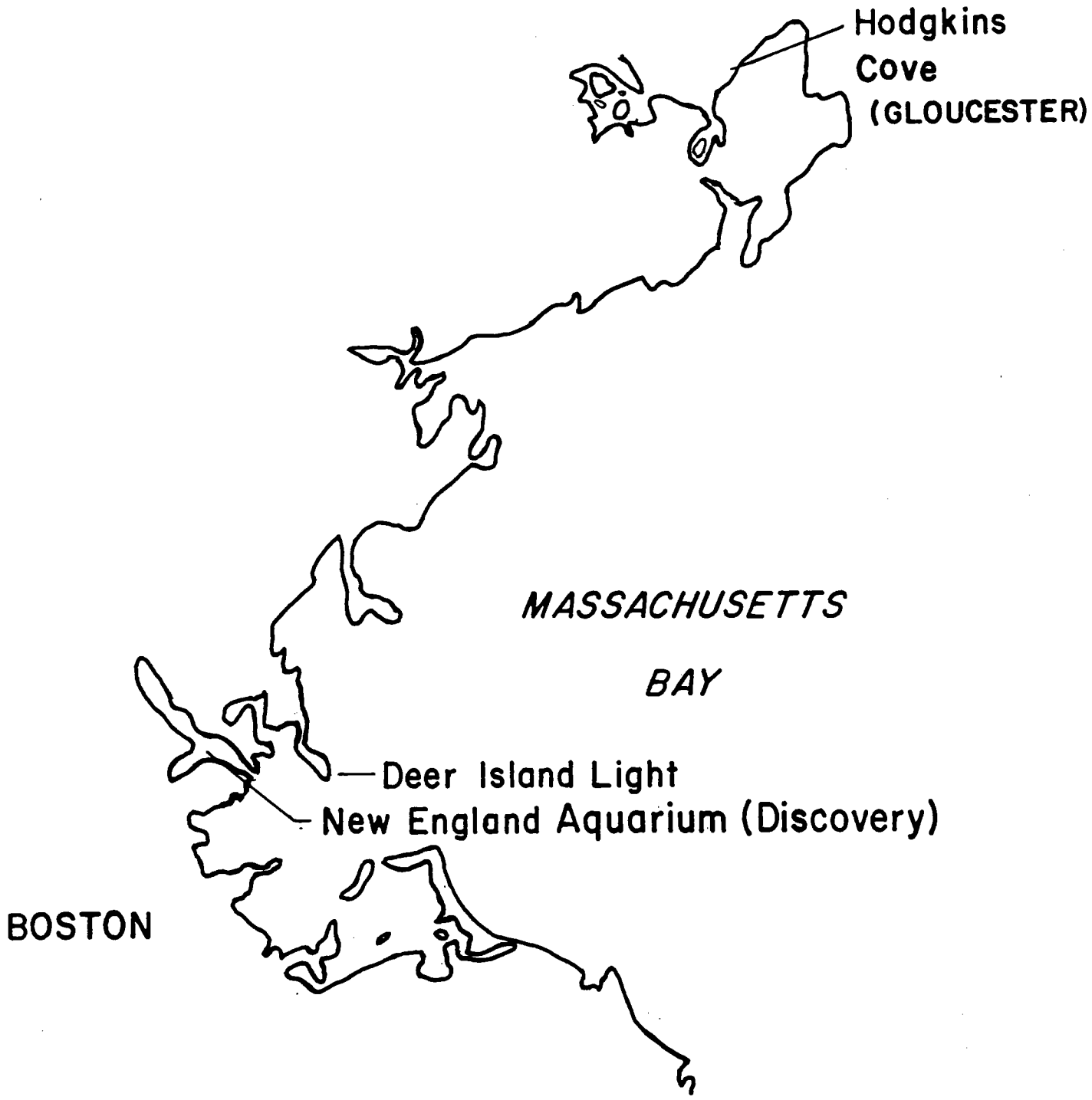

Figure 1. Location of mussel deployment areas for bioaccumulation study, 1991. Hodgkins Cove, source of mussels for study and control area; Deer Island light and New England Aquarium, exposed areas.

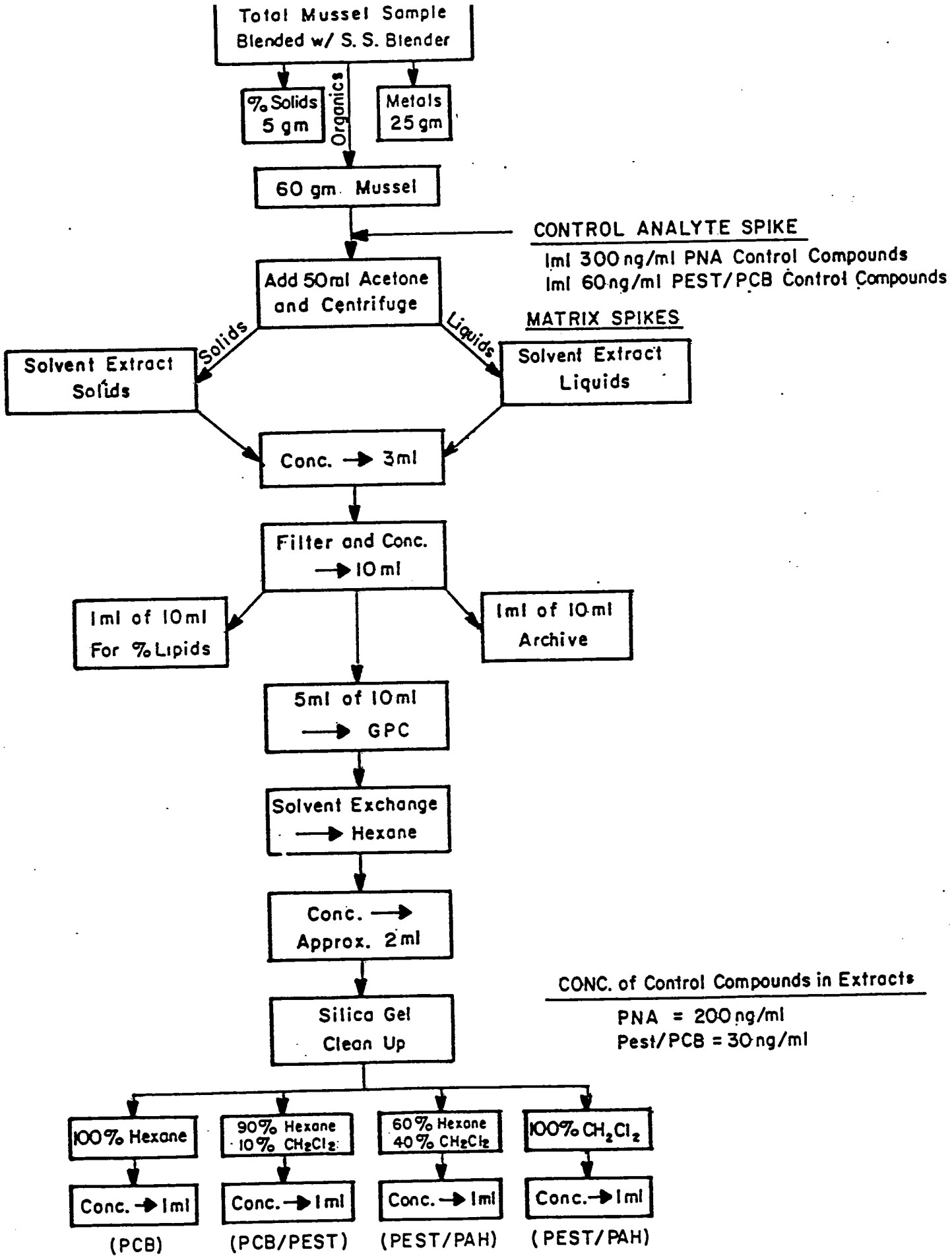

Figure 2. Extraction procedures and analytical methods for organic compounds.

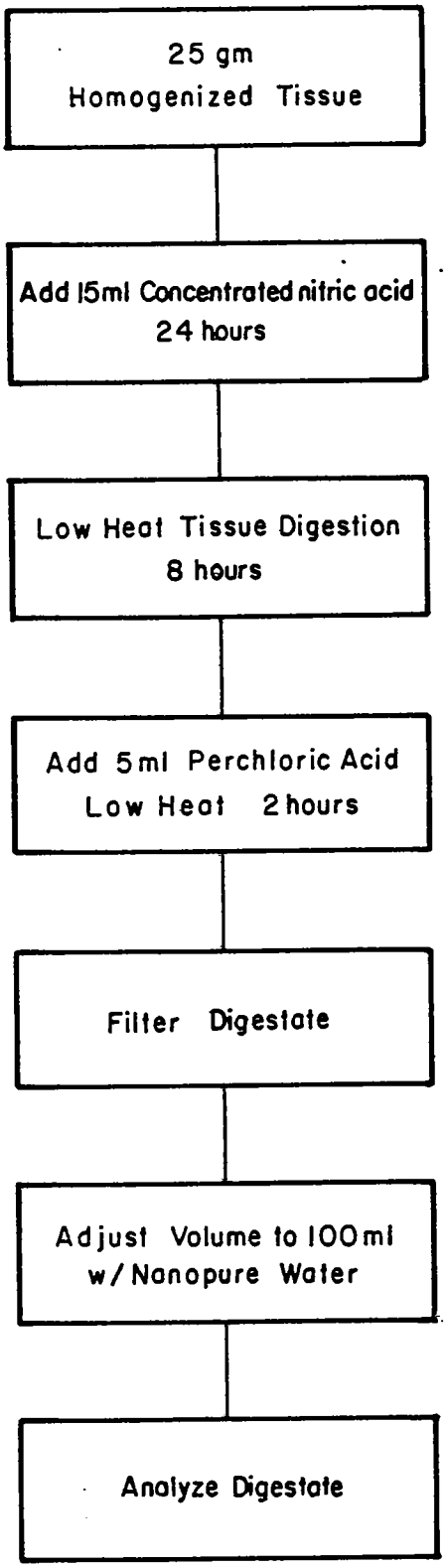

Figure 3. Methodology used for metal analysis of mussel tissues.

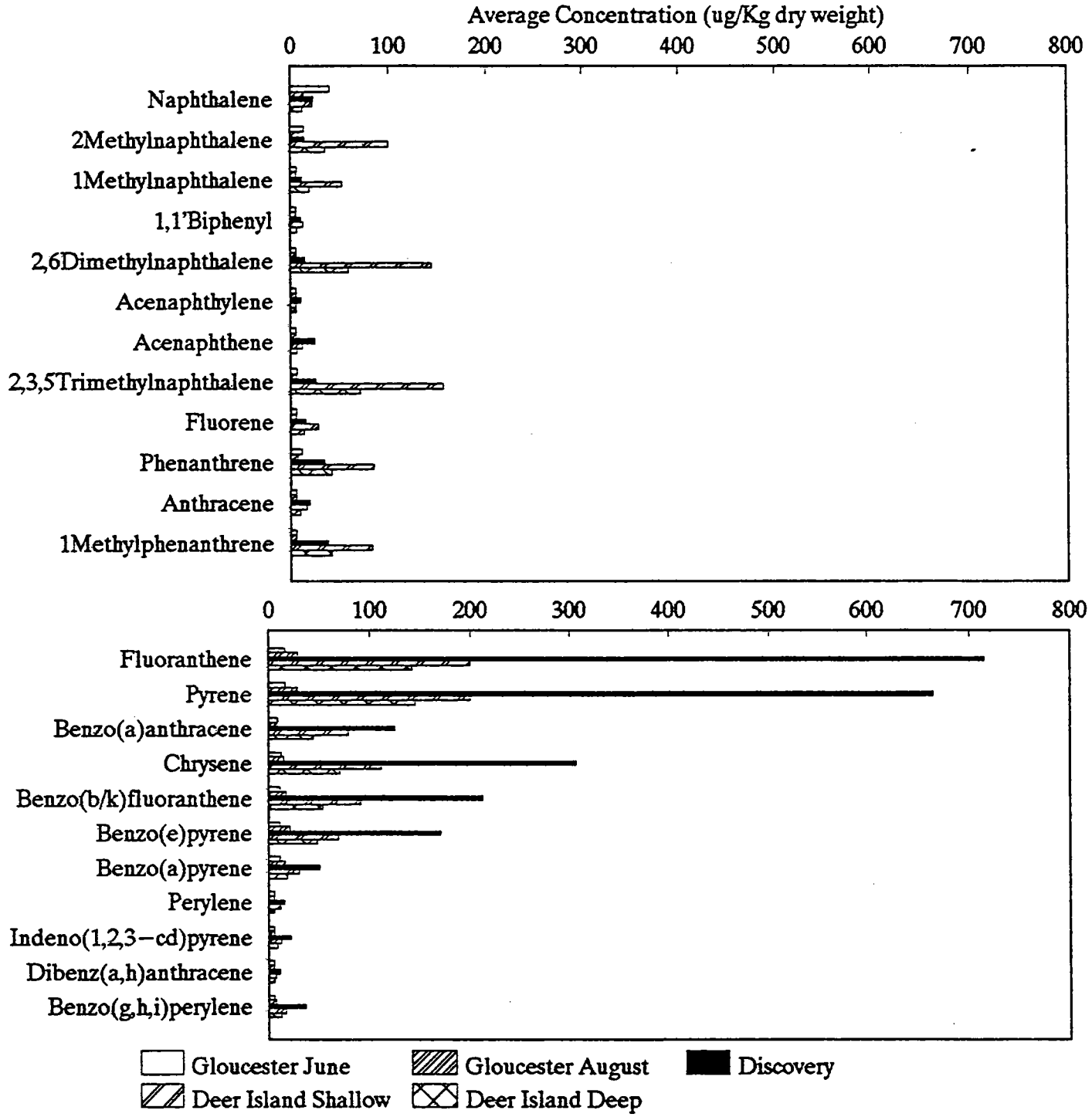

Figure 4. Average concentration of polynuclear aromatic hydrocarbons in mussel tissue collected from the three stations.

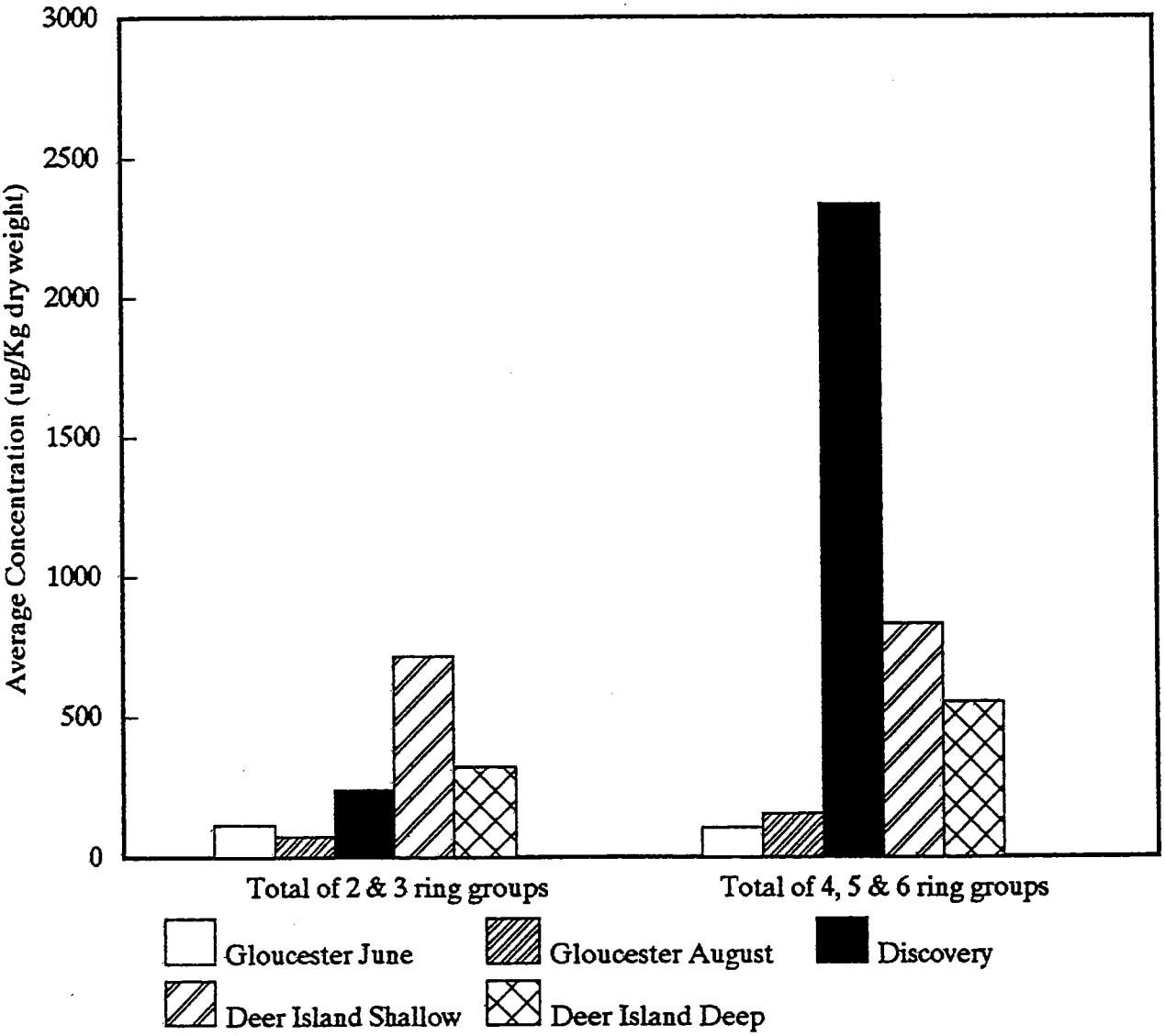

Figure 5. Average concentration of two groups (2 and 3 ring; 4, 5 and 6 ring) of polynuclear aromatic hydrocarbons in mussel tissue collected from the three stations.

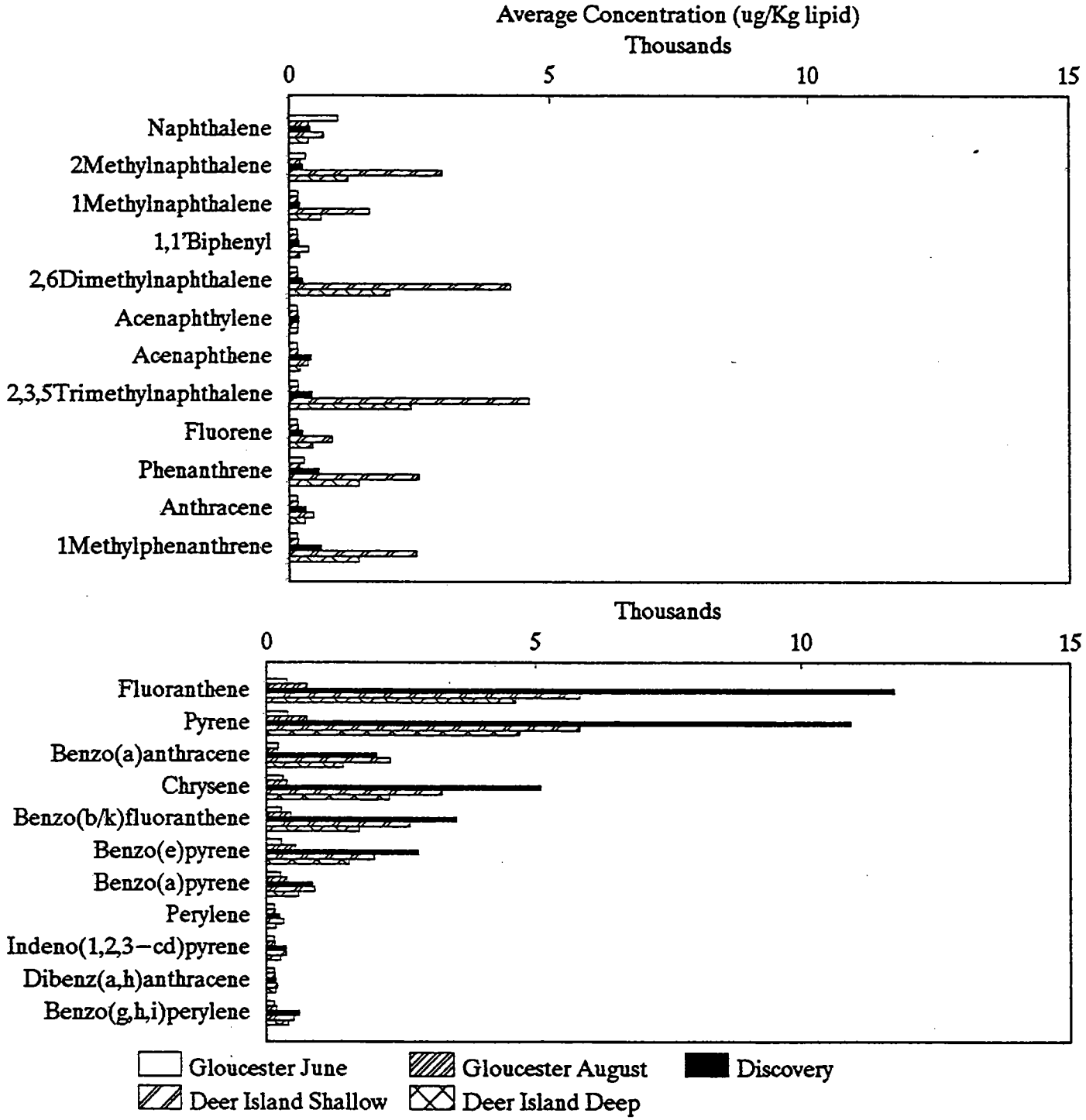

Figure 6. Average concentration (ug/Kg lipid) of polynuclear aromatic hydrocarbons in mussel tissue collected from the three stations.

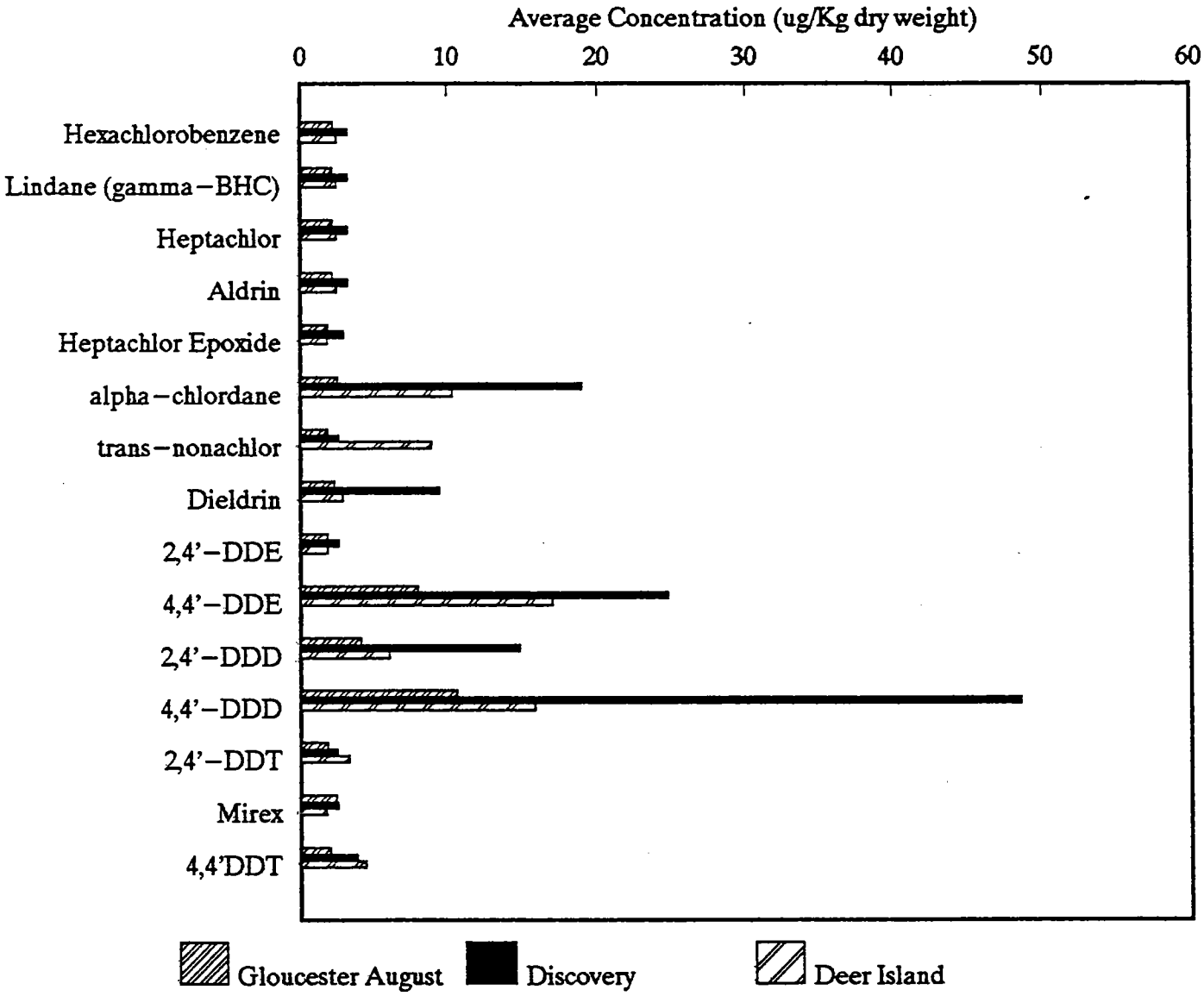

Figure 7. Average concentration of pesticides in mussel tissue collected from the three stations.

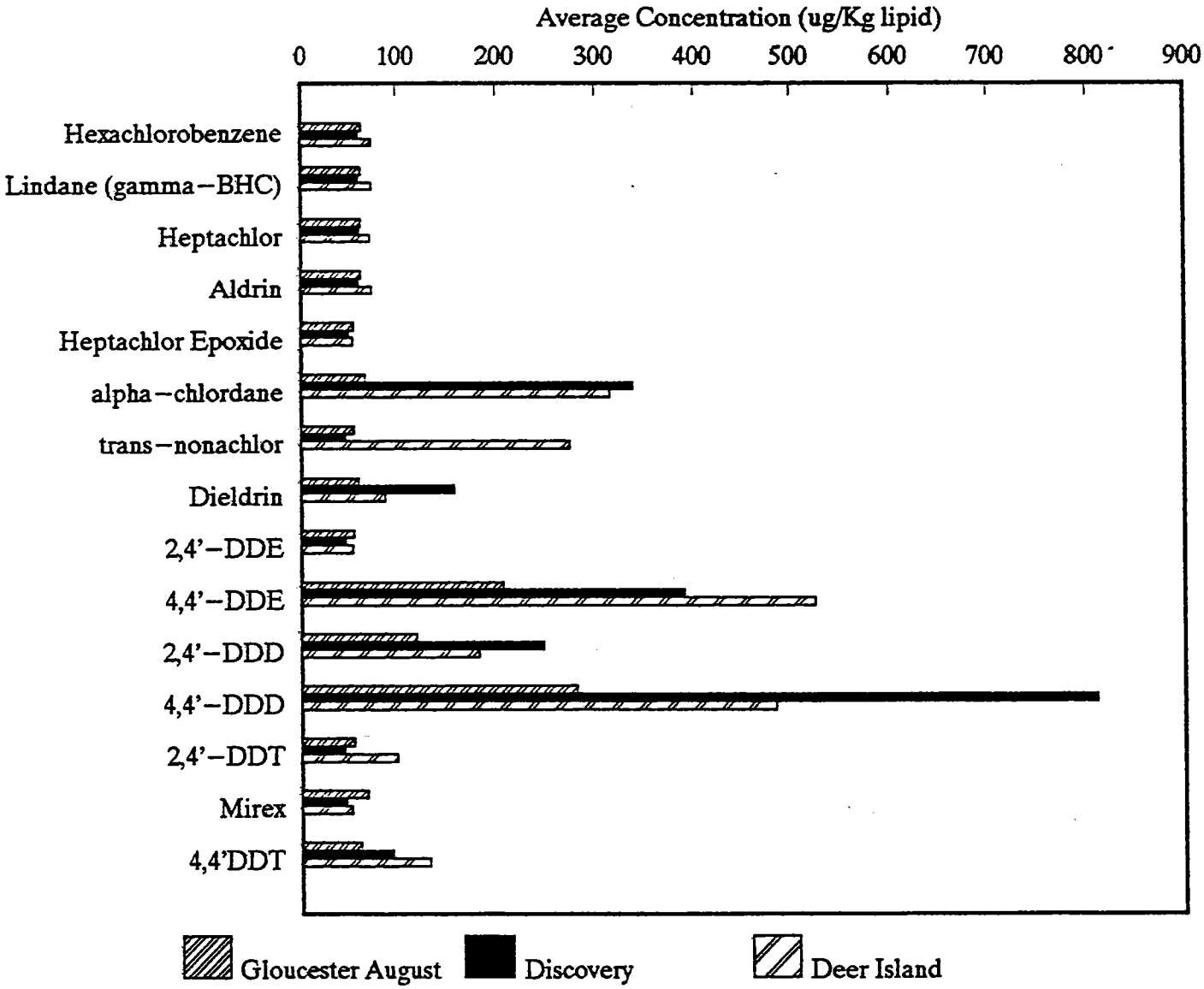

Figure 8. Average concentration (ug/Kg lipid) pesticides in mussel tissue collected from the three stations.

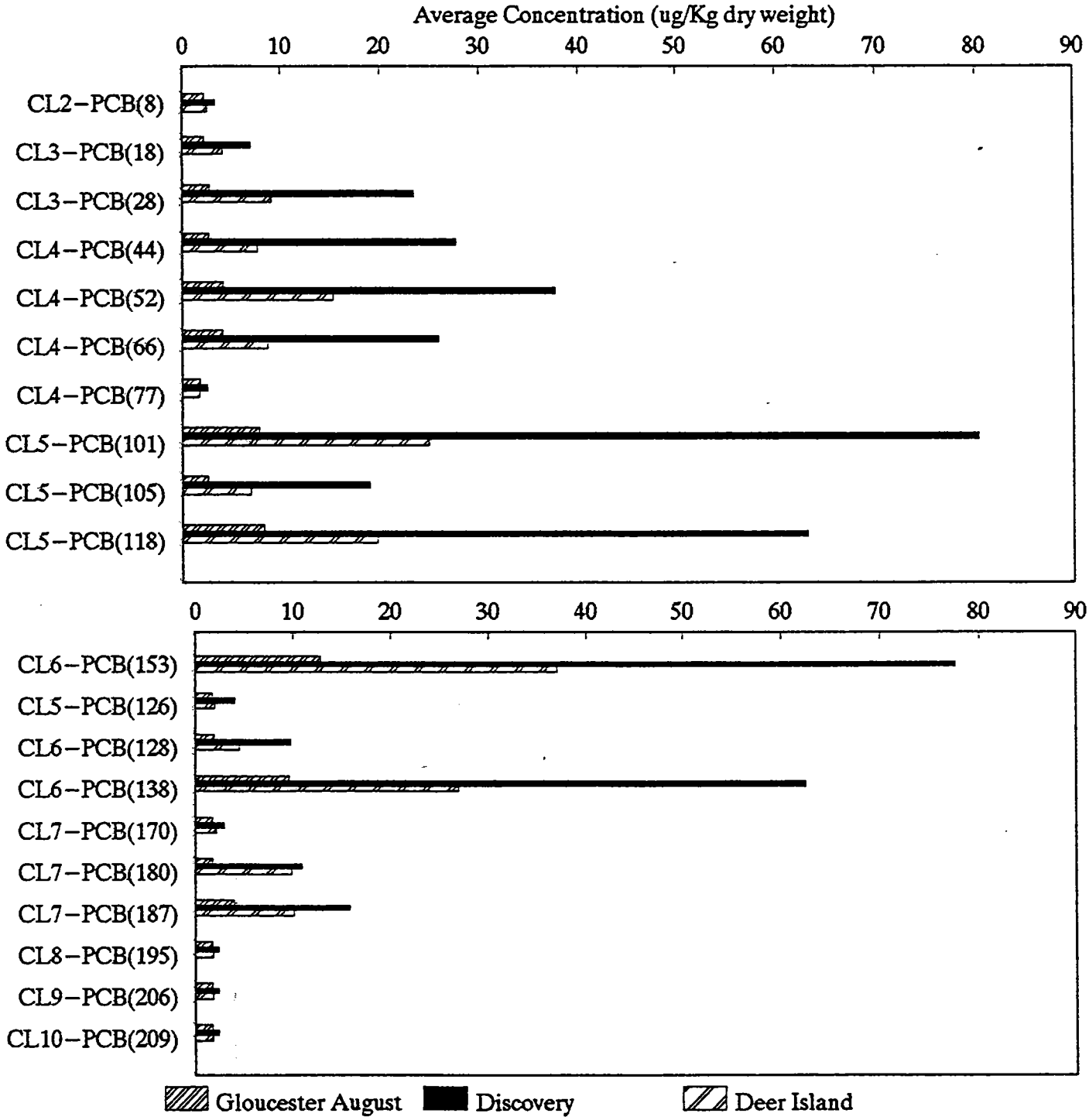

Figure 9. Average concentration of polychlorinated biphenyls in mussel tissue collected from the three stations.

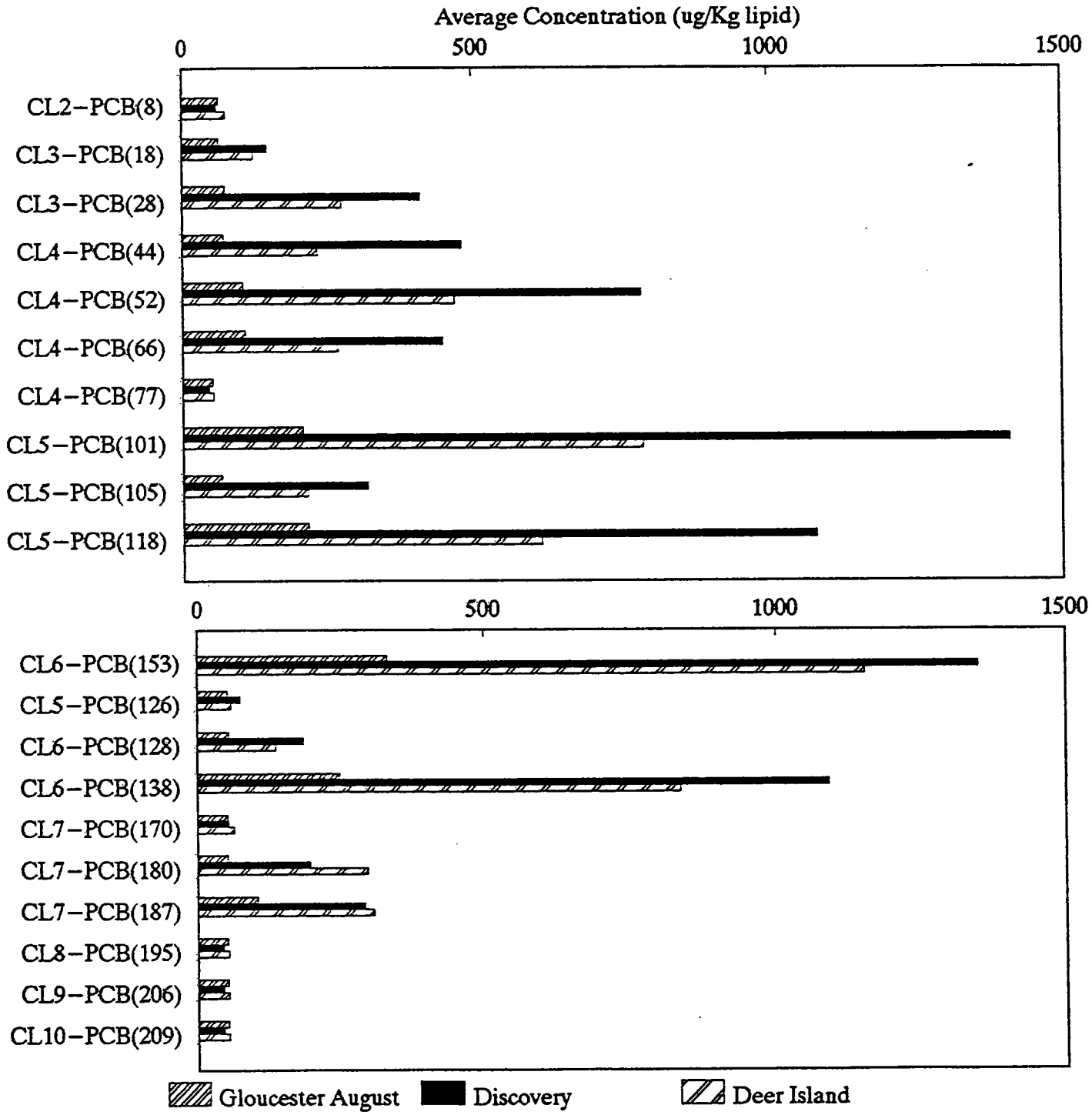

Figure 10. Average concentration (ug/Kg lipid) of polychlorinated biphenyls in mussel tissue collected from the three stations.

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