Bioaccumulation of selected organic compounds and metals in mussels deployed near Deer Island discharge and in Massachusetts Bay, 1993.

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Bioaccumulation of Selected Organic Compounds and Metals in Mussels Deployed Near Deer Island Discharge and in Massachusetts Bay, 1993

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EXECUTIVE SUMMARY

A mussel (Mytilus edulis) bioaccumulation study was conducted in 1993 for the Massachusetts Water Resources Authority (MWRA). This 1993 study was a continuation of a previous studies (Downey and Young 1992; Downey et al. 1993). The objectives of the 1993 study were to determine whether selected Polynuclear Aromatic Hydrocarbons (PAHs), pesticides, and Polychlorinated Biphenyls (PCBs) bioaccumulate in mussels deployed near the Deer Island Publicly Owned Treatment Works (POTW) and to obtain background data on uptake of target compounds by mussels deployed offshore near the projected new Deer Island outfall.

Mussels harvested from Hodgkins Cove (Gloucester) were deployed on June 25, 1993 at three locations: approximately 75 meters (m) east of the Deer Island Light; off the stern of the Discovery (New England Aquarium); and in the vicinity of the Large Navigation "B" Buoy (LNB) approximately nine miles offshore. The Discovery deployment was used as a 'dirty' control, the Deer Island was the 'test' location, and the LNB deployment was the 'background' station for assessment of contamination near the proposed new offshore outfall.

A random subsample (generally 30 mussels) of harvested mussels was selected from each array and used to determine the average shell length, average wet weight, the proportion of females and males present, sexual maturity, and two condition indices for each station. The remaining mussels from each array were used to make 10 mussel composite samples.

The 60-day harvested mussels examined for the stage of gametogenesis were also examined for abnormalities in the soft tissue. No lesions or parasites were observed on any of the mussels examined.

Although average shell length increased by 1.4-1.9 mm for mussels deployed for 60 days at the three stations, the differences were not statistically significant.

Average lipid percent composition of Discovery mussels was significantly less than the Gloucester and Large Navigation Buoy mussels.

No statistical differences in lipids were observed between Deer Island and Discovery mussels.

Average percent solids of mussels were highest in LNB mussels and lowest in Discovery mussels. Deer Island solids percentage was also significantly less than LNB mussels but significantly more than Discovery mussels.

Average total Polynuclear Aromatic Hydrocarbons (tPAH) tissue concentrations of 1321 ug/Kg dry weight in Discovery mussels were significantly higher than all other mussel deployment groups. Deer Island deployed average tPAH body burdens (665 ug/kg dry weight) were significantly greater than either Gloucester predeployment or LNB deployed mussels which averaged 188 ug/kg and 166 ug/kg, respectively. Although the LNB average tPAH body burdens were numerically lower than Gloucester predeployment body burdens, these differences were not significant.

As observed in previous years (1991-1992) the methylnaphthalenes (1-methylnaphthalene, 2-methylnaphthalene, 2,6-dimethylnaphthalene, and 2,3,5-trimethylnaphthalene) and 1-methylphenanthrene were typically found in Deer Island mussel tissue concentrations that were two to four times greater than Discovery mussels. In contrast to the low molecular weight PAHs (LMW-PAHs), the average high molecular weight (HMW-PAHs) were found in the highest tissue concentrations in the Discovery mussels.

There were several analytical difficulties encountered for pesticides (and PCB analyses) which confounded the quantification of tissue concentrations and subsequent data interpretation. The predeployment mussels suffered from significant analytical variability, particularly for several of the DDTs and DDT metabolites (i.e., DDD, DDEs). Due to the inherent difficulties of the Gloucester predeployment data set, this station's average mussel DDT body burden was not formally compared to other stations in this study.

Average alpha-chlordane body burdens were found at similar concentrations for Discovery mussels (10.5 ug/kg dry weight) and Deer Island mussels (8.2 ug/Kg dry weight). Mussels harvested from the LNB (3.8

ug/Kg dry weight) and Gloucester predeployment (2.9 ug/Kg dry weight) body burdens were found at significantly lower concentrations than either Deer Island and/or Discovery deployed mussels.

As noted above GC/ECD analytical difficulties confounded the Gloucester predeployment pesticide/PCB body burden evaluations. The CL4-PCB(52), CL5-PCB(101), CL5-PCB(118), CL5-PCB(138), and CL7-PCB(187) congeners appeared unusually high in the Gloucester predeployment mussels and may also have been affected by the analytical difficulties previously noted for DDTs. Consequently, the higher 1993 Gloucester predeployment body burdens are probably over estimated and comparisons to other stations and previous years mussel body burdens should be viewed with caution.

Two other congeners (CL4-PCB(66) and CL4-PCB(77)) were believed to have been the result of coelution of other (nontarget) organic compounds. These two reported (coeluted) PCB's concentrations were a major component of tPCB concentrations in mussels harvested from the three stations in 1993. As a result, the tPCB concentrations in all four stations' mussels were probably overestimated due to confounding effects of these two coeluted PCB congeners.

Of the twenty target individual PCB congeners, six congeners were found at or near the detection levels in mussels harvested after the 60-days deployment. Generally, the Discovery individual PCB congener concentrations were the highest observed (of those detected) from the four stations in 1993. Deer Island congener concentrations were routinely similar to or less than congener concentrations observed for Discovery mussels. Four of the PCB congeners (CL3-PCB(28), CL4-PCB(44), CL5-PCB(101) and CL6-PCB(138)) were detected in significantly higher concentrations in Deer Island mussels compared to Gloucester predeployment mussels. The LNB PCB body burdens were routinely less than mussels deployed at the other stations including Gloucester predeployment mussels.

The average Deer Island lead body burden (5880 ug/Kg dry weight) and average Gloucester predeployment mussel lead body burden (5120 ug/Kg dry weight) were similar. Mussels harvested from LNB had an average lead body

burden of 3713 ug/Kg dry weight which was significantly less than either the Deer Island or Gloucester predeployment mussels.

Average Gloucester predeployment mercury body burden (394 ug/kg dry weight) were higher than the average Deer Island mussels body burden (183 ug/kg dry weight) and the average LNB mussels body burden (99 ug/kg dry weight). The average LNB mussel mercury body burdens was also significantly lower than the Deer Island mussels.

The 1993 relative spatial trends of mussel body burdens for the three stations were consistent with spatial trends reported for 1991 and 1992 mussels. Total LMW-PAHs were found in highest concentrations in Deer Island mussels with the methylnaphthalenes (2-methylnaphthalene, 1-methylnaphthalene, 2,6-dimethylnaphthalene, and 2,3,5-trimethylnaphthalene) tissue concentrations the highest in the Deer Island tissues. These higher concentrations in the Deer Island mussels during all three studies suggest by inference that the Deer Island effluent is a important source of these contaminants for mussels deployed at Deer Island Light. In contrast, the higher HMW-PAH body burdens in Discovery mussels suggest that there are other source(s) of HMW-PAHs that are within the Boston Harbor which are of importance for mussel bioaccumulation of HMW-PAHs with Boston Harbor.

The results of this study have qualitatively mimicked previous (1991 and 1992) studies. Generally tPAHs, LMW-PAHs, HMW-PAHs and tPCBs displayed a trend of lower tissue concentrations in Deer Island 1991-1993 mussels compared to 1987 tissue concentrations. Annual variability in these total PAHs, total PCBs, and pesticides as well as total pesticide tissue concentrations for 1991-1993 Deer Island mussels has not revealed any consistent trends during this three year period.

The 1991-1993 studies have also indicated the Deer Island effluent probably contributes LMW-PAHs for bioaccumulation in mussels in proximity to the Deer Island discharges. Cursory comparisons of the bioaccumulation patterns and Deer Island water quality analyses indicate that biomonitoring techniques provide a useful tool in monitoring Deer Island effluent water quality trends for target PAH compounds and presumably other compounds that may bioaccumulate.

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1.0 OVERVIEW

This 1993 bioaccumulation study was conducted for the Massachusetts Water Resources Authority (MWRA) as part of Inchcape Testing Services Aquatec Laboratories (Aquatec) 1993 contract (Number S147) with MWRA. The objective of this study was to use the mussel (Mytilus edulis) as a test organism to determine whether selected compounds bioaccumulate in the tissue of mussels deployed near the outfalls of Deer Island Publicly Owned Treatment Works (POTW). An additional objective of the 1993 study was to obtain background data on uptake of target compounds by mussels deployed offshore near the projected new Deer Island outfall.

Several studies examining the potential bioaccumulation of analytes in mussels have been conducted at the Deer Island POTW. One study conducted by the MWRA in 1987 (MWRA 1988) used caged mussels deployed at the outfalls for 30-60 days to assess mussel tissue concentrations of selected organic compounds and heavy metals. In addition to the Deer Island sampling location, the projected new offshore discharge location was also sampled as part of that study.

A bioaccumulation study near the Deer Island Light in the Zone of Initial Dilution (ZID), an area that is exposed to Deer Island POTW effluent, was conducted by Aquatec, Inc. (Downey and Young 1992) from June through August 1991 with biological support provided by Marine Research Inc. (MRI, 1991). This study was designed to be generally comparable to the 1987 study conducted by MWRA. However, different analytical methodologies were used to attain lower detection limits in 1991 for organic compounds in mussel tissue.

The 1991 Aquatec study employed two 'control' locations: the stern of the vessel Discovery at the New England Aquarium; and at the Gloucester location in Hodgkins Cove on Cape Ann. The Discovery location served as the 'dirty' control with the mussel tissue analyses characterizing mussel exposure and bioaccumulation of target compounds in Boston's Inner Harbor. The Gloucester location served as the 'clean' control providing estimates of 'background' contaminant levels in mussel tissue. Mussels exposed at the Deer Island location were compared to mussels exposed at the two

control locations to glean apparent trends of target compounds in mussel tissue concentrations among mussels exposed at the three locations.

This study was continued in 1992 (Downey et al. 1993). The predeployment at Gloucester, Deer Island and Discovery locations and analytical methodologies were consistent with the 1991 study. However, mussels were deployed at the projected new offshore discharge location while the Gloucester location was used for mussel harvest only.

The current 1993 study was designed to mimic the 1991 and 1992 Aquatec studies and the 1987 MWRA study. Mussels were deployed at three locations in June 1993 with the Deer Island and Discovery locations again part of the 1993 study. The Large Navigation Buoy (LNB) near the site of the projected new offshore discharge, served as the third deployment site of this bioaccumulation study. This location was also used in the 1987 MWRA study and the 1992 Aquatec study. Tissue analyses were conducted using methods similar to those employed in 1991 and 1992.

2.0 METHODS

2.1 Mussel Collection

On June 24, 1993, approximately 940 mussels were collected for testing purposes from the University of Massachusetts' Research Station at Hodgkins Cove in Gloucester, Massachusetts (Table 1). This area was chosen because mussels from this location had been used in previous bioaccumulation studies: for the South Essex Sewage District (Camp, Dresser, and McKee, Inc. 1988), New Bedford, Massachusetts (MRI 1989) and the 1991 Deer Island study (Downey and Young 1992) and 1992 Deer Island Study (Downey, et al. 1993).

Mussels were harvested during low tide and each mussel individually checked for approximate total length. Mussels which fell into a nominal 55-65 mm range were retained for the study; mussels outside this range were returned to the beds. Of the approximate 940 mussels retained, 200 were randomly selected for measurement of total length. The total shell length (mm from umbo to distal gape) was measured with Vernier calipers to 0.1 mm to obtain an overall average size of the sample population (940 mussels) and to insure that the majority of the mussels fell within the desired length range. These mussels were then used along with the remaining mussels (740) and distributed to cages for deployment. Fifty (40 for LNB) mussels (both measured and unmeasured) were randomly distributed to each of 19 plastic cages (22.5cm x 22.5cm x 22.5cm) and submerged overnight in seawater by suspending the cages from the seawall adjacent to the Research Station. A subsample of 80 mussels was transported unfrozen on ice to Aquatec on June 25, 1993, for initial biological (total length, sex and sexual maturity, and tissue weights) and chemical analyses.

2.2 Mussel Deployment

On June 25, 1993, mussels in cages were deployed from Aquatec's 25' Research Vessel "Profile" at the following three sites (Figure 1):

1) Deer Island Light: located approximately 75 meters east of the navigation light and within the ZID of the Deer Island POTW effluent discharge outfalls. This site was the "target" study area for detection of potential contaminant bioaccumulation attributable to the Deer Island POTW.

2) The stern of the vessel "Discovery": located at the New England Aquarium, Boston Inner Harbor. This site served as "dirty" control to evaluate the extent of ambient contamination in Boston Inner Harbor.

3) Large Navigation Buoy: (LNB) located approximately one nautical mile (NM) south of the projected MWRA offshore discharge installation. This LNB site provided predischarge baseline data.

At the Deer Island Light each deployment array consisted of two replicate cages containing 50 mussels each for a total of 100 mussels per array. Both cages were attached to polypropylene line with nylon cable ties. Steel mooring weights and subsurface buoys were used to stabilize the location of each array in the water column. Deployment positions were documented using on-board Loran-C readings in latitude and longitude.

On June 25, 1993, three arrays were transported to an area east of the Deer Island Light. Each array consisted of a mooring and suspension system with about 100 Kg of weight and a 25 cm diameter Styrofoam subsurface buoy tethered to the anchor with polypropylene rope. About 75m length of polypropylene line tethered each array anchor to the riprap surrounding the light to facilitate later retrieval. The arrays at Deer Island were deployed in about 4-6 meters mean low water (MLW) approximately 75 meters east of Deer Island Light. On all arrays the subsurface buoy was located about 3 meters from the bottom and the two cages per array were fastened about 1 meter below the buoy (cage depth approximately 2 m from bottom).

A deployment array at the Discovery Station also consisted of two replicate cages containing 50 mussels per cage. On June 25, 1993, four cages (200 mussels) were suspended on a nylon line from the stern of Discovery (New England Aquarium) vessel. The four cages were attached in pairs (0.2m between pairs) with each pair considered to be a deployment array. The arrays were arranged approximately 2-2.5 meters from the bottom at a depth of 7-9 meters. This line was anchored with approximately 25 Kg of weight and tied off of the stern of the Discovery vessel.

The deployment array at the LNB Station consisted of three replicate cages containing 40 mussels per cage. On June 25, 1993, one array (3 cages per array) was deployed near the LNB using a mooring and suspension system in conjunction with a hydroacoustic release. The release array consisted

of a 30 cm diameter Styrofoam subsurface buoy tethered with nylon rope to one end of the release and anchored with approximately 100 Kg of weight. The cages, attached to the nylon rope between the buoy and the release, were approximately 2 meters below the subsurface buoy. When deployed, the cages were positioned approximately 13-14 meters below the surface.

The other two LNB arrays without a hydroacoustic release were deployed in the same manner as the hydroacoustic array. A 13 cm diameter Styrofoam surface (pot) buoy was tied to a subsurface 30 cm diameter buoy which was deployed about 13 meters below the surface. The pot buoy was allowed to float freely at the surface. The location and water depths for each array at the LNB was as follows:

	Corrected Latitude	Corrected Longitude	Total Water Depth (m)	Estimated Cage Depth (m)
Acoustic Array	42° 22.67'N	70° 46.86'W	34	13-14
Surface Buoy	42° 22.67'N	70° 46.89'W	33	13-14
Surface Buoy	42° 22.66'N	70° 46.84'W	33	13-14

2.3 Mussel Retrieval

On August 3, 1993, one array (120 mussels) was collected from the LNB (surface buoy array), Discovery (100 mussels) and Deer Island light (100 mussels). Exposure time was 40 days for all stations. Mussels were checked in the field for survival, frozen, and stored for future analyses. These mussels were not used during the remainder of the study.

The sixty-day harvest of mussels occurred on August 24, 1993, from the three stations. One array, approximately 100 mussels, was recovered from Deer Island Light. One array (two cages) at Deer Island was lost. At Discovery, one array approximately 100 mussels, was recovered while two arrays, about 240 mussels, were recovered from the LNB. Random subsamples of mussels were obtained for biological and chemical analyses. Mussels for chemical and biological analyses were stored separately in labeled plastic bags in coolers and kept cold during transport. On August 24, 1993, all mussels were transported on ice to Aquatec and stored frozen (for chemical analyses) or refrigerated (for biological analyses).

2.4 Biological Analyses

For biological analyses, a random subsample of 30 mussels was selected from the predeployment mussels and from each of the three stations 60-day collection. Mussels for biological analyses were processed to obtain total shell length, total wet weight and reproductive condition.

In the laboratory, each mussel was cleaned of attached material (barnacles, byssal threads, etc.). If the shell surface was muddy, the mussel was rinsed with deionized water. The total shell length (umbo to distal portion of valve gape) was measured with a Vernier caliper (to the nearest 0.1mm). The total soft tissue, gonadal tissue, and the non-gonadal tissue weights were measured on an electronic balance to the nearest 0.01g wet weight.

Each mussel was opened by slicing the adductor muscles between the valves with a microtome blade. The gill tissue was drawn back to expose the gonad. A small aliquot of macerated gonad tissue was transferred to a slide and examined under a compound microscope for the sex and sexual maturity. Sexually mature males were identified by sperm motility and immature males by lack of sperm motility. Sexually mature females were identified by presence of eggs with a diameter greater than 60 microns; otherwise the female mussel was identified as an immature.

2.5 Chemical Analyses

A random subsample of mussels (50-80 depending on the station) was selected from the predeployment mussels and from each of the three stations 60-day mussel harvest. Replicate chemical analysis sample contained a composite of ten mussels. Mussel composite samples were prepared for low-level organic and metal analyses by dissection of each of the 10 mussels using disposable Teflon-coated stainless steel blades rinsed with methanol and deionized water prior to use. Each individual mussel was rinsed with deionized water and the shell surface was scrubbed to remove attached material. Byssal threads were removed and all soft tissue including fluids were shucked directly into an amber 500-ml I-Chem Certified clean bottle. The ten mussel composite sample was then homogenized using a Brinkman Polytron 3000 with a titanium generator.

The tissues were refrozen and held until chemical extraction was initiated. The extraction and analytical procedures for organics generally followed National Status and Trends Methodologies (Figure 2). As in 1991 and 1992, tissues were analyzed for Polynuclear Aromatic Hydrocarbons (PAH) using Gas Chromatography/Mass Spectrometry (GC/MS), while pesticides and polychlorinated biphenyls (PCBs) were analyzed using Gas Chromatography/ Electron Capture Detection (GC/ECD).

Generally, internal standards were spiked into each sample prior to extraction to achieve a 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 of the internal standards (summarized in Appendixes C and D) were used for correction of the reported results for target analytes in the mussels. The polychlorinated biphenyls were referred to by level of chlorination followed by the BZ congener number designation in parenthesis.

Blank analyses, laboratory matrix spike (MS) and matrix spike duplicates (MD) were conducted routinely. For each type of analysis, at least two MS and MD analyses were conducted for approximately 10 percent quality control sampling. A sample of Standard Reference Material (SRM) (Organics in Mussel Tissue) obtained from the National Institute of Standards & Technology (NIST) as part of the interlaboratory comparison study was analyzed for polynuclear aromatic hydrocarbons as part of the project quality control program. Preliminary reports on laboratory results were summarized in Appendix C and are based upon our interpretation of

participating laboratory data. Lipid determinations were completed following the National Status and Trends Methodologies.

Tissue extraction for metals was completed following procedures depicted in Figure 3. Analyses of lead was completed using Graphite Furnace Atomic Absorption (Method 7421) while mercury was analyzed using cold vapor atomic absorption (Method 7471).

In the 1993 organic analyses, several analytical difficulties arose, particularly for the initial predeployment mussels harvested from Gloucester in June. Vials of extracts were sealed with faulty septa which resulted in drying of the samples for organic analyses. Although these samples were refilled with solvent and the PAH analysis conducted, the data were judged to be non-representative due to extremely low internal surrogate recoveries (around 1 percent). There were also several samples from three other stations which suffered from a lack of tissue available in the composite sample to complete all analyses (generally at least 90 g of mass was needed). Several of these samples were rerun (when adequate tissue mass was available), while other samples were created using extra mussels for ten mussel composites. These mussels were obtained from "backup" mussels which had been kept frozen since their respective 60-day harvest from the various Station locations. The re-extracted samples were designated with an "R" as a suffix for the laboratory number. The history of these analyses are summarized in Appendix C.

Initial examination of the pesticide and PCB data of the predeployment mussels composite samples did not detect significant data quality variations due to the septa problems. However, upon closer scrutiny, the analyses of the predeployment mussels became suspect. Analyses of the rerun samples (see above) did not contain internal surrogate spikes for pesticides and PCBs quantification, thus results were not reported (and corrected) for sample specific surrogate spike recoveries. These data are presented in Appendix D (Tables D1 and D2) and were used to make qualitative inferences regarding the predeployment mussel tissue pesticides and PCB concentrations.

Another variation encountered in 1993 was that the pesticides/PCB's column configuration differed from previous years (specifically 1991 and 1992). In 1993, the pesticide/PCB analyses were conducted with a two-capillary column arrangement using the RTx-5 and RTx-35 columns. Prior to 1993, the two capillary column arrangement consisted of RTx-5 and RTx-1701 columns. Initially, this difference was believed to be acceptable since these columns can be used interchangeably when analyzing samples following standard accepted practices (i.e., Method 8080 for analyses of water and wastewater). However, inspection of the results of this study (discussed below) suggest that changes in the two column configuration shifts retention time windows for at least some compounds. These probable shifts were most noticeable for 4,4'DDT and the PCB congeners CL4-PCB (66) and CL4-PCB (77).

Several of these samples which had reportedly high CL4-PCB (77) concentrations were reanalyzed by this column confirmation. The presence of the CL4-PCB (77) congener was not confirmed suggesting that the reported values reflected concentrations of other coeluting PCB congeners.

For these compounds, unexpectedly high tissue concentrations were found in many analyses which were believed to have been the result of coelution of other (probably nontarget) compounds. In addition to inflated tissue concentration estimates of these three compounds, the tDDTs and tPCBs tissue concentrations were likely biased high due to these reported coeluted compounds. Whenever possible, the potential confounding effects on the reported results, by this introduced analytical variation was taken into consideration when evaluating potential differences in pesticide and PCB concentrations of mussels harvested from the various stations.

Although the original experimental design stipulated specific numbers of samples at each station (see Table 1), the analytical issues encountered in 1993 resulted in additional tissue composite samples being analyzed and reported.

2.6 Statistical Analyses

Both parametric and nonparametric statistics were used for evaluation of the data. Biological measurements were analyzed using Analysis of

Variance (ANOVA) and t-tests 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 a 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 samples 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).

Tissue analyte concentrations were reported on a dry weight basis. Average calculations (used in both tables and figures) of PAHs, PCBs, and pesticides (i.e., sum of individual sample analytes) were determined using the detection limit value for the analyte as an estimated concentration for those analytes not detected. Lipid-adjusted average dry weight values for the PAHs, PCBs, and pesticides were normalized by dividing the dry weight tissue concentration by the sample-specific dry weight lipid mass. These lipid-adjusted average values were plotted for comparison among the stations.

Tissue analyte concentrations of metals were reported on a dry weight basis. Metal concentrations were also reported on a non-gonadal adjusted dry weight basis. Generally, it is believed that metal bioaccumulation in mussels occurs primarily in non-gonadal tissue and was adjusted as follows:

$$Me_{(NON)} = Me\ (TST/NGT)$$

where:

$Me_{(NON)}$ = non-gonadal metal concentration (ug/Kg dry weight)
Me = metal concentration (ug/Kg dry weight)
TST = total soft tissue mass (g) (from biological analysis)
NGT = non-gonadal tissue mass (g) (from biological analysis)

3.0 RESULTS

3.1 1993 Biological

3.1.1 Survival

On August 3, 1993, (40 days post-deployment) one array was harvested from each of the three locations. The cages were removed from the deployment moorings and mussels examined for gross abnormalities, apparent survival and fouling of the cages. No abnormalities were observed and survival was 100% at all stations (Table 2).

Fouling varied among locations after forty days. The LNB cages had light coelenterate and bryozoan growth. At the Discovery station, cages were moderately to extensively covered with slime with some occlusion of the spaces between the bars of the cage. Sea squirts were abundant on and within cages. The two Deer Island cages were moderately fouled with bryozoans and silt-like material. Mussels obtained from the three locations were harvested, enumerated, and stored frozen in the laboratory. Since the August 60-Day retrieval was successful, these mussels were not used further for biological or chemical analyses.

Mussels were harvested at the end of the 60-day exposure from the three locations on August 24, 1993. Mussel survival was very high for all three locations; 95 percent for Discovery mussels, 99 percent for LNB mussels and 100 percent of the Deer Island mussels (Table 2).

Cages retrieved from the LNB on August 24, 1993, were moderately coated with bryozoans and coelenterates predominantly attached to and covering the bars of the cage. With the exception of light bryozoan infestation of several mussel shells (estimated at less then 5 percent of the mussels) and several barnacles on the shells, fouling was judged to be moderate. Mussels were attached to each other within the cages by byssus threads. The overall health and condition of the mussels was excellent with no abnormalities, lesions, or parasites noted.

Deer Island cages were extensively covered with bryozoans and fine silt-like material. Mussels within the cages were also fouled with fine silt-like material. Barnacles present on several of the mussels (less than

10 percent) were believed to be predominantly carryover from incomplete removal during the initial harvest at Hodgkins Cove.

The Discovery cages exhibited extensive fouling - predominantly sea squirts which covered the cage bars. Silt-like material was also found on surfaces not occupied by the sea squirts including the shells of the mussels. Spaces between mussels also commonly contained large amounts of this silt-like material with accumulations of several millimeters on shells. Several mussels had barnacles attached to the shell, probably acquired prior to deployment.

3.1.2 Sexual Maturity

A representative sample of randomly selected mussels was examined from the four locations to determine the sex ratio and stage of gametogenesis of mussels (Table 2). Female gonads were generally orange in color while the males were more of a yellow color.

For the 30 mussels examined from Gloucester in June, all females (12) were mature while 15 of the 18 males were mature. All females obtained from Deer Island (19) and Discovery (10) on 24 August 1993 were mature while 22 out of 24 LNB female mussels were mature.

The 60-day harvested mussels examined for the stage of gametogenesis were also examined for abnormalities, such as lesions or parasites in the soft tissue. No lesions or parasites were observed on any of the mussels examined.

3.1.3 Growth and Condition

Although average shell length increased by 1.4-1.9 mm for mussels deployed at the three stations, these differences were not statistically significant ($P>0.05$) (Table 3). Mean shell wet weights were also non-significant among predeployment and 60-day mussels harvested from the three stations ($P>0.05$).

The average (both gonadal and non-gonadal measurements) soft tissue wet weights of Deer Island and LNB mussels were significantly larger than the predeployment and Discovery mussels ($P<0.05$). The Discovery average

gonadal tissue was significantly higher than the predeployment mussels while the non-gonadal tissues were not statistically different from predeployment mussels ($P>0.05$).

3.2 1993 Tissue Concentrations

3.2.1 Lipids and Solids

Average lipid percent of mussels was not significantly different among mussels harvested from the Gloucester (predeployment), LNB, and Deer Island stations ($P>0.05$) (Table 4). The average lipid percent composition of Discovery mussels (5.3 percent dry weight) was significantly less than the Gloucester and the LNB mussels ($P<0.05$). No statistical differences in lipids were observed between Deer Island and Discovery mussels ($P>0.05$).

The average percent solids of mussels (14.4 percent) harvested from Deer Island was similar to the solids composition of the Gloucester predeployment mussels (11.9 percent) but was significantly less than the LNB mussels (18.5 percent) ($P<0.05$) (Table 4). The average percent solids (10.7 percent) of Discovery mussels was significantly less than the average percent solids of mussels harvested from Deer Island and LNB stations.

3.2.2 Polynuclear Aromatic Hydrocarbons

The average total Polynuclear Aromatic Hydrocarbons (tPAHs) body burdens were low in both the Gloucester predeployment (188 ug/Kg dry weight) and LNB (166 ug/Kg dry weight) with concentrations at or near detection level for many of the compounds (Tables 5 and 6). Deer Island average mussel tissue tPAH concentrations (665 ug/Kg dry weight) were significantly higher than Gloucester predeployment and LNB mussels ($P<0.05$). Average tPAH tissue concentrations of 1321 ug/Kg dry weight in Discovery mussels were significantly higher than all other mussel deployment groups ($P<0.05$).

The Low Molecular Weight (LMW) PAHs which were calculated as the sum of the two and three ring groups, were significantly higher in both Deer Island (169 ug/Kg dry weight) and Discovery mussels (110 ug/Kg dry weight) than the Gloucester predeployment and LNB deployed mussels ($P<0.05$) (Figure 4). The LNB LMW-PAH tissue concentrations and the Gloucester predeployment

mussels tissue concentrations were similar averaging 66 ug/Kg dry weight for each station ($P>0.05$).

Although the LMW-PAHs body burdens did not differ significantly between Deer Island and Discovery mussels, many of the individual LMW-PAHs were significantly higher in Deer Island mussels (Table 6 and Figure 5). The methylnaphthalenes (1-methylnaphthalene, 2-methylnaphthalene, 2,6-bimethylnaphthalene, and 2,3,5-trimethylnaphthalene) and 1-methylphenanthrene were typically found in tissue concentrations that were two to four times greater than Discovery mussels ($P<0.05$). The LMW-PAH, 1,1-biphenyl, was also found in statistically higher concentrations in Deer Island mussels, but this difference was believed to be attributable to variability around the detection level.

The High Molecular Weight (HMW) PAHs, which were calculated as the sum of the four through six ring compounds, were found in significantly higher concentrations in Discovery mussels (1210 ug/Kg dry weight) compared to the Deer Island mussels (496 ug/Kg dry weight) (Table 6 and Figure 5). The Discovery and Deer Island mussels HMW-PAH body burdens were significantly higher than both the Gloucester predeployment (122 ug/Kg dry weight) and the LNB mussels (101 ug/Kg dry weight) ($P<0.05$). The HMW-PAHs found in LNB deployed mussels were numerically lower but not significantly different from the Gloucester predeployment mussels ($P>0.05$).

Discovery mussel body burdens of individual HMW-PAHs tended to be higher than Deer Island body burdens ($P<0.05$) (Figure 5). Of the twelve HMW-PAHs, eight analytes were more than two times higher in Discovery mussels compared to Deer Island mussels ($P<0.05$).

The lipid-adjusted tissue concentrations were similar to the dry weight trends (Figure 6). Most of the LMW-PAH lipid-adjusted tissue concentrations were higher for Deer Island while the HMW-PAH lipid-adjusted tissue concentrations were higher in Discovery mussels.

3.2.3 Pesticides

Hexachlorobenzene (HCB) was reported in all of the Gloucester predeployment and Discovery mussels, in most of the Deer Island mussels

(Tables 7 and 8), and in blank analyses run as part of the 'QA/QC' program (Appendix D). Since it was found in the blank analysis, it is believed that the concentrations of this compound was likely due to laboratory contamination.

As discussed in the methods (Section 2.5), there were several analytical difficulties encountered which confounded the quantification of tissue concentrations and subsequent data interpretation. The predeployment mussels suffered from significant analytical variability, particularly for 2,4'DDD, 4.4'DDD and total DDTs (tDDTs), probably due to faulty septa and coelution of these compounds. The probable effects of this analytical variability on Gloucester predeployment mussels is supported by additional analyses conducted on the Gloucester mussels for another study (see Discussion, Section 4.0). Due to the inherent difficulties of the Gloucester predeployment data set, Gloucester mussels DDE/DDD/DDT analyte body burdens were not formally compared to other stations in this study.

Five pesticides - heptachlor, aldrin, heptachlor epoxide, 2,4' DDE, and mirex - were found at or near detection levels at all stations (Tables 7 and 8; Figure 7). Lindane was found in similar tissue concentration at all three stations; Deer Island (2.7 ug/Kg dry weight), Discovery (2.3 ug/Kg dry weight) and LNB (1.7 ug/Kg dry weight) ($P>0.05$).

Alpha-chlordane body burdens were found at similar tissue concentrations in the Discovery (10.5 ug/kg dry weight) and Deer Island (8.2 ug/kg dry weight) mussels ($P>0.05$). Mussel body burdens at these two stations were significantly higher than mussels harvested from the LNB (3.8 ug/Kg dry weight) and Gloucester predeployment (2.9 ug/Kg dry weight) body burdens ($P<0.05$).

The analyses of trans-nonachlor revealed higher body burdens in Discovery (11.0 ug/Kg) and Deer Island mussels (10.7 ug/Kg dry weight) than either the LNB mussels (4.0 ug/Kg dry weight) or the Gloucester predeployment mussels (4.8 ug/Kg dry weight) ($P<0.05$).

The Deer Island mussel tDDT tissue concentrations (63 ug/Kg dry weight) was significantly higher compared to LNB mussels (30 ug/Kg dry weight) but less than the Discovery mussel body burdens (130 ug/Kg dry weight) ($P<0.05$).

Dieldrin was found in similar concentrations at Discovery (4.5 ug/Kg dry weight) and Deer Island (3.4 ug/Kg dry weight) stations. The LNB mussel dieldrin concentrations (2.2 ug/Kg dry weight) were similar to Deer Island body burdens ($P>0.05$) but LNB body burdens were significantly less than the Discovery mussels body burdens ($P<0.05$).

Lipid-adjusted pesticide concentrations in mussels collected from the four stations displayed trends similar to those observed for pesticides dry weight comparisons (Figure 8).

3.2.4 Polychlorinated Biphenyls

As discussed previously (Section 3.2.3 Pesticides) GC/ECD analytical difficulties confounded the Gloucester predeployment pesticide/PCB body burden evaluations. The CL4-PCB(52), CL5-PCB(101), CL5-PCB(118), CL5-PCB(138), and CL7-PCB(187) congeners appeared unusually high in the Gloucester predeployment mussels and may also have been affected by the analytical difficulties encountered.

Two other congeners (CL4-PCB(66) and CL4-PCB(77)) were believed to have been the result of coelution of other (nontarget) organic compounds. The concentrations of these two (coeluted) PCB's were a major component of tPCB concentrations in mussels harvested from all stations in 1993. As a result, the tPCB concentrations in mussels from all four stations mussels were probably over estimated due to confounding effects of these two coeluted PCB congeners.

Mussel tissue were analyzed for twenty polychlorinated biphenyls (PCBs) congeners (Table 9). There were six PCB congeners (CL2-PCB(8), CL5-PCB(126), CL7-PCB(170), CL8-PCB(195), CL9-PCB(206), and CL10-PCB(209)) which were generally found at or near the detection levels in mussel tissue from the three stations.

With the exception of the CL5-PCB(105) congener, which was not statistically significant, and the six PCB congeners previously mentioned, the LNB tissue concentrations were significantly less than Deer Island tissue concentrations ($P<0.05$) (Table 10 and Figure 9). The LNB mussels PCB concentrations were also generally equal or less than Gloucester predeployment tissue concentrations.

There were six PCBs (CL3-PCB(18), CL4-PCB(52), CL4-PCB(118), CL6-PCB(153), CL7-PCB(180), and CL7-PCB(187)) that did not differ significantly in tissue concentration between Gloucester predeployment and Deer Island mussels ($P>0.05$).

Four PCB congeners (CL3-PCB(28), CL4-PCB(44), CL5-PCB(101), and CL6-PCB(138)) were detected in significantly higher concentrations in Deer Island mussels compared to Gloucester predeployment mussels ($P<0.05$) (Table 10 and Figure 9). Average LNB mussel tissue concentrations of congeners CL6-PCB(101) and CL6-PCB(138) were significantly less than Gloucester predeployment tissue concentrations ($P<0.05$). The Discovery mussels CL5-PCB(44), CL5-PCB(101), CL5-PCB(118), CL6-PCB(153), CL6-PCB(128) and CL6-PCB(138) congener concentrations were significantly higher than Deer Island mussels ($P<0.05$). The LNB mussel body burdens were typically lower than the corresponding Deer Island congener body burdens.

Average total PCBs (tPCB) concentration of Deer Island of 321 ug/Kg dry weight did not significantly differ from the average Gloucester predeployment tPCB tissue concentration of 239 ug/Kg dry weight ($P>0.05$). The lack of apparent statistical significance of tPCB tissue concentration was partially attributed to the high tPCB tissue concentration variability observed in the Gloucester predeployment mussels, particularly sample number 188941. This sample was biased high due to the CL4-PCB (66) coelution concentrations reflecting analytical difficulties encountered (see Methods, Section 2.5) having an effect on the statistical sensitivity of the analyses.

The LNB mussel average tPCB body burden (110 ug/Kg dry weight) were significantly less than either the Gloucester predeployment or Deer Island mussels ($P<0.05$). Discovery mussels had the highest tPCB concentrations

(596 ug/Kg) of the mussels harvested from the four locations ($P<0.05$). The lipid-adjusted PCB tissue concentrations were similar to those trends reported for the dry weight tissue concentrations (Figure 10).

3.2.5 Mercury and Lead

Mussels collected from Gloucester predeployment (June), LNB (August), and Deer Island (August) were analyzed for selected metals (Table 11). The average Gloucester predeployment mercury body burden (394 ug/Kg dry weight) was higher than the average Deer Island mussels body burden (183 ug/Kg dry weight) and the average LNB mussels body burden (99 ug/Kg dry weight) ($P<0.05$). The average LNB mussel mercury body burden was lower than Deer Island ($P<0.05$).

The average Deer Island lead body burden (5880 ug/Kg dry weight) and average Gloucester predeployment mussel lead body burden (5120 ug/Kg dry weight) were similar ($P>0.05$). Mussels harvested from LNB had an average lead body burden of 3713 ug/Kg dry weight which was significantly less than either the Deer Island or Gloucester predeployment mussels ($P<0.05$).

The non-gonadal tissue adjustment of mercury concentration in mussels was similar to the dry weight trends; mercury was found in highest concentrations in predeployment mussels and in lowest concentration in LNB mussels ($P<0.05$). Numerically, non-gonadal lead concentrations were highest in Deer Island mussels but none of the non-gonadal adjusted average tissue concentrations from the three stations were significantly different ($P>0.05$).

3.3 Temporal Trends

3.3.1 Polynuclear Aromatic Hydrocarbons

The LNB mussel body burdens in 1993 compared favorably to those body burdens reported in 1992 (Table 12). Overall the LNB PAH body burdens were at or near detection level. Total PAH body burdens in LNB mussels were less than either Deer Island and/or Discovery mussels for both years.

Many of the individual PAH analyte concentrations in Deer Island and Discovery mussels were numerically lower in 1993 than in the previous two

years (Figures 11 and 12). The LMW-PAHs were found in highest concentrations in 1991 at both Deer Island and Discovery stations and at intermediate (between 1991 and 1993) concentrations in 1992. An apparent decrease during the three years was noticeable for the 2-methyl, 1-methyl-, 2,6-dimethyl- and 2,3,5-trimethylnaphthalenes in the Deer Island mussels. Although the HMW-PAHs were generally the lowest in 1993 for most of the individual analytes, the highest tissue concentrations were typically observed in the 1992 for mussels collected from both Deer Island and Discovery stations.

3.3.2 Pesticides

Hexachlorobenzene (HCB) tissue concentrations were reported at appreciable levels for mussels collected in 1993 from both stations. Blank contamination with HCB suggests that these reported values were confounded by laboratory contamination.

The LNB mussel body burdens of total-chlordane and total DDTs were about twice as high in 1993 compared to 1992 (Table 12). These concentrations were similar, although numerically slightly higher than 1993 60-day harvest of Gloucester mussel body burdens harvested as part of the Lynn Study (Downey, 1994).

The alpha-chlordane concentrations of Deer Island mussels was similar among the three years (Figure 13). The alpha-chlordane levels of Discovery mussels were similar in 1991 and 1992 but were about 40 percent lower in 1993 Discovery mussels (Figure 14).

Discovery tissue concentrations of 2,4'-DDD, 2,4'-DDT and 4,4'-DDT were higher in 1993 than in 1991 and 1992 deployed mussels. Higher Deer Island 4,4'-DDT body burdens were also observed in 1993. These observed body burdens may reflect the beginning of a trend of increased DDT concentrations, or may also be an analytical artifact of the different capillary column configuration used in 1993 compared to 1991-1992.

3.3.3 Polychlorinated Biphenyls

Three individual PCB congeners (CL4-PCB(52), CL5-PCB(101), and CL6-PCB(138)) from Deer Island mussels displayed noticeably higher body

burdens in 1993 (Figure 15). As noted above (Section 3.2.4) the 1993 Deer Island body burdens of two congeners, (CL4-PCB(66) and CL4-PCB(77)) were believed to be an artifact of the analytical methodologies employed in 1993. Generally, the remaining congeners were similar to Deer Island mussel body burdens observed in 1991 and 1992.

Two of the congeners, CL6-PCB(138) and CL7-PCB(187), were noticeably higher in 1993 Discovery mussels compared to 1991 and 1992 Discovery deployed mussels (Figure 16). Generally, the remaining individual congener concentrations were highest in Discovery 1992 mussels particularly the congeners CL4-PCB(52), CL5-PCB(101), CL5-PCB(118) and CL6-PCB(153).

The tPCB body burdens were higher in Gloucester, LNB and Deer Island mussels in 1993 compared to their respective deployment stations in 1991 and 1992 (Table 12). Discovery mussel tPCB body burdens in 1993 were intermediate; higher than 1991 body burdens and lower than 1992 body burdens. A significant factor in these apparent high tPCB body burdens at all deployments in 1993 were the congeners CL4-PCB(66) and CL4-PCB(77). On the average these two congeners represented about one quarter of the tPCB body burdens in mussels harvested from all four stations. However, the 1993 tPCB body burdens in Deer Island, LNB and Gloucester mussels, excluding CL4-PCB(66) and CL4-PCB(77) congeners, were still higher than reported 1991 and 1992 body burdens of mussels deployed at the same stations. Another factor which may have contributed to the apparent elevated body burdens of the 1993 Gloucester predeployment mussels may have been the analytical difficulties encountered and previously discussed in Section 2.5.

4.0 Discussion

In 1993, analytical difficulties were encountered with several of the GC/ECD organic analyses. Specifically, the predeployment body burdens of mussels from the Gloucester control station were much higher than body burdens observed in previous years from this station. These samples were analytically problematic, due to faulty septa on the vials and limited sample mass available, and column configuration which likely resulted in significant variability among the replicate samples.

The hypothesis that laboratory variability may have confounded the 1993 analytical results of pesticide and PCB body burdens of predeployment mussels is supported by analytical data on additional predeployment Gloucester mussel samples and analyses of Hodgkin Cove deployed mussels in the Lynn Study (Downey, 1994). The evaluation of additional predeployment samples (Table D1) was completed by assuming a conservative but reasonable internal spike recovery (40%) since these samples were not internal spike corrected. Qualitative comparison of reported predeployment pesticide body burdens (Tables 7 and 8) varied widely with the calculated qualitative results found in Table D1. Those values reported in Tables 7 and 8 for lindane, trans-nonachlor, 4,4'-DDD, 2,4'-DDT, and 4,4'-DDT were 2-3 times higher than the qualitative values of Table D1 suggesting analytical difficulties may have occured during the analysis of predeployment mussels.

In the Lynn Study, the 60-day retrieval (September 7, 1994) of Hodgkins Cove mussels had 86 ug/Kg dry weight tPCB concentrations or about one-third of the predeployment concentrations of this study. This 86 ug/Kg compares quite favorably with results from the 1991 and 1992 MWRA study for Gloucester (Hodgkins Cove) predeployment mussels, supporting the interpretation that predeployment mussel tPCB analyses were confounded. The reported results for these average predeployment pesticide concentrations (Tables 7 and 8) were also at least 2 times higher than estimated values of the body burdens of mussels deployed 60-day at Hodgkins Cove and retrieved in September (Downey, 1994).

Several congeners ((CL3-PCB(28), CL4-PCB(44), CL4-PCB(52), CL7-PCB(187)) may also have been affected by laboratory problems encountered within the predeployment mussel analyses (see Tables 9, 10 and

D2 for comparisons). Because of these possible inherent difficulties with precisely quantifying predeployment pesticide and PCB body burdens, the discussion of the 1993 spatial and temporal patterns generally focused only on the Deer Island, Discovery and LNB body burdens.

The two years of data (1992-1993) for LNB mussels did not display any significant trends in PAH body burdens. Although selected pesticides and tPCB's were increased in LNB mussels in 1993, this increase was likely due to analytical variability.

The 1993 tPAH tissue concentrations in Deer Island and Discovery mussels were at the lowest levels observed for the three years (1991-1993) of study. Lower tPAHs primarily reflect the decreased LMW-PAH contributions to the tPAH body burdens. This reduction may in fact represent a trend of decreasing PAH exposure concentrations for mussels among years as reported in previous studies (Downey and Young, 1992; Downey et al. 1993). Comparison of the 1991-1993 data at Deer Island to the 1987 mussel data reported by MWRA (1988) lends additional support for this interpretation.

This trend, however, needs to be considered with caution. As with any study, methodologies which are similar throughout years of study also have analytical variability associated with the results due to the limitations of available protocols. This variability may have contributed significantly to apparent differences among studies conducted in different years. The presence of analytical variability was highlighted by the results of body burden analyses conducted on the 1993 Gloucester predeployment mussels. It is unknown how much analytical variability may have contributed to these apparent trends.

The 1993 relative spatial trends of mussel body burdens for the three stations were consistent with spatial trends reported for 1991 and 1992 mussels. The total LMW-PAHs were found in highest concentrations in Deer Island mussels with methylnaphthalenes (2-methylnaphthalene, 1-methylnaphthalene, 2,6-dimethylnaphthalene, and 2,3,5-trimethylnaphthalene) tissue concentrations the highest in the Deer Island tissues. These high methylnaphthalene concentrations in the Deer Island mussels during all

three studies suggest, by inference, that the Deer Island effluent is an important source of these contaminants for mussels deployed at Deer Island Station.

In contrast, HMW-PAHs, total pesticides and total PCBs were generally found in higher tissue concentrations in Discovery mussels but were also significantly elevated in the Deer Island mussels. These observations suggest that the direct effluent exposure may not be the primary source of these contaminants for bioaccumulation. Other source(s) of these contaminants appear to be more widespread throughout Boston Harbor and seem to have a significant influence on the distribution and availability for bioaccumulation of these contaminants at both Deer Island and Discovery stations. Consistently higher bioaccumulated concentrations of HMW-PAHs in Discovery mussels suggest that this "ambient" HMW-PAH contamination is not uniform throughout Boston Harbor.

Total DDT in Deer Island mussels was higher in 1993 compared to 1991-1992 Deer Island mussels; a trend also reflected in the Discovery stations. The 1993 Deer Island body burdens were similar to 1987 Deer Island body burdens. As noted previously, analytical difficulties encountered in 1993 obscure the annual comparisons of body burdens.

The tPCBs displayed a similar 1991-1993 trend as tDDTs with highest tissue concentrations on 1993. The 1991-1993 Deer Island tPCB mussel concentrations were one-half (or more) less than 1987 Deer Island mussels, which suggests a reduction in mussel exposure at this station.

The 1993 lead body burdens in Deer Island mussels was virtually identical to those body burdens reported for Deer Island mussels deployed in 1991. Mercury concentrations in 1993 Deer Island mussel tissues ranged between the national "average" and the "high" values reported by the mussel watch program.

The results of this study have qualitatively mimicked previous (1991 and 1992) studies. Generally tPAHs, LMW-PAHs, HMW-PAHs and tPCBs displayed a trend of lower tissue concentrations in Deer Island 1991-1993 mussels compared to 1987 tissue concentrations. Annual variability in tPAH, tPCB,

and total pesticides tissue concentrations for 1991-1993 Deer Island mussels has not revealed any consistent trends during this three year period.

The 1991-1993 studies have also indicated the Deer Island effluent probably contributes LMW-PAHs, particularly methylnaphthalenes, for bioaccumulation in mussels in proximity to the discharges. Triplicate analyses of Deer Island effluent samples collected in 1992 for individual PAHs found that LMW-PAHs, specifically the methyl-naphthalenes, (2-methyl-, 1-methyl-, 2,6-dimethyl-, and 1,6,7-trimethyl- napthalenes) represented nearly 75 percent of the total PAHs detected in the effluent samples. The HMW-PAH component of the effluent samples (12 individual PAHs) represented less than 4 percent of the tPAHs in the same samples (personal communication, Mr. Maury Hall, MWRA Project Director). Cursory comparisons of the bioaccumulation patterns and Deer Island water quality analyses indicate that these biomonitoring techniques provide a useful tool in monitoring Deer Island effluent water quality trends of the target PAH compounds and presumably other compounds that are bioaccumulated by mussels.

5.0 LITERATURE CITED

Camp, Dresser and McKee, Inc. 1988. Plan for bioaccumulation assessment, City of New Bedford, Massachusetts. November 23, 1988.

Downey, Philip and Kirk Young. 1992. Bioaccumulation of selected metals and organic compounds in mussels deployed near the Deer Island Discharge. Submitted to the Massachusetts Water Resources Authority, Boston, Massachusetts.

Downey, Philip C., Joseph K. Comeau, Roger C. Binkerd and John W. Williams. 1993. Bioaccumulation of selected organic compounds in mussels deployed near Deer Island Discharge and in Massachusetts Bay, 1992. Submitted to the Massachusetts Water Resources Authority.

Downey, Philip C. 1994. Mussel Bioaccumulation of selected metals and organic compounds in mussels deployed near the Lynn Municipal Discharge, 1993. Submitted to Camp, Dresser & McKee, Cambridge, Massachusetts.

MRI (Marine Research, Inc.). 1989. Investigation of mussels for City of New Bedford Plan Bioaccumulation Assessment. Submitted to GHR Engineering, Inc., Lakeville, Massachusetts.

MRI (Marine Research, Inc.). 1991. Investigations of mussels for bioaccumulation assessment for Massachusetts Water Resource Authority. Submitted to Aquatec, Inc., Colchester, Vermont.

MWRA (Massachusetts Water Resources Authority). 1988. Secondary Treatment Facilities Plan, Volume V Appendix X Bioaccumulation. MWRA, Boston, Massachusetts.

Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill Book Company, New York, New York.

Snedecor, G. and Cochran, W. 1973. Statistical Methods. Sixth edition. The Iowa State University Press, Ames, Iowa.

93019D23NOV93

Table 1. Mussel harvest and analysis experimental design summary for 1993. Square brackets represent the number of cages.

		Initial Deployment and Analyses				Forty-Day Harvest		Sixty-Day Harvest			
		Deployment		Analyses		Harvest		Harvest		Analyses	
Location	Deployment Method	Arrays (N)	Mussels (N)	Potential Body Burden[1] (N)	Biology[2] (N)	Arrays (N)	Mussels (N)	Arrays (N)	Mussels (N)	Potential Body Burden[1] (N)	Biology[2] (N)
Gloucester	--	--	80	5	30	--	--				
Discovery	Suspended	2	200	--	--	1	100 [2]	1	100 [4]	5	30
Deer Island Light	Subsurface Buoy Array	3	300	--	--	1	100 [2]	2	100 [4]	5	30
Off-Shore	Surface Buoy Array	2	240	--	--	1	120 [3]	1	120 [3]	8	30
	Acoustic Buoy Array	1	120	--	--	--	--	1	120 [3]	8	30
	Total Mussels		940								

1. Body burden included the chemical analyses of mussel tissue. Each body burden sample consisted of ten mussels composited. Samples were stored frozen until analysis.

2. Biology included sex, sexual maturity, wet weight of gonad-mantle and non-gonadal soft tissue, shell weight, and total shell length determinations.

93020D4JUN93

Table 2. Survival and stage of gametogenesis of mussels for predeployment Gloucester, and for the "forty" and "sixty"-day mussel retrieval from the three stations.

	Num.	% Survival	Sample size	Females		Males	
				Mature	Immature	Mature	Immature
"Predeployment"							
Gloucester	--	--	30	12	0	15	3
"Forty"-day							
Discovery	120	100	--	--	--	--	--
Deer Island	123	100	--	--	--	--	--
LNB	123	100	--	--	--	--	--
"Sixty"-day							
Discovery	99	95	30	10	0	19	1
Deer Island	99	100	30	19	0	10	1
LNB	240	99.6	30	22	2	6	0

-- Not applicable

Table 3. Summary of various biological measurements expressed as mean values for mussels. Predeployment Gloucester represents measurements on mussels at beginning of the study and 60-day retrieval represent values at end of study. All values reported on a wet basis.

Location	Mean Shell Length (mm)	Mean Total Wet Weight (g)	Mean (g)		
			Gonad-Mantle	Non-gonadal Soft Tissue	Shell
Predeployment					
Gloucester (30)	60.1	22.65	2.10	4.43	11.84
60-Day Retrieval					
Discovery (30)	61.5	28.17	2.92	5.16	13.41
Deer Island (30)	61.8	27.68	3.93	6.26	13.54
LNB (30)	62.0	26.86	4.39	6.51	13.54

93019D7DEC93

Table 4. Percent lipids and solids of mussels collected from four stations, 1993. On several samples duplicate (and triplicate) analyses were conducted. These replicate analyses were averaged and the average value for the sample was used in calculating mean population concentrations listed below.

		Tissue Composition					
		Percent Lipids (dry weight)			Percent Solids		
Location	N	Mean	SD	Range	Mean	SD	Range
Predeployment							
Gloucester	5	8.0	1.7	6.5-10.7	11.9	1.9	9.8-14.7
60-Day Retrieval							
LNB	8	7.1	0.9	6.0-8.6	18.5	0.7	17.5-19.7
Deer Island	5	6.5	1.7	4.9-9.2	14.4	0.5	13.5-14.9
Discovery	5	5.3	0.5	4.6-5.8	10.7	0.4	10.3-11.1

Table 6. Polynuclear aromatic hydrocarbon (ug/Kg dry weight) concentrations in mussels exposed at the four stations. The total PAHs and total PAHs summed by group (ie. 2 & 3 ring and 4, 5 & 6 ring) were calculated using detection limit value as an estimated concentration when individual analytes were not detected.

	Gloucester Predeployment, June 1993						Large Navigation Buoy, August 1993							
Laboratory ID:	203262R	203263R	203264R	203284	203288	203291	196376	196377	203265R	196379	203279	203266R	196382	196383
Parameter														
Naphthalene	<5	<5	<5	18	6	7	<5	<5	<5	<5	<5	6	<5	<5
2-Methylnaphthalene	<5	<5	<5	11	5	6	6	5	<5	<5	<5	6	5	5
1-Methylnaphthalene	<5	<5	<5	6	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
1,1-Biphenyl	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
2,6-Dimethylnaphthalene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Acenaphthylene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Acenaphthene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
2,3,5-Trimethylnaphthalene	<5	<5	<5	<5	<5	<5	10	<5	7	5	5	<5	<5	<5
Fluorene	6	5	<5	8	10	9	<5	<5	<5	<5	<5	10	7	7
Phenanthrene	<5	<5	<5	<5	<5	<5	12	6	13	8	6	6	<5	<5
Anthracene	<5	<5	<5	<5	<5	<5	<5	<5	10	<5	<5	<5	<5	<5
1-Methylphenanthrene	61	60	60	83	66	67	6	<5	<5	<5	<5	<5	<5	<5
Total of 2 & 3 ring groups	17	10	9	22	20	27	74	61	75	63	61	68	62	62
Fluoranthene	17	10	10	16	14	23	32	22	20	28	16	20	27	26
Pyrene	8	<5	<5	<5	6	8	16	11	12	13	9	12	12	12
Benz(a)anthracene	14	7	6	12	12	19	5	<5	<5	<5	<5	<5	<5	<5
Chrysene	11	5	<5	8	8	10	9	7	5	8	<5	6	7	7
Benzo(b)fluoranthene	9	<5	<5	12	7	10	5	<5	<5	7	<5	5	5	5
Benzo(e)pyrene	9	5	<5	7	6	7	12	<5	<5	6	<5	<5	6	5
Benzo(a)pyrene	<5	<5	<5	13	<5	10	7	<5	<5	<5	<5	<5	<5	<5
Perylene	8	<5	<5	6	6	8	18	<5	<5	<5	<5	<5	<5	<5
Indeno(1,2,3-cd)pyrene	5	<5	<5	<5	<5	5	6	<5	<5	6	<5	<5	<5	<5
Dibenzo(a,h)anthracene	9	<5	<5	81	18	21	<5	<5	<5	<5	<5	5	<5	<5
Benzo(g,h,i)perylene	9	<5	<5	7	8	11	43	5	7	5	<5	34	10	<5
Benzo(k)fluoranthene	121	72	70	194	115	159	<5	<5	5	5	5	6	5	<5
Total of 4, 5 & 6 ring groups	182	132	130	277	181	226	163	85	84	98	75	113	97	90
Total PAH's							237	146	159	161	136	181	159	152

	Discovery, August 1993						Deer Island, August 1993					
Laboratory ID:	196389	203269R	196391	196392	203270R	203280	203267R	203268R	196386	196387	196388	203285
Parameter												
Naphthalene	11	11	10	9	8	9	6	7	13	13	7	11
2-Methylnaphthalene	9	<5	9	10	<5	<5	11	10	28	25	16	18
1-Methylnaphthalene	<5	<5	<5	<5	<5	<5	7	6	18	14	9	10
1,1-Biphenyl	<5	<5	6	6	<5	<5	7	<5	7	7	7	7
2,6-Dimethylnaphthalene	<5	<5	6	<5	<5	<5	17	14	32	29	17	26
Acenaphthylene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Acenaphthene	8	<5	8	8	7	<5	<5	<5	10	8	<5	6
2,3,5-Trimethylnaphthalene	10	13	8	8	<5	<5	24	21	46	46	24	32
Fluorene	6	11	7	10	<5	<5	7	<5	11	9	7	6
Phenanthrene	22	51	17	26	14	10	18	17	43	30	23	29
Anthracene	14	52	13	17	13	11	7	7	11	8	6	9
1-Methylphenanthrene	7	13	6	7	<5	<5	9	10	25	20	12	19
Total of 2 & 3 ring groups	107	181	100	116	82	75	123	112	249	214	138	178
Fluoranthene	327	249	259	311	252	252	83	72	160	139	84	144
Pyrene	301	212	237	273	224	223	65	58	128	108	66	114
Benz(a)anthracene	135	71	108	106	74	76	16	18	51	35	26	32
Chrysene	209	139	171	187	144	145	38	39	91	71	45	69
Benzo(b)fluoranthene	145	105	116	117	99	116	18	22	55	42	61	39
Benzo(e)pyrene	150	118	131	132	111	106	25	35	65	56	68	43
Benzo(a)pyrene	55	37	45	40	33	34	6	15	19	13	16	12
Perylene	17	15	14	12	12	11	<5	19	7	7	6	8
Indeno(1,2,3-cd)pyrene	41	23	33	31	15	18	7	9	24	25	31	10
Dibenzo(a,h)anthracene	24	12	23	24	9	10	<5	<5	18	16	33	<5
Benzo(g,h,i)perylene	31	53	26	21	37	31	9	111	19	20	29	21
Benzo(k)fluoranthene	75	51	68	58	47	45	12	15	43	31	39	22
Total of 4, 5 & 6 ring groups	1510	1085	1231	1312	1057	1067	289	418	680	563	504	519
Total PAH's	1617	1266	1331	1428	1139	1142	412	530	929	777	642	697

Table 6. Average concentrations of PAHs (ug/Kg dry weight) from mussels harvested during predeployment at Gloucester and during the 60-day retrieval from the three stations. Averages were calculated using the detection limit value as an estimated concentration when individual analytes were not detected.

	June Predeployment Gloucester (Sample size - 6)			August 60-Day Retrieval Large Navigation Buoy (Sample size - 8)			August 60-Day Retrieval Discovery (Sample size - 6)			August 60-Day Retrieval Deer Island (Sample size - 6)		
Parameter	AVE	SD	Range	AVE	SD	Range	AVE	SD	Range	AVE	SD	Range
Naphthalene	8	5	5 - 18	5	0	5 - 6	10	1	8 - 11	10	3	6 - 13
2-Methylnaphthalene	6	2	5 - 11	5	0	5 - 6	7	2	5 - 10	18	7	10 - 28
1-Methylnaphthalene	5	0	5 - 6	5	0	5 - 5	5	0	5 - 5	11	5	6 - 18
1,1-Biphenyl	5	0	5 - 5	5	0	5 - 5	5	1	5 - 6	7	1	5 - 7
2,6-Dimethylnaphthalene	5	0	5 - 5	5	0	5 - 5	5	0	5 - 6	23	7	14 - 32
Acenaphthylene	5	0	5 - 5	5	0	5 - 5	5	0	5 - 5	5	0	5 - 5
Acenaphthene	5	0	5 - 5	5	0	5 - 5	7	1	5 - 8	7	2	5 - 10
2,3,5-Trimethylnaphthalene	5	0	5 - 5	6	2	5 - 10	8	3	5 - 13	32	11	21 - 46
Fluorene	5	0	5 - 5	5	0	5 - 5	7	3	5 - 11	8	2	5 - 11
Phenanthrene	7	2	5 - 10	9	3	6 - 13	23	15	10 - 51	27	10	17 - 43
Anthracene	5	0	5 - 5	6	2	5 - 10	20	16	11 - 52	8	2	6 - 11
1-Methylphenanthrene	5	0	5 - 5	5	0	5 - 6	7	3	5 - 13	16	6	9 - 25
Total of 2 & 3 ring groups	66	9	60 - 83	66	6	61 - 75	110	38	75 - 181	169	54	112 - 249
Fluoranthene	18	7	9 - 27	24	5	16 - 32	275	35	249 - 327	114	38	72 - 160
Pyrene	15	5	10 - 23	12	2	9 - 16	245	35	212 - 301	90	30	58 - 128
Benz(a)anthracene	6	1	5 - 8	5	0	5 - 5	95	26	71 - 135	30	13	16 - 51
Chrysene	12	5	6 - 19	7	1	5 - 9	166	28	139 - 209	59	21	38 - 91
Benzo(b)fluoranthene	8	2	5 - 11	5	1	5 - 7	116	16	99 - 145	40	17	18 - 61
Benzo(e)pyrene	8	3	5 - 12	6	2	5 - 12	125	16	106 - 150	49	17	25 - 68
Benzo(a)pyrene	7	2	5 - 9	5	1	5 - 7	41	8	33 - 55	14	4	6 - 19
Perylene	7	3	5 - 13	7	5	5 - 18	14	2	11 - 17	9	5	5 - 19
Indeno(1,2,3-cd)pyrene	6	1	5 - 8	5	0	5 - 6	27	10	15 - 41	18	10	7 - 31
Dibenzo(a,h)anthracene	5	0	5 - 5	5	0	5 - 5	17	7	9 - 24	14	11	5 - 33
Benzo(g,h,i)perylene	23	29	5 - 81	14	15	5 - 43	33	11	21 - 53	35	38	9 - 111
Benzo(k)fluoranthene	8	2	5 - 11	5	0	5 - 6	57	12	45 - 75	27	13	12 - 43
Total of 4, 5 & 6 ring groups	122	49	70 - 194	101	28	75 - 163	1210	179	1057 - 1510	496	133	289 - 680
Total PAH's	188	56	130 - 277	166	31	136 - 237	1321	183	1139 - 1617	665	182	412 - 929

Table 7. Pesticide (ug/Kg dry weight) concentrations in mussels exposed at the four stations. The total pesticides were calculated by using the detection limit value as an estimated concentration when individual analytes were not detected.

	Gloucester Predeployment, June 1993					Large Navigation Buoy, August 1993							
Laboratory ID:	186933	186934	186936	186937	186941	196376	196377	196378	196379	196380	196381	196382	196383
Parameter													
Hexachlorobenzene	5.5	24.2	13.0	2.4	13.0	<2.5	<2.7	<1.0	<2.4	<2.1	<1.4	<2.0	0.5
Lindane (gamma-BHC)	11.0	3.7	3.9	2.2	4.2	<2.5	<2.7	<1.0	<2.4	<2.1	1.1	1.0	0.7
Heptachlor	<1.5	<2.3	<3.4	<1.8	<4.2	<2.5	<2.7	<1.0	<2.4	<2.1	<1.4	<2.0	<0.9
Aldrin	<1.5	<2.3	<3.4	<1.8	<4.2	<2.5	<2.7	<1.0	<2.4	<2.1	<1.4	<2.0	<0.9
Heptachlor Epoxide	<1.5	<2.5	<4.0	<2.1	<4.5	<2.5	2.6	<1.2	<2.2	<2.0	<1.3	<2.0	<1.0
alpha-chlordane	1.5	<2.5	<4.0	<2.1	<4.5	4.6	3.4	3.9	3.9	3.5	3.5	4.4	3.3
trans-nonachlor	3.7	6.9	4.3	4.1	4.8	4.4	3.5	3.6	3.3	4.6	4.3	4.3	4.3
Dieldrin	<1.5	<2.5	<4.0	<2.1	<4.5	2.1	2.0	2.6	2.2	2.3	2.3	2.3	2.1
2,4'-DDE	<1.5	<2.5	<4.0	<2.1	<4.5	<2.5	<2.6	<1.2	<2.2	<2.0	<1.3	<2.0	<1.0
4,4'-DDE	10.0	16.0	14.0	10.0	15.0	7.6	5.5	6.0	7.5	7.2	7.4	7.6	7.0
2,4'-DDD	12.0	15.0	7.5	16.0	18.0	9.6	7.4	11.0	<2.2	7.6	4.9	4.1	3.9
4,4'-DDD	8.9	20.0	21.0	14.0	22.0	6.6	4.8	4.0	6.3	6.4	6.1	6.5	5.7
2,4'-DDT	<1.5	9.1	<4.0	54.0	64.0	<2.5	16.0	11.0	<2.2	<2.0	1.1	1.0	1.0
Mirex	<1.4	<2.3	<5.3	<2.1	<6.0	<3.1	<2.9	<0.9	<2.1	<2.1	<1.4	<2.1	<1.0
4,4'DDT	5.0	7.3	12.0	4.5	14.0	5.3	4.4	3.4	3.8	4.1	4.5	4.8	4.4
Dieldrin/Aldrin group	3.0	4.8	7.4	3.9	8.7	4.6	4.7	3.6	4.6	4.4	3.7	4.3	3.0
Chlordane group	17.7	15.6	16.2	10.5	18.0	14.0	12.2	9.7	11.8	12.2	10.2	11.7	9.3
DDD/DDE/DDT	38.9	69.9	62.5	100.6	137.5	34.1	40.7	36.6	24.2	29.3	25.3	26.0	23.0

	Discovery, August 1993				Deer Island, August 1993				
Laboratory ID:	196389	196390	196391	196392	196384	196385	196386	196387	196388
Parameter									
Hexachlorobenzene	15.0	10.0	30.0	1.8	<2.4	1.6	2.6	4.3	4.8
Lindane (gamma-BHC)	2.3	3.3	1.3	2.4	<2.4	2.7	3.0	3.0	2.4
Heptachlor	<2.1	<1.2	<1.0	<3.5	<2.4	<1.9	<3.9	<3.6	<1.3
Aldrin	<2.1	<1.2	<1.0	<3.5	<2.4	<1.9	<3.9	<3.6	<1.3
Heptachlor Epoxide	<2.2	<1.3	<1.0	<3.2	<2.4	<2.0	<3.9	2.3	<1.3
alpha-chlordane	12.0	11.0	7.8	11.0	8.2	9.7	9.5	8.6	5.2
trans-nonachlor	14.0	11.0	7.8	11.0	8.6	13.0	12.0	13.0	6.8
Dieldrin	6.5	2.5	4.3	4.8	2.4	5.3	4.0	4.1	<1.3
2,4'-DDE	<2.2	<1.3	<1.0	<3.2	<2.4	<2.0	<3.9	<3.2	<1.3
4,4'-DDE	26.0	27.0	25.0	21.0	16.0	22.0	15.0	20.0	11.0
2,4'-DDD	22.0	74.0	14.0	14.0	6.4	<2.0	9.4	19.0	<1.3
4,4'-DDD	42.0	42.0	35.0	33.0	11.0	19.0	23.0	22.0	8.3
2,4'-DDT	56.0	23.0	2.4	4.1	1.4	<2.0	<3.9	<3.2	<1.3
Mirex	<2.3	<3.3	<1.0	<3.3	<2.4	<3.4	<4.4	<4.1	<2.0
4,4'DDT	12.0	21.0	8.0	8.4	9.8	23.2	20.0	19.0	12.0
Dieldrin/Aldrin group	8.6	3.7	5.3	8.3	4.8	7.2	7.9	7.7	2.6
Chlordane group	30.5	26.6	17.9	27.6	21.6	27.4	28.4	26.9	15.7
DDD/DDE/DDT	162.2	188.3	85.4	83.7	47.0	70.2	75.2	86.4	35.2

Table 8. Average concentrations of pesticides (ug/Kg dry weight) from mussels harvested during predeployment at Gloucester and during the 60-day retrieval from the three stations. Averages were calculated using detection limit value as an estimated concentration when individual analytes were not detected.

	June Predeployment Gloucester (Sample size - 5)			August 60-Day Retrieval Large Navigation Buoy (Sample size - 8)			August 60-Day Retrieval Discovery (Sample size - 4)			August 60-Day Retrieval Deer Island (Sample size - 5)		
Parameter	AVE	SD	Range	AVE	SD	Range	AVE	SD	Range	AVE	SD	Range
Hexachlorobenzene	11.62	8.43	2.40 - 24.20	1.82	0.78	0.49 - 2.70	14.20	11.86	1.80 - 30.00	3.14	1.35	1.60 - 4.80
Lindane (gamma-BHC)	5.00	3.44	2.20 - 11.00	1.69	0.81	0.71 - 2.70	2.33	0.82	1.30 - 3.30	2.70	0.30	2.40 - 3.00
Heptachlor	2.64	1.13	1.50 - 4.20	1.88	0.69	0.93 - 2.70	1.95	1.14	1.00 - 3.50	2.62	1.11	1.30 - 3.90
Aldrin	2.64	1.13	1.50 - 4.20	1.88	0.69	0.93 - 2.70	1.95	1.14	1.00 - 3.50	2.62	1.11	1.30 - 3.90
Heptachlor Epoxide	2.92	1.28	1.50 - 4.50	1.85	0.61	1.00 - 2.60	1.93	0.99	1.00 - 3.20	2.38	0.95	1.30 - 3.90
alpha-chlordane	2.92	1.28	1.50 - 4.50	3.81	0.48	3.30 - 4.60	10.45	1.83	7.80 - 12.00	8.24	1.81	5.20 - 9.70
trans-nonachlor	4.76	1.26	3.70 - 6.90	4.04	0.49	3.30 - 4.60	10.95	2.53	7.80 - 14.00	10.68	2.82	6.80 - 13.00
Dieldrin	2.92	1.28	1.50 - 4.50	2.24	0.18	2.00 - 2.60	4.53	1.65	2.50 - 6.50	3.42	1.57	1.30 - 5.30
2,4'-DDE	2.92	1.28	1.50 - 4.50	1.85	0.61	1.00 - 2.60	1.93	0.99	1.00 - 3.20	2.56	1.02	1.30 - 3.90
4,4'-DDE	13.00	2.83	10.00 - 16.00	6.98	0.79	5.50 - 7.60	25.25	3.10	21.00 - 28.00	16.80	4.32	11.00 - 22.00
2,4'-DDD	13.70	4.09	7.50 - 18.00	6.34	3.05	2.20 - 11.00	31.00	28.91	14.00 - 74.00	7.62	7.17	1.30 - 19.00
4,4'-DDD	17.18	5.58	8.90 - 22.00	5.80	0.93	4.00 - 6.60	38.00	4.69	33.00 - 42.00	16.66	6.64	8.30 - 23.00
2,4'-DDT	26.52	29.99	1.50 - 64.00	4.60	5.68	1.00 - 16.00	21.38	24.90	2.40 - 56.00	2.36	1.15	1.30 - 3.90
Mirex	3.42	2.08	1.40 - 6.00	1.95	0.81	0.90 - 3.10	2.48	1.09	1.00 - 3.30	3.26	1.04	2.00 - 4.40
4,4'DDT	8.56	4.25	4.50 - 14.00	4.34	0.59	3.40 - 5.30	12.35	6.04	8.00 - 21.00	16.80	5.66	9.80 - 23.20
Dieldrin/Aldrin group	5.56	2.40	3.00 - 8.70	4.12	0.60	3.03 - 4.70	6.48	2.38	3.70 - 8.60	6.04	2.29	2.60 - 7.90
Chlordane group	15.60	3.02	10.50 - 18.00	11.39	1.56	9.31 - 14.00	25.65	5.42	17.90 - 30.50	24.00	5.34	15.70 - 28.40
DDD/DDE/DDT	81.88	38.11	38.90 - 137.50	29.90	6.50	23.00 - 40.70	129.90	53.44	83.70 - 188.30	62.80	21.08	35.20 - 86.40

Table 9. Polychlorinated biphenyl (ug/Kg dry weight) concentrations in mussels exposed at the four stations. The total PCBs were calculated using the detection limit value as an estimated concentration when individual analytes were not detected.

	Gloucester Predeployment, June 1993					Large Navigation Buoy, August 1993							
Laboratory ID:	188933	188934	188936	188937	188941	196376	196377	196378	196379	196380	196381	196382	196383
Parameter													
CL2-PCB(8)	<1.50	<2.30	<3.40	<1.80	<4.20	<2.50	<2.70	<1.00	<2.40	<2.10	<1.40	<2.00	<0.93
CL3-PCB(18)	<1.50	8.40	3.60	2.50	9.20	1.40	1.40	2.50	1.60	2.10	1.50	1.30	1.50
CL3-PCB(28)	<1.50	5.50	3.80	2.20	<4.20	2.50	1.90	2.70	3.40	4.60	2.50	2.30	2.10
CL4-PCB(44)	4.10	5.30	5.90	2.60	<4.20	1.80	1.60	1.70	1.80	2.20	2.20	1.90	1.80
CL4-PCB(52)	12.00	16.00	10.00	9.50	16.00	7.00	7.30	5.90	6.20	9.60	6.60	12.00	5.20
CL4-PCB(66)	46.00	6.90	18.00	28.00	179.00	16.00	14.00	14.00	16.00	12.00	13.00	24.00	15.00
CL4-PCB(77)	19.00	34.00	26.00	20.00	30.00	12.00	10.00	11.00	12.00	12.00	11.90	2.00	12.00
CL5-PCB(101)	15.00	24.00	21.00	14.00	18.00	12.00	8.60	10.00	11.00	11.00	12.00	13.00	13.00
CL5-PCB(105)	<1.50	<2.50	4.00	<2.10	<4.50	3.80	3.30	3.20	4.10	4.50	4.30	<4.10	4.20
CL5-PCB(118)	12.00	18.00	16.00	12.00	19.00	8.30	8.20	8.60	7.90	8.20	9.00	9.00	8.50
CL6-PCB(153)	21.00	31.00	26.00	19.00	<4.50	14.00	10.00	11.00	14.00	13.00	13.00	14.00	13.00
CL5-PCB(126)	<1.40	<2.30	<5.30	<2.10	<6.00	<3.10	<2.90	1.10	<2.10	1.60	1.50	2.10	2.00
CL6-PCB(128)	<1.40	4.60	<5.30	3.00	7.20	2.90	2.40	1.80	2.80	2.90	2.90	2.30	2.40
CL6-PCB(138)	19.00	28.00	30.00	18.00	33.00	16.00	13.00	10.00	12.00	13.00	14.00	14.00	13.00
CL7-PCB(170)	<1.40	<2.30	<5.30	<2.10	<6.00	<3.10	<2.90	<0.90	<2.10	<2.10	<1.40	<2.10	1.00
CL7-PCB(180)	4.70	3.80	7.30	3.00	7.20	2.40	2.90	2.10	1.80	1.90	1.80	2.20	2.30
CL7-PCB(187)	19.00	14.00	30.00	12.00	24.00	5.50	5.20	4.60	4.40	4.60	4.90	4.70	4.60
CL8-PCB(195)	<1.40	<2.30	<5.30	<2.10	<6.00	<3.10	<2.90	<0.90	<2.10	<2.10	<1.40	<2.10	<1.00
CL9-PCB(206)	1.30	<2.30	<5.30	<2.10	<6.00	<3.10	<2.90	<0.90	<2.10	<2.10	<1.40	<2.10	<1.00
CL10-PCB(209)	<1.40	<2.30	<5.30	<2.10	<6.00	<3.10	<2.90	<0.90	<2.10	<2.10	<1.40	<2.10	<1.00
Total PCB's	186.10	215.80	236.80	160.20	394.20	123.60	107.00	94.80	111.90	113.70	108.10	119.30	105.53

	Discovery, August 1993				Deer Island, August 1993				
Laboratory ID:	196389	196390	196391	196392	196384	196385	196386	196387	196388
Parameter									
CL2-PCB(8)	11.00	2.00	2.50	<3.50	<2.40	27.00	8.90	<3.60	<1.30
CL3-PCB(18)	6.70	9.10	6.50	7.60	3.30	9.40	9.00	9.70	5.40
CL3-PCB(28)	16.00	13.00	12.00	15.00	6.10	12.00	11.50	13.00	5.80
CL4-PCB(44)	17.00	15.00	13.00	15.00	6.30	9.40	9.80	10.00	5.30
CL4-PCB(52)	37.00	36.00	27.00	36.00	16.00	24.00	43.00	28.00	14.00
CL4-PCB(66)	43.00	33.00	47.00	37.00	26.00	28.00	19.00	28.00	16.00
CL4-PCB(77)	122.00	100.00	96.00	98.00	34.00	47.00	52.00	49.00	23.00
CL5-PCB(101)	94.00	77.00	63.00	76.00	32.00	45.00	40.00	45.00	23.00
CL5-PCB(105)	25.00	<1.30	<1.00	19.00	8.40	<2.00	12.00	13.00	<1.30
CL5-PCB(118)	57.00	57.00	44.00	47.00	18.00	27.00	29.00	29.00	13.00
CL6-PCB(153)	80.00	70.00	57.00	62.00	30.00	38.00	47.00	39.00	20.00
CL5-PCB(126)	<2.30	<3.30	<1.00	<3.30	2.90	<3.40	<4.40	<4.10	<2.00
CL6-PCB(128)	14.00	24.00	9.30	10.00	4.70	11.30	7.50	9.30	5.10
CL6-PCB(138)	92.00	180.00	59.00	64.00	31.00	74.00	47.00	57.00	33.00
CL7-PCB(170)	2.00	3.50	1.00	<3.30	<2.40	2.90	<4.40	2.60	1.40
CL7-PCB(180)	12.00	17.00	10.00	8.50	5.30	13.20	8.90	9.40	4.90
CL7-PCB(187)	27.00	50.00	19.00	19.00	9.60	23.40	16.00	18.00	11.00
CL8-PCB(195)	<2.30	<3.30	<1.00	<3.30	<2.40	<3.40	<4.40	<4.10	<2.00
CL9-PCB(206)	<2.30	<3.30	12.30	<3.30	<2.40	<3.40	<4.40	<4.10	<2.00
CL10-PCB(209)	<2.30	<3.30	1.00	<3.30	<2.40	<3.40	<4.40	<4.10	<2.00
Total PCB's	664.90	701.10	482.60	534.10	245.60	407.20	382.60	380.00	191.50

Table 10. Average concentrations of PCBs (ug/Kg dry weight) from mussels harvested during predeployment at Gloucester and during the 60-day retrieval from the three stations. Averages were calculated using the detection limit value as an estimated concentration when individual analytes were not detected.

Parameter	June Predeployment Gloucester (Sample size - 5)			August 60-Day Retrieval Large Navigation Buoy (Sample size - 8)			August 60-Day Retrieval Discovery (Sample size - 4)			August 60-Day Retrieval Deer Island (Sample size - 5)		
	AVE	SD	Range	AVE	SD	Range	AVE	SD	Range	AVE	SD	Range
CL2-PCB(8)	2.64	1.13	1.50 - 4.20	1.88	0.69	0.93 - 2.70	4.75	4.21	2.00 - 11.00	8.64	10.67	1.30 - 27.00
CL3-PCB(18)	5.04	3.52	1.50 - 9.20	1.66	0.42	1.30 - 2.50	7.48	1.18	6.50 - 9.10	7.36	2.86	3.30 - 9.70
CL3-PCB(28)	3.44	1.60	1.50 - 5.50	2.75	0.87	1.90 - 4.60	14.00	1.83	12.00 - 16.00	9.68	3.45	5.80 - 13.00
CL4-PCB(44)	4.42	1.27	2.60 - 5.90	1.88	0.22	1.60 - 2.20	15.00	1.63	13.00 - 17.00	8.16	2.19	5.30 - 10.00
CL4-PCB(52)	12.70	3.15	9.50 - 16.00	7.48	2.25	5.20 - 12.00	34.00	4.69	27.00 - 37.00	25.00	11.58	14.00 - 43.00
CL4-PCB(66)	55.58	70.48	6.90 - 179.00	15.50	3.70	12.00 - 24.00	40.00	6.22	33.00 - 47.00	23.40	5.55	16.00 - 28.00
CL4-PCB(77)	25.80	6.42	19.00 - 34.00	10.36	3.45	2.00 - 12.00	104.00	12.11	96.00 - 122.00	41.00	12.19	23.00 - 52.00
CL5-PCB(101)	18.40	4.16	14.00 - 24.00	11.33	1.51	8.60 - 13.00	77.50	12.71	63.00 - 94.00	37.00	9.46	23.00 - 45.00
CL5-PCB(105)	2.92	1.28	1.50 - 4.50	3.94	0.47	3.20 - 4.50	11.58	12.29	1.00 - 25.00	7.34	5.47	1.30 - 13.00
CL5-PCB(118)	15.40	3.29	12.00 - 19.00	8.46	0.39	7.90 - 9.00	51.25	6.75	44.00 - 57.00	23.20	7.29	13.00 - 29.00
CL6-PCB(153)	20.30	9.98	4.50 - 31.00	12.75	1.49	10.00 - 14.00	67.25	10.05	57.00 - 80.00	34.80	10.23	20.00 - 47.00
CL5-PCB(126)	3.42	2.08	1.40 - 6.00	2.05	0.68	1.10 - 3.10	2.48	1.09	1.00 - 3.30	3.36	0.96	2.00 - 4.40
CL6-PCB(128)	4.30	2.21	1.40 - 7.20	2.55	0.40	1.80 - 2.90	14.33	6.77	9.30 - 24.00	7.58	2.79	4.70 - 11.30
CL6-PCB(138)	25.60	6.73	18.00 - 33.00	13.13	1.73	10.00 - 16.00	98.75	56.08	59.00 - 180.00	48.40	17.83	31.00 - 74.00
CL7-PCB(170)	3.42	2.08	1.40 - 6.00	1.95	0.81	0.90 - 3.10	2.45	1.17	1.00 - 3.50	2.74	1.09	1.40 - 4.40
CL7-PCB(180)	5.20	1.97	3.00 - 7.30	2.18	0.37	1.80 - 2.90	11.88	3.71	8.50 - 17.00	8.34	3.40	4.90 - 13.20
CL7-PCB(187)	19.80	7.36	12.00 - 30.00	4.81	0.37	4.40 - 5.50	28.75	14.66	19.00 - 50.00	15.60	5.57	9.60 - 23.40
CL8-PCB(195)	3.42	2.08	1.40 - 6.00	1.95	0.81	0.90 - 3.10	2.48	1.09	1.00 - 3.30	3.26	1.04	2.00 - 4.40
CL9-PCB(206)	3.40	2.10	1.30 - 6.00	1.95	0.81	0.90 - 3.10	5.30	4.69	2.30 - 12.30	3.26	1.04	2.00 - 4.40
CL10-PCB(209)	3.42	2.08	1.40 - 6.00	1.95	0.81	0.90 - 3.10	2.48	1.09	1.00 - 3.30	3.26	1.04	2.00 - 4.40
Total PCB's	238.62	91.70	160.20 - 394.20	110.49	8.87	94.80 - 123.60	595.67	104.06	482.60 - 701.10	321.38	96.39	191.50 - 407.20

Table 11. Target metals (ug/Kg dry weight) concentrations in mussels exposed at Gloucester and two stations. Total metals were calculated using the detection limit value as an estimated concentration when individual analytes were not detected. Tissue weight data were obtained from Table 3.

Gloucester Predeployment, June 1993								Total Weight (g)		NON-GONADAL TISSUE CONCENTRATION ADJUSTED	
Laboratory ID:	188933	188934	188936	188937	188941	AVE	STD	Soft Tissue	Non-Gonadal	AVE	STD
Parameter											
Mercury	250	230	390	630	470	394	165.2	6.5	4.4	581	243.5
Lead	5100	4100	6600	4900	4900	5120	912.1	6.5	4.4	7547	1344.5

Large Navigation Buoy, August 1993												
Laboratory ID:	196376	196377	196378	196379	196380	196381	196382	196383	AVE	STD		AVE	STD
Parameter													
Mercury	96	108	102	86	88	101	126	87	99	13.4	10.9 6.5	161	15.5
Lead	5100	4600	3600	3600	3500	3300	2300	3700	3713	840.8	10.9 6.5	6831	1215.5

Deer Island, August 1993									
	196384	196385	196386	196387	196388	AVE	STD		AVE	STD
Parameter										
Mercury	173	220	150	174	200	183	27.1	10.2 6.3	299	44.0
Lead	4300	10400	4100	2800	7800	5880	3133.2	10.2 6.3	9571	5100.2

Table 12. Comparison of body burdens of deployed mussels for select organic compounds and metals.

Parameters	Mussel Watch National Mean AVE	Mussel Watch National High (1) AVE	MWRA 1987 Deer Island AVE	MWRA 1991 Gloucester AVE	MWRA 1991 Discovery AVE	MWRA 1991 Deer Island AVE	MWRA 1992 Gloucester AVE	MWRA 1992 LNB AVE	MWRA 1992 Discovery AVE	MWRA 1992 Deer Island AVE	MWRA 1993 (2) Predeployment Gloucester AVE	MWRA 1993 (2) LNB AVE	MWRA 1993 (2) 60-day Discovery AVE	MWRA 1993 (2) 60-day Deer Island AVE	Lynn 1993 60-DAY Gloucester AVE	Lynn 1993 60-DAY Lynn AVE
PAH (ug/Kg dry weight)			1221	113	239	516	80	61	199	427	66	66	110	169	70	90
LMW PAH			1123	104	2330	691	136	69	3347	1507	122	101	1210	496	113	143
HMW PAH			2343	217	2569	1207	216	129	3546	1934	188	166	1321	665	183	232
Total PAH	260	890														
Pesticides (ug/Kg dry weight)				7	24	28	6	6	47	19	16	11	26	24	9	15
Total Chlordane	14	31	63	28	94	48	15	12	103	25	82	30	130	63	24	36
Total DDT	37	120														
Polychlorinated Biphenyls (ug/Kg dry weight)																
Total PCB	110	470	630	77	477	199	65	44	652	133	239	110	596	321	86	134
Metals (mg/Kg dry weight)																
Lead	1.80	4.30	1.94	6.50	6.40	5.90					5.12	3.71		5.88	2.80	2.40
Mercury	0.09	0.24									0.39	0.10		0.18	0.56	0.17

1 "High" concentrations were reported by the Mussel Watch Program as one where the logarithmic value is more than the mean plus one standard deviation of the logarithms for all concentrations.

2 Concentrations may be biased high due to the GC/ECD methodologies for pesticides / PCB's employed in 1993. See text for discussion.

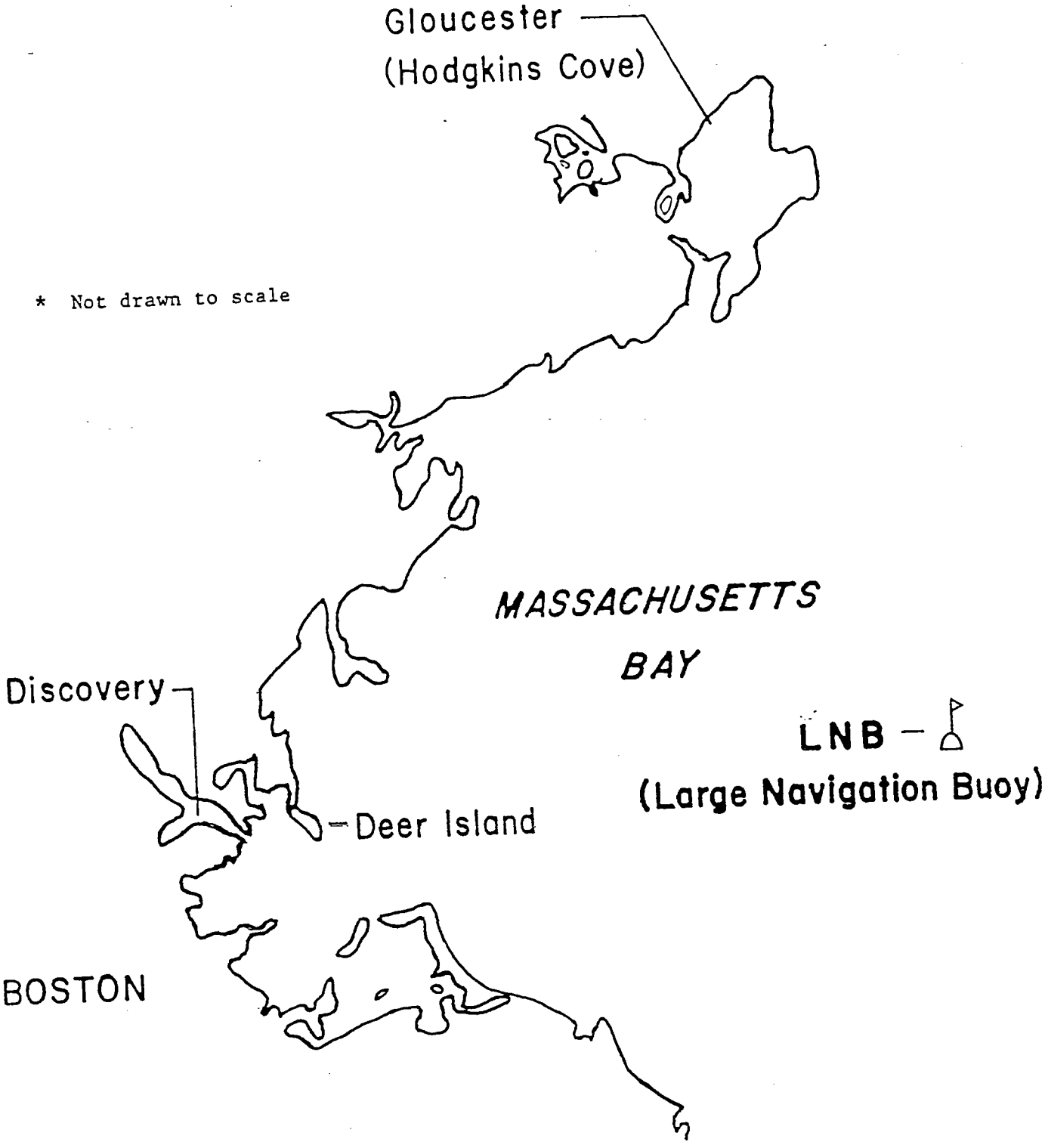

Figure 1. The mussel deployment locations for the 1993 bioaccumulation study. The Gloucester location was the source of all mussels for the study.

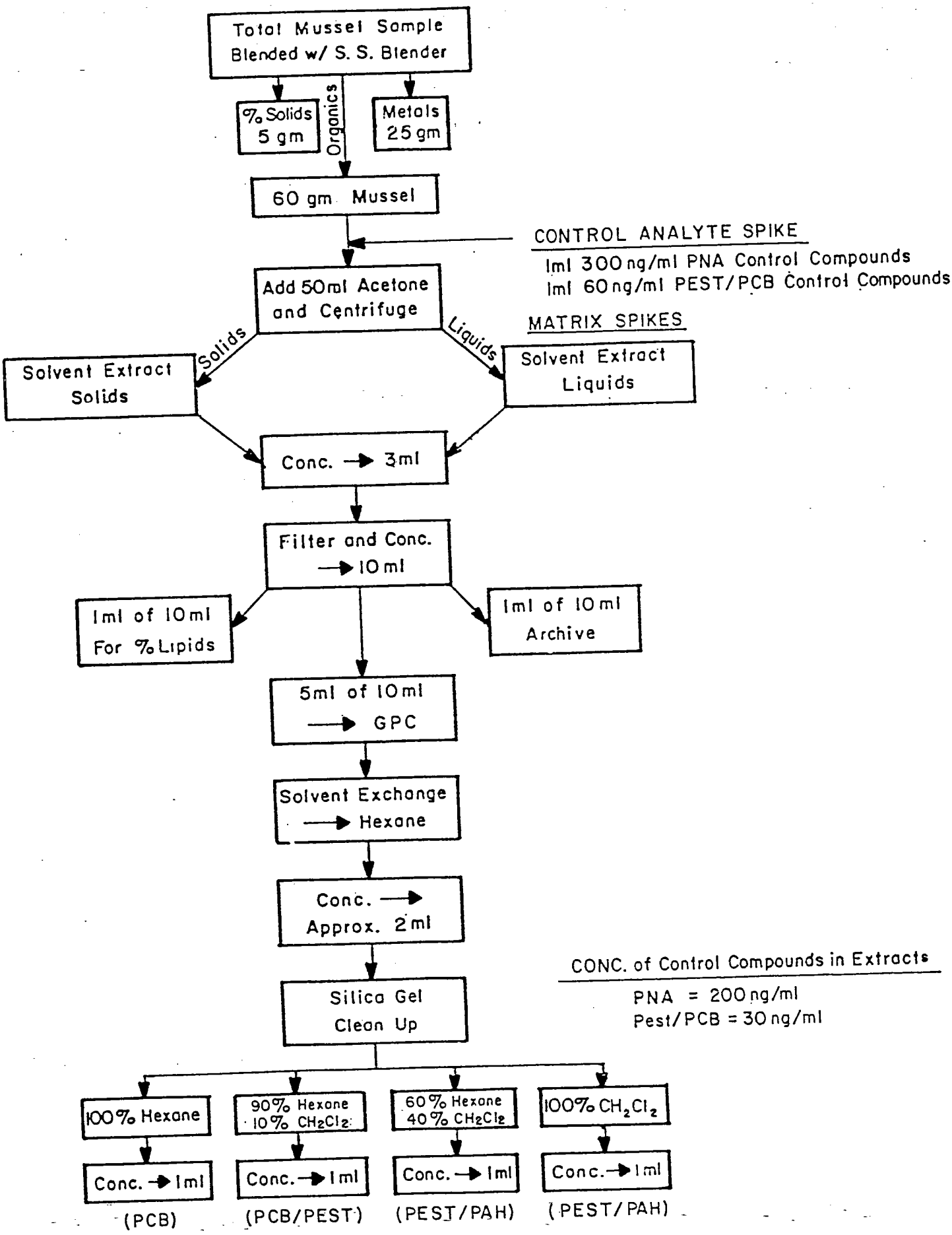

Figure 2. Extraction procedures and analytical methods for organic compounds.

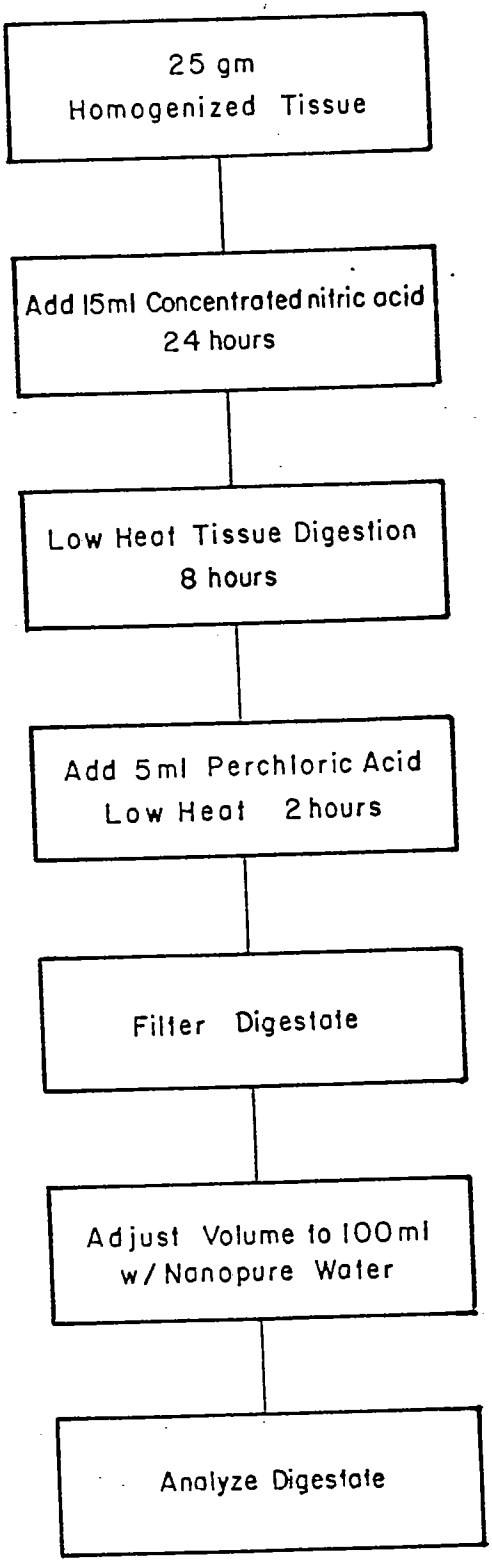

Figure 3. Methodology used for metal analysis of mussel tissues.

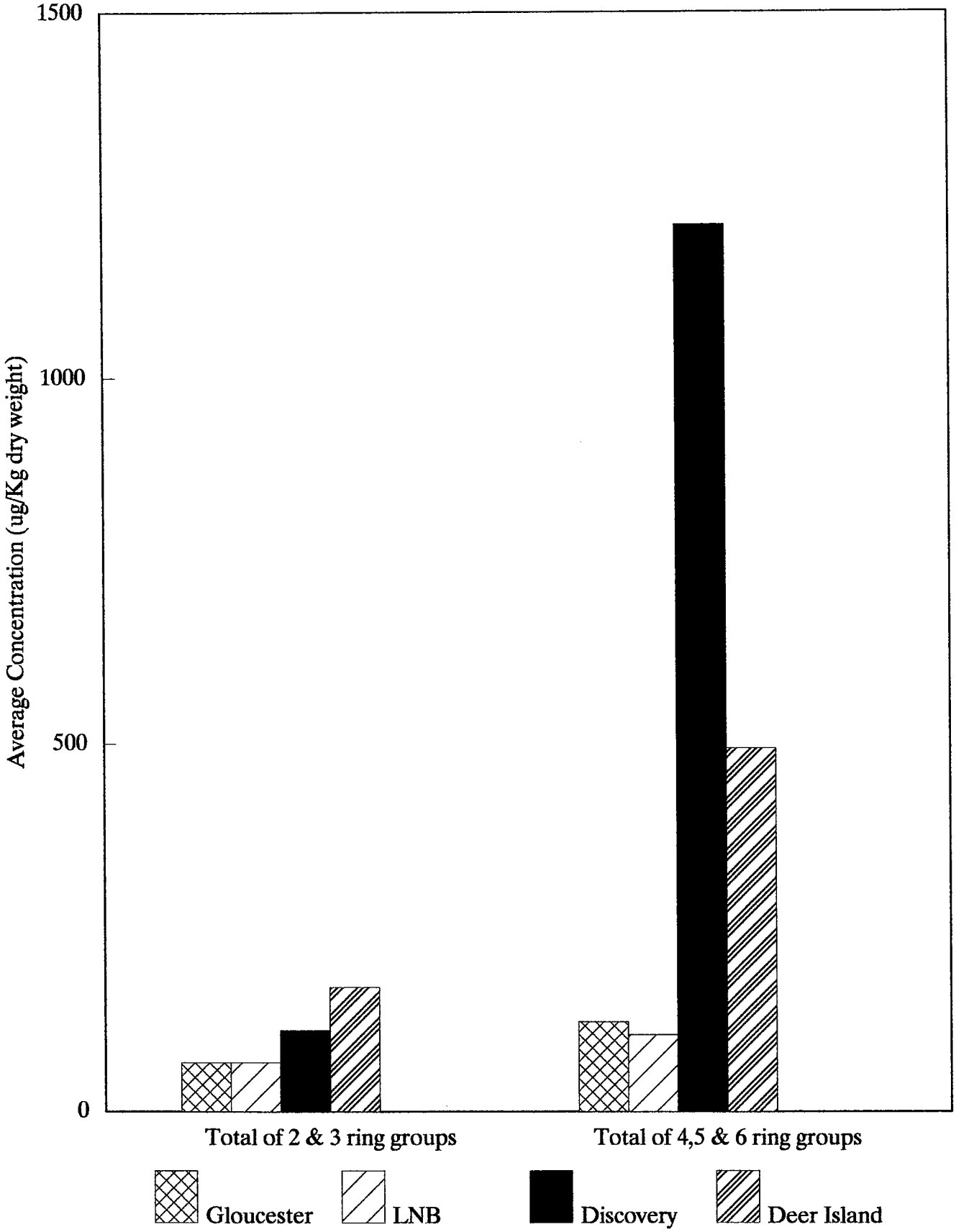

Figure 4. Average concentrations of two groups (2 & 3 ring; 4, 5 & 6 ring) of polynuclear aromatic hydrocarbons in mussel tissue collected from the four stations.

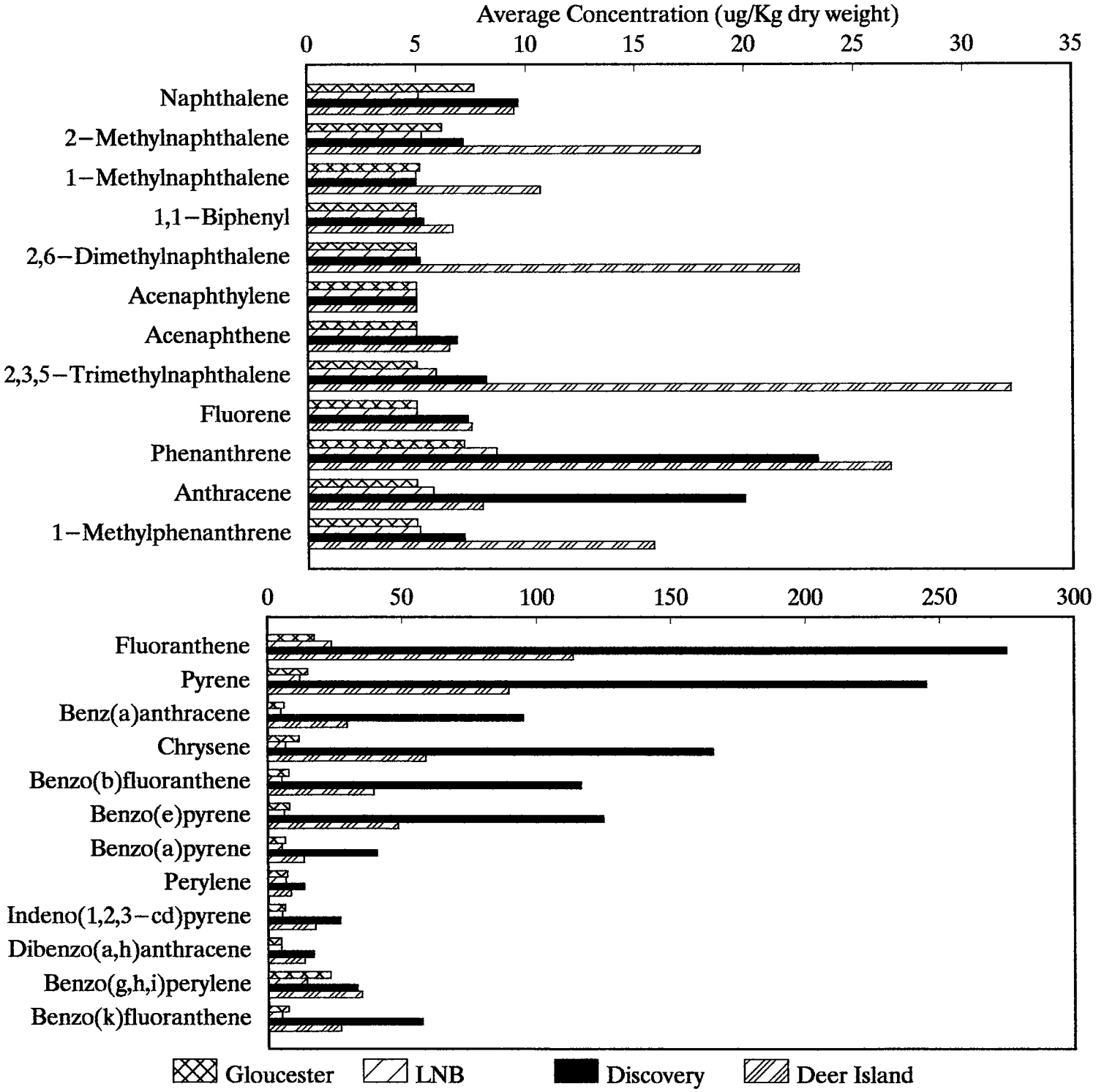

Figure 5. Average concentrations of polynuclear aromatic hydrocarbons in mussel tissue collected from the four stations.

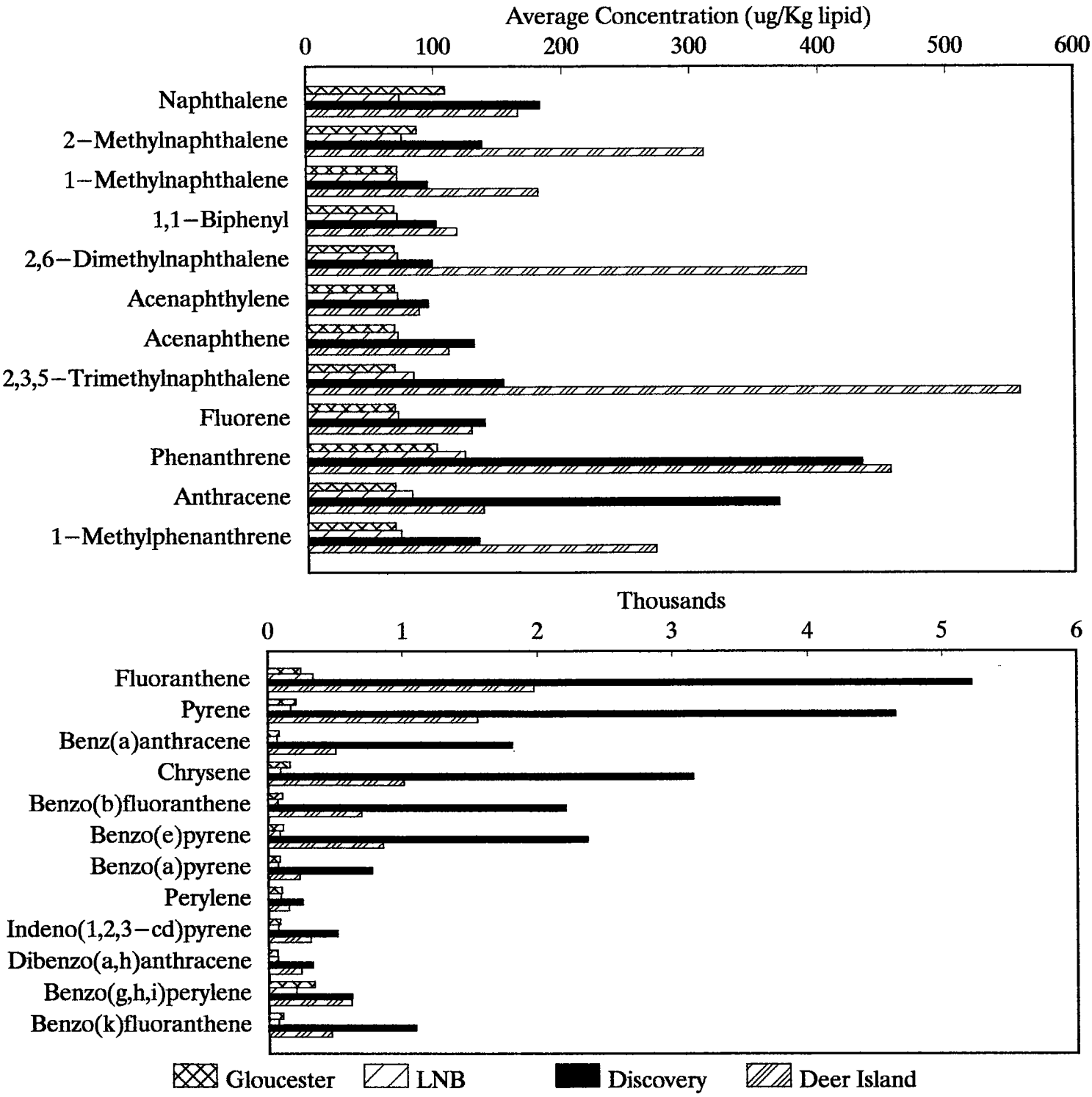

Figure 6. Lipid−adjusted average concentrations of polynuclear aromatic hydrocarbons in mussel tissue collected from the four stations.

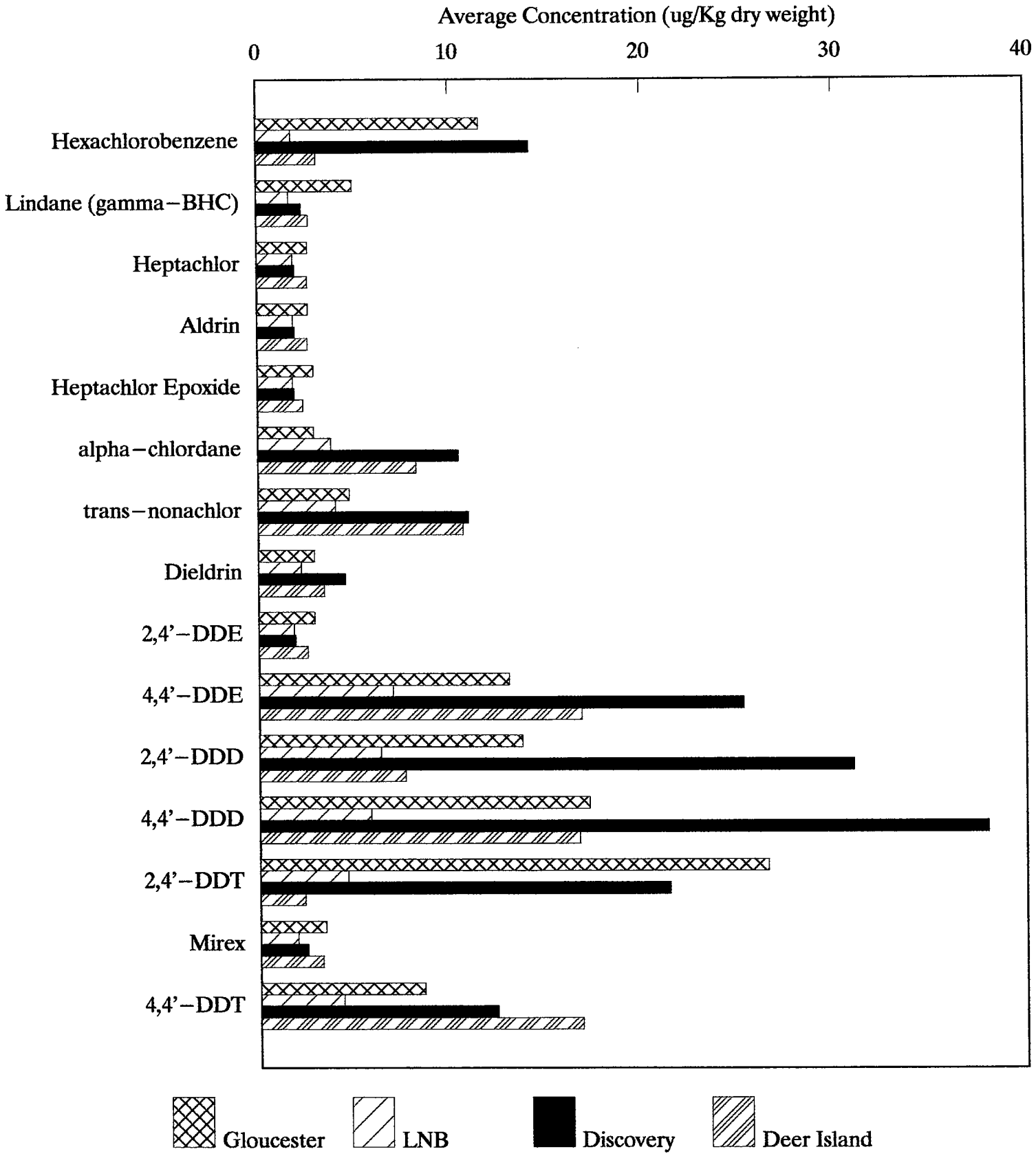

Figure 7. Average concentrations of pesticides in mussel tissue collected from the four stations.

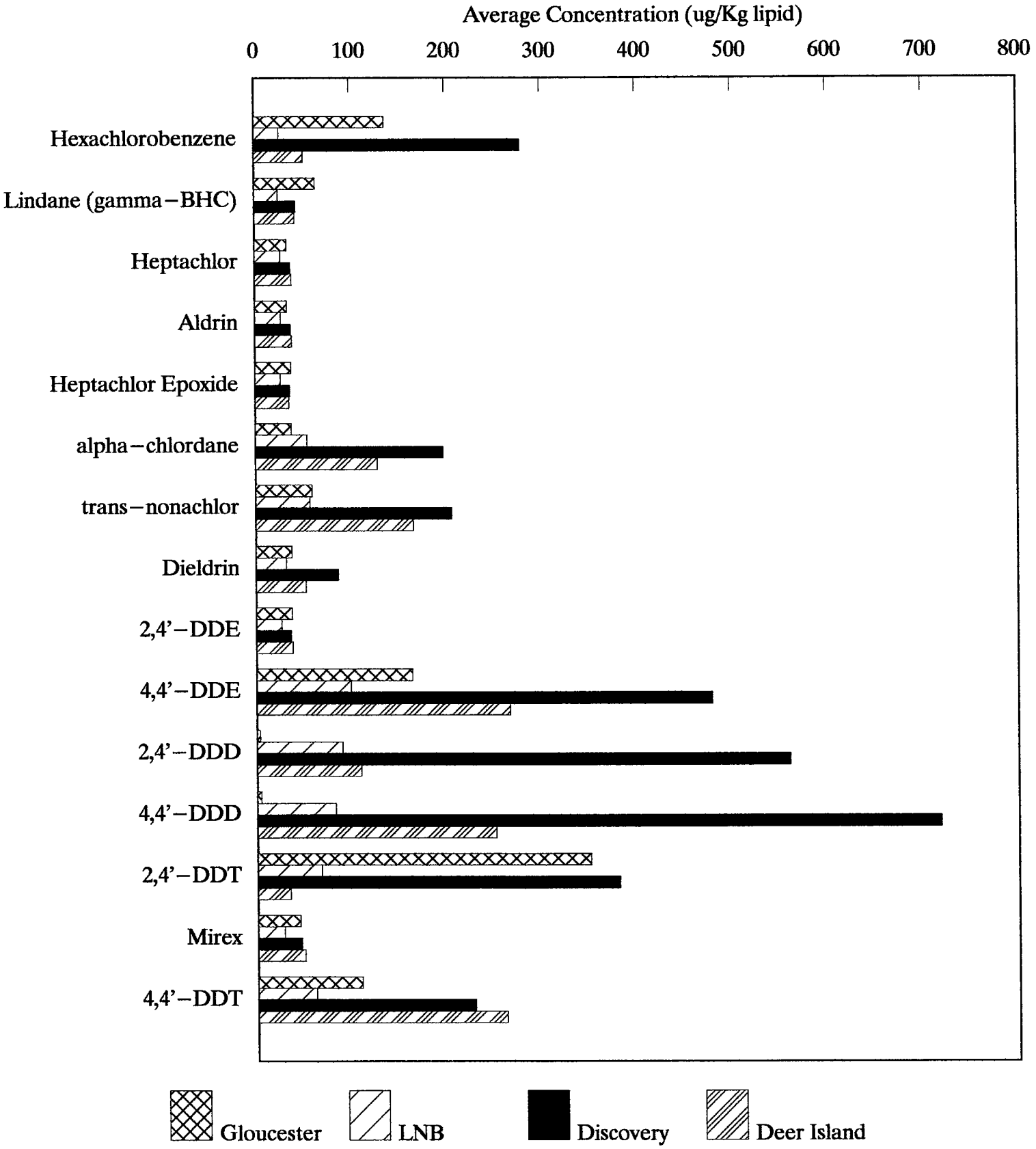

Figure 8. Lipid–adjusted average concentrations of pesticides in mussel tissue collected from the four stations.

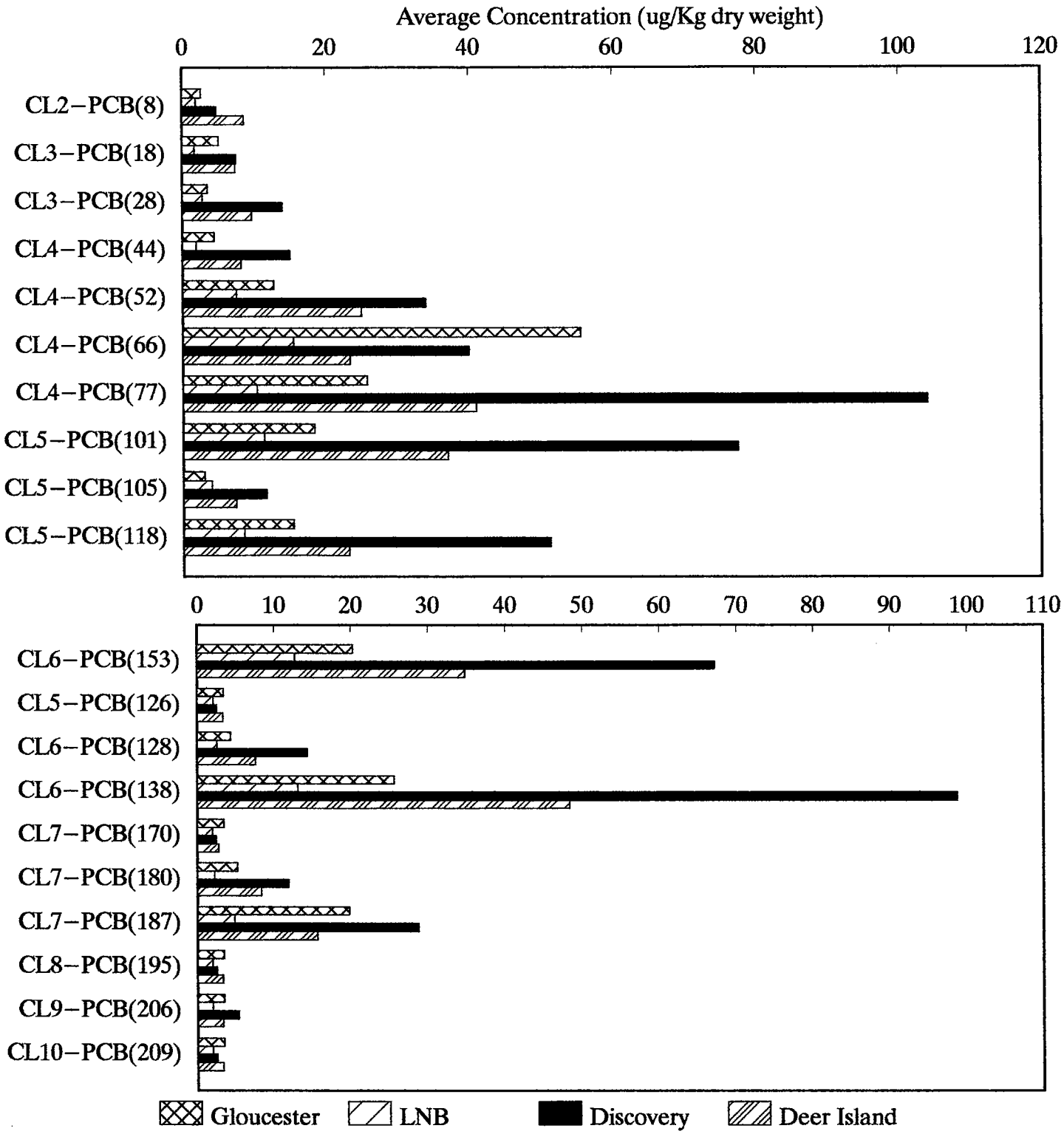

Figure 9. Average concentrations of polychlorinated biphenyls in mussel tissue collected from the four stat

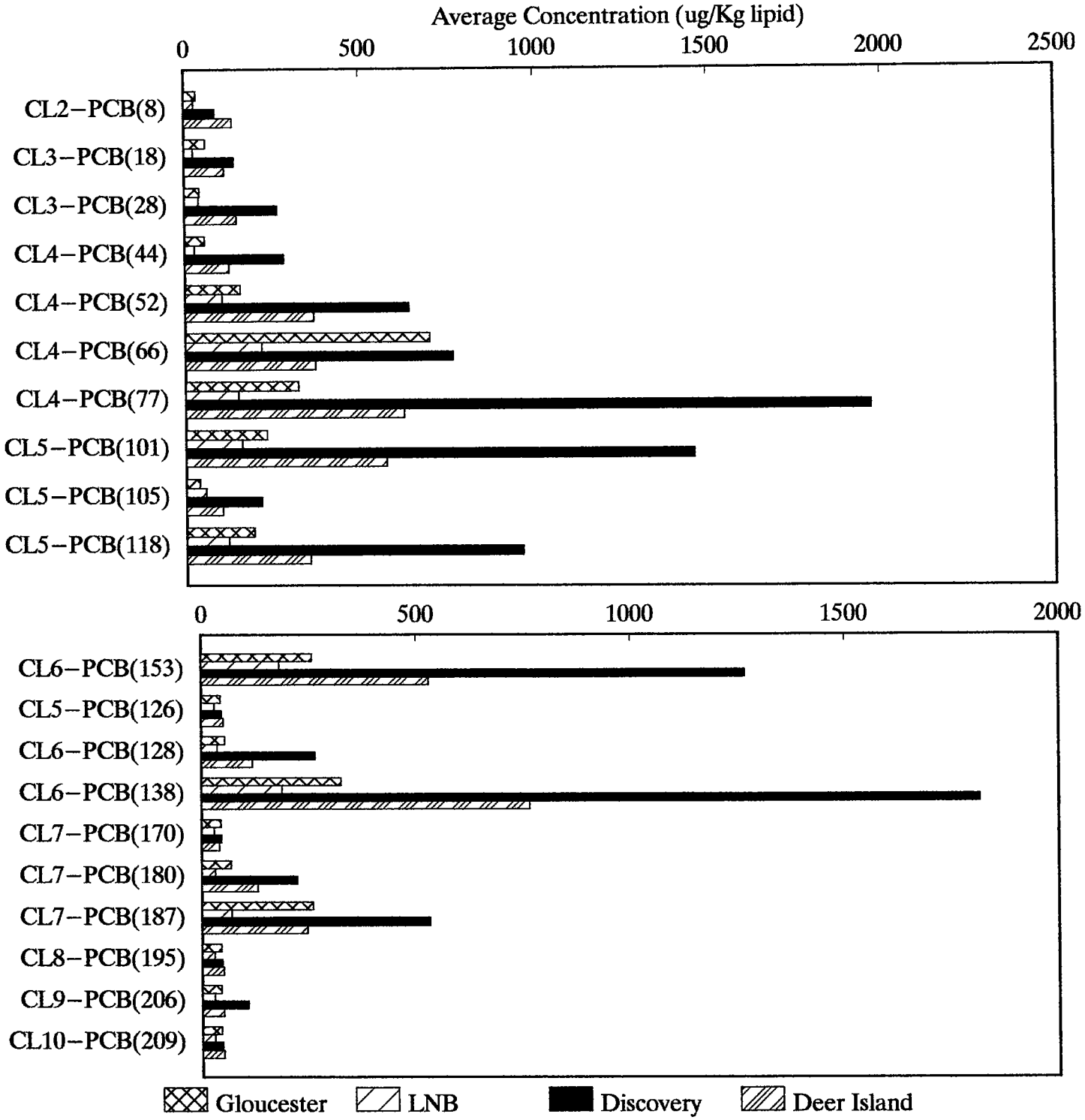

Figure 10. Lipid-adjusted average concentrations of polychlorinated biphenyls in mussel tissue collected from the four stations.

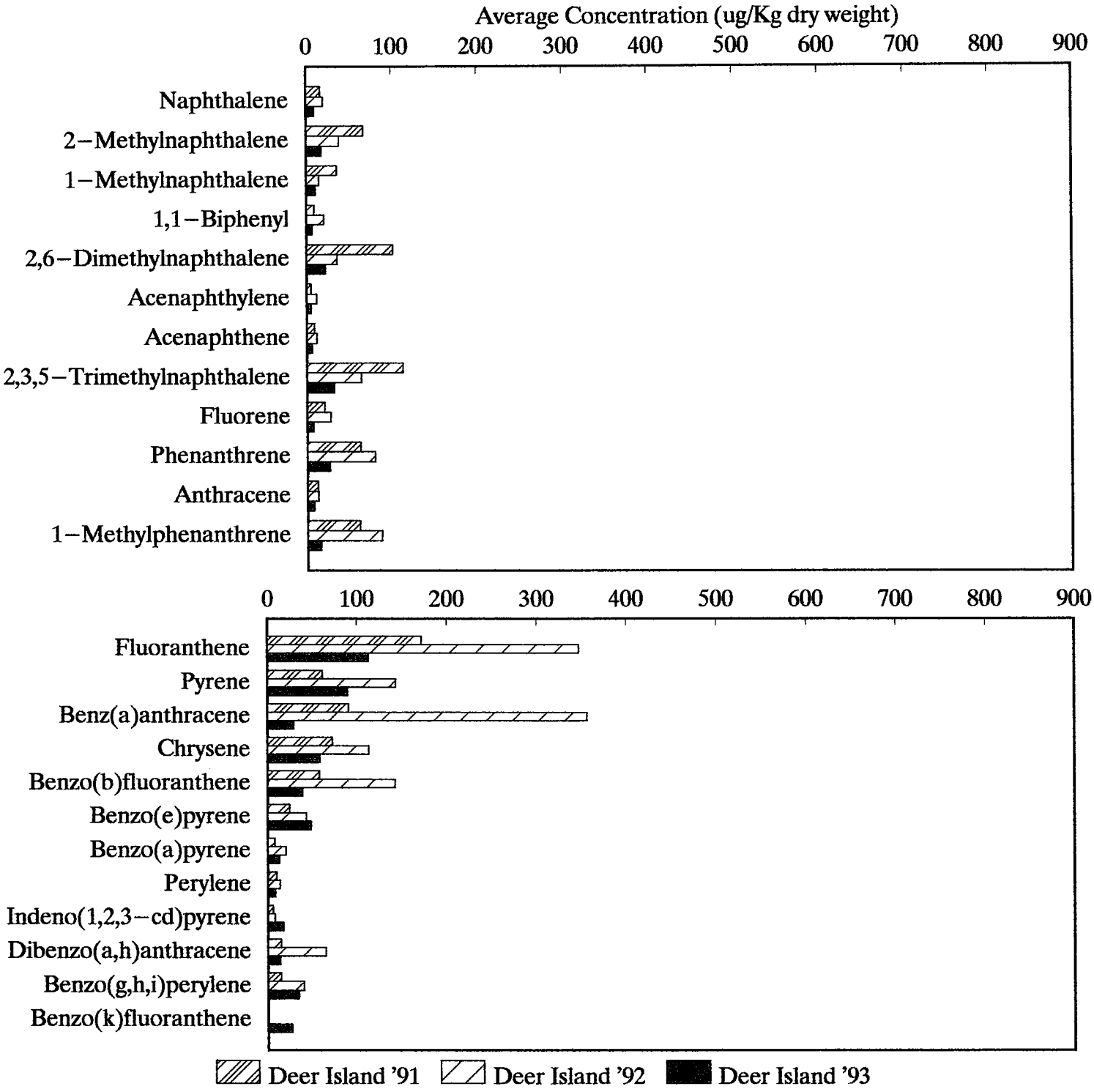

Figure 11. Average concentrations of polynuclear aromatic hydrocarbons in mussel tissue collected from Deer Island, 1991 – 1993.

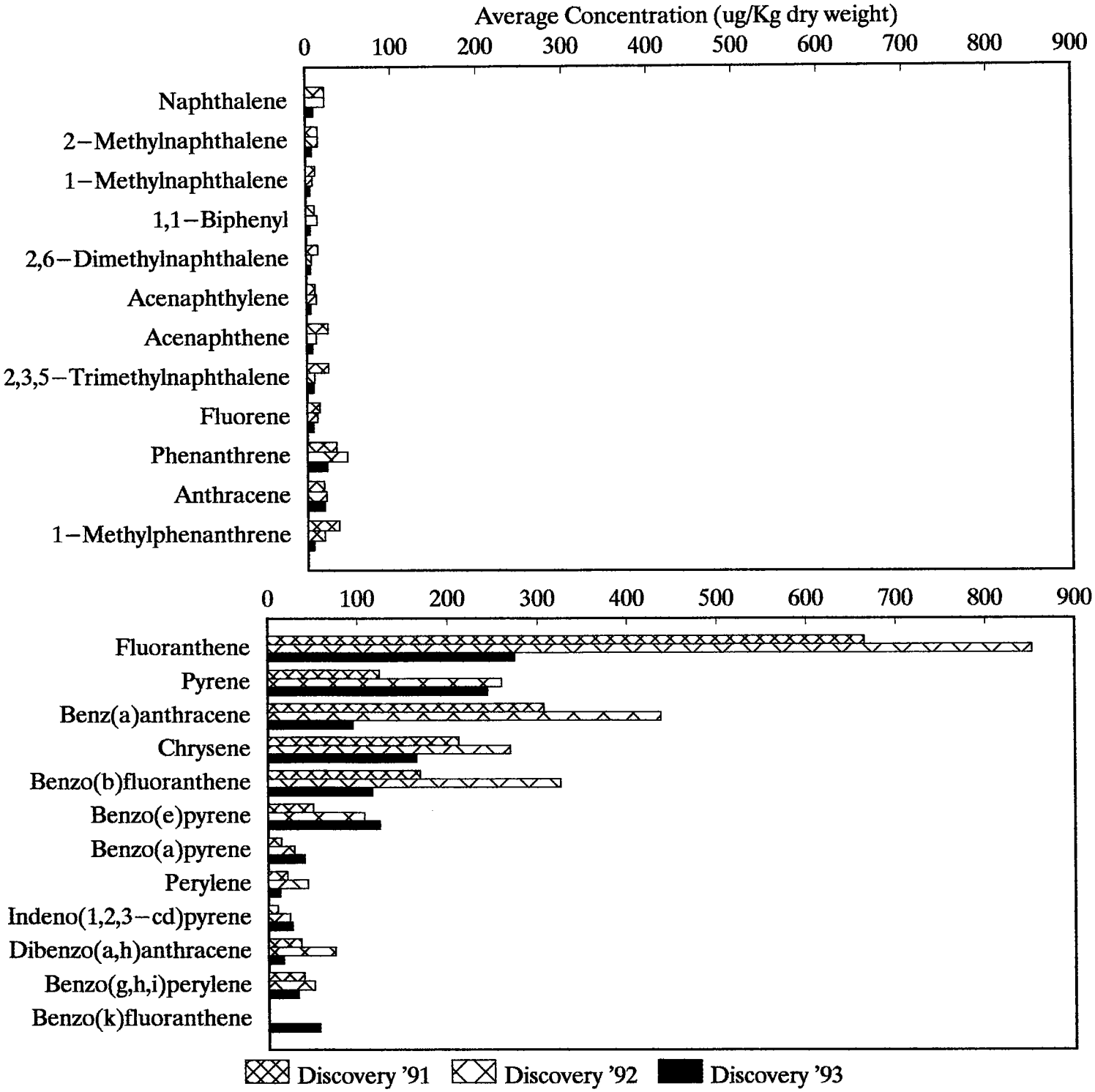

Figure 12. Average concentrations of polynuclear aromatic hydrocarbons in mussel tissue collected from Discovery, 1991 – 1993.

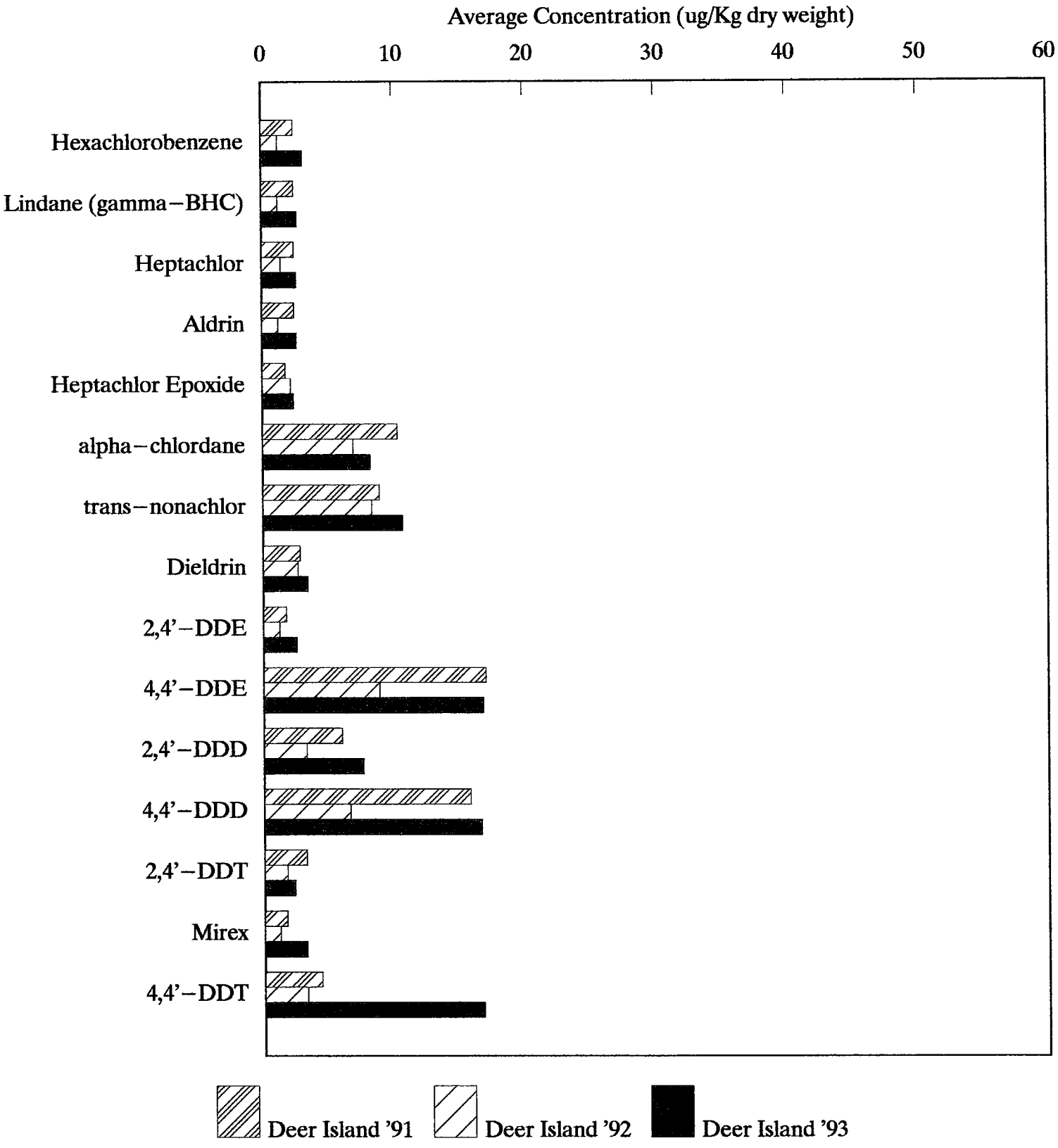

Figure 13. Average concentrations of pesticides in mussel tissue collected from Deer Island, 1991 – 1993.

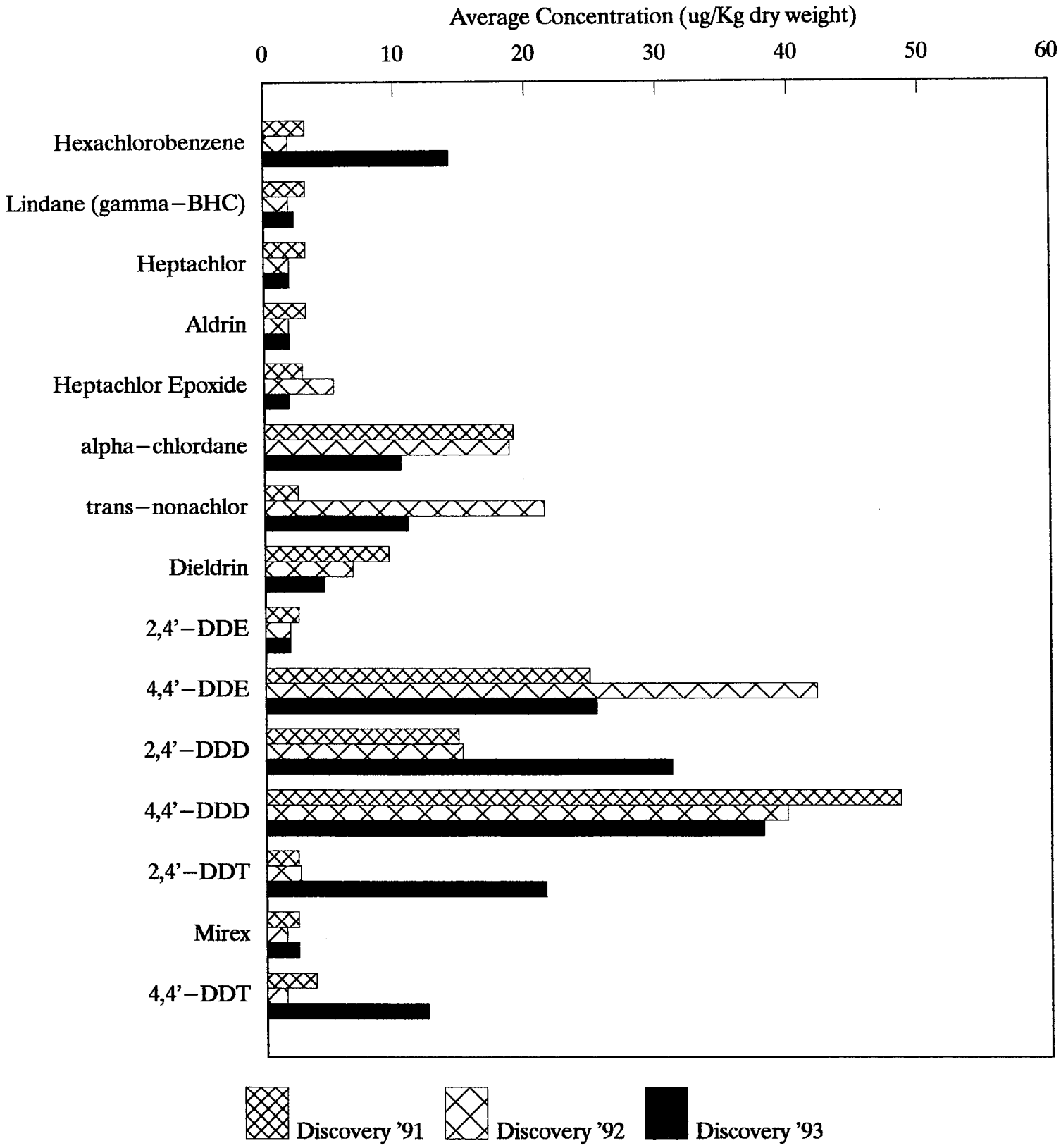

Figure 14. Average concentrations of pesticides in mussel tissue collected from Discovery, 1991 – 1993.

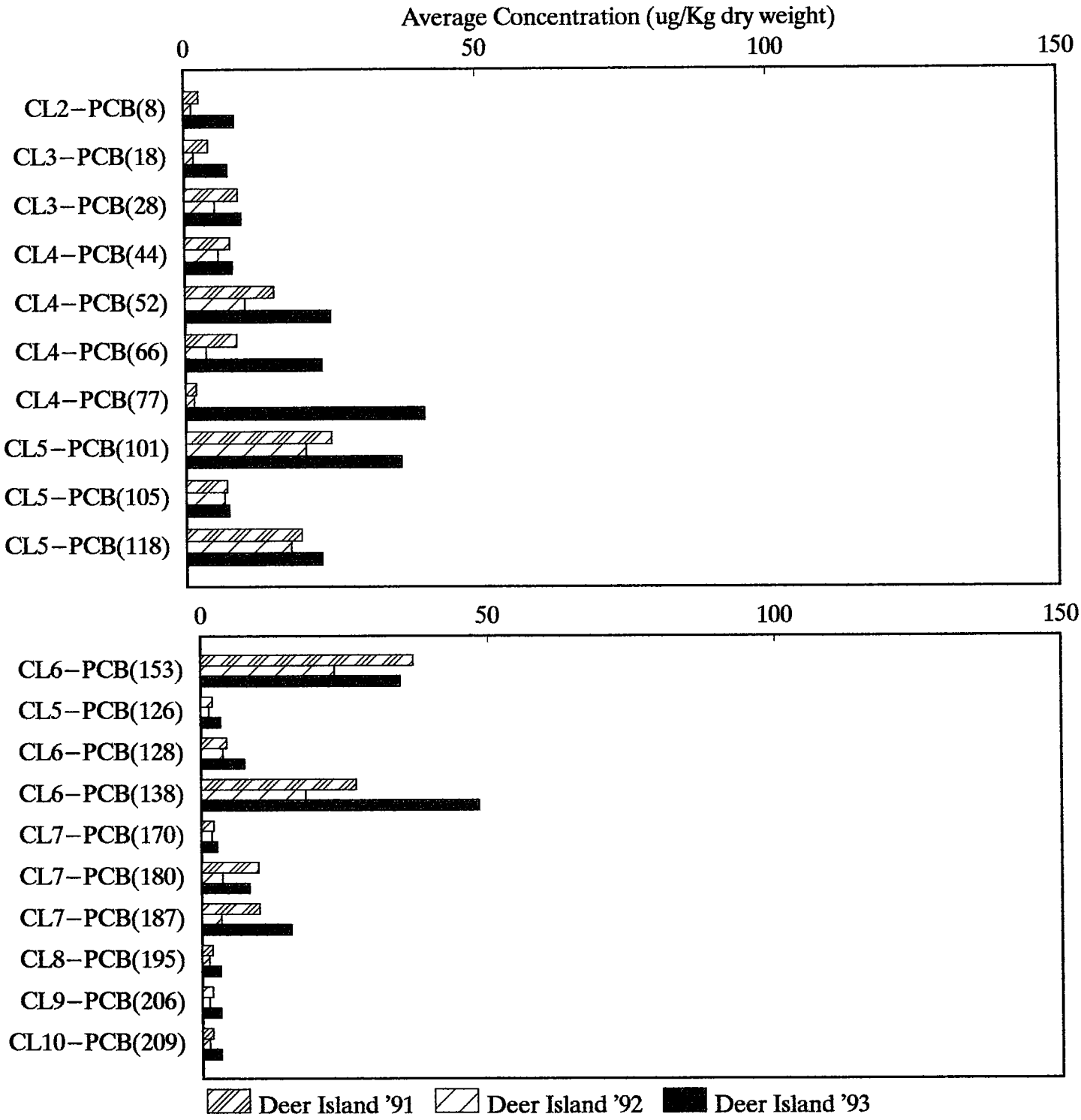

Figure 15. Average concentrations of polychlorinated biphenyls in mussel tissue collected from Deer Island, 1991 – 1993.

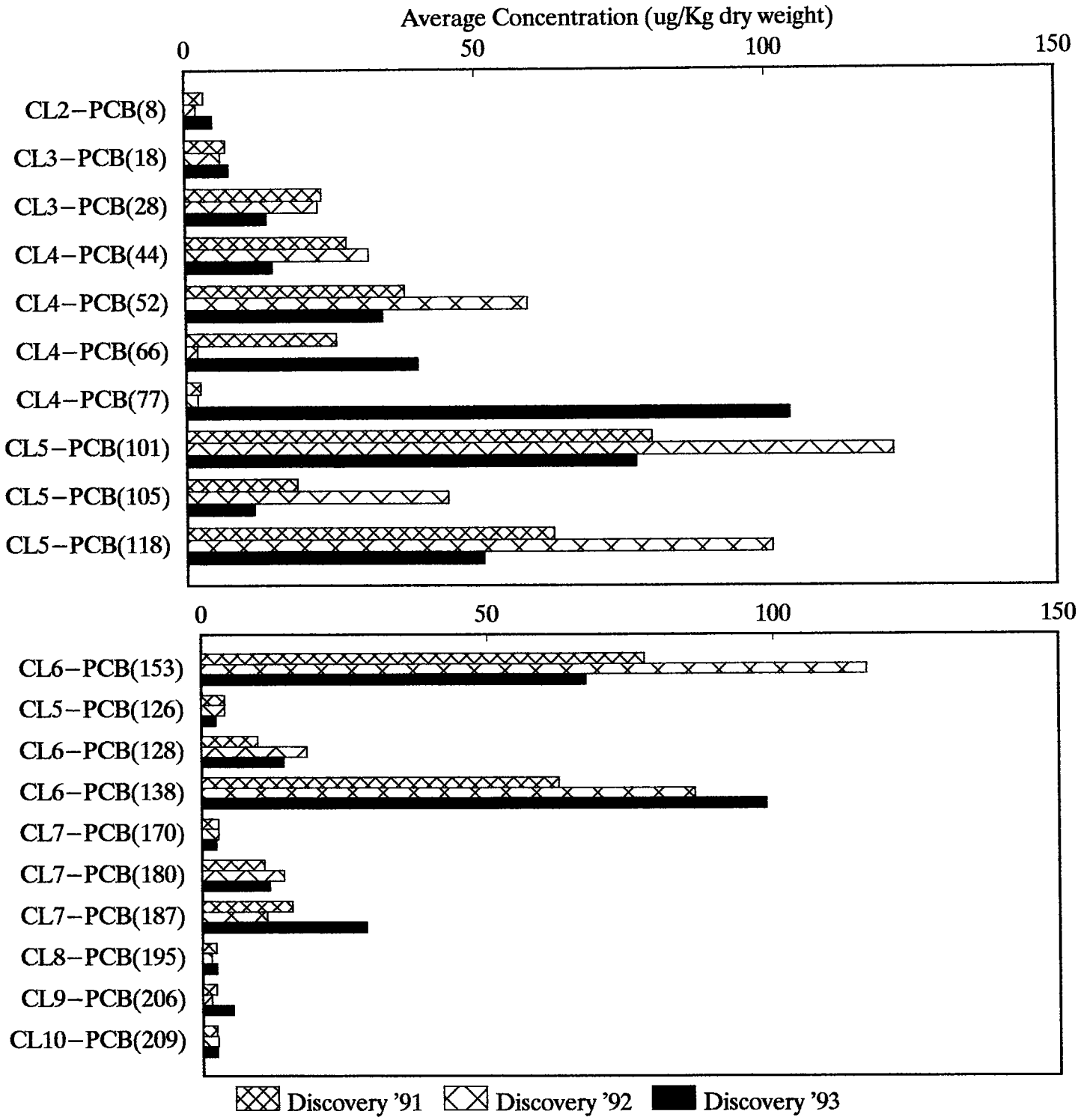

Figure 16. Average concentrations of polychlorinated biphenyls in mussel tissue collected from Discovery, 1991 – 1993.

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