NOAA Technical Memorandum NMFS-NE-167

Assessment and Characterization of Salt Marshes in the Arthur Kill (New York and New Jersey) Replanted after a Severe Oil Spill

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

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Assessment and Characterization of Salt Marshes in the Arthur Kill (New York and New Jersey) Replanted after a Severe Oil Spill

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Acronyms

AAS	=	atomic absorption spectrophotometry
ANOVA	=	analysis of variance
BOD	=	biological oxygen demand
CPI	=	carbon preference index
DARP	=	(NOAA) Damage Assessment and Restoration Program
DDI	=	double de-ionized
DIW	=	de-ionized water
FID	=	flame ionization detection (detector)
GC	=	gas chromatography (chromatogram)
GC-FID	=	gas chromatography - flame ionization detection
GC/MS	=	gas chromatography/mass spectrometry
HDPE	=	high-density polyethylene
HP	=	Hewlett-Packard
LC	=	labile carbon
MDL	=	method detection limit
MS	=	mass spectrometry
nd	=	not detected
NIST	=	(U.S. Department of Commerce) National Institute of Standards and Technology
NJDEP	=	New Jersey Department of Environmental Protection
NMFS	=	(U.S. Department of Commerce, NOAA) National Marine Fisheries Service
NRC	=	National Research Council
NYCDEP	=	New York City Department of Environmental Protection
OC	=	organic carbon
PAH	=	polycyclic aromatic hydrocarbon
PCA	=	principal component analysis
PD	=	percent difference
QA	=	quality assurance
RPD	=	relative percentage difference
RSD	=	relative standard deviation
SMRT	=	(New York City Department of Parks and Recreation) Salt Marsh Restoration Team
SRM	=	standard reference material
TIPH	=	total of individual petroleum hydrocarbons
TOC	=	total organic carbon
TPH	=	total petroleum hydrocarbons
WI	=	weathering index

PREFACE

For further information on the oil spill in the Arthur Kill, as well as pictures of the marsh sites and plantings, see the National Oceanic and Atmospheric Administration (NOAA), Damage Assessment and Restoration Program (DARP), *Exxon Bayway* Wetland Acquisition and Restoration webpage (*http://www.darp.noaa.gov/neregion/exbw.htm*). DARP is a collaborative effort among NOAA's National Ocean Service, National Marine Fisheries Service, and the Office of General Counsel. DARP's mission is to restore coastal and marine resources that have been injured by releases of oil or hazardous substances and to obtain compensation for the public's lost use and enjoyment of these resources.

ABSTRACT

On January 1 and 2, 1990, a 576,000-gal oil spill seriously damaged the salt marshes of the Arthur Kill, the strait separating Staten Island, New York, from New Jersey. The New York City Salt Marsh Restoration Team (SMRT) implemented a multiyear restoration and monitoring project to restore those parts of the marshes directly impacted by the oil spill. Restoration activities included successfully reintroducing Arthur-Kill-propagated saltmarsh cordgrass, *Spartina alterniflora*, and monitoring several parameters both in oiled marshes that were replanted and in oiled marshes that were left for natural recovery. Those parameters included: peak standing biomass, stem and flower density, and height of *S. alterniflora*; sediment total petroleum hydrocarbons (TPH); density of ribbed-mussels (*Geukensia demissa*); fish abundance and diversity; and wading bird (*i.e.*, egret) foraging success.

Results of the monitoring suggest that the replanting of *S. alterniflora* was very important for recovery and restoration of the saltmarsh ecosystem. This replanting of *S. alterniflora* provides much of the structural component of the marsh; restoring this component to levels found elsewhere in the Arthur Kill is important to the other members of the food web, such as the mussels, mummichogs, and birds. It is particularly significant in an urbanized landscape, where habitats are few and isolated.

However, questions remain as to the ecological viability and functional equivalency of these marshes. The problem is compounded because not only was almost every low marsh within the Arthur Kill affected to some extent by the 1990 spill, but this estuary is heavily urbanized and degraded; its marshes are continuously impacted by contaminants and other anthropogenic influences. In 1996 and 1997, the National Marine Fisheries Service (NMFS) sought to supplement the SMRT monitoring efforts via a preliminary characterization and assessment of marshes that were oiled and replanted, marshes that were oiled but not planted, and nearby pre-existing *S. alterniflora* reference marshes, with a view toward noting any differences among the marshes, especially those that might be attributable to the replanting efforts. The measured parameters include trace metal and hydrocarbon contaminants in ribbed-mussels and sediments, sediment biogeochemistry, age and growth of ribbed-mussels, macrobenthic distribution and abundance, and diets of the mummichog (*Fundulus heteroclitus*). Sampling occurred in fall 1996 and spring-summer 1997.

Results of the NMFS study are less clear than those of the previous SMRT monitoring effort with regard to the benefits of replanting, or even to the differences among sites. Trace metal concentrations in the sediments at each marsh were site specific and more dependent upon the general characteristics of the sediment, such as the percentage of fine-grained sediments and iron content, than upon whether or not the marsh was replanted. Compared to concentrations from a reference marsh outside the Arthur Kill, metal concentrations in sediments from the entire Arthur Kill were elevated. There were no consistent differences in metal concentrations in mussels collected from replanted and unplanted marshes, while concentrations of many metals in mussels from two of three reference marshes were significantly lower. However, as with the metal concentrations in the sediments, replanting may not have had a great effect on the levels of trace metals in the mussels.

The TPH concentrations in surface sediments from the southernmost reference marsh were numerically the lowest, those from the northernmost oiled and replanted marsh were intermediate, and those from one oiled but unplanted barren marsh were the highest; residual oil is still evident in sediments at this latter marsh. The lower levels of oil at the reference and replanted marshes may be due to oxidation and weathering of the oil, perhaps caused by the physical disturbance of planting and by the mineralization of oil by microbes around the roots of *S. alterniflora*. The TPH concentrations in mussels from all marshes were low, were not significantly different, and showed no temporal trend; thus, replanting efforts do not appear to have affected the levels of TPH in the mussels.

For biogeochemistry, the spatio-temporal patterns of porewater redox potential, soluble sulfide, and total organic carbon in the marsh sediments showed statistically significant differences with depth and season. However, these differences were not meaningful for assessment of replanting success because they appeared to owe more to the peculiarities of individual sampling stations within each of the marshes than to replanting status. Quantitative differences among station data within each marsh were so large, and distributions of values at those stations were so skewed, as to render differences uninterpretable in terms of replanting. No patterns characteristic of replanted, unplanted, or reference marshes were identified, nor were characteristic differences among sites fitting these treatment categories evident. The biogeochemistry appears to be mediated by factors not clearly related to replanting. The marshes were heterogeneous with respect to these factors, confounding efforts to identify replanting-specific effects. Among those confounding factors were differences in grain size distribution, surface and subsurface hydrology, macrobiotic activity, and anthropogenic influences.

Ribbed-mussels from the replanted sites were younger, smaller, weighed less, and grew slower than mussels from the southernmost Arthur Kill reference site. The older, larger mussels collected at the reference marsh represent cumulative growth processes over many generations at a mature and relatively undisturbed marsh that was minimally affected by the oil spill. The younger, smaller mussels collected at the replanted sites most likely reflect growth processes since replanting. Although the chronic effect of oil from the spill and the disturbance caused by the replanting process may have affected growth rates at the replanted sites, other natural and anthropogenic site-specific factors may also have been responsible.

The invertebrate taxa found within the sediments of the Arthur Kill marshes appear to be similar to invertebrate taxa found in *S. alterniflora* marshes elsewhere. Abundances of most taxa were highest in the spring. Although there may be similarities in invertebrate abundances between the replanted and reference marshes, quantitative evaluation was confounded due to the low number of replanted and reference sites sampled and to the high variability in the data, which is typical of benthic surveys.

The high percentages of detritus and algae, as opposed to live prey, in the mummichog stomachs may indicate a poor diet in a polluted environment, as suggested by previous studies. The mummichog diets may or may not have been site specific. A more thorough investigation would be necessary to discern such patterns in the data, as has been demonstrated for several of our other investigations.

In conclusion, although replanting of the oil-damaged Arthur Kill marshes by SMRT may have successfully "restored" them, at least structurally, to the level of the existing marshes found within the Arthur Kill, because this is an urban estuary, the extent to which the ecological functions of these marshes have been restored is more difficult to ascertain due to confounding factors such as pollution and other anthropogenic impacts. Also, the time span of the NMFS studies may have been too short and the number of treatment sites chosen may have been too small to accurately assess the performance of the replanted marshes, especially given the many scales of natural spatial and temporal variability and anthropogenic perturbations inherent in this ecosystem. Nevertheless, SMRT continues to replant and monitor these marshes where necessary, insuring that this vital habitat is protected from further loss and degradation.

I. INTRODUCTION

On January 1 and 2, 1990, an oil spill of 576,000 gal of No. 2 heating oil from an underwater Exxon pipeline seriously affected wildlife and aquatic plant communities of the Arthur Kill, the strait separating Staten Island, New York, from New Jersey (Burger 1994; Figures 1 and 2). The leak occurred at Morses Creek in the northern reach of the Kill, and affected areas as far north as the Kill van Kull and Newark Bay, and as far south as the Outerbridge Crossing. The total petroleum hydrocarbon (TPH) content of sediments in the area was as high as 120,000 µg/g, and exceeded 1000 µg/g in about 50% of the sediments tested (Louis Berger and Associates 1991). In areas closest to the spill, the dominant vegetation of the low marsh -- saltmarsh cordgrass (*Spartina alterniflora*) -- was eradicated, and mussel beds were heavily damaged, locally experiencing up to 100% mortality (Louis Berger and Associates 1991). Approximately 700 aquatic birds were killed outright, and the 1990 breeding season was seriously disrupted.

The New York City Department of Parks and Recreation's Salt Marsh Restoration Team (SMRT) implemented a multiyear restoration and monitoring project to restore those parts of the marshes directly impacted by the 1990 oil spill. Restoration activities included the successful reintroduction of over 9 acres of Arthur Kill-propagated *S. alterniflora* (Bergen *et al.* 2000). The SMRT has been monitoring several parameters both in oiled marshes that were replanted and in oiled marshes that were left for natural recovery. Those parameters included: peak standing biomass, stem and flower density, and height of saltmarsh cordgrass; sediment TPH; density of ribbed-mussels (*Geukensia demissa*); fish abundance and diversity; and wading bird (egret) foraging success (Bergen *et al.* 2000; C. Alderson *et al.*, Salt Marsh Restoration Team, Natural Resources Group, New York City Parks, 200 Nevada Ave., Staten Island, NY, pers. comm. and unpubl. data).

Understanding the development and functional value of restored salt marshes requires an understanding of how natural salt marshes function. There have been several studies comparing the relative and functional value of restored marshes to natural marshes (*e.g.*, Cammen 1976; Race and Christie 1982; Pacific Estuarine Research Laboratory 1990; LaSalle *et al.* 1991; Minello and Zimmerman 1992; Zedler 1993; Matthews and Minello 1994; Sacco *et al.* 1994; Havens *et al.* 1995; Thompson *et al.* 1995; Levin *et al.* 1996; Simenstad and Thom 1996; see also Kentula 2000). However, many restored wetlands have not been scientifically evaluated for their success in approaching the equivalent functional levels of natural wetland habitats; indeed, determining the "functional equivalency" of a restored wetland compared to a natural wetland is very difficult, and appraising the success of a restoration is problematic (*e.g.*, see Simenstad and Thom 1996; Kentula 2000; Zedler and Callaway 2000). Lewis (2000) noted that "no generally accepted and applied criteria for establishing goals for coastal wetland restoration projects exist even today," although authors such as Short *et al.* (2000) are in the process of developing success criteria for estuarine restoration projects. In fact, the term "restored" itself is not quite correct: most current research in this field focuses on *created* or *constructed* salt marshes [marshes created in response to mitigation efforts; *e.g.*, Zedler *et al.* (1997)], rather than those that have been *restored* or *rehabilitated* as a result of a severe environmental impact. Thus, although the replanting of *S. alterniflora* in the Arthur Kill was considered both successful and exceptional, and some SMRT monitoring results showed increased aquatic faunal and avian abundances at replanted sites (C. Alderson *et al.*, Salt Marsh Restoration Team, Natural Resources Group, New York City Parks, 200 Nevada Ave., Staten Island, NY, pers. comm. and unpubl. data), questions remain as to the ecological viability and functional equivalency of these marshes.

The problem is compounded because not only was almost every low marsh within the Arthur Kill affected to some extent by the 1990 spill, but this estuary is also heavily urbanized, and the marshes are continuously impacted by urban runoff, contaminants, floatables, bank erosion, and illegal dumping which together can severely restrict natural recolonization of *S. alterniflora*. Thus, it may be difficult to detect differences in the ecosystem functions between the replanted marshes and the pre-existing marshes within the Arthur Kill. Even if differences are detected, it may be impossible to attribute these differences to the replanting efforts or to the oil from the spill after so many years. These difficulties are often encountered when undertaking environmental impact or restoration studies, particularly in urban wetland habitats (Ehrenfeld 2000). Thus, as a first step, Ehrenfeld (2000) states: "Measures of restoration success and functional performance [in urban wetlands] must start with an appreciation and assessment of the particular conditions imposed by the urban environment. These conditions can be identified, measured, and incorporated into assessment protocols for individual wetland functions."

Therefore, the primary goal of this study is to supplement the SMRT monitoring efforts via a preliminary characterization and assessment of marshes that were oiled and replanted, marshes that were oiled but not planted, and nearby pre-existing *S. alterniflora* reference marshes, with a view toward noting any differences among sites, especially those that might be attributable to the replanting efforts. Measured parameters include trace metals and hydrocarbon contaminants in ribbed-mussels and sediments, sediment biogeochemistry, age and growth of ribbed-mussels, macrobenthic distribution and abundance, and diets of the common mummichog (*Fundulus heteroclitus*). Monitoring by itself often centers only on the structural attributes of the wetland; explicit measures of function, such as biogeochemistry and the trophic linkages between the fish and benthic communities (*e.g.*, Moy and Levin 1991) can pro-

vide a more integrated assessment of ecosystem processes, as well as measure the progress of restoration (Simenstad and Thom 1996). Thus, this preliminary characterization, although limited, both complements and goes beyond the current monitoring studies of New York's SMRT, and may allow us to better evaluate our ability to restore the functional attributes of this habitat, as well as to identify potential indicators of habitat and living marine resource health, impacts, and recovery within a heavily urbanized and degraded estuary.

SITE DESCRIPTIONS

Six Arthur Kill marshes were selected: two oiled and replanted, two oiled but unplanted, and two pre-existing *S. alterniflora* reference marsh sites (Figures 1 and 2). For the trace metals and hydrocarbon analysis studies, mussels were collected farther south and east in the relatively pristine Sandy Hook Bay (Figure 1) to use as an additional reference.

Sampling occurred in September 1996 and May 1997. Mummichogs were scarce in spring 1997, so that year, sampling for those fish occurred from May until early August.

Replanted and Unplanted Sites

Old Place Creek and marsh surrounds the Goethal's Bridge in the northern end of the Arthur Kill between Elizabethport Reach and Gulfport Reach. The site is almost directly across from the origin of the spill and was heavily oiled, with replanting occurring around 1993. Oily residues were still found at this site in 1996-97. The shoreline was heavily impacted by tugboat and wind-generated waves. The combination of wave energy and Old Place Creek's close proximity to the Bayway Refinery have left parts of the shoreline devoid of both vegetation and the thick layers of peat generated since the last glaciation. Some parts of the marsh (outside of our study area) were fouled by an asphalt spill in the 1980s, and the substrate was later stripped. For a further description of this marsh, the impact of the oil spill, and subsequent replanting, see Bergen *et al.* (2000), as well as Blanchard *et al.* (2001).

The Consolidated Edison Tower (*i.e.*, "Con Ed Tower") site is located at the junction of the northern end of Prall's Creek and the Arthur Kill. The area was not replanted (although it may be in the near future) and was barren; the substrate consisted of a combination of asphalt-covered peat, exposed peat, and sand-and-gravel-covered peat or asphalt. The substrate still had oily residues at the time of our sampling.

The Saw Mill Creek North marsh site is located on the northern shoreline of Saw Mill Creek. The replanted site occupied a narrow 3-6 m wide band which ran 91 m in length from the mouth of the creek east into the full marsh. Damage and destruction by oil at this site consisted of the loss of *S. alterniflora* and subsequent erosion of peat and adjacent high marsh. Replanting occurred in 1992.

The unplanted Saw Mill Creek South site is on the opposite (south) shore of the creek. The width of the denuded area was not as wide as that on the north shore. Since the oil spill, erosion of the denuded south banks has occurred, but *S. alterniflora* has re-established itself without the need for replanting. Unlike the barren Con Ed Tower site, the unplanted Saw Mill Creek South site was visually indistinguishable from the replanted Saw Mill Creek North site by 1996.

Reference Sites

Many authors have noted the importance of choosing reference sites that adequately reflect the conditions of the restoration site, and that encompass the known variation of the group of wetlands in the study (*e.g.*, Brinson and Rheinhardt 1996; Kentula 2000; Short *et al.* 2000). Reference sites in urban areas will, and should, reflect the realities of the urban context [see Ehrenfeld (2000) and authors cited therein for an extended discussion of reference sites in urban wetland restoration studies]. Thus, at least one of the two pre-existing *S. alterniflora* reference marshes we chose was affected to some degree by the oil spill, and both are continually affected by anthropogenic impacts, as are all marshes within the Arthur Kill itself. In fact, it would not have been possible or even feasible to find or use a "pristine" marsh within the Arthur Kill.

The first site, Tufts Point, is located midway on the New Jersey side, and extends out into the Kill where it turns sharply to the west between Fresh Kills Reach and Port Reading Reach. After the oil spill, the site suffered some "medium oiling" according to Louis Berger and Associates (1991). There was a high mortality of the ribbed-mussel, a common bivalve mollusk residing in the low marsh and predominantly attached to the stems and roots of *S. alterniflora*. Nevertheless, relative to the more northern marshes, the site did not suffer extensive damage after the 1990 spill, and was considered by SMRT to be in good condition. Therefore, we considered it as a reference marsh.

The second reference site, Mill Creek marsh, is located in the Outerbridge Reach, just to the south of the Outerbridge Crossing on Staten Island. It was our southernmost site. The study marsh itself was located on an island right at the mouth of the creek; at very low tides the water over the surrounding mudflats was shallow enough to allow easy access to the mainland. Although Mill Creek marsh was located in the "lightly-impacted" zone (Louis Berger and Associates 1991) of the 1990 spill, Louis Berger and Associates (1991) nevertheless observed no oiling there, and declared it a control site.

The Sandy Hook reference site used for contaminant analyses was located on the western shoreline of the barrier beach peninsula, in Sandy Hook Bay (Figure 1), where there are a series of marshes and mud flats that are exposed

during periods of low tide in an area south of Spermaceti Cove and north of Plum Island. The site was considered to be relatively clean, especially compared to the Arthur Kill.

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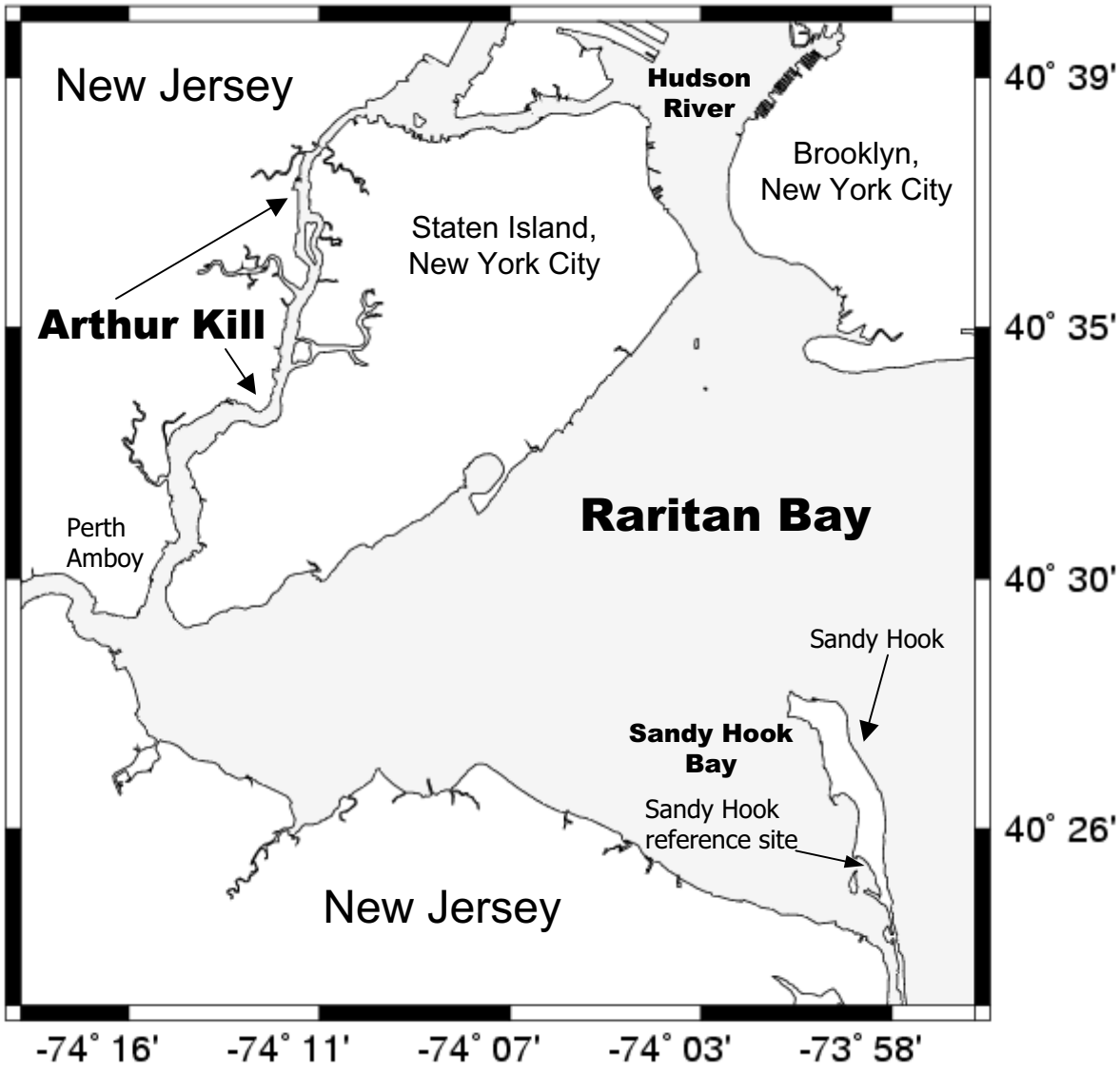

Figure 1. Map showing the general location of the Arthur Kill within the Hudson-Raritan Estuary, and the location of the Sandy Hook reference site on Sandy Hook, New Jersey.

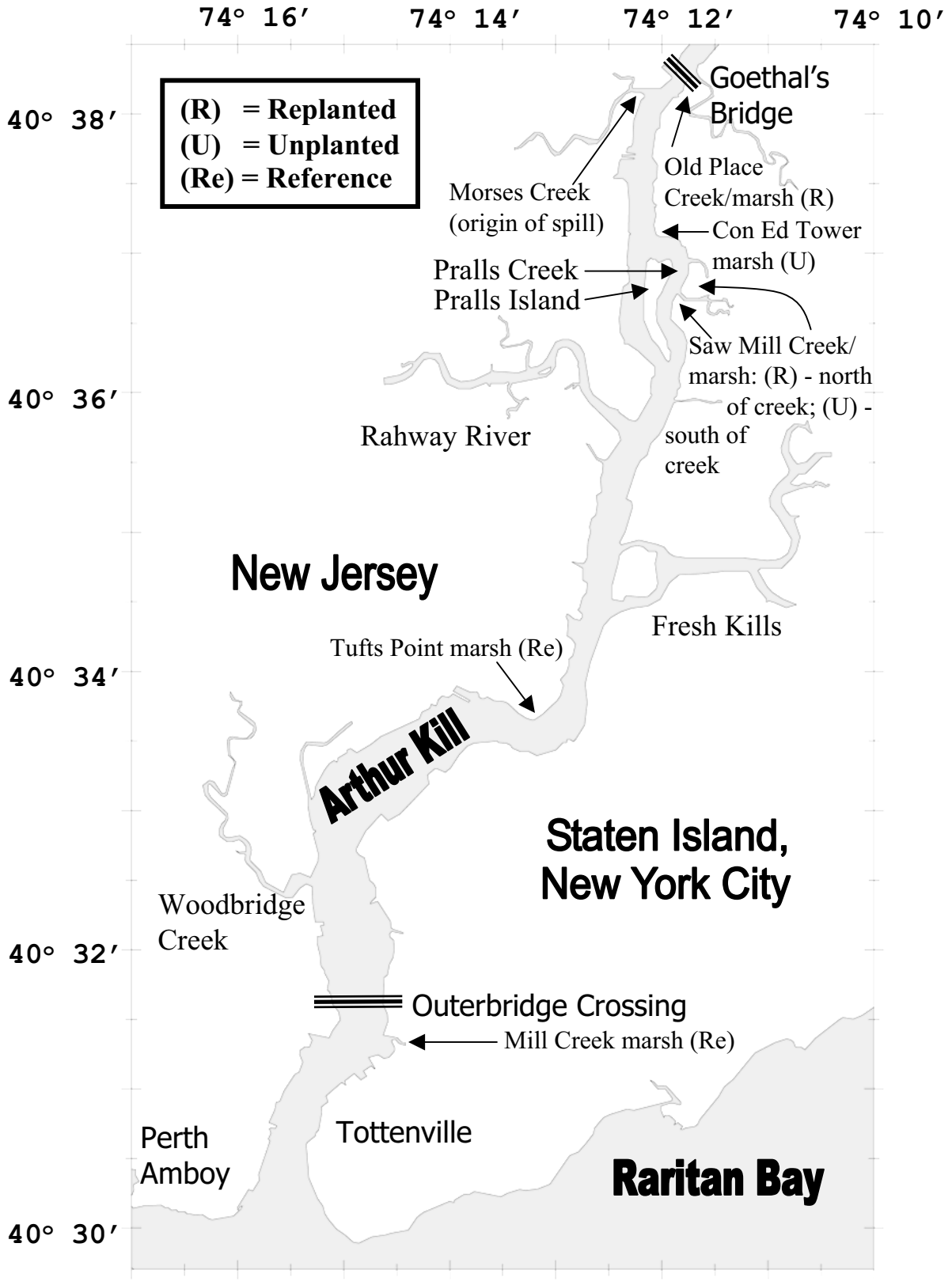

Figure 2. Map of the Arthur Kill showing station locations and the point of origin of the 1990 oil spill.

II. TRACE METAL CONTAMINANTS IN SEDIMENTS AND RIBBED-MUSSELS (*Geukensia demissa*)

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INTRODUCTION

Bioaccumulation of metals in mussels depends not only on metal concentrations in the sediments (Hummel *et al.* 1997), but also the physiological state of the organism (*e.g.*, season and environmental factors) and the biogeochemistry of the sediments (*e.g.*, iron (Fe) content, organic carbon (OC) content, and oxidation-reduction condition). Trace metals were analyzed in mussels and sediments in the Arthur Kill to determine if the biogeochemical processes that control bioaccumulation were affected by replanting of *S. alterniflora* at the previously oiled sites. Since the replanted sites were not sampled before replanting, pairs of unplanted, replanted, and reference sites in the Arthur Kill were sampled for mussels and sediments in September 1996 and May 1997. Sampling at the unplanted sites (*i.e.*, Con Ed Tower and Saw Mill Creek South sites) occurred 6 yr after the 1990 *Exxon Bayway* oil spill. At the time of initial sampling, *S. alterniflora* planted in 1992 had been growing at the Saw Mill Creek North site for 4 yr, while the *S. alterniflora* planted at the Old Place Creek site in 1993 had been growing for 3 yr. Two Arthur Kill reference sites (*i.e.*, Tufts Point and Mill Creek) and a regional reference site (*i.e.*, Sandy Hook) were also sampled.

This chapter only addresses: 1) the level of contamination of Arthur Kill sediments and mussels, and 2) whether replanting is the dominant factor controlling metal concentrations in sediment and mussels. More specific interactions between bioaccumulation in mussels and sediment geochemistry will not be addressed in this chapter.

METHODS AND MATERIALS

All implements and plastic containers used for collecting, transporting, processing, and storing sediment and mussel samples for metals analyses were decontaminated by rinsing in dilute, ultrapure nitric acid, then doubly in deionized (DDI) water.

Sediments

For collecting sediment samples, four stations were selected along a transect at 0.2 m above the mid-tide level at each of the six sites within the Arthur Kill. Locations with equal tidal height were chosen to minimize station-to-station differences in surface (tidal) hydrology. The positions of the stations along the transect were chosen based on the need to minimize disturbance to the site. Also, access to the specific sites was affected by unique logistical difficulties. For this reason, distances between stations along the transect at a site ranged from 2 to 20 m apart, and the total length of the transects among sites ranged from 12 m at Saw Mill Creek South to 39.5 m at Old Place Creek. At the replanted and reference marsh sites, stations along the transect were located within the vegetated zone. At Con Ed Tower, the transect was in a wide unvegetated area, and stations were located in mud and peat that contained chunks of asphalt. At Saw Mill Creek South, the transect was along the edge of the cordgrass and barren mud and peat banks.

Sediment samples for grain size analysis were collected at each of the four stations within each of the six sites in September 1996 (one core per station) by using 28-mm-internal-diameter, plastic-core tubes, and were frozen for transport back to the laboratory. The particle size distribution of the sediment mineral fraction was determined by modifying the standard wet and dry sieving procedures of Ingram (1971), Galehouse (1971), and Folk (1980). The particle upper size limit chosen was $\geq -2\phi$ (*i.e.*, pebble/granule boundary), and the particle lower size limit was $>4\phi$ (*i.e.*, mud, composed of silt and clay). The top 5 cm of each frozen core were extracted, treated with several milliliters of 30% H_2O_2, and heated to digest any organic material. The samples often contained large sections of *S. alterniflora* rhizomes and stems, which were removed. Each sample was then wet sieved with a 63-µm sieve to separate the coarse sediment from the mud. While the mud remained in distilled water, the coarse fraction was dried and mechanically sieved through different-sized sieves to separate out the various

coarse size fractions, plus any remaining mud. After weighing the dried coarse fractions, the mud from both wet and dry sieving procedures was combined, dried, and weighed. For samples from the Con Ed Tower site, deposits of tar prevented us from performing any grain size analysis.

For determination of total OC in the sediments, see Chapter IV, "Sediment Biogeochemistry."

For trace metal analyses, sediment cores were collected with 31-mm-diameter acrylic tubes at the four representative locations within each of the six Arthur Kill sites and at two locations within the regional reference site (*i.e.*, Sandy Hook). The top 1-cm section from each core was dried overnight at 60-65°C, the debris was removed, and the remaining sample was pulverized. Ten milliliters of trace-metal-grade concentrated HCl was added to a 100-ml Pyrex beaker containing 1-10 g of dried sediment, and was allowed to react with the sediment for 15 min (Zdanowicz *et al.* 1995). After the addition 10 ml of concentrated HNO_3, the sediment slurry was then allowed to stand for 2 hr. The slurry was then taken to dryness over low heat. After the addition of 25 ml of 0.1-M aqua regia, this slurry stood overnight at room temperature. The volume of liquid was reduced to about 10 ml over low heat, and the slurry was filtered through acid-cleaned, #41 Whatman filter paper using additional DDI to rinse the beaker. DDI was added to bring the filtrate to a final volume of 25 ml.

The resulting solutions were analyzed for iron (Fe), chromium (Cr), copper (Cu), nickel (Ni), zinc (Zn), manganese (Mn), and lead (Pb) by using flame atomic absorption spectrophotometry (AAS). Six procedural blanks and five replicates of standard reference material (SRM) NIST 1645 (river sediment) obtained from the National Institute of Standards and Technology (NIST) were also analyzed by the same procedure. Table 1 shows the quality assurance data for the trace metals. Except for Ni and Pb in the May 1997 Sandy Hook samples, metal values in the sediments were above detection limits (see Table 2). Recoveries for NIST 1645 ranged between 90 and 98% . Within the Arthur Kill samples, outliers were identified using the Grubbs test (Sokal and Rohlf 1981), and were not used to calculate any statistical parameter. Differences in mean metal concentrations among groups of samples from different sites for each year were investigated using analysis of variance (ANOVA; $P = 0.05$) and Duncan's multiple range test.

Mussels

Ribbed-mussels were collected randomly at each site in September 1996 and May 1997. Owing to the sparse density of the mussels, to the limited time available for sampling (*i.e.*, between high tides), and to the desire not to disturb the sites any more than necessary, the first 60-70 specimens that were found were collected. At the Saw Mill Creek South site, sampling was impeded by tall *S. alterniflora*, so it was possible to collect only 34 specimens in 1996.

After being transported to the NMFS James J. Howard Marine Sciences Laboratory in Sandy Hook, New Jersey, in plastic bags under ice, mussels from each site were separated by size into two roughly identical groups, one for metals analysis and one for hydrocarbon analysis. In order to obtain specimens of comparable size at each site for metal analysis, a length range between 55 and 67 mm was selected. This was the smallest size range that provided at least five individuals per site. At sites where there were more than five specimens within this range, samples were selected using the following procedure. The size range was divided into five bins. One specimen per bin was selected randomly. If a bin contained no specimens, an alternate bin was selected at random, and a specimen was selected randomly from it. For the given length range, the average wet weight (15.65±2.70 g) of tissue collected in May 1997 from the Mill Creek site was significantly greater than the weights of samples for the 13 other collections (13.32±2.10 g).

Mussel specimens for metal analysis were allowed to depurate overnight in ambient, laboratory supplied seawater at 4°C. After removing extraneous material from the shell (mud, barnacles, etc.), total weight and length were recorded for each specimen. The tissue (*i.e.*, soft parts) was then excised, and stored in a vial at -20°C until analysis. Five or six individual samples per site were analyzed for metals. After thawing, the entire soft tissue was placed in a Teflon vial and weighed. The tissue was dried overnight at 60-65°C and reweighed to obtain a dry weight. Five milliliters of ultrapure concentrated HNO_3 was added to the sample which was typically 1 g. The vials were allowed to stand at room temperature for 2-4 hr. Vials were then capped and placed inside Teflon-lined bombs, and the tissue was digested overnight at 120°C. After cooling, bombs were vented, the vials were removed, and the digests were allowed to degas at room temperature overnight. The digests were then quantitatively transferred to 25-ml glass graduated cylinders and brought to volume using DDI water. The resulting solutions were analyzed for Fe, Cu, and Zn by using flame AAS, for Cr, Ni, silver (Ag),and cadmium (Cd) by using graphite furnace AAS, and for mercury (Hg) by using cold-vapor AAS. Nine procedural blanks and nine replicates of NIST 1566a (freeze-dried oyster tissue) were also analyzed using the same procedure. Details of the sample digestion and analysis procedure can be found in Zdanowicz *et al.* (1993).

Values for all specimens were above detection limits. Average SRM recoveries ranged from 96-102% (Table 1). A majority of variables for two Con Ed Tower samples collected in May 1997 were found to be outliers, and all data from these two samples were disregarded (see Table 6).

RESULTS

Sediments

The general characteristics of the sediments analyzed in this study differ significantly (Tables 2 and 3). The sediments at the two Saw Mill Creek sites, the Tufts Point site, and the Mill Creek site in 1996 were predominately fine grained (*i.e.*, on average, between 71.3 and 98.3% of samples, by weight, were <63 μm by weight), and had OC content that ranged, on average, between 5.8 and 11.1% by weight (Figure 3; results of the OC analyses are from Chapter IV, "Biogeochemistry"). In contrast, the Old Place Creek and Sandy Hook sites contained, on average, 11.9 and 2.8% fine material, respectively; the Old Place Creek site contained, on average, 1.3% or less OC. The size distribution of the Con Ed Tower site could not be determined because the OC content of the sediments in 1996 averaged 35.0%, a significant portion of this OC being oil. The average Fe content of the four fine-grained sediment sites (*i.e.*, Saw Mill Creek North and South, Tufts Point, and Mill Creek) ranged between 3.29 and 3.91% by weight. The coarser nature of the Old Place Creek and Sandy Hook sediments was reflected in their lower average sediment Fe concentrations of 0.9 and 0.3% by weight, respectively. The mere dilution of fine-grained material by the presence of abundant organic matter (*i.e.*, over 40% by weight OC at some stations) at the Con Ed Tower site also reduced Fe concentrations. Similar to Fe, Mn concentrations at the Old Place Creek and Sandy Hook sites were also low. However, there was considerable variability in the Mn concentrations at the fine-grained sites, with the southern sites (*i.e.*, Tufts Point and Mill Creek) having significantly higher Mn concentrations.

The sediment texture was also reflected in the concentrations of Cu, Zn, Cr, and Pb in sediment, with the sites with coarser sediments (*i.e.*, Old Place Creek and Sandy Hook) having significantly lower concentrations (Figure 4). However, there was considerable variation in metal concentrations among the sites having fine-grained sediments. These metal concentrations are within the range reported for Arthur Kill sediments by other investigators (Meyerson *et al.* 1981; Adams *et al.* 1998). Cr, Cu, Zn, and Pb were significantly higher in all Arthur Kill samples (Table 4) relative to marine sediments with similar Fe concentrations collected from sparsely populated coasts (Daskalakis and O'Connor 1995). Ni concentrations of Arthur Kill sediments (Tables 2 and 3) were lower or similar to marine sediments collected from less-impacted coasts. The Cu, Zn, and Pb concentrations at the Mill Creek reference site were significantly higher than the New York Harbor, Western Long Island Sound, and Newark Bay averages (Table 4).

Trace metals generally concentrate on the Fe, Al, and Mn oxide and OC coatings of sediments (Olsen *et al.* 1982). Fe concentrations in these Arthur Kill sediments were significantly larger than Mn concentrations, suggesting the Fe oxides were the dominant oxide coating of the surfaces of sediment particles. Normalization of Cu, Zn, Cr, and Pb concentrations to Fe accounts for the differences in sediment texture of each individual sediment sample. These normalized concentrations were used to determine significant differences in metal concentrations among sites. The normalized concentrations of Cu, Zn, and Pb were lower at the Sandy Hook station compared with the Arthur Kill sites (Figure 5), while normalized Cr concentrations at Sandy Hook were not significantly difference than those at Old Place Creek, Tufts Point, and Mill Creek sites. Normalized Cu, Zn, and Pb concentrations at Mill Creek in 1996 were significantly higher than those of most of the other Arthur Kill sites. In general, normalized concentrations of metals at the unplanted, planted, and Tufts Point (reference) sites were similar, with the exception of higher normalized concentrations of Zn at Tufts Point in 1997, higher Cr at the Saw Mill Creek North and Con Ed Tower sites in 1996, and higher Ni at Con Ed Tower sites in 1996 (not shown). There was little difference in the normalized metal concentrations between the two adjacent Saw Mill Creek sites, except for the higher Pb value at the restored Saw Mill Creek North site.

Mussels

The metal data for mussels also indicate that Tufts Point was not a suitable reference site, but rather reflected the higher metal concentrations as a result of the overall pollution of the Arthur Kill, including oil spills (Tables 5 and 6). For instance, the highest Cd concentrations found in any specimen in each season were from specimens collected from Tufts Point. Fe, Cr, Ni, Zn and Hg concentrations from Tufts Point were not significantly different than the concentrations from the oiled sites. Therefore, the Tufts Point sample is grouped with the other Arthur Kill sites in the following discussion.

The range of metal concentration data from September 1996 was wide, resulting in much overlap in ranges among sites. However, some significant seasonal differences were found (Figures 6 and 7). The unplanted Saw Mill Creek South site was anomalous in that the Ni concentration in mussels was greater in May 1997 than in September 1996, but there were no significant seasonal differences found for the other seven elements. In contrast, concentrations of Cr, Ag, and Hg at four other Arthur Kill sites were generally higher in September, and highly variable.

The decrease in Ag, Cr, Cu, and Hg concentrations in mussels from the oiled sites between September and May might be a result of natural processes. A significant seasonal difference in metal concentrations between the replanted and unplanted sites was observed only for Cu. Therefore, it is unlikely that the seasonal difference in metal

concentrations in mussels was influenced by the replanting effort.

Only the May data were used to determine geographical differences in metal concentrations in mussels, since the September data were so highly variable. Relative to the oiled sites, Cr, Cu, and Hg concentrations in mussels were significantly lower at the Mill Creek and Sandy Hook sites, while Fe and Cu were significantly lower only at the Sandy Hook site. The range of concentrations of Ag, Ni, and Zn in mussels at both these reference sites significantly overlapped the concentrations of some of the oiled sites.

For all elements in mussels, there were no clear differences between the replanted and unplanted sites. The mussels from the unplanted Saw Mill Creek South site contained the highest concentrations of Fe, Cr, Cu, Ni, Ag, and Hg. The close proximity and similar sediment characteristics (*i.e.*, % fines and OC content) of the unplanted Saw Mill Creek South and the replanted Saw Mill Creek North sites provide a valid comparison to test the effects of replanting. The concentrations of Ag and Cd were significantly higher ($P < 0.05$) at the unplanted Saw Mill Creek South site, while the concentrations of Zn were significantly higher at the Saw Mill Creek North site. No significant differences were found for Cr, Cu, Ni, Hg, and Fe.

Although mussels have been used extensively in marine monitoring programs, these programs primarily use the blue mussel, *Mytilus edulis*. In one of the few studies in which the accumulation of metals was compared in different species of mussels, Nelson *et al.* (1995) state, "these findings highlight the fact that metal uptake in bivalves is a complicated process that can be affected by many exogenous and endogenous factors." In keeping with their caution, our ribbed-mussel data were compared only with other ribbed-mussel data (Table 7). Cr, Cu, and Zn concentrations in ribbed-mussels from Sandy Hook are comparable with those from a clean site in East Sandwich, MA (Nelson *et al.* 1995). In contrast, the metal concentrations in ribbed-mussels from the Arthur Kill are similar to those from the polluted New Bedford Harbor, Massachusetts, and Inner Mystic River Estuary, Connecticut (Nelson *et al.* 1995; Miller 1988).

DISCUSSION

Sediments

Correlations among metal concentrations, grain size, and OC content were determined by two separate analyses because of incomplete data. No correlations, though, could be calculated for the Sandy Hook site because of lack of sufficient grain size data and lack of any OC data. In the first analysis, correlations were determined for the metal and OC data from each site for both 1996 and 1997 sampling periods. In the second analysis, correlations were determined for the metal and grain size data from each site except the Con Ed Tower site for just the 1996 sampling period.

For the Old Place Creek site, the significant variability in both metal and OC concentrations among individual sediment samples appears to be related to the portion of fine-grained sediments found in each sample. The 1996 metal data from Old Place Creek, excluding Mn and Cu, were correlated with the percentage of fine-grained sediment found in each sample. When the entire Old Place Creek data set is subjected to correlation analysis using OC data (Table 8), the entire correlation matrix table is significant ($r \geq 0.80$). For the fine-grained-sediment sites (*i.e.*, Saw Mill Creek North and South, Mill Creek, and Tufts Point), no significant correlations were found between Fe vs. Cr, Ni, Cu, Zn, or Pb. This lack of correlation is not surprising since Fe concentrations within a site varied only over a very small range (Figure 3). For these fine-grained sediments, correlations among trace metals are not controlled by the concentrations of Fe oxides, but are controlled by how the trace metals interact with the Fe oxide coating or by phases other than Fe oxides.

Different subsets of trace metals were highly correlated for the data sets from different sites. For instance, significant correlations were found among Pb, Cr, and Cu at the Saw Mill Creek North site (Table 8). It is interesting to note that these three metals were negatively correlated with the percentage of fine-grained sediments. This negative correlation suggests that Pb, Cr, and Cu are associated with a coarser type of particle. Significant correlations were also found among Cr, Ni, and Zn at the Con Ed Tower site, and among Cr, Cu, Ni, and Pb at the Saw Mill South site.

The entire metals data set was subjected to principal components analysis (PCA) using both the OC and grain size data (see eigenvectors in Appendix Tables A1 and A2). When OC data are used, both sampling periods could be analyzed, but without the Sandy Hook site. The Old Place Creek site is distinguished because of its lower metal concentration (Figure 8). Except for one sample, the Mill Creek site is separated from the other fine-grained stations in the Arthur Kill. Although the 1996 Con Ed Tower site is separated from the rest of the sites with finer sediment, there is no distinct difference in replanted and unplanted sites. When only the 1996 metal data set was used with percentage of fine-grained sediment data (Figure 9), the Sandy Hook and Old Place Creek sites again are differentiated from the fine-grained sediment sites. Among the fine-grained sediment sites, only Mill Creek is distinguished.

Mussels

Trace metal concentrations in mussels were higher and more highly variable in September 1996 than in May 1997. Of the eight metals analyzed, four (*i.e.*, Cr, Ni, Cd, and Hg) were significantly lower in mussels at both reference sites relative to the other Arthur Kill sites, and two others (*i.e.*, Fe and Cu) were significantly lower only at the Sandy Hook reference site. Five metals showed higher concentrations in mussels at the unplanted Saw Mill Creek South site com-

pared to the nearby replanted Saw Mill Creek North site. The lack of strong and consistent trends required higher-level statistical analysis of the data in order to draw any conclusions concerning the effects of replanting. Correlations among metal concentrations in mussels were examined for each station to determine if biogeochemical processes were causing similar trends for a subset of the metals studied. In addition, the entire mussel data set was subjected to PCA to determine if the data were separable by type (*i.e.*, unplanted, planted, or reference).

A few significant correlations between the concentration of pairs of metals in mussels within a site were found at three of the five oiled sites, and at both reference sites (*i.e.*, Mill Creek and Sandy Hook; Table 8). Although length and weight of mussels were highly correlated, only one out of the possible 108 correlations between metals and these physical characteristics of mussels is >0.80 (*i.e.*, Zn was negatively correlated with length at Saw Mill Creek South). Zn is correlated with Cd in mussels at Sandy Hook and the replanted Old Place Creek sites. Fe is correlated with Cr at the Saw Mill Creek North replanted site and the Mill Creek reference site, and with Ni at the Con Ed Tower unplanted site. Metal concentrations in mussels at the Saw Mill Creek North site were the most coherent, with four metal pairs having correlations >0.80; however, the Ag is negatively correlated with Cr. Hg is correlated with Zn at Old Place Creek and Mill Creek, and also with Cr at Saw Mill Creek North. No significant correlations were found in mussels at the unplanted Saw Mill Creek South site, which tended to have the highest concentrations in May.

Only the metal data from the entire data set were subjected to PCA because the correlations of metals with length or weight for the individual sites were weak. Among the metals data, the highest correlation (r = 0.65) was found between Zn and Cd. The eigenvectors of the first principal component (Appendix Table A3) ranged between 0.29 for Fe and 0.43 for Hg. A plot of the first principal component versus the second principal component clearly distinguished the two reference sites, Mill Creek and Sandy Hook, to the left (Figure 10). The replanted and unplanted sites could not be distinguished from points plotted in the middle of the plot. The principal component analysis and Duncan multiple range tests suggest that the five oiled sites were not significantly different from each other; the means for mussels from these five sites are given in Table 7. The Fe and Cu concentrations in Sandy Hook mussels were lower than those at the Mill Creek reference site.

CONCLUSIONS

Metal concentrations in the sediments at each site depended more on the general characteristics of the sediment, such as the percentage of fine-grained sediments and Fe content, than on whether or not the site was replanted. Compared to concentrations from the regional reference sites and from other regional studies, metal concentrations in sediments from the entire Arthur Kill were elevated. In fact, the Mill Creek reference site farthest from the location of the spill had the highest concentrations of Cu and Pb when normalized to the sediment Fe content. Higher levels at Mill Creek may have been due to past industrial discharges in this area of the Kill (C. Alderson *et al.*, Salt Marsh Restoration Team, Natural Resources Group, New York City Parks, 200 Nevada Ave., Staten Island, NY, pers. comm.).

For each site, concentrations of groups of metals were highly correlated, but the correlations were not consistent among sites. For instance, concentrations of Pb, Ni, Cu, and Zn were highly correlated at the Mill Creek reference site, while Pb, Cr, Ni, and Cu were highly correlated at the Saw Mill Creek South site. The negative correlation of Cr, Cu, and Pb with the percentage of fine-grained sediments present at the Saw Mill Creek South site suggests that these metals were associated with coarse sediment. PCA distinguished the two coarse-grained sediment sites, but there was no distinction between replanted and unplanted sites.

There were no consistent differences in metal concentrations in mussels collected from replanted and unplanted sites. Concentrations of many metals in mussels from the southernmost Arthur Kill reference site (Mill Creek) were significantly lower than those in mussels from the other five Arthur Kill sites. PCA distinguished the Mill Creek reference site as well as the Sandy Hook regional reference site, but replanted and unplanted sites affected by the spill were not distinguished. Cr, Hg, and Ag concentrations in mussels from many of the Arthur Kill sites were lower in spring than in fall, while Ni concentrations were lower in fall. Since this Arthur Kill reference site and the regional reference site did not show the same seasonal differences in mussel metal concentrations, the differences found for the affected Arthur Kill sites were probably a result of the availability of metal contaminants to the mussel rather than due to any endogenous factors.

Replanting of *S. alterniflora* has little effect on the trace metal concentrations in sediments affected by oil spills. Oil contamination is generally not a major source of metals. In contrast, bioaccumulation of metals by mussels from the sediments is affected by biogeochemical properties of the sediments. Planting of *S. alterniflora* can produce subtle changes in the sediments that affect bioaccumulation. In this study, increases in Cu concentrations in mussels collected from the replanted sites were the only significant and consistent change that appeared to be related to replanting.

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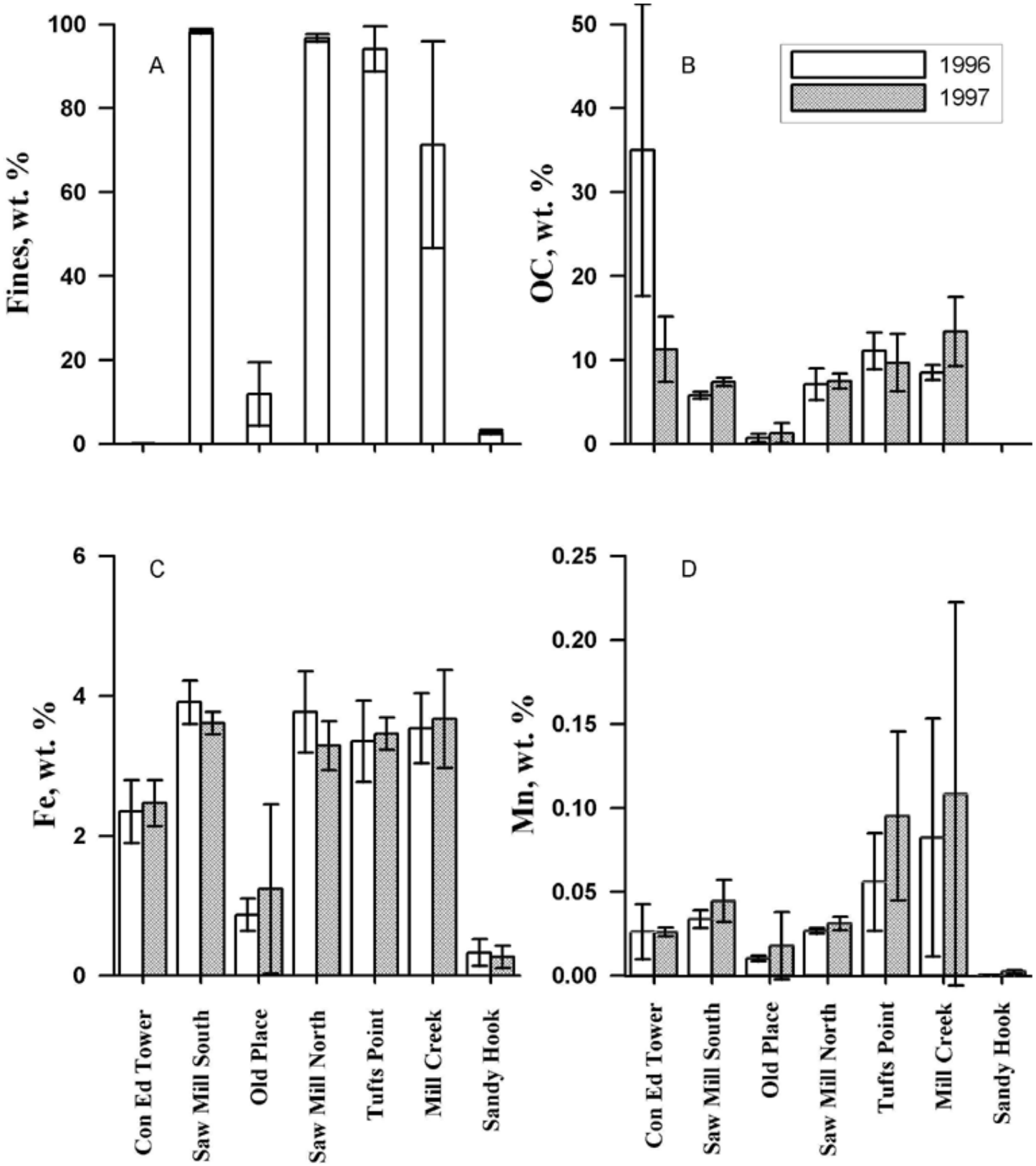

Figure 3. Concentration of major phases of sediments collected in September 1996 and May 1997: A) fines (<0.063 mm), B) OC, C) Fe, and D) Mn.

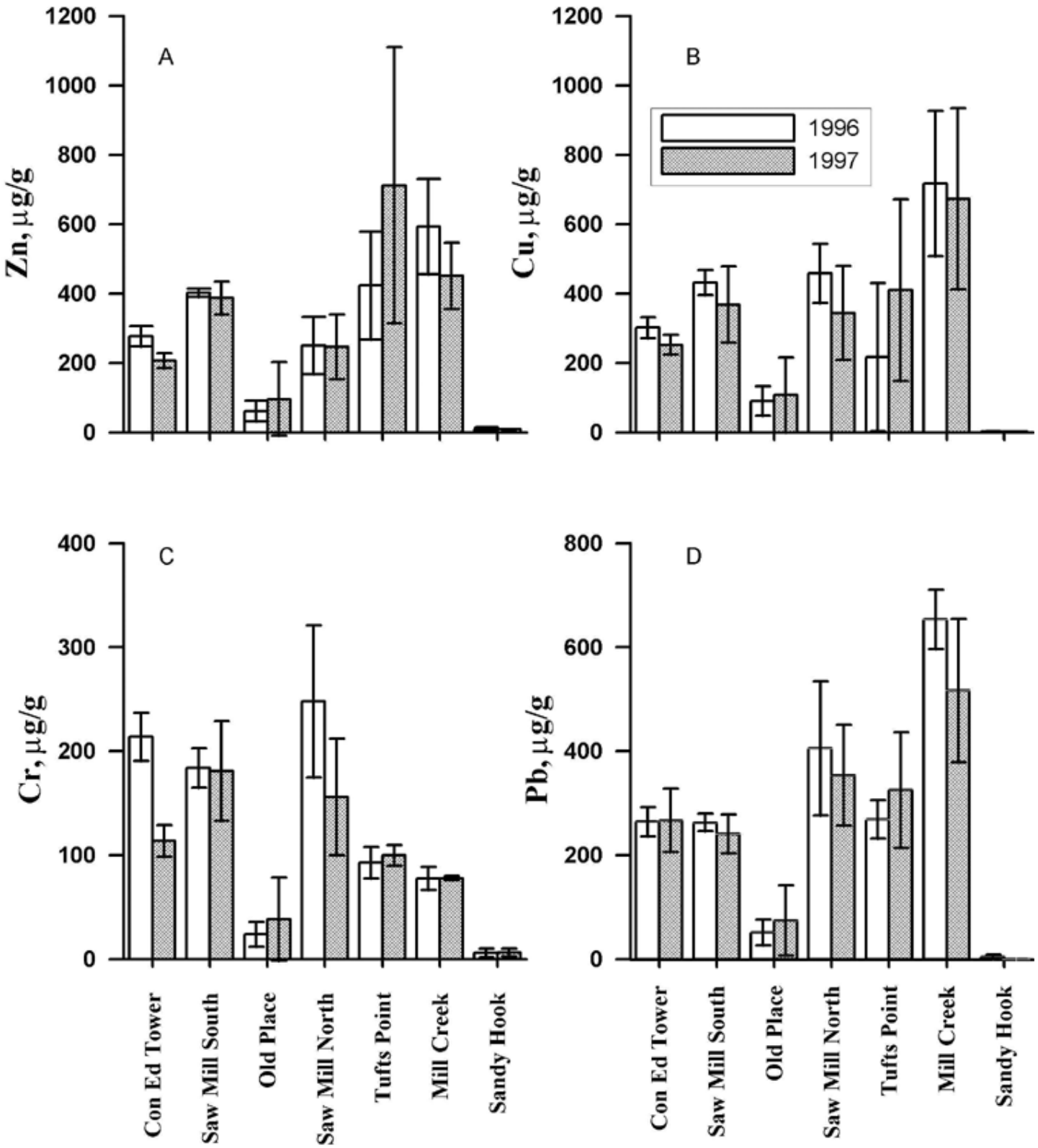

Figure 4. Trace metal concentrations in sediments collected in September 1996 and May 1997: A) Zn, B) Cu, C) Cr, and D) Pb.

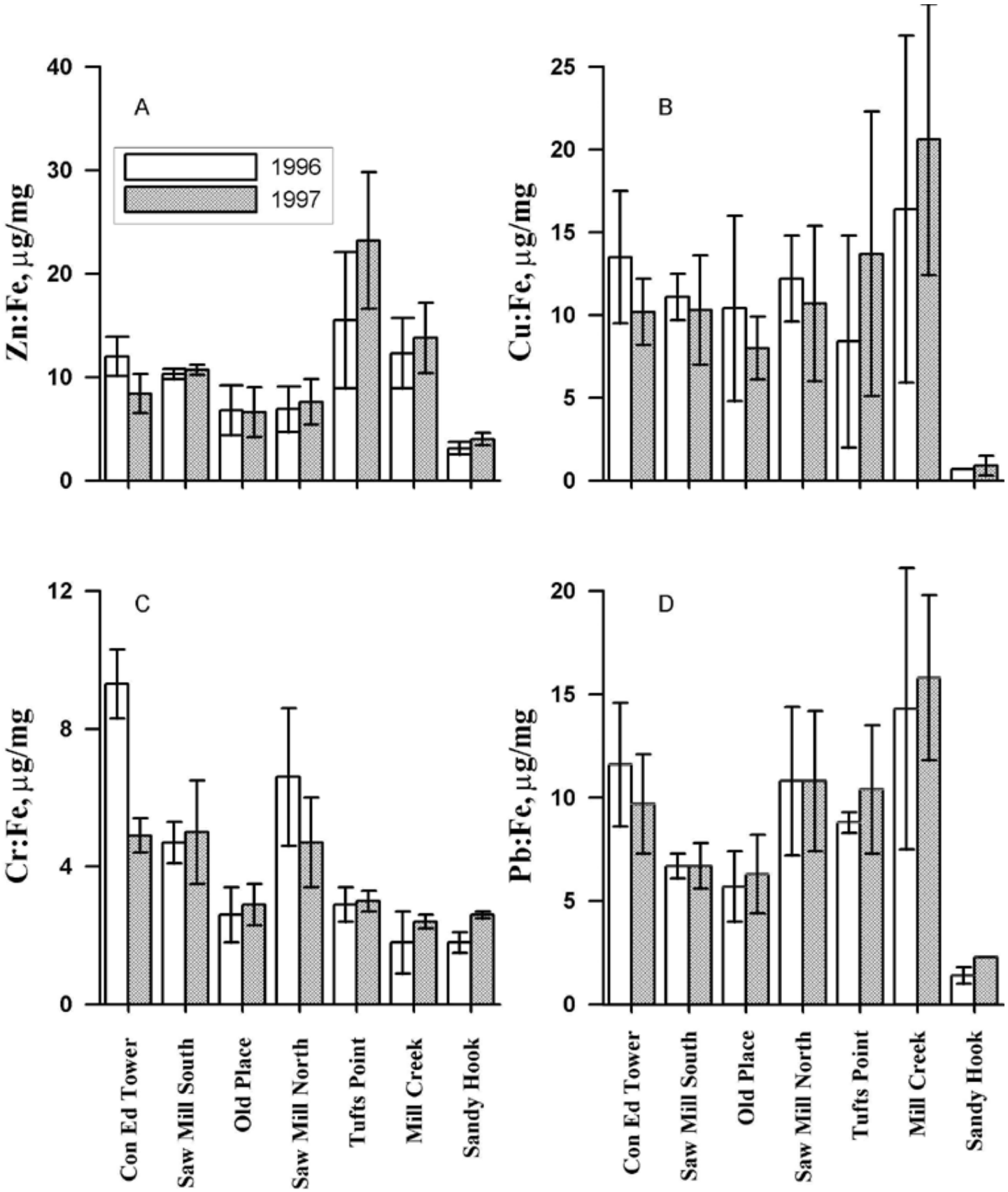

Figure 5. Trace metal:Fe ratios in sediments collected in September 1996 and May 1997: A) Zn, B) Cu, C) Cr, and D) Pb.

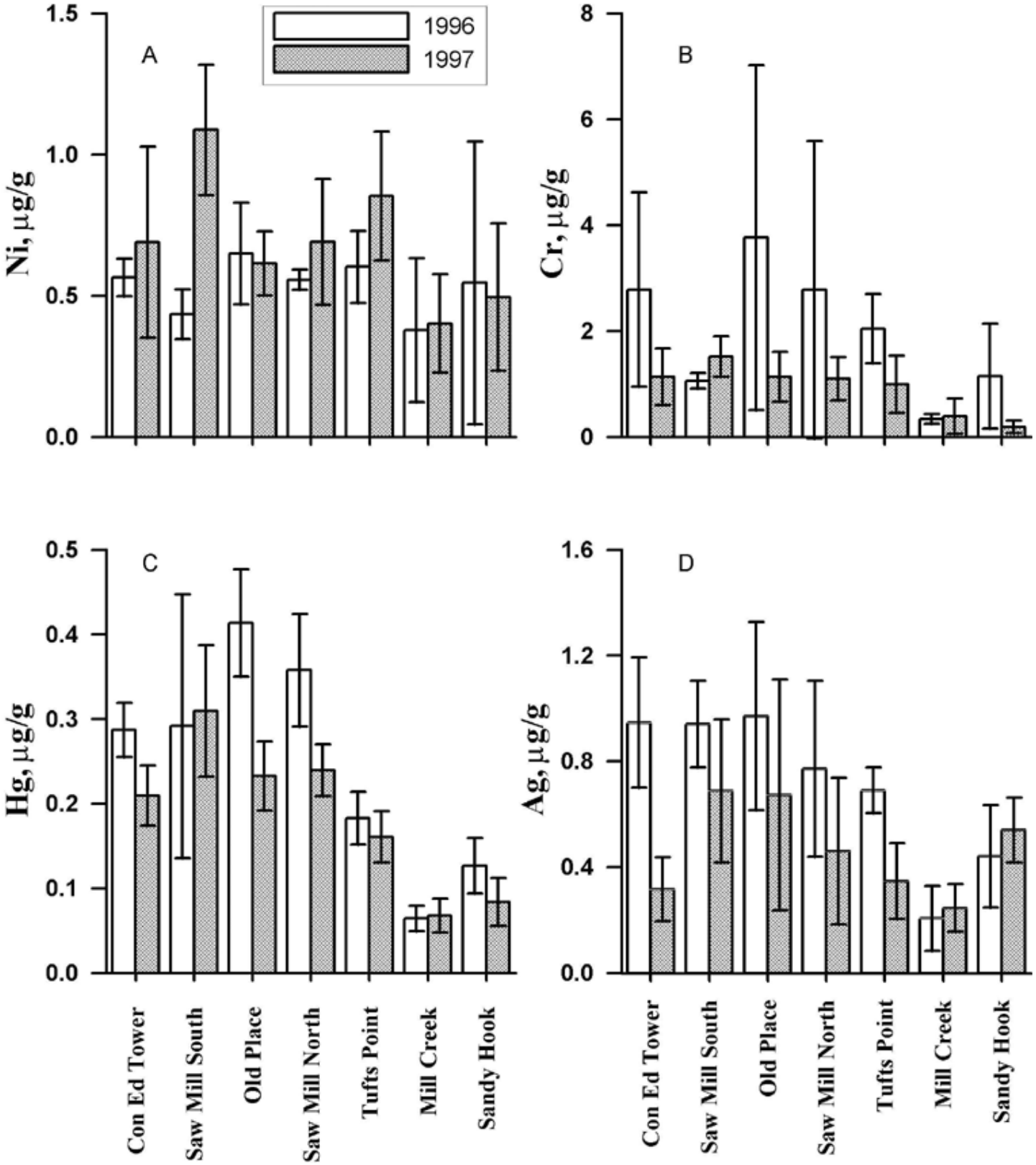

Figure 6. Concentrations in mussels collected in September 1996 and May 1997 for the metals exhibiting the greatest seasonal differences: A) Ni, B) Cr, C) Hg, and D) Ag.

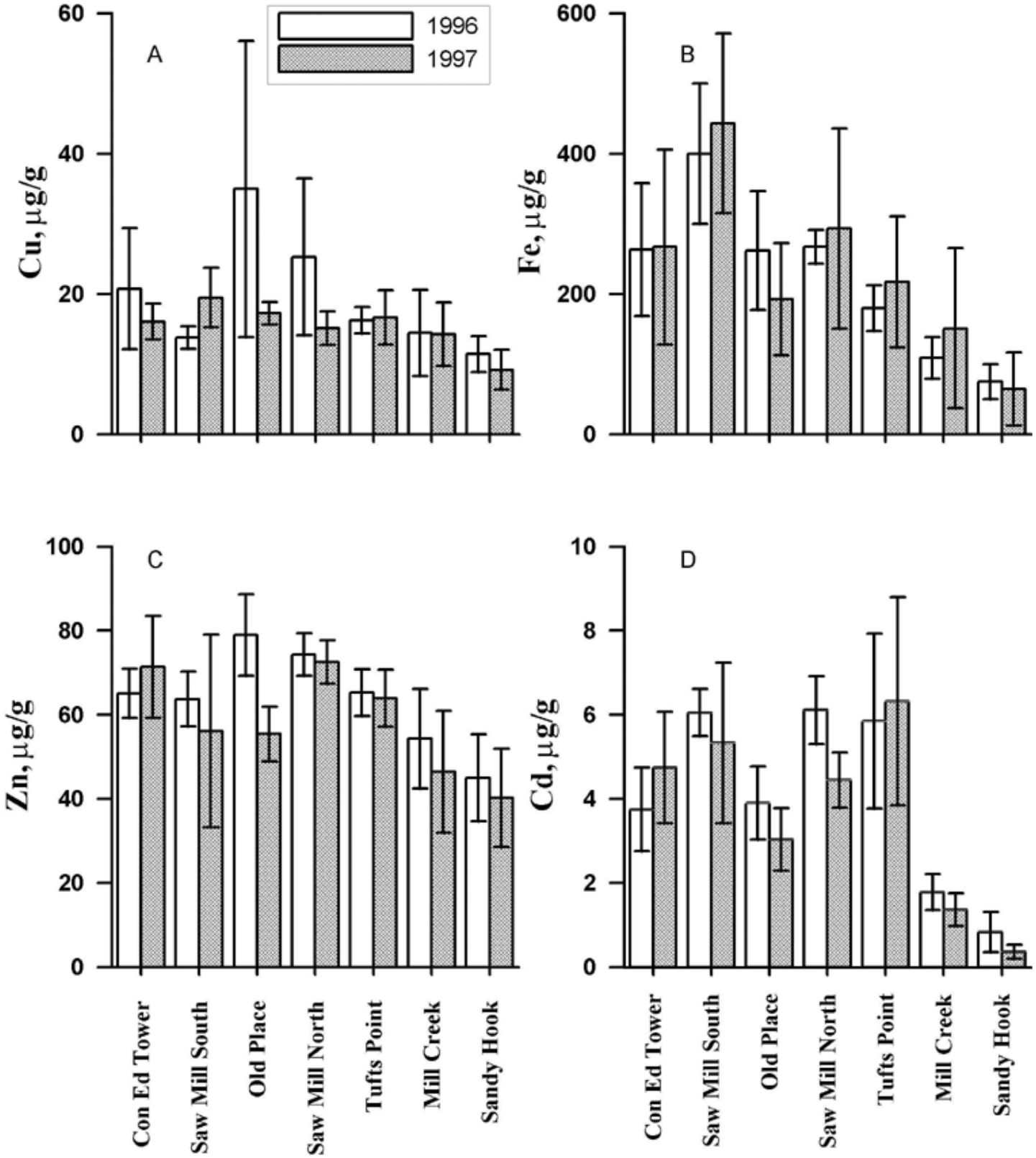

Figure 7. Concentrations in mussels collected in September 1996 and May 1997 for the metals exhibiting the least seasonal differences: A) Cu, B) Fe, C) Zn, and D) Cd.

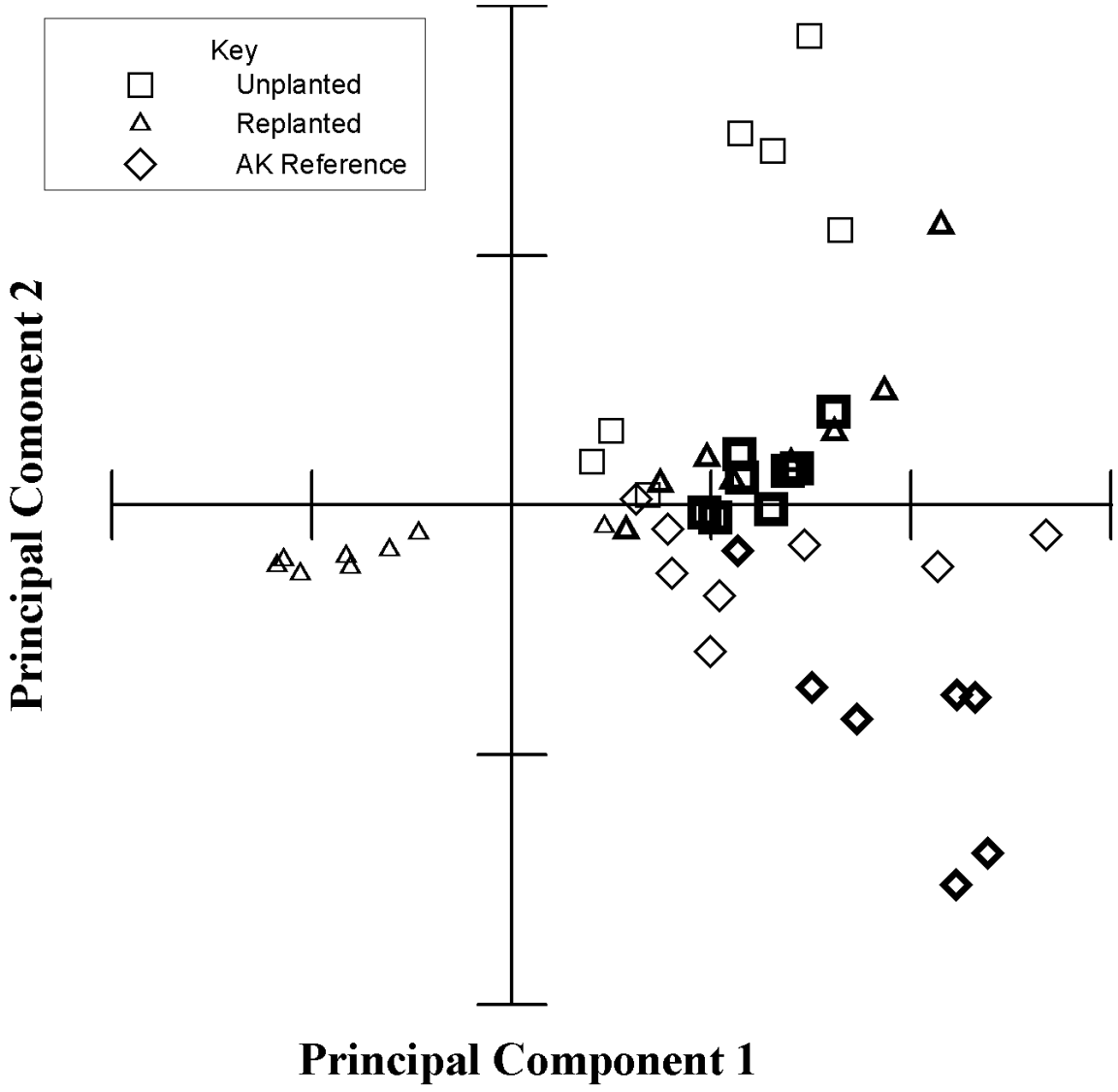

Figure 8. Principal component analysis of data for Fe, Cr, Cu, Ni, Zn, Mn, Pb, and OC data for sediments collected in September 1996 and May 1997 (bold symbols). (Unplanted = Con Ed Tower and Saw Mill Creek South; Replanted = Old Place Creek and Saw Mill Creek North; and AK Reference = Tufts Point and Mill Creek. No OC data available for Sandy Hook reference site.)

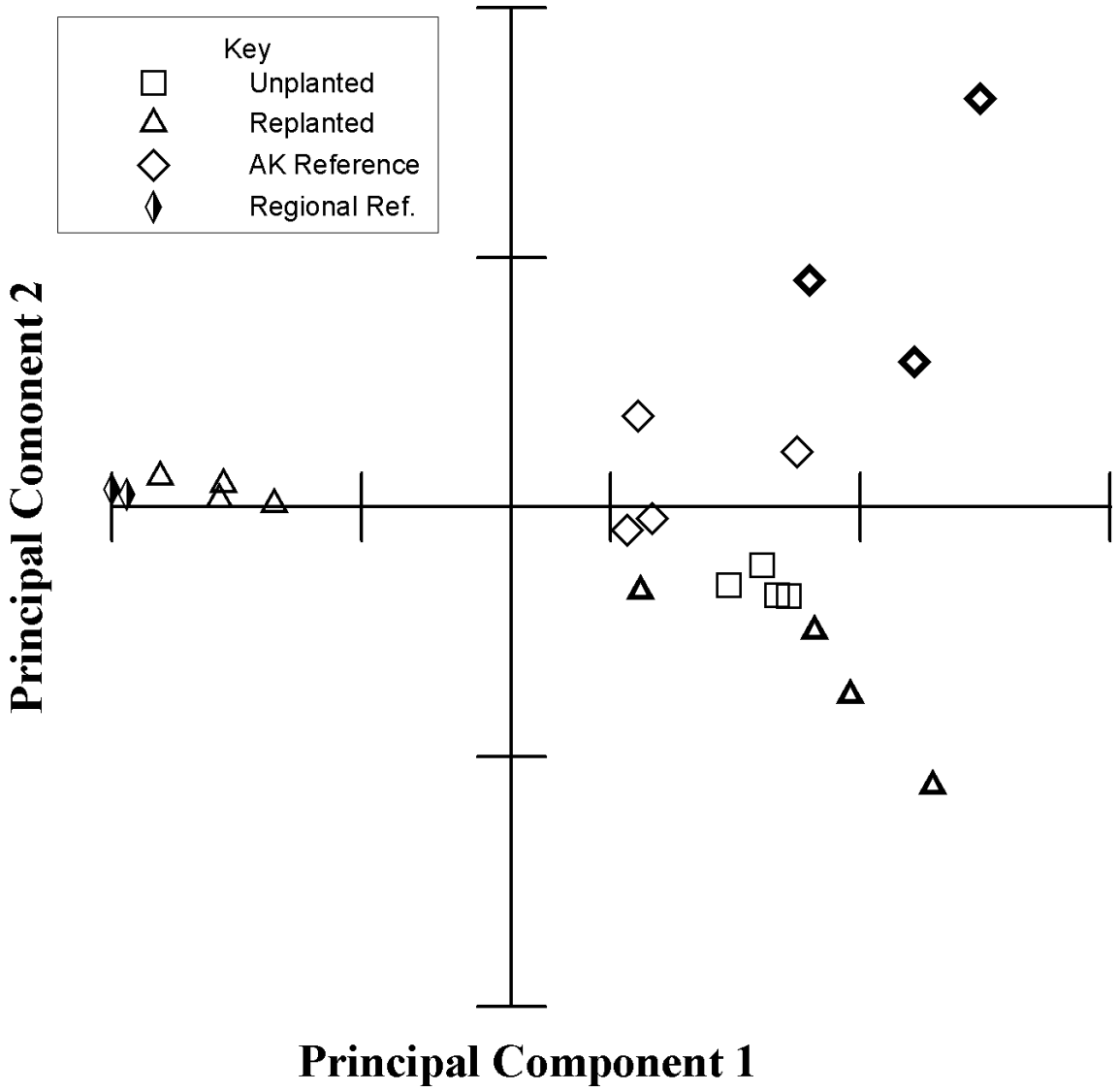

Figure 9. Principal component analysis of data for Fe, Cr, Cu, Ni, Zn, Mn, Pb, and grain size for sediments collected in September 1996. (Unplanted = Con Ed Tower and Saw Mill Creek South; Replanted = Old Place Creek and Saw Mill Creek North; AK Reference = Tufts Point and Mill Creek; and Regional Reference = Sandy Hook. No grain size data in 1997.)

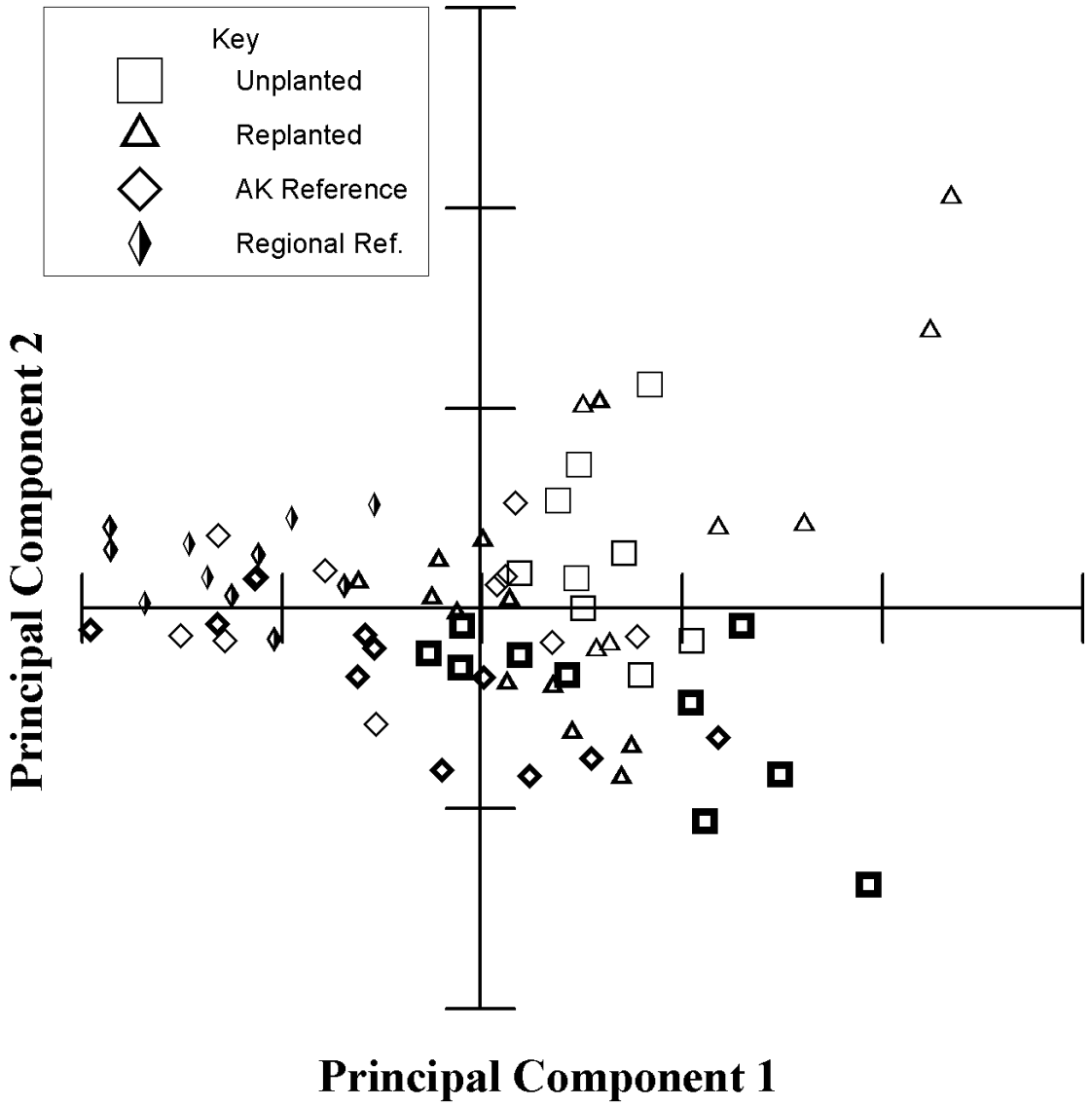

Figure 10. Principal component analysis of data for Ag, Cd, Cr, Cu, Ni, Zn, Hg, and Fe in mussels collected in September 1996 and May 1997 (bold symbols). (Unplanted = Con Ed Tower and Saw Mill Creek South; Replanted = Old Place Creek and Saw Mill Creek North; AK Reference = Tufts Point and Mill Creek; and Regional Reference = Sandy Hook.

Table 1. Trace metal quality assurance (QA) data

Parameter / QA measurement	Composition (wt %)	Concentration (mg/kg)								
	Fe	Cr	Cu	Ni	Zn	Mn	Pb	Hg	Ag	Cd
Sediments										
Detection limit[a]	0.0001	1.2	1.2	2.0	0.3	0.6	4.6			
NBS 1645 standard reference material:										
Certified	11.3	29,600	109	45.8	1720	785	714			
+/-	1.2	2800	19	2.9	170	97	28			
Observed mean (n = 5)	10.5	28,585	107	43.4	1674	708	693			
Std. dev.	0.3	248	2.6	0.9	74	23	6			
Recovery (%)	93	97	98	95	97	90	97			
Mussels										
Detection limit[b]	2.0	0.008	0.6	0.06	0.2			0.0054	0.003	0.002
NBS 1566A standard reference material:										
Certified	539	1.43	66.3	2.25	830			0.0654	1.68	4.15
+/-	15	0.46	4.3	0.44	57			0.0067	0.15	0.38
Observed mean (n = 9)	528	1.42	67.3	2.22	838			0.0650	1.63	3.97
Std. dev.	14	0.07	1.5	0.19	37			0.0035	0.08	0.14
Recovery (%)	98	100	102	99	101			99	97	96

[a]Based on three standard deviations of the six processing blanks, a typical sample weight of 1 g, and a volume of 25 ml.
[b]Based on three standard deviations of the nine processing blanks, a typical sample weight of 1 g, and a volume of 25 ml.

Table 2. Metal concentrations in sediments in September 1996

Station	Sediment Composition (wt %)			Metal Concentration (µg/g)					
	Fines[a]	Fe	OC	Cr	Cu	Ni	Zn	Mn	Pb
Con Ed Tower (unplanted)									
A		1.82	46.6	195	326	62	231	141	294
B		2.28	48.6	206	281	96	309	164	239
C		3.08	10.7	253	265	112	285	545	290
D		2.23	34.2	202	336	86	283	203	235
Mean (n = 4)		2.35	35.0	214	302	89	277	263	265
Std. dev.		0.45	17.4	23	30	18	29	164	28
Coef. of var.[b]		19%	50%	11%	10%	21%	10%	62%	10%
Saw Mill Creek South (unplanted)									
A	99.0	3.93	6.2	191	461	49	406	298	275
B	98.5	3.91	5.5	206	459	49	408	358	279
C	98.0	4.28	5.4	164	385	46	410	404	249
D	97.8	3.52	6.1	174	421	45	383	288	248
Mean (n = 4)	98.3	3.91	5.8	184	431	47	402	337	263
Std. dev.	0.5	0.31	0.4	19	36	2	12	54	17
Coef. of var.[b]	0.6%	8.0%	7.0%	10.0%	8.0%	4.0%	3.0%	16%	6.0%
Old Place Creek (replanted)									
A	2.1	0.64	0.2	9	37	6	23	117	22
B	20.6	1.18	1.3	37	101	17	97	118	83
C	11.6	0.91	0.4	27	79	12	57	96	49
D	13.3	0.76	0.8	23	141	10	68	85	53
Mean (n = 4)	11.9	0.87	0.7	24	90	11	61	104	52
Std. dev.	7.6	0.23	0.5	12	43	4	30	16	25
Coef. of var.[b]	64%	26%	73%	49%	48%	40%	50%	16%	48%
Saw Mill Creek North (replanted)									
A	96.4	3.53	9.8	321	485	103	247	267	499
B	96.0	4.77	7.1	292	516	53	186	281	459
C	96.5	3.44	5.4	237	517	56	313	252	458
D	98.1	3.35	6.1	141	313	39	252	270	210
Mean (n = 4)	96.7	3.77	7.1	248	458	63	250	267	406
Std. dev.	0.9	0.58	1.9	73	85	25	83	17	129
Coef of var.[b]	1%	15%	27%	29%	18%	40%	33%	6%	32%

Table 2. (Cont.)

Station	Sediment Composition (wt %)			Metal Concentration (µg/g)					
	Fines[a]	Fe	OC	Cr	Cu	Ni	Zn	Mn	Pb
Tufts Point (Arthur Kill reference)									
A	97.3	4.12	9.4	107	53	37	292	633	257
B	96.4	2.70	9.2	86	72	39	602	146	225
C	96.7	3.35	11.7	104	514	57	503	626	312
D	86.1	3.22	13.8	75	230	34	295	828	282
Mean (n = 4)	94.1	3.35	11.1	93	217	42	423	558	269
Std. dev.	5.4	0.58	2.2	15	213	10	155	290	37
Coef. of var.[b]	6%	17%	20%	16%	98%	24%	37%	52%	14%
Mill Creek (Arthur Kill reference)									
A	76.3	2.97	9.5	64	740	36	491	780	597
B	92.2	3.72	7.9	90	908	43	531	360	733
C	81.1	3.92	7.7	82	796	41	556	1840	650
D	35.8	9.50[c]	9.1	74	422	60	794	315	636
Mean (n = 4)	71.3	3.54	8.5	78	717	45	593	824	654
Std. dev.	24.6	0.50	0.9	11	209	11	137	709	57
Coef. of var.[b]	35%	14%	10%	14%	29%	24%	23%	86%	9%
Sandy Hook (regional reference)									
A	3.2	0.20		3.2	1.4	0.8	7.1	5.8	2.3
B	2.4	0.47		9.3	3.5	1.3	12.9	7.5	7.9
Mean (n = 2)	2.8	0.33		6.2	2.4	1.0	10.0	6.7	5.1
Std. dev.	0.5	0.19		4.4	1.4	0.3	4.0	1.2	4.0
Coef. of of var.[b]	19%	57%		70%	59%	33%	40%	18%	78%

[a]Fines are sediment <0.063 mm.
[b]Coefficient of variance is represented by the standard deviation divided by the mean.
[c]Value is outlier determined by using the Grubbs test, and is not included in the average.

Table 3. Metal concentrations in sediments in May 1997

Station	Sediment Composition (wt %) Fe	OC	Metal Concentration (µg/g) Cr	Cu	Ni	Zn	Mn	Pb
Con Ed Tower (unplanted)								
A	2.39	15.7	110	293	39	178	222	219
B	2.91	8.4	135	225	32	213	276	353
C	2.10	13.5	98	239	37	227	282	229
D	3.61	7.7	202	336	86	283	203	235
Mean (n = 4)	2.47	11.3	114	252	36	206	260	267
Std. dev.	0.33	3.9	15	29	3	21	27	61
Coef. of var.[a]	14%	34%	13%	12%	8%	10%	10%	23%
Saw Mill Creek South (unplanted)								
A	3.60	7.7	242	510	57	451	324	295
B	3.40	7.4	197	398	44	365	357	237
C	3.77	6.6	145	270	43	388	569	217
D	3.66	7.8	139	295	41	343	540	217
Mean (n = 4)	3.61	7.4	181	368	46	387	447	241
Std. dev.	0.16	0.5	48	110	7	47	125	37
Coef. of var.[a]	4%	7%	27%	30%	16%	12%	28%	15%
Old Place Creek (replanted)								
A	0.35	0.1	7	19	4	17	64	14
B	1.36	2.6	47	136	20	104	116	96
C	2.90	8.0[b]	93	248	35	243	475	162
D	0.33	1.2	10	27	4	18	56	28
Mean (n = 4)	1.24	1.3	39	107	16	96	178	75
Std. dev.	1.21	1.2	40	108	15	106	200	68
Coef. of var.[a]	98%	95%	102%	100%	92%	111%	112%	91%
Saw Mill Creek North (replanted)								
A	3.61	7.7	214	455	42	228	285	460
B	2.80	8.4	153	457	47	242	291	399
C	3.55	7.8	161	216	45	252	293	351
D	3.18	6.2	97	248	36	262	380	206
Mean (n = 4)	3.29	7.5	156	344	42	246	312	354
Std. dev.	0.35	0.9	56	135	8	93	40	97
Coef. of var.[a]	11%	13%	36%	39%	19%	38%	13%	28%

Table 3. (Cont.)

Station	Sediment Composition (wt %) Fe	OC	Metal Concentration (µg/g) Cr	Cu	Ni	Zn	Mn	Pb
Tufts Point (Arthur Kill reference)								
A	3.62	6.4	98	240	46	428	960	233
B	3.67	7.2	101	354	84	1062	698	374
C	3.37	13.1	113	795	94	1044	498	461
D	3.18	12.1	89	250	38	312	1647	236
Mean (n = 4)	3.46	9.7	100	410	66	712	951	326
Std. dev.	0.23	3.4	10	262	28	398	502	111
Coef. of var.[a]	7%	35%	10%	64%	42%	56%	53%	34%
Mill Creek (Arthur Kill reference)								
A	4.68	16.2	77	598	31	432	2764	478
B	3.49	10.7	80	1038	44	575	361	705
C	3.04	17.4	80	420	33	453	393	374
D	3.46	9.1	75	636	34	343	816	512
Mean (n = 4)	3.67	13.4	78	673	36	451	1083	517
Std. dev.	0.70	4.1	2	261	6	95	1140	138
Coef. of var.[a]	19%	31%	3%	39%	16%	21%	105%	27%
Sandy Hook (regional reference)								
A	0.15		3.9	2.0	<MDL	8.9	32.3	6.9
B	0.38		9.5	1.8	<MDL	7.5	18.6	<MDL
Mean (n = 2)	0.27		6.7	1.9	8.2	25.4		
Std. dev.	0.16		3.9	0.1	1.0	9.7		
Coef. of var.[a]	62%		58%	7%	12%	38%		

[a]Coefficient of variance is represented by the standard deviation divided by the mean.
[b]Value is outlier determined by using the Grubbs test, and is not included in the average.

Table 4. Trace metal statistics for sediments from the Arthur Kill and other areas in the region

Site (depth section of core)	Statistic	Composition (wt %)	Concentration (µg/g)					Reference
		Fe	Cr	Cu	Ni	Zn	Pb	
Arthur Kill								
Arthur Kill (upper 1 cm)	Average (n = 39)	2.84	136	299	46	308	251	This study
	Std. dev.	1.15	79	171	26	221	127	
	Coef. of var.	40%	58%	57%	57%	72%	50%	
Mill Creek (upper 1 cm)	Average (n = 7)	3.61	78	695	40	522	586	This study
	Std. dev.	0.58	7	220	9	133	122	
	Coef. of var.	16%	10%	32%	23%	25%	21%	
Arthur Kill (upper 5 cm)	Minimum					80	160	Meyerson *et al.* 1981
	Maximum					2300	3209	
Arthur Kill (upper 2 cm)	Minimum	3.73	110	283	45	349	229	Adams *et al.* 1998
	Maximum	4.52	195	650	85	523	440	
Unimpacted regions based on Mill Creek Fe content			69	16	56	24	24	Daskalakis and O'Connor 1995
Other Areas within the Region								
Sandy Hook (upper 1 cm)	Average (n = 4)	0.30	6.5	2.2	1.1	9.1	5.4	This study
	Std. dev.	0.15	3.4	0.9	0.6	2.6	2.6	
	Coef. of var.	50%	52%	41%	51%	29%	48%	
Newark Bay (upper 5 cm)	Minimum					120	70	Meyerson *et al.* 1981
	Maximum					1100	530	
Newark Bay (upper 2 cm)	Area-weighted average	3.4	137	227	51	308	194	Adams *et al.* 1998
	Minimum	0.84	27	10	10	46	12	
	Maximum	4.71	244	66	65	786	550	
New York Harbor (upper 2 cm)	Area-weighted average	2.35	78	72	24	170	78	Adams *et al.* 1998
	Minimum	0.69	26	4	6	29	19	
	Maximum	4.28	171	1030	65	342	246	
Western Long Island Sound (upper 2 cm)	Area-weighted average	2.81	81	70	27	177	57	Adams *et al.* 1998
	Minimum	0.67	25	10	7	47	15	
	Maximum	4.01	135	136	42	280	130	

Table 5. Metal concentrations in ribbed-mussels in September 1996

Sample	Mussel Size Length (mm)	Mussel Size Weight (g)	Mussel Concentration (µg/g) Fe	Cr	Cu	Ni	Zn	Hg	Ag	Cd
Con Ed Tower (unplanted)										
Specimen 1	54.1	10.42	140	1.18	28.3	0.51	73	0.28	0.85	3.57
Specimen 2	58.2	12.86	301	3.02	13.5	0.57	62	0.30	0.61	3.48
Specimen 3	60.6	13.24	380	15.38[b]	31.8	0.66	65	0.33	0.89	5.38
Specimen 4	62.8	14.51	198	5.28	15.2	0.49	68	0.26	1.19	3.67
Specimen 5	65.2	17.40	298	1.66	15.0	0.58	57	0.26	1.19	2.67
Mean (n = 5)	60.2	13.69	263	2.78	20.7	0.56	65	0.29	0.95	3.75
Std. dev.	4.3	2.55	95	1.84	8.6	0.07	6	0.03	0.25	0.99
Coef. of var.[a]		19%	36%	66%	42%	12%	9%	11%	26%	26%
Saw Mill Creek South (unplanted)										
Specimen 1	56.1	11.53	461	1.10	13.5	0.54	61	0.38	0.68	5.81
Specimen 2	62.5	14.00	290	0.82	14.1	0.31	72	0.36	1.03	6.46
Specimen 3	62.6	12.17	532	1.19	12.1	0.49	59	0.38	1.03	6.60
Specimen 4	65.8	16.89	399	1.03	12.8	0.44	57	0.32	0.89	5.20
Specimen 5	66.8	13.66	317	1.16	16.3	0.40	69	0.02	1.08	6.19
Mean (n =5)	62.8	13.65	400	1.06	13.8	0.43	64	0.29	0.94	6.05
Std. dev.	4.2	2.08	100	0.15	1.6	0.09	7	0.16	0.16	0.56
Coef. of var.[a]		15%	25%	14%	12%	20%	10%	53%	17%	9%
Old Place Creek (replanted)										
Specimen 1	54.8	11.33	361	9.50	28.5	0.68	85	0.35	0.96	4.07
Specimen 2	55.1	9.21	314	2.09	25.8	0.81	85	0.47	1.00	4.42
Specimen 3	58.5	14.75	283	1.70	73.7[b]	0.52	85	0.43	0.40	3.74
Specimen 4	58.7	12.54	157	3.31	66.1	0.82	76	0.47	1.34	4.77
Specimen 5	65.1	19.06	194	2.22	19.4	0.41	63	0.35	1.16	2.52
Mean (n = 5)	58.4	13.38	262	3.76	35.0	0.65	79	0.41	0.97	3.90
Std. dev.	4.1	3.76	85	3.26	21.1	0.18	10	0.06	0.36	0.86
Coef. of var.[a]		28%	32%	87%	60%	28%	12%	15%	37%	22%
Saw Mill Creek North (replanted)										
Specimen 1	54.9	10.00	272	0.77	39.0	0.61	75	0.33	0.74	6.70
Specimen 2	56.2	9.67	293	1.14	14.4	0.54	68	0.35	0.62	6.25
Specimen 3	59.1	11.44	269	0.89	18.1	0.56	72	0.33	0.49	5.93
Specimen 4	62.7	14.40	235	3.82	72.7[b]	0.52	75	0.31	0.66	4.83
Specimen 5	66.5	15.76	1331[b]	7.27	29.6	1.47[b]	82	0.47	1.34	6.86
Mean (n = 5)	59.9	12.25	267	2.78	20.2	0.56	74	0.36	0.77	6.11
Std. dev.	4.8	2.71	24	2.81	14.9	0.04	5	0.07	0.33	0.81
Coef. of var.[a]		22%	9%	101%	74%	6%	7%	19%	43%	13%

Table 5. (Cont.)

Sample	Mussel Size: Length (mm)	Mussel Size: Weight (g)	Mussel Concentration (µg/g): Fe	Cr	Cu	Ni	Zn	Hg	Ag	Cd
Tufts Point (Arthur Kill reference)										
Specimen 1	54.0	11.66	179	2.48	15.3	0.67	60	0.15	0.68	4.34
Specimen 2	55.6	9.00	227	2.84	14.3	0.71	73	0.23	0.64	7.50
Specimen 3	55.5	12.61	147	1.15	15.8	0.61	68	0.15	0.70	8.64
Specimen 4	56.5	12.73	153	1.97	16.7	0.65	60	0.18	0.61	4.71
Specimen 5	61.5	15.10	193	1.79	19.2	0.38	66	0.20	0.83	4.06
Mean (n = 5)	56.6	12.22	180	2.04	16.2	0.60	65	0.18	0.69	5.85
Std. dev.	2.9	2.20	32	0.65	1.8	0.13	6	0.03	0.09	2.08
Coef. of var.[a]		18%	18%	32%	11%	21%	8%	17%	13%	36%
Mill Creek (Arthur Kill reference)										
Specimen 1	58.4	14.93	92	0.43	22.3	0.19	41	0.04	0.21	1.29
Specimen 2	58.7	11.72	82	0.19	9.8	0.31	56	0.07	0.12	1.54
Specimen 3	59.1	13.86	144	0.35	19.5	0.36	58	0.08	0.41	1.78
Specimen 4	61.1	14.59	88	0.31	8.3	0.21	45	0.06	0.10	1.89
Specimen 5	67.0	14.53	137	0.42	12.2	0.82	71	0.07	0.20	2.44
Mean (n = 5)	60.9	13.93	109	0.34	14.4	0.38	54	0.06	0.21	1.79
Std. dev.	3.6	1.29	29	0.10	6.1	0.26	12	0.02	0.12	0.43
Coef. of var.[a]		9%	27%	28%	43%	67%	22%	23%	60%	24%
Sandy Hook (regional reference)										
Specimen 1	55.7	10.44	75	0.29	7.2	0.28	32	0.09	0.21	0.49
Specimen 2	56.9	11.78	46	0.65	11.1	0.26	36	0.12	0.32	0.46
Specimen 3	57.4	10.30	57	0.54	10.2	0.33	43	0.10	0.29	0.53
Specimen 4	58.6	14.23	109	2.26	13.6	0.48	51	0.15	0.64	1.26
Specimen 5	60.2	12.58	88	0.58	12.4	0.37	49	0.13	0.67	0.69
Specimen 6	62.0	12.88	1392[b]	2.56	14.1	1.56[b]	60	0.17	0.52	1.59
Mean (n = 6)	58.5	12.03	75	1.15	11.4	0.34	45	0.13	0.44	0.84
Std. dev.	2.3	1.51	25	0.99	2.6	0.09	10	0.03	0.19	0.47
Coef. of var.[a]		13%	33%	86%	22%	26%	23%	26%	44%	57%

[a]Coefficient of variance is represented by the standard deviation divided by the mean.
[b]Value is outlier determined by using the Grubbs test, and is not included in the average.

Table 6. Metal concentrations in ribbed-mussels in May 1997

Sample	Mussel Size		Mussel Concentration (µg/g)							
	Length (mm)	Weight (g)	Fe	Cr	Cu	Ni	Zn	Hg	Ag	Cd
Con Ed Tower (unplanted)										
Specimen 1	56.6[b]	11.15[b]	952[b]	3.27[b]	49.3[b]	1.65[b]	94[b]	0.36[b]	2.25[b]	12.22[b]
Specimen 2	57.7	12.15	465	1.93	18.5	1.20	83	0.26	0.20	4.56
Specimen 3	58.7	14.00	228	1.02	16.6	0.55	58	0.21	0.23	3.04
Specimen 4	59.9	13.51	235	0.80	16.8	0.49	80	0.18	0.45	5.21
Specimen 5	61.9	14.43	140	0.80	12.5	0.52	65	0.19	0.39	6.19
Specimen 6	62.2[b]	15.44[b]	1218[b]	4.34[b]	83.3[b]	18.62[b]	268[b]	0.23[b]	0.45[b]	3.07[b]
Mean (n = 4)	59.6	13.52	267	1.14	16.1	0.69	71	0.21	0.32	4.75
Std. dev.	1.8	0.99	139	0.54	2.5	0.34	12	0.19	0.36	4.81
Coef. of var.[a]		7%	52%	47%	16%	49%	17%	92%	112%	101%
Saw Mill Creek South (unplanted)										
Specimen 1	56.9	9.26	681	1.94	12.9	1.17	74	0.41	0.50	8.52
Specimen 2	57.6	11.58	318	1.30	17.3	1.24	61	0.38	1.22	5.18
Specimen 3	59.1	13.75	369	0.94	23.4	0.99	55	0.22	0.55	2.97
Specimen 4	59.0	11.96	474	1.87	20.5	1.42	69	0.32	0.66	5.46
Specimen 5	60.7	15.15	384	1.38	24.5	0.78	11	0.23	0.52	3.93
Specimen 6	62.0	13.84	432	1.68	18.2	0.93	66	0.30	0.68	5.95
Mean (n = 6)	59.2	12.59	443	1.52	19.5	1.09	56	0.31	0.69	5.34
Std. dev.	1.9	2.10	128	0.38	4.3	0.23	23	0.08	0.27	1.91
Coef. of var.[a]		17%	29%	25%	22%	21%	41%	25%	39%	36%
Old Place Creek (replanted)										
Specimen 1	55.3	14.38	196	1.93	16.4	0.70	64	0.22	0.54	3.26
Specimen 2	55.5	14.26	231	0.80	16.8	0.63	50	0.20	0.60	2.31
Specimen 3	55.0	12.61	145	1.12	19.3	0.54	63	0.30	1.55	4.09
Specimen 4	57.9	13.95	331	1.06	14.8	0.78	55	0.20	0.54	3.64
Specimen 5	58.8	15.78	134	1.35	18.3	0.57	52	0.27	0.46	2.51
Specimen 6	59.3	13.43	116	0.56	17.8	0.47	48	0.21	0.35	2.39
Mean (n = 6)	57.0	14.07	192	1.14	17.2	0.61	55	0.23	0.67	3.03
Std. dev.	1.9	1.06	80	0.47	1.6	0.11	7	0.04	0.44	0.74
Coef. of var.[a]		8%	42%	42%	9%	18%	12%	18%	65%	25%
Saw Mill Creek North (replanted)										
Specimen 1	56.5	12.82	405	1.32	18.1	1.03	77	0.26	0.21	3.43
Specimen 2	57.9	13.41	249	0.95	13.0	0.88	79	0.24	0.41	4.91
Specimen 3	58.7	12.89	138	0.59	13.4	0.47	69	0.20	0.96	4.13
Specimen 4	62.6	13.83	491	1.68	16.5	0.63	72	0.29	0.25	5.33
Specimen 5	65.9	16.21	142	0.75	12.5	0.50	65	0.22	0.57	4.58
Specimen 6	65.7	16.44	333	1.29	17.1	0.64	73	0.22	0.36	4.30
Mean (n = 6)	61.2	14.27	293	1.10	15.1	0.69	73	0.24	0.46	4.45
Std. dev.	4.1	1.64	143	0.41	2.4	0.22	5	0.03	0.28	0.66
Coef. of var.[a]		11%	49%	37%	16%	32%	7%	13%	60%	15%

Table 6. (Cont.)

Sample	Mussel Size		Mussel Concentration (µg/g)							
	Length (mm)	Weight (g)	Fe	Cr	Cu	Ni	Zn	Hg	Ag	Cd
Tufts Point (Arthur Kill reference)										
Specimen 1	56.5	13.45	226	1.09	16.7	0.78	68	0.18	0.34	9.58
Specimen 2	57.5	12.93	145	0.70	13.7	0.50	57	0.15	0.29	3.67
Specimen 3	58.5	12.43	379	2.01	19.2	0.90	74	0.20	0.60	9.26
Specimen 4	62.5	15.21	249	0.79	14.6	1.14	60	0.16	0.39	5.32
Specimen 5	64.8	15.78	188	0.91	23.1	0.75	66	0.11	0.27	5.11
Specimen 6	65.6	15.77	116	0.45	12.8	1.05	58	0.16	0.18	4.98
Mean (n = 6)	60.9	14.26	217	0.99	16.7	0.85	64	0.16	0.35	6.32
Std. dev.	3.9	1.50	93	0.54	3.9	0.23	7	0.03	0.14	2.47
Coef. of var.[a]		11%	43%	55%	23%	27%	11%	19%	41%	39%
Mill Creek (Arthur Kill reference)										
Specimen 1	56.7	12.07	153	0.29	17.5	0.63	65	0.10	0.35	1.49
Specimen 2	56.8	13.52	32	0.09	7.8	0.18	29	0.05	0.37	0.22
Specimen 3	57.5	12.99	34	0.12	12.1	0.60	46	0.08	0.66	0.35
Specimen 4	58.9	13.16	73	0.19	7.1	0.53	42	0.11	0.51	0.35
Specimen 5	59.8	11.04	21	0.07	8.3	0.19	26	0.05	0.48	0.25
Specimen 6	60.9	17.66	162	0.37	6.5	0.65	39	0.12	0.52	0.68
Mean (n = 6)	61.7	15.65	151	0.39	14.2	0.40	46	0.07	0.25	1.37
Std. dev.	4.2	2.70	114	0.33	4.5	0.17	14	0.02	0.09	0.39
Coef. of var.[a]		17%	76%	85%	32%	43%	31%	29%	37%	28%
Sandy Hook (regional reference)										
Specimen 1	55.7	9.49	65	0.28	13.4	0.83	59	0.09	0.71	0.36
Specimen 2	56.8	13.52	32	0.09	7.8	0.18	29	0.05	0.37	0.22
Specimen 3	57.5	12.99	34	0.12	12.1	0.60	46	0.08	0.66	0.35
Specimen 4	58.9	13.16	73	0.19	7.1	0.53	42	0.11	0.51	0.35
Specimen 5	59.8	11.04	21	0.07	8.3	0.19	26	0.05	0.48	0.25
Specimen 6	60.9	17.66	162	0.37	6.5	0.65	39	0.12	0.52	0.68
Mean (n = 6)	58.3	12.98	65	0.19	9.2	0.50	40	0.08	0.54	0.37
Std. dev.	2.0	2.76	52	0.12	2.8	0.26	12	0.03	0.12	0.17
Coef. of var.[a]		21%	81%	62%	31%	53%	29%	34%	23%	45%

[a]Coefficient of variance is represented by the standard deviation divided by the mean.
[b]Value is outlier determined by using the Grubbs test, and is not included in the average.

Table 7. Trace metal statistics for ribbed-mussels from the Arthur Kill and other areas in the region

Site	Statistic	Concentration (µg/g)								Reference
		Fe	Cr	Cu	Ni	Zn	Hg	Ag	Cd	
Arthur Kill – All Sites Except Mill Creek										
Old Place Creek, Saw Mill Creek North & South, Con Ed Tower, & Tufts Point	Mean (n = 53)	274	1.8	19	0.67	66	0.27	0.68	4.9	This study
	Std. dev.	129	1.6	9	0.26	12	0.10	0.33	1.7	
	Coef. of var.	47%	91%	46%	39%	18%	36%	49%	35%	
Arthur Kill – Mill Creek Site Only										
Mill Creek	Mean (n = 11)	132	0.4	14	0.39	50	0.07	0.23	1.6	This study
	Std. dev.	86	0.2	5	0.20	13	0.02	0.10	0.4	
	Coef. of var.	65%	66%	35%	52%	27%	26%	45%	28%	
Other Areas within the Region with Contaminated Sediments										
Inner Mystic River Estuary, CT	Mean	300-450		15-70		65-75				Miller 1988
New Bedford Harbor, MA	Mean	198	1.94	15	0.25	51				Nelson *et al.* 1995
Other Less-Impacted Areas within the Region										
Sandy Hook	Mean (n = 12)	69	0.7	10	0.43	43	0.11	0.49	0.6	This study
	Std. dev.	40	0.8	3	0.21	11	0.04	0.16	0.4	
	Coef. of var.	58%	126%	27%	49%	25%	35%	33%	69%	
Outer Mystic River Estuary, CT	Mean	150		15		55				Miller 1988
Great Sippewissett Marsh, MA	Mean	126	0.8	14		53			4.1	Giblin *et al.* 1982
East Sandwich, MA	Mean	202	0.5	8	0.14	34			1.1	Nelson *et al.* 1995

Table 8. Correlations[a] between metals and sediment characteristics, and among metals, in ribbed-mussels, where $r \geq 0.80$

Site	Sediments		Mussels
	With Organic Carbon (OC) in 1996 and 1997	With % Fines in 1996[b]	
Con Ed Tower	Cr vs. Ni (0.94) and Zn (0.80) Ni vs. Zn (0.89)	(no % fine data)	Fe vs. Ni (0.86)
Saw Mill Creek South	Cr vs. Cu (0.91) and Ni (0.90) Cu vs. Ni (0.86), Mn (-0.91), and Pb (0.95) Pb vs. Ni (0.94), Zn (0.84), and Cr (0.89) Ni vs. Zn (0.91)	% fines vs. Ni (0.85)	None
Old Place Creek	All metals with all metals and with OC	% fines vs. Fe (0.90), Cr (0.98), Ni (0.95), Zn (0.99), and Pb (0.99)	Zn vs. Cd (0.80) and Hg (0.82)
Saw Mill Creek North	Pb vs. Cr (0.86) and Cu (0.82)[c]	% fines vs. Cr (-0.89), Cu (-0.97), and Pb (-0.94)	Fe vs. Cr (0.94) Cr vs. Ag (-0.83) and Hg (0.94) Ni vs. Zn (0.83)
Tufts Point	Ni vs. Zn (0.94) and Cu (0.82) Pb vs. Cu (0.97), Ni (0.93), and Zn (0.83) Fe vs. Mn (0.83)	% fines vs. Cr (0.82)	None
Mill Creek	Pb vs. Cu (0.96), Ni (0.90), and OC (-0.80) Ni vs. Zn (0.82)	% fines vs. Fe (-0.93) and Zn (-0.92)	Fe vs. Cr (0.93) Zn vs. Hg (0.80)
Sandy Hook	(no OC data)	(insufficient % fines data)	Cd vs. Zn (0.84) and Cr (0.93)

[a]Correlations between two metals are not repeated. For instance, in the correlations that included OC data for Con Ed Tower, the 0.94 correlation between Cr vs. Ni in the first row is not repeated as a Ni vs. Cr correlation in the second row.
[b]Only the correlations with % fines are shown, not the correlations among metals.
[c]The correlation coefficient for Cr vs. Cu is 0.79.

III. PETROLEUM HYDROCARBONS IN SEDIMENTS AND RIBBED-MUSSELS (*Geukensia demissa*)

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INTRODUCTION

The goal of our study was to assess the effectiveness of the replanting effort for removing petroleum hydrocarbon contaminants from the Arthur Kill marshes, and to assess the usefulness of ribbed-mussels as possible biomarkers of petroleum-related spills. Our field protocol included collection of sediment and ribbed-mussel samples from the six saltmarsh sites in the Arthur Kill and from one saltmarsh site on Sandy Hook (Appendix Table B1). Samples from Sandy Hook provided a relatively uncontaminated regional reference for samples from the Arthur Kill marshes.

METHODS AND MATERIALS

Sediment Collection and Sectioning

Four stations were selected at each marsh site in the Arthur Kill. Each station was located 0.2 m above the mid-tide, and the stations were spaced within 2-20 m of each other (see description of the sampling transect in Chapter II, "Trace Metal Contaminants in Sediments and Ribbed-Mussels"). No cores were collected at the Sandy Hook site. All sediment samples were archived at the Howard Laboratory either at -20°C or at -80°C.

During September 1996, one sediment core was taken by hand at each station using a chrome-plated copper tube (3.8-cm o.d. × 22.9-cm length). A total of 24 sediment cores (*i.e.*, 6 sites × 4 stations per site × 1 core per station) were collected. Sediment cores from Old Place Creek, Con Ed Tower, and Mill Creek were sectioned using a core-sectioning device built at the Howard Laboratory (Figure 11). The cores contained large amounts of diverse plant and other materials that prevented precise sectioning. Each core was sectioned into five individual sections, with each section being approximately 1-cm thick and weighing approximately 10 g. With four stations at each site and five sections per core per station, a total number of 60 core sections were prepared for the three marsh sites.

Diverse plant and other materials in the sediments prevented precise sampling of the Arthur Kill surface sediments. During May 1997, an approximately 1-cm section of surface sediment was collected at four stations at each of the six sites in the Arthur Kill using a stainless steel spoon. One surface sediment sample from Sandy Hook was collected during August 1997.

Mussel Collection, Processing, and Selection for Analysis

Mussels were collected randomly at each site in the Arthur Kill during September 1996 and May 1997. The number of mussels available for collection varied by site and sampling period. Thus, 17-34 mussels were collected at each site in September 1996, while only 6-15 mussels were collected at each site in May 1997. Sandy Hook mussels were collected during February 1997.

Live mussels were brought to the Howard Laboratory, and placed overnight in a 4°C, temperature-controlled room. Material for the determination of method detection limits (MDLs) in the mussels was obtained by overnight depuration of 12 additional Sandy Hook mussels in aerated seawater at 4°C. All mussels were dissected within 24 hr using implements cleaned with methylene chloride. After removal of extraneous materials from mussel shells (mud, barnacles, etc.), the physical characteristics were recorded for each specimen (Appendix Table B2). Mussel tissues were then excised, placed in precleaned glass containers, and archived at the Howard Laboratory at -80°C.

The length of an individual mussel was assumed to be related to its age, and possibly, the contaminant body burden. Since the length-frequency distribution of mussels varied by site and sampling period (Figures 12 and 13), a length range of 55-74 mm (inclusive) -- visually identified to be common to all sampling periods -- was selected as the bin range for analyses.

Five mussels at each site in the Arthur Kill were targeted for analyses. The bin range was divided into five groups (*i.e.*, 55-58 mm, 59-62 mm, 63-66 mm, 67-70 mm, and 71-74 mm), ensuring that mussels of different lengths were included in the analyses. Each mussel was assigned a random number. Mussels with the highest random numbers were sequentially selected from each group. When there were no mussels in one or more groups, mussels were selected in a two-step procedure. In step 1, the mussel with the highest random number within each group containing mussels was selected. In step 2, the mussel with the highest random number from all remaining mussels within the

bin range was selected. Step 2 was repeated until the requirement of five mussels per site was met.

Seven out of the 12 undepurated mussels from Sandy Hook were targeted for analyses. The bin range was divided into seven groups (*i.e.*, 55-56 mm, 57-58 mm, 59-60 mm, 61-62 mm, 63-64 mm, 65-66 mm, and 67-68 mm), and random numbers were assigned to each mussel. Mussels with the highest random number in each group were selected for analysis.

Extraction of Hydrocarbons in Sediments

Twenty core sections each from Old Place Creek, Con Ed Tower, and Mill Creek; four surface scoop samples each from Old Place Creek and Con Ed Tower; and a single surface scoop sample from Sandy Hook were processed in four extraction batches (Appendix Table B3). All sediment samples were dried with sodium sulfate before extraction. In the first batch, we extracted the sediments by shaking them with methylene chloride in an Erlenmeyer flask. The shaking/extraction procedure was manual and laborious, and did not save as much on extraction time or glassware as we initially thought. Therefore, Batches 2-4 samples were extracted with methylene chloride using automated Soxhlet extraction systems.

Batch 1 sediment samples were extracted by shaking sodium-sulfate-dried sediments with methylene chloride. Approximately 10 g of each Batch 1 sediment sample were placed into a mortar, then mixed by pestle with 60-80 g of anhydrous sodium sulfate until the mixture was dry. Approximately, 5 cc of activated copper were added to the sample for the bulk removal of elemental sulfur, and the mixture was transferred to an Erlenmeyer flask. Surrogate internal standard (20 µg of o-terphenyl) and any other spiking solutions, as appropriate, were added to the sample. Approximately 60 ml of methylene chloride were added to the Erlenmeyer flask, and the sample was shaken overnight. Methylene chloride was decanted, and the procedure was repeated two more times. The combined extract was concentrated to approximately 40 ml.

Batches 2-4 sediment samples were dried with sodium sulfate, and extracted with a Soxhlet extraction apparatus. Approximately 10 g of each sample from Batches 2-4 were placed into a mortar, then mixed by pestle with 60-80 g of anhydrous sodium sulfate until the mixture was dry. The sample was then transferred to a cellulose thimble. Surrogate internal standard (20 µg of o-terphenyl) and any other spiking solutions, as appropriate, were added to the sample. The thimble was then transferred to a labeled Soxhlet extraction apparatus. Hydrocarbons were extracted with methylene chloride for 18-24 hr. Activated copper gauze was placed in the extraction apparatus for the bulk removal of elemental sulfur. The methylene chloride extract was concentrated to approximately 40 ml.

Initially, we experimented with the volume of concentrate from each site to ensure that the flame ionization detector (FID) did not become overloaded during gas chromatographic (GC) analyses. We assumed that all potential interfering compounds in the 40-ml extract were at a very low level, and that they would not cause any chromatographic problems. Therefore, we injected 1 µL of this extract directly into a gas chromatographic column without any additional cleanup. The samples in which hydrocarbons were not detected were concentrated in a stepwise manner until the hydrocarbons were detected. After completing the screening of representative samples from each site, the methylene chloride extracts of all samples were subjected to silica-alumina glass column chromatographic removal of polar biogenic interferences. Column-cleaned extracts were then concentrated to appropriate final volumes for the GC analyses. GC internal standard (5-α-androstane) was added to each final extract before GC analyses.

Extraction of Hydrocarbons in Mussels

A total of 60 mussels from six Arthur Kill sites and seven mussels from one Sandy Hook site were processed in three extraction batches (Appendix Table B4).

Each mussel sample (3.2-15.4 g) was placed into a mortar, then mixed by pestle with 80 g of anhydrous sodium sulfate until the mixture was dry. The sample was then transferred to a cellulose thimble, and surrogate internal standard (20 µg of o-terphenyl) and any other spiking solutions, as appropriate, were added to the sample. The thimble was then transferred to a labeled Soxhlet extraction apparatus. Hydrocarbons in mussels were extracted with methylene chloride over 18-24 hr.

In Batch 1, we experimented with the volume of concentrate to ensure that the FID did not become overloaded during GC analyses. Initially, our total extract volume was 50 ml, and we used 10 ml of this extract for the lipid determination. We assumed that all potential interfering compounds in the remaining 40 ml of extract were at a very low level, and that they would not cause any chromatographic problems. Therefore, we injected 1 µL of this extract directly into the GC column without any additional cleanup. Contrary to our expectations based on the oil spill history in the Arthur Kill marshes, we barely observed any peaks in this dilute mussel extract. The remaining mussel extract was eluted through a silica-alumina glass column for the removal of polar lipids and other polar biogenic interferences, and the sample was concentrated to a volume of 5 ml. Surprisingly, a 1-µL injection of this extract did not overload the FID either, and the peak sizes were still very minute. This initial work suggested that our standard protocol of concentrating the sample to a final volume of 1 ml was also suitable for Arthur Kill and Sandy Hook mussels. All mussel extracts were

then subjected to silica-alumina glass column chromatographic cleanup. The column-cleaned extract was concentrated to about 700-750 µL, the GC internal standard was added (200 µL of 5-α-androstane, 20 µg total), and the final sample volume was brought to 1 ml using methylene chloride.

Gas Chromatographic Analyses of Hydrocarbons

Instrument Operating Parameters

Sediment and mussel samples were analyzed for a total of 33 normal-chain hydrocarbons and two branched-chain hydrocarbons (Appendix Table B5) using a Hewlett Packard (HP) 5880A GC-FID. One microliter of the final sample extract was injected into a fused silica capillary column in splitless mode using an HP 7673A autosampler. Extracts of all mussel samples and extracts of sediment samples from Batches 1, 2 (excluding the nine samples from Con Ed Tower), and 3 were injected into an HP-5 (0.32-mm i.d. × 30-m length × 0.25-µm film thickness) capillary column. Extracts of Batch 2 sediment samples from the Con Ed Tower site and extracts of sediments from Batch 4 were injected into a J&W DB-5 (0.45-mm i.d. × 30-m length × 0.42-µm film thickness) capillary column. The injector port temperature was set at 300°C, while the detector temperature was set at 280°C. An initial purge time of 1 min was used to maximize the amount of higher-boiling hydrocarbons that reached the top of the GC column. The column oven temperature was held at 50°C for 1 min after sample injection, and then programmed to reach 310°C at a rate of 3°C/min. The oven temperature was held at the final temperature of 310°C for 30 min, resulting in a total run time of 120 min. We used 5-α-androstane as a time reference standard and as a GC internal standard for monitoring sample-to-sample variation in peak retention time and sample-to-sample variation in GC-FID response. We used o-terphenyl as a time reference standard and as a surrogate internal standard for assessing analyte recoveries. The chromatographic peaks were recorded with an HP 5880A Series GC terminal. The data in the electronic format were collected with a Perkin-Elmer Nelson 970 interface and Perkin-Elmer Nelson Turbochrom 4.0 chromatographic software. Generation of calibration curves, identification of peaks, and integrations were done with the Turbochrom software. The text files generated by Turbochrom software were imported into a Microsoft Excel spreadsheet for the determination of final analyte concentrations. The analyte concentrations are expressed as µg/g (ppm) on a wet-weight basis.

Chromatographic Performance Evaluation

New Jersey Department of Environmental Protection (NJDEP 1995) guidelines were employed in the evaluation of chromatographic performance. The evaluation criteria included chromatographic separation of analytes, resolution of critical pairs of peaks, mass discrimination, and curve correlation coefficients.

Separation of Individual Analytes and Internal Standards

The GC temperature program successfully separated all 35 hydrocarbon peaks (*i.e.*, n-C_8 to n-C_{40}, including pristane and phytane) and two internal standard peaks in a mid-point calibration mixture (*i.e.*, a mixture in which all hydrocarbon and internal standard concentrations are 10 ng/µL; Figure 14), and all identifiable hydrocarbon peaks and two internal standard peaks in a diesel fuel oil #2 standard (Figure 15).

Resolution of Critical Pairs of Peaks

Resolution (R) of critical pairs of peaks of hydrocarbons was calculated as:

$$R = 2(RT_2-RT_1)/(W_1+W_2) \quad \text{Eq. 1}$$

where RT = retention time and W = baseline peak width of the respective hydrocarbon (NJDEP 1995). The R values for the n-C_{17}/pristane pair and the n-C_{18}/phytane pair were >0.8 for all mussel chromatographic batches. Resolutions for the two pairs of hydrocarbons for the sediment chromatographic batches were verified only visually and were found to be satisfactory.

Mass Discrimination

The NJDEP guideline for mass discrimination in the injector port (n-C_{32} peak area/n-C_{20} peak area >0.8) was met in all mussel and sediment chromatographic batches.

Calibration Curve Correlation Coefficients

Correlation coefficient squares (r^2) for each analyte in the five-point (*i.e.*, 2, 5, 10, 20, and 50 ng/µL; internal standards at 10 ng/µL) calibration curves were consistently >0.99 for all mussel and sediment batches.

Typical Gas Chromatographic Batch

A series of sequential steps were performed at the beginning of the study and prior to the analyses of a fresh batch of samples. First, we replaced the GC injection port

septum, injection port liner, gold-plated seal, and the ring. Then we verified background cleanliness of overall instrument components using an instrument blank solution that contained only the GC internal standards. The GC column resolution check was followed by the verification of a minimum mass discrimination criterion using the ratio of the n-C_{32} peak area to the n-C_{20} peak area. Finally, a five-point calibration curve was generated for the identification and quantification of all detectable analytes.

Before beginning the analyses, column performance and detector stability were verified using a mid-point calibration solution that contained the analytes and GC internal standards at a concentration of 10 ng/μL. We then injected a set of 4-5 unknown samples. The instrument performance was verified after completing the analyses of these 4-5 samples. These steps, including the analyses of a set of unknown samples and the verification of instrument performance, were repeated until the remaining samples were analyzed. This sequence of steps provided a calibration chromatogram for every 4-5 samples or 10-12 hr of instrument operation. An HP 5880A controller program limited the maximum number of injections in a sequence to 26.

Quantification of Hydrocarbons in Sediments

The GC-FID chromatograms of sediment extracts were often complex, and exhibited areas of unresolved envelops (Appendix Figures E1-E14). Chromatographic complexities also created a potential for coelution of internal standards with unknown interfering compound(s). Sediment extracts were quantified using an external standard calculation method due to uncertainties in the identifications of internal standards.

A second-order curve equation was used to fit the hydrocarbon calibration data:

$$Y = C_0 + C_1X + C_2X^2 \qquad \text{Eq. 2}$$

where, Y is the response of the analyte in the calibration sample, X is the amount of analyte in the calibration sample, and C_0, C_1, and C_2 are various curve coefficients for each analyte. For a given value of Y in an unknown sample, the Turbochrom software uses the first quadratic solution to Equation 2 to calculate the amount X near the origin of the curve:

$$X = \{-C_1 + [C_1^2 - 4C_2(C_0 - Y)]^{1/2}\}/2C_2 \qquad \text{Eq. 3}$$

Calculations Using Individual Hydrocarbons

For each hydrocarbon analyte, a second-order curve given by Equation 2 was used to fit the calibration data. Values of $r^2 > 0.99$ were obtained for each analyte fit.

In an unknown sample, the analyte amount X is calculated from Equation 3 given the measured analyte peak area Y. Amount X in this equation represents the analyte amount in 1 μL of the injected sample. The actual concentration of analyte in the sample is then calculated by multiplying X by a factor that incorporates the final extract volume and sample weight.

Calculations Using the Sum of Individual Hydrocarbons

In this method of calculation, X is defined as the sum of individual hydrocarbon amounts, and Y is defined as the sum of peak areas for individual hydrocarbons ranging from n-C_8 to n-C_{40}, including pristane and phytane. The X and Y values for each calibration solution were then used in Equation 2 to determine the new curve coefficients. Values of $r^2 > 0.99$ were obtained for this fit.

The total alkyl hydrocarbon concentrations in an unknown sample were calculated using Equation 3 with a new set of curve coefficients and the value of Y defined as the sum of peak areas for individual hydrocarbons.

Calculations Using the Sum of All Peaks Eluting between n-C_8 and n-C_{40}

In this method of calculation, all peaks eluting between n-C_8 and n-C_{40} were assumed to be a mixture of various normal-chain hydrocarbons, branched-chain hydrocarbons, and cyclic hydrocarbons. In Equation 2, X is defined as the sum of individual hydrocarbon amounts, and Y is defined as the sum of peak areas for the individual hydrocarbons n-C_8 to n-C_{40}, including pristane and phytane. The X and Y values for each calibration solution were used in Equation 2 to determine the curve coefficients.

For an unknown sample, the value for Y was calculated as Y = A-(B+C), where A is the sum of the areas for "all" peaks eluting between n-C_8 and n-C_{40}, B is the peak area for o-terphenyl, and C is the peak area for 5-α-androstane. We assumed that other hydrocarbons did not coelute with o-terphenyl and 5-α-androstane. The peak summation window began 15 sec before the retention time of the n-C_8 peak and ended 15 sec after the retention time of the n-C_{40} peak. The value for X in Equation 2 is the sum of amounts of individual hydrocarbons, including n-C_8 to n-C_{40}, pristane, and phytane, in the individual hydrocarbon calibration mixture. The values for curve coefficients for the sum of individual hydrocarbons were used in Equation 3, to calculate TPH concentrations after applying an appropriate multiplication factor characteristic of sample weight and final volume of sample extract.

Quantification of Soil SRM 765

Soil SRM (*i.e.*, SRM 765) obtained from Environmental Resource Associates was extracted with each sediment ex-

traction batch. A one-point linear calibration was prepared using a standard solution of diesel fuel oil #2 from Restek Corporation. The linear equation Y = mX+C was used in this quantification. In this equation, Y was calculated as Y = A-(B+C), where A is the sum of areas for "all" peaks eluting between n-C_8 and n-C_{40}, B is the peak area for o-terphenyl, and C is the peak area for 5-α-androstane. We assumed that other hydrocarbons did not coelute with o-terphenyl and 5-α-androstane. The peak summation window began 15 sec before the retention time of the n-C_8 peak and ended 15 sec after the retention time of the n-C_{40} peak. Also in this equation, X is the amount of Restek diesel fuel oil in a 1-µL injection, m is the slope of the line, and C is the intercept (where C = 0 because the line is forced through the origin). The concentration of diesel fuel oil in SRM 765 was calculated by multiplying X by a factor that incorporated the final extract volume and sample weight.

Quality Assurance for Sediment Analyses

Quality assurance criteria listed in Appendix Table C1 were used for evaluating the quality of sediment data. Results of quality assurance of sediment analyses are summarized for method detection limit, laboratory method blanks, surrogate internal standard recovery, matrix spike recovery, soil standard reference material analyses, and replicate sediment analyses.

Method Detection Limit

The target MDL value for TPH was 10 µg/g, and was based on the New Jersey Department of Environmental Protection's quality assurance document (NJDEP 1995). We spiked each replicate MDL sediment matrix with 20 µg of each hydrocarbon in approximately 10-g MDL replicate sediment samples. With 35 hydrocarbons used for spiking, and 20 µg spiked per hydrocarbon, the total spiked hydrocarbon amount was 700 µg, or 70 µg/g of sediment. The MDL for sediments was calculated as MDL = σt; where σ is the standard deviation of seven replicate measurements and t is Student's t value of 3.143 with six degrees of freedom (EPA 1984). The MDL values for sediments varied from analyte to analyte, and ranged from 0.53 to 8.25 µg/g, wet weight, with a majority of MDL values between 1 and 2 µg/g (Appendix Table C2). Since n-C_8 was not detected in MDL samples, its MDL was not determined.

The EPA (1984) protocol for MDL determination recommends that the spiked amount be approximately 2-5 times greater than the target MDL. Our spiked amounts were 1.4-3.5 times greater than the EPA-recommended amounts in order to accommodate the poor sensitivity of the GC/FID. Most relative standard deviation (RSD) values for MDL determinations in the present study were around 10%, indicating a good precision in hydrocarbon determinations. [Relative standard deviation is the standard deviation divided by the mean, and is expressed as a percentage.]

Laboratory Method Blanks

For laboratory method blank samples, 134 out of 136 values were less than three times the MDL (data not provided). The blank criterion was not applied to n-C_8 because this compound was not detected in the MDL study.

Surrogate Internal Standard Recovery

Forty-four of 94 samples exceeded the surrogate internal standard recovery criterion (Appendix Tables C3-C6), with the exceedances mostly occurring in the Con Ed Tower samples containing complex chromatograms. The high values probably resulted from the coelution of surrogate standards with interfering peaks which increased peak area of the surrogate standard.

Matrix Spike Recovery

Matrix spike recoveries for four sediment extraction batches are listed in Appendix Table C7. We added 100 µg of each hydrocarbon to the Batch 1-3 matrix spike samples, and 50 µg of each hydrocarbon to the Batch 4 matrix spike sample.

In Extraction Batch 1, 25 of 33 analytes met the matrix spike recovery criterion. Matrix spike recovery values were below the lower criterion value of 50% for n-C_9 and for n-C_{34} to n-C_{40}, with recoveries ranging from 12.5 to 42.2%. Hydrocarbons n-C_8 and n-C_{29} were not detected in any of the Batch 1 sediment samples.

In Extraction Batch 2, 20 of 35 analytes met the matrix spike recovery criterion. Matrix spike recovery values were below the lower criterion value of 50% for n-C_8 to n-C_{16} and for n-C_{35} to n-C_{40}, with recoveries ranging from 23.4 to 47.8%.

In Extraction Batch 3, 29 of 35 analytes met the matrix spike recovery criterion. The matrix spike recovery value was below the lower criterion value of 50% for n-C_8 (28.6%), while the recovery values were higher than the upper criterion value of 120% for n-C_{31} (122%) and for n-C_{19} to n-C22, with recoveries ranging from 121 to 123%.

In Extraction Batch 4, 4 of 35 analytes met the matrix spike recovery criterion. Matrix spike recovery values were below the lower criterion value of 50% for n-C_8 to n-C_{19},with recoveries ranging from 2.58 to 46.7%, and for n-C_{24} to n-C_{40}, with recoveries ranging from 17.8 to 47.7%.

Soil Standard Reference Material Analyses

Except for Batch 1, the SRM analyses in all batches gave recovery values that were lower than the lower criterion recovery value of 70% (Appendix Table C8). The SRM analyses in Batch 2 and two of the three replicate SRM analyses in Batch 4 gave slightly lower recoveries (58.7-63.1%) than the lower criterion value of 70% recovery. The

SRM analyses for Batch 3 and for the third SRM replicate in Batch 4 (a suspected outlier which was not included in any calculations) gave lower recoveries than the lower criterion recovery value of 70%. The average SRM recovery for five replicates was 58.4% with an RSD of 21.7%. Since the diesel fuel standard used in the preparation of soil SRM was not available for instrument calibration, a diesel fuel standard from Restek Corporation was used in instrument calibration. The difference in the types of two diesel fuels, and possibly their hydrocarbon contents, may have resulted in the lower recovery values.

Replicate Sediment Analyses

Seven replicates of spiked sediments were used in the MDL determination study (Appendix Table C2). Except for a slightly higher RSD value for n-C_9 (27.06%), all other hydrocarbons met the replicate analysis criterion of 25% RSD. Octane hydrocarbons (*i.e.*, n-C_8) were not detected in any of the seven replicates. Three replicates of Soil SRM 765 were additionally extracted in Batch 4 (Appendix Table C9). One soil SRM replicate gave poor recovery (2.5%) of diesel oil, and was discarded from further discussion. The percentage difference for the two remaining soil SRM replicates was 3.9, based on the total diesel oil concentration. On an individual hydrocarbon basis, 13 of 35 hydrocarbons met the replicate criterion, 21 hydrocarbons were undetected, and although n-C_8 was detected, no MDL value was measured for this hydrocarbon.

Quantification of Hydrocarbons in Mussels

Mussel GC-FID chromatograms were considerably less complex than sediment chromatograms, and the internal standards were easily identifiable (Appendix Figures E15 and E16). Hydrocarbons in mussel extracts were therefore quantified using the more accurate method of internal standard calculation.

A second-order calibration curve was used to calculate the concentrations of hydrocarbons in mussels. In Equation 2, Y is the ratio of the response of the analyte to the response of the internal standard in the calibration sample, and X is the ratio of the amount of the analyte to the amount of the internal standard in the calibration sample. For an unknown sample, the first quadratic solution to Equation 2 provides a value for X for a given Y (Equation 3). The final determination of analyte concentration required additional calculations.

Calculations Using Individual Hydrocarbons

In Equation 2, Y is the ratio of the individual hydrocarbon peak area to the GC internal standard (5-α-androstane) peak area, and X is the ratio of the individual hydrocarbon amount to the GC internal standard (5-α-androstane) amount. Values of $r^2 > 0.99$ were obtained for each analyte fit.

For a measured-area-ratio Y in an unknown sample, the amount-ratio X is determined from Equation 2. The amount of analyte in an unknown sample is calculated by multiplying X by the amount of 5-α-androstane added to the unknown sample. Amount X in this equation represents the analyte amount in 1 µL of the injected sample. The actual amount of analyte in the unknown sample is calculated by multiplying X by a factor that incorporates the final extract volume, aliquot of sample extract taken for lipid determination, and sample weight.

Calculations Using the Sum of Individual Hydrocarbons

In Equation 2, Y is the ratio of the sum of peak areas for the individual hydrocarbons (n-C_8 to n-C_{40}, including pristane and phytane) to the peak area of 5-α-androstane, and X is the ratio of the sum of amounts of individual hydrocarbons (n-C_8 to n-C_{40}, including pristane and phytane) to the amount of 5-α-androstane. The curve coefficients were obtained by first calculating the values of X and Y for each calibration solution, and then by using these values in a fit. Values of $r^2 > 0.99$ were obtained for this fit.

Total alkyl hydrocarbon concentrations were then calculated using Equation 3. The amount of 5-α-androstane added to the sample and other sample factors were used in the calculations.

Calculations Using the Sum of All Peaks Eluting between n-C_8 and n-C_{40}

The TPH concentrations for mussel samples were determined using a procedure similar to that used for sediment samples. The curve coefficients used in Equation 2 were the same as those calculated for the sum of individual hydrocarbons in mussels using the internal standard method.

For an unknown sample, the value for Y was calculated as Y = [A-(B+C)]/C, where A is the sum of the areas for "all" peaks eluting between n-C_8 and n-C_{40}, B is the peak area for o-terphenyl, and C is the peak area for 5-α-androstane. It was assumed that other hydrocarbons did not coelute with o-terphenyl and 5-α-androstane. The peak summation window began 15 sec before the retention time of the n-C_8 peak and ended 15 sec after the retention time of the n-C_{40} peak. The calculated value for X from Equation 3 is the ratio of the sum of amounts of "all" hydrocarbons eluting between n-C_8 and n-C_{40} to the amount of 5-α-androstane. When the value of X is calculated from Equation 3, the concentration is determined by multiplying X by the amount of 5-α-androstane in the sample and other sample-related factors.

Quality Assurance for Mussel Analyses

Quality assurance criteria listed in Appendix Table C1 were used for evaluating the quality of mussel data. Results of quality assurance of mussel analyses are summarized for MDL, laboratory method blanks, surrogate internal standard recovery, matrix spike recovery, diesel fuel spike recovery, mussel SRM analyses, and replicate mussel analyses. Possible anomalies are also covered.

Method Detection Limit

The MDL for mussels was calculated as MDL = σt; where σ is the standard deviation of seven replicate measurements and t is Student's t value of 3.143 with six degrees of freedom (EPA 1984). The MDL values for individual hydrocarbon analytes ranged from 0.06 to 2.47 µg/g, wet weight, with numerous values around 0.1 µg/g (Appendix Table C10).

The MDL guideline for hydrocarbons in mussels is not specified in the NJDEP protocol. Since mussel extracts were expected to be relatively cleaner than sediment extracts, we assumed a target MDL of 1 µg/g for mussels, which was 10 times less than a target MDL of 10 µg/g for sediments.

We spiked mussels with higher-than-recommended amounts of hydrocarbons to accommodate the higher detection limits of GC-FID. A majority of RSD values around 10% indicated good precision, but the higher spiked amounts gave higher values for standard deviations that resulted in approximately five-times-greater MDL values.

Laboratory Method Blanks

For laboratory method blank samples, 95 out of 105 values were less than three times the MDL (data not provided).

Surrogate Internal Standard Recovery

Eighty-two of 86 internal surrogate values met the criterion for surrogate internal standard recovery (Appendix Tables C11-C13).

Matrix Spike Recovery

Matrix spike recoveries for the three mussel extraction batches are listed in Appendix Table C14. For Extraction Batch 1, 26 of 35 analytes met the matrix spike recovery criterion. As expected from the relatively low boiling points of n-C_8, n-C_9, and n-C_{10}, poor recoveries were obtained for these three relatively volatile hydrocarbons. If these three hydrocarbons were not included in the data, 81% of values would meet the matrix spike recovery criterion.

For Extraction Batch 2, seven replicate mussel samples were spiked with individual hydrocarbons (total spiked amount per analyte = 4 µg) for the MDL determination. Similar to Batch 1 sample results, we decided not to include the data for n-C_8, n-C_9, and n-C_{10}. If these hydrocarbons are not included in the data, 180 of 224 values (80%) met the matrix spike recovery criterion.

For Extraction Batch 3, 26 of 35 analytes (74%) met the matrix spike recovery criterion. If recoveries for n-C_8, n-C_9, and n-C_{10} are not included, 26 of 32 analytes (81%) met the matrix spike recovery criterion.

Diesel Fuel Spike Recovery

In Batch 2, diesel fuel oil #2 was spiked into Sandy Hook mussel homogenate. Chromatograms of background mussel extract, spiked mussel extract, and Restek diesel fuel oil #2 used in spiking the mussels are depicted in Figure 16. Matrix spike recovery was calculated for individual hydrocarbons as well as diesel fuel (Appendix Table C14). Recoveries of individual hydrocarbons were calculated by comparing the areas of hydrocarbons in mussel homogenate with the areas of hydrocarbons in the diesel fuel standard. Recoveries of hydrocarbons from n-C_{11} to n-C_{20}, including pristane and phytane, ranged from 52% to 100%. Recoveries of other hydrocarbons did not meet the data quality objectives criterion due to interfering peaks.

To calculate the recovery of diesel fuel, the sum of areas of representative hydrocarbon peaks in the matrix spike sample was compared with that in the diesel fuel standard. We selected n-C_{12}, n-C_{13}, n-C_{14}, n-C_{15}, n-C_{17}, and pristane as representative hydrocarbons based on their GC-FID responses in the spiked sample and diesel fuel calibration standard, and minimal interference in the vicinity of these respective hydrocarbons. The matrix spike recovery of diesel fuel oil #2 was then calculated to be 76.8%.

Mussel Standard Reference Material Analyses

Concentrations of various hydrocarbons listed for NIST Mussel SRM 1974a are noncertified values, and range in the low ng/g (ppb) levels. NIST scientists determined the concentrations of these hydrocarbons using gas chromatography / mass spectrometry (GC/MS), and these concentrations are <10 times the MDLs of this study. In addition, hydrocarbon analyses in the present study were performed using GC/FID, which is 1-2 orders of magnitude less sensitive than the GC/MS. We concluded that SRM 1974a was not an appropriate SRM for the evaluation of the quality of our mussel data. Hydrocarbons detected above MDL were considered false positives based on relatively low values reported by NIST (Appendix Table C15). Quality assurance criteria other than those based on SRM were therefore used in the validation of mussel data.

Replicate Mussel Analyses

Thirty of 34 hydrocarbons met the replicate analysis criterion of 25% RSD in the mussel MDL determination study (Appendix Table C10). In addition, one large mussel from Mill Creek weighing 35.2 g was homogenized, and the homogenate was extracted in triplicate. None of the individual hydrocarbon values in the mussel homogenates were >10 times the MDL (Appendix Table C16). Therefore, replicate analysis criteria were not applicable to these mussel homogenates.

Possible Anomalies

One mussel sample from the Con Ed Tower site and one mussel sample from the Mill Creek site contained relatively higher concentrations of n-C_{31}. After examining the concentrations of other hydrocarbons in these mussels, as well as concentrations of n-C_{31} in other mussels from these sites, it appeared that the higher concentrations of n-C_{31} are possible anomalies. One additional mussel from Con Ed Tower appeared to have relatively elevated, but possibly anomalous, concentrations of n-C_{21} and n-C_{23}. One mussel sample from Sandy Hook also appeared to have relatively elevated, but possibly anomalous, concentrations of n-C_{29} and n-C_{30}.

We hypothesized that some of these elevated concentrations may have arisen from contributions of hydrocarbons from natural sources, including terrestrial plants, phytoplankton, and algae (Blumer *et al.* 1971, 1973; Prahl *et al.* 1980; Douglas *et al.* 1981; Sauer and Uhler 1994).

Indicators of Hydrocarbon Source and Weathering

Hydrocarbon patterns and ratios of certain hydrocarbons were used to examine the hydrocarbon source, weathering/biodegradative losses of spilled hydrocarbons, and contribution of biogenic hydrocarbons to the petrogenic hydrocarbons.

Farnsane (2,6,10-trimethyldodecane), 2,6,10-trimethyltridecane, nor-pristane, pristane, and phytane represent a class of branched-chain hydrocarbons that degrade slowly compared to normal-chain hydrocarbons (Wang and Fingas 1997; Atlas 1981; Atlas *et al.* 1981). Since farnsane, 2,6,10-trimethyltridecane, and nor-pristane were not included in the instrument calibration mixture, the discussion of hydrocarbon weathering was limited to pristane and phytane, the dominant hydrocarbons in partially weathered petroleum products (Broman *et al.* 1987). Typical ratios used as indicators of hydrocarbon source and weathering are given for the three petroleum products listed in Appendix Table C17.

Ratio of Pristane to n-C_{17} and of Phytane to n-C_{18}

Ratios of pristane to n-C_{17} and of phytane to n-C_{18} indicate the extent of degradation of normal-chain hydrocarbons, with higher ratios suggesting greater losses of normal-chain hydrocarbons (Cripps 1989; reciprocals of these ratios used by Wang and Fingas 1995). Since natural sources of pristane (*e.g.*, copepods) may alter the pristane to n-C_{17} ratio in the sediments, this ratio should be interpreted with caution (NRC 1985; Douglas *et al.* 1996).

Ratio of Pristane to Phytane

Because of the resistance of pristane and phytane to biodegradation, the pristane-to-phytane ratio is used as a marker in measuring the early degradation rate of oil (Sauer and Uhler 1994). The ratio of pristane to phytane can also be used to examine if the hydrocarbon mixtures from different locations or from different sediment core sections originated from a common source. Since natural sources of pristane (*e.g.*, copepods) may alter the pristane-to-phytane ratio in sediment, this ratio should be interpreted with caution. Also, pristane and phytane are lost at different rates in the later stages of biodegradation that may confound the identification of source oil (Douglas and Uhler 1993).

Carbon Preference Index

Carbon preference index (CPI) is a ratio of the sum of odd-numbered hydrocarbons to the sum of even-numbered hydrocarbons (Farrington and Meyers 1975; NRC 1985). Hydrocarbon mixtures originating from plant materials show a predominance of odd-numbered carbon chains with CPI values >5-7 (Farrington and Tripp 1977). A CPI value of 1.0 indicates a petrogenic origin of the hydrocarbons. Values of CPI >1.0 indicate the contribution of odd-numbered hydrocarbons of biogenic origin (Choiseul *et al.* 1998).

Weathering Index

The weathering index (WI) is a ratio of the sum of n-C_8, n-C_{10}, n-C_{12}, and n-C_{14} to the sum of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28} (Wang and Fingas 1994; Wang *et al.* 1994). A lower value for WI indicates weathering losses of the lower-boiling hydrocarbons. We did not include n-C_8 in the calculation of WI because: 1) it was not recovered in the spiked replicates used in the MDL determination (Appendix Tables C2 and C10), 2) coelution of n-C_8 with unknown interferences resulted in its inadequate quantification, 3) artifact

concentrations of n-C_8 were not internally consistent with concentrations of other homologs for the Old Place Creek sediments, and 4) the ratios for Old Place Creek sediments were solely driven by n-C_8 concentrations.

Total Organic Carbon

Guida and Draxler in the following chapter, "Sediment Biogeochemistry," describe the determination of total organic carbon (TOC) in the surface sediments.

Reporting of Hydrocarbon Concentrations

In addition to calculating the concentrations of individual petroleum hydrocarbon components, the sums of the concentrations of such compounds were calculated for the following groups in each sample: 1) total of individual petroleum hydrocarbons (TIPH); 2) branched-chain hydrocarbons (*i.e.*, pristane + phytane); 3) odd-numbered, normal-chain hydrocarbons; 4) even-numbered, normal-chain hydrocarbons (starting with n-C_{10}); 5) representative lower-boiling-point, normal-chain hydrocarbons (*i.e.*, n-C_{10} + n-C_{12} + n-C_{14}); and 6) representative higher-boiling-point, normal-chain hydrocarbons (*i.e.*, n-C_{22} + n-C_{24} + n-C_{26} + n-C_{28}).

If an analyte was not detected in a particular sample, then that analyte was not included in the aforementioned summations nor in any of the subsequent hydrocarbon ratios. If an analyte concentration determined for a particular sample was less than the MDL, then that analyte is reported as "not detected" (nd). Only analyte values above the MDL are reported. For "not detected" analytes, a concentration value equal to one-half of the MDL value was used in the summations and subsequent statistical calculations. The core and station averages for sediments and the station averages for mussels for a given analyte are reported as "nd" if a given analyte was absent in all samples used for averaging. If the concentration of a given analyte was greater than the MDL in at least one sample, then one-half of the MDL value was used for the "not detected" samples in that particular group for the calculation of the average concentration value. If the average concentration value was less than the MDL, then it is reported as "<MDL." Only averages greater than the MDL are reported.

The MDL for TPH was determined as MDL = σt; where σ is the standard deviation of seven replicate TPH measurements, and t is Student's t value of 3.143 with six degrees of freedom (EPA 1984). Those TPH concentrations below the TPH MDL are reported as "<MDL"; only TPH concentrations above the MDL are reported.

Group MDLs, such as those for TIPH, branched-chain hydrocarbons, odd-numbered normal-chain hydrocarbons, even-numbered normal-chain hydrocarbons, representative lower-boiling-point normal-chain hydrocarbons, and representative higher-boiling-point normal-chain hydrocarbons, were calculated by summation of individual MDLs in a given group.

Hydrocarbon analyses were performed on sections of sediment cores from the first collection period and on surface sediments from the second collection period. A slight uncertainty in the precise measurement of 1-cm-thick core sections and 1-cm-deep surface scoops was inevitable because of the complex nature of the sediment matrix in the Arthur Kill marshes. Since this uncertainty varies from station to station and from site to site in an unknown way, the correction factors to compensate for this uncertainty could not be determined. This uncertainty is presumed to be minimal and insignificant in the interpretation of the data.

Statistics

One-half of the MDL value was used for "not detected" values for the purpose of statistical analyses. Since replicate sediment samples were not collected for any given station, intrastation differences could not be examined. The nonparametric, Kruskal-Wallis, one-way, analysis-of-variance (ANOVA)-on-ranks test was used to detect differences among sites with respect to hydrocarbon concentrations. If differences were detected in the Kruskal-Wallis test, then pairwise, multiple-comparison tests (*i.e.*, Dunn's and Student-Newman-Keuls) were performed, *post hoc*, to isolate the group(s) that differed from others. Correlation analyses were performed to examine if there existed any relationships between: 1) TPH and TOC in sediments, 2) TPH and lipid contents of mussels, 3) TPH in mussels and TPH in sediments, 4) TPH in mussels and TOC in sediments, 5) TPH in mussels and length of mussels, and 6) length of mussels and lipid content of mussels.

RESULTS

Hydrocarbons in Sediment Core Sections

The concentrations for individual and total hydrocarbons detected in the core sections from the cores collected in September 1996 were compared. These comparisons were done between sections of the same core and sections of cores from other stations from the site.

Old Place Creek -- Oiled and Replanted Site

When the GC-FID chromatograms were integrated over the entire envelope of peaks ranging from n-C_8 to n-C_{40}, the TPH concentrations ranged from "not detected" to 3280 µg/g (Figure 17). The TPH concentrations were highest for the bottom two core sections from Station D (Appendix Table D1; 3280 µg/g for the 3-4 cm deep section, and 2910 µg/g for the 4-5 cm deep section). The next highest concentration of about 1000 µg/g was for 2-3 cm deep section from Station D and the bottom-most section from Station B.

Stations A and C

With a few exceptions, most individual hydrocarbons were below the MDL values in sediment core sections from the first collection period. The hydrocarbon n-C_{31} was detected in all core sections from Station C (Appendix Table D1).

Station B

Hydrocarbons n-C_{14} to n-$C_{21,}$ including pristane and phytane, were most consistently detected in the bottom four core sections from Station B (Appendix Table D1). Hydrocarbons n-C_{31} and n-C_{32} were detected in three out of five core sections at this station. Other hydrocarbons were detected only occasionally. The highest TPH concentration was generally found in the bottom core section; the TPH concentration in the top section was negligibly small. The TIPH and TPH values in the 2-3 cm deep core section and the 3-4 cm deep core section were similar, suggesting that these two sections are actually subsamples of one contiguous sediment section.

The CPI value of 1.22 for the 3-4 cm deep core section indicated a slight contribution of biogenic hydrocarbons to the petroleum hydrocarbons. Ratios of pristane to phytane, pristane to n-$C_{17,}$ and phytane to n-C_{18} were similar in the 2-3 cm deep core section and the 3-4 cm deep core section, indicating identical and approximately equally degraded hydrocarbon mixture in these core sections.

Station D

Hydrocarbons n-C_{11} to n-C_{21}, including pristane and phytane, were most consistently detected in the bottom three core sections from Station D. There was no particular pattern related to the other hydrocarbons. The TPH concentrations in the 3-4 cm deep core section and the 4-5 cm deep core section were approximately three times greater than those in the 2-3 cm deep core section. The TPH concentrations in the top two core sections were negligible.

The CPI index for the 2-3 cm deep core section was significantly >1.0, indicating a contribution from the odd-numbered biogenic hydrocarbons. The CPI indices for the 3-4 cm deep core section and the 4-5 cm deep core section were approximately 1.0, indicating hydrocarbons of petrogenic origin. Ratios of phytane to n-C_{18} in the bottom three sections were similar, indicating the presence of a similarly degraded hydrocarbon mixture. Ratios of pristane to phytane, and of pristane to n-C_{17}, were inconclusive, probably due to the biogenic contribution of pristane.

Con Ed Tower -- Oiled and Unplanted Site

Individual as well as TPH concentrations in core sections from the Con Ed Tower marsh were generally higher than those from all other sections analyzed in this study (Figure 18; Appendix Table D2). The lowest hydrocarbon concentrations were found in the top three sections from Station C, and n-C_{36} was consistently absent in all core sections.

Stations A and B

With the exception of n-C_{36}, the target hydrocarbons were generally detected in sections of sediment cores from Stations A and B. The TPH concentrations increased with depth for Station A. A similar trend was observed for Station B except for the TPH concentration in the bottom-most section which was between the concentrations in the top two core sections (Figure 18; Appendix Table D2). The TPH concentrations in core sections from Station A and Station B were higher than the TPH concentrations in the corresponding sections from Station C and Station D.

A CPI value of about 1.0 in the top four core sections from Station A and the 0-1 cm, 1-2 cm, and 3-4 cm core sections from Station B indicated hydrocarbons related to a petroleum product. A CPI value of 1.0 is considered to have a petrogenic origin. The CPI value increases with contributions from the biogenic sources. A clear-cut differentiation between petrogenic and biogenic origins can be subjective, although a CPI value >3 is considered to be dominated by the biogenic sources (Farrington and Tripp 1977; Sauer and Uhler 1994; Ramirez 1997). Higher values of CPI in the bottom-most core sections indicated the contributions of hydrocarbons of biogenic origin. Based upon pristane:phytane ratios, Stations A and B appear to have experienced input of different petroleum products in different core sections. Both stations showed similar patterns of pristane:phytane ratios in core sections of similar depths.

Generally, lower WI values for the bottom sections compared to the top section indicated weathering of lighter hydrocarbons in the bottom core sections for Stations A and B.

Station C

With a few exceptions, individual hydrocarbons were not detected in the top two core sections from Station C (Appendix Table D2). With two exceptions, the hydrocarbons n-C_9 to n-C_{14} were not detected in any core sections. The hydrocarbon n-C_{17} was the only one detected in all core sections. The TPH concentrations increased with depth of the sediment core.

A CPI value of about 1.0 for the bottom three core sections indicated hydrocarbons of petroleum origin.

The low WI value of 0.19 for the bottom-most section indicated high degradation of lighter hydrocarbons.

Station D

Besides the total absence of hydrocarbons n-C_{31}, n-C_{33}, and n-C_{36}, the distribution of other hydrocarbons did not exhibit any particular pattern in the sediment core sections from Station D (Appendix Table D2). An increasing gradient of TPH concentrations was observed with depth.

A CPI value of near 1.0 for the middle three core sections indicated the presence of petroleum-related hydrocarbons in these sections. A higher value of CPI for the 4-5 cm deep core section indicated a contribution of hydrocarbons of biogenic origin.

Low WI values for the middle three sections indicated degradative losses of lighter hydrocarbons. The bottom-most core section seemed less weathered than the middle three sections.

Mill Creek -- Reference Site

With the exception of hydrocarbons n-C_{29}, n-C_{31}, n-C_{33}, and n-C_{36}, a large majority of hydrocarbons were not detected in the sediment core sections from Stations A-C (Figure 17; Appendix Table D3). The bottom three sections from Station D generally contained low concentrations of hydrocarbons n-C_{13} to n-C_{20}, including pristane and phytane. The hydrocarbon n-C_{17} was present in all core sections from Station D.

The TPH concentrations for Stations A-C were all below the MDL of 181 µg/g. The TPH concentrations in the bottom three sections from Station D were higher than the concentration in the 1-2 cm deep core section (Figure 17). The TPH concentration in the top core section from Station D was below the MDL

Because many hydrocarbons were not detected, CPI and WI values were noncalculable, unreliable, or inconclusive.

Hydrocarbons in Surface Sediments

Surface sediments from Old Place Creek and Con Ed Tower marshes from the May 1997 collection were compared with the top core sections from sediment cores collected in September 1996. Mill Creek surface sediments were not analyzed for the 1997 collection, thus there is no comparison for that site. Concentrations of individual as well as total hydrocarbons in surface sediments from Old Place Creek and Con Ed Tower were generally similar to those in the top sections of sediment cores from the 1996 collection (Figure 18). The average TPH concentration from the top core sections from Con Ed Tower was higher than the average concentrations from all other top core sections and surface sediments (Figure 19).

Old Place Creek -- Oiled and Replanted Site

Except for a few isolated values, the concentrations of individual hydrocarbons in all surface sediment samples from Old Place Creek were below the MDL values (Figure 17; Appendix Table D1). The TPH concentration was above the MDL of 181 µg/g only for the surface sediment from Station B.

Con Ed Tower -- Oiled and Unplanted Site

Except for a few hydrocarbon values for Station A, and some isolated values for Stations C and D, the concentrations of individual hydrocarbons in surface sediments from Con Ed Tower were below the MDL values (Figure 18; Appendix Table D2). Except for Station A, the TIPH concentrations in surface sediments from all stations were below the MDL of 59 µg/g.

Sandy Hook -- Reference Site

One surface sediment sample from Sandy Hook was analyzed during sediment MDL determination. With the exception of hydrocarbons n-C_{29}, n-C_{31}, and n-C_{32}, the concentration of all other individual hydrocarbons in surface sediment samples from Sandy Hook were below the MDL values (Appendix Table D4). The TPH and TIPH concentrations were below the MDL of 181 and 59 µg/g, respectively.

Hydrocarbons in Ribbed-Mussels

Concentrations of individual hydrocarbons (TIPH) in almost all ribbed-mussels analyzed in this study were low,

and the sum of n-C_8 to n-C_{40} hydrocarbons was in the low µg/g range.

The average TPH concentrations in mussels from both collection periods are compared for each site in the Arthur Kill and Sandy Hook marshes (Figure 20). The TPH concentrations overall ranged from 20.6 to 541 µg/g. These TPH values included target hydrocarbon analytes and other unidentified compounds assumed to be a variety of branched-chain hydrocarbons and cyclic hydrocarbons. Although the significance of the method used to determine TPH concentrations in mussels is unclear, the method permitted the correlation analyses of mussel and sediment data.

Old Place Creek -- Oiled and Replanted Site

With the exception of one sample, hydrocarbons n-C_{10} to n-C_{16}, n-C_{18}, n-C_{20}, n-C_{22} to n-C_{25}, n-C_{29}, and n-C_{30} were absent in mussels from both collection periods in the Old Place Creek marsh (Appendix Table D5). For the first collection period, the hydrocarbon patterns in mussels were dominated by the heavier hydrocarbons, suggesting exposure to highly weathered petroleum mixtures. Comparatively few heavier hydrocarbons were detected in mussels from the second collection period.

For the second collection period, the TPH concentration was above the MDL of 53.6 µg/g for only one mussel.

The CPI values >1.0 suggested the contribution of odd-numbered biogenic hydrocarbons in mussels from the first collection period.

Con Ed Tower -- Oiled and Unplanted Site

With a few exceptions, hydrocarbons n-C_{10} to n-C_{16}, n-C_{18}, n-C_{20}, n-C_{22}, and n-C_{24} to n-C_{30} were absent in mussels from both collection periods from the Con Ed Tower marsh (Appendix Table D6). For the first collection period, the hydrocarbon patterns in mussels were dominated by heavier hydrocarbons, suggesting exposure to highly weathered petroleum mixtures. Comparatively few heavier hydrocarbons were detected in mussels from the second collection period.

The CPI values >1.0 in mussels from both collection periods suggested contributions of odd-numbered biogenic hydrocarbons.

Saw Mill Creek North -- Oiled and Replanted Site

With a few exceptions, hydrocarbons n-C_{10} to n-C_{15}, n-C_{18}, n-C_{20}, and n-C_{24} to n-C_{30} were absent in mussels from both collections from Saw Mill Creek North (Appendix Table D7). For the first collection period, the hydrocarbon patterns in mussels were dominated by heavier hydrocarbons, suggesting exposure to highly weathered petroleum mixtures.

The CPI values >1.0 in mussels from both collection periods indicated contributions of odd-numbered biogenic hydrocarbons.

Saw Mill Creek South -- Oiled and Unplanted Site

With a few exceptions, hydrocarbons n-C_{10} to n-C_{16}, n-C_{18} to n-C_{20}, n-C_{22} to n-C_{26}, n-C_{30}, n-C_{34}, n-C_{37}, and pristane were absent in mussels from both collection periods from Saw Mill Creek South (Appendix Table D8). For the first collection period, mussel averages for individual hydrocarbons were mostly below the MDL values.

The TPH concentrations were comparatively higher in mussels from the second collection period (Figure 20).

Higher CPI values for two mussels from the second collection period indicated contributions of odd-numbered biogenic hydrocarbons.

Tufts Point -- Reference Site

With a few exceptions, hydrocarbons n-C_{10} to n-C_{16}, n-C_{18}, n-C_{20}, n-C_{22} to n-C_{25}, n-C_{30}, pristane, and phytane, were absent in mussels from both collections from Tufts Point (Appendix Table D9). For the first collection period, hydrocarbon patterns in mussels were dominated by heavier hydrocarbons, suggesting exposure to highly weathered petroleum mixtures. Relatively few heavier hydrocarbons were detected in mussels from the second collection period.

The CPI values did not exhibit any particular trend for mussels in the first collection period. The CPI values >1.0 for four mussels from the first collection period indicated contributions of odd-numbered biogenic hydrocarbons.

Mill Creek -- Reference Site

With a few exceptions, hydrocarbons n-C_{10} to n-C_{15}, n-C_{18}, n-C_{20}, n-C_{23} to n-C_{30}, and pristane were absent in mussels from both collection periods from Mill Creek (Appendix Table D10). For the first collection period, hydrocarbon patterns in mussels were dominated by heavier hydrocarbons, suggesting exposure to highly weathered petroleum mixtures. Relatively few heavier hydrocarbons were detected in mussels from the second collection period.

The CPI values >1.0 in mussels from both collections indicated contributions of odd-numbered biogenic hydrocarbons.

Sandy Hook -- Reference Site

With a few exceptions, hydrocarbons n-C_{10} to n-C_{16}, n-C_{18}, n-C_{20}, n-C_{23} to n-C_{36}, pristane, and phytane were absent in mussels from Sandy Hook (Appendix Table D11).

A CPI value >1.0 indicated contributions of odd-numbered biogenic hydrocarbons in one mussel sample. Component hydrocarbons for the determination of CPI values were below the MDL values in other mussels from Sandy Hook.

Lipids in Mussels

Lipid contents of ribbed-mussels varied from mussel to mussel and ranged from 0.4 to 2.97% (Appendix Table B2). While the average lipid contents in mussels from Old Place Creek, Saw Mill Creek North, Tufts Point, and Mill Creek from the September 1996 collection were greater than those from the May 1997 collection, a reverse trend was observed for mussels from Con Ed Tower and Saw Mill Creek South.

DISCUSSION

Hydrocarbons in Sediments

Surface Sediments

The TIPH and TPH concentrations in surface sediments from three Arthur Kill marsh sites from both collection periods and in those from Sandy Hook varied by station, site, and collection period (Table 9), and the concentrations exhibited non-normal distributions ($P = <0.001$). Median TIPH and TPH values for Con Ed Tower surface sediments from the first collection period were higher than the corresponding values for all other sites and collection periods (Figure 21 for TPH). Since only one data point was collected for Sandy Hook, further statistical analyses were limited only to the Arthur Kill marshes.

In a nonparametric, Kruskal-Wallis, one-way, ANOVA-on-ranks test, the differences in median values among Arthur Kill sites were greater than would be expected by chance. Therefore, the median TPH values were considered significantly different ($H = 10.396$ with 4 degrees of freedom, $P = 0.034$). The Kruskal-Wallis, one-way, ANOVA-on-ranks test examines the hypothesis of no difference between several treatment groups, but does not determine which groups may be different, or the size of any differences.

Dunn's all-pairwise, multiple-comparison test was performed, *post hoc*, to isolate the sites that differed from the others. The TPH concentration in surface sediments from Con Ed Tower from the first collection period was found to be significantly different from surface sediments from Mill Creek (difference of ranks = 11.000, $P = 5$, $Q = 2.968$, and $P < 0.05$). However, this difference was insignificant when the data were analyzed, *post hoc*, by the Student-Newman-Keuls all-pairwise, multiple-comparison test. The lower power of the Kruskal-Wallis, one-way, ANOVA-on-ranks test ($P = 0.034$) apparently resulted in contradictory results from two separate, all-pairwise, multiple-comparison tests. The numerical difference between these two sites was therefore considered to be a borderline significant difference. Statistical differences in TPH concentrations in surface sediments were not detected among other sites or other collections.

The TPH and TOC in surface sediments from Old Place Creek, Con Ed Tower, and Mill Creek had a correlation coefficient value (r) of 0.756 ($P = 0.05$) and a negative intercept on the Y-axis (Figure 22). Thus, total hydrocarbons in sediments increased with TOC, but in a proportion less than the corresponding increment in the TOC value.

Sediment Cores

Average TPH and TIPH concentrations for individual sediment cores from Old Place Creek, Con Ed Tower, and Mill Creek varied by station and site (Table 10). In contrast to the surface sediments, the TPH concentrations in sediment cores exhibited a normal distribution pattern ($P = 0.057$). The differences in median TPH concentrations among the three sites were greater than would be expected by chance in a parametric ANOVA test ($P = 0.003$), as well as in nonparametric Kruskal-Wallis, one-way, ANOVA-on-ranks test ($H = 8.140$ with 2 degrees of freedom, $P = 0.005$).

The average TPH concentration for sediment cores from Con Ed Tower was significantly higher than that for Mill Creek in a *post hoc* Dunn's all-pairwise, multiple-comparison procedure ($P < 0.05$). The Con Ed Tower average concentration was significantly higher than both Mill Creek and Old Place Creek average concentrations in *post hoc* Tukey test ($P < 0.05$) and Student-Newman-Keuls test ($P < 0.05$).

A statistically significant difference in average TPH was not detected between sediment cores from Mill Creek and Old Place Creek ($P < 0.05$).

Hydrocarbons in Mussels

The TIPH and TPH concentrations in mussels from six Arthur Kill marshes from both collection periods and in those from Sandy Hook varied by site and collection period (Table 11), and exhibited non-normal distributions ($P = <0.001$). In nonparametric Kruskal-Wallis, one-way, ANOVA-on-ranks test, the differences in median TIPH and TPH values for mussels from different marshes from different collection periods were greater than the differences that would be expected by chance. Median values of TIPH and TPH were thus found to be significantly different (TIPH: $P = 0.025$, $H = 24.677$ with 13 degrees of freedom; TPH: $P = 0.041$, $H = 21.709$ with 12 degrees of freedom). Since we analyzed five mussels at each site in the Arthur Kill, and seven mussels in the Sandy Hook marsh, the group sizes available for statistical comparison became unequal. In Dunn's all-pairwise, multiple-comparison test, the only available *post hoc* test for isolating groups of unequal size, no mussel groups were significantly different from one another.

The TPH concentrations in mussels from Tufts Point and Saw Mill Creek North covaried with lipid content (Tufts Point: $r = 0.875$, $P = 0.05$, Figure 23B; Saw Mill Creek North:

$r = 0.872$, $P = 0.05$, Figure 24A). Similar correlation was not detected for mussels from other marsh sites. Surprisingly, there was no correlation between TPH concentrations in mussels and TPH concentrations in sediments for both collection periods ($r = 0.101$, $P = 0.05$). Also, there was no correlation between TPH concentrations in mussels and TOC concentrations in sediments ($r = 0.084$, $P = 0.05$ for September 1996 collection; $r = 0.084$, $P = 0.05$ for May 1997 collection). Except for a negative correlation between TPH concentrations in mussels and mussel length for Tufts Point ($r = 0.746$, $P = 0.05$, Figure 23A), there was no relationship between mussel length and TPH concentrations in mussels. Lipid content and mussel length correlated positively for Mill Creek ($r = 0.707$, $P = 0.05$, Figure 24C); however, they correlated negatively for Saw Mill Creek South ($r = 0.787$, $P = 0.05$, Figure 24B) and Tufts Point ($r = 0.629$, $P = 0.05$, Figure 23C).

CONCLUSIONS

The TPH concentrations in surface sediments from Mill Creek (*i.e.*, a reference site) were numerically the lowest, those from Old Place Creek (*i.e.*, an oiled and replanted site) were intermediate, and those from Con Ed Tower (*i.e.*, an oiled but unplanted site) were the highest. Residual oil can easily be seen, felt, and smelled in the sediments at the latter site. The lower background levels at the Mill Creek and Old Place Creek sites may be due to oxidation and weathering of the oil, perhaps caused by the physical disturbance of planting (at Old Place Creek) and by the mineralization of oil by microbes around the roots of *S. alterniflora*. For the 1996 collection, surface sediments from Con Ed Tower and Mill Creek were statistically different in one *post hoc* test; however, the power of this test was considerably low ($P = 0.034$). Surface sediments from other sites were not statistically different from one another.

Hydrocarbon patterns and concentrations in sediment core sections varied by core section for a given station within a given site, suggesting heterogeneity of sediment composition, sediment deposition, and possibly, oil spillage chronology. Deeper core sections of Con Ed Tower sediments generally contained higher levels of hydrocarbons compared to the surface and subsurface core sections. The core average for TPH concentrations in sediment cores from Con Ed Tower was significantly higher than that in Mill Creek, and possibly to a smaller degree, than that in Old Place Creek.

The TPH concentrations in mussels from all Arthur Kill sites and the Sandy Hook marsh were at low levels, these concentrations were not significantly different, and there was no temporal trend for the two collection periods. When detectable concentrations were present, the mussel hydrocarbon patterns were dominated by heavier hydrocarbons, suggesting the exposure of these mussels to the highly weathered petroleum mixtures.

Lack of a distinct hydrocarbon pattern in any sediment or mussel sample may have resulted from a combination of factors, including extensive weathering of diesel fuel oil spilled in January 1990, and other reported and unreported oil spills in the Arthur Kill.

The TPH concentrations in sediments correlated with TOC concentrations in sediments with a correlation coefficient of 0.763. The TPH concentrations in mussels correlated with lipid content for Tufts Point and Saw Mill Creek North only. An absence of correlation between either TPH or TOC concentrations in sediments and TPH concentrations in mussels suggests a limited utility of this technique for the monitoring of old petroleum spills.

Except for Tufts Point mussels, the TPH concentrations did not correlate with mussel length, which contradicted our assumption that the hydrocarbon concentration is directly proportional to the mussel length and its age. Given that oil spills occur relatively frequently in the Arthur Kill, the coincidental timing of the sampling with the timing, location, and extent of an oil spill appears to be a major determining factor in finding hydrocarbon contaminants in mussels. The factor of chronic exposure of mussels to low levels of hydrocarbons in relatively pristine habitats that plausibly leads to gradual biomagnification of contaminants and a positive length (age) - contaminant relationship appears to be less significant for the Arthur Kill mussels.

The CPI of about 1.0 for the top sections of sediment cores from Con Ed Tower suggests petroleum origin, possibly from fresh input(s). The higher CPI values in the bottom sediments indicated biogenic hydrocarbon contributions.

Except for the first collection period for Tufts Point, the CPI for all ribbed-mussels was >1.0, indicating contributions of biogenic hydrocarbons.

Ratios of pristane to phytane, pristane to n-C_{17}, and phytane to n-C_{18} indicated degradation of normal-chain hydrocarbons, and were useful in discerning petroleum origins in some sediment core sections.

Generally lower values of WI in the bottom sediment core sections indicated weathering losses of lower-boiling-point petroleum hydrocarbons.

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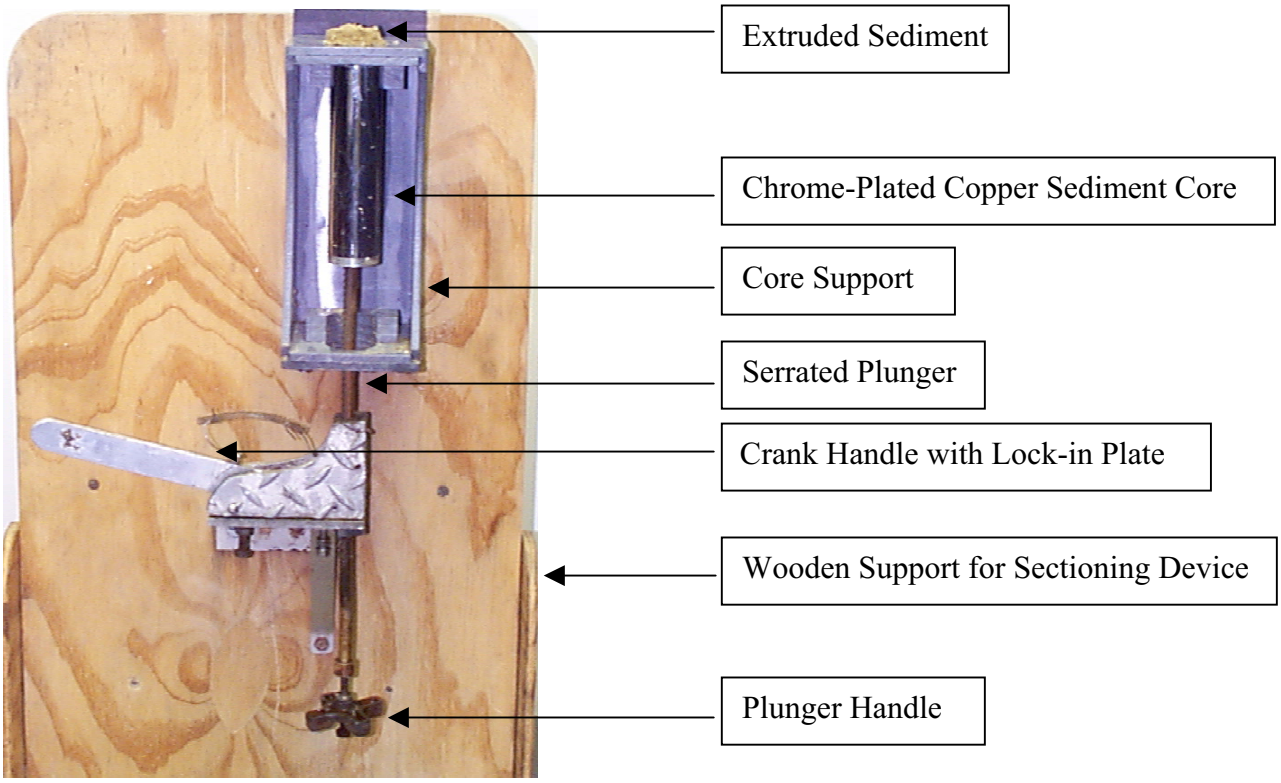

Figure 11. Sediment core sectioning device.

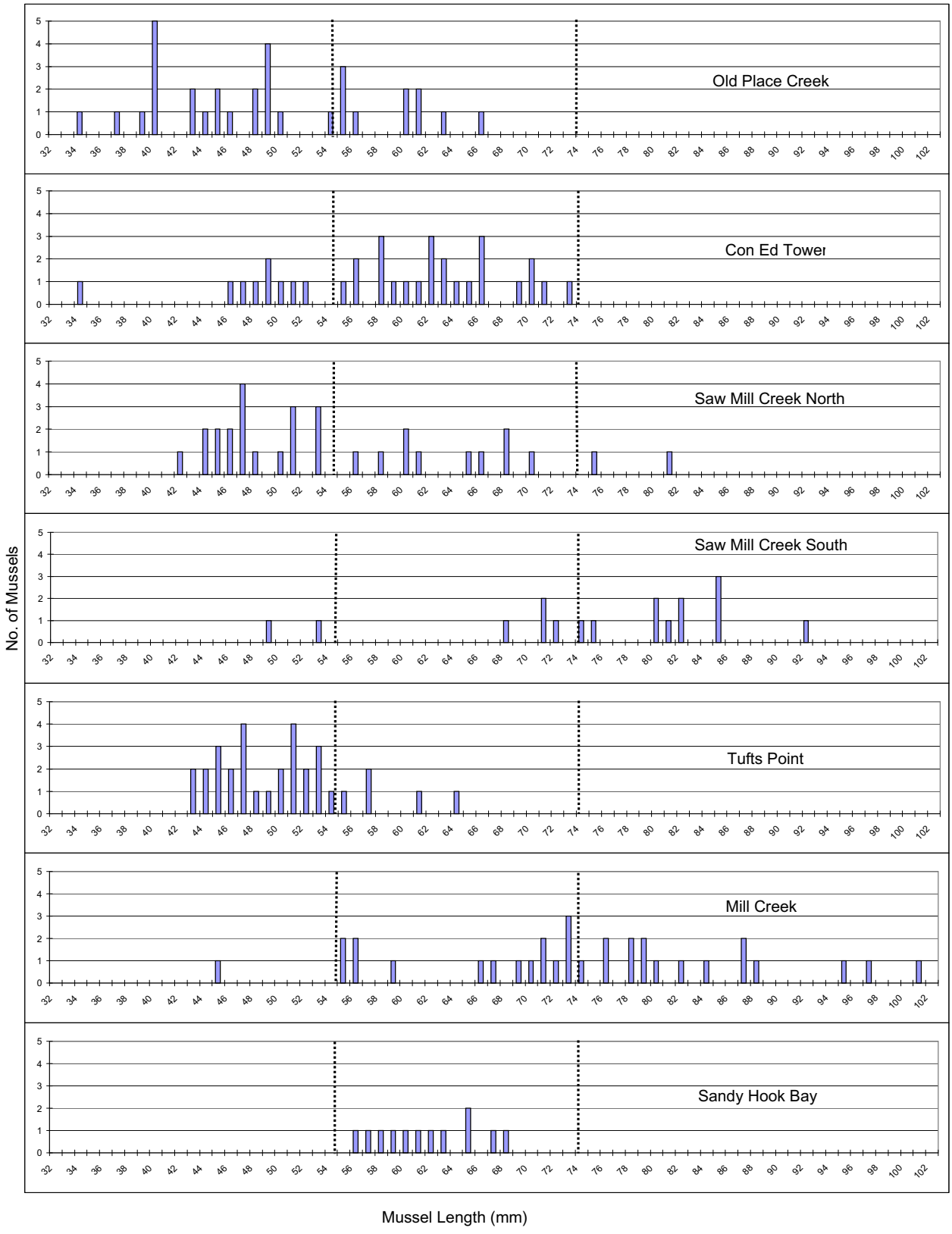

Figure 12. Mussel length distribution for each site for the Arthur Kill September 1996 collection and for the Sandy Hook Bay February 1997 collection. (Mussels for analysis were chosen within the length range designated by the dotted lines (55-74 mm).)

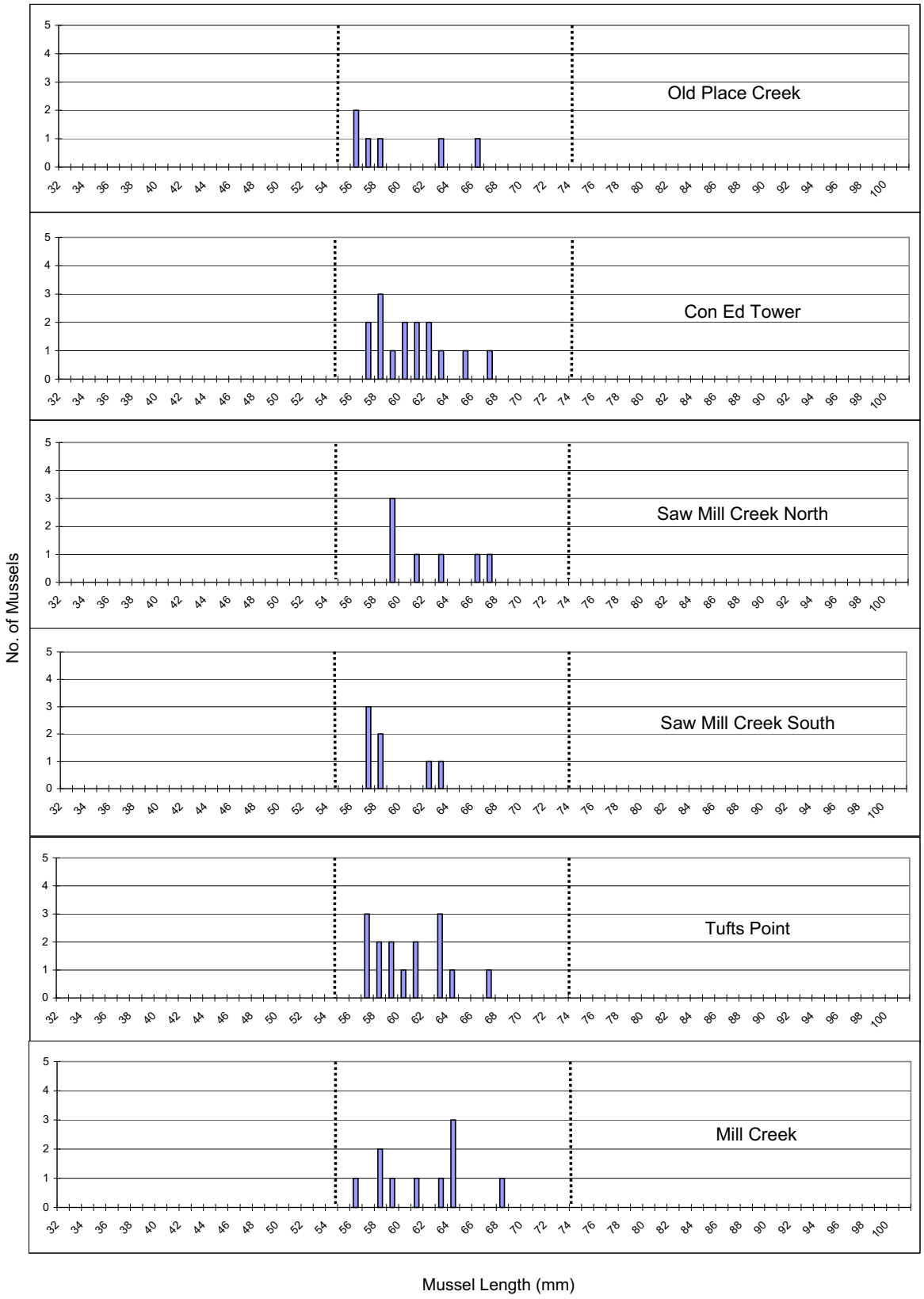

Figure 13. Mussel length distribution for each site for the Arthur Kill May 1997 collection. (Mussels for analysis were chosen within the length range designated by the dotted lines (55-74 mm). No additional mussels were collected at Sandy Hook Bay during May 1997.)

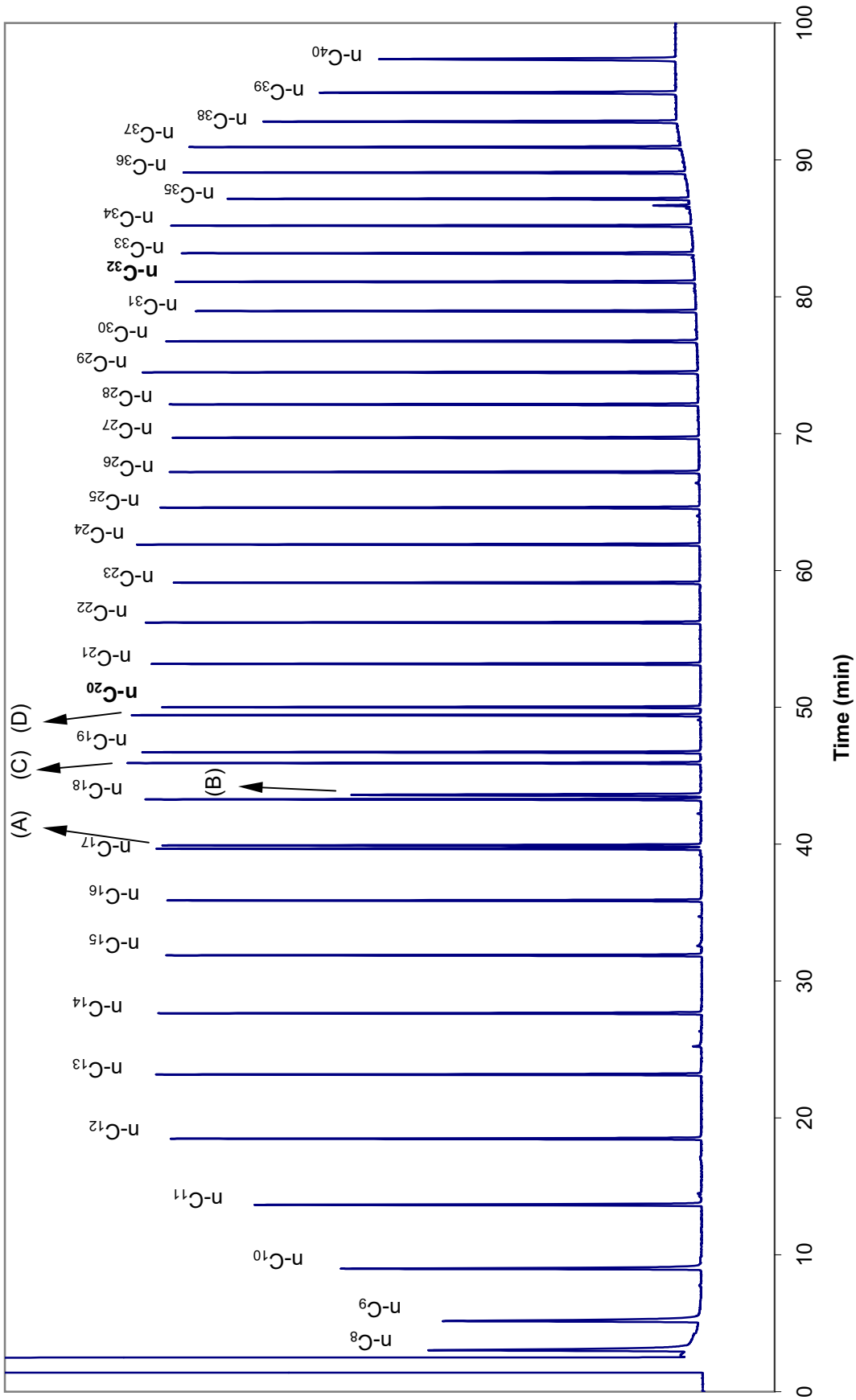

Figure 14. Full GC-FID calibration chromatogram of all individual hydrocarbons and internal standards. (The hydrocarbons n-C_{20} and n-C_{32} are used to monitor mass discrimination in the calibration chromatograms. (A) = pristane; (B) = phytane; (C) = o-terphenyl, an internal standard; and (D) = 5-α-androstane, also an internal standard.)

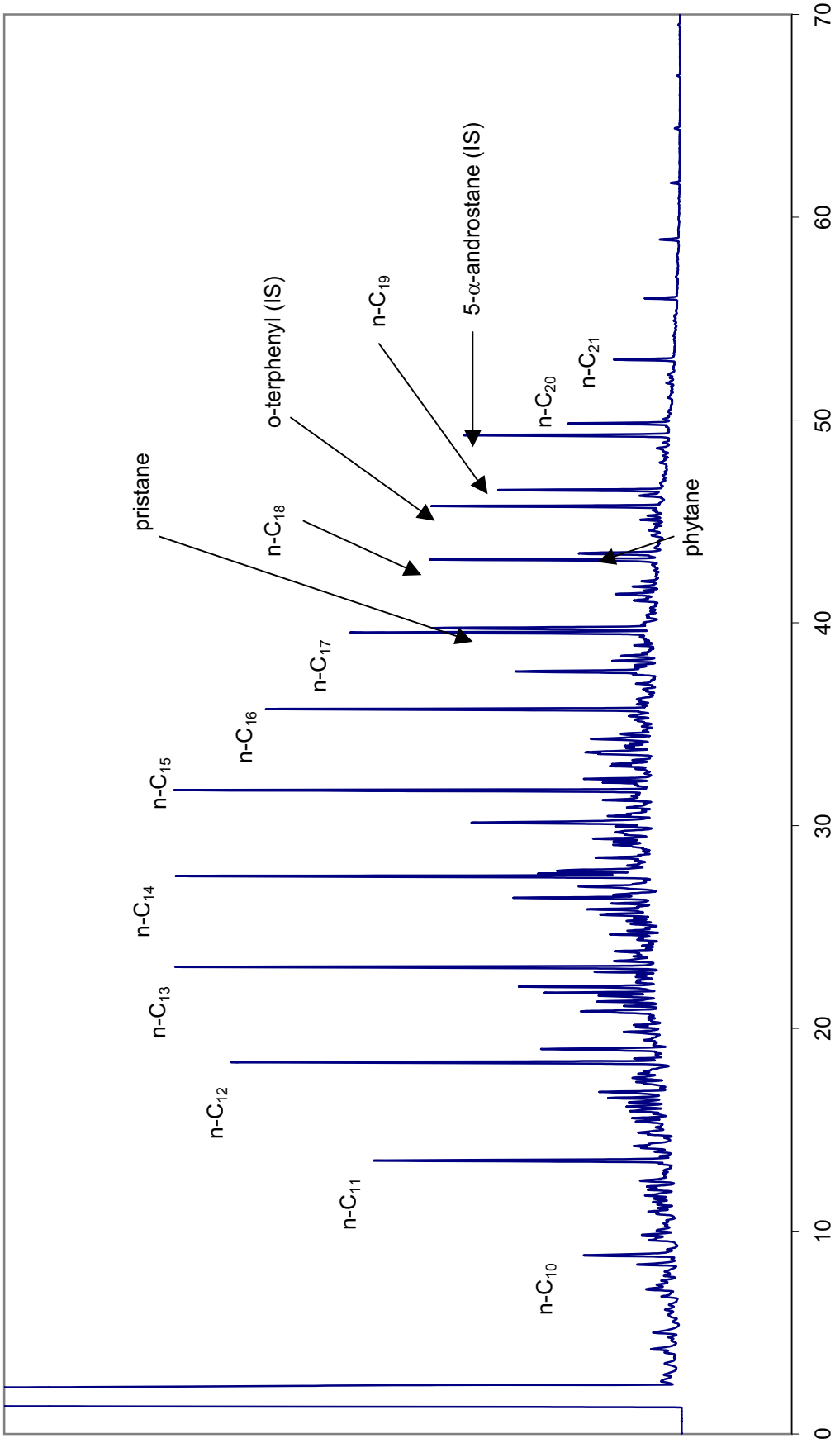

Figure 15. Chromatogram of a solution of the Restek diesel fuel oil #2 standard (unweathered, Cat 31233) in methylene chloride with internal standards added. ((A) = 2,6,10,14-tetramethyldodecane; (B) = 2,6,10,14 tetramethyltridecane; (C) = norpristane; and IS = internal standard.)

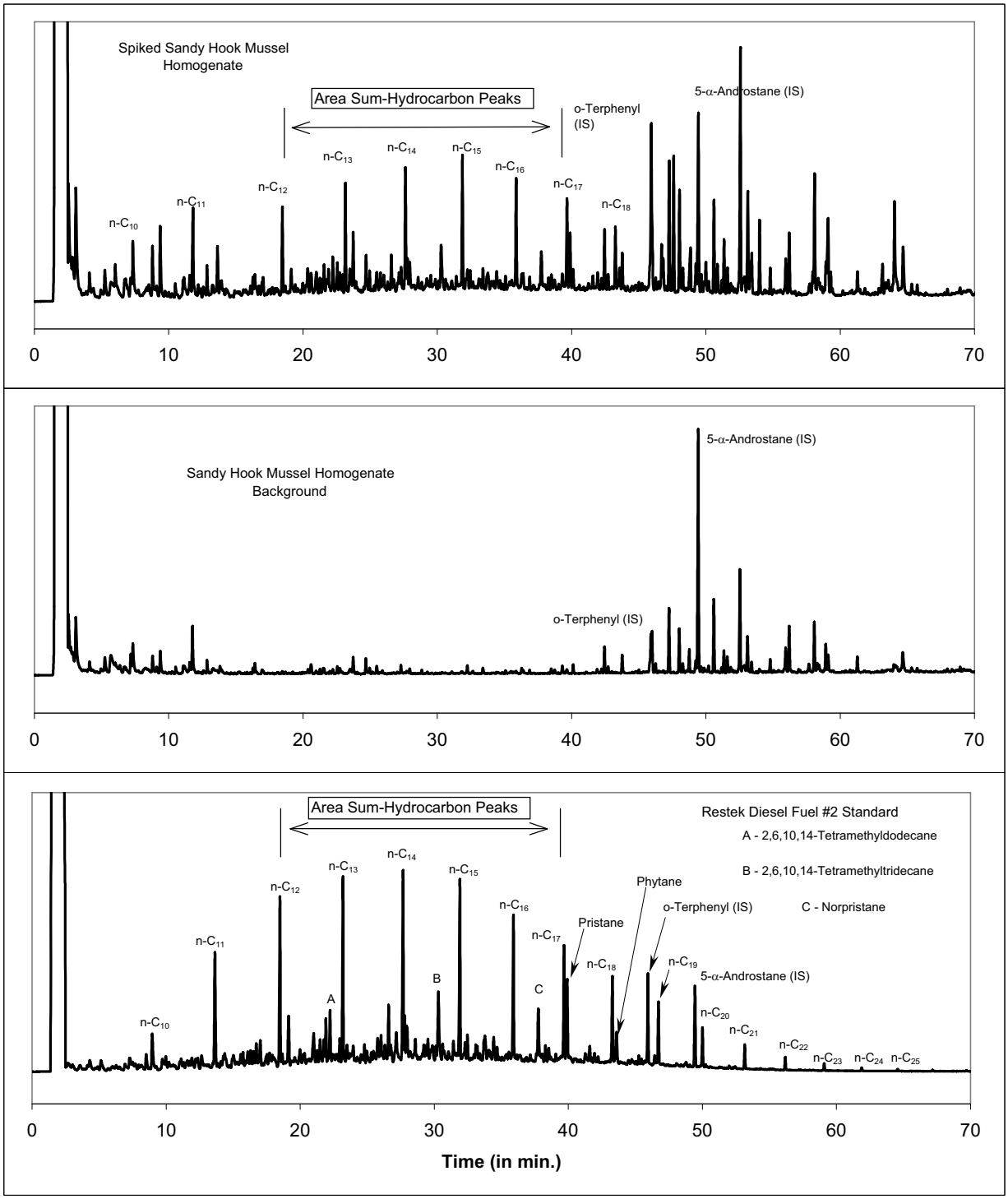

Figure 16. Chromatograms of Sandy Hook ribbed-mussel homogenate spiked with 1000 µg of Restek diesel fuel oil #2 standard. ("Area Sum - Hydrocarbon Peaks" = sum of peak areas for n-C_{12}, n-C_{13}, n-C_{14}, n-C_{15}, n-C_{16}, and n-C_{17} only.)

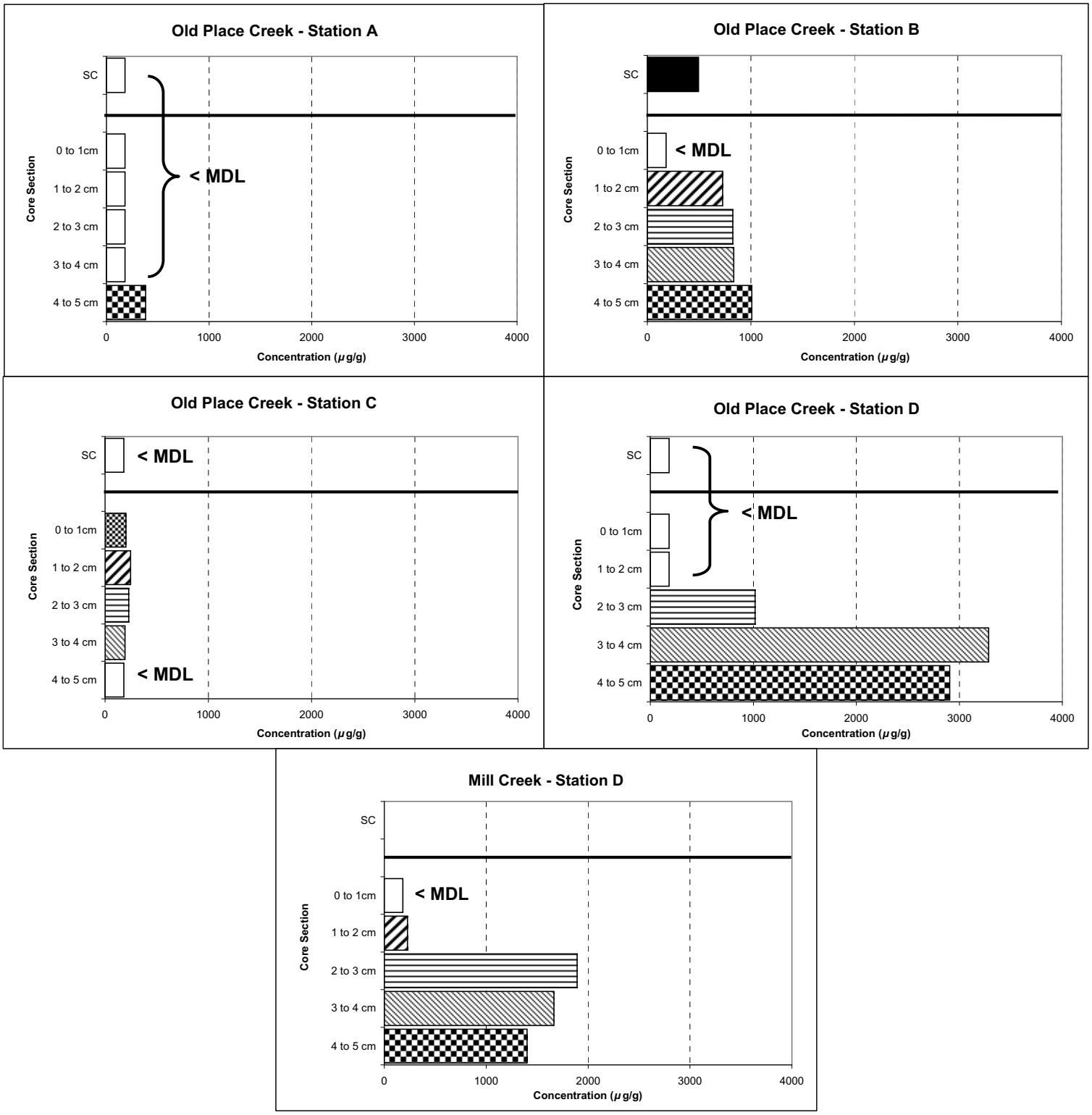

Figure 17. TPH concentrations (µg/g, wet weight) for Old Place Creek and Mill Creek sediment samples. (Each analyzed sediment sample, either core section or surface scoop, is represented by a bar. The bars for samples in which concentrations exceed the MDL value of 181 µg/g are filled with different patterns to identify the type or location of the sample. The bar is unfilled for samples in which the concentration is less than the MDL. Each core section from Mill Creek marsh was analyzed except for core section 5 from Station A which was lost during sample processing. All core section from all stations, except for Station D, had TPH values less than the MDL. The plot of the distribution of TPH values for Station D is given in the figure. No surface scoop samples were analyzed for Mill Creek marsh. SC = surface scoop sample.)

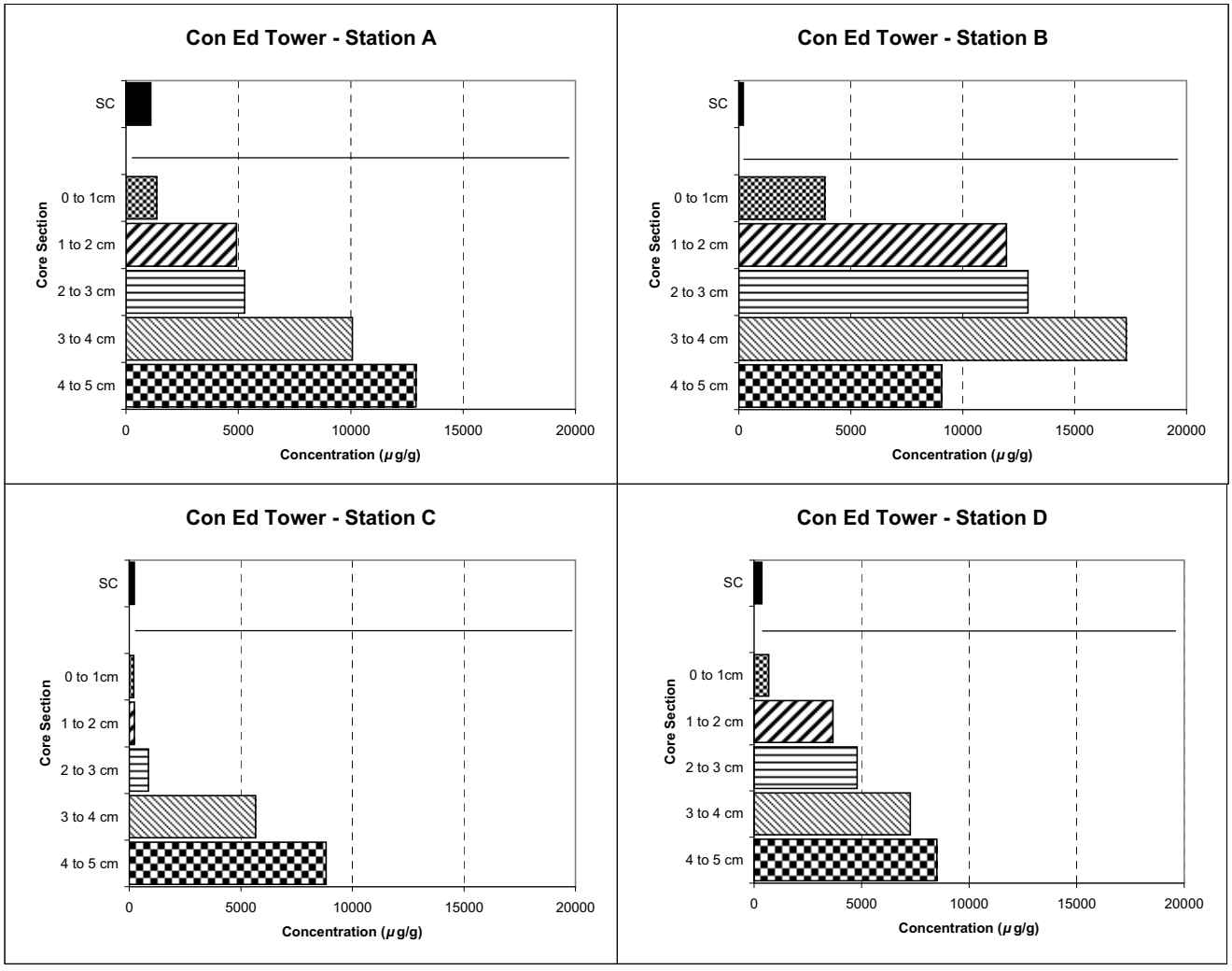

Figure 18. TPH concentrations (µg/g, wet weight) for Con Ed Tower sediment samples. (Each analyzed sediment samples is represented by a bar. The bars for samples in which concentrations exceed the MDL value of 181 µg/g are filled with different patterns to identify the type or location of the sample. The bar is unfilled for samples in which the concentration is less than the MDL. SC = surface scoop sample.)

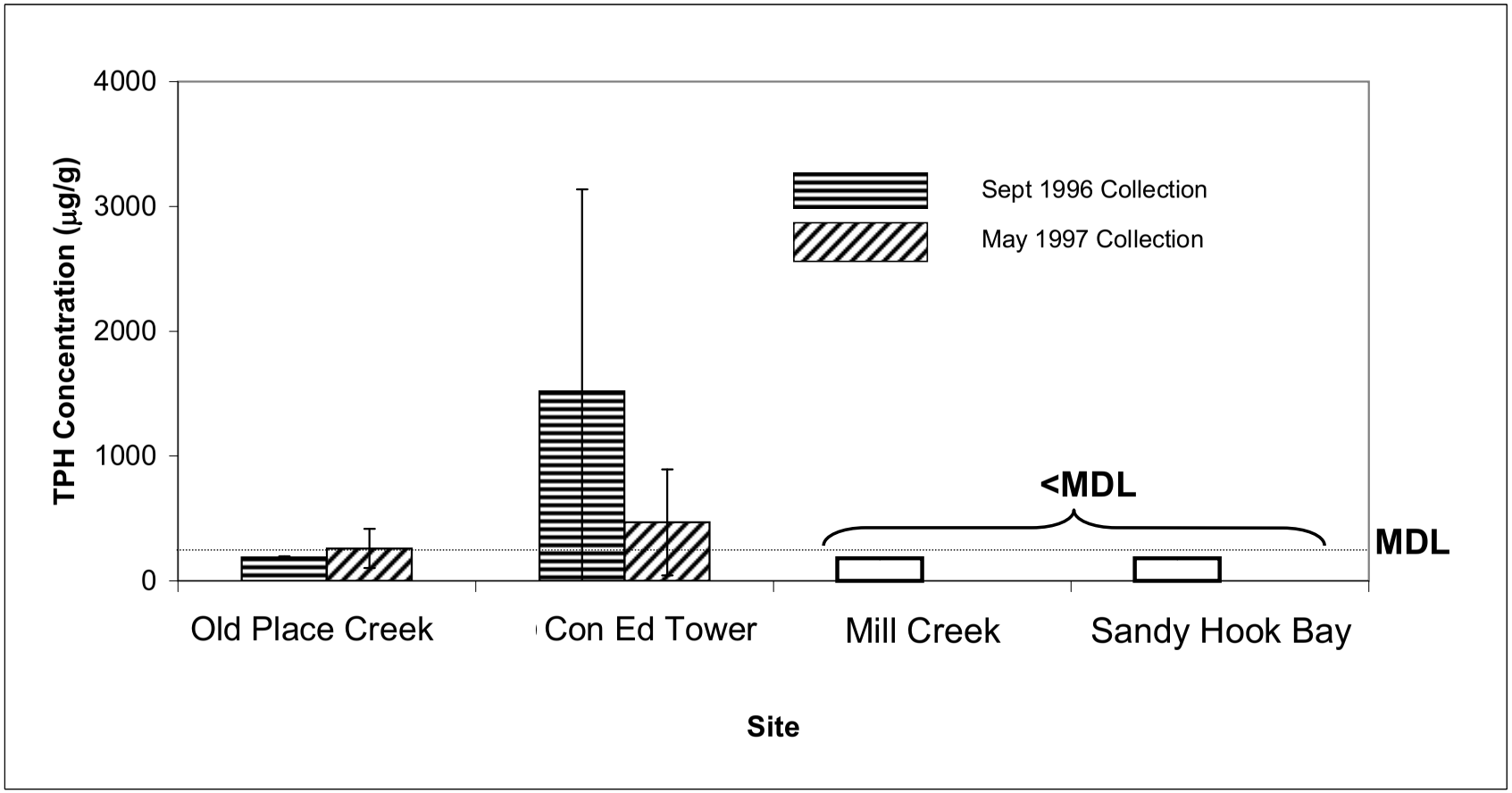

Figure 19. Average TPH concentrations (µg/g, wet weight) in surface sediments by site. (Concentrations for the September 1996 collection were from the top-most core sections (*i.e.*, depth = 0-1 cm) for each station. Concentrations for the May 1997 collection were from individual surface scoops from each station. No sediment surface scoop samples from Mill Creek marsh were analyzed. Only one set of sediment samples was collected from Sandy Hook Bay. All concentrations in the figures are greater than or equal to the MDL value of 181 µg/g.)

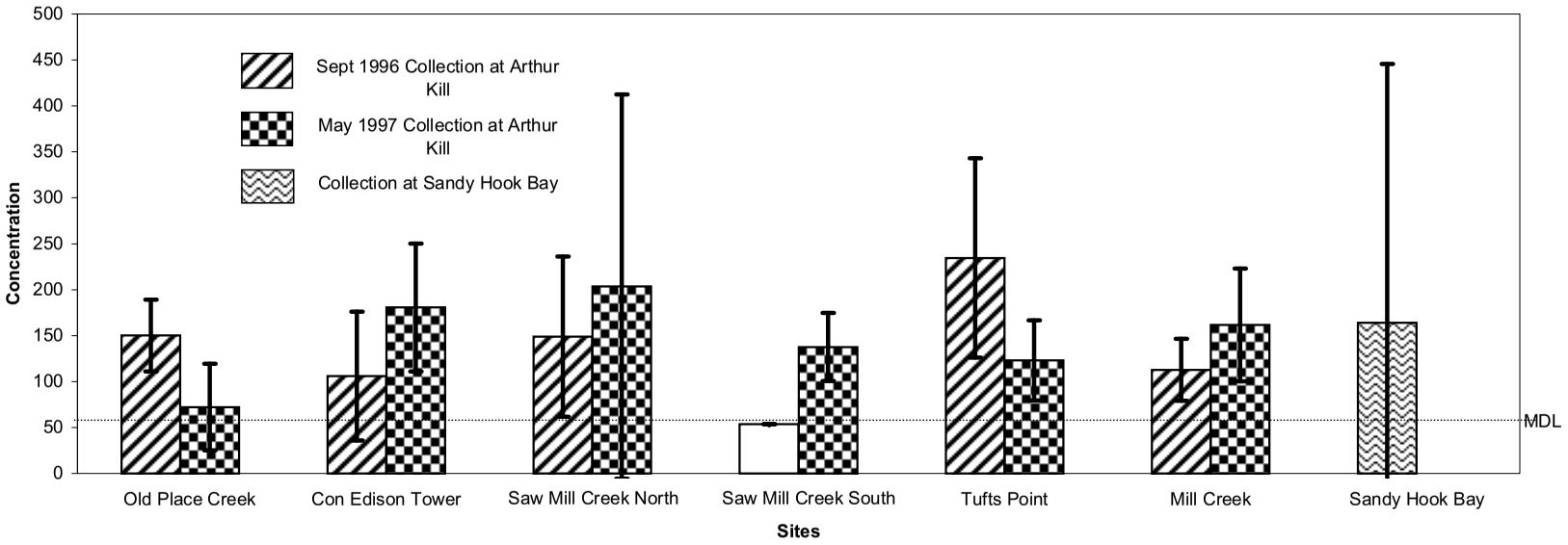

Figure 20. Average TPH concentrations (µg/g, wet weight) in ribbed-mussels by site. (One set of ribbed-mussels was collected at Sandy Hook Bay between the collection dates for the two sets of Arthur Kill samples. To calculate the average where some members had values less than the MDL, one-half of the MDL was used. When the average value exceeded the MDL, the bars are filled. The average for the Saw Mill Creek South September 1996 collection was less than the MDL (53.6 µg/g). The value for the MDL was used in the plot, and the bar was not filled.)

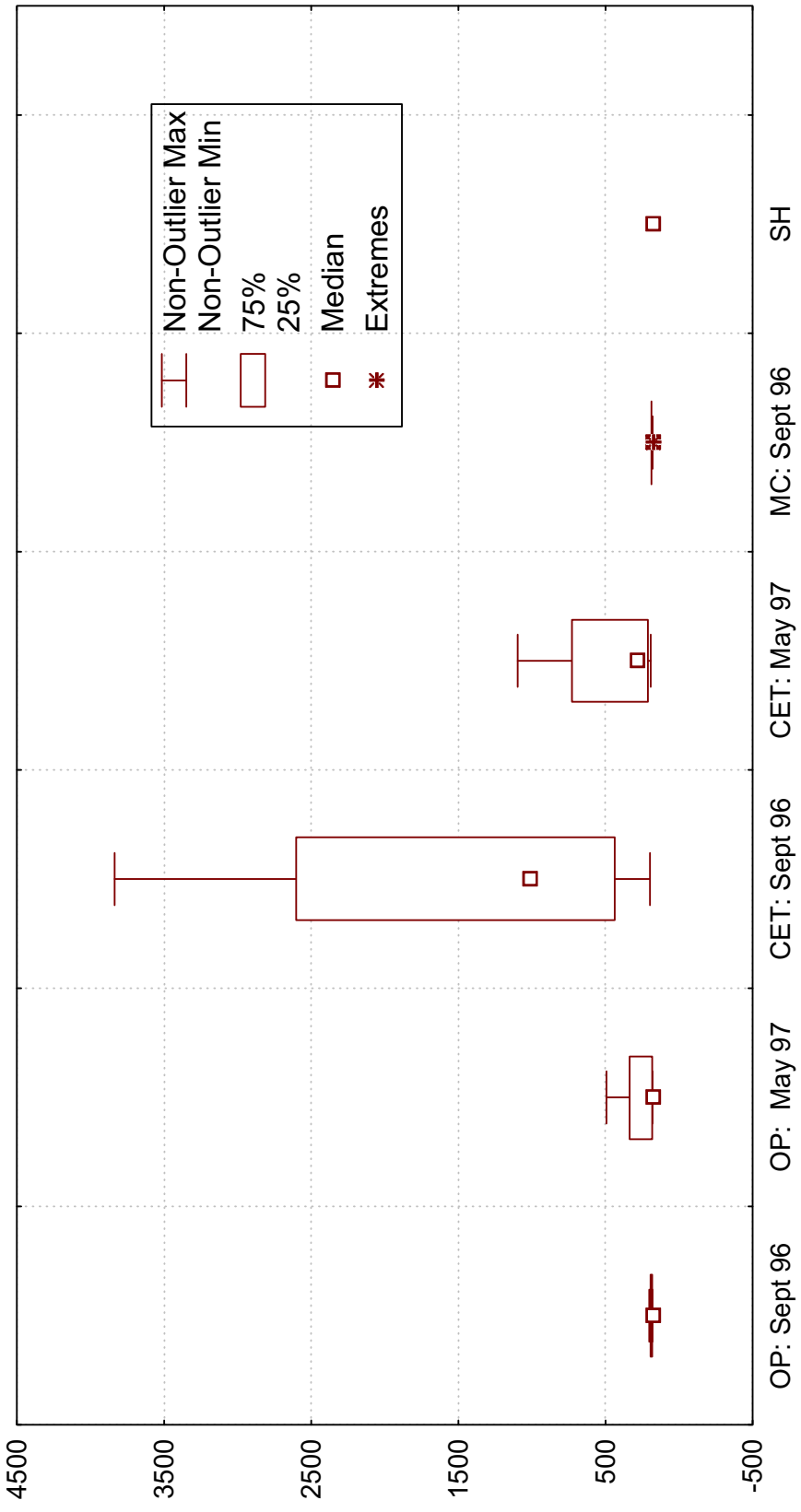

Figure 21. Box plot of the TPH concentrations (µg/g, wet weight) in surface sediments. (OP = Old Place Creek; CET = Con Ed Tower; MC = Mill Creek; and SH = Sandy Hook Bay.)

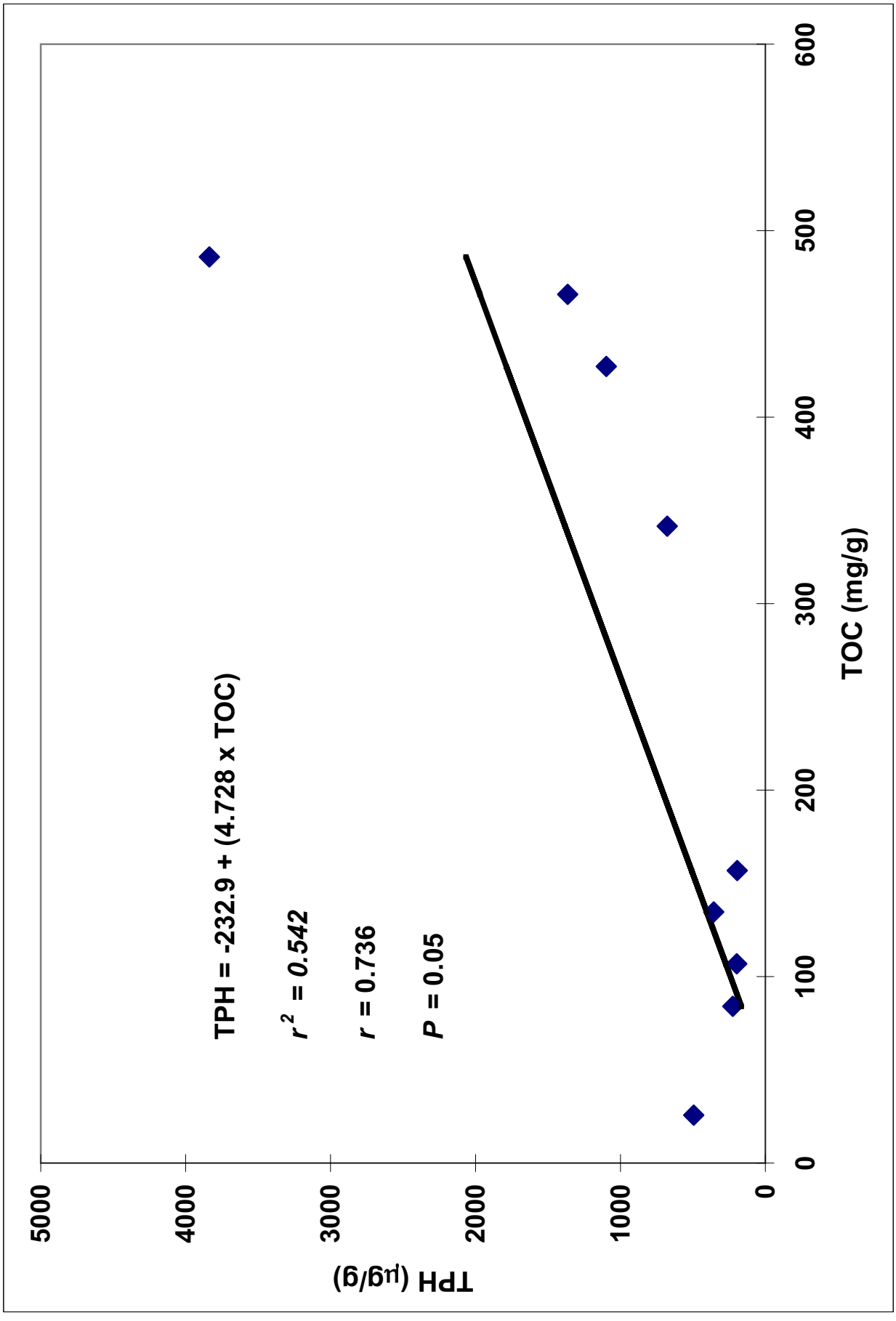

Figure 22. Correlation between TPH concentrations (µg/g) and TOC concentrations (mg/g) in Arthur Kill surface sediments from Old Place Creek, Con Ed Tower, and Mill Creek marshes. (All TPH values used for this analysis were greater than the MDL (181 µg/g). The TPH values used for the September 1996 cores are from the top-most core sections (*i.e.*, depth = 0-1 cm). The stations used for the September 1996 collection were: Old Place Creek - Station C; and Con Ed Tower - all stations. The stations used for the May 1997 collection were: Old Place Creek - Station B; and Con Ed Tower - all stations.)

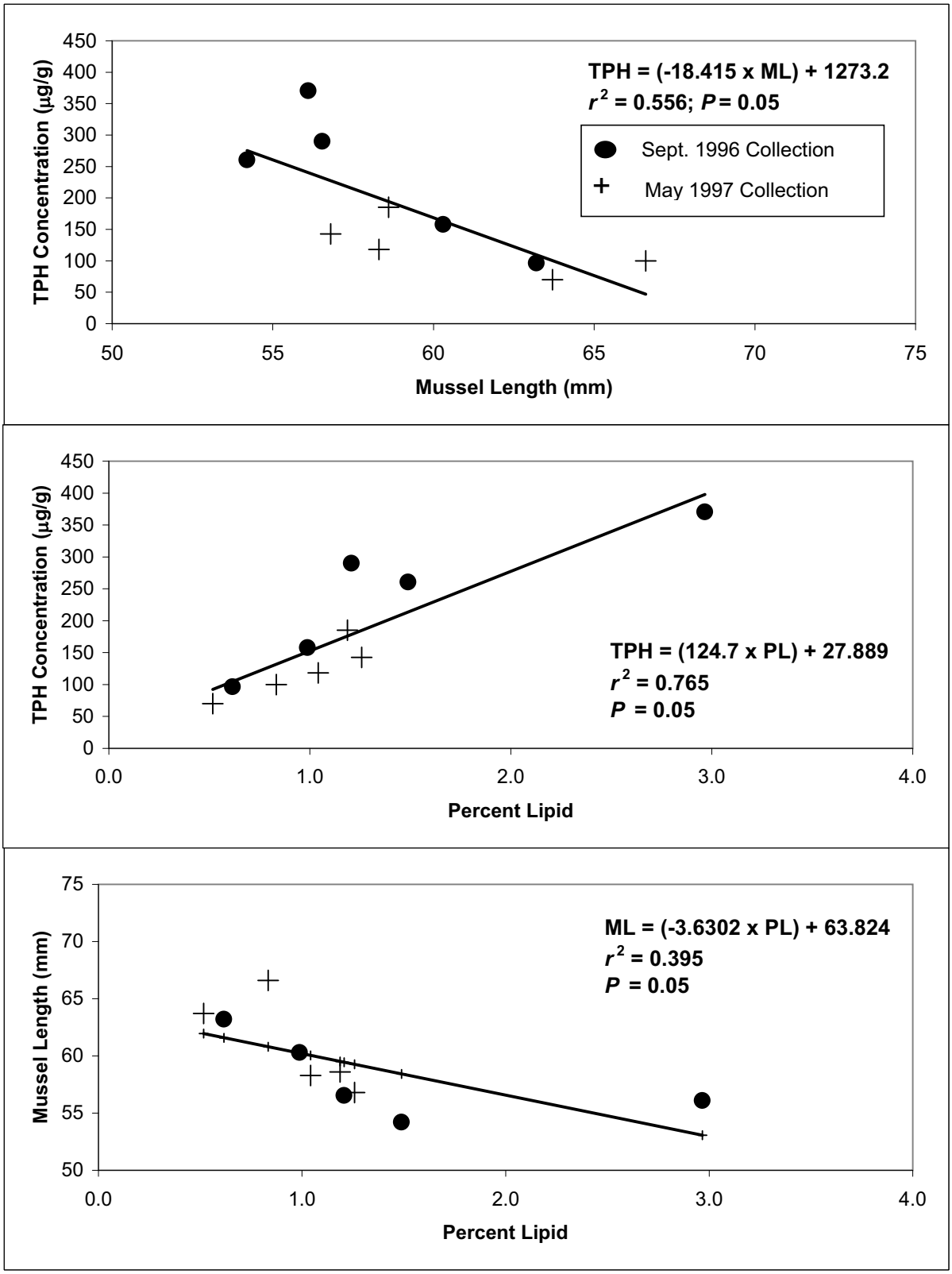

Figure 23. Correlation between TPH concentrations (µg/g), mussel length (mm), and percent lipid for Tufts Point ribbed-mussels. (The mussel MDL value is 54 mg/g. ML = mussel length (mm); and PL = percent lipid.)

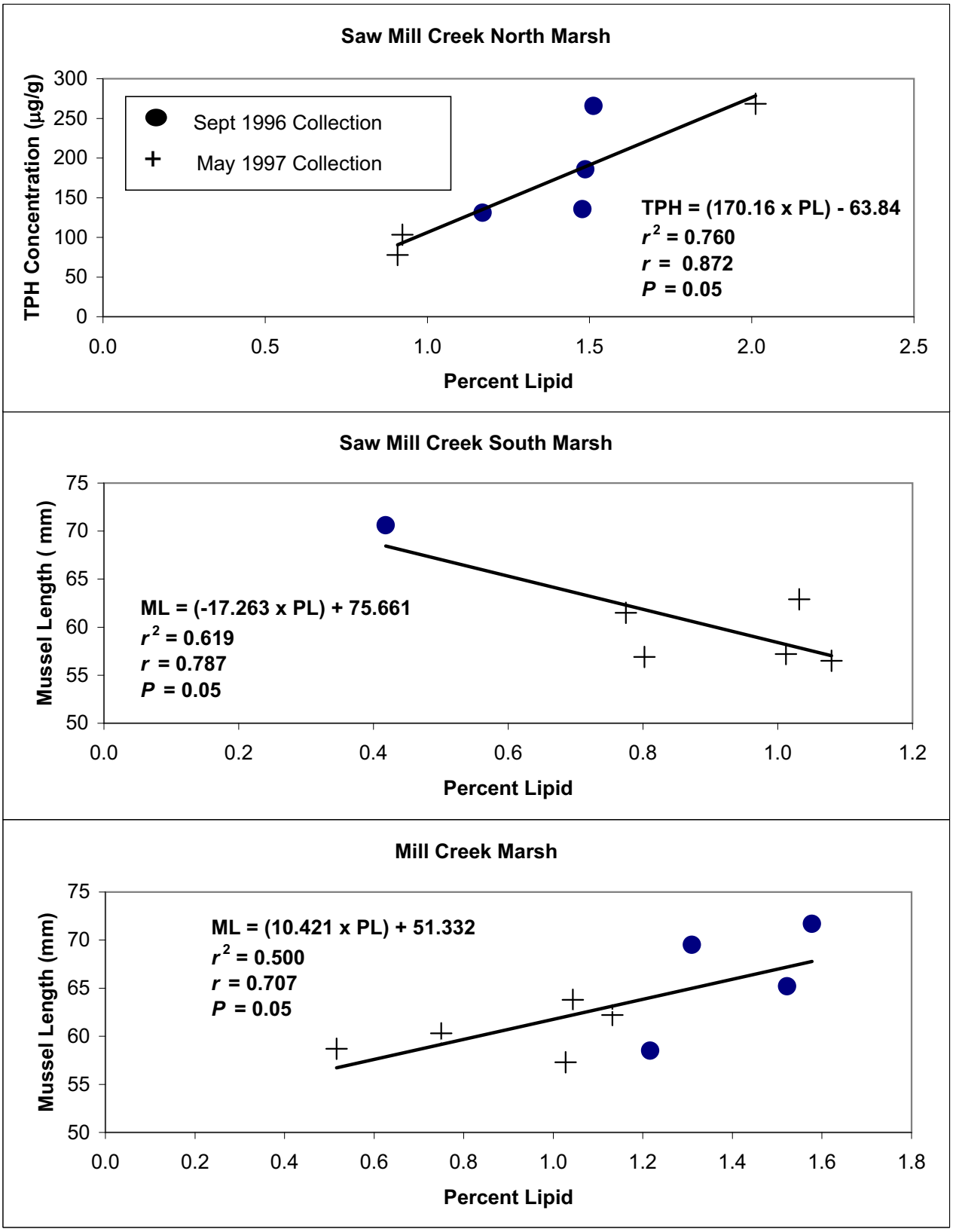

Figure 24. Correlation between TPH concentrations (µg/g) and percent lipid in Saw Mill Creek North ribbed-mussels, correlation between mussel length (mm) and percent lipid in Saw Mill Creek South ribbed-mussels, and correlation between mussel length (mm) and percent lipid in Mill Creek ribbed-mussels. (The mussel MDL value is 54 mg/g. ML = mussel length (mm); and PL = percent lipid.)

Table 9. Concentrations of total petroleum hydrocarbons (TPH) and of the total of the individual petroleum hydrocarbons (TIPH) for surface sediments. (TPH MDL = 181µg/g, wet weight; TIPH MDL = 59.0 µg/g, wet weight; and nd = not detected.)

Site	Collection Period	Station	No. of Samples	Concentration (µg/g, wet weight) TPH[a]	TIPH[b]
Old Place marsh	September 1996[c]	A	1	nd	nd
		B	1	nd	nd
		C	1	203	nd
		D	1	nd	nd
		Mean	4	<MDL	<MDL
		Std. dev.		-	-
	May 1997[d]	A	1	nd	nd
		B	1	494	nd
		C	1	nd	nd
		D	1	nd	nd
		Mean	4	192	<MDL
		Std. dev.		202	-
Con Ed Tower marsh	September 1996[c]	A	1	1360	213
		B	1	3840	646
		C	1	198	nd
		D	1	677	61.6
		Mean	4	1520	237
		Std. dev.		1620	284
	May 1997[d]	A	1	1100	71
		B	1	194	nd
		C	1	225	nd
		D	1	357	nd
		Mean	4	468	<MDL
		Std. dev.		425	-
Mill Creek marsh	September 1996[c]	A	1	nd	nd
		B	1	nd	nd
		C	1	nd	nd
		D	1	nd	nd
		Mean	4	nd	nd
		Std. dev.		-	-
Sandy Hook Bay marsh	February 1997[e]		1	153	nd

[a]TPH = sum of all peaks eluting within the range of the target hydrocarbon analytes (see Appendix Table A5).
[b]TIHC = sum of target hydrocarbon analytes.
[c]Values are for core section 1 (*i.e.*, depth 0-1 cm).
[d]Values are for the surface scoops.
[e]Only one surface sediment sample from Sandy Hook Bay was analyzed.

Table 10. Concentrations of total petroleum hydrocarbons (TPH) and of the total of the individual petroleum hydrocarbons (TIPH) for sediment core sections. (TPH MDL = 181µg/g, wet weight; TIPH MDL = 59.0 µg/g, wet weight; and nd = not detected.)

Site	Station	No. of Samples	Concentration (µg/g, wet weight) TPH[a] Mean[c]	TPH[a] Std. Dev.	TIPH[b] Mean[c]	TIPH[b] Std. Dev.
Old Place marsh	A	5	<MDL	-	nd	-
	B	5	697	354	59.4	17.3
	C	5	193	61.0	nd	-
	D	5	1480	1530	115	96.9
	Mean	20	629.1	908.4	<MDL	-
Con Ed Tower marsh	A	5	6900	4560	587	285
	B	5	10,900	5040	998	574
	C	5	3150	3910	239	277
	D	5	4980	3080	377	245
	Mean	20	6490	4860	550	449
Mill Creek marsh	A	4	nd	-	nd	-
	B	5	nd	-	<MDL	-
	C	5	nd	-	<MDL	-
	D	5	1310	1110	73.6	41.1
	Mean	19	413	1030	<MDL	-

[a]TPH = sum of all peaks eluting within the range of the target hydrocarbon analytes (see Appendix Table A5).
[b]TIPH = sum of target hydrocarbon analytes.
[c]Values are the average of all core sections at that station. When the values for all core sections are below the MDL, the average is given as "nd." When some of the values are below the MDL, ½ MDL is used instead of these values. The average is given as "<MDL" when this average is less than the MDL.

Table 11. Concentrations of total petroleum hydrocarbons (TPH) and of the total of the individual petroleum hydrocarbons (TIPH) for ribbed-mussels. (TPH MDL = 53.6 µg/g, wet weight; and TIPH MDL = 8.2 µg/g, wet weight.)

Site	Collection Period	No. of Samples	Concentration (µg/g, wet weight) TPH[a] Mean[c]	TPH[a] Std. Dev.	TIPH[b] Mean[c]	TIPH[b] Std. Dev.
Old Place Creek marsh	September 1996	5	150	39.1	11.0	1.70
	May 1997	5	72.2	47.1	8.20	6.64
Con Ed Tower marsh	September 1996	5	106	70.0	22.5	31.9
	May 1997	5	181	69.5	17.8	18.3
Saw Mill Creek North marsh	September 1996	5	149	87.2	10.3	3.93
	May 1997	5	203	209	13.1	8.40
Saw Mill Creek South marsh	September 1996	5	<MDL	-	<MDL	-
	May 1997	5	138	37.0	12.5	2.86
Tufts Point marsh	September 1996	5	235	108	16.5	5.75
	May 1997	5	123	43.7	<MDL	-
Mill Creek marsh	September 1996	5	113	33.6	23.0	26.2
	May 1997	5	162	61.4	10.9	4.58
Sandy Hook Bay marsh	February 1997	7	164	281	15.4	23.0

[a]TPH = sum of all peaks eluting within the range of the target hydrocarbon analytes (see Appendix Table A5).
[b]TIHC = sum of target hydrocarbon analytes.
[c]Values are the average of all mussels at that site. When the values for all mussels are below the MDL, the average is given as "nd." When some of the values are below the MDL, ½ MDL is used instead of these values. The average is given as "<MDL" when this average is less than the MDL.

IV. SEDIMENT BIOGEOCHEMISTRY

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INTRODUCTION

Knowledge of soil biogeochemistry in salt marshes is essential to an understanding of the role of these wetlands in promoting fisheries. Biogeochemistry is the chemistry that mediates interactions among atmosphere, water, minerals, microbiota, and higher organisms in the environment. It is characterized by both linear and cyclic transformations of materials, yielding deposits of end products for some materials, a dynamic steady state for other materials, and the generation of metabolic energy that sustains the structure of the ecosystem.

Organic wetland soils (*i.e.*, hydric histosols) such as those in salt marshes have a great capacity for transformations of forms of carbon, nitrogen, phosphorus, sulfur, and transition metals. These transformations are essential to the productivity and structure of salt marshes, and thereby to the functioning of these marshes as critical fisheries habitat (Boesch and Turner 1984). The same transformations are also critical as exporters of production to adjacent waters (Haines 1979).

Saturation of wetland soils with water impedes the diffusion of gaseous atmospheric oxygen into such soils. Water, through which oxygen diffuses slowly, fills the interstices between solid particles that would otherwise be filled with gas, through which oxygen diffuses rapidly. At the same time, water saturation facilitates the diffusion of nongaseous water-soluble materials. The result is a sharp decline in the reducing-oxidizing (*i.e.*, redox) potential with depth that is characteristic of wetland soils, and one that leads to other characteristics typical of wetland soils (Mitsch and Gosselink 1986).

Some of these other characteristics include anoxia which allows the net accumulation of organic matter from dead plant parts that cannot be converted entirely to carbon dioxide and water without an oxidant, thus allowing the development and maintenance of the characteristically high organic matter content of the histosol. Another characteristic resulting from the abundant organic matter and redox potential gradient is the variety of microenvironments favoring an array of microbiota with extremely diverse metabolic capabilities. These capabilities include the cyclic redox transformations of nitrogen, sulfur, iron, and manganese that are essential to maintaining primary production, and a variety of organic decay mechanisms that allow transfer of energy from refractory lignocellulose plant remains into the trophic web (Howes *et al.* 1984; Newell 1993).

The aforementioned characteristics are those of established, functioning wetland soils. The re-establishment of productive stands of *S. alterniflora* has clearly been successful in the replanted salt marshes of the Arthur Kill (Bergen *et al.* 2000). We have sought to determine if the re-establishment of normal wetland soil characteristics has been as successful. Indeed, we seek to understand to what extent oiling and other urban influences have affected these unseen, but vital biogeochemical features of the Arthur Kill salt marshes.

Previous studies found that created wetlands had lower OC and nitrogen content, but higher redox potential values (measured as E_h) and higher manganese and iron content, than natural wetlands (Craft *et al.* 1991; Zedler 1993). Other studies have shown that sediment organic content appears to develop slowly in newly created salt marshes, and may take years to reach natural levels (LaSalle *et al.* 1991; Moy and Levin 1991; Minello and Zimmerman 1992). Likewise, development of saltmarsh nitrogen cycling rates can require years (Thompson *et al.* 1995). These differences between newly created and established wetlands are related to the low organic matter content of soils used for *de novo* wetland creation as compared with that of natural marsh soil. Such findings suggest that marshes planted on nonwetland soils cannot immediately duplicate the biogeochemical functions of older, natural systems.

Unlike wetlands that have been "created" though, the Arthur Kill marshes such as the one at Old Place Creek have been replanted on old wetland soils, although ones which have been highly altered in this urban environment. Prior to replanting, those sites were denuded due to the oil spill, and were barren for a few years until replanted. By comparing these replanted wetlands with the denuded areas that were not replanted and with areas that were not denuded, we hoped to investigate what effect these varied histories may have had on the organic matter essential for soil function.

The abundance of soluble inorganic sulfide, primarily in the forms of the dissolved hydrosulfide ion (HS^-) and hydrogen sulfide (H_2S), is of particular interest because it is an indicator of microbial activity and recent redox history, and because it has a strong influence on primary production. Soluble sulfide is a product of a bacterial respiratory pathway that utilizes the abundant sulfate ion (SO_4^{-2}) in saline interstitial water as a source of oxidizing power where other oxidants (including O_2 and NO_3^-) have been depleted. Sulfate reduction is a major form of respiration in salt marshes (Howarth and Giblin 1983), and the sulfide produced is

known to inhibit root uptake of nitrogen in *S. alterniflora* and other wetland plants (Bradley and Morris 1990a; Koch *et al.* 1990). In the case of *S. alterniflora*, sulfide inhibition of nitrogen uptake, along with salinity inhibition, are potentially important sources of productivity limitation since growth of this grass appears to be nitrogen-limited in most Gulf and Atlantic Coast marshes (Bradley and Morris 1992).

While measurement of sulfide deals with a narrow set of redox species, measurement of soil E_h integrates the influence of many such chemical species (*e.g.*, O_2, Fe^{+3}, Fe^{+2}, Mn^{+4}, Mn^{+2}, NH_4^+, NO_3^-, H_2S, HS^-, CH_4, H_2, etc.). Typical depth profiles for E_h in saltmarsh soils have high positive values at the surface, indicating the penetration of hydrospheric and atmospheric O_2. This surface layer is underlain by a rapid decline in values within the first few centimeters, indicating exhaustion of O_2. Below this rapid decline, there is a continuous slow decline in E_h toward values characterizing sulfide presence, perhaps underlain by still lower values indicating exhaustion of sulfate substrate and supporting only fermentative metabolism (Howes *et al.* 1981).

Aside from depth in the soil, E_h values are influenced by the presence or absence of vegetation, the type of vegetation, and the seasonal state (*i.e.*, dormancy vs. active growth) of vegetation (de la Cruz *et al.* 1989). During the growing season, *S. alterniflora* oxidizes marsh soil (increases E_h) by conducting oxygen downward into its roots and by diffusion to the adjacent soil root zone via specialized aerenchyma tissues. In addition, the grass lowers soil water saturation levels by transferring interstitial water to the atmosphere via evapotranspiration (Howes *et al.* 1981). Such processes are not active during the dormant season (fall-winter) or where grass has been intentionally burnt or clipped or has died back of other causes; such factors result in lower E_h values that appear to inhibit recolonization in dieback areas where rhizosphere oxidation cannot be reestablished simply by reactivation of existing root and rhizome systems (Bertness 1991). On the other hand, low E_h values can also result in the release into interstitial water of dissolved inorganic nutrients essential to plant growth (DeLaune *et al.* 1981).

The presence of living *S. alterniflora*, with its seasonal oxidizing influence (*i.e.*, raising E_h values) and release of soluble organic materials into soils, has important consequences for the biogeochemistry of salt marshes. In addition to raising the E_h, the microzones around cordgrass roots: 1) exhibit lower pH; 2) accumulate and immobilize forms of such potentially toxic metals as copper, zinc, and lead, presumably due to the tight binding of such metals to abundant organic ligands (Caçador *et al.* 1996); 3) oxidize sulfide (Howes *et al.* 1981); 4) mobilize iron (Kostka and Luther 1995); and 5) facilitate the redox cycling of iron via organic ligand complexes (Luther *et al.* 1992). These alterations in cordgrass root microzones form a positive feedback on the growth of cordgrass, for which iron is essential and sulfide and excess heavy metals are toxic. Such biogeochemical functions are presumably lost when cordgrass roots die, resulting in greater mobility of heavy metals, higher sulfide levels, and immobilization of iron, making soil less suitable for re-establishment and growth of *S. alterniflora*.

Finally, there is the effect of residual petroleum contamination on biogeochemical functions in Arthur Kill marshes. Early research with crude oil suggested that this substance may not be very toxic to such important microbial processes as the fixation of nitrogen (Thomson and Webb 1984), the reduction of nitrate, manganese, iron, and sulfate, and the production of methane and ammonia (DeLaune *et al.* 1979). However, subsequent work with specific oil components has shown that naphthalene can inhibit sulfate reduction in saltmarsh sediments while increasing methanogenesis (Keine and Capone 1984). Indeed, there is evidence that fuel oil can increase detrital decay rates (Hershner and Lake 1980), and that low levels of a light hydrocarbon mixture can stimulate CO_2 production, methanogenesis, nitrogen fixation, and denitrification in saltmarsh soils (Li *et al.* 1990).

Because of the key roles played by soil organic matter, sulfide, and redox potential in controlling saltmarsh structure and productivity, we have chosen to measure total and labile (*i.e.*, readily degraded by aerobic microbiota) organic matter in soil, and soluble sulfide and E_h values in interstitial water, as means of characterizing and assessing the comparative biogeochemical condition of Arthur Kill marshes and the possible efficacy of the replanting efforts.

METHODS AND MATERIALS

At each of the six sites, four stations were selected at 0.2 m above mid-tide. The separation between replicate stations at a site ranged between 2 and 20 m (see description of the sampling transect in Chapter II, "Trace Metal Contaminants in Sediments and Ribbed-Mussels"). In order to take into account seasonal variations, sampling regimes were performed during two intervals: September-October 1996 representing fall, and May 1997 representing spring.

Redox Potential

Duplicate vertical profiles of redox potential (measured as E_h) were taken *in situ* within 10 cm of each other at each station using a Fisher Scientific Model 640 portable pH/millivolt meter. The instrument was calibrated to within 1 mV at 10, 100, and 1000 mV using a Cole-Parmer pH-mV calibrator (#5657-10). A platinum electrode (Thomas Scientific #4096-D20) with a band of platinum (6-mm dia. × 4-mm height) was used as the sample electrode. The reference electrode was a Fisher Scientific (#13-639-62) sleeve-junction calomel electrode. This system was calibrated using three $K_3Fe(CN)_6$-$K_4Fe(CN)_6$ solutions of differing redox potentials (ZoBell 1946; Orion Research, Inc. 1983).

Depth in the sediment was measured to the center of the band except for the "zero" reading which was made with

the band just immersed in the sediment. Before each profile, the electrode system was equilibrated in water collected in the Arthur Kill adjacent to the site. In the first profile, measurements were made in overlying surface water at 1 cm above the soil surface, at the soil surface (0), 0.5 cm below the surface, and 1-5 cm below the surface at 1-cm intervals, soil penetrability permitting. In the second profile, measurements were made 1-10 cm below the soil surface at 1-cm intervals, soil penetrability permitting. Readings at each depth interval were accepted when the rate of change was <1 mV in 10 s.

Soluble Sulfide

Samples for porewater sulfide determination were obtained with the use of de-ionized water (DIW) equilibration devices, or "peepers" (Hesslein 1976; C. Wigand, U.S. Environmental Protection Agency, 27 Tarzwell Dr., Narragansett, RI, pers. comm.; Figure 25). These devices obtained time-integrated, particulate-free samples of water with the same dissolved chemical composition as interstitial water by allowing an extended period of equilibrations between water outside the peeper and DIW inside the peeper across membranes with molecule-sized pores. Each peeper consisted of a body and two face plates (one on each side) of high-density polyethylene (HPDE) held together with stainless steel screws and washers. Sandwiched between the body and face plates and enclosing five pairs of cylindrical equilibration chambers (each 2.54-cm dia. × 1.9-cm depth, with a capacity of 9.7 ml) were two cellulose dialysis membranes (Spectra/Por1) made from regenerated cellulose and having a molecular weight cutoff of 6000-8000 Daltons.

In order to avoid contamination of subsurface soil and porewater with molecular oxygen from the peepers, the HPDE peeper parts were soaked for 25 days in DIW which had been continuously sparged with N_2 gas in order to remove adsorbed O_2 prior to assembly. To minimize O_2 absorption before insertion in marsh soil, peeper chambers were filled with N_2-sparged DIW, and the assembled peepers were wrapped in polyvinylidine chloride film and were transported in N_2-sparged water. Peepers used in 1996 had a single set of vertical chambers, while those used in 1997 had two sets, as depicted in Figure 25. As each chamber spanned 2.54 cm in the vertical dimension, samples from the five pairs of samples represent conditions from the following height/depth ranges (+ is above the soil surface and - is below): 1) +3.2 to +0.6 cm (mean = +1.9 cm); 2) -0.6 to -3.2 cm (mean = -1.9 cm); 3) -4.4 to -7.0 cm (mean = -5.7 cm); 4) -8.3 to -10.8 cm (mean = -9.5 cm); and 5) -13.3 to -15.9 cm (mean = -14.6 cm).

Each peeper was driven into the soil with a rubber mallet at one (1996) or two (1997) randomly chosen stations from among the four stations at each site so that four sets of chambers were below the surface of the soil and one above (Figure 25). The peepers were left undisturbed to equilibrate with the porewater for 13-14 days. Upon retrieval, the cellulose membranes covering each chamber were punctured with a Teflon needle (reused after flushing with surface seawater), and samples were withdrawn from the chamber with disposable syringes and transferred to 1.5-ml polypropylene centrifuge tubes for immediate addition of colorimetric reagents and dilution water (*i.e.*, N_2-sparged, filtered seawater). Sample dilution by 10- or 100-fold was necessary to overcome the limitations of the analytical method.

Analysis was performed by a micromethod derived from the method of Strickland and Parsons (1972), with reagents calibrated against iodometric titration, and standardization performed using serial dilutions of sulfide-enriched, N_2-sparged seawater. Optical absorbance of the samples was determined with a Perkin Elmer Lambda 3B spectrophotometer within 4 hr of collection. Tests of this microprocedure have shown a 2.07±3.04% (*i.e.*, mean ± standard deviation; n = 8) decrease in absorbance of samples after 7 hr of reaction time. Total procedural error for the method was ±10% (n = 26) for sulfide values up to 900 µM. Values between 900 and 3000 µM were ±30%. Values beyond 3000 could not be estimated by our method, and were recorded as "≥3000 µM."

Total Organic Carbon

Sediment samples for the determination of TOC were manually collected in 28-mm (internal diameter) butyrate cores, one core per station, to an average depth of 10 cm. Care was taken to prevent disturbance of the sediment surface layer by maintaining the cores upright on ice for the return to the laboratory, where they were frozen at -20°C until processed. Frozen sediment cores were transferred to a 4°C cold room and defrosted. The cored sediment was extruded; the surface layer (to a depth of 1 cm) was collected in individual precleaned glass containers. Due to the vegetated nature of the collection sites, sectioning of the sediment was accomplished with a serrated stainless steel blade. Sectioned sediments were dried overnight at 50°C. All large carbonaceous fragments (>1 mm) were removed; samples were then homogenized with a glass rod. A 100-mg subsample was transferred into an acid-cleaned, uncapped scintillation vial. The acidification technique of Yamamuro and Kayanne (1995) was employed to remove carbonate, while avoiding the dissolution of acid-soluble organic material.

Aliquots, ranging from 10 to 50 mg, were taken from the acidified samples, placed into tin combustion cups, and sealed in preparation for organic carbon and nitrogen analyses by flash combustion in oxygen at 1020°C on a Carlo Erba 1108 elemental analyzer equipped with a 120-position autosampler. Combustion products pass over a catalyst and then over copper to remove excess oxygen and to reduce the nitrogen oxides to elemental nitrogen. Upon separation by gas chromatography, the CO_2 and N_2 eluent peaks are integrated and reported as organic carbon and nitrogen.

Instrument calibration was maintained by performing a series of linear regressions using an acetanilide standard. These standard and additional TOC SRMs (*e.g.*, PACS-1) were placed into the sample rotation for further verification of optimal operation.

Labile Carbon

The 0.1-cm^3 sediment surface samples for labile carbon (LC) analysis were obtained by coring marsh sediments using disposable 10-ml plastic syringes with the tapered end cut off. These cores included the upper 1 cm of the soil column. Duplicate samples were taken at each of two randomly chosen stations at each site during May 1997.

The LC content of these samples was estimated via measurement of dissolved oxygen consumption by the microbiota during a 13-day incubation of the sample in a 300-ml BOD (biological oxygen demand) bottle filled with natural seawater and maintained at 20°C (Draxler 1995). Sediment oxygen consumption was compared with oxygen consumption by D-glucose under the same conditions. Therefore, sediment LC, hereafter reported as "μM-C/cm^3," signifies micromoles of glucose carbon equivalents per cubic centimeter of sediment.

Data Analysis

Statistical analyses of data were performed with the aid of Jandel Scientific SigmaStat 2.0. Procedures included the use of Kruskal-Wallis, one-way ANOVA and the Mann-Whitney rank sum test for site-by-site comparison of redox potential, sulfide concentrations, and TOC content of soil, with the use of Tukey, Dunn's, or Student-Newman-Keuls pairwise tests, as appropriate, and of Student's *t*-tests, for seasonal comparison of redox potential.

RESULTS

Redox Potential

A total of 965 measurements of E_h were made for the purpose of creating duplicate depth profiles for redox potential in soil at four stations (designated A through D) at each of the six sites in each of two seasons: fall 1996 and spring 1997 (Figures 26-28). Depths in the soil in these and all subsequent presentations are indicated in terms of negative (-) elevations, with a zero value denoting the soil surface. Most, though not all, sites demonstrated the classic declining gradient in E_h with depth, described in the introduction to this chapter. The highest values were generally at the surface. In most cases, a zone of rapid decline of redox potential was within a depth of 2 cm, with more slowly declining values between -2 and -5 cm, then consistently low values below -5 cm.

Values of E_h for surface water collected adjacent to the sites were +268±37 mV (n = 47) during fall 1996, and +314±23 mV (n = 46) during spring 1997 (Figures 26-28). Since the E_h range of oxygenated pure water is above +350 mV, these low values suggest poor quality in water overlying the marsh during high tide (*i.e.*, little dissolved oxygen and/or an abundance of reductants such as organic matter).

Beneath the soil surface, some profiles within each station diverged from the classic pattern, yielding both extraordinarily low and extraordinarily high E_h values at depth (*e.g.*, Figure 26A). While replanted sites appeared more prone to high subsurface values (Figure 26), this phenomenon was not uniformly demonstrated at all stations nor in all seasons within that treatment group, nor was it exclusively present there (Figures 27 and 28). Of the 40 highest values (+374 to +478 mV), 26 were taken at Old Place Creek - Station A during both fall and spring, and 11 from Saw Mill Creek North - Station B in spring, making these the stations with the most oxic sediments. Paradoxically, Old Place Creek (a replanted site) was also the site where the lowest (*i.e.*, most reduced) values of the study were recorded. Of the 21 lowest values (≥-251 mV), 16 came from Old Place Creek - Stations B, C, and D (replanted), making the deeper layers at these stations the most anoxic sediments of the study -- a sharp contrast to the highly oxic character of sediments at Old Place Creek - Station A. Extremely low values were evident at the reference sites (*e.g.*, Figure 27A) as well.

While E_h declined with depth in the soil at most stations, it increased with depth in a few profiles, including those for Old Place Creek - Station A (replanted), Saw Mill Creek North - Station B (replanted), and Tufts Point - Station C (reference) in both fall and spring, and for Con Ed Tower - Stations A and C (unplanted) in spring only. Other stations at those sites did not exhibit this pattern.

Unequal variances and deviations from normality prevented the use of parametric, three-way ANOVA of E_h data to detect significant differences by depth, season, restoration status, and station. Therefore, a separate nonparametric test (*i.e.*, the Kruskal-Wallis, one-way, ANOVA-on-ranks test) for depth, restoration status, and station, and another (*i.e.*, the Mann-Whitney rank sum test) for season, were employed to test the significance of each of these factors. There was a significant difference associated with depth ($P < 0.001$), and indeed, a significant linear correlation with that factor ($r^2 = 0.433$, $P < 0.01$). There were also significant differences by season, by treatment, and by station (all $P < 0.001$). Spring E_h values were significantly higher than fall values. Dunn's pairwise comparison test showed significant differences ($P < 0.05$) between replanted and unplanted sites, and between replanted and reference sites; replanted marshes had significantly higher redox potentials than unplanted or reference marshes.

While the last finding suggests an effect of replanting status upon redox potentials, that pattern was not borne out by examination of E_h values by station. Dunn's pairwise comparison test demonstrated that high redox values for replanted marshes were driven largely by exceptionally high

values from Old Place Creek. Despite some very low values, Old Place Creek (replanted) had significantly higher median redox potential than Mill Creek (reference), Con Ed Tower (unplanted), and Saw Mill Creek South (unplanted) sites (all P <0.05), while redox potential values from Saw Mill Creek North, the other replanted site, were only significantly greater than Mill Creek (reference) values (P <0.05). The only other significant comparison was between the two marshes in the reference treatment group, Tufts Point and Mill Creek; Tufts Point had the higher values. Site was more influential than treatment.

The possible effect of replanting on patterns of seasonal shifts in redox potential (*i.e.*, treatment × seasonal effects) was also investigated. Seasonal changes in redox values from fall to spring included cases of significant increases, significant decreases, and no significant change. Statistical comparison of E_h data across seasons in the face of strong depth gradients was accomplished by performing Student's *t*-tests on mean data for the three depth zones (*i.e.*, 0 to -2 cm, -3 to -5 cm, and below -5 cm) suggested by the zonation patterns mentioned previously. The E_h values in 24 of the 72 site-depth zone combinations (33%) were significantly greater (more oxidized) in spring 1997 than in fall 1996 (P <0.05). This phenomenon occurred at all depths and at sites under all treatment regimes, including Con Ed Tower (unplanted), but not at all stations. Eight combinations (11%) had more oxidized conditions in the fall, including Old Place Creek (replanted) - Stations A and B , Con Ed Tower (unplanted) - Station C, and Saw Mill Creek South (unplanted) - Stations A and C. In terms of magnitude of significant changes, increases also predominated over decreases. Seasonal changes in redox potential were significantly larger where they increased ($|\Delta E_h|$ = 243±148 mV) from fall to spring than where they decreased ($|\Delta E_h|$ = 79±51 mV) during that interval (P = 0.005). However, with the largest number of station-depth zone combinations (32 of the 72, or 44%), no significant seasonal change in redox potential was found.

The stations with the most consistently reducing conditions between -3 and -10 cm despite the change of seasons were Saw Mill Creek South (unplanted) - Stations A and B and Mill Creek (reference) - Stations B and C. Values for soil measurements organized by depth zone, and the results of seasonal statistical comparisons, are summarized by station in Appendix Tables F1-F3. As with E_H values and profile shapes, seasonal redox changes did not sort into recognizable patterns by replanting status. Rather, patterns in seasonal change or lack thereof appear to be station specific.

Soluble Sulfide

Soluble sulfide was measured in 120 "peeper" water samples. As with the related E_h measurements, interstitial sulfide concentrations demonstrated distinct and fairly consistent patterns with respect to depth and season. Sulfide increased with depth (P <0.05) and was more abundant in fall 1996 than in spring 1997 at four of the six sites (Figures 29-31) The exceptions were Con Ed Tower (unplanted) and Tufts Point (reference).

At all stations within all sites, soluble sulfide concentrations above the soil surface were <2 μM, and were <80 μM within 3 cm of the sediment interface. With these data removed, site-to-site comparisons of sulfide showed significant differences (P <0.05), but treatment-to-treatment comparisons did not (*i.e.*, Kruskal-Wallis, one-way, ANOVA-on-ranks test). Below the 5-cm depth in fall, Old Place Creek - Station C (replanted) had concentrations exceeding the analytical limit of the analysis employed (≥3000 μM). Elsewhere, sulfide concentration approached this level only deeper than 14 cm in fall at Mill Creek - Station C (reference; 2700 μM) and at Saw Mill Creek South - Station D (unplanted; 2650 μM). In spring, values at Old Place Creek - Station A for all depths were <2 μM, while Old Place Creek - Station B contained 1250 μM below 14 cm in depth. Values at Saw Mill Creek North - Station C (also replanted) never exceeded 200 μM in fall, or 100 μM in spring. At the Con Ed Tower (unplanted) and especially Tufts Point (reference) sites, the concentration pattern seen elsewhere of high fall and low spring values was reversed. The most similar pairs of patterns did not share common replanting status: Saw Mill Creek South (unplanted) - Mill Creek (reference) (Figures 30B and 31B), and Con Ed Tower (unplanted) - Saw Mill Creek North (replanted) (Figures 30A and 29B).

Total Organic Carbon

Marked differences among TOC values for surface soils from the Arthur Kill sites showed a closer association with site identity than with replanting treatment status (Figure 32). Comparison of TOC values by site demonstrated significant differences (Kruskal-Wallis, one-way, ANOVA-on-ranks test; P <0.001). Pairwise comparison of sites showed all pairs except Tufts Point:Mill Creek (reference stations) to be significantly different (Student-Newman-Keuls test, P<0.05).

Apparent loss of TOC at Con Ed Tower over the September-to-May interval (Figure 32) was significantly greater (P <0.05) than at any other site. Indeed, most stations at other sites show small increases in TOC from September to May. Site-to-site differences in levels and seasonal patterns of organic matter content obscured any underlying pattern by replanting treatment.

Labile Carbon

The LC content of sediment surface samples from two stations at each site yielded no significant differences by treatment (P = 0.091) or by station (P = 0.152; Kruskal-Wallis, one-way, ANOVA-on-ranks test), although the highest mean values occurred at Con Ed Tower (Figure 33). Mean May

LC values correlated weakly, but significantly, with May values for %TOC ($r^2 = 0.413$; n = 12; $P = 0.024$).

The LC content of tidewater samples from all sites (Saw Mill Creek North and Saw Mill Creek South are combined due to proximity to one another) was remarkably uniform: 160±28 μM-C/cm^3 (mean ± standard deviation; n = 5). Standard deviations for replicate values from each site were within 10% of mean values for the same site except in the case of the Saw Mill Creek samples (standard deviation = 41% of mean).

Summary of Results

A brief summary of all of the biogeochemical data arranged by treatment, site, station, and season (Table 12) indicates the wide variation of values for median E_h, median sulfide concentration, and LC concentrations within sites and/or within treatments. Soil surface TOC was somewhat more consistent by site (*e.g.*, low values at Old Place Creek and high values at Con Ed Tower), but not between sites within treatment groups. Expected patterns of treatment-related values were nowhere evident.

Seasonal changes in E_h, median sulfide, and TOC values also illustrated no discernable patterns associated with replanting status.

DISCUSSION

The Arthur Kill provides a locus for the study of an urban gradient system, with unique opportunities to investigate spatio-temporal scales of ecological patterning, the roles of disturbance, and the integral role of humans in the larger ecology of the system (McDonnell and Pickett 1990). Anthropogenic effects include continuous waste discharge into the air and water, episodic pollution events, upland and shoreline alteration, channel dredging, and maritime traffic effects. While the Arthur Kill salt marshes have much in common with salt marshes in other locations, they have a unique character that results from the interaction of such influences with the natural system, as well as from a very deliberate attempt to maintain estuarine wetland systems along a heavily populated, industrialized, and trafficked urban waterway. Extremely high and low soil redox potentials in close proximity, extremely high soil OC levels, and reversals of normal seasonal trends in soil organic carbon were found co-existing with values and trends more typical of systems that are clearly fulfilling wetlands ecological functions, including the provision of fisheries habitat.

Spatio-temporal patterns of porewater redox potential, soluble sulfide, and OC in marsh soils did not correspond with replanting status alone. Statistically significant differences were found for these biogeochemical measures with depth and season. However, these differences were not meaningful for assessment of replanting success because they appeared to owe more to the peculiarities of individual stations than to any common characteristics of replanted, unplanted, and reference marshes, or the particular sites in question (Table 12). Furthermore, quantitative differences among station data within each site were so large, and distributions of values at those stations were so skewed, as to render statistical differences uninterpretable in terms of replanting. No patterns characteristic of replanted, unplanted, or reference marshes were identified, nor were characteristic differences among sites fitting these treatment categories evident. Redox potentials, soluble sulfide and organic levels, depth profile shapes, and seasonal patterns appeared to be mediated by smaller-scale gradients in factors not clearly related to replanting. Our stations and sites were heterogeneous with respect to these factors, likely confounding our efforts to identify replanting-specific effects. Among those likely confounding factors were differences in grain size distribution (see Table 2 for results of grain size analysis), differences in surface and subsurface hydrology, differences in macrobiotic activity, and anthropogenic influences.

Influence of Grain Size Distribution

One possible confounding factor that could explain some of the variation in biogeochemical characteristics is difference in grain size distribution (see Table 2 for results of grain size analysis). Osgood and Zieman (1993) and Osgood *et al.* (1995) found that sandy marsh sediments associated with newly-developed natural marshes in Virginia had higher redox potentials, lower interstitial sulfide concentrations, and lower organic content than older, siltier sites nearby. Similarly, it appears that the upper layers of sediment at Old Place Creek and probably also Con Ed Tower have been maintained in relatively "young" condition by exposure to strong currents and by wave action associated with wakes from large vessels. Air enters the interstices among the grains of rigid (incompressible) sandy deposits as water drains or evaporates away during low tide, promoting penetration of oxic conditions to the extent allowed by soil column drying. Soils composed largely of silt and clay compress (collapse) as they lose water, leaving no air-filled interstices. Such soils continue to have low permeability to oxygen during subaerial exposure despite water loss, allowing anaerobic conditions to persist during low tide. Soils of intermediate grain size composition exhibit partial compression. Indeed, compressibility has been found to be linearly correlated to silt-clay content (Bradley and Morris 1990b).

Sediments from Arthur Kill marshes span the gamut of textures represented in the compressibility vs. silt-clay content regression of Bradley and Morris (1990b). The high energy sediments at Old Place Creek (replanted) - Station A fall at the totally incompressible end of the relationship (compressibility = 0%). Assuming a rapid rate of lateral

drainage for this site as a result of proximity to a porous creekbank (Howes and Goehringer 1994), the presence of high redox potential well beneath the surface, the low organic content, and the lack of sulfide at this site are not surprising, even if the actual values of E_h (up to +450 mV) are beyond the maximum values generally reported for saltmarsh soils (*e.g.*, Howes *et al.* 1986; de la Cruz *et al.* 1989; Craft *et al.* 1991; Osgood and Zieman 1993; Osgood *et al.* 1995; Thompson *et al.* 1995; Ewing *et al.* 1997; Madureira *et al.* 1997).

All stations at Saw Mill Creek North, Saw Mill Creek South, Tufts Point, and Mill Creek, with the exception of Mill Creek - Station D, fit near the totally compressible end (compressibility = 89%) of the regression, which should result in low E_h and sulfide values beneath the surface layers. While this is true in many cases, paradoxically high E_h and low sulfide values at some of these sites (*e.g.*, Saw Mill Creek North - Station C in fall and Saw Mill Creek North - Station B in spring) must be the result of factors not associated with grain size distribution and its influence on compressibility and porosity. Predicted compressibility values for the remaining Old Place Creek and Mill Creek stations lie toward the incompressible end (Old Place Creek - Station B = 20%, Old Place Creek - Station C = 9%, Old Place Creek - Station D = 11%, and Mill Creek - Station D = 39%), and might thus be expected to have intermediate values of E_h, sulfide, and organic content. This is true of most OC content values at Old Place Creek (Station C in spring excepted), but not for Mill Creek - Station D, and not true regarding E_h or sulfide. Exceptionally low redox values (Old Place Creek - Stations B and C) and high sulfide levels (Old Place Creek - Station C) at these stations must again be attributed to factors other than grain size distribution.

While grain size determinations on Con Ed Tower sediments were not possible (see Chapter II, "Trace Metal Contaminants in Sediments and Ribbed-Mussels"), that site's exposed location along the Arthur Kill navigational channel suggests sandy/gravelly sediments similar to Old Place Creek - Station A, which fit with high redox potentials and low sulfide concentrations at Con Ed Tower - Station C in fall and Con Ed Tower - Stations A and D in spring. Although the TOC and LC methods used here did not allow us to distinguish between petroleum hydrocarbons and "natural" (*e.g.*, algal, root/rhizome, detrital, and microbiological) organic matter, extraordinarily high OC levels at Con Ed Tower undoubtedly resulted from high levels of residual petroleum hydrocarbons (see Chapter III, "Petroleum Hydrocarbons in Sediments and Ribbed-Mussels"), visible as a tarry crust.

Subsurface Hydrology

Air can enter saltmarsh soil as a result of water removal by means of lateral subsurface drainage, which is a dominant mechanism along creekbanks, and by evapotranspiration as mediated by *S. alterniflora* and other vascular plants (Howes *et al.* 1986). Indeed, lateral drainage is the more rapid process where conditions permit, and its rate increases with proximity to the nearest creekbank (Howes and Goehringer 1994).

A pattern of exceptionally high E_h values (> +350 mV) that increase with depth regardless of season was observed at two of the eight replanted stations: Old Place Creek - Station A and Saw Mill Creek North - Station B. This type of redox profile has not been reported from natural marshes, but has occurred in marsh soil that had been experimentally drained of interstitial water for an extended period (Portnoy and Valiela 1997). Old Place Creek - Station A and Saw Mill Creek North - Station B, unlike other stations at those sites, were evidently subject to very rapid drainage and air entry during low tide. We believe that these processes occurred because these stations were closer to creekbanks than the other stations, despite all of the stations being at the same intertidal elevation. In the case of Old Place Creek - Station A, rapid drainage was facilitated by a very coarse grain size distribution (*i.e.*, complete incompressibility). In the case of Saw Mill Creek North - Station B, it appears that drainage was promoted by the heavy riddling of the adjacent bank by fiddler crab burrows.

Surface Hydrology

Care was taken to ensure that each station was located at the same tidal height (*i.e.*, 0.2 m above mean sea level) so as to eliminate possible variations in biogeochemistry stemming from differing frequency and duration of tidal flooding that attend small differences in elevation (Cahoon and Reed 1995). However, our six stations were subject to differing wave and current regimes, and to differing surface water quality. Old Place Creek and Con Ed Tower were subject to the greatest wave and current energies (wind-, tide-, and vessel-driven), as indicated by the low silt/clay content of Old Place Creek sediments. Differences in silt/clay content among stations within Old Place Creek suggest hydrological differences on a scale of a few meters or less at that site, resulting in differences in deposition of detrital material that contributes to TOC and LC. Sediments at more sheltered sites (*e.g.*, Saw Mill Creek North and Saw Mill Creek South) have more uniform sediment textures and relatively less variable TOC values. Less uniformity at Tufts Point and Mill Creek suggest at least occasional episodes of higher energy, despite sheltered locations.

During 1998, there were also north-to-south gradients in average water quality measures in the Arthur Kill, including dissolved oxygen, inorganic nutrients, fecal coliform counts, and degree of water column stratification (NYCDEP 1998). Gradients in these or other unmeasured water quality parameters could result in biogeochemical differences among sites. Considering the high level of LC in the water adjacent to these sites, tidal inundation may dominate bio-

geochemical processes in this urban marsh complex, with the greatest effect being exerted in the north.

Macrobiotic Activity

Leaving aside those sites with heterogeneous sediment texture, the remaining sites -- based on their porewater E_h and soluble sulfide values -- demonstrated large differences among stations within site. Two elements of site macrobiota may be influencing these differences: saltmarsh cordgrass and burrowing crabs. At all vegetated sites except Con Ed Tower, the redox and sulfide profile differences may be attributable to highly localized variations in soil aeration associated with variations in density of *S. alterniflora* roots and rhizomes (Luther and Church 1988; Madureira *et al.* 1997), despite station-to-station similarity in above-ground biomass (C. Alderson *et al.*, Salt Marsh Restoration Team, Natural Resources Group, New York City Parks, 200 Nevada Ave., Staten Island, NY, unpubl. data). Soil aeration via diffusion from *S. alterniflora* roots may explain our frequent observation of higher redox values in spring as compared with fall in irregular, narrow depth bands (regions of maximum root density) at vegetated sites (see Figures 26-28), and as also reported elsewhere (Howes *et al.* 1981; de la Cruz *et al.* 1989).

The same kind of fall-spring redox increases at Con Ed Tower are not explainable in terms of cordgrass aeration; there was no cordgrass. We suspect that subsurface drainage of presumably incompressible, sandy sediments there was more evident during our spring visit than during our fall one, thus mimicking the redox behavior of vegetated sites.

Some sites (*i.e.*, Saw Mill Creek North and Tufts Point) were heavily populated by mixed populations of two fiddler crab species: the Atlantic marsh fiddler, *Uca pugnax*, and the redjointed fiddler, *U. minax*. Fiddler crabs contribute substantially to increasing E_h values and decreasing soluble sulfide along inner-marsh-to-creekbank gradients (Gardner *et al.* 1988). This effect is due to the increase in surface area (Katz 1980), and hence gas exchange (Montague 1981), promoted directly by the presence of the burrows, and indirectly by the increase in production of cordgrass (Bertness 1985) with its attendant increase in soil aeration potential. Close to the creekbank, we suspect an added effect due to a propensity for burrows to facilitate lateral drainage. These burrow effects are probably the cause of extremely variable E_h values at Saw Mill Creek North and Tufts Point, and of low soluble sulfide values at all Saw Mill Creek North stations and at Tufts Point - Station D in fall. Those low fall values at Tufts Point - Station D created an apparent reversal of the expected seasonal pattern of high fall - low spring values. Results might have been different had another Tufts Point station been utilized in September-October 1996. Lower densities of fiddler crabs at Saw Mill Creek South resulted in much less variable values of redox and soluble sulfide.

Anthropogenic Influences

Another confounding factor was continued anthropogenic impacts. The Arthur Kill marshes are receiving substantial and unequal organic matter subsidies (including petroleum hydrocarbons) as a result of their location on an urban waterway. This may be the cause of extremely low redox and high TOC values at Old Place Creek - Station C. Other authors have not reported E_h below -350 mV in saltmarsh soils (*e.g.*, Patrick and DeLaune 1977; Howes *et al.* 1981; Armstrong *et al.* 1985; de la Cruz *et al.* 1989; Bertness 1991; Osgood and Zieman 1993; Ewing *et al.* 1997; Madureira *et al.* 1997). Given the unique history of the site, extremely low redox values at Old Place Creek suggest pockets of very reduced organic material, probably petroleum of patchy spatial distribution. Indeed, the occasional odor of volatile petroleum components from soil at that site, and a single exceptional value for TOC at Old Place Creek - Station C in spring (*i.e.*, 8% among values ranging from 0.1% to 2.5%, and well above the maximum value predicted from grain sizes), support the existence of such pockets. We speculate that pockets of volatile hydrocarbons persisted at Old Place Creek because spill remnants there were buried soon after deposition, quite possibly by the replanting process itself. Burial prevented weathering, so volatile components persisted. By contrast, spilled petroleum left exposed at Con Ed Tower was heavily weathered, leaving only surficial tarry deposits that did not produce low redox values despite exceedingly high TOCs.

The very high TOC values (approaching 50%) at Con Ed Tower exceed the values (~25-40%) in even very peaty unaltered marsh soil in Massachusetts (Portnoy and Giblin 1997), and far exceed those reported from other saltmarsh soils (Williams *et al.* 1994). The refractory nature of the weathered petroleum that accounts for these high values at Con Ed Tower is evident in the comparison of LC at Con Ed Tower stations with that at other stations with far lower TOC values. While TOC values are as much as five times higher at Con Ed Tower than at other sites, LC values are only marginally higher than at most other sites, and are statistically indistinguishable from all of the other sites as a whole. Apparently, the excessive OC at Con Ed Tower cannot be metabolized readily by the microbiota, even under aerobic circumstances.

We found no evidence for persistent derangement of biogeochemical metabolic processes resulting from the 1990 oiling of the Arthur Kill marshes. Heterotrophic bacterial activity, and presumably biogeochemical function, in salt marshes can become highly disturbed by oiling (Vacelet *et al.* 1985). In particular, polycyclic aromatic hydrocarbons (PAHs) are known to inhibit sulfate reduction while stimulating methanogenesis, probably via elimination of substrate competition between sulfate-reducing and methanogenic bacteria (Keine and Capone 1984). If acute effects like these persisted as chronic conditions in the Arthur Kill marshes,

especially at Old Place Creek and Con Ed Tower, the result should be low E_h values associated with fermentative methane production but without sulfide production. Where such disturbances were expected to be minimal (*i.e.*, reference marshes), a loose correlation would therefore be expected between E_h and soluble sulfide, since sulfate reduction is a major metabolic process in sulfate-rich marine waters in contact with organic matter in the absence of molecular oxygen. Any disturbance in the E_h:sulfide relationship in other treatment groups or at other sites, as evidenced by significantly different regressions, would indicate an important shift in biogeochemical function. The relationships between soluble sulfide concentrations and mean E_h in the Arthur Kill salt marshes were logarithmic, as anticipated from the Nernst equation (Figure 34). All regressions by treatment were significant ($P < 0.003$).

Analysis of covariance with these three regressions demonstrated no significant difference ($P = 0.52$) in the relationship when data were plotted by treatment. Neither did the six regressions calculated by station demonstrate any significant difference ($P = 0.68$). Thus, no persistent disturbance was evident in the E_h:sulfide relationship associated with replanting status or stations, providing no evidence for inhibition of sulfate reduction. Indeed, the higher soluble sulfide levels in the Arthur Kill marshes (3+ mM) were toward the high end of values reported for saltmarsh soil interstitial water, but within values (approaching 6 mM) reported for Massachusetts (Teal and Howes 1996). Sufficient data were not available for analysis of relationships grouped by individual stations.

While we found no metabolic disturbance attributable to oiling, the gross composition of sediments at some unplanted and replanted sites was measurably different from that of all of the other sites. Extraordinarily high TOC values resulted from petroleum residues. The OC at Con Ed Tower, and possibly at Old Place Creek - Station C, presumably residual petroleum at least in part, was not subject to the same deposition, sorting, retention, and loss processes as elsewhere. When plotted against percent silt/clay content, most %TOC values fell below the line defined by the equation, %TOC = 0.20 × %silt/clay, which is roughly consistent with the positions of most Old Place Creek and spring Mill Creek values (Figure 35). The data from Old Place Creek and Mill Creek (spring only) were chosen for regression to represent a "maximum biogenic TOC limit," because they were from stations exhibiting high TOC over a wide range of grain size distributions, and from sites that were not visibly tarry. The Old Place Creek - Station C spring value, which has more than twice the predicted TOC content, is an exception to this scheme. The TOC values for Con Ed Tower were also beyond predictions. While Con Ed Tower values were not plotted due to the inability to perform grain size analysis, the %TOC for Con Ed Tower - Stations A, B, and D in fall and Station A in spring (35-49%) was 10-24% beyond the predicted maximum of 25% for pure silt/clay sediments. The TOC values (8-16%) for the remaining Con Ed Tower station-date combinations suggest either substantial silt content, or sandy sediments with values exceeding predictions.

Hydrocarbon contamination of salt marshes decreases naturally over time, as demonstrated by long-term monitoring of the Ile Grande marsh damaged by the *Amoco Cadiz* spill in 1978 (Mille *et al.* 1998). Recent laboratory investigations have indeed suggested that bacterial community structure in oil-contaminated saltmarsh soil returns toward that of uncontaminated soil as oil components are degraded (Bachoon 1999), suggesting a concomitant restoration of biogeochemical function. Paradoxically, the urban environs of the Arthur Kill marshes may have aided this recovery of soil microbiological function. Fertilization of oil-contaminated saltmarsh soil with inorganic nitrogen has been shown to accelerate the bacterial metabolism of alkane and PAH fractions (Jackson and Pardue 1999), as well as to directly stimulate growth of *S. alterniflora* (Lin and Mendelssohn 1998). High nutrient levels associated with urban discharges may well have aided these processes in this case. Average dissolved inorganic nitrogen (*i.e.*, ammonium + nitrate + nitrite) for the waters of the northern end of the Arthur Kill during the summer of 1998 was in the range of 72-89 µg-at/L, and total phosphorus for the same area and time was in the range of 7-10 µg-at/L (NYCDEP 1998).

CONCLUSIONS

Had confounding factors not been active, we still might have had difficulty detecting clear differences in marsh biogeochemistry attributable to the replanting efforts. We believe that previous investigators readily found such distinctions because the soils in their restoration sites were not originally marsh soils with previous exposure to regular tidal inundation (*e.g.*, Craft *et al.* 1991; Thompson *et al.* 1995). At our Arthur Kill sites, by contrast, restoration was attempted by replanting *S. alterniflora* in formerly vegetated marsh soil which had been, and continued to be, exposed to regular tidal inundation (*i.e.*, without hydrological regime alteration).

While it may require years for nonmarsh soils to attain the organic content and other biogeochemical characteristics of natural marsh soil, we propose that it also requires years for marsh soil to lose its organic content, corresponding redox and sulfide profiles, and perhaps other biogeochemical properties if the hydrological regime remains unaltered. Our data suggest that Arthur Kill soils have retained their biogeochemical characteristics for several years despite oiling damage and subsequent periods of barrenness. This, in part, may explain why replanting has been extraordinarily successful in re-establishing vegetation in oil-damaged salt marshes in this location.

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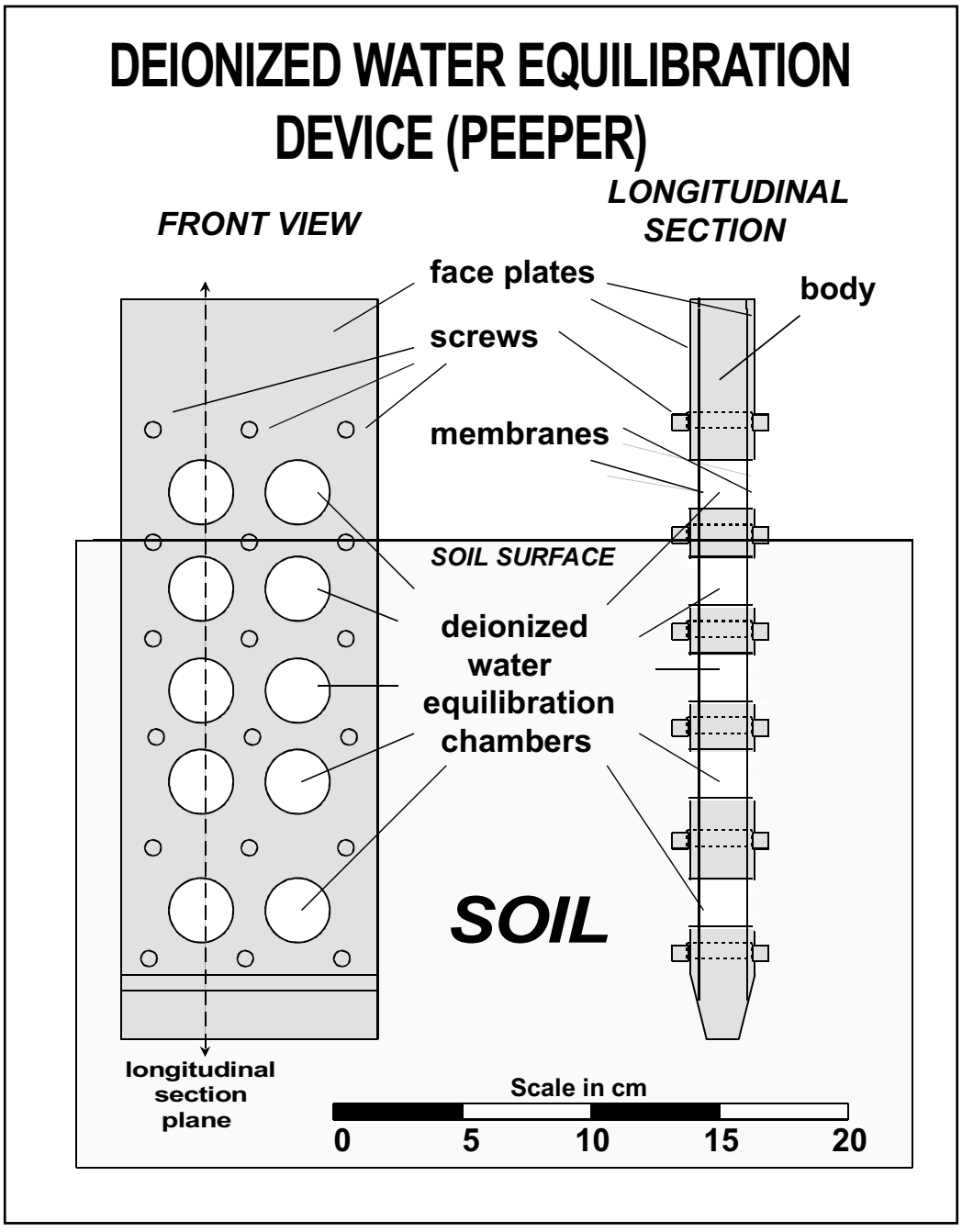

Figure 25. Diagramatic view of DIW equilibration device (peeper) in soil.

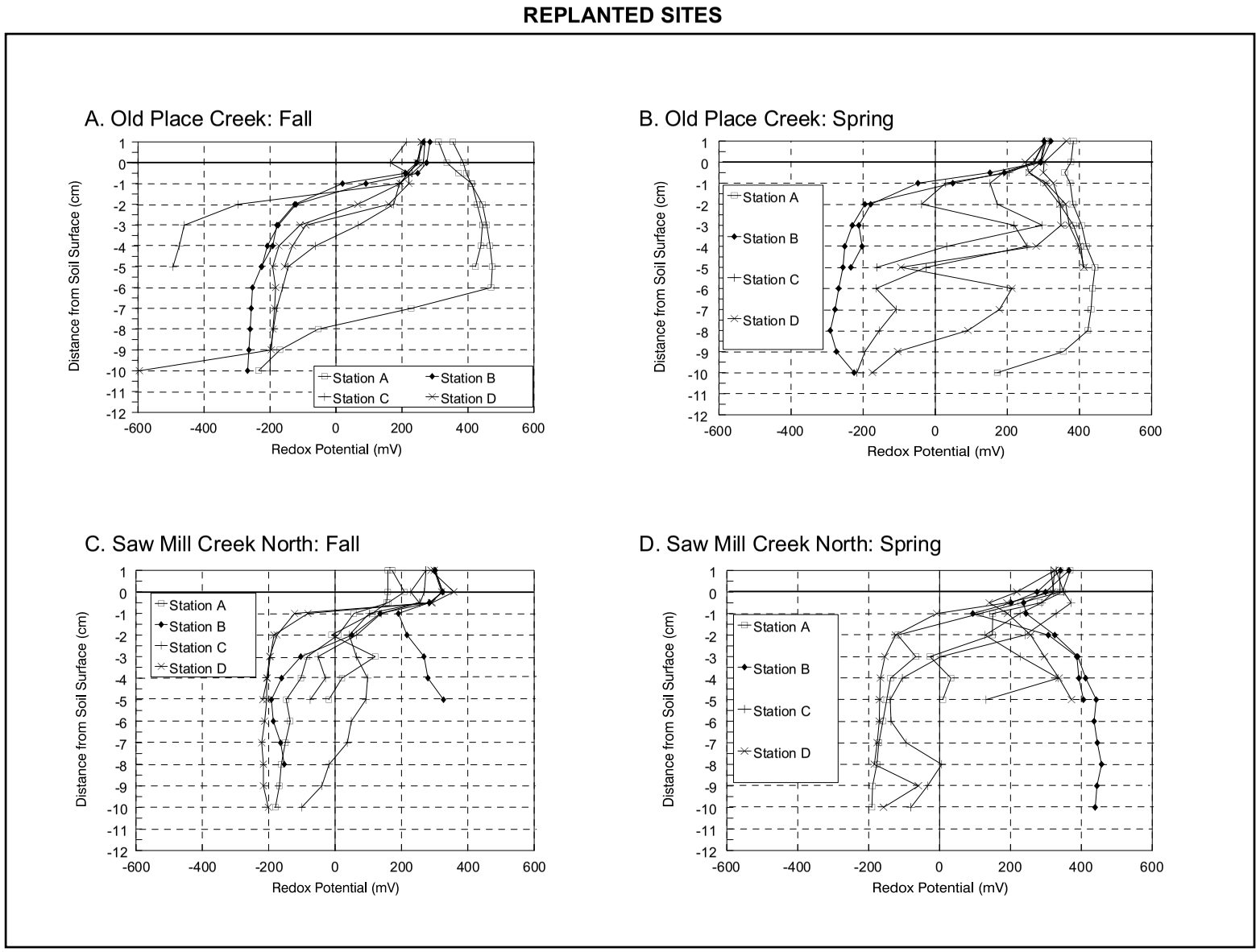

Figure 26. Depth profiles of redox potential (E_h) for stations at replanted marsh sites in fall 1996 and spring 1997, including duplicate (short) profiles for each station.

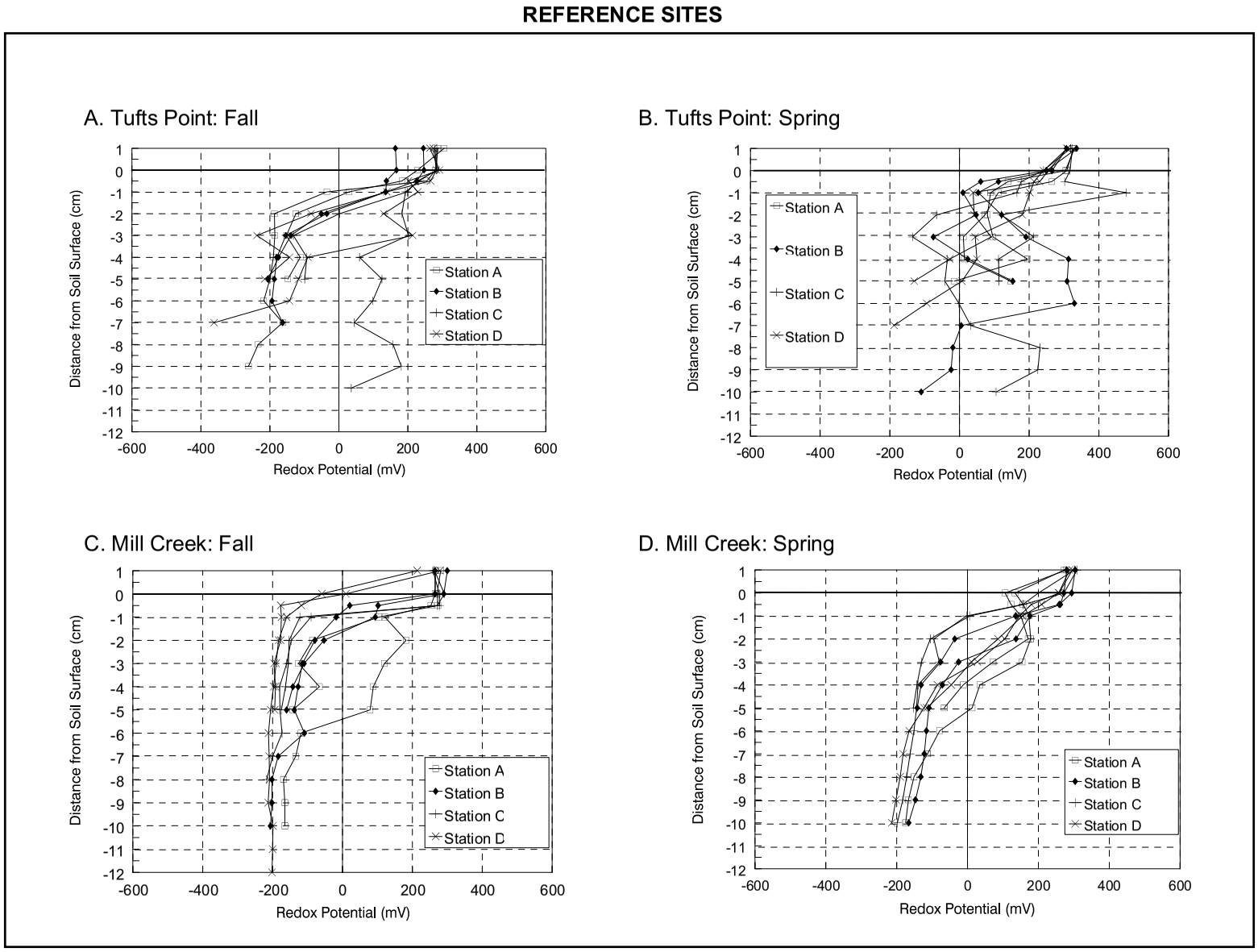

Figure 27. Depth profiles of redox potential (E_h) for stations at reference marsh sites in fall 1996 and spring 1997, including duplicate (short) profiles for each station.

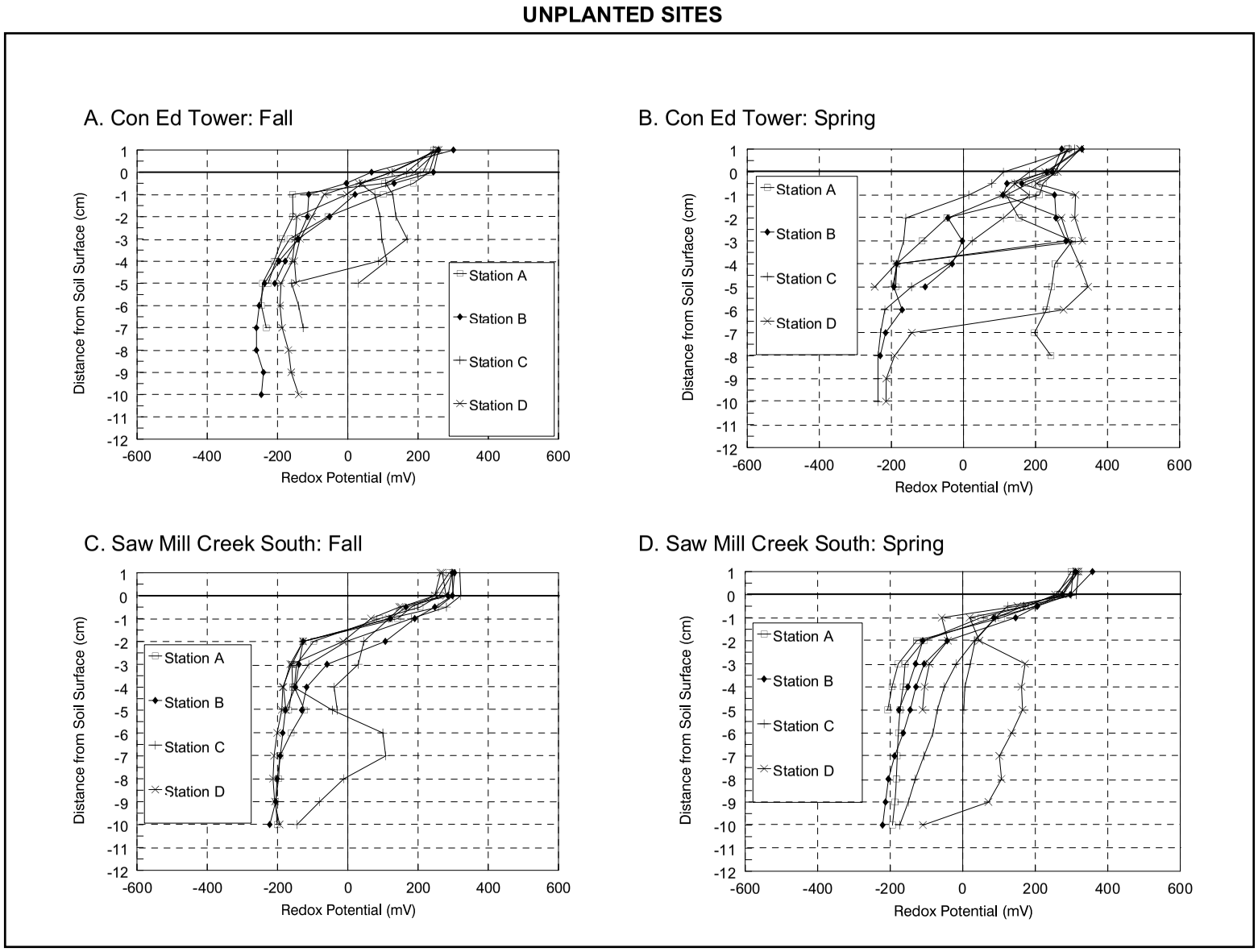

Figure 28. Depth profiles of redox potential (E_h) for stations at unplanted marsh sites in fall 1996 and spring 1997, including duplicate (short) profiles for each station.

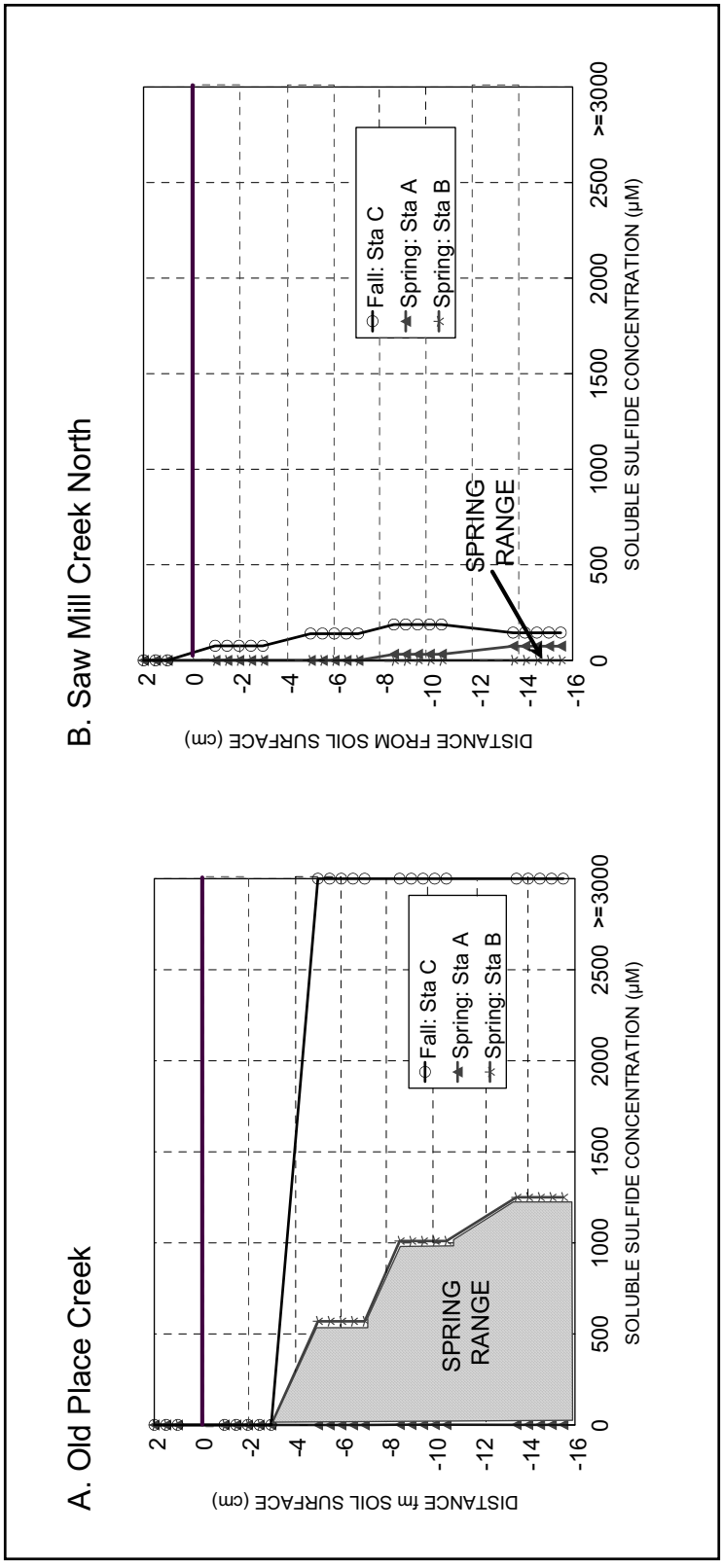

Figure 29. Seasonal patterns in interstitial soluble sulfide from replanted marsh stations.

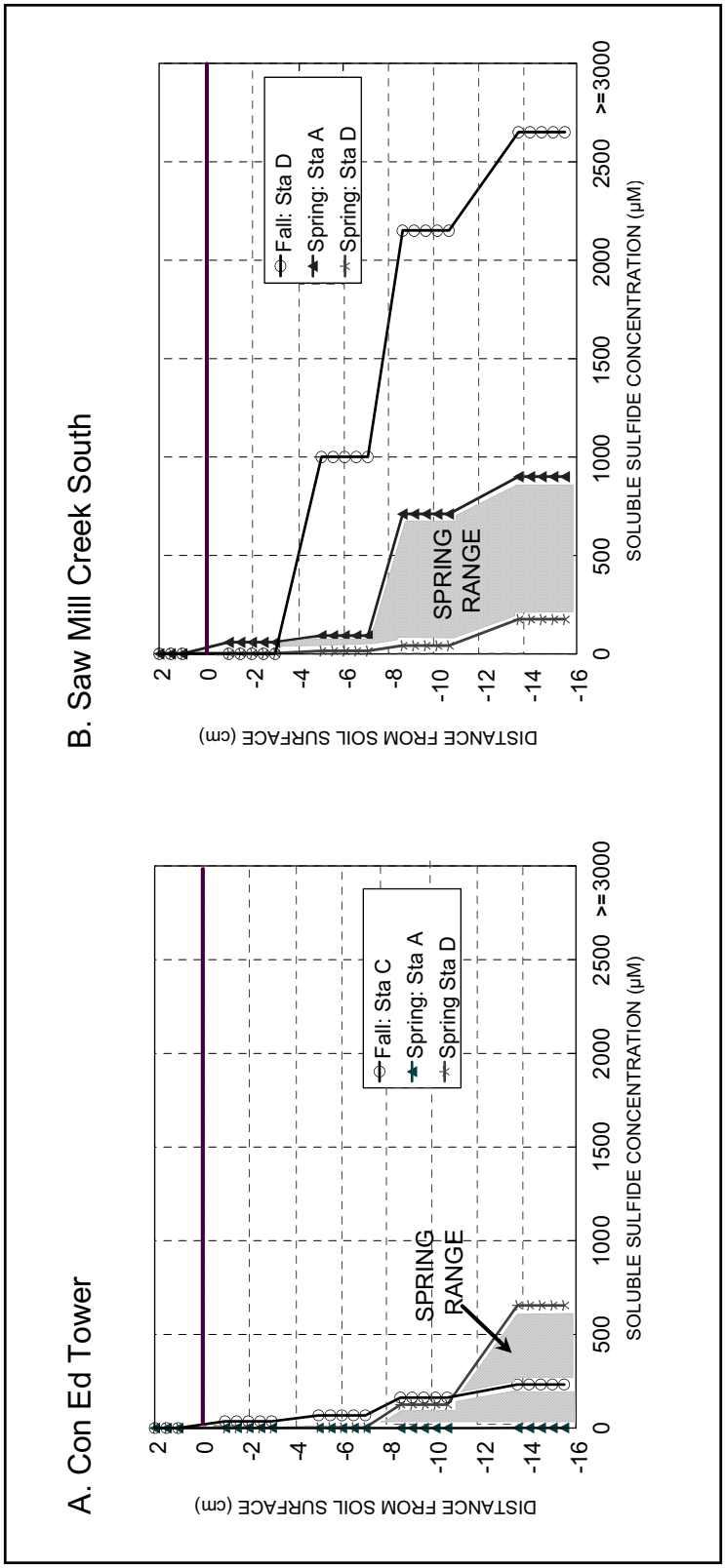

Figure 30. Seasonal patterns in interstitial soluble sulfide from unplanted marsh stations.

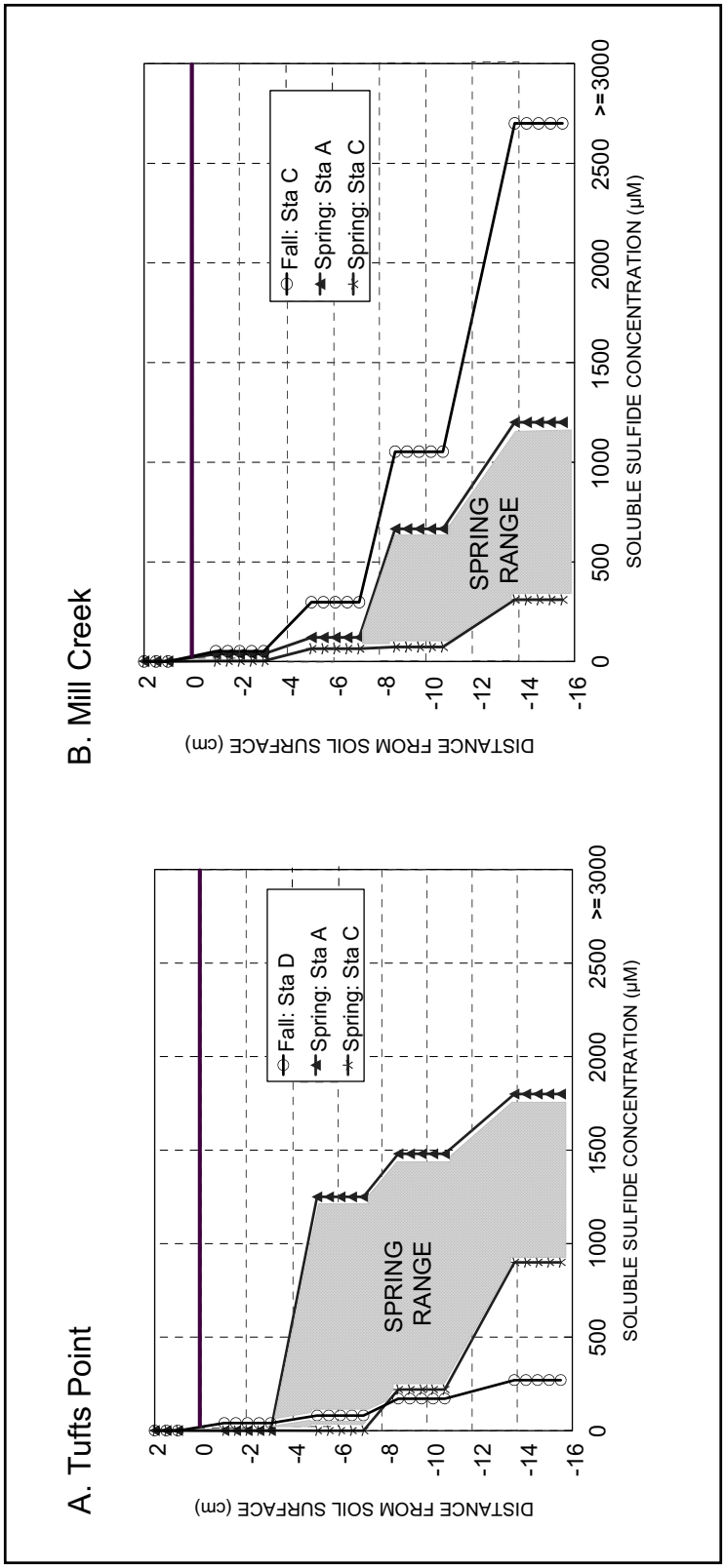

Figure 31. Seasonal patterns in interstitial soluble sulfide from reference marsh stations.

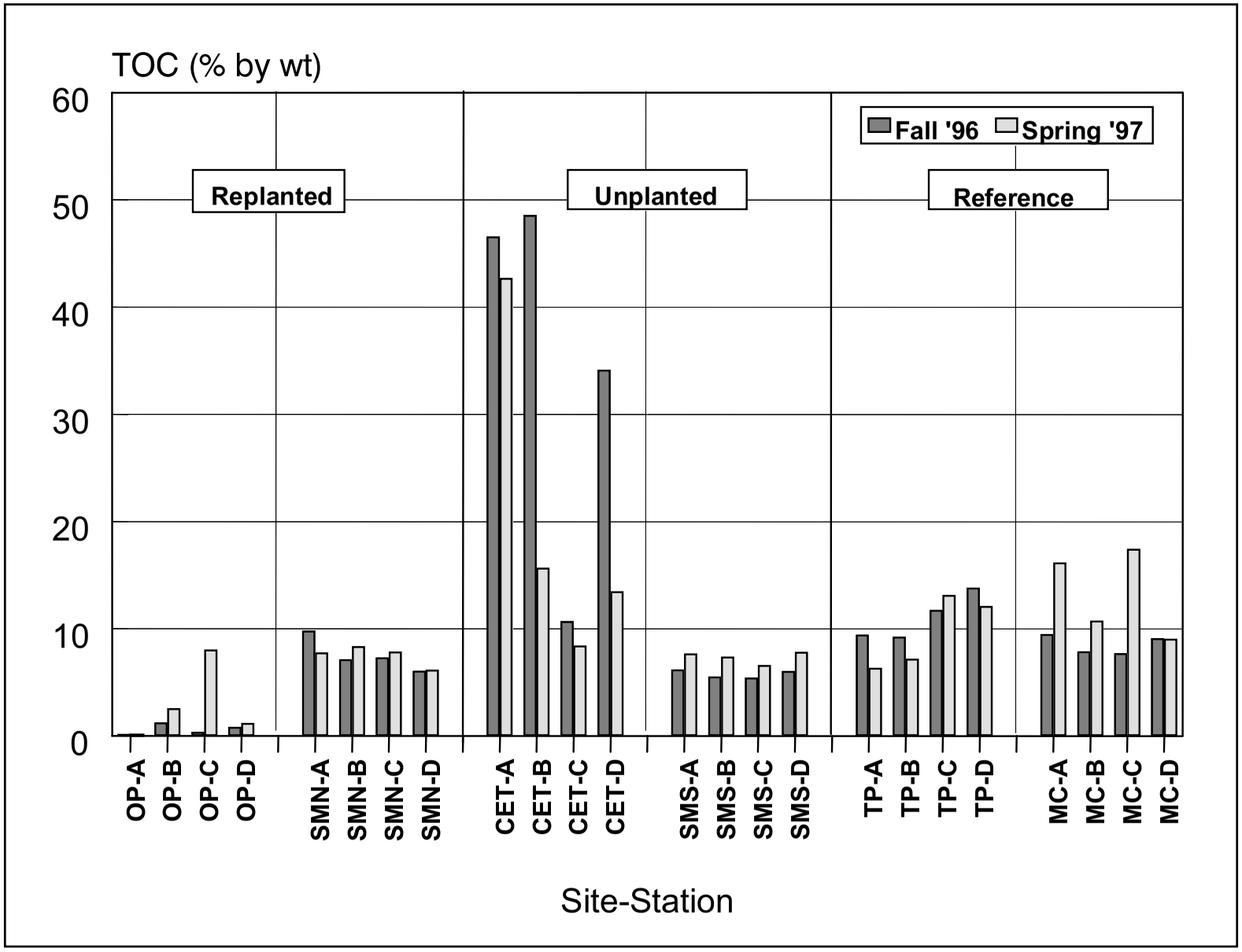

Figure 32. Seasonal values of TOC in surface sediments arranged by station, site, and replanting treatment. (CET = Con Ed Tower; MC = Mill Creek; OP = Old Place Creek; SMN = Saw Mill Creek North; SMS = Saw Mill Creek South; and TP = Tufts Point.)

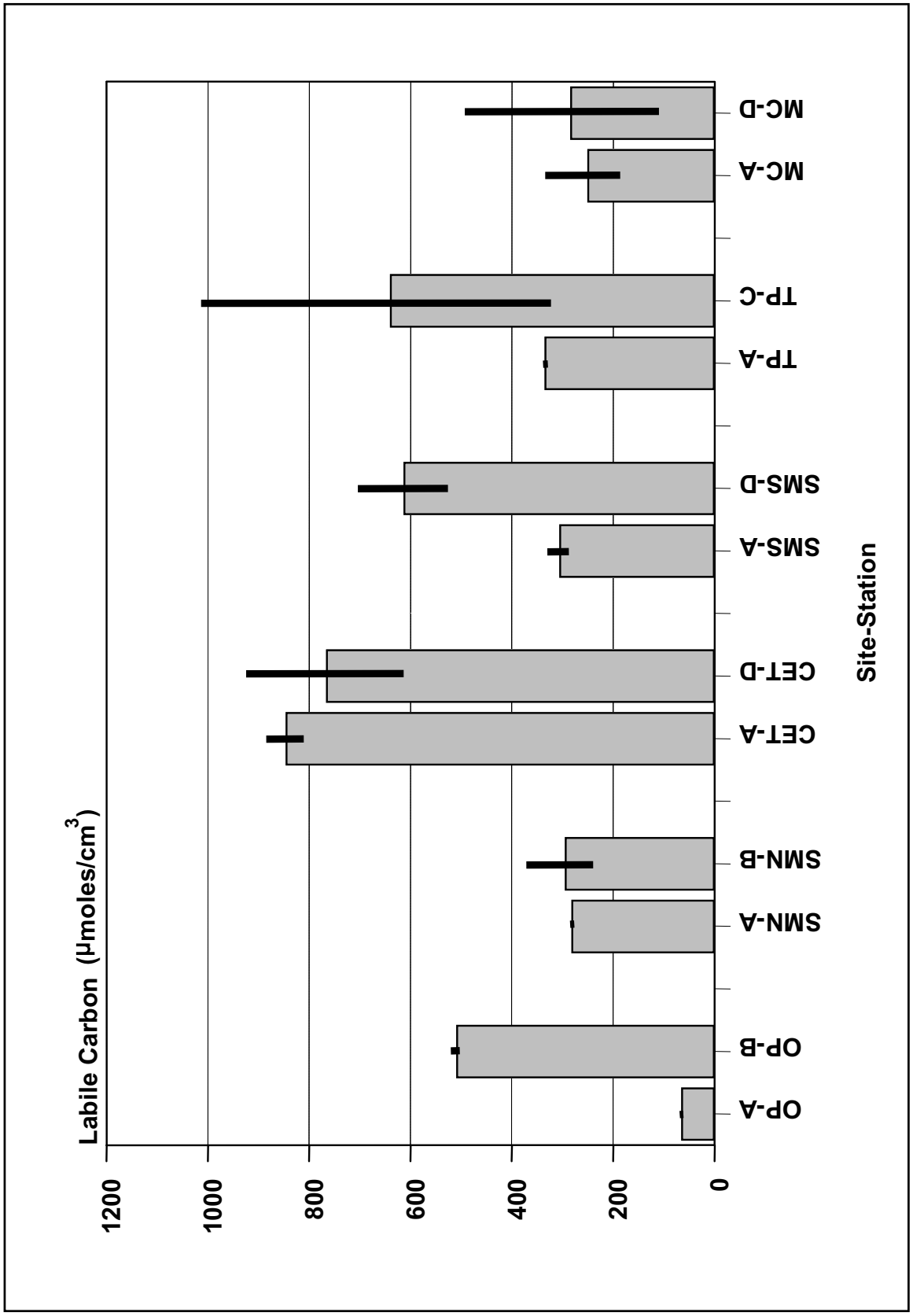

Figure 33. Mean LC in surface sediments taken from two stations per site in May 1998. (Error bars = ±1 standard deviation (n = 2). CET = Con Ed Tower; MC = Mill Creek; OP = Old Place Creek; SMN = Saw Mill Creek North; SMS = Saw Mill Creek South; and TP = Tufts Point.)

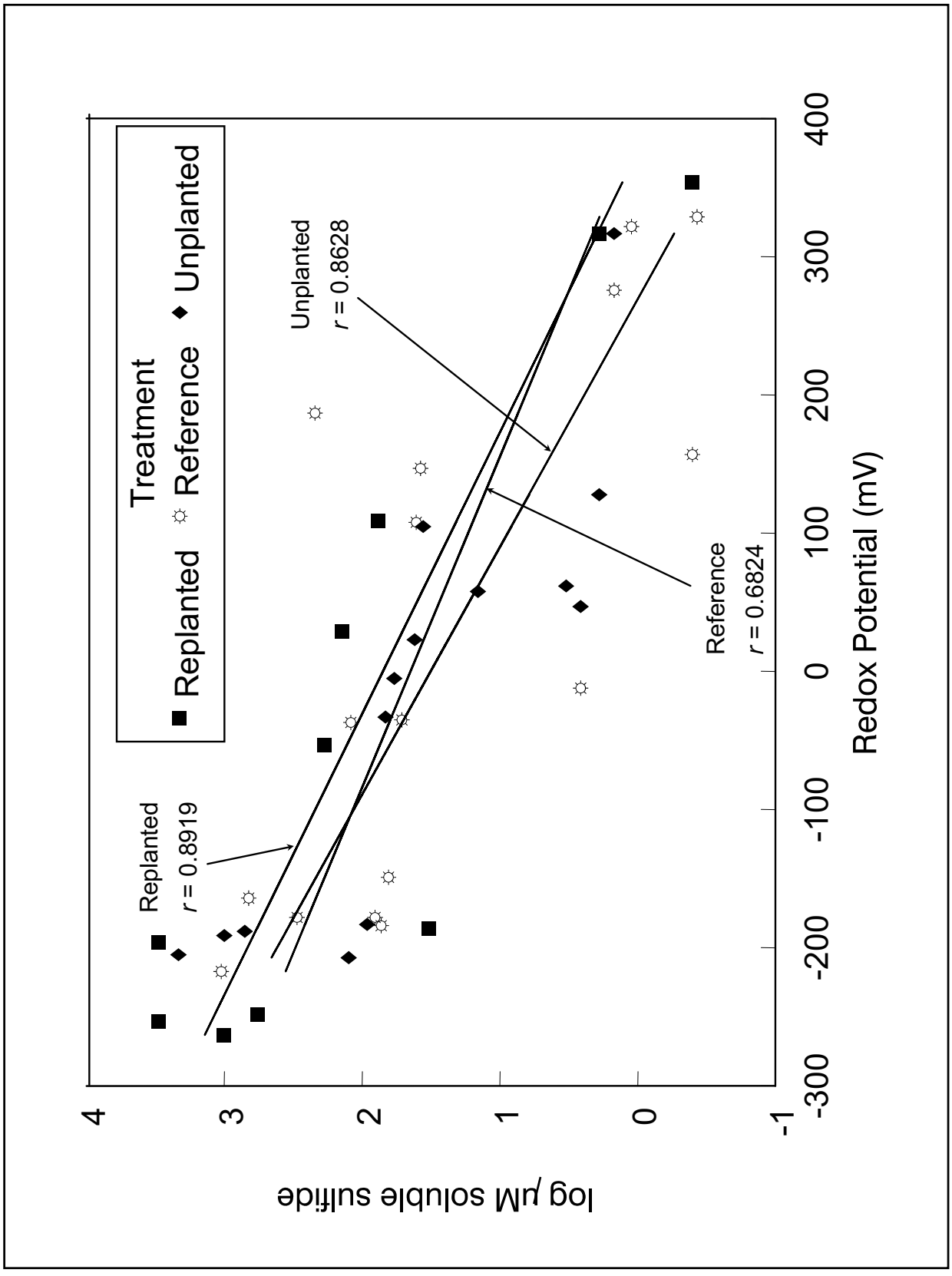

Figure 34. Log_{10} soluble sulfide (in mM) plotted against mean redox potential (E_h in mV) for all nonzero sulfide values grouped by marsh replanting status.

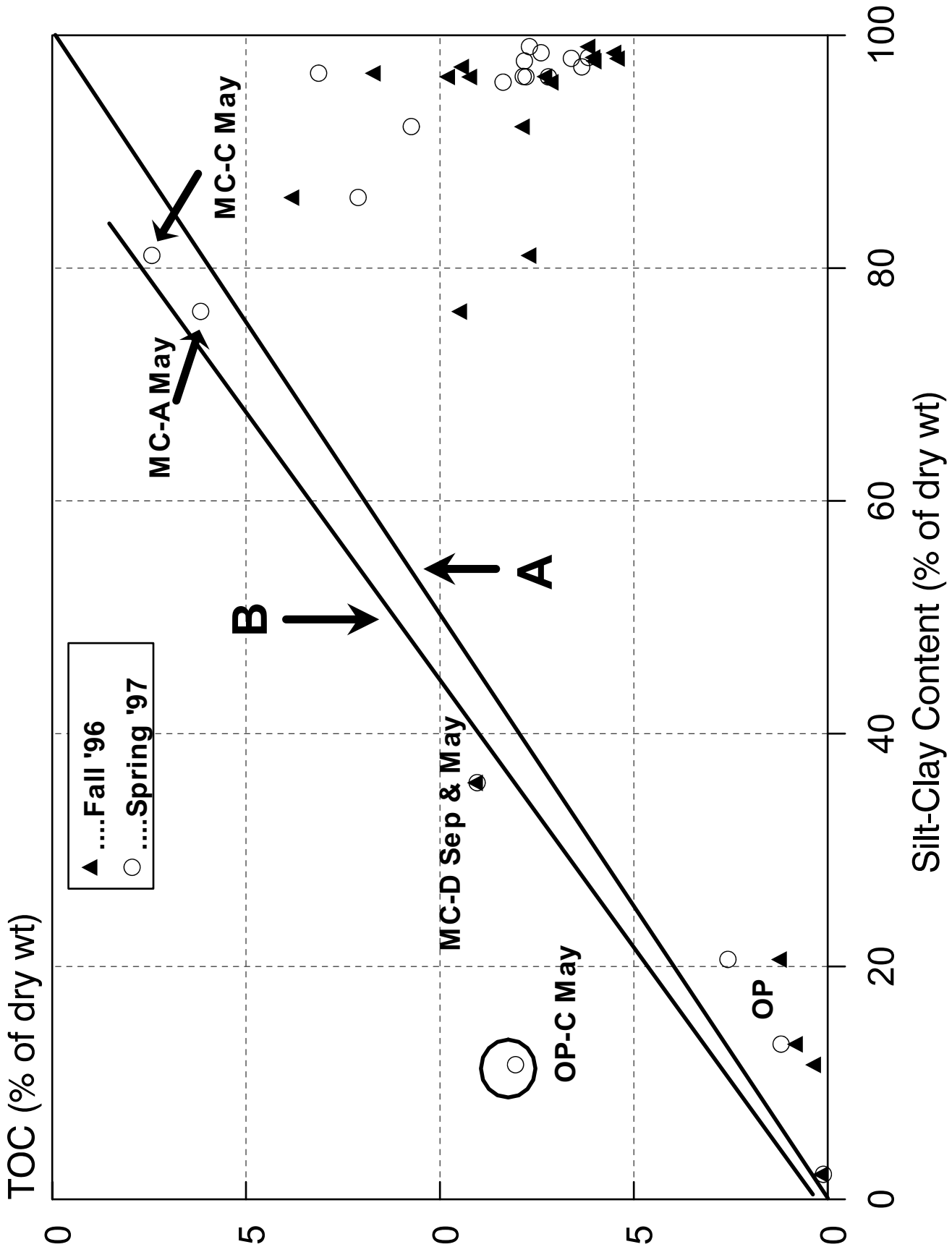

Figure 35. Relationship between sediment surface TOC and silt/clay content. (*A* = reference line defined by equation, %TOC = 0.20 × %silt/clay; *B* = regression of Old Place Creek data -- both spring and fall -- and Mill Creek spring data; OP = Old Place Creek; and MC = Mill Creek. Old Place Creek - Station C in May (circled) lies outside of the zone delineated by all other Old Place Creek station-season combinations. Con Ed Tower data are not plotted due to lack of grain size data. Grain size data are from Chapter II, "Trace Metal Contaminants in Sediments and Ribbed-Mussels.")

Table 12. Arthur Kill marsh biogeochemistry by treatment, site, station, and season

Treatment	Site	Station	Biogeochemical Factor: Median E_h (mV) Fall	Median E_h (mV) Spring	Median Sulfide (µM) Fall	Median Sulfide (µM) Spring	Surface TOC (% of dry wt.) Fall	Surface TOC (% of dry wt.) Spring	Surface LC (µM/cm^3) Spring
Replanted	Old Place Creek	A	+410	+382		0	0.18	0.11	65
		B	-175	-203		570	1.25	2.57	509
		C	-63	+152	>3000		0.37	8.05	
		D	-91	+302			0.84	1.20	
	Saw Mill Creek North	A	+9	+9		0	9.81	7.78	282
		B	+217	+387		0	7.13	8.37	295
		C	+65	+227	140		7.30	7.85	
		D	-195	+191			6.06	6.17	
Unplanted	Con Ed Tower	A	-157	+221		0	45.58	42.72	846
		B	-141	+110			48.59	15.69	
		C	+103	-39	68		10.69	8.41	
		D	-140	+262		3	34.15	13.47	767
	Saw Mill Creek South	A	-127	-159		92	6.19	7.69	306
		B	-117	-110			5.52	7.39	
		C	+46	+21			5.43	6.61	
		D	-160	+107	1000	14	6.01	7.82	613
Reference	Tufts Point	A	-137	+125		1250	9.45	6.34	335
		B	-43	+112			9.24	7.20	
		C	+181	+165		1	11.73	13.13	640
		D	+135	+71	81		13.81	12.11	
	Mill Creek	A	+88	+106		121	9.50	16.17	251
		B	-109	-36			7.88	10.74	
		C	-153	-105	820	90	7.71	17.43	
		D	-190	+28			9.09	9.04	284

V. AGE, GROWTH, AND ALLOMETRIC RELATIONSHIPS OF RIBBED-MUSSELS (*Geukensia demissa*)

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INTRODUCTION

The ribbed-mussel is a dominant species in tidal salt marshes of the eastern United States. This bivalve mollusk attaches by byssal threads to the stems and roots of *S. alterniflora* and other substrates, and is usually most abundant within the tall *S. alterniflora* along the marsh edge (Bertness 1984). The ribbed-mussel enhances the survival of *S. alterniflora* by binding the root mat together, effectively stabilizing the substrate and strengthening the plant and the entire marsh against erosion (Bertness 1984). The ribbed-mussel also plays a major role in the food web and in the cycling of carbon, nutrients, and minerals through the saltmarsh ecosystem. This bivalve is a filter feeder on phytoplankton and suspended detritus (much of which is dead *S. alterniflora*), and a considerable amount of its fecal matter is deposited on the marsh surface. The ribbed-mussel is preyed upon by blue crabs (*Callinectes sapidus*), other crustaceans, gastropods, and birds (Bertness 1980, 1984).

Since ribbed-mussels are important in the ecology of tidal salt marshes, site-specific differences in abundance, biomass, age structure, growth rate, and the allometric relationships of ribbed-mussel populations can be explored as indicators of the success of marsh replanting. Sampling problems and restrictions, however, prevented us from quantitatively sampling the populations of ribbed-mussels at our replanted, unplanted, and reference sites in the Arthur Kill. We will therefore restrict data presentation and analysis to descriptive comparisons of several variables based on measurements of mussels taken from each site.

METHODS AND MATERIALS

A preferred method to sample ribbed-mussel populations quantitatively is to place quadrats of known dimensions randomly at similar tidal heights within the *S. alterniflora* zone at each site (Bertness 1980). The mussels are then destructively removed from each quadrat for enumeration and measurement. This sampling protocol could not be implemented in this study. We were not allowed to destructively sample directly in the replanted areas with the magnitude required to obtain quantitative samples of the mussel population. Mussels were also needed for determination of trace metals and hydrocarbon concentrations in the mussel meats (see "Methods" in Chapters II, "Trace Metal Contaminants in Sediments and Ribbed-Mussels," and III, "Petroleum Hydrocarbons in Sediments and Ribbed-Mussels). To minimize damage to the replanted marsh sites and also to the unplanted and reference sites in the already impacted Arthur Kill, we attempted to make a single mussel collection at each site based on the sampling protocols needed for contaminant analysis of mussels. The mussel shells would be used for age and growth determinations, and the mussel meats would be used for contaminant analyses. This attempt failed to yield adequate numbers of mussels and it was necessary to make another collection for the age-and-growth portion of the study.

A minimum of 60 ribbed-mussels were randomly collected at each of the six sites during September 1996. At the reference sites, dense aggregations of mussels were found within a narrow area in the *S. alterniflora* zone. At the unplanted sites, mussels were sparse and had to be collected from both vegetated and unvegetated locations over a much larger area of the marsh and undoubtedly from different tidal levels. At the replanted sites, sampling was restricted to areas within the replanted zone, but away from permanent quadrats set up by SMRT to monitor the *S. alterniflora*.

In the laboratory, the sediment, epiphytes, and byssal threads were removed from each shell, the mussel was opened, and its tissue was removed. Dry weights for both shell and tissue were determined after drying to a constant weight at 60°C. After weighing, each mussel was measured with vernier calipers to determine shell length (maximum anterior-posterior dimension), width (maximum lateral dimension), and height (maximum dorsal-ventral dimension). Each mussel was aged by counting external growth rings (annuli). Length at age was determined by measuring the maximum anterior-posterior dimension at each annulus.

RESULTS

The information presented below summarizes the measurements made on mussels collected from each site. Since

sampling was not quantitative, rigorous statistical comparisons among the sites were not performed.

The collections yielded 64 mussels at Old Place Creek, 60 at Saw Mill Creek North, 67 at Saw Mill Creek South, 53 at Con Ed Tower, 92 at Tufts Point, and 69 at Mill Creek. Age-frequency histograms (Figure 36) indicated that the distributions of ribbed-mussels from Old Place Creek and Saw Mill Creek North (replanted) were skewed toward younger individuals, while the distributions of mussels from Saw Mill Creek South (unplanted) and Mill Creek (reference) were more evenly distributed among age classes. Length-frequency histograms (Figure 37) indicated that Saw Mill Creek South (unplanted) and Mill Creek (reference) had larger individuals (up to 100 mm) compared to the other sites, and that the distributions of mussels from Con Ed Tower (unplanted) and Mill Creek (reference) were skewed toward larger individuals.

To reduce the variability associated with year-class differences when summarizing data on average shell dimensions, shell weight, meat weight, and allometric relationships, and when estimating growth rates, we only summarized data for individuals that were in the same age class. Based on the number of individuals in each age class at each site (Figure 36), we chose to compare separately these measures for the 2-, 3-, and 4-yr-old mussels.

For each age class, the average shell length, width, and height, shell weight, and body weight were greater at Mill Creek (reference) than at any other site (Table 13). Mussels from Mill Creek (reference) had the highest growth rates in all three age classes, while mussels from Saw Mill Creek North (replanted) had virtually the lowest growth rates in those age classes (Figure 38).

Although differences detected in the absolute growth of ribbed-mussels among sites may be due to the influence on growth of site-specific environmental factors, allometric growth measures may or may not reflect these same differences (Seed 1980). Two-, three-, and four-year-old mussels collected from Mill Creek consistently had higher body-weight-to-shell-weight ratios compared to Old Place Creek (Table 13). No large differences among sites were found in the other allometric ratios.

DISCUSSION

We will limit our discussion to a descriptive comparison of the mussel data from the two replanted sites, Old Place Creek and Saw Mill Creek North, and from the reference site, Mill Creek. Since all mussels from these three sites were collected within the *S. alterniflora* zone, there is a greater possibility that differences found in mussel measures indicate actual differences among these sites. There is less confidence that the data from mussels collected at Con Ed Tower and Saw Mill Creek South (both unplanted sites) accurately describe differences either between these sites or among all sites. At Con Ed Tower and Saw Mill Creek South, mussels were sampled over a wide tidal area that included both vegetated and unvegetated habitats. Tufts Point is not discussed because, although it is a reference site, it was affected to some degree by the oil spill; in certain areas, marsh grasses and mussels were destroyed, while in adjacent areas, there was no apparent effect.

The smaller, younger mussels collected at the replanted sites reflect life cycle and growth processes since the disturbance caused by the replanting procedures in 1992 and 1993. The older, larger mussels at Mill Creek (reference) represent cumulative life cycle processes over many generations at a site presumably unaffected by this particular oil spill.

Two-, three-, and four-year-old mussels from Mill Creek (reference) grew faster than same-age mussels at the two replanted sites. The slower growth rates at the replanted sites could be due to the longer-term effects of the oil spill, the disturbance caused by the replanting process, and/or the stage of maturity of the replanted marsh compared to the reference marsh. Other site-specific factors, ultimately controlled by differences in physical factors, may have also influenced growth rates. Other studies have attributed among-site variability in growth rates of ribbed-mussels to differences in shore level, temperature, salinity, current exposure, quantity and quality of food resources, and stress from contaminants (Seed 1980; Bertness 1984; Franz 1993; Franz and Tanacredi 1993). There are site-specific differences in current exposure, salinity, etc., in the Arthur Kill (C. Alderson *et al.*, Salt Marsh Restoration Team, Natural Resources Group, New York City Parks, 200 Nevada Ave., Staten Island, NY, unpubl. data) but it is unknown to what extent, if any, these factors may have influenced growth rates of the ribbed-mussels compared to the effects of replanting.

Consistent with differences found in growth rates between the reference and replanted sites, mussels from Mill Creek (reference) were larger and weighed more than the same-age mussels at the planted sites. The lower meat-weight-to-shell-weight ratio found in mussels at Old Place Creek (replanted) compared to Mill Creek (reference) could be due to differences in stress levels among the sites that may cause mussels to differentially secrete and dissolve shell material related to weight fluctuations (Bertness 1984; Franz 1993).

Shell-shape allometric ratios do not appear to be sensitive measures of differences among marsh sites in the Arthur Kill, despite differences found in growth rates and overall size of ribbed-mussels at our sites. Similar results were reported by Bertness (1984) for three different sites along the Maryland coast, and by Franz (1993) in relationships at two shore levels in Jamaica Bay, New York.

The assessment of replanting success at sites in the Arthur Kill using measures of ribbed-mussel age structure, size-and-shape relationships, and growth rates was prob-

lematic due to sampling difficulties, and was confounded by site-specific differences in environmental factors. Depressed growth rates and sizes in mussels of the same age may be typical of the northern reaches of the Arthur Kill [Old Place Creek and Saw Mill Creek North (replanted)] compared to the southern areas [Mill Creek (reference)].

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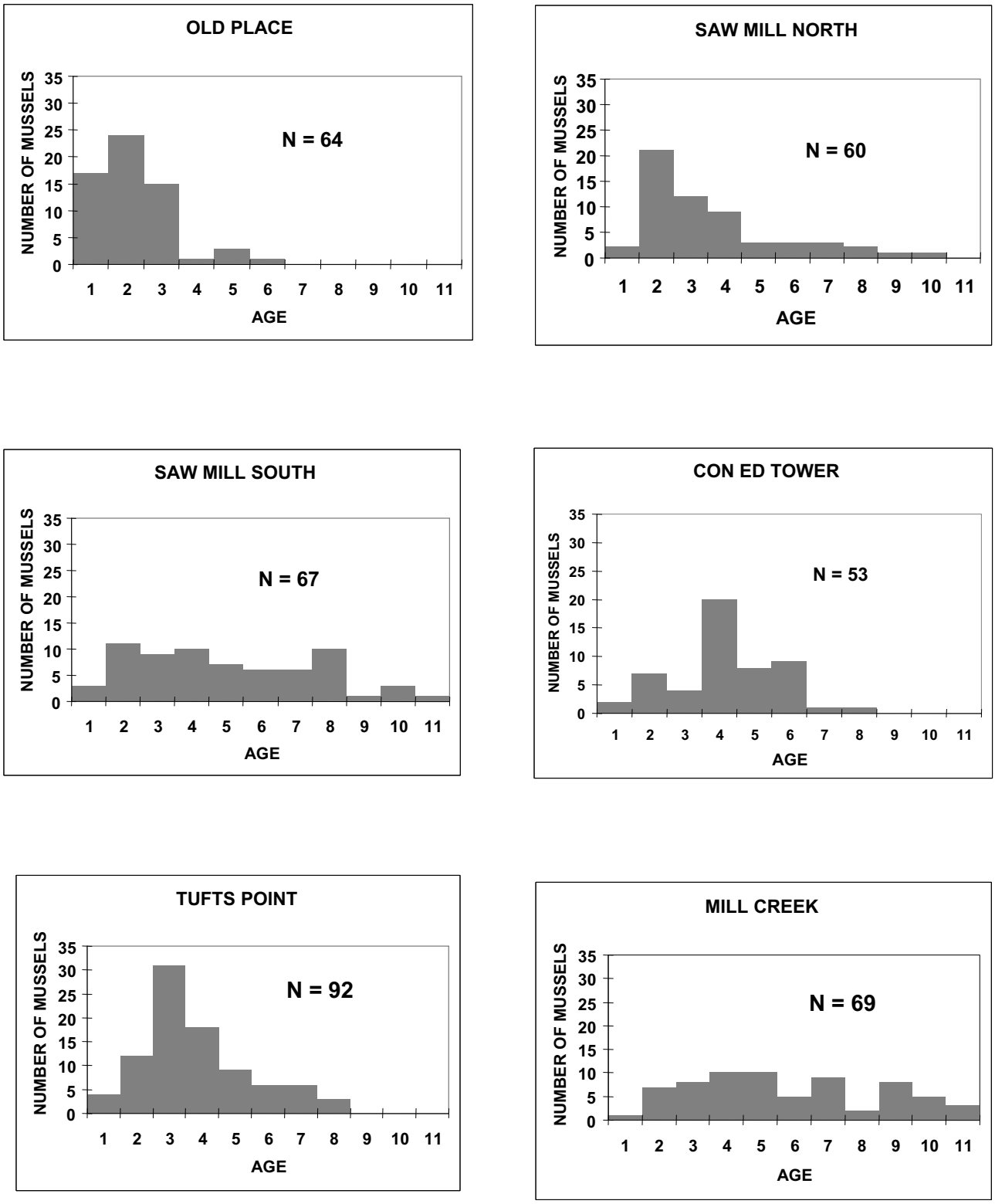


Figure 36. Age-frequency distribution of ribbed-mussels collected at Old Place Creek and Saw Mill Creek North (replanted), Saw Mill Creek South and Con Ed Tower (unplanted), and Tufts Point and Mill Creek (reference) in September 1996.

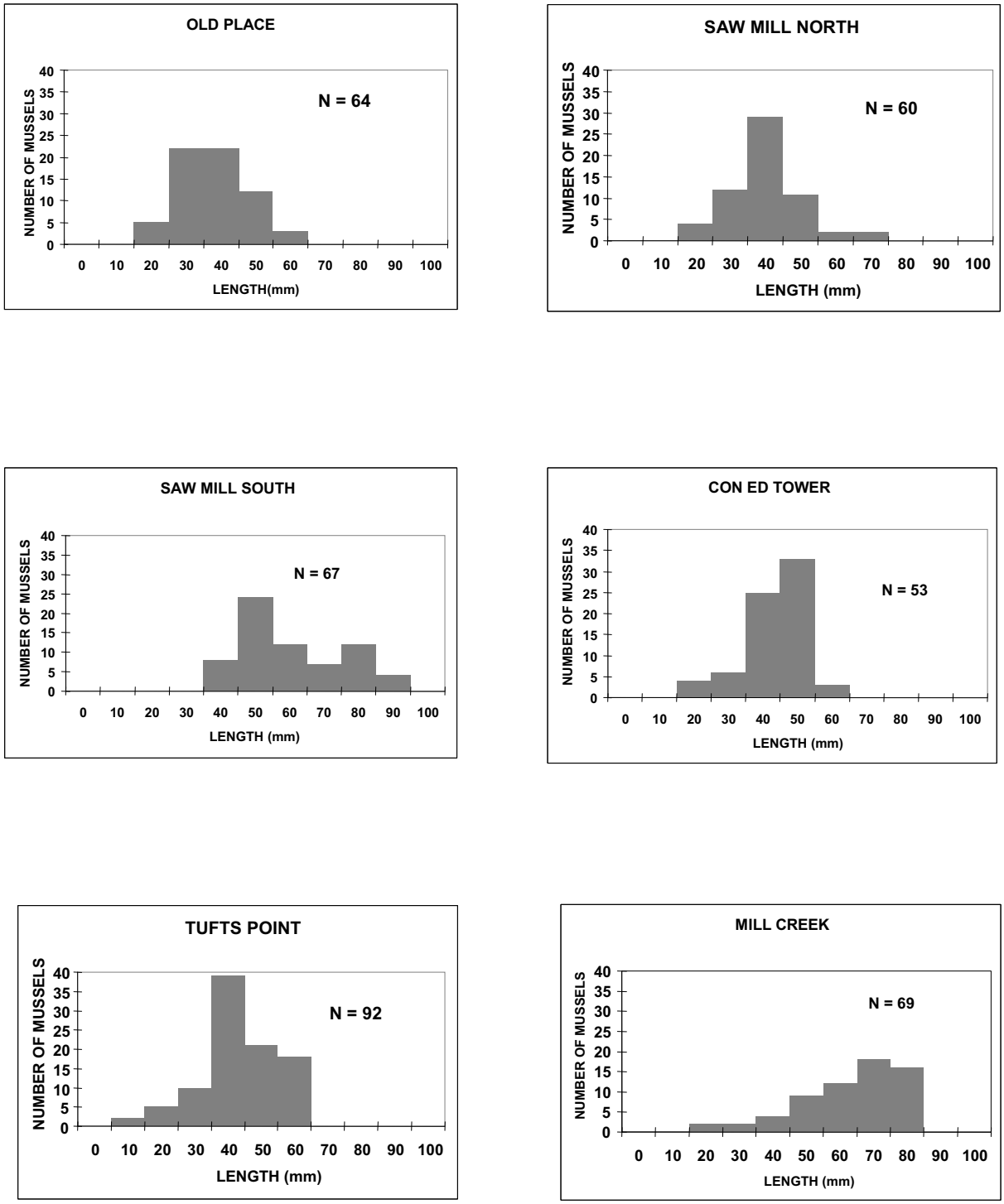
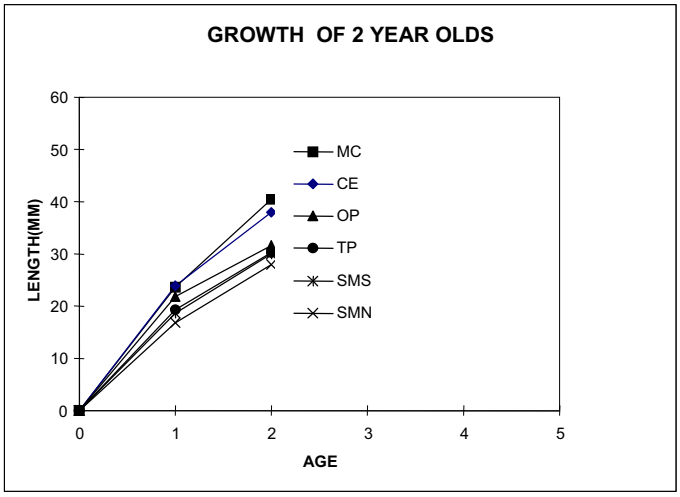
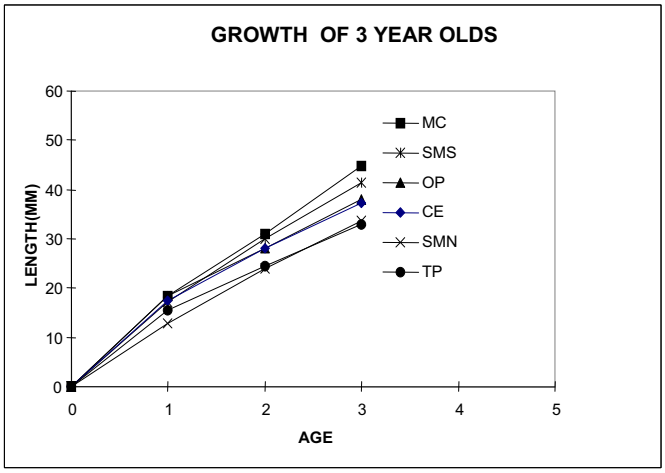


Figure 37. Length-frequency distribution of ribbed-mussels collected at Old Place Creek and Saw Mill Creek North (re-planted), Saw Mill Creek South and Con Ed Tower (unplanted), and Tufts Point and Mill Creek (reference) in September 1996.





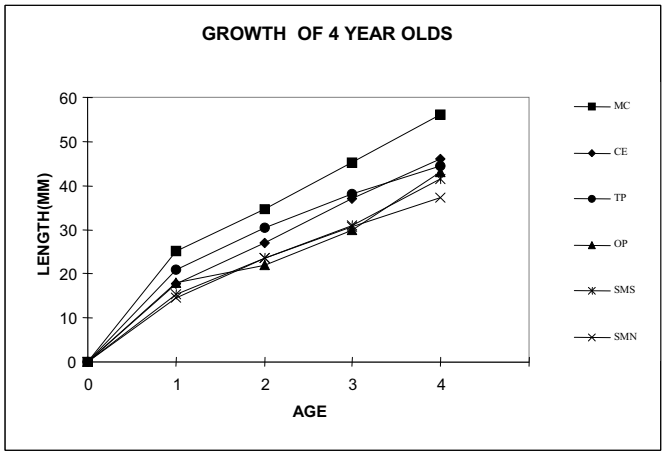


Figure 38. Growth of 2-, 3-, and 4-yr-old ribbed-mussels collected at the six Arthur Kill sites during September 1996. (CET = Con Ed Tower; MC = Mill Creek; OP = Old Place Creek; SMN = Saw Mill Creek North; SMS = Saw Mill Creek South; and TP = Tufts Point.)

Table 13. Average shell dimensions, shell dry weight, meat dry weight, and shell shape and body size relationships for 2-, 3-, and 4-yr-old ribbed-mussels collected at the six Arthur Kill sites during September 1996.

Site	No. of Samples	Physical Measure					Allometric Relationship			
		Shell Length (mm)	Shell Width (mm)	Shell Height (mm)	Shell Weight (g)	Meat Dry Weight (g)	Meat Dry Weight vs. Shell Weight	Shell Width vs. Shell Length	Shell Height vs. Shell Length	Shell Height/ Shell Width vs. Shell Length
Age 2										
Old Place Creek	23	31.7	19.8	13.3	3.01	0.15	0.049	0.63	0.42	0.021
Saw Mill Creek North	21	28.0	20.9	14.3	3.10	0.17	0.056	0.75	0.51	0.025
Saw Mill Creek South	11	30.1	23.3	15.4	3.53	0.22	0.064	0.77	0.51	0.022
Con Ed Tower	8	38.0	23.2	16.5	4.52	0.23	0.052	0.61	0.44	0.019
Tufts Point	12	30.3	19.8	13.5	3.09	0.15	0.050	0.65	0.44	0.022
Mill Creek	7	40.4	26.5	19.1	6.30	0.58	0.087	0.66	0.47	0.018
Age 3										
Old Place Creek	15	37.9	21.8	15.1	4.07	0.18	0.045	0.58	0.40	0.018
Saw Mill Creek North	13	33.6	21.6	14.3	3.15	0.18	0.057	0.64	0.42	0.020
Saw Mill Creek South	9	41.3	26.5	17.9	5.21	0.39	0.073	0.64	0.43	0.016
Con Ed Tower	4	37.3	21.3	16.8	4.95	0.21	0.044	0.57	0.45	0.021
Tufts Point	30	32.9	19.2	13.8	3.00	0.14	0.049	0.58	0.42	0.022
Mill Creek	8	44.9	27.8	20.2	6.76	0.46	0.066	0.62	0.45	0.016
Age 4										
Old Place Creek	1	43.0	22.6	15.4	4.42	0.21	0.046	0.52	0.36	0.016
Saw Mill Creek North	9	37.2	22.4	14.8	3.36	0.20	0.061	0.60	0.40	0.018
Saw Mill Creek South	10	41.6	27.6	19.6	6.32	0.38	0.060	0.66	0.47	0.017
Con Ed Tower	20	46.1	23.2	16.9	4.59	0.23	0.052	0.50	0.37	0.016
Tufts Point	18	44.5	23.3	16.8	4.99	0.24	0.051	0.52	0.38	0.016
Mill Creek	10	56.1	30.8	22.4	9.53	0.62	0.064	0.55	0.40	0.013

VI. BENTHIC INVERTEBRATES

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INTRODUCTION

Benthic invertebrates are important members of the saltmarsh ecosystem since they are part of detrital food webs linking marsh productivity to resource species (Moy and Levin 1991; Minello and Zimmerman 1992). The effects of oil or its components on invertebrates and their habitats are well documented (Saunders *et al.* 1980; Suchanek 1993; Burger 1994; Jewett *et al.* 1999). There is also considerable information available on the benthic invertebrates of created salt marshes compared to those of nearby natural marshes (Moy and Levin 1991; Minello and Zimmerman 1992; Sacco *et al.* 1994; Levin *et al.* 1996). Little information is available, however, about the benthic invertebrate assemblages at restored *S. alterniflora* marshes that were not only destroyed by an oil spill, but also historically affected by petroleum products, trace metals, and other contaminants similar to the sites studied in the Arthur Kill.

METHODS AND MATERIALS

Sampling methods for benthic invertebrates follow those of Sacco *et al.* (1994). A 3-cm-diameter (7 cm^2) metal coring tube was used to collect 5-cm-deep sediment samples from the marsh surface. During each sampling month and at low tide, two core samples were taken at each of the four stations along the transect at each site, for a total of eight core samples per site per sampling month. Sediments and biota were removed from the core and fixed in 10% buffered Formalin in seawater with rose bengal added to aid in sorting and identification of the invertebrates. Prior to sorting, samples were sieved through a 0.3-mm stainless steel sieve. The retained sediments and invertebrates were transferred to 70% ethanol with 5% glycerin, and were examined using dissecting microscopes. All organisms were removed, identified to the lowest practicable taxonomic level, and counted.

Benthic invertebrates are often divided by size and/or taxonomy into: 1) meiofauna (usually defined as organisms passing through a 0.5-mm-mesh sieve, and dominated by nematodes, harpactacoid copepods, oligochaetes, and small polychaetes); or 2) macrofauna (larger polychaetes, crustaceans, mollusks, echinoderms, etc.) that are retained on the 0.5-mm sieve. Since oligochaetes are important members of the saltmarsh ecosystem (Sacco *et al.* 1994; Levin *et al.* 1998), a 0.3-mm sieve was used in this study to retain a portion of these smaller invertebrates. Both the meiofauna and macrofauna retained on the 0.3-mm sieve will be referred to as "benthic invertebrates."

RESULTS

Forty-one taxa were identified in the study collections. Oligochaetes were the most abundant taxon, comprising 60% of all individuals counted. Nematodes were the next most abundant taxon, comprising 20% of all individuals counted, followed by the small tube-building fan worm, *Manayunkia aestuarina*, comprising 14% of all individuals counted. Together these three taxa made up approximately 94% of all individuals in the samples. Although most of the individuals found are considered meiofauna, juveniles of larger invertebrates, including the ribbed-mussel, were also present. Larger amphipods, isopods, and aquatic insects were found at most sites (Table 14).

There were greater mean abundances of benthic invertebrate individuals at all sites in the May samples compared to the September samples. Oligochaetes contributed most to this seasonal increase, except at Con Ed Tower (unplanted) where nematodes contributed the most, and at Saw Mill Creek North (replanted) where *M. aesturina* contributed the most. In the September survey, *M. aesturina* was found in greatest abundance at Con Ed Tower, while in the May survey, it was found in greatest abundances at the replanted sites Old Place Creek and Saw Mill Creek North. In September, Old Place Creek had the largest numbers of taxa (19), while both Con Ed Tower and Sawmill Creek South (unplanted) had the lowest numbers of taxa (10); in May, there were 22 taxa at Tufts Point (reference) and only eight taxa at Sawmill Creek North (Table 15).

DISCUSSION

The invertebrate taxa found at the six marsh sites (Table 15) appear to be typical of invertebrates found in tidal *S. alterniflora* marshes elsewhere. Most of these invertebrates increase in abundance in late spring to early summer,

and decrease in abundance in late summer to early fall (Tables 14 and 15). Predation, species-specific reproductive strategies, and the availability of food are important interactive factors controlling fluctuations in densities (Rader 1984; Moy and Levin 1991; Minello and Zimmerman 1992; Sacco *et al.* 1994; Sarda *et al.* 1994, 1995, 1998; Levin *et al.* 1996, 1998; Posey *et al.* 1997).

The variability in the data, which is typical of benthic invertebrate studies, the site-specific differences, and the low number of sites sampled confounded the determination of the effect of replanting of *S. alterniflora* on benthic invertebrate abundances in the Arthur Kill. Similarities were observed, however, in the abundances of all invertebrates, oligochaetes, and *M. aestuarina* between the replanted site, Old Place Creek, and at the reference site, Tufts Point, both in September and May (Table 15). Although these preliminary findings suggest, in terms of benthic fauna, structural similarities between the replanted and reference sites in the Arthur Kill, the functional equivalency of these marsh sites could not be determined.

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Table 14. Invertebrate taxa collected at the six study sites in the Arthur Kill

Platyhelminthes
unidentified
Nemertinea
unidentified
Nematoda
unidentified
Mollusca
unidentified bivalve
Anadara sp.
Mytilus edulis
Geukensia demissa
Siliqua costata
Annelida
Eteone heteropoda
Eumida sanguinea
Nereis grayi
Drilonereis longa
Polydora sp.
Polydora websteri
Streblospio benedicti
Polydora cornuta
Pygospio elegans
Spio filicornis
Capitella spp.
Manayunkia aestuarina
Oligochaeta
Arthropoda
Halacarus sp.
Scaptognathus sp.
unidentified copepods
Leptochelia savignyi
Cyathura polita
Edotea triloba
Gammarus palustris
Gammarus mucronatus
Elasmopus levis
Ampelisca abdita
Ampithoe valida
Jassa marmorata
Sesarma reticulatum
Anurida maritima
Thysanoptera
Ceratopogonidae
Chironomidae larvae
Dolichopodidae
Tabanidae
Muscidae

Table 15. Means (+/- one standard deviation)/7-cm^2 core (n = 8) for the abundances of all benthic invertebrates, oligochaetes, nematodes, and *Manayunkia aestuarina* at each of the six study sites and two sampling dates in the Arthur Kill. (Also given are the total number of taxa in all cores for each site and sampling month.)

Taxa	Site					
	Old Place Creek	Saw Mill Creek North	Saw Mill Creek South	Con Ed Tower	Tufts Point	Mill Creek
			September 1996			
All invertebrates	55.8 (21.1)	14.9 (7.7)	107.8 (30.2)	155.3 (63.0)	79.0 (69.9)	43.3 (20.7)
Oligochaetes	21.3 (12.7)	3.6 (1.7)	83.9 (22.3)	86.5 (35.1)	48.3 (45.0)	24.3 (13.6)
Nematodes	2.4 (1.5)	0	11.4 (5.7)	19.9 (8.7)	0.4 (0.4)	5.4 (4.3)
Manayunkia aestuarina	22.3 (11.8)	1.9 (1.0)	5.8 (3.5)	46.1 (22.5)	22.6 (22.6)	6.6 (3.7)
Total taxa	19	15	10	10	16	15
			May 1997			
All invertebrates	276.1 (85.7)	95.0 (34.2)	189.4 (70.5)	300.9 (106.6)	215.6 (29.3)	123.0 (36.8)
Oligochaetes	185.8 (58.3)	36.4 (12.0)	161.4 (61.3)	67.4 (24.7)	168.5 (23.7)	106.5 (31.9)
Nematodes	32.3 (15.2)	15.6 (7.6)	21.9 (10.2)	211.0 (91.6)	4.3 (1.4)	6.0 (2.9)
Manayunkia aestuarina	35.3 (11.2)	39.6 (15.2)	4.9 (1.4)	15.3 (7.8)	29.4 (12.2)	2.0 (0.7)
Total taxa	12	8	9	12	22	12

VII. FOOD HABITS OF THE MUMMICHOG (*Fundulus heteroclitus*)

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INTRODUCTION

The intertidal salt marsh is used as a source of food or feeding grounds for a number of estuarine organisms, including fish and invertebrates. Some of these organisms are in turn prey for larger organisms. The mummichog, or common killifish, *Fundulus heteroclitus*, lives along the saltmarsh fringe and is generally considered an important link in the estuarine food web supporting valued biological resources. The mummichog uses the tidally flooded marsh to access *S. alterniflora* stems as a refuge from predation, and to feed on whatever (*e.g.*, detritus, algae, fish larvae, amphipods, tanaids, copepods, and insects) is available (Kneib and Stiven 1978; Weisberg *et al.* 1981; Werme 1981; Abraham 1985; Moy and Levin 1991; Allen *et al.* 1994; Kneib and Wagner 1994; Halpin 2000).

Within the ecologically stressed Arthur Kill, the mummichog is considered the only widely abundant fish (Howells and Brundage 1977). It can be an important prey item for protected wading birds and for larger fish such as American eel (*Anguilla rostrata*), juvenile bluefish (*Pomatomus saltatrix*), summer flounder, (*Paralichthys dentatus*), and possibly striped bass (*Morone saxatilus*) that are common in the Arthur Kill area (Rountree and Able 1992; Parsons 1994; Wilk *et al.* 1996). Thus, it serves as an important energy transfer mechanism between the Arthur Kill marshes and their adjacent waters (Valiela *et al.* 1977; Weisberg and Lotrich 1982; Kneib 1986; Kneib and Wagner 1994).

Given the mummichog's close association with salt marshes, it is possible that residual effects of the 1990 oil spill, or any differences among the replanted, unplanted, or reference marshes, may be reflected in its diet. The potential or actual impact of oil on fishery resources and their food have been recognized since the earliest part of this century (Gutsell 1921), but studies on the interactions between these impacts and habitat restoration have just begun. Brzorad and Burger (1994) suggest that the diet of the mummichog in the Arthur Kill has been altered in these polluted waters by restricting the availability of its prey. However, the mummichog is moderately tolerant of oil contamination, except under thermal or osmotic stress (Abraham 1985). The mummichog diet can also suggest pathways by which oil and other anthropogenic contaminants can be transferred from sediments, substrates, and lower biological levels of the marsh ecosystem to higher trophic levels.

Gut content analysis can also support and enhance the results of stable isotope analysis for understanding trophodynamics. For example, Kneib *et al.* (1980) and Hughes and Sherr (1983) used isotopic analysis to show two main sources of plant carbon being incorporated into mummichog tissue, and Griffin and Valiela (2001) used isotopic analysis to show that the mummichog moves up approximately one step within the benthic trophic food web during a single growing season, consistent with an increase in length. Analysis of stomach contents can define the original and intermediate transfer of these and possibly other sources of plant carbon, as was true for the Griffin and Valiela (2001) study. Examination of the diet of the mummichog, the most common bottom fish along the marsh fringe, contributes to interpreting algal and benthic invertebrate community structures at restoration study sites, as these structures can be altered by the feeding of mummichogs (Vince *et al.* 1976; Kneib and Stiven 1982).

The functional evaluation of restored salt marshes is important for the assessment and improvement of restoration efforts. Presence or absence of predators such as fish, and variations in their abundances in restored habitats, are valuable indicators of general habitat suitability, but these variables can only suggest that the habitat has recovered its normal ecological function. Trophic relationships and biological energy transfers are considered useful functional endpoints to a restoration, *i.e.*, the diet and feeding of a forage species such as the mummichog can indicate the restoration of an important ecosystem link (Kelly and Harwell 1990). In addition, the mummichog is, as Halpin (1997) states, an "excellent model for studying not only the ecology of saltmarsh fish but rules governing the invasion of marginal habitats by mobile animals."

The mummichog is also an ideal candidate for this study because of its assumed fidelity to the study sites. It is thought to have a limited home range, generally <36 m of shoreline/marsh fringe (Lotrich 1975), although a recent study shows that its home range can be quite a bit larger (Sweeney *et al.* 1998). However, Halpin (1997) shows that this species is restricted to areas representing a very small proportion of the total available habitat; it also displays fine-scale differences of habitat usage, with patterns of habitat usage varying seasonally (Allen *et al.* 1994), and appears to remain and feed within the small estuaries in which it was hatched (Griffin and Valiela 2001).

This chapter presents and discusses the results of a preliminary examination of the diets of the mummichogs collected as part of the Arthur Kill study in fall 1996 and spring-summer 1997. The diets of these fish were examined for differences which might be correlated with the replanting efforts following the 1990 oil spill.

METHODS AND MATERIALS

Fish were collected in September 1996 and between May and early August 1997 with standard, tubular, galvanized-wire-mesh killitraps with open funnels at either end, baited with either a fish-based, orange-colored, canned cat food or freshly broken whole northern quahogs (*Mercenaria mercenaria*) or Atlantic surfclams (*Spisula solidissima*). The bait was contained within ultrafine synthetic mesh bags. Some trap samples from the Old Place Creek and Con Ed Tower marsh sites were obtained from cooperative collections with SMRT; SMRT used bread as bait in their traps. These baits were readily identifiable in the stomachs, thus allowing separation from the other stomach contents when the fish actually ingested the bait.

Traps were required for collection as seining was not feasible because of conditions at most sites. Since the objective of this study was to examine how mummichogs were using the marshes for feeding, and since the fish mostly fed in the marsh at high tide, the traps were deployed at the marsh fringe just before high tide. Saltmarsh fringes are considered important factors for fish in marsh restorations (Peterson and Turner 1994). The traps were left for 2-3 hr and were retrieved when water had retreated from the marsh surface so that stomach contents of trapped fish would best represent recent feeding on the marsh surface. Butner and Brattstrom (1960) and Allen *et al.* (1994) reported that mummichog stomachs are mostly full at or after high tide.

Upon trap retrieval, at least 30 mummichogs of mixed sizes were removed and preserved in 10% Formalin. The spring-summer 1997 collections were problematic as an unusually cool spring seemed to retard the mummichog's return to all of the marshes, and required an extended collection period to obtain sufficient samples at all sites. In colder months, mummichogs tend to remain higher up in creeks or in saltmarsh tide pools (Fritz *et al.* 1975; Smith and Able 1994; Halpin 1997).

In the laboratory, 30 fish were selected from each of the six sites for both collection periods, for a total of 360 fish. Each set of 30 fish contained 10 each of the largest-, smallest-, and intermediate-sized fish. Fish were measured to total length and were sexed, then their stomachs and intestines were removed and examined under a dissecting microscope. The total stomach volume was estimated, then the contents were examined and separated into definable food types. Organismal prey were identified to the lowest practical taxonomic level, their proportional contribution to the total volume was visually estimated, and countable items were enumerated. Because meiofauna were found in the stomachs, the contents were specifically examined for copepods, foraminifera, nematodes, oligochaete fragments, and diatoms. These latter taxa could provide clues to specific microhabitat use, such as feeding on the algal mats growing at the base of *S. alterniflora* stems (Werme 1981). A variety of estuarine invertebrate taxonomic keys were used to identify stomach contents, *e.g.*, Wilson (1932), Gosner (1971), Bousfield (1973), and Weiss (1995). When bait was detected in the stomachs, it was noted and the upper intestine was also examined in case the bait had pushed natural food out of the stomachs. Gastrointestinal evacuation can be fairly rapid for mummichogs, often on the order of several hours (C.L. MacKenzie, National Marine Fisheries Serv., 74 Magruder Rd., Highlands, NJ, 07732, pers. comm.).

Comparative analysis of the diets among sites and treatments for this preliminary study included the percent frequency of occurrence of specific food items or prey in the stomachs, and the estimated mean percentage of total stomach volume associated with a specific food item or prey. Numerical analysis was not feasible because of the abundance of noncountable material in the stomachs (*e.g.*, detritus, algal material). The small sample sizes, especially per fish length class, and the preliminary nature of the study, precluded the use of extensive statistical treatments.

RESULTS

As the focus of this preliminary study is on possible differences among collection sites and treatments and not on seasonal or interannual variability, the results for each collection period are presented separately.

September 1996

The sizes of the 180 mummichogs examined for this sampling period ranged from 3.3-10.5 cm. This size range was consistent among sampling sites. The results of the stomach content analysis among sites and treatments for this period are presented in Tables 16 and 17.

The data on percent frequency of occurrence (Table 16) shows that detritus was the most commonly occurring material at all sites and treatments. Algae, both strands (mixed chains of diatoms or variously colored filamentous tubes) and macrophytes, were next in overall, but variable, importance, especially at Con Ed Tower (unplanted), Tufts Point (reference), and Mill Creek (reference) sites. Insects, mostly fragments of adult forms, but including Diptera larvae, were eaten at all sites at a low frequency. Decapod shrimp (mostly *Palaemonetes* fragments) commonly occurred only at Tufts Point, while the marsh hopper amphipod, *Orchestia grillus*, commonly occurred only at Mill Creek. The shrimp

Palaemonetes sp. was also often collected in the fish traps at some sites, but was found only in the stomachs of the larger fish.

The data on mean percent stomach volume (Table 17) show that detritus was less important and occurrence of bait was more obvious. The use of detritus was highest at the two northernmost sites, Old Place Creek and Con Ed Tower. The occurrence of bait in stomachs was generally highest at all four oiled sites, and is a sampling artifact, although it may indicate limited food availability. Algal strands and blades were important at the two reference sites. Again, decapod shrimp were notable only at Tufts Point, while *Orchestia grillus* was notable only at Mill Creek. Microscopic items in the stomachs (*e.g.*, foraminifera) appear to be minor contributors to the food requirements of the mummichog.

May-August 1997

The sizes of the 180 fish examined for this sampling period ranged from 3.2 to 9.9 cm, which is similar to the previous sampling period. The results of the stomach examinations for this period are presented in Tables 18 and 19.

The most frequently occurring item was amphipod fragments, probably *Gammarus* sp., with detritus being next in frequency; detritus was less frequent at the two reference sites (Table 18). Insects again and nematodes occurred at all sites. Algal strands were found only at the unplanted and reference sites, while algal blades were found only at the oiled (both replanted and unplanted) sites. Some new food items appeared in this collection period, but only the occurrence of some unidentified invertebrate eggs (perhaps crustacean) at Mill Creek was notable. Harpacticoid copepods commonly occurred only at Tufts Point. Items that were relatively frequent in September, but that were rare or undetected in this period, were foraminifera, the marsh snail *Melampus bidentatus*, *Orchestia grillus*, decapod shrimp, spiders, and bait.

As contributors to total stomach volume, amphipod fragments and detritus were about equal, combined to make up about half (49.9%) of the total estimated stomach volumes, and were notable at all sites (Table 19). Algal strands were found only at the unplanted and reference sites, while algal blades were found only at the oiled sites and were 2-3 fold higher at the oiled/replanted sites. The reference sites differed from the oiled sites in the volume of detritus, algal blades, insects (*i.e.*, all three items being higher at the oiled sites), and of harpacticoid copepods and invertebrate eggs (*i.e.*, both items basically occurring only at reference sites).

DISCUSSION

There are some suggested differences in the mummichog diets between the replanted (*i.e.*, Old Place Creek and Sawmill North) and unplanted (*i.e.*, Con Ed Tower and Sawmill South) marshes, and between all the oiled marshes and the reference sites (*i.e.*,Tufts Point and Mill Creek). The following discussion on diets focuses on a few diet items to highlight those suggested differences.

In September 1996 (Table 16), the greatest differences (*i.e.*, greater than or equal to a factor of 2, at levels >5%, with a "+" after a diet item indicating that the highest value for that item was associated with a replanted site) between replanted and unplanted sites were in the mean percent frequency of occurrence of algal strands, algal blades (+), plant fragments, foraminifera (+), nematodes (+), insects (+), *Oithonia* (+), *Gammarus lawrencianus* (+), *G. mucronatus*, and organic matter (+). In 1997, algal strands, nematodes, organic matter, and crab fragments showed strong differences in mean percent frequency of occurrence at the replanted and unplanted sites (Table 18). On a mean percent stomach volume basis, strong differences (*i.e.*, same criteria as those for mean percent frequency of occurrence) between replanted and unplanted sites in September 1996 were noted for algal strands, spiders, and organic matter (Table 17), and in 1997 for algal strands, algal blades (+), organic matter, and *Cirolana* (+) (Table 19). The other differences among diet items at the replanted and unplanted sites were for items of minor importance (<5%) or were differences less than a factor of 2. The use of the 5% level of importance and a factor of 2 as suggesting meaningful differences is tentative, but probably reasonable given the natural expected variability in diets.

There were greater differences in mean percent frequency of occurrence and mean percent total stomach volume values when comparing the four oiled sites with the two reference sites. For September 1996, there were notable differences (*i.e.*, greater than or equal to a factor of 2, at levels >5%, with a "+" after a diet item indicating that the highest value for that item was associated with a reference site) between the oiled and reference sites in the mean percent frequency of occurrence of algal strands (+), algal blades (+), foraminifera, *Melampus bidentatus*, insects, harpacticoid copepods, *Orchestia grillus* (+), and decapod shrimp (+) (Table 16). For 1997, these differences in mean percent frequency of occurrence were notable for detritus, algal strands (+), algal blades, insects, harpacticoid copepods (+), invertebrate eggs (+), and slug-like items (+) (Table 18). In September, notable (*i.e.*, same criteria as those for mean percent frequency of occurrence) mean percent stomach volume differences are suggested for detritus, algal strands (+), algal blades (+), *Orchestia grillus* (+), decapod shrimp (+), and organic matter (Table 17). In 1997, there were differences for detritus, algal blades, insects, harpacticoid copepods (+), organic matter, invertebrate eggs (+), and slug-like items (+) (Table 19).

Overall, the diets of the mummichogs collected in the Arthur Kill at the various sites appear similar to the diets reported in previous studies (*e.g.*, Vince *et al.* 1976; Kneib *et al.* 1980; Abraham 1985; Joyce and Weisberg 1986; Allen

et al. 1994). Much of the material or prey found in the Arthur Kill mummichog stomachs, such as the algal strands, insects, spiders, marsh snails (*Melampus bidentatus*), marsh amphipods (*Orchestia grillus*), *Gammarus*, decapod shrimp, and the detritus may have easily been obtained within the flooded marsh, the small drainage channels on the marsh surface, the marsh fringe, and in the adjacent marsh creeks and channels. The seasonal differences in the diets are expected and have been reported in other studies (Werme 1981; Valiela *et al.* 1977).

The relatively high mean percent frequency of occurrence and/or mean percent stomach volume levels for detritus, algae, and other plant material at all sites may indicate a poor diet (Prinslow *et al.* 1974; Targett 1979; Kneib *et al.* 1980; Allen *et al.* 1994; Brzorad and Burger 1994). The Arthur Kill suffers from multiple-source pollution, and previous studies have demonstrated that mummichogs from Piles Creek, a mercury-polluted tributary of the Arthur Kill, show reduced longevity and rates of prey capture, feeding, growth, and fin regeneration, as well as increased vulnerability to predation by blue crabs, compared to conspecifics from uncontaminated reference sites (Toppin *et al.* 1987; Weis and Khan 1990, 1991; Smith and Weis 1997). The guts of fish from an unpolluted site on the southern New Jersey shore contained five times as much freshly killed prey by weight as those of fish from Piles Creek, and twice the amount of shrimp (Smith and Weis 1997). The vast bulk (85%) of the Piles Creek fishes' diet consisted of detritus. However, Allen *et al.* (1994) suggest that the ingestion of detritus and algae may sometimes be deliberate and may contribute to the nutrition of the fish, and Jeffries (1972) concluded from fatty acid analysis of mummichog gut contents and muscles that a reasonable diet for this species included five times as much detritus as marsh invertebrates. Moy and Levin (1991) found that the diet of mummichogs from a created marsh in North Carolina consisted mostly of polychaetes and algae, while a large percentage of the diets of fishes from natural marshes consisted of detritus and insects. Moy and Levin (1991) suggest that this difference in diet is due to differences in macrofaunal composition between their natural and created sites; oligochaetes were actually abundant in the natural marshes, but inaccessible to the mummichogs. This may be true for the mummichogs from the Arthur Kill, as oligochaetes were fairly abundant as macrofauna at all of the sites except perhaps for Saw Mill Creek North (see Chapter VI, "Benthic Invertebrates"), but were almost completely absent from the stomachs. In any case, it appears that the highest use of detritus in this study was in the northern reaches of the Arthur Kill.

The preliminary results and discussion presented here are just that, and a more detailed analysis would be required to confirm that any of the differences among the sites suggested here were significant or real and related to habitat quality or to the replanting efforts.

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Table 16. Percent frequency of occurrence of items or prey in mummichog stomachs from the six Arthur Kill sites during September 1996. (n = 30 at all sites.)

Item/Prey	Replanted Sites		Unplanted Sites		Reference Sites	
	Old Place Creek	Saw Mill Creek North	Con Ed Tower	Saw Mill Creek South	Tufts Point	Mill Creek
Detritus	70	70	90	33	57	70
Algal strands	7	0	47	3	70	27
Algae, green blade	13	0	3	0	23	37
Plant fragments	7	0	10	7	0	7
Foraminifera	17	20	10	0	0	7
Nematodes	7	3	3	0	0	10
Melampus bidentatus	3	13	0	30	0	7
Oligochaetes	3	3	3	0	0	0
Polychaetes	0	0	3	0	0	0
Spider, small brown	0	10	0	7	0	7
Springtail, *Anurida*	0	0	0	3	0	0
Insect fragments[a]	30	7	3	13	3	7
Copepod, harpacticoid	13	0	20	0	0	7
Copepod, *Argulus* sp.	0	0	0	3	0	0
Copepod, *Oithonia* sp.	7	0	0	0	0	0
Gammarus lawrencianus	13	7	7	0	0	7
G. mucronatus	0	0	7	0	0	3
Amphipod, *Photis* sp.	7	0	0	0	0	0
Orchestia grillus	7	0	0	0	0	43
Decapod shrimp[b]	0	0	0	0	43	0
Pagurus sp. Fragments	0	0	0	0	3	0
Organic matter	0	3	3	33	3	7
Bait only	17	23	0	10	0	0
Artifacts, human	3	0	3	0	7	7

[a]Includes Orthoptera, Coleoptera, Hymenoptera, and Diptera fragments and larvae.
[b]Mostly *Palaeomonetes* sp.

Table 17. Mean percent stomach volume estimates of items or prey in mummichog stomachs from the six Arthur Kill sites during September 1996. (n = 30 at all sites.)

	Replanted Sites		Unplanted Sites		Reference Sites	
Item/Prey	Old Place Creek	Saw Mill Creek North	Con Ed Tower	Saw Mill Creek South	Tufts Point	Mill Creek
Detritus	34.9	5	51	6.8	10	14.9
Algal strands	<0.1	0	13	<0.1	36.8	11.8
Algae, green blade	4.1	0	0.3	0	11.8	16.8
Plant fragments	<0.1	0	3.3	0.8	0	1
Foraminifera	<0.1	<0.1	<0.1	0	0	<0.1
Nematodes	<0.1	<0.1	<0.1	0	0	<0.1
Melampus bidentatus	<0.1	<0.1	0	3.8	0	<0.1
Oligochaetes	<0.1	<0.1	<0.1	0	0	0
Polychaetes	0	0	<0.1	0	0	0
Spider, small brown	0	<0.1	0	6.2	0	<0.1
Springtail, *Anurida*	0	0	0	<0.1	0	0
Insect fragments[a]	0.4	<0.1	1	3	1.2	<0.1
Copepod, harpacticoid	<0.1	0	0.3	0	0	<0.1
Copepod, *Argulus* sp.	0	0	0	<0.1	0	0
Copepod, *Oithonia* sp.	0	0	0	<0.1	0	0
Gammarus lawrencianus	3.4	<0.1	0.2	0	0	3.3
G. mucronatus	0	0	3.7	0	0	<0.1
Amphipod, *Photis* sp.	<0.1	0	0	0	0	0
Orchestia grillus	0	0	0	0	0	21.9
Decapod shrimp[b]	0	0	0	0	26.8	0
Pagurus sp. fragments	0	0	0	0	2.2	0
Organic matter	0	3.3	2.3	26.3	<0.1	2.3
Bait only	57.1	91.7	24.6	53.1	11.2	28
Artifacts, human	<0.1	0	0.3	0	<0.1	<0.1

[a]Includes Orthoptera, Coleoptera, Hymenoptera, and Diptera fragments and larvae.
[b]Mostly *Palaeomonetes* sp.

Table 18. Percent frequency of occurrence of items or prey in mummichog stomachs from the six Arthur Kill sites during May-August 1997. (n = 30 at all sites.)

Item/Prey	Replanted Sites		Unplanted Sites		Reference Sites	
	Old Place Creek	Saw Mill Creek North	Con Ed Tower	Saw Mill Creek South	Tufts Point	Mill Creek
Detritus	47	57	63	30	17	20
Algal strands	0	0	17	3	3	20
Algae, green blade	20	13	17	20	0	0
Plant fragments	7	7	17	0	3	7
Nematodes	7	7	17	20	13	23
Melampus bidentatus	3	0	0	0	0	3
Oligochaetes	0	0	3	0	0	0
Polychaetes[a]	10	0	7	0	3	0
Spider	0	0	3	0	0	0
Insect fragments[b]	33	10	27	27	0	17
Copepod, harpacticoid	0	0	0	0	50	0
Gammarus sp.	7	0	10	0	3	0
Amphipod fragments[c]	70	33	50	53	17	47
Decapod shrimp[d]	0	0	3	0	0	0
Organic matter	0	10	20	30	3	20
Fish eggs	0	0	0	0	0	13
Invertebrate eggs	3	0	3	3	0	57
Clam fragments	3	0	0	0	0	0
Cirolana	13	0	7	0	0	0
Crab fragments	0	0	7	0	0	0
Slug-like	0	3	0	0	27	0
Cyathura	0	3	0	3	0	3

[a]Mostly *Nereis succinea*.
[b]Includes Orthoptera, Coleoptera, Hymenoptera, and Diptera fragments and larvae.
[c]Mostly *Gammarus* sp.
[d]Mostly *Palaemonetes* sp.

Table 19. Mean percent stomach volume estimates of items or prey in mummichog stomachs from the six Arthur Kill sites during May-August 1997. (n = 30 at all sites.)

	Replanted Sites		Unplanted Sites		Reference Sites	
Item/Prey	Old Place Creek	Saw Mill Creek North	Con Ed Tower	Saw Mill Creek South	Tufts Point	Mill Creek
Detritus	20.3	43.4	39.1	24.0	13.9	14.1
Algal strands	0	0	9.2	0.2	0.4	2.7
Algae, green blade	8.8	8.7	2.7	3.8	0	0
Plant fragments	0.7	0.7	1.7	0	1.9	0.4
Nematodes	0.3	0.1	0.3	0.5	0.7	0.5
Melampus bidentatus	2.5	0	0	0	0	0.1
Oligochaetes	0	0	<0.1	0	0	0
Polychaetes[a]	2.4	0	3.1	0	2.9	0
Spider	0	0	<0.1	0	0	0
Insect fragments[b]	8.3	1.8	3.6	8.2	0	2.0
Copepod, harpacticoid	0	0	0	0	42.9	0
Gammarus sp.	2.5	0	1.0	0	3.8	0
Amphipod fragments[c]	43.3	20.5	15.9	32.3	9.8	22.5
Decapod shrimp[d]	0	0	3.3	0	0	0
Organic matter	0	6.0	9.4	23.8	0.8	8.2
Fish eggs	0	0	0	0	0	4.1
Invertebrate eggs	<0.1	0	<0.1	<0.1	0	34.8
Clam fragments	0.8	0	0	0	0	0
Cirolana	6.5	0	0.5	0	0	0
Crab fragments	0	0	3.7	0	0	0
Slug-like	0	0.2	0	0	22.9	0
Cyathura	0	1.7	0	0.3	0	0.3

[a]Mostly *Nereis succinea*.
[b]Includes Orthoptera, Coleoptera, Hymenoptera, and Diptera fragments and larvae.
[c]Mostly *Gammarus* sp.
[d]Mostly *Palaemonetes* sp.

VIII. CONCLUSIONS

Before discussing the overall conclusions of the NMFS study, it is important to summarize the monitoring results and conclusions of the SMRT study for *S. alterniflora* biomass and stem densities, ribbed-mussel densities, mummichog abundances, and wading bird foraging success.

SMRT STUDY

The following summary of the SMRT study is based on Bergen *et al.* (2000) and Alderson *et al.* (Salt Marsh Restoration Team, Natural Resources Group, New York City Parks, 200 Nevada Ave., Staten Island, NY, pers. comm. and unpubl. data). No specific numbers will be given, and the results are confined to Old Place Creek and Con Ed Tower. In terms of *S. alterniflora*, above-ground biomass at Old Place Creek -- an oiled and replanted site -- has reached levels comparable to those reported in other studies at this latitude. In comparison, little or no *S. alterniflora* has been found at Con Ed Tower -- an oiled and unplanted site; natural recolonization via rhizomatous growth and seedling recruitment has failed to re-establish vegetation there. At Old Place Creek, annual increases in stem densities, and the height of *S. alternilfora* plants, indicate that the conditions for seed dispersal and possible germination, as well as the baffling and accretion of sediments, are being met at that site. The replanting of grass to areas at Old Place Creek denuded by oil, and the subsequent success of the seedlings and transplants, were not suggested by previous studies; indeed, at the time of the spill, managers considered replanting unnecessary (C. Alderson *et al.*, Salt Marsh Restoration Team, Natural Resources Group, New York City Parks, 200 Nevada Ave., Staten Island, NY, pers. comm.). At Con Ed Tower, though, the grass does not appear to be able to return on its own, and a net loss of marsh greater than that caused by the oil spill may in fact be occurring due to erosion of the denuded shoreline (C. Alderson *et al.*, Salt Marsh Restoration Team, Natural Resources Group, New York City Parks, 200 Nevada Ave., Staten Island, NY, pers. comm.).

Densities of mussels at Old Place Creek have increased annually, while the mussels at Con Ed Tower are still at very low densities.

Greater numbers of mummichogs were trapped at Old Place Creek, suggesting a preference by that species for the heterogeneous habitat provided by the replanted *S. alterniflora* as compared to the bare surface of the Con Ed Tower site. Other studies have also shown greater direct use of salt marshes by fishes in comparison with nonvegetated habitat (*e.g.*, Rozas and Minello 1998).

For snowy (*Egretta thula*) and great egrets (*Casmerodius albus*), the number and duration of foraging visits, the number of strike attempts, and the number of successful strikes were significantly greater at Old Place Creek. This increased foraging success suggests that there were greater numbers of prey (*i.e.*, mummichogs) available to the birds at the replanted site. Thus, the replanted site appears to provide better foraging habitat for the wading birds. Supplementary data show that the heterogeneity of the habitat in the replanted marsh is positively correlated with improved foraging success.

These monitoring studies by the SMRT suggest that the replanting of *S. alterniflora* after the 1990 oil spill was very important for the recovery and restoration of the saltmarsh ecosystem, especially at Old Place Creek, and even in such a heavily urbanized and degraded estuary as the Arthur Kill. The *S. alterniflora* provides much of the structural component of the marsh; restoring this component is important to the other members of the food web, such as the mussels, mummichogs [*e.g.*, as a refuge from predation (Moy and Levin 1991; Halpin 2000)], and birds. It is particularly important in an urbanized landscape where habitats are isolated and their availability is limited (Simenstad and Thom 1996; Ehrenfeld 2000), and where restoration is critical for species of particular concern such as the great and snowy egrets.

NMFS STUDY

Bearing in mind that the NMFS assessment was limited in scope, our results are less clear in terms of the benefits of replanting, or even in evaluating the differences among the sites. Ehrenfeld (2000) stated that in urban wetlands, the range of variability, both within and among wetlands, is much higher than in nonurban wetlands, and this is certainly true in the Arthur Kill. For example, for the benthic infauna, while there may be similarities in invertebrate abundances between the replanted and reference sites, quantitative evaluation was confounded by the high variability in the data and the low number of replanted and reference sites sampled. What is clear is that many of the fauna found in these marshes appear to be tolerant of contaminants; however, this pollution and other anthropogenic impacts may affect their overall health and longevity (*e.g.*, mummichogs). While it is true that the ribbed-mussels from the Mill Creek reference marsh grew faster and were larger and heavier than mussels from both replanted sites, this is more likely due to the relative undisturbed nature of this mature marsh, as well as differences in site-specific factors.

All the Arthur Kill marshes are polluted of course, as evidenced by, for example, the residual oil in the sediments (see also Bergen *et al.* 2000), and as suggested by the high percentages of detritus and algae as opposed to live prey in the mummichog stomachs, which may indicate a poor diet due to a polluted environment. However, the levels of contaminants are often site specific, depending, for example, as with sediment trace metals, on the types of sediment found

at each site. Replanting may have reduced the amount of TPH in the sediments -- compare Old Place Creek to Con Ed Tower, and see also Bergen *et al.* (2000); however, replanting may not have had a great effect on the levels of other contaminants, such as trace metals in both sediments and mussels, and TPH in mussels.

Some measures of ecological function, such as biogeochemistry, also appear to be site specific, but are subject to many confounding factors, and it is questionable whether the biogeochemistry was affected by replanting. Others measures, such as mummichog food habits, may or may not be site specific, but a more thorough investigation would be necessary to discern any real patterns in the data, as has been demonstrated for several of our other investigations.

COMBINED STUDIES

In conclusion, replanting the oil-damaged marshes of the Arthur Kill may have successfully "restored" them, at least structurally, to the level of the existing marshes found within the Kill. Because this is an urban estuary, the extent to which the ecological functions of these marshes have been restored is more difficult to ascertain due to confounding factors such as pollution and other anthropogenic impacts.

Also, the time span of this preliminary assessment program may have been too short and the number of treatment sites chosen may have been too small to assess accurately the performance of the replanted marshes, especially given the many scales of natural spatial and temporal variability and anthropogenic perturbations inherent in this ecosystem. A number of habitat restoration investigators have also noted the value and importance of long-term studies of ecosystem processes in restoration research in order to obtain a better understanding of the time required to achieve functional equivalency and to also take into account this kind of variability (*e.g.*, Simenstad and Thom 1996; Kentula 2000; West *et al.* 2000). Nevertheless, New York City's SMRT continues to replant and monitor these marshes where necessary, insuring that this vital habitat is protected from further loss and degradation.

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APPENDIX A

PRINCIPAL COMPONENT ANALYSIS OF TRACE METALS

Table A1. Eigenvectors for trace metals and organic carbon content in sediments from the September 1996 and May 1997 collections, excluding the Sandy Hook site

	Principal Vector			
Component	**1**	**2**	**3**	**4**
Fe	0.428	-0.111	-0.273	0.438
Cr	0.293	0.510	-0.401	0.304
Cu	0.423	-0.220	-0.074	-0.418
Ni	0.366	0.457	0.066	0.002
Zn	0.381	-0.169	0.129	-0.279
Mn	0.224	-0.447	0.437	0.618
Pb	0.440	-0.200	-0.070	-0.279
Org. C	0.171	0.449	0.737	-0.057

Table A2. Eigenvectors for trace metals and % fines in sediments from the September 1996 collection, excluding the Con Ed Tower site

	Principal Vector			
Component	**1**	**2**	**3**	**4**
Fe	0.399	-0.116	-0.266	0.157
Cr	0.310	-0.556	0.180	0.259
Cu	0.359	0.242	0.549	-0.255
Ni	0.367	-0.345	0.097	0.134
Zn	0.351	0.262	-0.436	-0.543
Mn	0.244	0.594	-0.145	0.712
Pb	0.377	0.228	0.451	-0.118
% fines	0.395	-0.163	-0.415	-0.100

Table A3. Eigenvectors for trace metals in ribbed-mussels from the September 1996 and May 1997 collections

	Principal Vector			
Component	**1**	**2**	**3**	**4**
Ag	0.288	0.541	-0.413	-0.258
Cd	0.384	-0.292	-0.145	-0.387
Cr	0.315	0.336	-0.086	0.786
Cu	0.291	0.396	0.731	-0.165
Ni	0.321	-0.431	0.363	0.233
Zn	0.393	-0.070	0.149	-0.187
Hg	0.435	0.106	-0.191	-0.112
Fe	0.373	-0.387	-0.276	0.190

APPENDIX B

SAMPLE CHARACTERISTICS FOR ANALYSIS OF PETROLEUM HYDROCARBONS

Table B1. The location and collection dates for sediment and ribbed mussels from the Arthur Kill and Sandy Hook Bay.

Sediments[1]

	Latitude	Longitude	Collection Period 1	Collection Period 2
Old Place Marsh[2]	40° 38.13'	74° 11.79'	September 04, 1996	May 01, 1997
Con Edison Tower Marsh[2]	40° 37.13'	74° 12.00'	September 04, 1996	May 01, 1997
Saw Mill North Marsh	40° 36.77'	74° 11.75'	September 09, 1996	May 01, 1997
Saw Mill South Marsh	40° 36.66'	74° 11.84'	September 09, 1996	May 01, 1997
Tufts Point Marsh	40° 33.72'	74° 13.24'	September 05, 1996	May 01, 1997
Mill Creek Marsh[2]	40° 31.34'	74° 14.36'	September 06, 1996	May 01, 1997
Sandy Hook Bay Marsh[2]	40° 26.90'	73° 59.91'	Collected August 11, 1997	

Ribbed Mussels

	Latitude	Longitude	Collection Period 1	Collection Period 2
Old Place Marsh	40° 38.13'	74° 11.79'	September 06, 1996	May 08, 1997
Con Edison Tower Marsh	40° 37.13'	74° 12.00'	September 05, 1996	May 05, 1997
Saw Mill North Marsh	40° 36.77'	74° 11.75'	September 10, 1996	May 07, 1997
Saw Mill South Marsh	40° 36.66'	74° 11.84'	September 11, 1996	May 07, 1997
Tufts Point Marsh	40° 33.72'	74° 13.24'	September 12, 1996	May 05, 1997
Mill Creek Marsh	40° 31.34'	74° 14.36'	September 13, 1996	April 30, 1997
Sandy Hook Bay Marsh	40° 26.90'	73° 59.91'	Collected February 20, 1997	

[1] Sediment cores were obtained during the first collection period while surface sediment samples were obtained during the second.

[2] Sediment samples collected from these Arthur Kill sites were analyzed.

Table B2. Date of collection, physical parameters, and percent lipid for analyzed ribbed mussels.

Sample ID	Length (mm)	Width (mm)	Thickness (mm)	Total Weight (g)	Tissue Weight (g)	Lipid Percent
Old Place Marsh - A Replanted Site						
First Collection: Collected September 06, 1996						
197020410	54.4	26.5	17.3	9.6	3.7	1.58
197020413	54.9	27.3	17.2	9.3	3.6	1.34
197020412	60.1	27.1	19.5	11.9	4.8	0.75
197020411	60.5	29.8	18.4	10.3	3.4	1.31
197020414	65.1	32.1	21.2	15.9	6.4	1.15
Second Collection: Collected May 08, 1997						
497051411	65.2	30.8	20.0	13.2	5.3	1.22
497051412	62.3	30.4	21.0	17.8	9.8	0.66
497051413	56.3	25.5	17.1	10.5	5.9	0.63
497051414	55.4	28.8	17.5	11.0	4.0	1.10
497051415	55.6	26.1	17.4	12.1	6.4	0.93
Con Edison Tower Marsh - An Unplanted Site						
First Collection: Collected September 05, 1996						
197020421	58.0	28.9	17.1	10.6	5.3	1.18
197020422	61.5	29.2	19.7	13.1	5.2	1.22
197020423	63.0	32.1	18.8	15.5	7.2	0.66
197020425	70.6	34.1	27.9	28.6	14.4	0.55
297031701	69.8	34.6	20.3	16.2	6.0	1.50
Second Collection: Collected May 05, 1997						
497051422	66.5	32.0	21.0	13.7	5.0	1.45
497051423	56.2	26.9	17.3	9.5	3.8	1.22
497051424	61.6	27.6	21.4	14.4	6.9	0.90
497051425	57.5	25.6	18.3	11.7	5.6	1.19
497051426	59.2	28.1	20.0	12.6	5.8	1.11
Saw Mill North Marsh - A Replanted Site						
First Collection: Collected September 10, 1996						
197020415	55.8	27.4	17.0	8.3	3.2	1.49
197020409	65.5	31.6	21.8	13.0	4.1	1.48
197020401	67.1	32.5	21.9	14.7	5.4	1.51
197020402	67.4	34.0	23.1	15.5	4.8	1.17
297031702	69.9	32.4	20.7	17.5	8.1	0.72
Second Collection: Collected May 07, 1997						
497051405	58.4	27.4	17.3	13.4	6.7	0.56
497051406	60.1	25.7	19.4	13.4	6.9	0.92
497051409	67.1	30.0	24.7	24.1	11.1	0.66
497051407	58.3	28.5	18.7	10.6	3.8	2.01
497051410	62.4	29.6	21.4	18.1	9.7	0.91

Table B2. Continued.

Sample ID	Length (mm)	Width (mm)	Thickness (mm)	Total Weight (g)	Tissue Weight (g)	Lipid Percent
Saw Mill South Marsh - An Unrestored Site						
First Collection: Collected September 11, 1996						
197020426	67.3	33.2	21.0	17.9	10.5	0.48
297031703	70.6	32.8	19.6	18.0	10.6	0.42
297031704	71.0	34.4	24.8	26.1	15.0	0.43
297031705	71.8	34.0	24.3	25.4	15.4	0.43
297031706	73.5	32.0	23.2	21.9	12.4	0.40
Second Collection: Collected May 07, 1997						
497051432	62.9	28.0	18.0	14.1	7.3	1.03
497051401	61.5	26.1	18.5	12.5	6.7	0.77
497051402	57.2	26.0	16.9	10.9	5.9	1.01
497051403	56.5	24.9	17.0	10.6	5.6	1.08
497051404	56.9	23.5	17.4	8.9	4.4	0.80
Tufts Point Marsh - A Reference Site						
First Collection: Collected September 12, 1996						
197020403	54.2	24.0	15.4	7.1	3.2	1.49
197020404	56.5	24.2	18.0	10.1	4.6	1.21
197020405	56.1	24.9	17.1	9.1	3.3	2.97
197020408	60.3	26.9	18.5	11.7	6.4	0.99
197020406	63.2	27.2	19.0	13.1	5.8	0.62
Second Collection: Collected May 05, 1997						
497051427	66.6	26.7	21.7	17.4	9.3	0.83
497051428	56.8	25.1	16.5	10.2	4.0	1.26
497051429	58.3	26.6	17.7	11.2	5.5	1.04
497051430	58.6	27.0	17.7	12.6	6.4	1.19
497051431	63.7	29.6	20.4	15.1	7.6	0.52
Mill Creek Marsh - A Reference Site						
First Collection: Collected September 13, 1996						
197020407	54.2	24.3	17.8	8.1	3.3	2.47
197020417	58.5	26.5	17.3	11.4	5.6	1.22
197020418	65.2	29.1	19.6	12.3	4.8	1.52
197020420	71.7	28.0	22.0	18.5	10.5	1.58
197020419	69.5	32.4	24.1	18.9	8.9	1.31
Second Collection: Collected April 30, 1997						
497051417	60.3	28.8	20.6	14.8	7.9	0.75
497051418	58.7	28.7	19.2	15.0	8.3	0.52
497051419	63.8	26.5	19.0	13.8	6.8	1.04
497051420	57.3	26.3	17.9	11.3	5.5	1.03
497051421	62.2	27.5	20.7	13.9	6.5	1.13
Sandy Hook Bay Marsh - A Reference Site						
First Collection: Collected February 20, 1997						
297031715	55.4	22.7	18.0	10.8	5.1	1.33
297031711	67.2	26.7	19.7	14.9	7.1	1.29
297031714	57.7	25.5	19.3	12.3	5.7	1.01
297031716	60.5	26.0	20.7	14.8	6.3	1.22
297031710	65.0	27.7	18.8	11.9	6.1	2.22
297031712	59.7	28.0	21.2	15.2	7.0	1.36
297031713	62.7	25.7	19.4	13.7	6.1	1.29

Table B3. Members of each batch for cleanup and analysis of Arthur Kill sediments.

Batch 1 contained a total of 19 samples:

4 surface scoop sediments from Old Place Marsh collected May 1997,
4 surface scoop sediments from Con Edison Tower Marsh collected May 1997,
1 Sandy Hook Bay sediment,
7 Sandy Hook Bay sediments used for determination of method detection limit spiked with 20 μg of each hydrocarbon,
1 SRM - ERA SRM 765 – Diesel Oil in Soil,
1 matrix spike – Sandy Hook Bay sediment spiked with 100 μg of each hydrocarbon, and,
1 method blank sample.

Batch 2 contained a total of 32 samples:

20 core sections from Old Place Marsh collected September 1996,
9 core sections from Con Edison Tower Marsh collected September 1996,
1 SRM - ERA SRM 765 – Diesel Oil in Soil,
1 matrix spike – Sandy Hook Bay sediment spiked with 100 μg of each hydrocarbon, and,
1 method blank sample.

Batch 3 contained a total of 24 samples:

1 core section from Con Edison Tower Marsh collected September 1996,
20 core sections from Mill Creek Marsh collected September 1996,
1 SRM - ERA SRM 765 – Diesel Oil in Soil,
1 matrix spike – Sandy Hook Bay sediment spiked with 100 μg of each hydrocarbon, and,
1 method blank sample.

Batch 4 contained a total of 15 samples:

10 core sections from Con Edison Tower Marsh collected September 1996,
3 replicate SRM samples - ERA SRM 765 – Diesel Oil in Soil,
1 matrix spike – Sandy Hook Bay sediment spiked with 50 μg of each hydrocarbon, and,
1 method blank sample.

Table B4. Members of each batch for cleanup and analysis of Arthur Kill mussels.

Batch 1 contained a total of 32 samples:

5 samples from Old Place Marsh collected September 1996,
5 samples from Con Edison Tower Marsh collected September 1996,
5 samples from Saw Mill North Marsh collected September 1996,
1 sample from Saw Mill South Marsh collected September 1996,
5 samples from Tufts Point Marsh collected September 1996,
5 samples from Mill Creek Marsh collected September 1996,
3 replicate samples - homogenized Mill Creek mussel #54814[1],
1 method blank sample,
1 matrix spike - SRM 1974a spiked with 25 μg of each hydrocarbon, and,
1 SRM - NIST SRM 1974a - Organics in Mussel Tissue.

Batch 2 contained a total of 24 samples:

4 samples from Saw Mill South Marsh collected September 1996,
1 repeat sample from Con Edison Tower[2],
1 repeat sample from Saw Mill North Tower[3],
7 non-depurated mussels from the Sandy Hook Bay[4],
1 method blank sample,
1 SRM - NIST SRM 1974a - Organics in Mussel Tissue
1 background check sample for method detection limit study samples[5], and
7 method detection limit samples spiked with 40 μg of each hydrocarbon[5].
1 matrix spike - mussel homogenate spiked with 1000 μg No 2 diesel fuel oil[6].

Batch 3 contained a total of 32 samples:

30 Arthur Kill mussels collected May 1997,
1 method blank,
1 matrix spike – Sandy Hook Bay mussel composite homogenate spiked with 25 μg of each hydrocarbon.

[1] This mussel was the longest (100.5 mm) and the heaviest (35.2 g) of all mussels collected.

[2] Two samples were repeated because of problems encountered during the cleanup of Batch 1 sample extracts. The repeat samples were taken from the same group as the original samples with the next highest random number assignment.

[3] Two samples were repeated because of problems encountered during the cleanup of Batch 1 sample extracts. The repeat samples were taken from the same group as the original samples with the next highest random number assignment.

[4] Seven non-depurated mussels from the Sandy Hook Bay were analyzed to examine for differences between the Arthur Kill sites and a non-Arthur Kill site.

[5] Twelve depurated Sandy Hook Bay mussel samples were composited to provide 7 replicate samples for MDL measurements, 1 sample as MDL background sample, and 1 matrix sample for spiking with No 2 Diesel fuel oil.

[6] Sandy Hook Bay mussel homogenate was used as the tissue matrix for the oil spiking.

Table B5. Aliphatic hydrocarbons analyzed.

Chemical Name	Abbreviation
Normal Aliphatic Hydrocarbons	
n-Octane[1]	n-C_8
n-Nonane	n-C_9
n-Decane	n-C_{10}
n-Undecane	n-C_{11}
n-Dodecane	n-C_{12}
n-Tridecane	n-C_{13}
n-Tetradecane	n-C_{14}
n-Pentadecane	n-C_{15}
n-Hexadecane	n-C_{16}
n-Heptadecane	n-C_{17}
n-Octadecane	n-C_{18}
n-Nonadecane	n-C_{19}
n-Eicosane	n-C_{20}
n-Heneicosane	n-C_{21}
n-Docosane	n-C_{22}
n-Tricosane	n-C_{23}
n-Tetracosane	n-C_{24}
n-Pentacosane	n-C_{25}
n-Hexacosane	n-C_{26}
n-Heptacosane	n-C_{27}
n-Octacosane	n-C_{28}
n-Nonacosane	n-C_{29}
n-Triacontane	n-C_{30}
n-Hentriacontane	n-C_{31}
n-Dotriacontane	n-C_{32}
n-Tritriacontane	n-C_{33}
n-Tetratriacontane	n-C_{34}
n-Pentatriacontane	n-C_{35}
n-Hexatriacontane	n-C_{36}
n-Heptatriacontane	n-C_{37}
n-Octatriacontane	n-C_{38}
n-Nonatriacontane	n-C_{39}
n-Tetracontane	n-C_{40}
Branched Aliphatic Hydrocarbons	
2,6,10,14-Tetramethylhexadecane	Pristane
2,6,10,14-Tetramethylpentadecane	Phytane

[1] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8.

APPENDIX C

QUALITY CONTROL FOR ANALYSIS OF PETROLEUM HYDROCARBONS

Table C1. Data quality objectives for analyses of petroleum hydrocarbons in sediments and ribbed mussels.

Parameters/ QC Measurements	Frequency	Control Limit Criteria
Method Detection Limit	1 per matrix	Target MDL of 10 μg/g for sediments Target MDL of 1 μg/g for ribbed mussels Warning limit - analyst should use best judgement if measured MDLs exceed the target MDLs
Laboratory Method Blank	1 per 20 samples	Warning limit - analyst should use best judgment if analytes are detected at or up to 3 times the MDL. Action limit - no analyte should be detected at > 3 times the MDL.
Surrogate Internal Standards	Each sample	40 -150% recovery. Recommended control limit is < 50% (PD; percent difference) between accuracy-based material surrogate and sample surrogate recoveries.
Matrix Spike	1 per 20 samples	Recovery should be within 50 - 120% for at least 80% of the analytes.
Laboratory Triplicates	1 per 20 samples	≤ 25% relative standard deviation (RSD) for analytes > 10 times the MDL.
Accuracy-Based Materials	1 per 20 samples	≤ 30% (PD) of certified or consensus value on average for analytes > 10 times the MDL.

Table C2. Method Detection Limit (MDL) analysis using sediment replicates from Sandy Hook Bay.[1]

Sample ID	Nonane ($n\text{-}C_9$)	Decane ($n\text{-}C_{10}$)	Undecane ($n\text{-}C_{11}$)	Dodecane ($n\text{-}C_{12}$)	Tridecane ($n\text{-}C_{13}$)	Tetradecane ($n\text{-}C_{14}$)	Pentadecane ($n\text{-}C_{15}$)	Hexadecane ($n\text{-}C_{16}$)	Heptadecane ($n\text{-}C_{17}$)	Pristane	Octadecane ($n\text{-}C_{18}$)	Phytane	Nonadecane ($n\text{-}C_{19}$)	Eicosane ($n\text{-}C_{20}$)	Heneicosane ($n\text{-}C_{21}$)	Docosane ($n\text{-}C_{22}$)	Tricosane ($n\text{-}C_{23}$)
Sediment MDL Determination Using External Standard Calculations (μg/g, wet wt.)																	
897081109	2.95	4.23	4.52	4.57	4.69	4.96	5.05	5.29	5.87	5.38	5.90	5.61	6.03	5.93	6.16	7.20	6.68
897081110	4.31	3.78	4.39	4.69	4.63	4.92	4.94	4.90	5.32	4.94	5.07	4.96	5.29	5.22	5.30	5.39	5.44
897081111	2.59	3.29	3.90	4.27	4.34	4.60	4.87	5.08	5.63	5.22	5.59	5.33	5.69	5.55	5.83	6.89	6.18
897081112	3.36	3.24	3.70	4.01	4.07	4.23	4.58	4.69	5.19	4.81	5.00	4.90	5.26	5.16	5.31	5.28	5.40
897081113	3.24	3.24	4.20	4.59	4.84	5.15	5.67	5.80	6.35	5.90	6.09	5.94	6.33	6.33	6.52	6.60	6.83
897081114	1.61	2.16	2.59	2.89	3.05	3.36	3.95	4.40	5.12	4.77	5.22	5.02	5.42	5.40	5.57	5.65	5.82
897081115	3.09	3.36	3.42	3.66	3.82	4.06	4.33	4.51	5.08	4.70	5.11	4.88	5.36	5.32	5.50	5.46	5.62
Average	3.02	3.33	3.82	4.10	4.21	4.47	4.77	4.95	5.51	5.10	5.43	5.23	5.63	5.56	5.74	6.07	6.00
Std Dev	0.82	0.63	0.67	0.64	0.63	0.63	0.55	0.49	0.47	0.43	0.44	0.41	0.41	0.43	0.46	0.80	0.58
%RSD or %CV	27.06	19.02	17.46	15.73	14.88	14.07	11.56	9.86	8.53	8.39	8.03	7.82	7.33	7.67	7.99	13.20	9.74
MDL[2]	2.57	1.99	2.09	2.03	1.97	1.98	1.73	1.53	1.48	1.35	1.37	1.29	1.30	1.34	1.44	2.52	1.84

[1] The sediment was collected from Horseshoe Cove, Sandy Hook. The sediment was then mixed into a composite and portions of this composite was used for the MDL analysis. Each sample was with 20 μg of each individual hydrocarbon.

[2] MDL = σt; where σ is the standard deviation and t is the Students t value. For 99% confidence level, 6 degrees of freedom (one-tailed), t = 3.143.

Table C2. Continued.

Sample ID	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})	Total Petroleum Hydrocarbons[2]
Sediment MDL Determination Using External Standard Calculations (µg/g, wet wt.)																		
897081109	6.19	6.68	6.08	7.46	6.53	12.39	5.79	9.01	5.21	8.07	2.33	2.40	1.30	1.04	0.84	0.71	0.60	464
897081110	5.33	5.77	5.36	6.33	5.39	10.89	5.29	8.79	5.63	4.17	2.55	2.58	1.45	1.33	1.08	0.92	0.81	361
897081111	5.82	6.32	5.60	6.88	5.89	12.37	5.70	8.40	4.78	6.35	3.05	3.46	1.77	1.61	1.39	1.20	1.08	340
897081112	5.26	5.64	5.14	6.34	5.56	11.97	5.46	9.00	5.27	3.68	2.56	2.27	1.68	1.26	1.08	0.92	0.79	341
897081113	6.49	7.04	6.32	7.92	6.07	13.63	6.16	10.22	5.86	10.76	2.68	2.34	1.80	1.50	1.17	1.01	0.91	389
897081114	5.53	5.83	5.36	6.49	5.06	11.13	5.20	8.21	4.36	5.24	2.45	2.56	1.22	1.03	0.82	0.71	0.56	281
897081115	5.41	5.79	5.28	6.45	5.69	10.97	5.40	8.82	5.43	3.77	2.65	2.56	1.65	1.26	1.05	0.90	0.76	323
Average	5.72	6.15	5.59	6.84	5.74	11.91	5.57	8.92	5.22	6.00	2.61	2.59	1.55	1.29	1.06	0.91	0.79	357
Std Dev	0.47	0.54	0.44	0.62	0.48	1.00	0.33	0.65	0.51	2.62	0.23	0.40	0.23	0.22	0.19	0.17	0.18	57.6
%RSD or %CV	8.20	8.73	7.92	9.12	8.35	8.36	6.01	7.24	9.77	43.70	8.66	15.37	14.93	16.74	18.28	18.60	22.78	16.2
MDL[1]	1.47	1.69	1.39	1.96	1.51	3.13	1.05	2.03	1.60	8.25	0.71	1.25	0.73	0.68	0.61	0.53	0.56	181

[1] MDL = σt; where σ is the standard deviation and t is the Students t value. For 99% confidence level, 6 degrees of freedom (one-tailed), t = 3.143.

[2] Determined from the total peak areas in the chromatogram from n-C_6 to n-C_{40} minus any contributions from the internal standard areas.

Table C3. Percentage recoveries of the surrogate internal standard, o-terphenyl from sediment quality control samples.[1]

Sample ID	Location	Batch No	Percentage Recovery
Samples for Method Detection Limit (MDL) Analysis [2]			
897081109	Sandy Hook Bay	1	122
897081110	Sandy Hook Bay	1	108
897081111	Sandy Hook Bay	1	116
897081112	Sandy Hook Bay	1	114
897081113	Sandy Hook Bay	1	262
897081114	Sandy Hook Bay	1	107
897081115	Sandy Hook Bay	1	116
Samples for Matrix Spike Analysis [2,3]			
897081117 [3A]	Sandy Hook Bay	1	112
998021031 [3A]	Sandy Hook Bay	2	79.8
1098032330 [3A]	Sandy Hook Bay	3	105
1198082515 [3B]	Sandy Hook Bay	4	41.2
Standard Reference Material (SRM) Samples [4]			
897081118	-	1	131
998021030	-	2	108
1098032331	-	3	162
1198082517	-	4	12.6
1198082518	-	4	170
1198082519	-	4	170
Method Blank Samples			
897081119 [5]	-	1	99.6
998021032	-	2	94.2
1098032332	-	3	71.2
1198082516	-	4	36.4

[1] The values of the recoveries for the surrogate internal standards were determined using external standard calculations.

[2] The sediment matrix used for each of the samples used for MDL and spiked analyte recoveries was collected at Sandy Hook Bay. Each MDL sample was spiked with 20 μg of each individual hydrocarbon.

[3] The spiking level for these samples were:
3A: 100 μg of each individual hydrocarbon.
3B: 50 μg of each individual hydrocarbon.

[4] The Standard Reference Material (SRM) used for this analysis was Diesel Fuel in Soil #765 from Environmental Resource Associates.

[5] The recovery value was determined using internal standard calculations.

Table C4. Percentage recoveries of the surrogate internal standard, o-terphenyl from sediment samples collected from Old Place marsh.[1]

Sample ID	Batch No	Station	Section No [2]	Percentage Recovery
September 1996 Collection				
998021001	2	A	1	88.4
998021002	2	A	2	95.2
998021003	2	A	3	106
998021004	2	A	4	80.8
998021005	2	A	5	741
998021006	2	B	1	158
998021007	2	B	2	218
998021008	2	B	3	189
998021009	2	B	4	206
998021010	2	B	5	173
998021011	2	C	1	130
998021012	2	C	2	133
998021013	2	C	3	110
998021014	2	C	4	118
998021015	2	C	5	118
998021016	2	D	1	138
998021017	2	D	2	120
998021018	2	D	3	168
998021019	2	D	4	130
998021020	2	D	5	599
May 1997 Collection				
897081101	1	A	SC	104
897081102	1	B	SC	53.7
897081103	1	C	SC	120
897081104	1	D	SC	105

[1] The values of the recoveries for the surrogate internal standards were determined using external standard calculations.

[2] The meaning of the Section No is:

1: Core section with depth 0 to 1 cm.
2: Core section with depth 1 to 2 cm.
3: Core section with depth 2 to 3 cm.
4: Core section with depth 3 to 4 cm.
5: Core section with depth 4 to 5 cm.
SC: Surface Scoop.

Table C5. Percentage recoveries of the surrogate internal standard, o-terphenyl from sediment samples collected from Con Edison Tower marsh.[1]

Sample ID	Batch No	Station	Section No [2]	Percentage Recovery
September 1996 Collection				
998021021	2	A	1	980
998021022	2	A	2	1690
998021023	2	A	3	965
998021024	2	A	4	724
998021025	2	A	5	1050
998021026	2	B	1	1150
998021027	2	B	2	2490
998021028	2	B	3	6510
998021029	2	B	4	9900
1098032325	3	B	5	224
1198082510	4	C	1	208
1198082511	4	C	2	107
1198082512	4	C	3	231
1198082513	4	C	4	4470
1198082514	4	C	5	6830
1198082505	4	D	1	304
1198082506	4	D	2	252
1198082507	4	D	3	1700
1198082508	4	D	4	2880
1198082509	4	D	5	3580
May 1997 Collection				
897081105	1	A	SC	37.2
897081106	1	B	SC	175
897081107	1	C	SC	144
897081108	1	D	SC	5.84

[1] The values of the recoveries for the surrogate internal standards were determined using external standard calculations.

[2] The meaning of the Section No is:

1: Core section with depth 0 to 1 cm.
2: Core section with depth 1 to 2 cm.
3: Core section with depth 2 to 3 cm.
4: Core section with depth 3 to 4 cm.
5: Core section with depth 4 to 5 cm.
SC: Surface Scoop.

Table C6. Percentage recoveries of the surrogate internal standard, o-terphenyl from sediment samples collected from Mill Creek and Sandy Hook Bay marshes.[1]

Sample ID	Batch No	Station	Section No [2]	Percentage Recovery
Mill Creek Marsh - September 1996 Collection				
1098032311	3	A	1	175
1098032312	3	A	2	124
1098032313	3	A	3	143
1098032314	3	A	4	133
1098032306	3	B	1	167
1098032307	3	B	2	25.4
1098032308	3	B	3	109
1098032309	3	B	4	114
1098032310	3	B	5	128
1098032301	3	C	1	128
1098032302	3	C	2	163
1098032303	3	C	3	143
1098032304	3	C	4	132
1098032305	3	C	5	123
1098032316	3	D	1	197
1098032317	3	D	2	38.0
1098032318	3	D	3	219
1098032319	3	D	4	36.1
1098032320	3	D	5	138
Sandy Hook Bay Marsh - Collected August 11, 1997				
897081116	1	-	-	125

[1] The values of the recoveries for the surrogate internal standards were determined using external standard calculations.

[2] The meaning of the Section No is:

- 1: Core section with depth 0 to 1 cm.
- 2: Core section with depth 1 to 2 cm.
- 3: Core section with depth 2 to 3 cm.
- 4: Core section with depth 3 to 4 cm.
- 5: Core section with depth 4 to 5 cm.
- SC: Surface Scoop.

Table C7. Percentage recovery of individual hydrocarbons from spiked Sandy Hook Bay sediment samples. [1-3]

Sample ID	Batch	Octane (n-C_8)	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})	Tetracosane (n-C_{24})
897081117 [4]	1	ND	42.2	60.0	75.3	83.0	87.9	92.8	95.9	99.1	102	102	105	105	108	111	113	112	114	113
998021031 [4]	2	30.7	30.4	31.8	28.3	23.4	24.9	29.5	39.2	47.8	59.7	59.7	64.7	67.8	72.2	73.9	77.4	78.1	80.8	78.0
1098032330 [4]	3	28.6	62.3	75.4	82.0	86.0	90.8	93.6	95.4	97.8	104	101	112	106	121	122	123	121	119	116
1198082515 [5,6]	4	9.66	2.58	4.72	6.83	8.01	9.30	11.0	13.5	17.1	25.2	24.8	37.0	34.2	46.7	51.6	53.0	52.2	50.9	47.7

[1] The sediment was collected from Horseshoe Cove, Sandy Hook. The sediment was then mixed into a composite and portions of this composite was used for the analysis

[2] The concentrations were determined using external standard calculations.

[3] Percent recovery is equal to: 100*(amount of analyte recovered) / (amount of analyte added to the sediment + background analyte amount in the sediment). Since no background sample was run in Batches 2, 3, or 4, a value of 0 was used for the background analyte amount in the equation for these batches.

[4] 100 μg of each individual hydrocarbon was spiked into sediments collected from Sandy Hook Bay.

[5] 50 μg of each individual hydrocarbon was spiked into sediments collected from Sandy Hook Bay.

[6] The surrogate internal standard recovery for this sample was 41.2%.

Table C7. Continued. [1,2]

Sample ID	Batch	Pentacosane ($n\text{-}C_{25}$)	Hexacosane ($n\text{-}C_{26}$)	Heptacosane ($n\text{-}C_{27}$)	Octacosane ($n\text{-}C_{28}$)	Nonacosane ($n\text{-}C_{29}$)	Triacontane ($n\text{-}C_{30}$)	n-Hentriacontane ($n\text{-}C_{31}$)	Dotriacontane ($n\text{-}C_{32}$)	Tritriacontane ($n\text{-}C_{33}$)	Tetratriacontane ($n\text{-}C_{34}$)	Pentatriacontane ($n\text{-}C_{35}$)	Hexatriacontane ($n\text{-}C_{36}$)	Heptatriacontane ($n\text{-}C_{37}$)	Octatriacontane ($n\text{-}C_{38}$)	Nonatriacontane ($n\text{-}C_{39}$)	Tetracontane ($n\text{-}C_{40}$)
897081117 [3]	1	116	114	114	118	NDTV [6]	99.4	85.5	69.9	75.4	36.8	30.4	23.7	19.6	16.1	14.2	12.5
998021031 [3]	2	79.5	77.3	80.8	76.6	78.7	76.1	79.2	69.5	68.5	55.5	43.2	41.2	38.2	34.1	33.9	37.1
1098032330 [3]	3	119	116	116	113	113	112	122	111	116	107	110	108	106	100	98.2	82.5
1198082515 [4,5]	4	45.0	40.5	37.2	33.0	30.2	28.2	26.3	25.1	24.6	22.4	21.2	19.7	19.0	17.9	17.8	17.8

[1] The concentrations were determined using external standard calculations.

[2] Percent recovery is equal to: 100*(amount of analyte recovered) / (amount of analyte added to the sediment + background analyte amount in the sediment). Since no background sample was run in Batches 2, 3, or 4, a value of 0 was used for the background analyte amount in the equation for these batches.

[3] 100 μg of each individual hydrocarbon was spiked into sediments collected from Sandy Hook Bay.

[4] 50 μg of each individual hydrocarbon was spiked into sediments collected from Sandy Hook Bay.

[5] The surrogate internal standard recovery for this sample was 41.2%.

[6] NDTV - the analyte was not detected and no percentage recovery could be calculated.

Table C8. Total petroleum hydrocarbon concentration (μg/g wet wt.) found in the soil SRM, Environmental Resource Associates Standard 765 (#2 Diesel in Soil).

Sample ID	Batch	Concentration TPH [1]
897081118	1	1020
998021030	2	834
1098032331	3	534
1198082518	4	862
1198082519	4	896
1198082517	4	35 [4]
Mean		829
Standard Deviation		180
%RSD [2]		21.7
Certified Value		1420
RPD [3]		41.6

[1] Concentration of total petroleum hydrocarbons (TPH) was calculated with respect to the Restek Diesel Fuel Oil #2 Standard (Cat. No. 31233) using the sum of the areas of all the peaks minus the internal standard peak areas from the chromatograms of the SRM extract and known amount of the oil standard.

[2] Percent relative standard deviation.

[3] Relative percent difference = 100 * (certified value - lab mean) / certified value.

[4] Value is suspected outlier and is not included in any calculations

Table C9. Analysis of Individual Hydrocarbons (μg/g, wet weight) in Soil SRM Replicate Samples [1-3].

Sample ID	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Total Petroleum Hydrocarbons (TPH)
1198082518	5.34	9.69	12.27	17.53	15.98	14.23	14.38	7.84	10.80	6.60	7.36	5.33	3.29	862
1198082519	4.91	8.95	10.22	15.53	14.13	12.93	13.43	7.35	10.12	6.18	7.35	4.94	3.01	896
Average	5.1	9.3	11.2	16.5	15.1	13.6	13.9	7.6	10.5	6.4	7.4	5.1	3.1	879
RPD[4]	8.4	8.0	18.2	12.1	12.3	9.5	6.9	6.5	6.5	6.7	0.2	7.6	8.9	3.9
MDL	2.09	2.03	1.97	1.98	1.73	1.53	1.48	1.35	1.37	1.29	1.30	1.34	1.44	181

1 The concentrations were determined using external standard calculations.

2 n-C_9, n-C_{10}, and n-C_{22} through n-C_{40} were not detected.

3 The soil SRM is Enviromental Resource Associates Standard 765 (#2 Diesel in Soil).

4 RPD Relative Percentage Difference = 100*(abs(Replicate1 - Replicate2))/Average.

Table C10. Method Detection Limit (MDL) Analysis Using Ribbed-Mussel Replicates from Sandy Hook Bay. [1]

Sample ID	Total Sample Wt (in g)	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
Mussel MDL Determination Using Internal Standard Calculations (µg/g, wet wt.)																		
297031717		0.23	0.09	0.15	0.18	0.23	0.36	0.43	0.45	0.47	0.43	0.44	0.45	0.49	0.48	0.70	0.93	0.56
297031718		0.02	0.11	0.19	0.25	0.30	0.40	0.44	0.43	0.44	0.40	0.40	0.41	0.47	0.45	0.72	0.95	0.83
297031719		0.02	0.11	0.20	0.23	0.27	0.33	0.43	0.44	0.48	0.38	0.39	0.39	0.45	0.52	0.88	1.35	1.41
297031720		0.02	0.09	0.15	0.19	0.25	0.36	0.43	0.46	0.48	0.45	0.45	0.46	0.51	0.56	0.74	1.19	1.68
297031721		0.02	0.15	0.27	0.28	0.33	0.43	0.52	0.50	0.52	0.46	0.46	0.47	0.54	0.59	0.86	1.42	2.07
297031722		0.02	0.11	0.19	0.24	0.30	0.42	0.49	0.51	0.51	0.47	0.47	0.46	0.53	0.61	1.04	0.99	2.58
297031723		0.02	0.11	0.20	0.26	0.31	0.41	0.46	0.46	0.48	0.41	0.41	0.41	0.47	0.45	0.75	1.37	0.53
Average		0.05	0.11	0.19	0.23	0.28	0.39	0.46	0.46	0.48	0.43	0.43	0.44	0.50	0.53	0.81	1.17	1.38
Std Dev (σ)		0.08	0.02	0.04	0.04	0.03	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.07	0.12	0.22	0.79
%RSD or %CV		147	18.6	20.1	15.8	12.2	9.33	7.73	6.18	5.50	7.40	7.35	6.94	6.98	12.6	15.0	18.5	56.9
MDL[2]		0.24	0.06	0.12	0.12	0.11	0.11	0.11	0.09	0.08	0.10	0.10	0.10	0.11	0.21	0.38	0.68	2.47

[1] The tissue matrix for these samples was prepared by combining together 12 depurated ribbed mussels collected at Sandy Hook Bay into a homogenate. Individual portions of this homogenate were then used for the MDL analysis. Each sample was spiked with 4µg of each individual hydrocarbon.

[2] MDL=σt; where σ is the standard deviation and t is the Students t value. For 99% confidence level, 6 degrees of freedom (one-tailed), t = 3.143.

Individual Analyte Recoveries from Mussel MDL Replicates[3]

		Analyte Amounts (µg) Added																
		3.99	3.99	3.96	4.03	4.03	3.99	4.03	3.99	4.02	4.01	4.03	4.00	4.03	4.02	4.04	4.02	4.04
		Non-Spiked Mussel Sample Analyte Concentrations (µg/g)																
297031724	7.99	0.02	0.02	0.04	0.03	0.01	0.04	0.02	0.04	0.04	0.00	0.00	0.00	0.02	0.04	0.29	0.35	0.10
		Mussel MDL Replicate Analyte Percent Recoveries																
297031717	7.97	43.7	17.6	28.9	33.3	44.4	67.4	81.7	83.6	85.6	85.4	87.0	89.8	93.1	89.0	88.0	108	92.4
297031718	7.99	4.51	20.8	36.5	46.9	57.8	73.5	83.7	79.1	81.0	78.4	79.1	82.7	88.0	83.4	90.8	111	137
297031719	7.99	4.51	20.4	38.3	43.4	51.9	61.9	80.7	80.9	87.6	76.2	77.2	78.6	84.9	96.2	111	158	233
297031720	7.99	4.51	17.8	27.6	35.1	48.8	66.3	81.0	85.2	88.4	88.4	89.4	92.0	96.2	104	94.1	139	277
297031721	7.97	4.51	29.4	49.8	52.1	63.5	79.9	97.5	91.7	95.1	90.6	91.6	92.9	103	109	108	166	341
297031722	7.99	4.51	21.3	36.0	43.9	58.0	78.0	93.5	93.3	94.0	92.5	92.8	92.4	99.8	113	132	115	425
297031723	7.98	4.51	21.3	36.8	47.9	59.1	75.3	87.9	84.8	87.3	81.3	81.5	81.3	89.2	83.7	94.9	160	87.2

[3] The mussel analyte recoveries in each MDL replicate was calculated using the formula: Percent Recovery is calculated as 100 * AMTMDL / (AMNTADD + AMNTBKGRD) where
AMNTMDL is the analyte amount measured followng extraction and cleanup of each MDL replicate, which is calculated as
(Sample Wt of the MDL Replicate in g) * (Analyte Concentration in µg/g in the MDL Replicate);
AMNTADD is the amount of analyte added to the unspiked mussel MDL replicate in µg; and
AMNTBKGRD is the measured analyte amount in the non-spiked sample following extraction and cleanup, which is calculated as
(Non-spiked Sample Wt in g) * (Analyte Concentration in µg/g in the Non-spiked Sample).

Table C10. (Continued).

Sample ID	Total Sample Wt (in g)	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})	Total Petroleum Hydrocarbons[2]
Mussel MDL Determination Using Internal Standard Calculations (µg/g, wet wt.)																			
297031717		0.46	0.49	0.47	0.45	0.48	0.47	0.46	0.47	0.48	0.45	0.46	0.43	0.42	0.37	0.33	0.29	0.26	32.5
297031718		0.43	0.52	0.43	0.42	0.43	0.43	0.45	0.45	0.45	0.41	0.42	0.39	0.37	0.50	0.29	0.27	0.23	35.6
297031719		0.47	0.73	0.42	0.44	0.43	0.44	0.47	0.52	0.56	0.50	0.42	0.37	0.34	0.42	0.33	0.26	0.22	47.2
297031720		0.49	0.49	0.47	0.46	0.49	0.50	0.49	0.48	0.50	0.46	0.45	0.44	0.39	0.50	0.29	0.25	0.24	33.9
297031721		0.51	0.59	0.48	0.49	0.50	0.52	0.53	0.56	0.55	0.48	0.47	0.43	0.41	0.38	0.32	0.28	0.25	42.7
297031722		0.69	0.62	0.52	0.44	0.62	0.92	0.88	0.49	0.52	0.48	0.47	0.44	0.41	0.49	0.31	0.28	0.25	81.2
297031723		0.43	0.54	0.43	0.43	0.44	0.44	0.48	0.50	0.45	0.41	0.40	0.37	0.35	0.44	0.26	0.24	0.22	37.2
Average		0.50	0.57	0.46	0.45	0.48	0.53	0.54	0.50	0.50	0.45	0.44	0.41	0.38	0.44	0.30	0.27	0.24	44.3
Std Dev (σ)		0.09	0.09	0.04	0.02	0.06	0.18	0.15	0.04	0.04	0.03	0.03	0.03	0.03	0.06	0.03	0.02	0.02	17.1
%RSD or %CV		18.3	15.1	7.94	5.51	13.4	33.4	28.4	7.29	8.62	7.41	6.34	7.98	7.98	12.8	8.67	6.73	7.45	38.5
MDL[1]		0.29	0.27	0.11	0.08	0.20	0.56	0.48	0.11	0.14	0.11	0.09	0.10	0.10	0.18	0.08	0.06	0.06	53.6

[1] MDL=σt; where σ is the standard deviation and t is the Students t value. For 99% confidence level, 6 degrees of freedom (one-tailed), t = 3.143.

[2] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

Individual Analyte Recoveries from Mussel MDL Replicates[3]

Analyte Amounts (µg) Added		4.03	4.03	4.01	3.99	4.02	4.02	3.99	3.91	3.99	3.99	4.03	4.03	4.04	4.03	4.03	4.04	4.04
Non-Spiked Mussel Sample Analyte Concentrations (µg/g)																		
297031724	7.99	0.01	0.07	0.00	0.00	0.01	0.00	0.03	0.04	0.00	0.02	0.02	0.03	0.04	0.06	0.07	0.09	0.10
Mussel MDL Replicate Analyte Percent Recoveries																		
297031717	7.97	88.9	85.1	91.6	89.5	93.4	93.2	86.9	88.4	94.9	85.9	88.1	81.0	76.4	64.9	57.1	49.0	42.9
297031718	7.99	82.8	91.2	84.9	83.7	84.0	84.6	84.5	84.8	90.0	78.4	80.0	73.5	67.9	88.4	51.7	45.0	37.4
297031719	7.99	90.0	127	82.3	87.6	84.0	86.3	89.6	97.7	111	94.9	80.7	68.6	62.7	74.3	58.3	44.0	35.8
297031720	7.99	94.4	86.5	93.6	92.8	96.8	99.0	92.2	89.9	100	88.5	85.8	82.9	70.7	89.1	50.0	42.9	39.3
297031721	7.97	98.2	102	94.7	98.7	96.9	102	99.6	105	110	90.9	90.5	81.0	73.8	66.9	55.2	47.3	40.6
297031722	7.99	134	109	102	88.7	120	183	165	92.3	104	91.0	89.1	81.8	75.1	86.2	53.6	47.1	42.1
297031723	7.98	83.1	94.1	83.9	86.4	86.4	86.2	89.6	93.3	90.7	78.1	76.5	69.8	63.2	77.6	44.9	40.1	35.9

[3] The mussel analyte recoveries in each MDL replicate was calculated using the formula: Percent Recovery is calculated as 100 * AMTMDL / (AMNTADD + AMNTBKGRD) where
AMNTMDL is the analyte amount measured followng extraction and cleanup of each MDL replicate, which is calculated as
(Sample Wt of the MDL Replicate in g) * (Analyte Concentration in µg/g in the MDL Replicate);
AMNTADD is the amount of analyte added to the unspiked mussel MDL replicate inµg; and
AMNTBKGRD is the measured analyte amount in the non-spiked sample following extraction and cleanup, which is calculated as
(Non-spiked Sample Wt in g) * (Analyte Concentration in µg/g in the Non-spiked Sample).

Table C11. Percentage recoveries of the surrogate internal standard, o-terphenyl from the mussel quality control samples.[1]

Sample ID	Location	Batch No	Percentage Recovery
Samples for Method Detection Limit (MDL) Analysis[2]			
297031717	Sandy Hook Bay	2	111
297031718	Sandy Hook Bay	2	107
297031719	Sandy Hook Bay	2	115
297031720	Sandy Hook Bay	2	115
297031721	Sandy Hook Bay	2	117
297031722	Sandy Hook Bay	2	116
297031723	Sandy Hook Bay	2	116
Samples Spiked with Analytes[3]			
197020431 [3A]	-	1	112
297031709 [3B]	Sandy Hook Bay	2	148
497051416 [3C]	Sandy Hook Bay	3	37.7
Sample Used to Measure Analyte Background in MDL and Matrix Spike Samples in Batch[4]			
297031724	Sandy Hook Bay	2	22.9
Standard Reference Material (SRM) Samples[5]			
197020430	-	1	108
297031707	-	2	112
Sample for Replicate Analysis[6]			
197020427	Mill Creek	1	118
197020428	Mill Creek	1	123
197020429	Mill Creek	1	136
Method Blank Samples			
197020432	-	1	52.0
297031708	-	2	87.1
497051408	-	3	99.8

[1] The values of the recoveries for the surrogate internal standards were determined using internal standard calculations.

[2] These samples were prepared from a depurated ribbed mussel homogenate prepared from 12 ribbed mussels collected from Sandy Hook. Each sample was spiked with 40 μg of each individual hydrocarbon.

[3] The tissue matrix and the spiking amount for these samples are:

3A: NIST SRM1974a (Organics in Mussel Tissue) spiked with 25 μg of each hydrocarbon.

3B: The same mussel homogenate from Sandy Hook Bay used for the MDL analysis spiked with 1000 μg Restek No 2 Diesel fuel oil.

3C: The same mussel homogenate from Sandy Hook Bay used for the MDL analysis spiked with 25 μg of each individual hydrocarbon.

[4] The depurated mussel homogenate from Sandy Hook Bay used for the MDL analysis was used to measure the analyte background for the MDL and matrix spike analysis.

[5] The Standard Reference Material (SRM) used was NIST SRM1974a (Organics in Mussel Tissue).

[6] The tissue matrix for these replicate samples came from a large ribbed mussel found at Mill Creek Marsh during the September 1996 collection. Since the length of this mussel was longer (100.5 mm) and heavier (35.2 g) than any mussel collected, it provided enough material for the replicate analysis. However, the analysis results will only be used for quality control purposes, since the length for this mussel exceeds the length criteria of 54 to 75 mm used for choosing mussels for this study.

Table C12. Percentage recoveries of the surrogate internal standard, o-terphenyl from Arthur Kill mussel samples.[1]

Sample ID	Batch No	Percent Recovery
1) Old Place Marsh		
September 1996 Collection		
197020410	1	110
197020411	1	122
197020412	1	122
197020413	1	115
197020414	1	122
May 1997 Collection		
497051411	3	94.3
497051412	3	83.7
497051413	3	84.0
497051414	3	97.9
497051415	3	105
2) Con Edison Tower Marsh		
September 1996 Collection		
197020421	1	124
197020422	1	136
197020423	1	88.2
197020425	1	102
297031701	2	124
May 1997 Collection		
497051422	3	98.6
497051423	3	96.1
497051424	3	93.4
497051425	3	532
497051426	3	95.4
3) Saw Mill North Marsh		
September 1996 Collection		
197020401	1	134
197020402	1	123
197020409	1	130
197020415	1	114
297031702	2	120
May 1997 Collection		
497051405	3	203
497051406	3	98.2
497051407	3	97.7
497051409	3	92.9
497051410	3	111

Sample ID	Batch No	Percent Recovery
4) Saw Mill South Marsh		
September 1996 Collection		
197020426	1	121
297031703	2	144
297031704	2	124
297031705	2	117
297031706	2	126
May 1997 Collection		
497051401	3	92.3
497051402	3	117
497051403	3	104
497051404	3	82.9
497051432	3	105
5) Tufts Point Marsh		
September 1996 Collection		
197020403	1	119
197020404	1	122
197020405	1	123
197020406	1	126
197020408	1	125
May 1997 Collection		
497051427	3	95.0
497051428	3	91.8
497051429	3	100
497051430	3	113
497051431	3	94.5
6) Mill Creek Marsh		
September 1996 Collection		
197020407	1	108
197020417	1	129
197020418	1	116
197020419	1	115
197020420	1	114
May 1997 Collection		
497051417	3	90.0
497051418	3	91.9
497051419	3	103
497051420	3	90.6
497051421	3	101

[1] The values of the recoveries for the surrogate internal standards were determined using internal standard calculations.

Table C13. Percentage recoveries of the surrogate internal standard, o-terphenyl from mussels from Sandy Hook Bay.[1,2]

Sample ID	Batch No	Percent Recovery
297031710	2	135
297031711	2	142
297031712	2	130
297031713	2	136
297031714	2	128
297031715	2	131
297031716	2	134

[1] The values of the recoveries for the surrogate internal standards were determined using internal standard calculations.

[2] Each of these mussel samples is an individual, non-depurated, ribbed mussel taken from Sandy Hook Bay on February 20, 1997.

Table C14. Percent Recovery of Individual Hydrocarbons and Diesel Fuel from Spiked Ribbed Mussel Samples.

Sample ID	Batch No	Tissue Matrix	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})
197020431[1]	1	NIST SRM1974a	10.3	41.3	54.9	68.7	78.0	83.6	86.4	87.4	84.9	86.8	88.0	87.0	93.6	89.7	80.1	88.2	90.8	91.4	92.4
297031709 [2-4]	2	Depurated Mussel Homogenate	185	23.6	52.1	57.9	62.0	81.2	82.0	94.1	87.9	81.2	81.9	74.2	93.4	100	569	650	1740	318	0.00
497051416 [5]	3	Depurated Mussel Homogenate	7.70	4.16	8.00	13.9	26.9	47.2	62.5	74.9	79.9	79.2	83.6	82.1	82.1	86.9	131	100	90.9	88.2	88.4

[1] 25μg of each individual hydrocarbon was spiked into a tissue matrix made from NIST SRM1974a (Organics in Mussel).

[2] 1000μg of Restek Diesel Fuel Oil #2 Standard (Cat. No 31233) was spiked into a mussel tissue homogenate prepared from ribbed mussels collected from Sandy Hook Bay.

[3] The fuel oil will elevate the levels of the individual hydrocarbons n-C8 through n-C26, pristane, and phytane only. The recoveries of only these hydrocarbons are significantly important.

[4] The concentrations of the individual hydrocarbons were not determined. The recoveries of individual hydrocarbons were calculated by comparing the peak areas for the hydrocarbons in the spiked extract to those in the Restek oil standard.

[5] 25μg of each individual hydrocarbon was spiked into a mussel tissue homogenate prepared from ribbed mussels collected from Sandy Hook Bay.

Table C14. (Continued).

Sample ID	Batch No	Tissue Matrix	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})	Total Restek Oil
197020431[1]	1	NIST SRM1974a	92.5	90.5	91.2	91.5	89.4	85.4	79.9	69.7	60.5	46.0	37.5	34.0	29.0	26.2	23.0	-
297031709 [2-6]	2	Depurated Mussel Homogenate	217	1880	1310	-	-	-	-	-	-	-	-	-	-	-	-	76.8
497051416 [7]	3	Depurated Mussel Homogenate	87.5	87.2	85.8	85.0	85.3	85.3	84.9	83.7	81.9	79.1	74.3	66.4	56.2	45.0	34.6	-

[1] 25μg of each individual hydrocarbon was spiked into a tissue matrix made from NIST SRM1974a (Organics in Mussel).

[2] 1000μg of Restek Diesel Fuel Oil #2 Standard (Cat. No 31233) was spiked into a mussel tissue homogenate prepared from ribbed mussels collected from Sandy Hook Bay.

[3] The fuel oil will elevate the levels of the individual hydrocarbons n-C_8 through n-C_{26}, pristane, and phytane only. The recoveries of only these hydrocarbons are significantly important.

[4] The higher recoveries of n-C27 and n-C28 resulted from the contribution of matrix peaks at the retention times of these compounds.

[5] The concentrations of the individual hydrocarbons were not determined. The recoveries of individual hydrocarbons were calculated by comparing the peak areas for the individual hydrocarbons in the spiked extract to those in the Restek oil standard.

[6] The recovery of the Restek oil standard from the spiked mussel sample is calculated by the summing of the peak areas for n-C_{12} through n-C_{17} plus pristane for the spiked sample and the Rrestek oil standard and comparing them.

[7] 25μg of each individual hydrocarbon was spiked into a mussel tissue homogenate prepared from ribbed mussels collected from Sandy Hook Bay.

Table C15. Individual hydrocarbon concentrations (ng/g wet wt.) found in NIST SRM1974a (Organics in Mussel Tissue).[1]

Sample ID	Heptadecane (n-C_{17})	Nonadecane (n-C_{19})	Docosane (n-C_{22})	Tetracosane (n-C_{24})	Hexacosane (n-C_{26})	Octacosane (n-C_{28})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})
197020430	152	194	nd	471	130	997	407	456	596
297031707	239	nd	737	nd	nd	nd	nd	nd	nd
Certified Value [2]	31.8	4.6	5.3	6.5	5.6	7.3	6.4		3.3
MDL [3]	83.7	108.7	681.2	286.3	114.5	203.8	135.7	105.7	88.1

[1] Only the individual hydrocarbons that have values above the MDL and have available certified or uncertified values are listed. Concentration values below the MDL are designated with nd. Since all the MDL are much greater than the certified values, all these numerical values are considered as false positives.

[2] Uncertified values are used.

[3] The units for the MDL are ng/g.

Table C16. Analysis of ribbed mussel replicate samples (μg/g, wet wt.) from Mill Creek marsh. [1,2]

Sample ID	Nonane (n-C_9)	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Nonadecane (n-C_{19})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})	Total Petroleum Hydrocarbons [4]
197020427	0.46	nd	0.16	0.20	0.88	nd	0.15	0.25	0.27	0.30	0.34	0.33	0.33	0.26	0.20	0.12	58.8
197020428	0.40	nd	0.16	nd	0.97	1.02	nd	0.20	0.22	0.27	0.32	0.32	0.32	0.26	0.19	0.12	64.5
197020429	0.96	0.15	0.17	nd	1.22	0.71	0.40	1.43	0.82	0.32	0.32	0.32	0.30	0.25	0.19	0.12	128
Mean	0.61	< MDL	0.16	< MDL	1.02	0.69	0.20	0.63	0.44	0.30	0.33	0.32	0.31	0.25	0.19	0.12	83.7
Std Deviation	0.31	-	0.01	-	0.18	0.34	0.18	0.70	0.33	0.02	0.01	0.01	0.02	0.004	0.01	0.002	38.3
%RSD [3]	50.5	-	5.8	-	17.4	49.2	88.4	110.9	75.9	7.4	3.3	2.7	4.9	1.6	3.8	1.9	45.8
MDL	0.24	0.09	0.08	0.11	0.38	0.68	0.11	0.14	0.11	0.09	0.10	0.10	0.18	0.08	0.06	0.06	53.6

1 This ribbed mussel from Mill Creek marsh was the longest (100.5 mm) and heaviest (35.2 g) collected in the Arthur Kill and provided enough tissue for triplicate analysis.

2 The hydrocarbons n-C_{10} through n-C_{15}, n-C_{18}, n-C_{20}, and n-C_{23} through n-C_{30} plus pristane and phytane were not detected in any mussel replicate samples and were not included in this table.

3 %RSD - Percent relative standard deviation.

4 Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

Table C17. Hydrocarbon concentrations (μg/ml) from different oil standards.[1-4]

	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
Restek Diesel Fuel Oil #2 Standard (Unweathered, Cat 31233) Dissolved in Methylene Chloride																	
	8.04	17.0	44.3	51.4	56.2	44.7	56.0	45.1	33.4	31.8	25.2	13.5	17.4	11.0	6.75	3.31	1.86
	6.43	15.6	45.1	50.6	63.9	51.3	56.9	41.2	34.5	32.6	24.1	11.5	17.7	11.5	6.40	3.28	1.93
	4.78	11.2	31.8	35.5	44.3	38.6	38.8	28.9	24.3	23.1	17.1	8.29	12.6	8.22	4.62	2.38	1.41
	4.22	12.4	32.9	37.6	45.9	50.0	44.2	34.5	29.0	28.0	19.6	11.9	13.4	9.19	5.58	2.68	1.34
	4.60	14.2	36.0	40.9	50.3	52.4	49.2	38.0	31.9	30.7	22.7	13.2	14.7	10.0	6.00	2.81	1.39
Average	5.61	14.1	38.0	43.2	52.1	47.4	49.0	37.6	30.6	29.2	21.8	11.7	15.2	10.00	5.87	2.89	1.59
Std. Dev.	1.60	2.31	6.31	7.39	8.03	5.74	7.74	6.22	4.11	3.84	3.34	2.08	2.30	1.34	0.82	0.40	0.28
Fuel Oil #2 from May 15, 1997 Oil Spill at the Arthur Kill Dissolved in Methylene Chloride																	
	12.9	17.8	41.2	45.5	66.5	97.3	136	97.7	102	61.7	81.8	34.5	83.7	53.9	37.9	23.5	14.5
	12.1	21.7	38.8	46.6	69.5	126	112	85.9	89.0	64.4	68.1	44.6	58.4	48.2	38.0	25.9	16.5
	12.1	21.7	38.8	46.5	71.0	124	112	79.6	88.8	64.0	67.4	44.5	58.1	48.3	38.2	26.4	17.1
Average	12.3	20.4	39.6	46.2	69.0	116	120	87.7	93.2	63.3	72.5	41.2	66.7	50.1	38.0	25.3	16.1
Std. Dev.	0.46	2.27	1.41	0.61	2.30	16.1	13.8	9.21	7.41	1.46	8.13	5.77	14.7	3.26	0.17	1.56	1.35
Home Heating Oil from January 19, 1996 North Cape Oil Spill at Rhode Island Dissolved in Methylene Chloride																	
	7.32	18.8	49.5	45.5	70.7	58.7	69.1	64.7	69.6	34.3	51.7	21.3	43.8	31.3	20.2	0.74	6.39

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] MDL values were not determined for these standards. A value of 0 was used for each nondetected analyte in the summation formulae. When the value of the average and standard deviation for an individual hydrocarbon equals zero, these values are replaced by nd.

[4] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8. A value of 0 was used for n-C_8 in summation formulae.

Table C17. Continued.[1-4]

	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
Restek Diesel Fuel Oil #2 Standard (Unweathered, Cat 31233) Dissolved in Methylene Chloride																	
	0.88	0.54	0.30	0.24	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	1.03	0.69	0.44	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	0.78	0.51	0.45	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	0.38	0.10	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.56	0.30	0.57
	0.38	0.03	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.18	0.29	nd
Average	0.69	0.37	0.24	0.05	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.15	0.12	0.11
Std. Dev.	0.30	0.29	0.22	0.11	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.24	0.16	0.25
Fuel Oil #2 from May 15, 1997 Oil Spill at the Arthur Kill Dissolved in Methylene Chloride																	
	7.08	3.23	1.44	0.56	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	7.62	3.24	0.74	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.29	nd
	8.11	3.65	1.01	0.13	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.29	nd
Average	7.60	3.37	1.06	0.23	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.19	nd
Std. Dev.	0.52	0.24	0.35	0.29	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.17	nd
Home Heating Oil from January 19, 1996 North Cape Oil Spill at Rhode Island Dissolved in Methylene Chloride																	
	3.27	1.68	1.04	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] MDL values were not determined for these standards. A value of 0 was used for each nondetected analyte in the summation formulae. When the value of the average and standard deviation for an individual hydrocarbon equals zero, these values are replaced by nd.

[4] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8. A value of 0 was used for n-C_8 in summation formulae.

Table C17. Continued.[1-4]

	Total Petroleum Hydrocarbons[5]	Total Concentrations of Individual Hydrocarbons[6]	Total: Pristane + Phytane	n-C_{17}/Pristane	n-C_{18}/Phytane	Pristane/Phytane	Total: Odd No Carbons[7]	Total: Even No Carbons[8]	Carbon Preference Index (CPI)[9]	Sum: C_{10}-C_{12}-C_{14}[10]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[11]	Weathering Index (WI)[12]
Restek Diesel Fuel Oil #2 Standard (Unweathered, Cat 31233) Dissolved in Methylene Chloride												
	1370	476	45.3	1.05	1.87	2.36	225	206	1.09	120	4.49	26.8
	1270	478	44.1	1.06	2.10	2.83	233	201	1.16	119	4.74	25.2
	903	339	31.4	1.05	2.07	2.79	163	145	1.13	86.6	3.61	24.0
	1100	387	39.9	1.04	1.65	2.36	177	170	1.04	102	2.91	35.2
	1200	422	43.9	1.04	1.72	2.32	194	184	1.06	110	3.18	34.5
Average	1170	421	40.9	1.05	1.88	2.53	199	181	1.10	108	3.79	29.1
Std. Dev.	179	59.7	5.70	0.01	0.20	0.26	30.2	25.0	0.05	13.9	0.80	5.32
Fuel Oil #2 from May 15, 1997 Oil Spill at the Arthur Kill Dissolved in Methylene Chloride												
	2990	1020	96.2	1.65	2.37	1.79	498	426	1.17	161	32.0	5.02
	2830	982	109	1.38	1.53	1.44	438	436	1.01	199	34.2	5.82
	2830	977	109	1.39	1.51	1.44	440	429	1.03	198	35.5	5.57
Average	2880	993	105	1.47	1.80	1.56	459	430	1.07	186	33.9	5.47
Std. Dev.	89.8	23.6	7.22	0.15	0.49	0.20	34.2	4.91	0.09	21.9	1.79	0.41
Home Heating Oil from January 19, 1996 North Cape Oil Spill at Rhode Island Dissolved in Methylene Chloride												
	2160	672	55.6	2.03	2.43	1.61	338	278	1.22	125	5.05	24.7

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] MDL values were not determined for these standards. A value of 0 was used for each nondetected analyte in the summation formulae. When the value of the average and standard deviation for an individual hydrocarbon equals zero, these values are replaced by nd.

[4] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8. A value of 0 was used for n-C_8 in summation formulae.

[5] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[6] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[7] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[8] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms.

[9] Carbon Preference Index (CPI) defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[10] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[11] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[12] Weathering Index (WI) defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

APPENDIX D

INDIVIDUAL AND TOTAL PETROLEUM HYDROCARBON CONCENTRATIONS

Table D1. Individual hydrocarbon and total petroleum hydrocarbon concentrations (in μg/g wet wt.) for sediment taken from Old Place marsh, a replanted site.[1-3]

Sample ID	Core Section No[4]	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
Station A																		
First Collection Period: Sediment Cores																		
998021001	1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021002	2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021003	3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021004	4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021005	5	2.58	nd	nd	nd	nd	nd	nd	nd	1.80	1.60	2.21	1.66	nd	1.91	2.08	nd	nd
Whole Core: Average[5,6]		< MDL	nd	nd	nd	nd	nd	nd	nd	< MDL	< MDL	< MDL	< MDL	nd	< MDL	< MDL	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Second Collection Period: Sediment Surface Skims																		
897081101		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Station B																		
First Collection Period: Sediment Cores																		
998021006	1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021007	2	nd	nd	nd	nd	nd	3.00	2.73	2.84	5.07	4.86	2.98	4.94	1.64	9.37	1.98	nd	nd
998021008	3	nd	nd	2.19	2.60	3.04	2.18	1.97	3.72	10.8	7.35	2.67	4.29	nd	1.60	1.88	nd	nd
998021009	4	nd	nd	nd	nd	nd	2.26	3.09	2.86	10.2	7.26	2.61	4.19	1.46	11.2	nd	nd	nd
998021010	5	nd	nd	nd	2.19	nd	3.39	3.48	6.07	9.88	6.95	3.35	4.49	2.16	nd	2.29	nd	nd
Whole Core: Average[5,6]		nd	nd	< MDL	< MDL	< MDL	2.36	2.43	3.25	7.35	5.42	2.46	3.71	1.31	4.70	1.52	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	0.92	1.03	1.92	4.35	2.84	1.04	1.74	0.66	5.15	0.74	-	-
Second Collection Period: Sediment Surface Skims																		
897081102		nd	nd	nd	nd	nd	nd	nd	3.03	7.39	10.6	2.34	nd	nd	1.76	nd	nd	nd
MDL		2.57	1.99	2.09	2.03	1.97	1.98	1.73	1.53	1.48	1.35	1.37	1.29	1.30	1.34	1.44	2.52	1.84

Table D1. Continued.[1,2]

Sample ID	Core Section No[4]	Tetracosane ($n\text{-}C_{24}$)	Pentacosane ($n\text{-}C_{25}$)	Hexacosane ($n\text{-}C_{26}$)	Heptacosane ($n\text{-}C_{27}$)	Octacosane ($n\text{-}C_{28}$)	Nonacosane ($n\text{-}C_{29}$)	Triacontane ($n\text{-}C_{30}$)	n-Hentriacontane ($n\text{-}C_{31}$)	Dotriacontane ($n\text{-}C_{32}$)	Tritriacontane ($n\text{-}C_{33}$)	Tetratriacontane ($n\text{-}C_{34}$)	Pentatriacontane ($n\text{-}C_{35}$)	Hexatriacontane ($n\text{-}C_{36}$)	Heptatriacontane ($n\text{-}C_{37}$)	Octatriacontane ($n\text{-}C_{38}$)	Nonatriacontane ($n\text{-}C_{39}$)	Tetracontane ($n\text{-}C_{40}$)
Station A																		
First Collection Period: Sediment Cores																		
998021001	1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021002	2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021003	3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021004	4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021005	5	nd	nd	nd	nd	nd	nd	nd	5.64	2.48	nd	nd	nd	1.23	1.09	1.35	1.34	1.13
Whole Core: Average[5,6]		nd	nd	nd	nd	nd	nd	nd	< MDL	< MDL	nd	nd	nd	< MDL	< MDL	< MDL	< MDL	< MDL
Whole Core: Std. Dev.		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Second Collection Period: Sediment Surface Skims																		
897081101		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Station B																		
First Collection Period: Sediment Cores																		
998021006	1	nd	nd	nd	nd	nd	nd	nd	4.90	3.27	11.2	nd	nd	0.84	nd	nd	nd	nd
998021007	2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021008	3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021009	4	nd	nd	nd	nd	nd	nd	nd	3.87	1.69	nd	nd	2.29	nd	nd	nd	nd	nd
998021010	5	nd	nd	nd	nd	nd	nd	nd	2.40	2.02	nd	nd	nd	nd	nd	nd	nd	nd
Whole Core: Average[5,6]		nd	nd	nd	nd	nd	nd	nd	2.64	1.72	< MDL	nd	< MDL	< MDL	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	-	-	1.73	1.02	-	-	-	-	-	-	-	-
Second Collection Period: Sediment Surface Skims																		
897081102		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MDL		1.47	1.69	1.39	1.96	1.51	3.13	1.05	2.03	1.60	8.25	0.71	1.25	0.73	0.68	0.61	0.53	0.56

Table D1. Continued.[1,2]

Sample ID	Core Section No[4]	Total Petroleum Hydrocarbons[7]	Total Concentrations of Individual Hydrocarbons[8,9,17]	Total: Pristane + Phytane[8,17]	Pristane/n-C_{17}[18]	Phytane/n-C_{18}[18]	Pristane/Phytane[18]	Total: Odd No Carbons[8,10,17]	Total: Even No Carbons[8,11,17]	Carbon Preference Index (CPI)[12,18]	Sum: C_{10}-C_{12}-C_{14}[8,13,17]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[8,14,17]	Weathering Index (WI)[15,18]
Station A													
First Collection Period: Sediment Cores													
998021001	1	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
998021002	2	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
998021003	3	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
998021004	4	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
998021005	5	383	nd	3.26	0.89	0.75	0.96	nd	nd	-	nd	nd	-
Whole Core: Average[5,6]		< MDL	nd	< MDL	-	-	-	nd	nd	-	nd	nd	-
Whole Core: Std. Dev.		-	-	-	-	-	-	-	-	-	-	-	-
Second Collection Period: Sediment Surface Skims													
897081101		nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Station B													
First Collection Period: Sediment Cores													
998021006	1	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
998021007	2	728	61.5	9.79	0.96	1.66	0.98	nd	26.3	-	nd	nd	-
998021008	3	826	64.0	11.6	0.68	1.61	1.71	nd	nd	-	nd	nd	-
998021009	4	834	73.3	11.5	0.71	1.60	1.73	34.0	27.9	1.22	nd	nd	-
998021010	5	1010	68.6	11.4	0.70	1.34	1.55	nd	24.0	-	6.57	nd	-
Whole Core: Average[5,6]		697	59.4	9.13	0.74[19]	1.51[19]	1.46[19]	< MDL	< MDL	-	< MDL	nd	-
Whole Core: Std. Dev.		354	17.3	4.43	-	-	-	-	-	-	-	-	-
Second Collection Period: Sediment Surface Skims													
897081102		494	nd	11.2	1.43	-	-	nd	nd	-	nd	nd	-
MDL		181	59.0[16]	2.63[16]				33.9[16]	22.4[16]		5.99[16]	6.89[16]	

Table D1. Continued.[1-3]

Sample ID	Core Section No[4]	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
Station C																		
First Collection Period: Sediment Cores																		
998021011	1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.51	nd	nd	nd	nd
998021012	2	nd	nd	nd	nd	nd	nd	nd	nd	1.61	nd	nd	nd	nd	nd	nd	nd	nd
998021013	3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021014	4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021015	5	nd	nd	nd	nd	nd	nd	nd	nd	1.53	nd	nd	nd	nd	nd	nd	nd	nd
Whole Core: Average[5,6]		nd	nd	nd	nd	nd	nd	nd	nd	< MDL	nd	nd	nd	< MDL	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Second Collection Period: Sediment Surface Skims																		
897081103		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Station D																		
First Collection Period: Sediment Cores																		
998021016	1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021017	2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021018	3	nd	nd	2.46	3.46	3.47	3.25	3.21	5.98	11.3	8.21	4.06	5.20	nd	2.54	2.31	nd	nd
998021019	4	nd	nd	12.9	13.8	5.04	10.1	11.4	6.57	15.7	15.8	23.0	30.6	15.2	2.86	3.85	4.27	3.98
998021020	5	nd	nd	6.48	5.78	10.8	13.4	9.05	20.2	38.1	31.0	13.9	19.6	6.08	31.3	3.97	2.70	1.94
Whole Core: Average[5,6]		nd	nd	4.78	5.01	4.26	5.75	5.07	6.86	13.3	11.3	8.47	11.3	4.64	7.61	2.32	< MDL	< MDL
Whole Core: Std. Dev.		-	-	5.05	5.28	4.05	5.69	4.86	7.96	15.4	12.7	9.76	13.3	6.33	13.3	1.60	-	-
Second Collection Period: Sediment Surface Skims																		
897081104		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MDL		2.57	1.99	2.09	2.03	1.97	1.98	1.73	1.53	1.48	1.35	1.37	1.29	1.30	1.34	1.44	2.52	1.84

Table D1. Continued.[1,2]

Sample ID	Core Section No[4]	Tetracosane ($n\text{-}C_{24}$)	Pentacosane ($n\text{-}C_{25}$)	Hexacosane ($n\text{-}C_{26}$)	Heptacosane ($n\text{-}C_{27}$)	Octacosane ($n\text{-}C_{28}$)	Nonacosane ($n\text{-}C_{29}$)	Triacontane ($n\text{-}C_{30}$)	n-Hentriacontane ($n\text{-}C_{31}$)	Dotriacontane ($n\text{-}C_{32}$)	Tritriacontane ($n\text{-}C_{33}$)	Tetratriacontane ($n\text{-}C_{34}$)	Pentatriacontane ($n\text{-}C_{35}$)	Hexatriacontane ($n\text{-}C_{36}$)	Heptatriacontane ($n\text{-}C_{37}$)	Octatriacontane ($n\text{-}C_{38}$)	Nonatriacontane ($n\text{-}C_{39}$)	Tetracontane ($n\text{-}C_{40}$)
Station C																		
First Collection Period: Sediment Cores																		
998021011	1	nd	nd	nd	nd	nd	nd	nd	6.13	nd	10.3	nd	nd	nd	nd	nd	nd	nd
998021012	2	nd	nd	nd	nd	nd	3.14	nd	5.36	nd	nd	nd	1.26	nd	nd	nd	nd	nd
998021013	3	nd	nd	nd	nd	nd	3.47	nd	6.44	4.80	nd	nd	nd	nd	nd	nd	nd	nd
998021014	4	nd	nd	nd	nd	nd	3.50	nd	5.43	6.33	nd	nd	nd	0.74	nd	nd	nd	nd
998021015	5	nd	nd	nd	nd	nd	nd	nd	4.46	6.35	nd	nd	2.23	nd	nd	nd	nd	nd
Whole Core: Average[5,6]		nd	nd	nd	nd	nd	< MDL	nd	5.56	3.82	< MDL	nd	< MDL	< MDL	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	-	-	0.77	2.82	-	-	-	-	-	-	-	-
Second Collection Period: Sediment Surface Skims																		
897081103		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Station D																		
First Collection Period: Sediment Cores																		
998021016	1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021017	2	nd	4.11	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021018	3	nd	nd	nd	nd	nd	nd	nd	6.33	2.15	nd	nd	nd	nd	nd	nd	nd	nd
998021019	4	nd	nd	nd	nd	nd	nd	3.46	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
998021020	5	nd	nd	nd	nd	nd	nd	nd	6.99	2.78	nd	nd	nd	nd	nd	nd	nd	nd
Whole Core: Average[5,6]		nd	< MDL	nd	nd	nd	nd	1.11	3.27	< MDL	nd	nd	nd	nd	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	-	1.31	3.10	-	-	-	-	-	-	-	-	-
Second Collection Period: Sediment Surface Skims																		
897081104		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MDL		1.47	1.69	1.39	1.96	1.51	3.13	1.05	2.03	1.60	8.25	0.71	1.25	0.73	0.68	0.61	0.53	0.56

Table D1. Continued.[1,2]

Sample ID	Core Section No[4]	Total Petroleum Hydrocarbons[7]	Total Concentrations of Individual Hydrocarbons[8,9,17]	Total: Pristane + Phytane[8,17]	Pristane/n-C_{17}[18]	Phytane/n-C_{18}[18]	Pristane/Phytane[18]	Total: Odd No Carbons[8,10,17]	Total: Even No Carbons[8,11,17]	Carbon Preference Index (CPI)[12,18]	Sum: C_{10}-C_{12}-C_{14}[8,13,17]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[8,14,17]	Weathering Index (WI)[15,18]
Station C													
First Collection Period: Sediment Cores													
998021011	1	203	nd	nd	-	-	-	nd	nd	-	nd	nd	-
998021012	2	248	nd	nd	-	-	-	nd	nd	-	nd	nd	-
998021013	3	229	nd	nd	-	-	-	nd	nd	-	nd	nd	-
998021014	4	193	nd	nd	-	-	-	nd	nd	-	nd	nd	-
998021015	5	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Whole Core: Average[5,6]		193	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Whole Core: Std. Dev.		61.0	-	-	-	-	-	-	-	-	-	-	-
Second Collection Period: Sediment Surface Skims													
897081103		nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Station D													
First Collection Period: Sediment Cores													
998021016	1	nd	-	nd	-	-	-	nd	nd	-	nd	nd	-
998021017	2	nd	-	nd	-	-	-	nd	nd	-	nd	nd	-
998021018	3	1020	81.8	13.4	0.73	1.28	1.58	40.7	27.7	1.47	7.70	nd	-
998021019	4	3280	195	46.4	1.01	1.33	0.52	79.0	69.3	1.14	24.9	nd	-
998021020	5	2910	239	50.6	0.81	1.41	1.58	93.5	95.2	0.98	20.2	nd	-
Whole Core: Average[5,6]		1480	115	22.6	0.85[19]	1.34[19]	0.99[19]	49.4	42.9	1.15[19]	11.8	nd	-
Whole Core: Std. Dev.		1530	96.9	24.2	-	-	-	35.4	37.6	-	10.2	-	-
Second Collection Period: Sediment Surface Skims													
897081104		nd	-	nd	-	-	-	nd	nd	-	nd	nd	-
MDL		181	59.0[16]	2.63[16]				33.9[16]	22.4[16]		5.99[16]	6.89[16]	

Table D1. Continued.

Footnotes:

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8. A value of 0 was used for each nondetected analyte in summation formulae.

[4] For the sediment cores, these numbers represent the depths into each core: 1 - depth 0 to 1 cm; 2 - depth 1 to 2 cm; 3 - depth 2 to 3 cm; 4 - depth 3 to 4 cm; and, 5 - depth 4 to 5 cm. For surface skims, the topmost 1 cm layer is removed from the sediment surface.

[5] The Whole Core Average and Standard Deviation is calculated using the concentrations for each analyte over all core sections.

[6] If all concentrations are nd, the average is replaced with nd. When there is at least one number in the data set to be averaged, each nd is replaced with 1/2*MDL, and an average is calculated. If this numeric value is less than the MDL, the average is replaced by < MDL; otherwise, the average is the calculated value. When a numeric value is found for the average, the standard deviation is then determined using the same number set used to calculate the average.

[7] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[8] These formulae use 1/2MDL values for each analyte not detected.

[9] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[10] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[11] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms. The contribution of n-C_8 is not included in the total.

[12] Carbon Preference Index (CPI) defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[13] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[14] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[15] Weathering Index (WI) is defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[16] These MDL values are calculated with the same summation formulae as the samples using the individual hydrocarbon MDL values.

[17] The summation totals for the samples are compared with calculated MDL values obtained using the same summation formulae as the samples. When these sample totals were less than the total MDL, its value was replaced by nd. The averages and standard deviations for the totals were treated in the same way as the individual hydrocarbons; see footnote 6.

[18] Numerical values of the CPI, WI, and the ratios: pristane/n-C_{17}, phytane/n-C_{18}, and pristane/phytane, will be calculated only when the defined quantity for each index or ratio has a numeric value.

[19] These results are not true averages, instead they are the ratios of the averages of the defined quantities, if these averages exist.

Table D2. Individual hydrocarbon and total petroleum hydrocarbon concentrations (in μg/g wet wt.) for sediment taken from Con Edison Tower marsh, an unplanted site.[1-3]

Sample ID	Core Section No[4]	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
Station A																		
First Collection Period - Sediment Cores																		
998021021	1	5.62	nd	nd	2.73	nd	2.75	3.09	2.15	28.9	6.13	2.76	9.26	11.4	nd	3.47	nd	7.57
998021022	2	6.64	3.19	4.27	5.56	2.94	3.87	6.08	11.2	61.8	7.18	19.9	43.0	29.7	20.9	32.4	19.6	46.6
998021023	3	2.69	nd	4.48	15.2	3.67	11.9	34.5	26.4	62.5	nd	14.4	41.0	17.6	23.6	29.5	31.8	7.08
998021024	4	nd	nd	3.59	31.7	30.1	7.77	11.8	50.7	101	47.1	6.43	8.03	26.8	35.9	6.98	38.8	21.4
998021025	5	nd	nd	7.15	26.0	47.3	15.2	19.4	39.1	119	67.7	nd	15.8	50.9	52.7	25.0	58.7	66.5
Whole Core: Average[5,6]		3.50	< MDL	4.11	16.2	17.0	8.28	15.0	25.9	74.6	25.8	8.83	23.4	27.3	26.8	19.5	30.1	29.8
Whole Core: Std. Dev.		2.49	-	2.18	12.6	20.7	5.25	12.6	19.8	35.6	29.9	8.10	17.2	15.1	19.3	13.3	21.5	26.0
Second Collection Period - Sediment Surface Skims																		
897081101		nd	nd	nd	nd	nd	3.57	nd	nd	3.27	12.8	4.66	8.64	2.70	5.99	nd	nd	nd
Station B																		
First Collection Period - Sediment Cores																		
998021026	1	5.43	nd	nd	4.24	2.52	11.3	20.7	32.5	97.4	53.2	35.9	75.7	26.7	9.99	21.9	8.15	20.5
998021027	2	12.6	8.70	12.3	8.12	nd	11.6	44.9	108	188	44.5	47.4	151	39.9	75.8	79.9	76.9	103
998021028	3	12.6	13.6	18.8	8.59	21.3	12.6	49.2	147	97.3	113	7.06	137	108	116	106	85.7	110
998021029	4	13.4	13.0	18.9	14.3	11.0	18.7	29.2	165	143	nd	29.6	238	21.2	134	139	84.1	142
1098032325	5	nd	nd	nd	nd	3.72	3.32	3.68	9.42	18.1	29.5	9.29	8.95	nd	2.92	3.22	7.50	3.98
Whole Core: Average[5,6]		9.06	7.47	10.4	7.26	7.90	11.5	29.5	92.5	109	48.1	25.9	122	39.3	67.7	70.0	52.5	75.9
Whole Core: Std. Dev.		5.42	6.20	8.96	5.02	8.42	5.47	18.5	69.0	63.2	41.3	17.4	85.7	41.0	59.8	56.8	40.9	60.3
Second Collection Period - Sediment Surface Skims																		
897081102		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MDL		2.57	1.99	2.09	2.03	1.97	1.98	1.73	1.53	1.48	1.35	1.37	1.29	1.30	1.34	1.44	2.52	1.84

Table D2. Continued.[1,2]

Sample ID	Core Section No[4]	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
Station A																		
First Collection Period - Sediment Cores																		
998021021	1	nd	3.21	2.33	5.45	5.40	8.78	5.13	6.77	3.54	nd	58.5	4.00	nd	3.54	4.48	5.73	nd
998021022	2	7.98	23.2	8.54	35.8	nd	5.55	41.7	10.6	13.9	nd	69.6	nd	nd	3.54	4.62	nd	9.37
998021023	3	nd	5.48	4.45	18.7	2.53	5.61	23.4	nd	13.2	nd	13.9	nd	nd	3.28	4.26	5.46	8.77
998021024	4	29.1	26.8	51.8	12.8	15.3	55.2	45.8	27.0	11.8	21.3	9.83	4.18	nd	3.29	4.02	4.59	7.31
998021025	5	13.3	52.8	61.3	24.6	nd	75.3	60.7	32.1	nd	nd	nd	nd	nd	2.92	4.01	4.99	nd
Whole Core: Average[5,6]		10.4	22.3	25.7	19.5	4.95	30.1	35.4	15.5	8.65	< MDL	30.4	2.01	nd	3.32	4.28	4.21	5.20
Whole Core: Std. Dev.		11.7	20.0	28.5	11.6	6.09	32.9	21.5	13.4	6.04	-	31.3	1.90	-	0.25	0.27	2.25	4.55
Second Collection Period - Sediment Surface Skims																		
897081101		nd	3.35	nd	nd	nd	nd	nd	3.62	nd	nd	nd	nd	nd	nd	nd	nd	nd
Station B																		
First Collection Period - Sediment Cores																		
998021026	1	2.75	9.16	nd	8.45	4.40	7.82	7.57	15.1	4.14	21.2	114	5.91	nd	3.23	3.97	nd	8.35
998021027	2	9.12	11.6	nd	33.5	19.8	15.7	51.7	18.3	14.0	26.7	84.3	nd	nd	5.21	5.27	6.44	nd
998021028	3	35.6	36.6	40.4	59.8	4.39	27.6	34.4	nd	7.49	14.0	7.88	nd	nd	2.70	nd	nd	7.48
998021029	4	57.1	28.5	13.8	15.6	nd	18.2	53.3	nd	nd	nd	nd	nd	nd	3.97	5.22	6.24	nd
1098032325	5	nd	3.12	3.29	4.70	nd	3.30	nd	16.9	7.38	nd	nd	nd	nd	nd	nd	nd	nd
Whole Core: Average[5,6]		21.1	17.8	11.8	24.4	6.03	14.5	29.5	10.5	6.77	14.0	41.4	1.68	nd	3.09	3.01	2.69	3.33
Whole Core: Std. Dev.		24.5	14.1	16.9	22.7	7.93	9.43	24.5	8.70	4.90	10.1	53.9	2.36	-	1.80	2.53	3.33	4.19
Second Collection Period - Sediment Surface Skims																		
897081102		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MDL		1.47	1.69	1.39	1.96	1.51	3.13	1.05	2.03	1.60	8.25	0.71	1.25	0.73	0.68	0.61	0.53	0.56

Table D2. Continued.[1,2]

Sample ID	Core Section No[4]	Total Petroleum Hydrocarbons[7]	Total Concentrations of Individual Hydrocarbons[8,9,17]	Total: Pristane + Phytane[8,17]	Pristane/n-C_{17}[18]	Phytane/n-C_{18}[18]	Pristane/Phytane[18]	Total: Odd No Carbons[8,10,17]	Total: Even No Carbons[8,11,17]	Carbon Preference Index (CPI)[12,18]	Sum:C_{10}-C_{12}-C_{14}[8,13,17]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[8,14,17]	Weathering Index (WI)[15,18]
Station A													
First Collection Period - Sediment Cores													
998021021	1	1360	213	15.4	0.21	3.35	0.66	104	94.1	1.10	6.47	9.73	0.67
998021022	2	4910	565	50.2	0.12	2.16	0.17	274	241	1.14	12.6	36.9	0.34
998021023	3	5270	444	41.6	-	2.85	-	206	196	1.05	28.1	39.6	0.71
998021024	4	10100	761	55.1	0.47	1.25	5.86	358	348	1.03	40.4	135	0.30
998021025	5	12900	953	83.5	0.57	-	4.29	534	335	1.59	42.1	134	0.31
Whole Core: Average[5,6]		6903.23	587	49.2	0.34[19]	2.65[19]	1.10[19]	295	243	1.22[19]	25.9	71.0	0.37[19]
Whole Core: Std. Dev.		4562.09	285	24.5	-	-	-	163	105	-	16.1	59.1	-
Second Collection Period - Sediment Surface Skims													
897081101		1100	71.2	21.5	3.92	1.85	1.48	-	23.1	-	-	-	-
Station B													
First Collection Period - Sediment Cores													
998021026	1	3840	646	129	0.55	2.11	0.70	267	249	1.07	16.6	16.0	1.04
998021027	2	12000	1320	195	0.24	3.19	0.29	599	522	1.15	28.4	107	0.27
998021028	3	12900	1440	249	1.16	19.4	0.82	666	529	1.26	34.8	166	0.21
998021029	4	17300	1430	238	-	8.03	-	597	591	1.01	46.1	156	0.30
1098032325	5	8570	156	38.5	1.63	0.96	3.30	69.0	48.5	1.42	-	12.3	-
Whole Core: Average[5,6]		10900	998	170	0.44[19]	4.72[19]	0.39[19]	440	388	1.13[19]	25.8	91.3	0.28[19]
Whole Core: Std. Dev.		5040	574	87.5	-	-	-	259	231	-	16.6	74.0	-
Second Collection Period - Sediment Surface Skims													
897081102		193.58	nd	-	0.00	-	-	-	-	-	-	-	-
MDL		181	59.0[16]	2.63[16]				33.9[16]	22.4[16]		5.99[16]	6.89[16]	

Table D2. Continued.[1-3]

Sample ID	Core Section No[4]	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
Station C																		
First Collection Period - Sediment Cores																		
1198082510	1	nd	nd	nd	nd	nd	nd	nd	nd	5.30	nd	nd	nd	nd	nd	nd	nd	nd
1198082511	2	nd	nd	nd	nd	nd	nd	nd	nd	2.11	nd	nd	nd	nd	nd	nd	nd	nd
1198082512	3	nd	nd	nd	nd	nd	nd	nd	2.26	8.18	nd	nd	7.43	1.55	5.71	6.80	5.66	2.03
1198082513	4	nd	nd	nd	nd	nd	nd	2.05	39.2	51.2	nd	7.27	63.2	25.8	52.5	36.4	31.5	22.5
1198082514	5	nd	nd	3.35	nd	nd	12.6	6.96	15.2	71.6	nd	13.0	100	44.7	118	60.4	56.8	25.9
Whole Core: Average[5,6]		nd	nd	< MDL	nd	nd	3.31	2.32	11.6	27.7	nd	4.47	34.4	14.7	35.5	21.0	19.3	10.5
Whole Core: Std. Dev.		-	-	-	-	-	5.20	2.65	16.6	31.7	-	5.57	45.1	19.9	50.9	26.5	24.5	12.6
Second Collection Period - Sediment Surface Skims																		
897081103		nd	nd	nd	nd	nd	nd	2.77	nd	7.08	nd	nd	nd	nd	nd	nd	nd	nd
Station D																		
First Collection Period - Sediment Cores																		
1198082505	1	nd	nd	nd	nd	nd	nd	nd	3.35	2.56	18.9	nd	nd	nd	nd	nd	nd	nd
1198082506	2	nd	nd	nd	8.33	nd	2.76	37.7	15.3	52.8	8.69	28.6	44.2	nd	24.0	22.9	24.4	nd
1198082507	3	nd	2.70	6.80	nd	7.78	10.0	9.85	6.97	52.8	nd	nd	50.3	1.95	28.8	5.07	37.6	7.22
1198082508	4	3.18	12.7	9.58	nd	8.75	11.8	15.2	56.5	73.9	nd	nd	96.0	3.65	nd	62.4	33.1	9.09
1198082509	5	4.34	5.13	10.4	nd	11.3	14.9	17.2	62.3	102	117	4.17	182	15.3	43.6	54.8	10.2	2.94
Whole Core: Average[5,6]		< MDL	4.51	5.77	2.48	5.97	8.10	16.2	28.9	56.8	29.2	6.96	74.7	4.44	19.5	29.2	21.3	4.22
Whole Core: Std. Dev.		-	4.90	4.51	3.27	4.73	5.98	13.6	28.3	36.5	49.7	12.2	69.0	6.20	18.7	28.2	15.3	3.75
Second Collection Period - Sediment Surface Skims																		
897081104		nd	nd	nd	nd	nd	nd	nd	nd	nd	4.01	nd	nd	nd	1.62	nd	nd	nd
MDL		2.57	1.99	2.09	2.03	1.97	1.98	1.73	1.53	1.48	1.35	1.37	1.29	1.30	1.34	1.44	2.52	1.84

Table D2. Continued.[1,2]

Sample ID	Core Section No[4]	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
Station C																		
First Collection Period - Sediment Cores																		
1198082510	1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	2.89	nd	nd	nd	nd	nd	nd
1198082511	2	nd	nd	nd	nd	nd	nd	nd	3.78	nd	nd	9.49	nd	nd	nd	nd	nd	nd
1198082512	3	4.38	nd	nd	4.08	nd	nd	4.60	nd	nd	nd	3.35	nd	nd	nd	nd	nd	nd
1198082513	4	4.82	11.8	nd	19.4	nd	nd	22.0	2.06	5.03	nd	2.34	nd	nd	1.12	nd	1.73	3.32
1198082514	5	10.9	6.83	7.59	14.6	nd	17.5	31.1	nd	nd	nd	nd	nd	nd	1.38	nd	2.26	3.77
Whole Core: Average[5,6]		4.32	4.23	2.07	8.00	nd	4.76	11.8	< MDL	1.65	nd	3.69	nd	nd	0.70	nd	0.96	1.59
Whole Core: Std. Dev.		4.18	4.96	3.08	8.46	-	7.14	14.0	-	1.89	-	3.44	-	-	0.51	-	0.96	1.79
Second Collection Period - Sediment Surface Skims																		
897081103		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Station D																		
First Collection Period - Sediment Cores																		
1198082505	1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	7.35	nd	1.56	1.83	nd	nd
1198082506	2	nd	nd	nd	6.56	nd	nd	23.5	nd	nd	nd	8.22	nd	nd	1.71	2.22	2.57	3.75
1198082507	3	nd	nd	5.32	4.30	nd	nd	24.7	nd	6.36	nd	nd	nd	nd	1.51	2.06	2.39	3.29
1198082508	4	5.48	2.62	3.60	nd	2.43	4.09	33.0	nd	nd	nd	nd	nd	nd	1.93	2.40	3.32	3.98
1198082509	5	nd	17.3	9.80	3.39	nd	nd	20.1	nd	1.78	nd	nd	nd	nd	1.17	1.16	1.71	3.24
Whole Core: Average[5,6]		1.69	4.49	4.02	3.24	< MDL	< MDL	20.4	nd	2.11	nd	1.93	1.97	nd	1.57	1.94	2.05	2.91
Whole Core: Std. Dev.		2.12	7.21	3.79	2.36	-	-	12.1	-	2.41	-	3.52	3.01	-	0.28	0.48	1.15	1.50
Second Collection Period - Sediment Surface Skims																		
897081104		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MDL		1.47	1.69	1.39	1.96	1.51	3.13	1.05	2.03	1.60	8.25	0.71	1.25	0.73	0.68	0.61	0.53	0.56

Table D2. Continued.[1,2]

Sample ID	Core Section No[3]	Total Petroleum Hydrocarbons[7]	Total Concentrations of Individual Hydrocarbons[8,9,17]	Total: Pristane + Phytane[8,17]	Pristane/n-C_{17}[18]	Phytane/n-C_{18}[18]	Pristane/Phytane[18]	Total: Odd No Carbons[8,10,17]	Total: Even No Carbons[8,11,17]	Carbon Preference Index (CPI)[12,18]	Sum: C_{10}-C_{12}-C_{14}[8,13,17]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[8,14,17]	Weathering Index (WI)[15,18]
Station C													
First Collection Period - Sediment Cores													
1198082510	1	198	nd	-	-	-	-	-	-	-	-	-	-
1198082511	2	233	nd	-	-	-	-	-	-	-	-	-	-
1198082512	3	852	76.5	8.10	-	-	-	35.6	32.9	1.08	-	11.5	-
1198082513	4	5660	421	63.9	-	8.69	-	184	173	1.06	-	37.8	-
1198082514	5	8830	638	101	-	7.68	-	264	273	0.96	14.6	76.1	0.19
Whole Core: Average[5,6]		3150	239	35.1	-	7.69 [19]	-	103	100	1.03 [19]	< MDL	26.5	-
Whole Core: Std. Dev.		3910	277	45.1	-	-	-	114	118	-	-	31.1	-
Second Collection Period - Sediment Surface Skims													
897081103		225	nd	-	-	-	-	-	-	-	6.19	-	-
Station D													
First Collection Period - Sediment Cores													
1198082505	1	677	61.6	19.5	7.39	-	-	-	-	-	-	-	-
1198082506	2	3670	336	52.9	0.16	1.55	0.20	137	145	0.94	12.1	26.6	0.45
1198082507	3	4790	292	50.9	-	-	-	109	132	0.83	13.7	44.5	0.31
1198082508	4	7260	470	96.7	-	-	-	204	169	1.21	25.6	44.6	0.57
1198082509	5	8510	728	300	1.15	43.8	0.64	249	180	1.39	21.1	21.5	0.98
Whole Core: Average[5,6]		4980	377	104	0.51 [19]	10.7 [19]	0.39 [19]	143	127	1.13 [19]	15.1	28.1	0.54 [19]
Whole Core: Std. Dev.		3080	245	113	-	-	-	89.6	67.6	-	8.70	17.3	-
Second Collection Period - Sediment Surface Skims													
897081104		357	nd	4.65	-	-	-	nd	nd	-	nd	nd	-
MDL		181	59.0 [16]	2.63 [16]				33.9 [16]	22.4 [16]		5.99 [16]	6.89 [16]	

Table D2. Continued.

Footnotes:

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8. A value of 0 was used for each nondetected analyte in summation formulae.

[4] For the sediment cores, these numbers represent the depths into each core: 1 - depth 0 to 1 cm; 2 - depth 1 to 2 cm; 3 - depth 2 to 3 cm; 4 - depth 3 to 4 cm; and, 5 - depth 4 to 5 cm. For surface skims, the topmost 1 cm layer is removed from the sediment surface.

[5] The Whole Core Average and Standard Deviation is calculated using the concentrations for each analyte over all core sections.

[6] If all concentrations are nd, the average is replaced with nd. When there is at least one number in the data set to be averaged, each nd is replaced with 1/2*MDL, and an average is calculated. If this numeric value is less than the MDL, the average is replaced by < MDL; otherwise, the average is the calculated value. When a numeric value is found for the average, the standard deviation is then determined using the same number set used to calculate the average.

[7] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[8] These formulae use 1/2MDL values for each analyte not detected.

[9] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[10] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[11] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms. The contribution of n-C_8 is not included in the total.

[12] Carbon Preference Index (CPI) defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[13] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[14] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[15] Weathering Index (WI) is defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[16] These MDL values are calculated with the same summation formulae as the samples using the individual hydrocarbon MDL values.

[17] The summation totals for the samples are compared with calculated MDL values obtained using the same summation formulae as the samples. When these sample totals were less than the total MDL, its value was replaced by nd. The averages and standard deviations for the totals were treated in the same way as the individual hydrocarbons; see footnote 6.

[18] Numerical values of the CPI, WI, and the ratios: pristane/n-C_{17}, phytane/n-C_{18}, and pristane/phytane, will be calculated only when the defined quantity for each index or ratio has a numeric value.

[19] These results are not true averages, instead they are the ratios of the averages of the defined quantities, if these averages exist.

Table D3. Individual hydrocarbon and total petroleum hydrocarbon concentrations (in μg/g wet wt.) for sediment cores taken from the Mill Creek marsh, a reference site.[1-4]

Sample ID	Core Section No[5]	Nonane ($n\text{-}C_9$)	Decane ($n\text{-}C_{10}$)	Undecane ($n\text{-}C_{11}$)	Dodecane ($n\text{-}C_{12}$)	Tridecane ($n\text{-}C_{13}$)	Tetradecane ($n\text{-}C_{14}$)	Pentadecane ($n\text{-}C_{15}$)	Hexadecane ($n\text{-}C_{16}$)	Heptadecane ($n\text{-}C_{17}$)	Pristane	Octadecane ($n\text{-}C_{18}$)	Phytane	Nonadecane ($n\text{-}C_{19}$)	Eicosane ($n\text{-}C_{20}$)	Heneicosane ($n\text{-}C_{21}$)	Docosane ($n\text{-}C_{22}$)	Tricosane ($n\text{-}C_{23}$)
Station A[6]																		
1098032311	1	nd	nd	nd	nd	nd	nd	nd	nd	2.11	nd	nd	nd	nd	nd	nd	nd	nd
1098032312	2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1098032313	3	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.57	nd	2.11	nd	nd	nd	nd	nd
1098032314	4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Whole Core: Average[7,8]		nd	nd	nd	nd	nd	nd	nd	nd	< MDL	< MDL	nd	< MDL	nd	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Station B																		
1098032306	1	nd	nd	nd	nd	nd	nd	nd	nd	2.24	nd	nd	nd	3.21	nd	nd	nd	nd
1098032307	2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1098032308	3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1098032309	4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.53	nd	nd	nd	nd
1098032310	5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Whole Core: Average[7,8]		nd	nd	nd	nd	nd	nd	nd	nd	< MDL	nd	nd	nd	1.34	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	-	-	-	-	-	-	-	1.12	-	-	-	-
Station C																		
1098032301	1	nd	nd	nd	nd	nd	nd	nd	nd	1.73	nd	nd	nd	nd	nd	nd	nd	nd
1098032302	2	nd	nd	nd	nd	nd	nd	nd	nd	2.24	nd	nd	nd	2.13	nd	nd	nd	nd
1098032303	3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1098032304	4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1098032305	5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Whole Core: Average[7,8]		nd	nd	nd	nd	nd	nd	nd	nd	< MDL	nd	nd	nd	< MDL	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Station D																		
1098032316	1	nd	nd	nd	nd	nd	nd	nd	nd	2.03	nd	nd	nd	nd	nd	nd	nd	nd
1098032317	2	nd	nd	nd	nd	nd	nd	nd	nd	2.52	nd	nd	nd	nd	nd	nd	nd	nd
1098032318	3	nd	nd	nd	nd	4.89	4.58	11.5	2.97	11.4	13.2	8.42	8.29	8.65	3.68	4.06	nd	nd
1098032319	4	nd	nd	2.56	3.06	5.08	19.6	nd	5.68	7.66	6.92	nd	nd	6.04	nd	nd	3.42	nd
1098032320	5	nd	8.66	nd	3.53	3.37	18.2	8.06	8.23	8.64	10.4	nd	3.16	1.58	1.37	nd	nd	nd
Whole Core: Average[7,8]		nd	2.53	< MDL	< MDL	3.06	8.87	4.43	3.68	6.45	6.37	2.23	2.68	3.51	1.41	< MDL	< MDL	nd
Whole Core: Std. Dev.		-	3.43	-	-	2.01	9.29	5.03	3.25	4.06	5.65	3.46	3.32	3.64	1.30	-	-	-
MDL		2.57	1.99	2.09	2.03	1.97	1.98	1.73	1.53	1.48	1.35	1.37	1.29	1.30	1.34	1.44	2.52	1.84

Table D3. Continued.[1-3]

Sample ID	Core Section No[5]	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
Station A[6]																		
1098032311	1	nd	nd	nd	nd	nd	3.66	nd	7.61	nd	17.9	nd	nd	nd	nd	nd	nd	nd
1098032312	2	nd	nd	nd	nd	nd	3.90	nd	7.02	nd	nd	nd	nd	nd	nd	nd	nd	nd
1098032313	3	nd	nd	nd	nd	nd	nd	nd	5.26	nd	20.2	nd	nd	1.52	nd	nd	nd	nd
1098032314	4	nd	nd	nd	nd	nd	3.56	nd	6.29	nd	nd	nd	nd	1.91	nd	nd	nd	nd
Whole Core: Average[7,8]		nd	nd	nd	nd	nd	3.17	nd	6.54	nd	11.6	nd	nd	1.04	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	1.08	-	1.01	-	8.67	-	-	0.80	-	-	-	-
Station B																		
1098032306	1	nd	nd	nd	nd	nd	3.47	nd	8.38	nd	17.1	nd	nd	nd	nd	nd	nd	nd
1098032307	2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1098032308	3	nd	nd	nd	nd	nd	3.56	nd	7.45	nd	12.7	nd	nd	0.91	nd	nd	nd	nd
1098032309	4	nd	nd	nd	nd	nd	nd	nd	5.68	nd	32.0	nd	nd	1.92	nd	nd	nd	nd
1098032310	5	nd	nd	nd	nd	nd	nd	nd	5.73	nd	42.4	nd	nd	1.42	nd	nd	nd	nd
Whole Core: Average[7,8]		nd	nd	nd	nd	nd	< MDL	nd	5.65	nd	21.7	nd	nd	1.00	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	-	-	2.84	-	15.4	-	-	0.68	-	-	-	-
Station C																		
1098032301	1	nd	nd	nd	nd	nd	nd	nd	8.18	nd	18.2	nd	nd	nd	nd	nd	nd	nd
1098032302	2	nd	nd	nd	nd	nd	3.61	nd	8.02	1.89	17.6	nd	nd	nd	nd	nd	nd	nd
1098032303	3	nd	nd	nd	nd	nd	4.85	nd	8.03	2.21	nd	nd	nd	0.90	nd	nd	nd	nd
1098032304	4	nd	nd	nd	nd	nd	5.27	nd	7.23	2.31	40.7	nd	nd	0.94	nd	nd	nd	nd
1098032305	5	nd	nd	nd	nd	nd	4.18	nd	7.66	1.95	nd	nd	nd	1.07	nd	nd	nd	nd
Whole Core: Average[7,8]		nd	nd	nd	nd	nd	3.90	nd	7.82	1.83	17.0	nd	nd	< MDL	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	-	1.45	-	0.38	0.60	15.0	-	-	-	-	-	-	-
Station D																		
1098032316	1	nd	nd	nd	nd	nd	3.29	nd	8.66	2.51	10.3	nd	nd	nd	nd	nd	nd	nd
1098032317	2	nd	nd	nd	nd	1.63	3.54	1.65	5.42	2.02	nd	0.74	nd	nd	nd	nd	nd	nd
1098032318	3	nd	nd	1.62	nd	3.04	4.42	3.75	3.05	nd	nd	nd	nd	nd	nd	nd	nd	nd
1098032319	4	nd	nd	1.89	2.03	1.74	3.98	2.77	2.57	nd	nd	0.74	nd	nd	nd	nd	nd	nd
1098032320	5	nd	2.13	nd	nd	3.43	3.81	nd	3.01	nd	nd	nd	nd	nd	nd	nd	nd	nd
Whole Core: Average[7,8]		nd	< MDL	< MDL	< MDL	2.12	3.81	1.85	4.54	< MDL	< MDL	< MDL	nd	nd	nd	nd	nd	nd
Whole Core: Std. Dev.		-	-	-	-	1.10	0.43	1.42	2.56	-	-	-	-	-	-	-	-	-
MDL		1.47	1.69	1.39	1.96	1.51	3.13	1.05	2.03	1.60	8.25	0.71	1.25	0.73	0.68	0.61	0.53	0.56

Table D3. Continued.[1-3]

Sample ID	Core Section No[5]	Total Petroleum Hydrocarbons[9]	Total Concentrations of Individual Hydrocarbons[10,11,19]	Total: Pristane + Phytane[10,19]	Pristane/n-C_{17}[20]	Phytane/n-C_{18}[20]	Pristane/Phytane[20]	Total: Odd No Carbons[10,12,19]	Total: Even No Carbons[10,13,19]	Carbon Preference Index (CPI)[14,20]	Sum: C_{10}-C_{12}-C_{14}[10,15,19]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[10,16,19]	Weathering Index (WI)[17,20]
Station A[6]													
1098032311	1	nd	nd	nd	-	-	-	40.8	nd	-	nd	nd	-
1098032312	2	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
1098032313	3	nd	nd	3.69	-	-	0.75	37.3	nd	-	nd	nd	-
1098032314	4	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Whole Core: Average[7,8]		nd	nd	< MDL	-	-	-	< MDL	nd	-	nd	nd	-
Whole Core: Std. Dev.		-	-	-	-	-	-	-	-	-	-	-	-
Station B													
1098032306	1	nd	nd	nd	-	-	-	43.3	nd	-	nd	nd	-
1098032307	2	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
1098032308	3	nd	nd	nd	-	-	-	34.0	nd	-	nd	nd	-
1098032309	4	nd	64.5	nd	-	-	-	50.4	nd	-	nd	nd	-
1098032310	5	nd	73.5	nd	-	-	-	59.9	nd	-	nd	nd	-
Whole Core: Average[7,8]		nd	< MDL	nd	-	-	-	40.9	nd	-	nd	nd	-
Whole Core: Std. Dev.		-	-	-	-	-	-	16.4	-	-	-	-	-
Station C													
1098032301	1	nd	nd	nd	-	-	-	39.2	nd	-	nd	nd	-
1098032302	2	nd	nd	nd	-	-	-	42.5	nd	-	nd	nd	-
1098032303	3	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
1098032304	4	nd	78.1	nd	-	-	-	63.5	nd	-	nd	nd	-
1098032305	5	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Whole Core: Average[7,8]		nd	< MDL	nd	-	-	-	35.8	nd	-	nd	nd	-
Whole Core: Std. Dev.		-	-	-	-	-	-	19.6	-	-	-	-	-
Station D													
1098032316	1	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
1098032317	2	210	nd	nd	-	-	-	nd	nd	-	nd	nd	-
1098032318	3	2540	114	21.5	1.16	0.98	1.59	58.4	34.2	1.71	6.59	nd	-
1098032319	4	1660	91.2	7.56	0.90	-	-	39.9	43.7	0.91	23.6	7.79	3.04
1098032320	5	2070	104	13.5	1.20	-	3.29	40.9	49.4	0.83	30.4	nd	-
Whole Core: Average[7,8]		1310	73.6	9.04	0.99[21]	1.20[21]	2.38[21]	34.6	29.9	-	13.3	< MDL	2.25[21]
Whole Core: Std. Dev.		1110	41.1	8.61	-	-	-	17.7	18.0	-	12.8	-	-
MDL		181	59.0[18]	2.63[18]				33.9[18]	22.4[18]		5.99[18]	6.89[18]	

Table D3. Continued.

Footnotes:

[1] No surface skim samples were analyzed for Mill Creek Marsh.

[2] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[3] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[4] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8. A value of 0 was used for each nondetected analyte in summation formulae.

[5] For the sediment cores, these numbers represent the depths into each core: 1 - depth 0 to 1 cm; 2 - depth 1 to 2 cm; 3 - depth 2 to 3 cm; 4 - depth 3 to 4 cm; and, 5 - depth 4 to 5 cm.

[6] The extract for core section 5 for Station A was lost during sample cleanup.

[7] The Whole Core Average and Standard Deviation is calculated using the concentrations for each analyte over all core sections.

[8] If all concentrations are nd, the average is replaced with nd. When there is at least one number in the data set to be averaged, each nd is replaced with 1/2*MDL, and an average is calculated. If this numeric value is less than the MDL, the average is replaced by < MDL; otherwise, the average is the calculated value. When a numeric value is found for the average, the standard deviation is then determined using the same number set used to calculate the average.

[9] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[10] These formulae use 1/2MDL values for each analyte not detected.

[11] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[12] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[13] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms. The contribution of n-C_8 is not included in the total.

[14] Carbon Preference Index (CPI) defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[15] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[16] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[17] Weathering Index (WI) is defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[18] These MDL values are calculated with the same summation formulae as the samples using the individual hydrocarbon MDL values.

[19] The summation totals for the samples are compared with calculated MDL values obtained using the same summation formulae as the samples. When these sample totals were less than the total MDL, its value was replaced by nd. The averages and standard deviations for the totals were treated in the same way as the individual hydrocarbons; see footnote 8.

[20] Numerical values of the CPI, WI, and the ratios: pristane/n-C_{17}, phytane/n-C_{18}, and pristane/phytane, will be calculated only when the defined quantity for each index or ratio has a numeric value.

[21] These results are not true averages, instead they are the ratios of the averages of the defined quantities, if these averages exist.

Table D4. Individual hydrocarbon concentrations (in μg/g wet wt.) for sediment surface skims taken from Sandy Hook Bay marsh, a reference site.[1,2]

Sample ID	Nonacosane ($n\text{-}C_{29}$)	n-Hentriacontane ($n\text{-}C_{31}$)	Dotriacontane ($n\text{-}C_{32}$)
897081116	6.19	5.09	1.68
MDL	3.13	2.03	1.60

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] Only the concentrations for $n\text{-}C_{29}$, $n\text{-}C_{31}$, and $n\text{-}C_{32}$ had concentrations above the MDL; all other analytes had values below the MDL and are not reported.

Table D5. Individual hydrocarbon and total petroleum hydrocarbon concentrations (in μg/g wet wt.) for ribbed mussels taken from Old Place marsh, a replanted site.[1-3]

Sample ID	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
First Collection																	
197020410	nd	nd	nd	nd	nd	nd	nd	nd	0.17	0.12	nd	nd	nd	nd	1.25	nd	nd
197020411	2.67	nd	nd	nd	nd	nd	nd	nd	0.15	0.12	nd	nd	0.16	nd	1.60	nd	nd
197020412	0.50	nd	nd	nd	nd	nd	nd	nd	0.11	nd	nd	nd	0.22	nd	1.59	nd	nd
197020413	0.76	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.36	nd	nd
197020414	0.43	nd	nd	nd	nd	nd	nd	nd	0.18	0.12	nd	nd	nd	nd	1.32	nd	nd
Average[4]	0.90	nd	nd	nd	nd	nd	nd	nd	0.13	< MDL	nd	nd	< MDL	nd	1.43	nd	nd
Std Dev	1.02	-	-	-	-	-	-	-	0.06	-	-	-	-	-	0.16	-	-
Second Collection																	
497051411	0.31	nd	nd	nd	nd	nd	nd	nd	0.67	nd	nd	0.10	0.30	0.54	1.05	1.35	nd
497051412	nd	nd	nd	nd	nd	nd	nd	nd	0.32	0.11	nd	nd	0.13	nd	0.65	nd	nd
497051413	nd	nd	nd	nd	nd	nd	nd	nd	0.28	nd	nd	nd	nd	nd	0.56	nd	nd
497051414	nd	nd	nd	nd	nd	nd	nd	0.13	0.57	0.17	nd	0.17	nd	0.36	nd	1.79	nd
497051415	nd	nd	nd	nd	nd	nd	nd	nd	0.25	nd	nd	0.10	nd	nd	nd	nd	nd
Average[4]	< MDL	nd	nd	nd	nd	nd	nd	< MDL	0.42	< MDL	nd	< MDL	0.12	0.24	0.53	0.83	nd
Std Dev	-	-	-	-	-	-	-	-	0.19	-	-	-	0.10	0.20	0.36	0.69	-
MDL	0.24	0.06	0.12	0.12	0.11	0.11	0.11	0.09	0.08	0.10	0.10	0.10	0.11	0.21	0.38	0.68	2.47

Table D5. Continued.[1-3]

Sample ID	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
First Collection																	
197020410	nd	nd	nd	0.26	0.42	nd	nd	0.41	0.42	0.58	0.65	0.75	0.73	0.73	0.56	0.41	0.26
197020411	nd	nd	0.13	nd	nd	nd	nd	0.55	0.43	0.56	0.59	0.72	0.68	0.68	0.52	0.39	0.24
197020412	nd	nd	nd	0.19	0.33	nd	nd	0.40	0.38	0.54	0.55	0.64	0.63	0.57	0.50	0.35	0.22
197020413	nd	nd	0.12	nd	nd	nd	nd	0.52	0.55	0.76	0.75	0.84	0.76	0.73	0.59	0.42	0.25
197020414	nd	nd	nd	nd	nd	nd	nd	0.34	0.56	0.20	0.36	0.41	0.38	0.39	0.31	0.23	0.14
Average[4]	nd	nd	< MDL	0.11	0.21	nd	nd	0.44	0.47	0.53	0.58	0.67	0.64	0.62	0.49	0.36	0.22
Std Dev	-	-	-	0.10	0.15	-	-	0.08	0.08	0.20	0.15	0.16	0.15	0.14	0.11	0.08	0.05
Second Collection																	
497051411	nd	nd	nd	nd	nd	nd	nd	8.89	3.40	0.29	nd	nd	nd	nd	0.09	nd	nd
497051412	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
497051413	nd	nd	0.12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.09	nd	nd
497051414	nd	nd	0.12	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.10	nd	0.12	0.07	nd
497051415	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Average[4]	nd	nd	< MDL	nd	nd	nd	nd	1.82	0.73	< MDL	nd	nd	< MDL	nd	< MDL	< MDL	nd
Std Dev	-	-	-	-	-	-	-	3.95	1.49	-	-	-	-	-	-	-	-
MDL	0.29	0.27	0.11	0.08	0.20	0.56	0.48	0.11	0.14	0.11	0.09	0.10	0.10	0.18	0.08	0.06	0.06

Table D5. Continued.[1-3]

Sample ID	Total Petroleum Hydrocarbons[5]	Total Concentrations of Individual Hydrocarbons[6,7,15]	Total: Pristane + Phytane[6,15]	Pristane/n-C_{17}[16]	Phytane/n-C_{18}[16]	Pristane/Phytane[16]	Total: Odd No Carbons[6,8,15]	Total: Even No Carbons[6,9,15]	Carbon Preference Index (CPI)[10,16]	Sum: C_{10}-C_{12}-C_{14}[6,11,15]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[6,12,15]	Weathering Index (WI)[13,16]
First Collection												
197020410	203	10.9	nd	0.73	-	-	6.55	4.16	1.57	nd	nd	-
197020411	158	13.3	nd	0.84	-	-	9.32	3.77	2.48	nd	nd	-
197020412	165	10.8	nd	-	-	-	6.92	3.73	1.86	nd	nd	-
197020413	106	11.6	nd	-	-	-	7.34	4.20	1.75	nd	nd	-
197020414	118	8.55	nd	0.63	-	-	5.42	2.97	1.82	nd	nd	-
Average[4]	150	11.0	nd	-	-	-	7.11	3.77	1.89 [17]	nd	nd	-
Std Dev	39.1	1.70	-	-	-	-	1.43	0.49	-	-	-	-
Second Collection												
497051411	152	20.0	nd	-	-	-	13.5	6.29	2.15	nd	1.66	-
497051412	54.4	nd	nd	0.33	-	-	nd	nd	-	nd	nd	-
497051413	58.6	nd	nd	-	-	-	nd	nd	-	nd	nd	-
497051414	69.4	nd	0.34	0.29	-	0.96	nd	3.44	-	nd	2.16	-
497051415	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Average[4]	72.2	8.20	< MDL	-	-	-	5.18	< MDL	-	nd	< MDL	-
Std Dev	47.1	6.64	-	-	-	-	4.67	-	-	-	-	-
MDL	53.6	8.19[14]	0.19[14]				5.09[14]	2.91[14]		0.29[14]	1.29[14]	

Table D5. Continued.

Footnotes:

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8.

[4] If all concentrations are nd, the average is replaced with nd. When there is at least one number in the data set to be averaged, each nd is replaced with 1/2*MDL, and an average is calculated. If this numeric value is less than the MDL, the average is replaced by < MDL; otherwise, the average is the calculated value. When a numeric value is found for the average, the standard deviation is then determined using the same number set used to calculate the average.

[5] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[6] These formulae use 1/2MDL values for each analyte not detected.

[7] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[8] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[9] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms. The contribution of n-C_8 is not included in the total.

[10] Carbon Preference Index (CPI) defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[11] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[12] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[13] Weathering Index (WI) is defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[14] These MDL values are calculated with the same summation formulae as the samples using the individual hydrocarbon MDL values.

[15] The summation totals for the samples are compared with calculated MDL values obtained using the same summation formulae as the samples. When these sample totals were less than the total MDL, its value was replaced by nd. The averages and standard deviations for the totals were treated in the same way as the individual hydrocarbons; see footnote 4.

[16] Numerical values of the CPI, WI, and the ratios: pristane/n-C_{17}, phytane/n-C_{18}, and pristane/phytane, will be calculated only when the defined quantity for each index or ratio has a numeric value.

[17] These results are not true averages, instead they are the ratios of the averages of the defined quantities, if these averages exist.

Table D6. Individual hydrocarbon and total petroleum hydrocarbon concentrations (in μg/g wet wt.) for ribbed mussels taken from Con Edison Tower marsh, an unplanted site.[1-3]

Sample ID	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
First Collection																	
197020421	0.41	nd	nd	nd	nd	nd	nd	0.13	0.20	nd	nd	nd	nd	nd	1.36	nd	nd
197020422	1.21	nd	nd	nd	nd	nd	nd	0.11	0.23	0.15	nd	nd	0.19	nd	1.91	nd	nd
197020423	0.73	nd	nd	nd	nd	nd	nd	nd	0.15	nd	nd	nd	nd	nd	0.88	nd	nd
197020425	0.49	nd	nd	nd	nd	nd	nd	nd	0.08	nd	nd	nd	nd	nd	nd	0.94	nd
297031701	nd	nd	nd	nd	nd	nd	nd	nd	0.26	0.12	nd	0.10	0.57	nd	0.94	nd	2.61
Average[4]	0.59	nd	nd	nd	nd	nd	nd	< MDL	0.18	< MDL	nd	< MDL	0.18	nd	1.06	< MDL	< MDL
Std Dev	0.41	-	-	-	-	-	-	-	0.07	-	-	-	0.22	-	0.64	-	-
Second Collection																	
497051422	0.25	nd	nd	nd	nd	nd	nd	nd	1.07	0.24	nd	0.18	0.92	nd	1.47	nd	nd
497051423	nd	nd	nd	nd	nd	nd	nd	nd	0.88	0.17	nd	0.12	0.14	nd	2.78	nd	2.50
497051424	nd	nd	nd	nd	nd	nd	nd	nd	0.75	nd	nd	0.15	nd	nd	1.33	nd	2.80
497051425	3.01	nd	nd	nd	nd	0.13	0.16	nd	5.65	0.41	0.13	0.75	7.62	0.66	12.6	4.80	10.9
497051426	nd	nd	nd	nd	nd	nd	nd	nd	0.95	nd	nd	0.14	0.15	nd	2.14	nd	nd
Average[4]	0.73	nd	nd	nd	nd	< MDL	< MDL	nd	1.86	0.18	< MDL	0.27	1.78	0.22	4.07	1.23	3.73
Std Dev	1.28	-	-	-	-	-	-	-	2.12	0.15	-	0.27	3.29	0.25	4.81	1.99	4.06
MDL	0.24	0.06	0.12	0.12	0.11	0.11	0.11	0.09	0.08	0.10	0.10	0.10	0.11	0.21	0.38	0.68	2.47

Table D6. Continued.[1-3]

Sample ID	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
First Collection																	
197020421	nd	nd	nd	0.08	nd	nd	nd	64.5	3.13	3.31	0.58	0.60	0.57	0.54	0.42	0.31	0.19
197020422	nd	nd	nd	nd	nd	nd	nd	0.52	0.89	0.65	0.49	0.55	0.51	0.52	0.39	0.29	0.18
197020423	nd	nd	nd	nd	nd	nd	nd	0.23	0.20	0.28	0.32	0.39	0.37	0.36	0.30	0.22	0.14
197020425	nd	nd	nd	nd	nd	nd	nd	0.13	nd	0.18	0.15	0.17	0.16	nd	0.12	0.09	0.06
297031701	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.21	nd	0.12	nd	nd	0.10	0.14	0.16
Average[4]	nd	nd	nd	< MDL	nd	nd	nd	13.1	0.87	0.93	0.32	0.37	0.33	0.32	0.27	0.21	0.15
Std Dev	-	-	-	-	-	-	-	28.8	1.31	1.35	0.22	0.22	0.22	0.22	0.15	0.09	0.05
Second Collection																	
497051422	nd	nd	nd	nd	nd	nd	nd	0.24	0.81	0.34	nd	0.11	0.11	nd	0.15	0.06	nd
497051423	nd	nd	nd	nd	nd	nd	nd	0.13	nd	nd	nd	0.14	0.12	nd	0.13	0.08	nd
497051424	nd	nd	nd	0.35	0.31	4.30	0.62	nd	0.22	nd	nd	nd	nd	nd	nd	nd	nd
497051425	0.44	0.95	0.45	nd	nd	nd	nd	0.28	nd	nd	nd	nd	nd	nd	0.10	0.06	nd
497051426	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.12	nd	nd	0.10	0.06	nd
Average[4]	< MDL	0.30	0.13	0.10	< MDL	1.08	< MDL	0.15	0.25	0.11	nd	< MDL	< MDL	nd	0.10	0.06	nd
Std Dev	-	0.36	0.17	0.14	-	1.80	-	0.10	0.32	0.13	-	-	-	-	0.04	0.02	-
MDL	0.29	0.27	0.11	0.08	0.20	0.56	0.48	0.11	0.14	0.11	0.09	0.10	0.10	0.18	0.08	0.06	0.06

Table D6. Continued.[1-3]

Sample ID	Total Petroleum Hydrocarbons[5]	Total Concentrations of Individual Hydrocarbons[6,7,15]	TOTAL: Pristane + Phytane[6,15]	Pristane/n-C_{17}[16]	Phytane/n-C_{18}[16]	Pristane/Phytane[16]	Total: Odd No Carbons[6,8,15]	Total: Even No Carbons[6,9,15]	Carbon Preference Index (CPI)[10,16]	Sum: C_{10}-C_{12}-C_{14}[6,11,15]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[6,12,15]	Weathering Index (WI)[13,16]
First Collection												
197020421	195	79.5	nd	-	-	-	73.2	6.21	11.8	nd	nd	-
197020422	161	11.9	nd	0.64	-	-	7.92	3.76	2.11	nd	nd	-
197020423	83.6	nd	nd	-	-	-	5.15	nd	-	nd	nd	-
197020425	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
297031701	63.1	nd	0.21	0.45	-	1.20	5.74	nd	-	nd	nd	-
Average[4]	106	22.5	< MDL	-	-	-	19.1	3.31	5.76 [17]	nd	nd	-
Std Dev	70.0	31.9	-	-	-	-	30.3	1.78	-	-	-	-
Second Collection												
497051422	135	9.20	0.42	0.22	-	1.35	6.41	nd	-	nd	nd	-
497051423	144	9.44	0.29	0.19	-	1.43	7.54	nd	-	nd	nd	-
497051424	235	12.7	0.20	-	-	-	10.3	nd	-	nd	nd	-
497051425	274	50.4	1.16	0.07	5.66	0.55	41.8	7.37	5.68	nd	5.79	-
497051426	115	nd	nd	-	-	-	5.60	nd	-	nd	nd	-
Average[4]	181	17.8	0.45	0.10 [17]	-	0.69 [17]	14.3	3.02	4.75 [17]	nd	1.71	-
Std Dev	69.5	18.3	0.41	-	-	-	15.5	2.46	-	-	2.28	-
MDL	53.6	8.19[14]	0.19[14]				5.09[14]	2.91[14]		0.29[14]	1.29[14]	

Table D6. Continued.

Footnotes:

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8.

[4] If all concentrations are nd, the average is replaced with nd. When there is at least one number in the data set to be averaged, each nd is replaced with 1/2*MDL, and an average is calculated. If this numeric value is less than the MDL, the average is replaced by < MDL; otherwise, the average is the calculated value. When a numeric value is found for the average, the standard deviation is then determined using the same number set used to calculate the average.

[5] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[6] These formulae use 1/2MDL values for each analyte not detected.

[7] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[8] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[9] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms. The contribution of n-C_8 is not included in the total.

[10] Carbon Preference Index (CPI) is defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[11] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[12] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[13] Weathering Index (WI) is defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[14] These MDL values are calculated with the same summation formulae as the samples using the individual hydrocarbon MDL values.

[15] The summation totals for the samples are compared with calculated MDL values obtained using the same summation formulae as the samples. When these sample totals were less than the total MDL, its value was replaced by nd. The averages and standard deviations for the totals were treated in the same way as the individual hydrocarbons; see footnote 4.

[16] Numerical values of the CPI, WI, and the ratios: pristane/n-C_{17}, phytane/n-C_{18}, and pristane/phytane, will be calculated only when the defined quantity for each index or ratio has a numeric value.

[17] These results are not true averages, instead they are the ratios of the averages of the defined quantities, if these averages exist.

Table D7. Individual hydrocarbon and total petroleum hydrocarbon concentrations (in μg/g wet wt.) for ribbed mussels taken from Saw Mill North marsh, a replanted site.[1-3]

Sample ID	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
First Collection																	
197020401	0.66	nd	nd	nd	nd	nd	0.12	0.14	0.29	0.11	nd	nd	0.23	nd	1.22	nd	nd
197020402	nd	nd	nd	nd	nd	nd	nd	0.11	0.23	0.16	nd	0.12	0.18	nd	1.62	nd	nd
197020409	nd	nd	nd	nd	nd	nd	nd	nd	0.20	nd	nd	nd	0.21	nd	1.54	nd	nd
197020415	0.65	nd	nd	nd	nd	nd	nd	nd	0.23	0.15	nd	nd	0.12	nd	1.45	nd	nd
297031702	nd	nd	nd	nd	nd	nd	nd	nd	0.13	nd	nd	nd	nd	nd	nd	nd	nd
Average[4]	0.33	nd	nd	nd	nd	nd	< MDL	< MDL	0.22	0.11	nd	< MDL	0.16	nd	1.20	nd	nd
Std Dev	0.29	-	-	-	-	-	-	-	0.06	0.05	-	-	0.07	-	0.59	-	-
Second Collection																	
497051405	nd	nd	nd	nd	nd	nd	nd	nd	0.96	nd	nd	nd	nd	0.24	2.52	1.01	4.53
497051406	nd	nd	nd	nd	nd	nd	nd	nd	0.89	nd	nd	0.13	0.12	nd	2.35	0.80	3.08
497051407	0.52	nd	nd	nd	nd	0.23	0.17	0.12	0.78	0.30	0.15	0.30	0.29	0.38	3.79	2.07	3.87
497051409	nd	nd	nd	nd	nd	nd	nd	nd	0.84	nd	nd	nd	nd	nd	nd	nd	nd
497051410	nd	nd	nd	nd	nd	nd	nd	nd	0.89	nd	nd	0.12	0.17	nd	nd	nd	nd
Average[4]	< MDL	nd	nd	nd	nd	< MDL	< MDL	< MDL	0.87	0.10	< MDL	0.13	0.14	< MDL	1.81	0.91	2.79
Std Dev	-	-	-	-	-	-	-	-	0.07	0.11	-	0.10	0.10	-	1.58	0.71	1.51
MDL	0.24	0.06	0.12	0.12	0.11	0.11	0.11	0.09	0.08	0.10	0.10	0.10	0.11	0.21	0.38	0.68	2.47

Table D7. Continued.[1-3]

Sample ID	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
First Collection																	
197020401	nd	nd	0.19	nd	nd	nd	nd	nd	3.13	3.65	0.32	0.43	0.39	0.41	0.32	0.24	0.15
197020402	nd	nd	nd	nd	nd	nd	nd	0.55	1.27	0.22	0.40	0.45	0.43	0.44	0.34	0.25	0.16
197020409	nd	nd	nd	nd	nd	nd	nd	0.40	0.33	0.41	0.46	0.52	0.50	0.49	0.39	0.29	0.18
197020415	nd	nd	nd	0.21	0.39	nd	nd	0.52	0.70	0.70	0.73	0.80	0.76	0.74	0.59	0.44	0.27
297031702	nd	nd	nd	nd	nd	nd	nd	0.14	nd	0.12	nd	nd	nd	nd	nd	0.10	0.12
Average[4]	nd	nd	< MDL	< MDL	< MDL	nd	nd	0.34	1.10	1.02	0.39	0.45	0.43	0.43	0.34	0.26	0.18
Std Dev	-	-	-	-	-	-	-	0.23	1.22	1.49	0.25	0.27	0.26	0.23	0.20	0.12	0.06
Second Collection																	
497051405	1.33	0.63	0.20	0.61	1.04	8.55	nd	0.42	0.72	0.20	nd	nd	0.14	0.18	0.16	0.10	nd
497051406	nd	nd	nd	nd	nd	nd	nd	0.12	nd	nd	nd	nd	nd	nd	nd	nd	nd
497051407	nd	nd	nd	nd	nd	nd	nd	0.60	3.31	0.29	nd	0.19	0.11	nd	0.14	0.08	nd
497051409	nd	nd	nd	nd	nd	nd	nd	nd	0.17	nd	nd	nd	nd	nd	nd	nd	nd
497051410	nd	nd	nd	nd	nd	nd	nd	0.30	1.60	0.14	nd	nd	nd	nd	nd	nd	nd
Average[4]	0.38	< MDL	< MDL	0.15	0.29	1.93	nd	0.30	1.18	0.14	nd	< MDL	< MDL	< MDL	0.09	< MDL	nd
Std Dev	0.53	-	-	0.26	0.42	3.70	-	0.22	1.34	0.10	-	-	-	-	0.06	-	-
MDL	0.29	0.27	0.11	0.08	0.20	0.56	0.48	0.11	0.14	0.11	0.09	0.10	0.10	0.18	0.08	0.06	0.06

Table D7. Continued.[1-3]

Sample ID	Total Petroleum Hydrocarbons[5]	Total Concentrations of Individual Hydrocarbons[6,7,15]	Total: Pristane + Phytane[6,15]	Pristane/n-C_{17}[16]	Phytane/n-C_{18}[16]	Pristane/Phytane[16]	Total: Odd No Carbons[6,8,15]	Total: Even No Carbons[6,9,15]	Carbon Preference Index (CPI)[10,16]	Sum: C_{10}-C_{12}-C_{14}[6,11,15]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[6,12,15]	Weathering Index (WI)[13,16]
First Collection												
197020401	266	15.0	nd	0.40	-	-	9.09	5.77	1.58	nd	nd	-
197020402	131	10.1	0.28	0.73	-	1.41	5.91	3.90	1.52	nd	nd	-
197020409	136	9.23	nd	-	-	-	6.03	3.10	1.95	nd	nd	-
197020415	186	12.5	0.20	0.63	-	-	7.69	4.58	1.68	nd	nd	-
297031702	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Average[4]	149	10.3	< MDL	0.49 [17]	-	-	6.32	3.78	1.67 [17]	nd	nd	-
Std Dev	87.2	3.93	-	-	-	-	2.33	1.59	-	-	-	-
Second Collection												
497051405	541	24.6	nd	-	-	-	19.1	5.40	3.54	nd	3.58	-
497051406	103	9.62	nd	-	-	-	7.54	nd	-	nd	nd	-
497051407	268	19.0	0.60	0.39	1.95	1.01	11.2	7.22	1.55	0.32	2.38	0.13
497051409	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
497051410	77.9	nd	nd	-	-	-	nd	2.99	-	nd	nd	-
Average[4]	203	13.1	0.23	0.11 [17]	-	0.77 [17]	9.01	3.82	2.36 [17]	< MDL	1.67	-
Std Dev	209	8.40	0.21	-	-	-	6.48	2.42	-	-	1.28	-
MDL	53.6	8.19[14]	0.19[14]				5.09[14]	2.91[14]		0.29[14]	1.29[14]	

Table D7. Continued.

Footnotes:

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8.

[4] If all concentrations are nd, the average is replaced with nd. When there is at least one number in the data set to be averaged, each nd is replaced with 1/2*MDL, and an average is calculated. If this numeric value is less than the MDL, the average is replaced by < MDL; otherwise, the average is the calculated value. When a numeric value is found for the average, the standard deviation is then determined using the same number set used to calculate the average.

[5] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[6] These formulae use 1/2MDL values for each analyte not detected.

[7] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[8] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[9] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms. The contribution of n-C_8 is not included in the total.

[10] Carbon Preference Index (CPI) is defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[11] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[12] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[13] Weathering Index (WI) is defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[14] These MDL values are calculated with the same summation formulae as the samples using the individual hydrocarbon MDL values.

[15] The summation totals for the samples are compared with calculated MDL values obtained using the same summation formulae as the samples. When these sample totals were less than the total MDL, its value was replaced by nd. The averages and standard deviations for the totals were treated in the same way as the individual hydrocarbons; see footnote 4.

[16] Numerical values of the CPI, WI, and the ratios: pristane/n-C_{17}, phytane/n-C_{18}, and pristane/phytane, will be calculated only when the defined quantity for each index or ratio has a numeric value.

[17] These results are not true averages, instead they are the ratios of the averages of the defined quantities, if these averages exist.

Table D8. Individual hydrocarbon and total petroleum hydrocarbon concentrations (in μg/g wet wt.) for ribbed mussels taken from Saw Mill South marsh, an unplanted site.[1-3]

Sample ID	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
First Collection																	
197020426	nd	nd	nd	nd	nd	nd	nd	nd	0.08	nd	nd	nd	nd	nd	0.49	nd	nd
297031703	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.14	nd	0.46	nd	nd
297031704	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
297031705	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
297031706	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Average[4]	nd	nd	nd	nd	nd	nd	nd	nd	< MDL	nd	nd	nd	< MDL	nd	< MDL	nd	nd
Std Dev	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Second Collection																	
497051401	nd	nd	nd	nd	nd	nd	nd	nd	1.75	nd	nd	0.14	nd	nd	2.28	0.68	2.82
497051402	0.41	nd	nd	nd	nd	nd	nd	nd	2.18	0.11	nd	0.17	nd	nd	1.49	nd	nd
497051403	nd	nd	nd	nd	nd	nd	nd	nd	2.54	0.16	nd	0.22	0.24	0.24	4.17	nd	4.85
497051404	0.36	nd	nd	nd	nd	nd	nd	nd	1.30	nd	nd	0.11	nd	nd	2.07	0.75	nd
497051432	0.91	nd	nd	nd	nd	nd	nd	nd	2.74	nd	nd	0.14	nd	nd	2.11	nd	nd
Average[4]	0.39	nd	nd	nd	nd	nd	nd	nd	2.10	< MDL	nd	0.16	< MDL	< MDL	2.42	< MDL	< MDL
Std Dev	0.32	-	-	-	-	-	-	-	0.59	-	-	0.04	-	-	1.02	-	-
MDL	0.24	0.06	0.12	0.12	0.11	0.11	0.11	0.09	0.08	0.10	0.10	0.10	0.11	0.21	0.38	0.68	2.47

Table D8. Continued.[1-3]

Sample ID	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
First Collection																	
197020426	nd	nd	nd	nd	nd	nd	nd	0.20	0.15	0.19	0.20	0.22	0.24	0.23	0.20	0.15	0.08
297031703	0.35	nd	nd	0.28	0.57	5.98	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.07	0.08
297031704	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.06
297031705	nd	nd	nd	0.12	0.22	1.96	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.06
297031706	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.06	0.07
Average[4]	< MDL	nd	nd	0.10	0.22	1.75	nd	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	< MDL	0.07	0.07
Std Dev	-	-	-	0.10	0.20	2.47	-	-	-	-	-	-	-	-	-	0.05	0.01
Second Collection																	
497051401	nd	nd	nd	nd	nd	nd	nd	0.32	0.97	0.13	nd	nd	0.86	nd	nd	nd	nd
497051402	nd	nd	nd	nd	nd	nd	nd	0.34	1.02	nd	nd	nd	0.68	nd	0.09	nd	nd
497051403	nd	0.31	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.16	nd	nd	0.11	0.06	nd
497051404	nd	nd	nd	0.08	nd	nd	nd	0.78	4.69	0.49	0.28	0.34	0.35	0.42	0.35	0.32	0.16
497051432	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Average[4]	nd	< MDL	nd	< MDL	nd	nd	nd	0.31	1.36	0.15	0.09	0.13	0.40	< MDL	0.13	0.09	< MDL
Std Dev	-	-	-	-	-	-	-	0.30	1.92	0.19	0.10	0.13	0.37	-	0.13	0.13	-
MDL	0.29	0.27	0.11	0.08	0.20	0.56	0.48	0.11	0.14	0.11	0.09	0.10	0.10	0.18	0.08	0.06	0.06

Table D8. Continued.[1-3]

Sample ID	Total Petroleum Hydrocarbons[5]	Total Concentrations of Individual Hydrocarbons[6,7,15]	Total: Pristane + Phytane[6,15]	Pristane/n-C_{17}[16]	Phytane/n-C_{18}[16]	Pristane/Phytane[16]	Total: Odd No Carbons[6,8,15]	Total: Even No Carbons[6,9,15]	Carbon Preference Index (CPI)[10,16]	Sum: C_{10}-C_{12}-C_{14}[6,11,15]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[6,12,15]	Weathering Index (WI)[13,16]
First Collection												
197020426	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
297031703	131	11.2	nd	-	-	-	8.88	nd	-	nd	1.31	-
297031704	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
297031705	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
297031706	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Average[4]	< MDL	< MDL	nd	-	-	-	< MDL	nd	-	nd	< MDL	-
Std Dev	-	-	-	-	-	-	-	-	-	-	-	-
Second Collection												
497051401	110	12.0	nd	-	-	-	8.26	3.51	2.35	nd	nd	-
497051402	159	9.91	0.27	0.05	-	0.63	6.55	3.09	2.12	nd	nd	-
497051403	133	15.2	0.38	0.06	-	0.71	13.2	nd	-	nd	nd	-
497051404	189	15.7	nd	-	-	-	8.04	7.47	1.08	nd	nd	-
497051432	97.9	9.60	nd	-	-	-	7.95	nd	-	nd	nd	-
Average[4]	138	12.5	0.24	-	-	-	8.79	3.44	2.56 [17]	nd	nd	-
Std Dev	37.0	2.86	0.09	-	-	-	2.53	2.42	-	-	-	-
MDL	53.6	8.19[14]	0.19[14]				5.09[14]	2.91[14]		0.29[14]	1.29[14]	

Table D8. Continued.

Footnotes:

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8.

[4] If all concentrations are nd, the average is replaced with nd. When there is at least one number in the data set to be averaged, each nd is replaced with 1/2*MDL, and an average is calculated. If this numeric value is less than the MDL, the average is replaced by < MDL; otherwise, the average is the calculated value. When a numeric value is found for the average, the standard deviation is then determined using the same number set used to calculate the average.

[5] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[6] These formulae use 1/2MDL values for each analyte not detected.

[7] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[8] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[9] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms. The contribution of n-C_8 is not included in the total.

[10] Carbon Preference Index (CPI) is defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[11] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[12] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[13] Weathering Index (WI) is defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[14] These MDL values are calculated with the same summation formulae as the samples using the individual hydrocarbon MDL values.

[15] The summation totals for the samples are compared with calculated MDL values obtained using the same summation formulae as the samples. When these sample totals were less than the total MDL, its value was replaced by nd. The averages and standard deviations for the totals were treated in the same way as the individual hydrocarbons; see footnote 4.

[16] Numerical values of the CPI, WI, and the ratios: pristane/n-C_{17}, phytane/n-C_{18}, and pristane/phytane, will be calculated only when the defined quantity for each index or ratio has a numeric value.

[17] These results are not true averages, instead they are the ratios of the averages of the defined quantities, if these averages exist.

Table D9. Individual hydrocarbon and total petroleum hydrocarbon concentrations (in μg/g wet wt.) for ribbed mussels taken from Tufts Point marsh, a reference site.[1-3]

Sample ID	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
First Collection																	
197020403	0.90	nd	nd	nd	nd	0.12	nd	nd	0.20	nd	nd	nd	0.29	nd	2.55	nd	nd
197020404	0.97	nd	nd	nd	nd	nd	nd	nd	0.15	nd	nd	nd	0.20	nd	1.86	nd	nd
197020405	2.03	nd	nd	nd	nd	0.19	nd	nd	0.21	nd	nd	nd	0.34	nd	2.89	nd	nd
197020406	0.29	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.09	nd	nd
197020408	0.66	nd	nd	nd	nd	nd	nd	nd	0.16	nd	nd	nd	nd	nd	1.55	nd	nd
Average[4]	0.97	nd	nd	nd	nd	< MDL	nd	nd	0.15	nd	nd	nd	0.19	nd	1.99	nd	nd
Std Dev	0.65	-	-	-	-	-	-	-	0.07	-	-	-	0.13	-	0.73	-	-
Second Collection																	
497051427	nd	nd	nd	nd	nd	nd	nd	nd	0.25	nd	nd	nd	nd	nd	0.79	nd	nd
497051428	nd	nd	nd	nd	nd	nd	nd	nd	0.28	0.10	nd	nd	nd	nd	1.54	nd	nd
497051429	nd	nd	nd	nd	nd	nd	nd	nd	0.31	nd	nd	nd	1.16	nd	1.59	nd	nd
497051430	nd	nd	nd	nd	nd	nd	nd	0.15	0.32	0.12	0.13	0.11	0.19	nd	2.70	nd	3.05
497051431	nd	nd	nd	nd	nd	nd	nd	nd	0.14	nd	nd	nd	nd	nd	1.87	nd	nd
Average[4]	nd	nd	nd	nd	nd	nd	nd	< MDL	0.26	< MDL	< MDL	< MDL	0.30	nd	1.70	nd	< MDL
Std Dev	-	-	-	-	-	-	-	-	0.07	-	-	-	0.48	-	0.69	-	-
MDL	0.24	0.06	0.12	0.12	0.11	0.11	0.11	0.09	0.08	0.10	0.10	0.10	0.11	0.21	0.38	0.68	2.47

Table D9. Continued.[1-3]

Sample ID	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
First Collection																	
197020403	nd	nd	0.14	nd	nd	nd	nd	1.52	6.13	0.43	0.80	0.89	0.89	0.81	0.68	0.50	0.31
197020404	0.47	nd	0.13	0.40	1.00	9.82	nd	0.84	0.41	0.46	0.60	0.68	0.68	0.65	0.55	0.41	0.25
197020405	0.48	nd	0.14	0.44	1.97	nd	nd	0.55	0.68	0.69	0.77	0.86	0.87	0.80	0.68	0.50	0.31
197020406	nd	nd	nd	nd	nd	nd	nd	0.60	1.31	0.60	0.40	0.43	0.43	0.40	0.33	0.24	0.15
197020408	nd	nd	0.15	nd	nd	nd	nd	0.81	2.24	0.22	0.48	0.50	0.46	0.47	0.35	0.26	0.16
Average[4]	< MDL	nd	0.12	0.19	0.66	2.19	nd	0.86	2.15	0.48	0.61	0.67	0.67	0.63	0.52	0.38	0.24
Std Dev	-	-	0.04	0.21	0.83	4.27	-	0.39	2.33	0.18	0.18	0.21	0.22	0.19	0.17	0.13	0.08
Second Collection																	
497051427	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.12	0.07	nd
497051428	nd	nd	nd	0.16	nd	0.79	nd	nd	nd	nd	nd	0.12	0.12	nd	0.14	0.08	nd
497051429	nd	nd	nd	nd	nd	nd	nd	0.13	nd	nd	nd	nd	0.11	nd	0.13	0.08	nd
497051430	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.10	nd	0.12	0.07	nd
497051431	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Average[4]	nd	nd	nd	< MDL	nd	< MDL	nd	< MDL	nd	nd	nd	< MDL	< MDL	nd	0.11	0.07	nd
Std Dev	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.04	0.02	-
MDL	0.29	0.27	0.11	0.08	0.20	0.56	0.48	0.11	0.14	0.11	0.09	0.10	0.10	0.18	0.08	0.06	0.06

Table D9. Continued.[1-3]

Sample ID	Total Petroleum Hydrocarbons[5]	Total Concentrations of Individual Hydrocarbons[6,7,15]	Total: Pristane + Phytane[6,15]	Pristane/n-C_{17}[16]	Phytane/n-C_{18}[16]	Pristane/Phytane[16]	Total: Odd No Carbons[6,8,15]	Total: Even No Carbons[6,9,15]	Carbon Preference Index (CPI)[10,16]	Sum: C_{10}-C_{12}-C_{14}[6,11,15]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[6,12,15]	Weathering Index (WI)[13,16]
First Collection												
197020403	260	20.2	nd	-	-	-	9.95	10.2	0.98	nd	nd	-
197020404	288	23.1	nd	-	-	-	18.0	5.02	3.58	nd	1.95	-
197020405	370	18.2	nd	-	-	-	11.1	6.96	1.60	nd	2.93	-
197020406	96.2	9.55	nd	-	-	-	5.60	3.85	1.46	nd	nd	-
197020408	158	11.7	nd	-	-	-	6.54	5.02	1.30	nd	nd	-
Average[4]	235	16.5	nd	-	-	-	10.2	6.21	1.65 [17]	nd	1.40	-
Std Dev	108	5.75	-	-	-	-	4.90	2.49	-	-	1.01	-
Second Collection												
497051427	99.8	nd	nd	-	-	-	nd	nd	-	nd	nd	-
497051428	143	nd	nd	0.37	-	-	nd	nd	-	nd	nd	-
497051429	118	nd	nd	-	-	-	5.44	nd	-	nd	nd	-
497051430	185	9.32	0.23	0.38	0.90	1.08	7.33	nd	-	nd	nd	-
497051431	69.9	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Average[4]	123	< MDL	< MDL	-	-	-	< MDL	nd	-	nd	nd	-
Std Dev	43.7	-	-	-	-	-	-	-	-	-	-	-
MDL	53.6	8.19[14]	0.19[14]				5.09[14]	2.91[14]		0.29[14]	1.29[14]	

Table D9. Continued.

Footnotes:

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8.

[4] If all concentrations are nd, the average is replaced with nd. When there is at least one number in the data set to be averaged, each nd is replaced with 1/2*MDL, and an average is calculated. If this numeric value is less than the MDL, the average is replaced by < MDL; otherwise, the average is the calculated value. When a numeric value is found for the average, the standard deviation is then determined using the same number set used to calculate the average.

[5] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[6] These formulae use 1/2MDL values for each analyte not detected.

[7] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[8] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[9] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms. The contribution of n-C_8 is not included in the total.

[10] Carbon Preference Index (CPI) is defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[11] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[12] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[13] Weathering Index (WI) is defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[14] These MDL values are calculated with the same summation formulae as the samples using the individual hydrocarbon MDL values.

[15] The summation totals for the samples are compared with calculated MDL values obtained using the same summation formulae as the samples. When these sample totals were less than the total MDL, its value was replaced by nd. The averages and standard deviations for the totals were treated in the same way as the individual hydrocarbons; see footnote 4.

[16] Numerical values of the CPI, WI, and the ratios: pristane/n-C_{17}, phytane/n-C_{18}, and pristane/phytane, will be calculated only when the defined quantity for each index or ratio has a numeric value.

[17] These results are not true averages, instead they are the ratios of the averages of the defined quantities, if these averages exist.

Table D10. Individual hydrocarbon and total petroleum hydrocarbon concentrations (in μg/g wet wt.) for ribbed mussels taken from Mill Creek marsh, a reference site.[1-3]

Sample ID	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
First Collection																	
197020407	0.98	nd	nd	nd	nd	nd	0.14	0.13	0.29	0.14	nd	nd	0.24	nd	2.41	0.81	nd
197020417	1.28	nd	nd	nd	nd	nd	nd	nd	0.12	nd	nd	nd	0.35	nd	1.52	1.03	nd
197020418	0.61	nd	nd	nd	nd	nd	nd	0.15	0.26	nd	nd	nd	0.13	nd	1.90	0.76	nd
197020419	0.42	nd	nd	nd	nd	nd	0.12	nd	0.19	nd	nd	nd	nd	nd	0.69	1.78	nd
197020420	nd	nd	nd	nd	nd	nd	nd	0.10	0.11	nd	nd	nd	nd	nd	1.04	nd	nd
Average[4]	0.68	nd	nd	nd	nd	nd	< MDL	0.09	0.19	< MDL	nd	nd	0.16	nd	1.51	0.95	nd
Std Dev	0.46	-	-	-	-	-	-	0.05	0.08	-	-	-	0.13	-	0.68	0.53	-
Second Collection																	
497051417	0.34	nd	nd	nd	nd	nd	nd	nd	0.76	nd	nd	0.10	nd	nd	1.31	nd	nd
497051418	0.42	nd	nd	nd	nd	nd	nd	nd	0.47	nd	nd	nd	nd	nd	1.18	nd	nd
497051419	0.27	nd	nd	nd	nd	nd	nd	nd	1.06	nd	nd	0.11	0.15	nd	3.43	1.04	4.22
497051420	nd	nd	nd	nd	nd	nd	nd	nd	1.29	nd	nd	nd	nd	nd	2.27	nd	nd
497051421	0.68	nd	nd	nd	nd	nd	nd	nd	1.15	nd	0.16	0.12	1.44	nd	1.85	nd	nd
Average[4]	0.37	nd	nd	nd	nd	nd	nd	nd	0.95	nd	< MDL	< MDL	0.35	nd	2.01	< MDL	< MDL
Std Dev	0.21	-	-	-	-	-	-	-	0.33	-	-	-	0.61	-	0.91	-	-
MDL	0.24	0.06	0.12	0.12	0.11	0.11	0.11	0.09	0.08	0.10	0.10	0.10	0.11	0.21	0.38	0.68	2.47

Table D10. Continued.[1-3]

Sample ID	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
First Collection																	
197020407	nd	0.30	0.19	nd	nd	nd	nd	0.48	0.64	0.68	0.75	0.83	0.77	0.80	0.56	0.45	0.26
197020417	nd	nd	nd	0.08	nd	nd	nd	0.52	0.56	0.58	0.59	0.63	0.57	0.53	0.43	0.31	0.18
197020418	nd	nd	nd	nd	nd	nd	nd	0.23	0.36	0.42	0.44	0.50	0.49	0.44	0.40	0.28	0.17
197020419	nd	nd	nd	nd	nd	nd	nd	0.16	0.24	0.26	0.27	0.32	0.32	0.32	0.25	0.18	0.11
197020420	nd	nd	nd	nd	nd	nd	nd	56.6	5.12	2.11	0.22	0.25	0.24	0.26	0.19	0.14	0.09
Average[4]	nd	< MDL	< MDL	< MDL	nd	nd	nd	11.6	1.38	0.81	0.45	0.51	0.48	0.47	0.37	0.27	0.16
Std Dev	-	-	-	-	-	-	-	25.1	2.09	0.74	0.22	0.23	0.21	0.21	0.15	0.12	0.07
Second Collection																	
497051417	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
497051418	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.09	nd	nd
497051419	nd	nd	nd	nd	nd	nd	nd	0.25	1.36	0.91	nd	nd	nd	nd	0.08	nd	nd
497051420	nd	nd	nd	nd	nd	nd	nd	0.84	4.89	2.09	nd	nd	nd	nd	0.10	0.06	nd
497051421	nd	nd	nd	nd	nd	nd	nd	0.59	1.81	1.52	nd	nd	nd	nd	0.08	nd	nd
Average[4]	nd	nd	nd	nd	nd	nd	nd	0.36	1.64	0.93	nd	nd	nd	nd	< MDL	< MDL	nd
Std Dev	-	-	-	-	-	-	-	0.35	1.97	0.90	-	-	-	-	-	-	-
MDL	0.29	0.27	0.11	0.08	0.20	0.56	0.48	0.11	0.14	0.11	0.09	0.10	0.10	0.18	0.08	0.06	0.06

Table D10. Continued.[1-3]

Sample ID	Total Petroleum Hydrocarbons[5]	Total Concentrations of Individual Hydrocarbons[6,7,15]	Total: Pristane + Phytane[6,15]	Pristane/n-C_{17}[16]	Phytane/n-C_{18}[16]	Pristane/Phytane[16]	Total: Odd No Carbons[6,8,15]	Total: Even No Carbons[6,9,15]	Carbon Preference Index (CPI)[10,16]	Sum: C_{10}-C_{12}-C_{14}[6,11,15]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[6,12,15]	Weathering Index (WI)[13,16]
First Collection												
197020407	148	14.4	nd	0.48	-	-	9.28	4.90	1.89	nd	nd	-
197020417	99.9	12.1	nd	-	-	-	7.72	4.24	1.82	nd	1.33	-
197020418	111	10.3	nd	-	-	-	6.62	3.62	1.83	nd	nd	-
197020419	64.6	8.46	nd	-	-	-	nd	3.86	-	nd	2.08	-
197020420	141	69.7	nd	-	-	-	62.5	7.14	8.76	nd	nd	-
Average[4]	113	23.0	nd	-	-	-	18.1	4.75	3.81 [17]	nd	<MDL	-
Std Dev	33.6	26.2	-	-	-	-	24.9	1.42	-	-	-	-
Second Collection												
497051417	110	nd	nd	-	-	-	nd	nd	-	nd	nd	-
497051418	90.0	nd	nd	-	-	-	nd	nd	-	nd	nd	-
497051419	208	14.7	nd	-	-	-	11.1	3.48	3.18	nd	1.34	-
497051420	233	15.2	nd	-	-	-	8.72	6.33	1.38	nd	nd	-
497051421	167	12.8	nd	-	0.78	-	9.26	3.35	2.76	nd	nd	-
Average[4]	162	10.9	nd	-	-	-	7.59	3.23	2.35 [17]	nd	< MDL	-
Std Dev	61.4	4.58	-	-	-	-	3.01	1.99	-	-	-	-
MDL	53.6	8.19[14]	0.19[14]				5.09[14]	2.91[14]		0.29[14]	1.29[14]	

Table D10. Continued.

Footnotes:

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8.

[4] If all concentrations are nd, the average is replaced with nd. When there is at least one number in the data set to be averaged, each nd is replaced with 1/2*MDL, and an average is calculated. If this numeric value is less than the MDL, the average is replaced by < MDL; otherwise, the average is the calculated value. When a numeric value is found for the average, the standard deviation is then determined using the same number set used to calculate the average.

[5] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[6] These formulae use 1/2MDL values for each analyte not detected.

[7] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[8] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[9] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms. The contribution of n-C_8 is not included in the total.

[10] Carbon Preference Index (CPI) is defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[11] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[12] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[13] Weathering Index (WI) is defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[14] These MDL values are calculated with the same summation formulae as the samples using the individual hydrocarbon MDL values.

[15] The summation totals for the samples are compared with calculated MDL values obtained using the same summation formulae as the samples. When these sample totals were less than the total MDL, its value was replaced by nd. The averages and standard deviations for the totals were treated in the same way as the individual hydrocarbons; see footnote 4.

[16] Numerical values of the CPI, WI, and the ratios: pristane/n-C_{17}, phytane/n-C_{18}, and pristane/phytane, will be calculated only when the defined quantity for each index or ratio has a numeric value.

[17] These results are not true averages, instead they are the ratios of the averages of the defined quantities, if these averages exist.

Table D11. Individual hydrocarbon and total petroleum hydrocarbon concentrations (in μg/g wet wt.) for ribbed mussels taken from Sandy Hook marsh, a reference site.[1-3]

Sample ID	Nonane (n-C_9)	Decane (n-C_{10})	Undecane (n-C_{11})	Dodecane (n-C_{12})	Tridecane (n-C_{13})	Tetradecane (n-C_{14})	Pentadecane (n-C_{15})	Hexadecane (n-C_{16})	Heptadecane (n-C_{17})	Pristane	Octadecane (n-C_{18})	Phytane	Nonadecane (n-C_{19})	Eicosane (n-C_{20})	Heneicosane (n-C_{21})	Docosane (n-C_{22})	Tricosane (n-C_{23})
297031710	nd	nd	nd	nd	nd	nd	nd	nd	0.09	nd	nd	nd	0.47	nd	0.58	1.30	3.42
297031711	0.47	nd	0.13	nd	nd	nd	nd	0.10	0.13	nd	nd	nd	0.60	nd	1.21	1.27	nd
297031712	0.34	nd	nd	nd	nd	nd	nd	nd	0.09	nd	nd	nd	0.31	nd	0.52	0.68	nd
297031713	0.30	nd	nd	nd	nd	nd	nd	nd	0.12	nd	nd	nd	nd	nd	1.09	1.42	nd
297031714	0.31	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.24	nd	0.93	0.95	nd
297031715	0.34	nd	nd	nd	nd	nd	nd	nd	0.12	nd	nd	nd	0.39	nd	1.58	1.04	nd
297031716	0.32	nd	nd	nd	nd	nd	nd	nd	0.12	nd	nd	nd	0.48	nd	0.89	0.72	nd
Average[4]	0.31	nd	< MDL	nd	nd	nd	nd	< MDL	0.10	nd	nd	nd	0.36	nd	0.97	1.06	< MDL
Std Dev	0.10	-	-	-	-	-	-	-	0.03	-	-	-	0.18	-	0.37	0.29	-
MDL	0.24	0.06	0.12	0.12	0.11	0.11	0.11	0.09	0.08	0.10	0.10	0.10	0.11	0.21	0.38	0.68	2.47

Table D11. Continued.[1-3]

Sample ID	Tetracosane (n-C_{24})	Pentacosane (n-C_{25})	Hexacosane (n-C_{26})	Heptacosane (n-C_{27})	Octacosane (n-C_{28})	Nonacosane (n-C_{29})	Triacontane (n-C_{30})	n-Hentriacontane (n-C_{31})	Dotriacontane (n-C_{32})	Tritriacontane (n-C_{33})	Tetratriacontane (n-C_{34})	Pentatriacontane (n-C_{35})	Hexatriacontane (n-C_{36})	Heptatriacontane (n-C_{37})	Octatriacontane (n-C_{38})	Nonatriacontane (n-C_{39})	Tetracontane (n-C_{40})
297031710	1.91	nd	0.34	0.96	6.69	33.7	15.7	0.61	nd	nd	nd	nd	nd	nd	0.11	0.15	0.17
297031711	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.10	nd	nd	0.38	0.10	0.11	0.13
297031712	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.23	nd	nd	nd	0.21	0.09	0.12	0.14
297031713	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.11	0.12	0.14
297031714	nd	nd	nd	nd	nd	nd	nd	nd	0.14	nd	nd	nd	0.11	0.26	0.15	0.14	0.16
297031715	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.24	0.11	0.14	0.16
297031716	nd	nd	nd	0.12	nd	nd	nd	nd	nd	0.11	nd	nd	nd	0.19	0.09	0.11	0.12
Average[4]	0.40	nd	< MDL	0.18	1.04	5.05	2.45	0.14	< MDL	< MDL	< MDL	nd	< MDL	0.21	0.11	0.13	0.15
Std Dev	0.67	-	-	0.35	2.49	12.6	5.85	0.21	-	-	-	-	-	0.10	0.02	0.02	0.02
MDL	0.29	0.27	0.11	0.08	0.20	0.56	0.48	0.11	0.14	0.11	0.09	0.10	0.10	0.18	0.08	0.06	0.06

Table D11. Continued.[1-3]

Sample ID	Total Petroleum Hydrocarbons[5]	Total Concentrations of Individual Hydrocarbons[6,7,15]	Total: Pristane + Phytane[6,15]	Pristane/n-C_{17}[16]	Phytane/n-C_{18}[16]	Pristane/Phytane[16]	Total: Odd No Carbons[6,8,15]	Total: Even No Carbons[6,9,15]	Carbon Preference Index (CPI)[10,16]	Sum: C_{10}-C_{12}-C_{14}[6,11,15]	Sum: C_{22}-C_{24}-C_{26}-C_{28}[6,12,15]	Weathering Index (WI)[13,16]
297031710	801	67.4	nd	-	-	-	40.6	26.8	1.52	nd	10.2	-
297031711	62.4	nd	nd	-	-	-	nd	nd	-	nd	1.58	-
297031712	54.7	nd	nd	-	-	-	nd	nd	-	nd	nd	-
297031713	57.5	nd	nd	-	-	-	nd	nd	-	nd	1.72	-
297031714	nd	nd	nd	-	-	-	nd	nd	-	nd	nd	-
297031715	71.3	nd	nd	-	-	-	nd	nd	-	nd	1.34	-
297031716	74.2	nd	nd	-	-	-	nd	nd	-	nd	nd	-
Average[4]	164	15.4	< MDL	-	-	-	9.46	5.84	1.62 [17]	< MDL	2.59	-
Std Dev	281	23.0	-	-	-	-	13.7	9.23	-	-	3.38	-
MDL	53.6	8.19[14]	0.19[14]				5.09[14]	2.91[14]		0.29[14]	1.29[14]	

Table D11. Continued.

Footnotes:

[1] The concentrations of the individual aliphatic hydrocarbons and the total petroleum hydrocarbons were determined using external standard calculations.

[2] When an individual aliphatic hydrocarbon was not detected, its concentration was replaced by nd.

[3] The concentrations for n-C_8 will be not reported, since it was difficult to identify this peak in samples and to determine MDL for n-C_8.

[4] If all concentrations are nd, the average is replaced with nd. When there is at least one number in the data set to be averaged, each nd is replaced with 1/2*MDL, and an average is calculated. If this numeric value is less than the MDL, the average is replaced by < MDL; otherwise, the average is the calculated value. When a numeric value is found for the average, the standard deviation is then determined using the same number set used to calculate the average.

[5] Determined from the total peak areas in the chromatogram from n-C_8 to n-C_{40} minus any contributions from the internal standard areas.

[6] These formulae use 1/2MDL values for each analyte not detected.

[7] Sum of the concentrations of the individual aliphatic hydrocarbons n-C_9 through n-C_{40} plus the concentrations of pristane and phytane.

[8] The total of the concentrations of the aliphatic hydrocarbons with an odd number of carbon atoms.

[9] The total of the concentrations of the aliphatic hydrocarbons with an even number of carbon atoms. The contribution of n-C_8 is not included in the total.

[10] Carbon Preference Index (CPI) is defined as the ratio of the total of the concentrations of the aliphatic hydrocarbons with an odd number of carbons to the total concentration of the alphatic hydrocarbons with an even carbon number.

[11] The total of the concentrations of n-C_{10}, n-C_{12}, and n-C_{14}.

[12] The total of the concentrations of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[13] Weathering Index (WI) is defined as the ratio of the total concentration of n-C_{10}, n-C_{12}, and n-C_{14} to the total concentration of n-C_{22}, n-C_{24}, n-C_{26}, and n-C_{28}.

[14] These MDL values are calculated with the same summation formulae as the samples using the individual hydrocarbon MDL values.

[15] The summation totals for the samples are compared with calculated MDL values obtained using the same summation formulae as the samples. When these sample totals were less than the total MDL, its total was replaced by nd. The averages and standard deviations for the totals were treated in the same way as the individual hydrocarbons; see footnote 4.

[16] Numerical values of the CPI, WI, and the ratios: pristane/n-C_{17}, phytane/n-C_{18}, and pristane/phytane, will be calculated only when the defined quantity for each index or ratio has a numeric value.

[17] These results are not true averages, instead they are the ratios of the averages of the defined quantities, if these averages exist.

APPENDIX E

CHROMATOGRAMS FOR ANALYSIS OF PETROLEUM HYDROCARBONS

[Note: For Figures E1-E14, each chromatogram was normalized to the overall response expected for 1 g of material from each core section or surface scoop sample. The value for TPH is given for each chromatogram. When the TPH value is smaller than the MDL value of 181 µg/g, the symbol "<MDL" is assigned to the TPH concentration, and the MDL is used to normalize the chromatogram.]

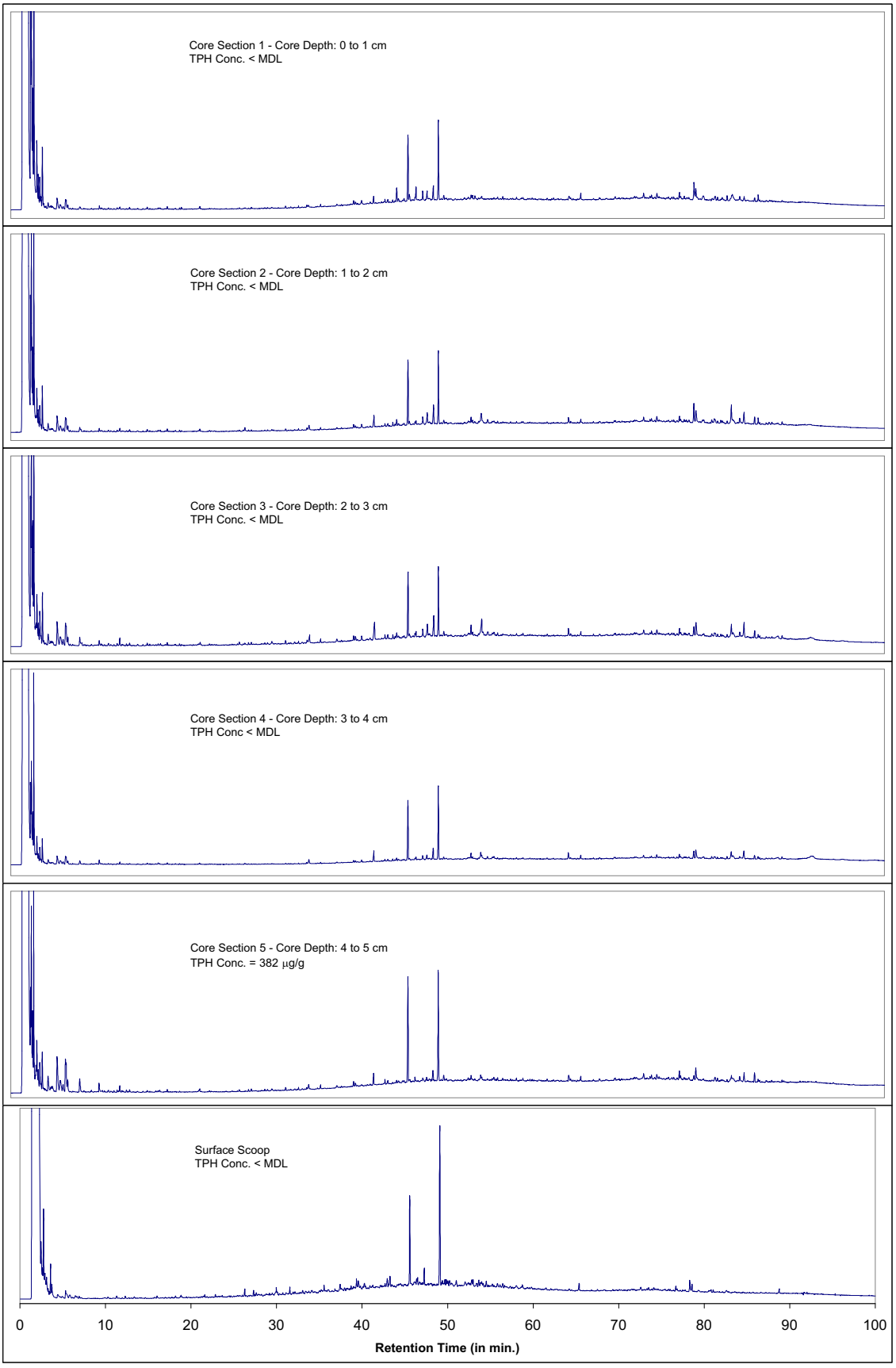


Figure E1. Normalized GC-FID chromatograms for Station A, Old Place Creek marsh sediment core sections (collected September 1996) and surface scoop (collected May 1997)

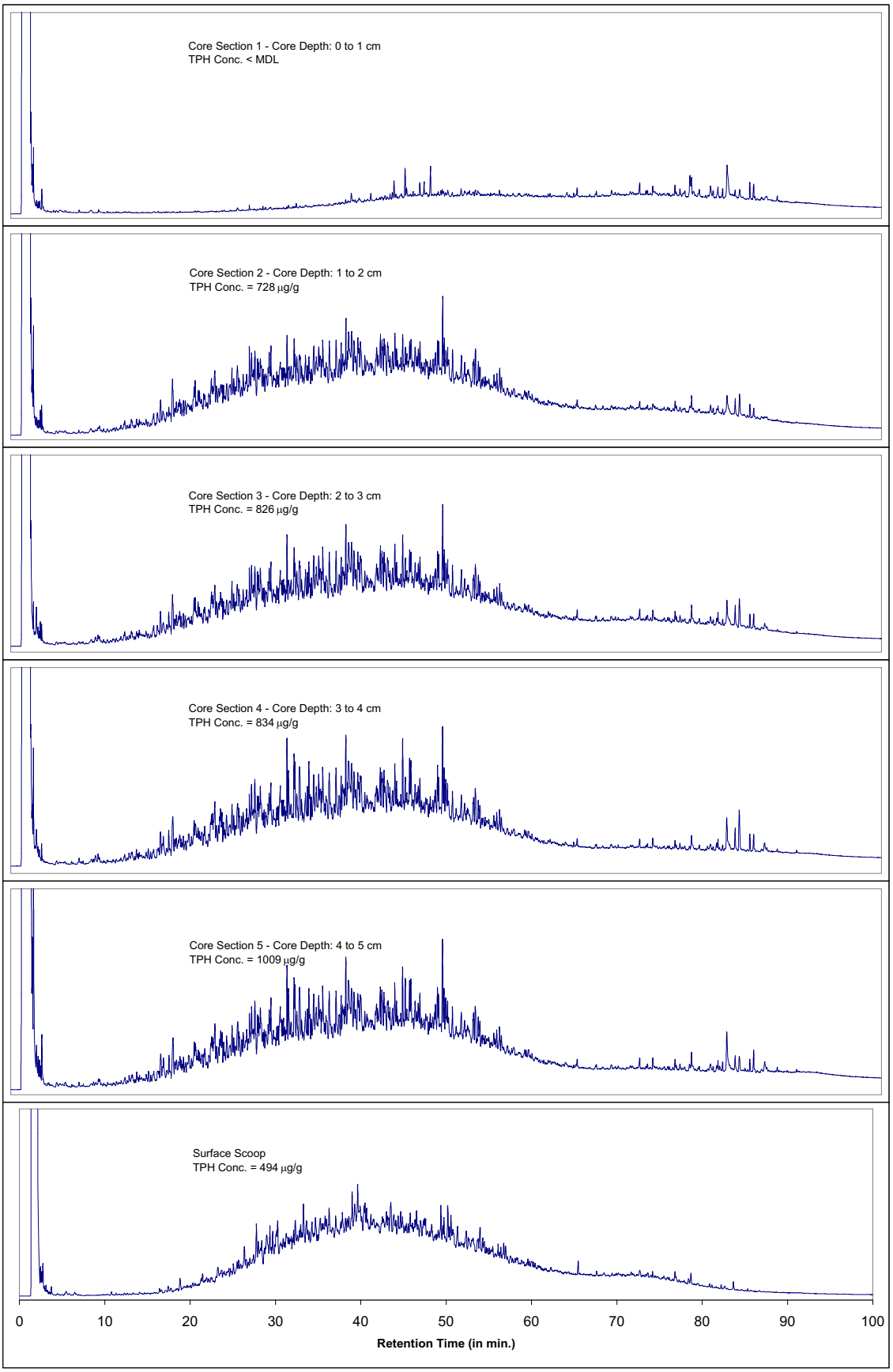


Figure E2. Normalized GC-FID chromatograms for Station B, Old Place Creek marsh sediment core sections (collected September 1996) and surface scoop (collected May 1997)

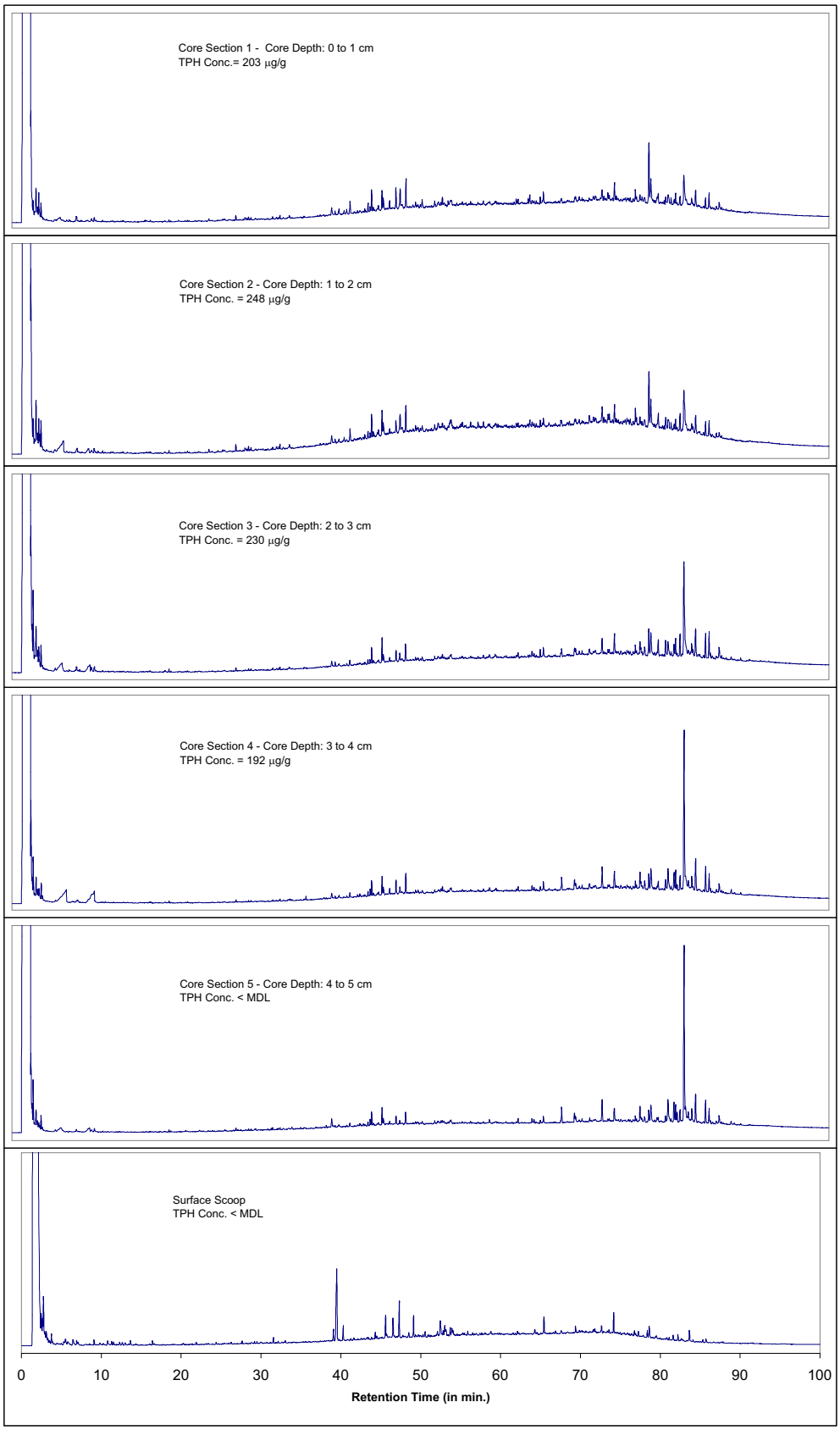


Figure E3. Normalized GC-FID chromatograms for Station C, Old Place Creek marsh sediment core sections (collected September 1996) and surface scoop (collected May 1997)

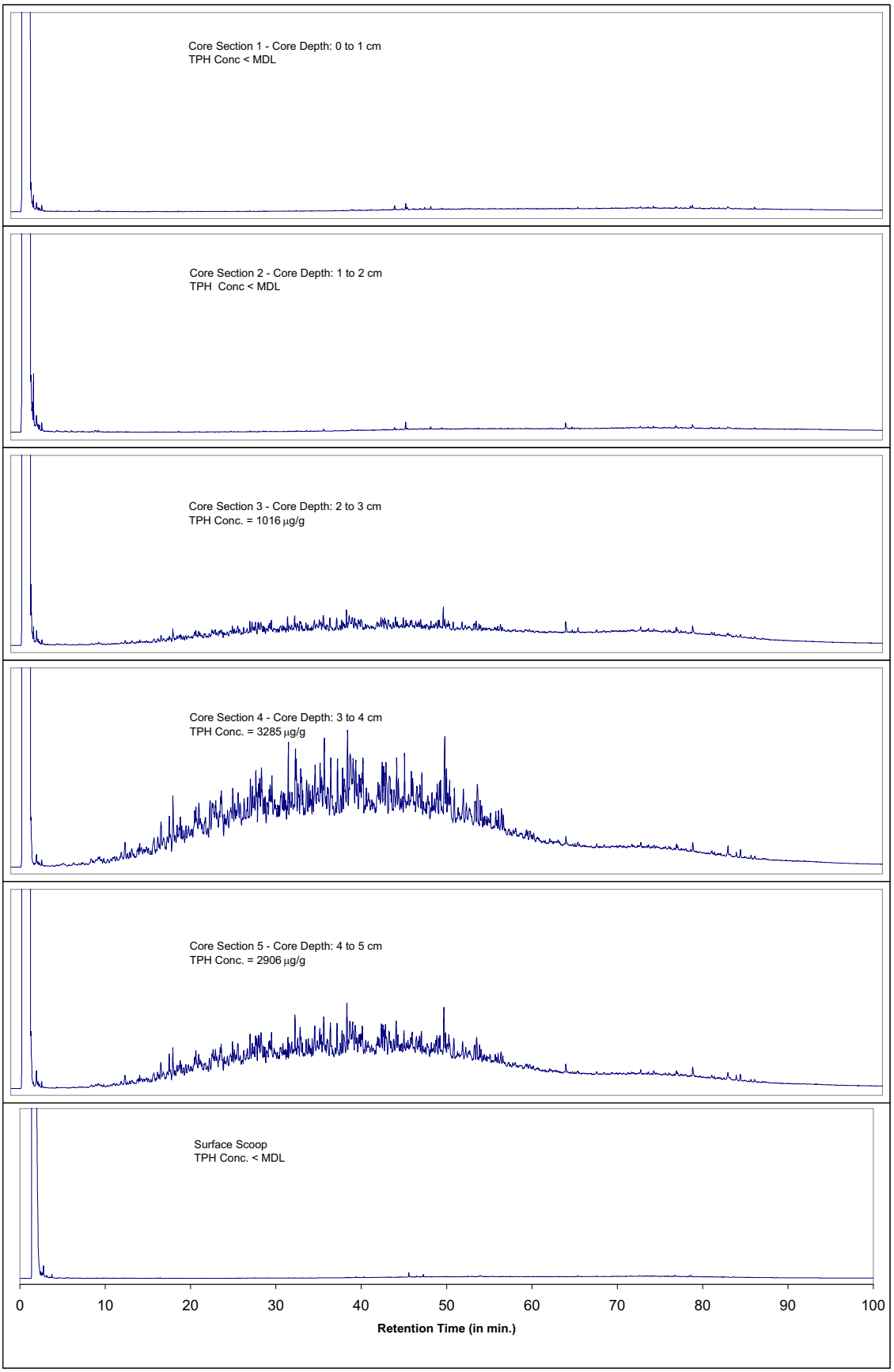


Figure E4. Normalized GC-FID chromatograms for Station D, Old Place Creek marsh sediment core sections (collected September 1996) and surface scoop (collected May 1997)

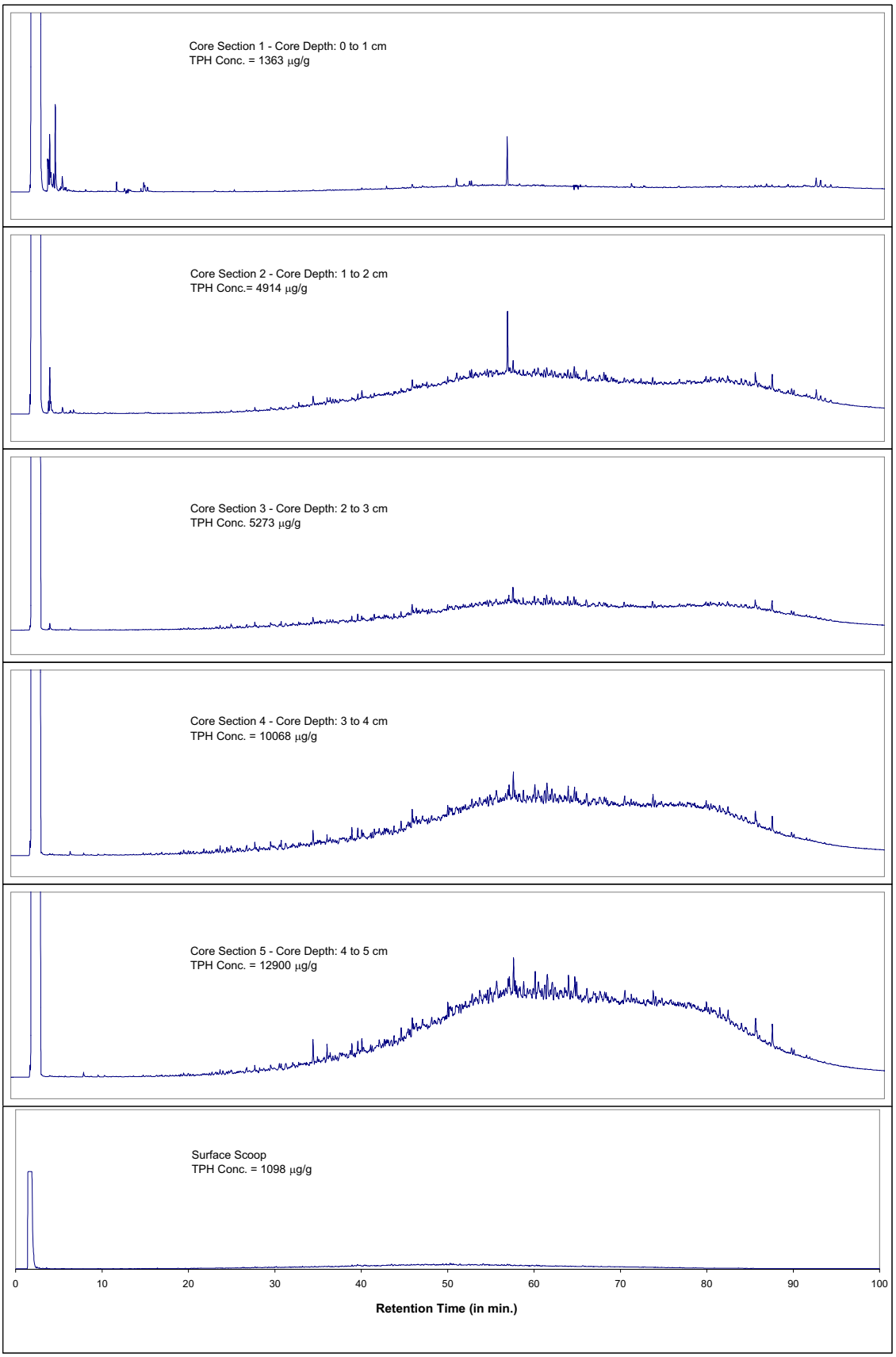


Figure E5. Normalized GC-FID chromatograms for Station A, Con Ed Tower marsh sediment core sections (collected September 1996) and surface scoop (collected May 1997)

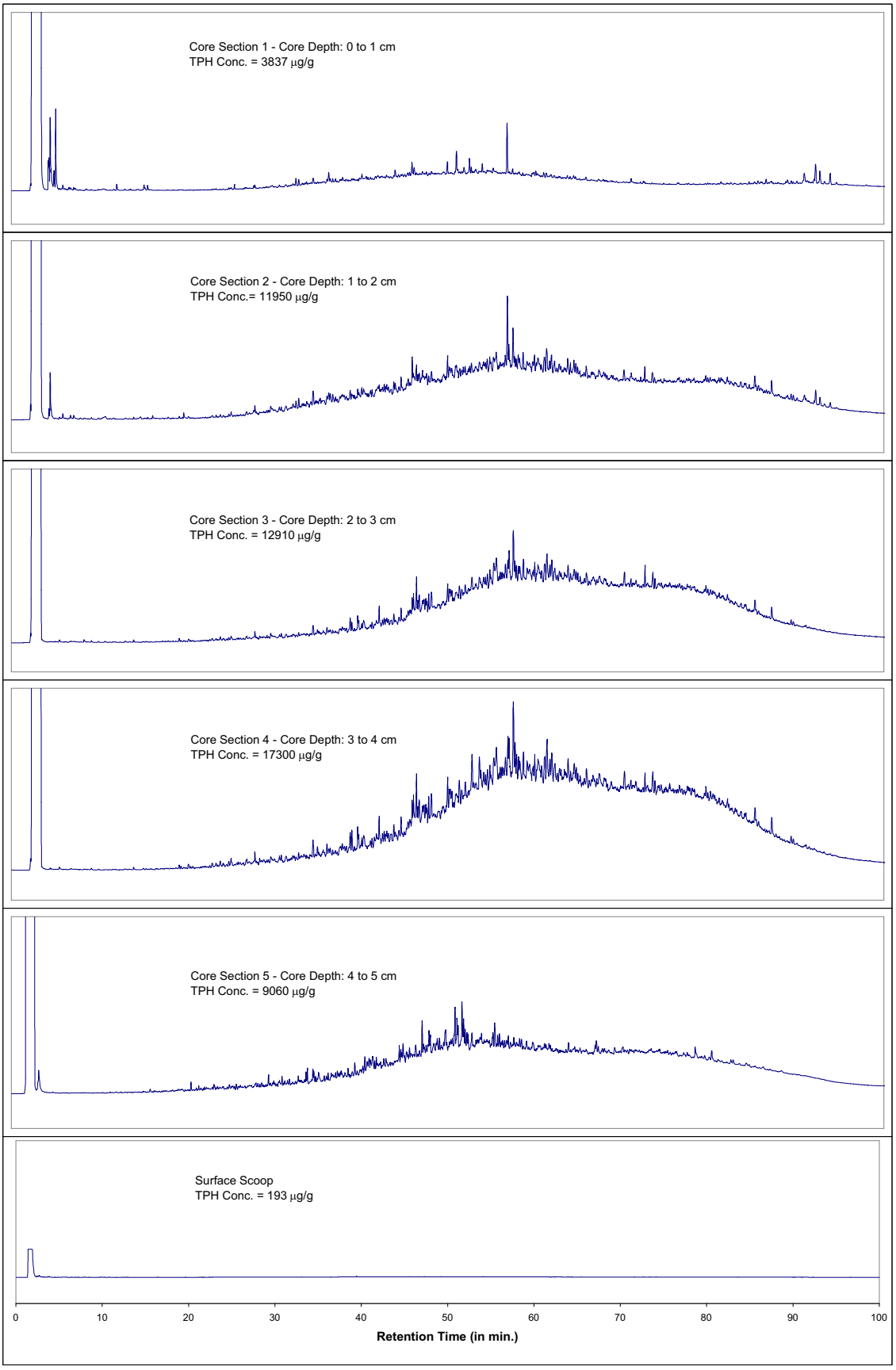


Figure E6. Normalized GC-FID chromatograms for Station B, Con Ed Tower marsh sediment core sections (collected September 1996) and surface scoop (collected May 1997)

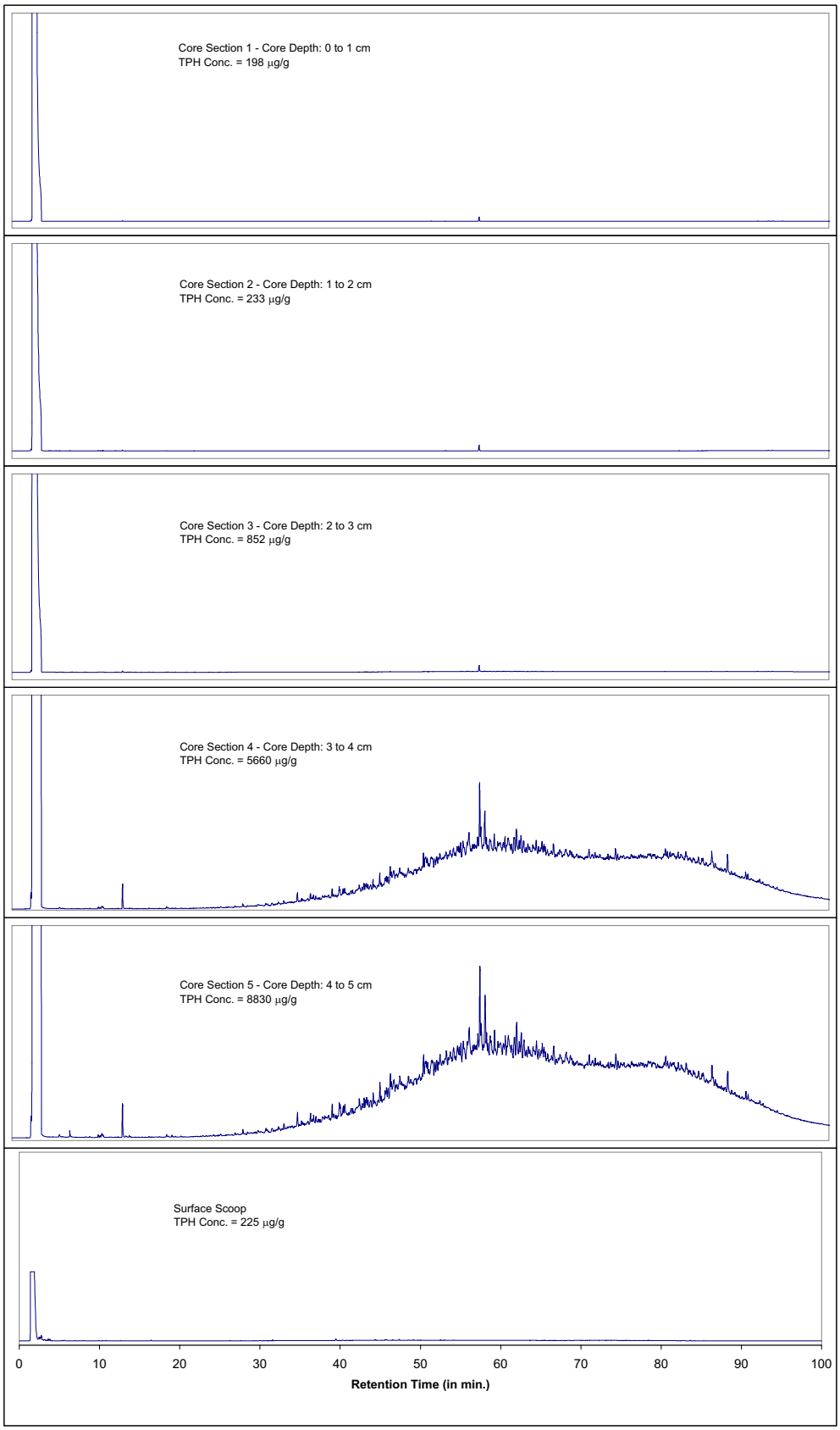


Figure E7. Normalized GC-FID chromatograms for Station C, Con Ed Tower marsh sediment core sections (collected September 1996) and surface scoop (collected May 1997)

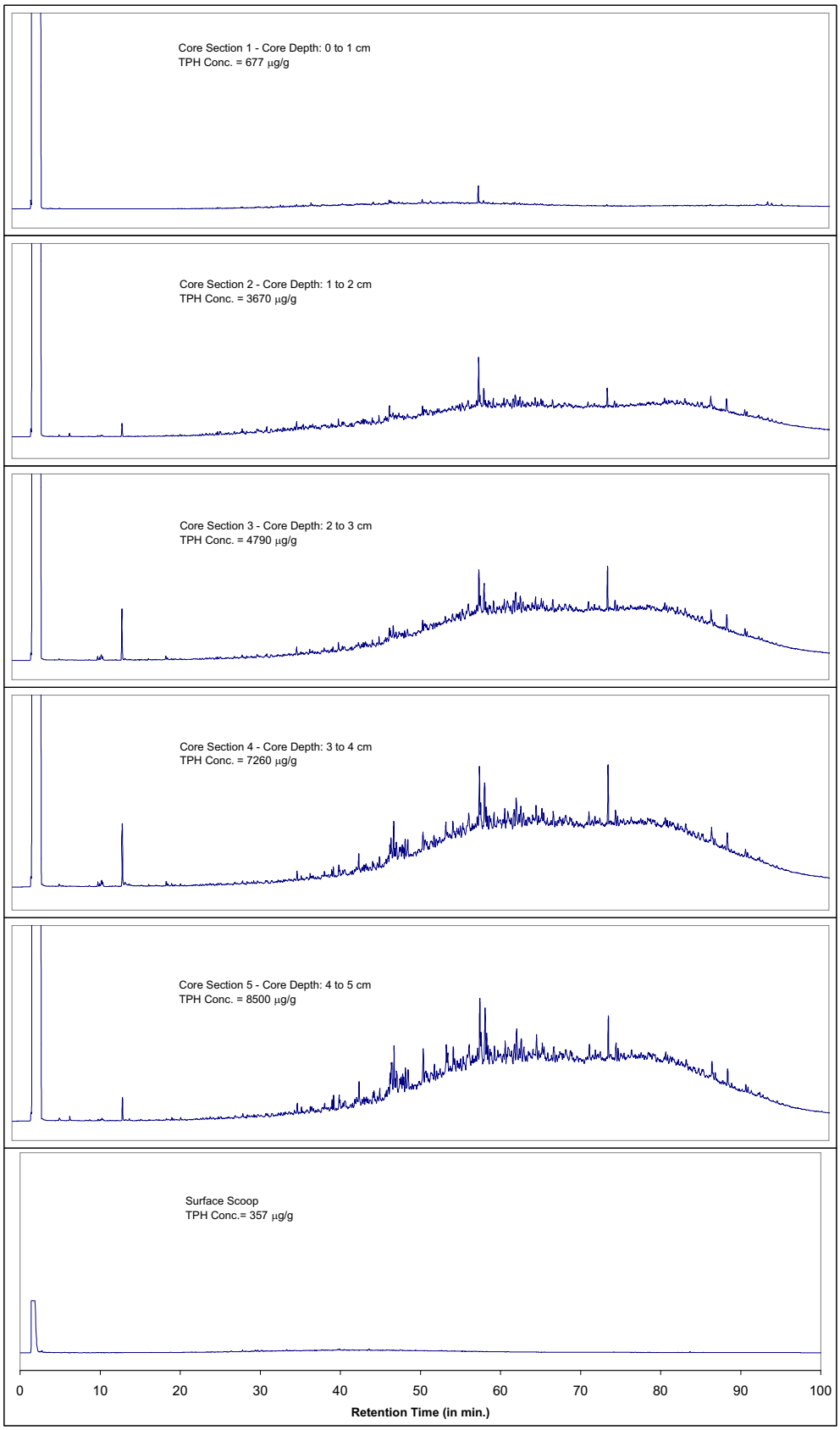


Figure E8. Normalized GC-FID chromatograms for Station D, Con Ed Tower marsh sediment core sections (collected September 1996) and surface scoop (collected May 1997)

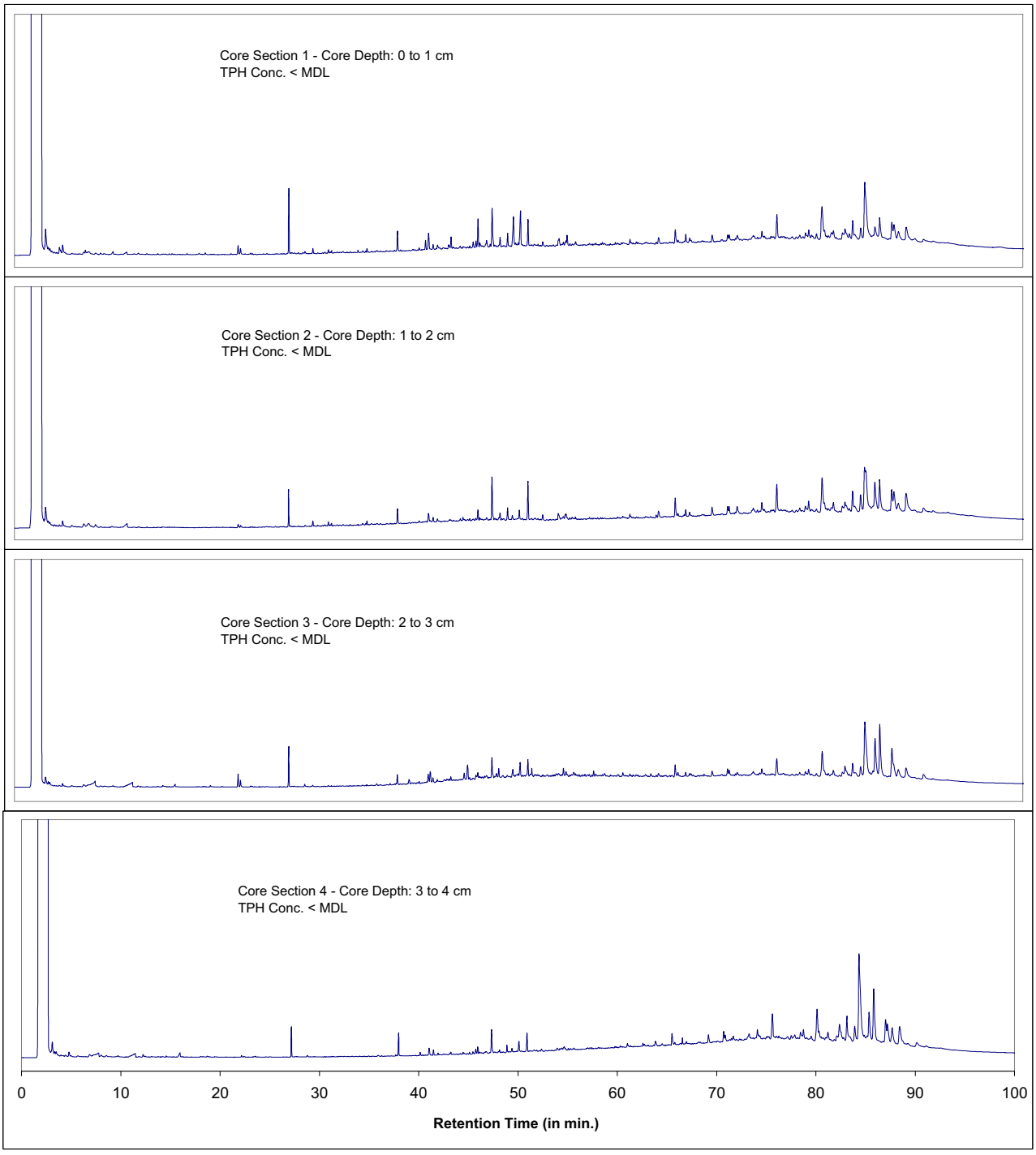


Figure E9. Normalized GC-FID chromatograms for Station A, Mill Creek marsh sediment core sections (collected September 1996)

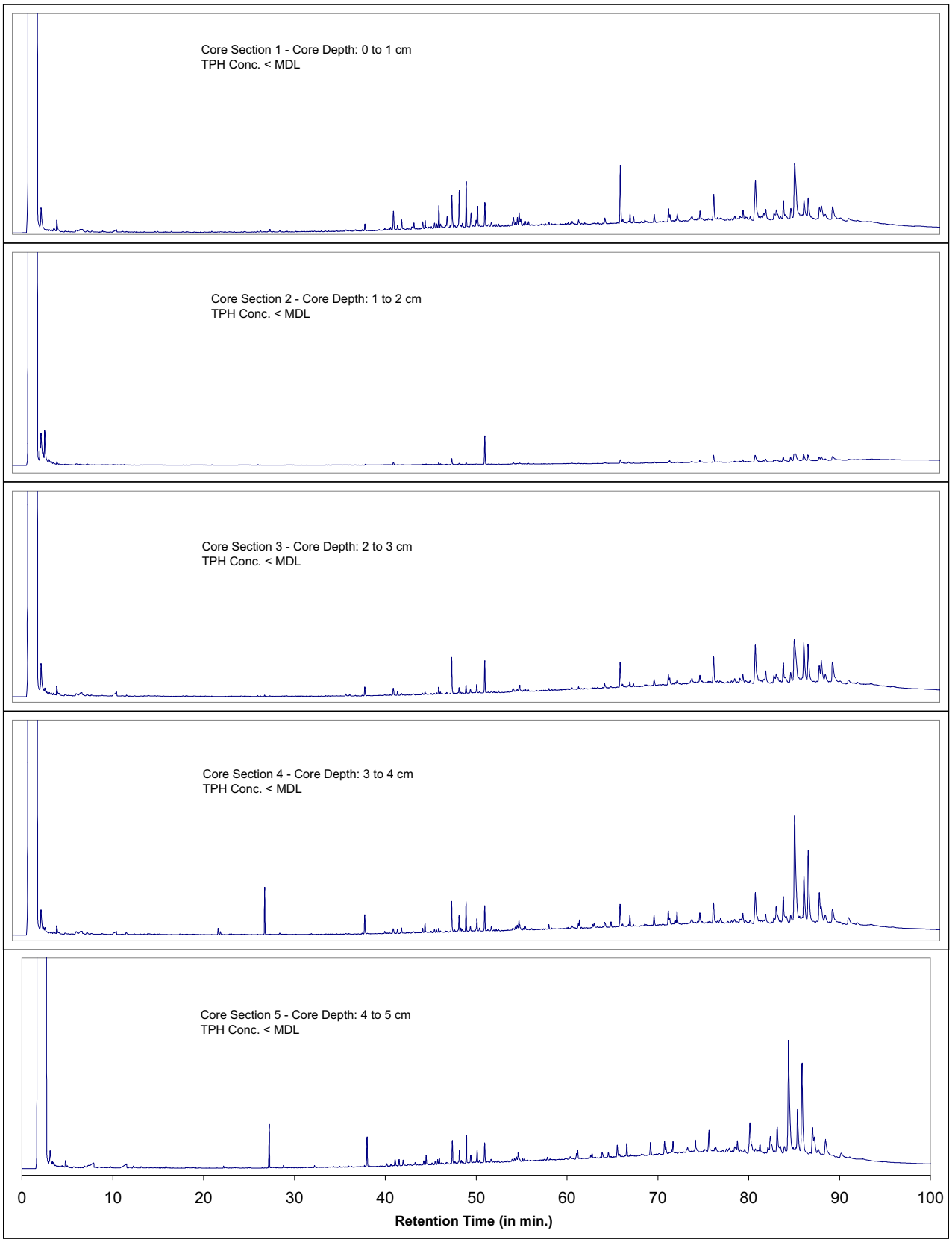


Figure E10. Normalized GC-FID chromatograms for Station B, Mill Creek marsh sediment core sections (collected September 1996)

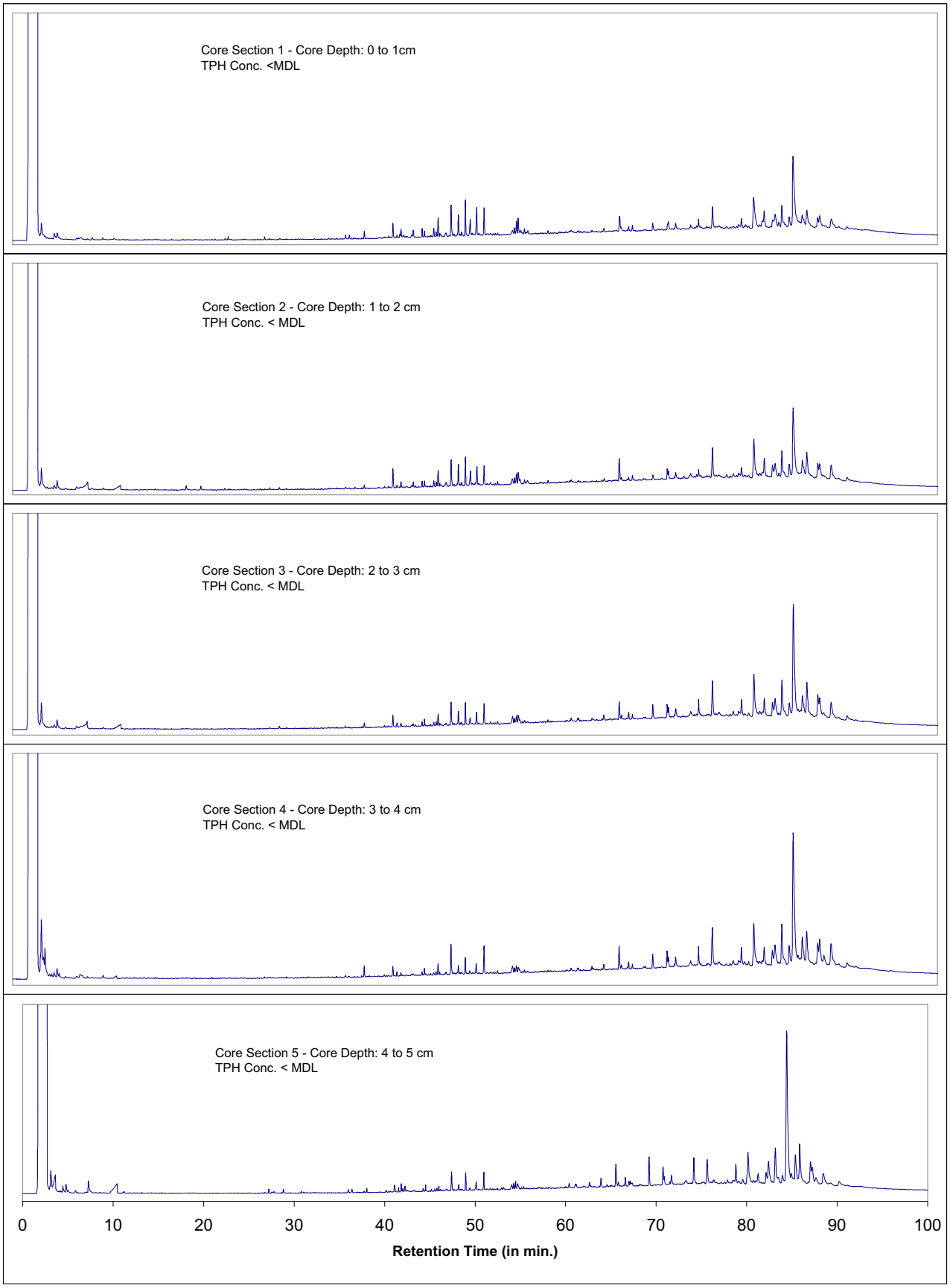


Figure E11. Normalized GC-FID chromatograms for Station C, Mill Creek marsh sediment core sections (collected September 1996)

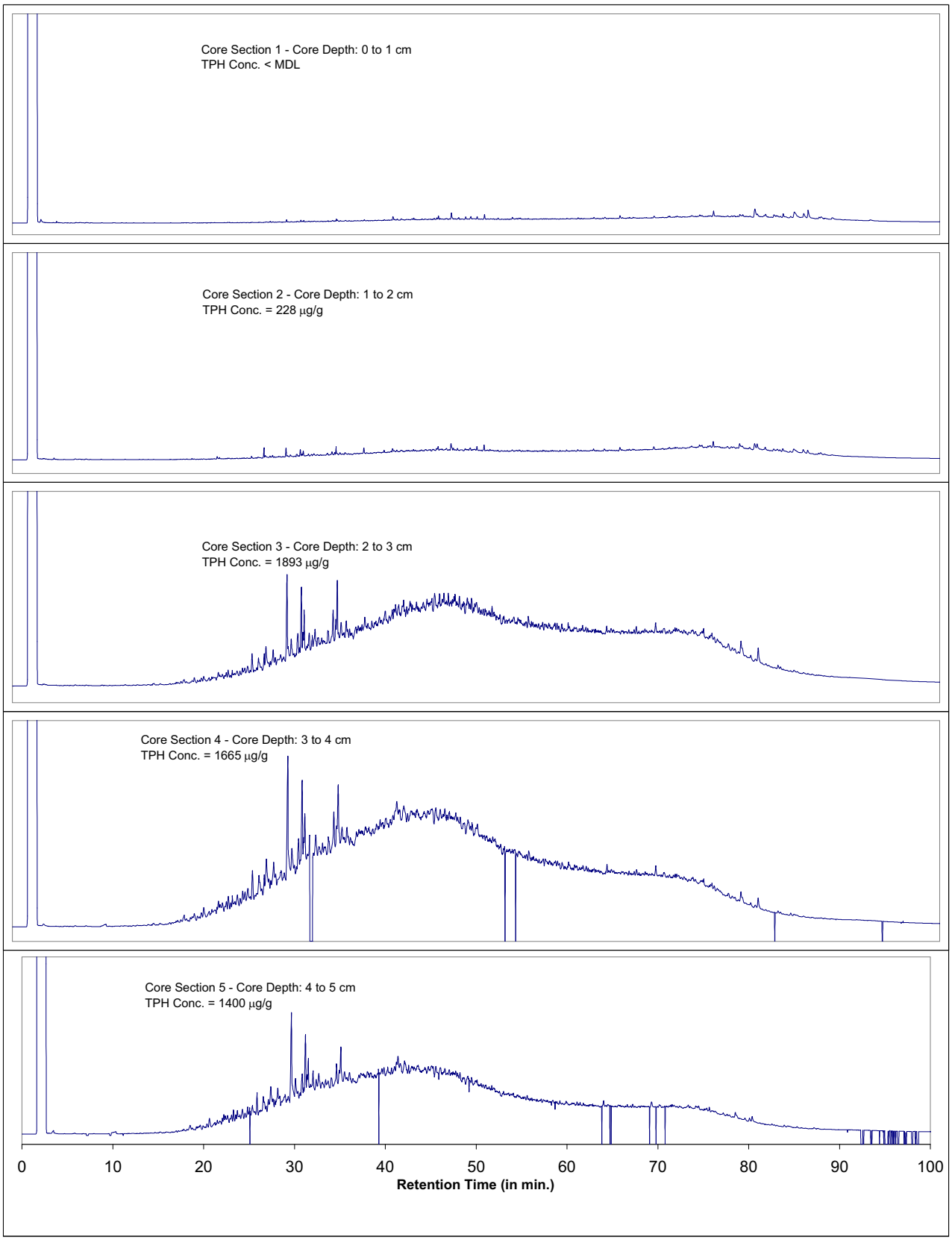
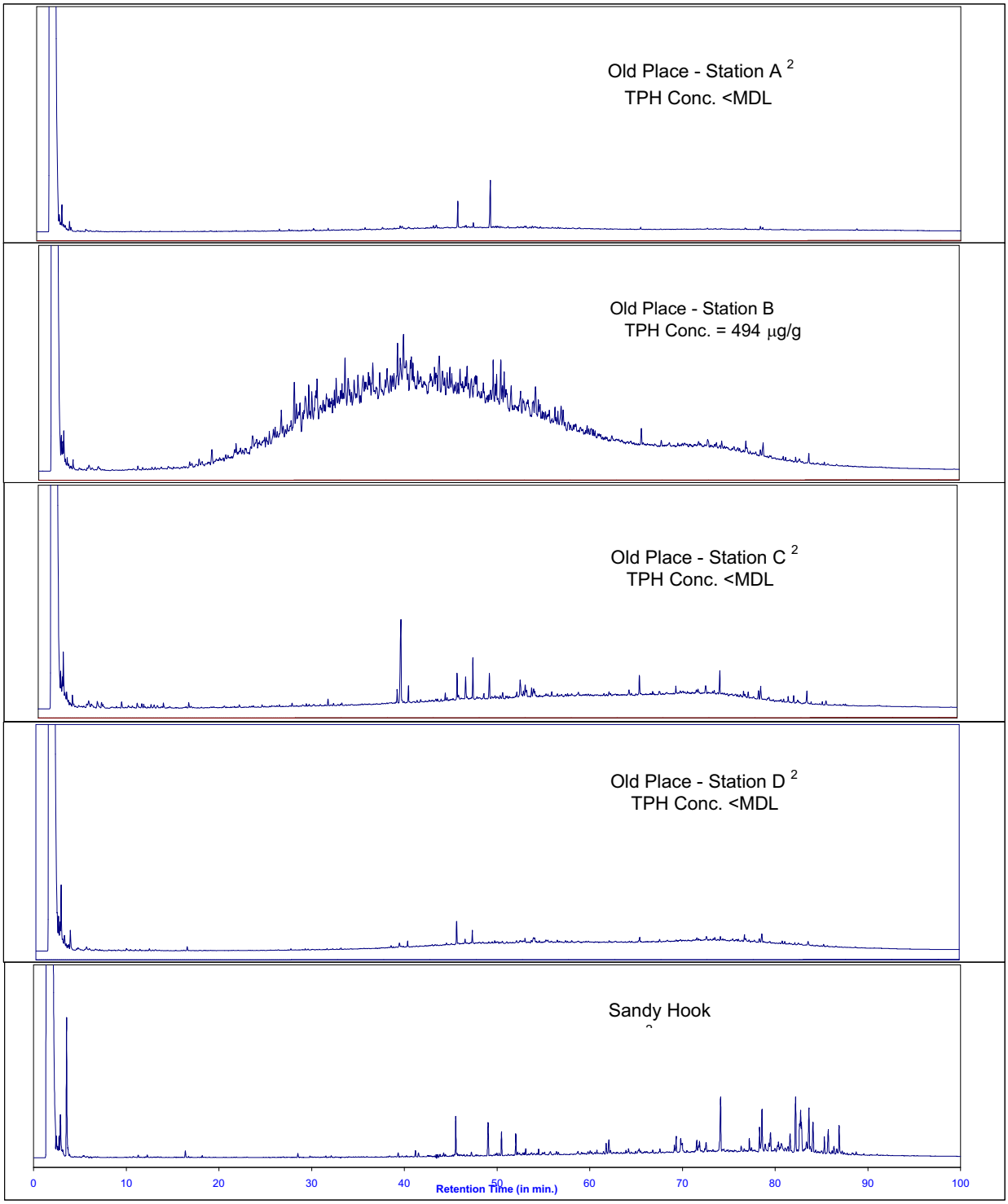


Figure E12. Normalized GC-FID chromatograms for Station D, Mill Creek marsh sediment core sections (collected September 1996)



[1] Each chromatogram was normalized with respect to the overall response expected for 1 gram of each surface scoop sample. The value for TPH is given for each chromatogram.

[2] The TPH value for these samples is smaller than the MDL value of 181 µg/g. The MDL value is used instead to normalize the chromatogram.

Figure E13. Normalized GC-FID chromatograms for Old Place Creek marsh and Sandy Hook Bay marsh surface scoop samples[1]

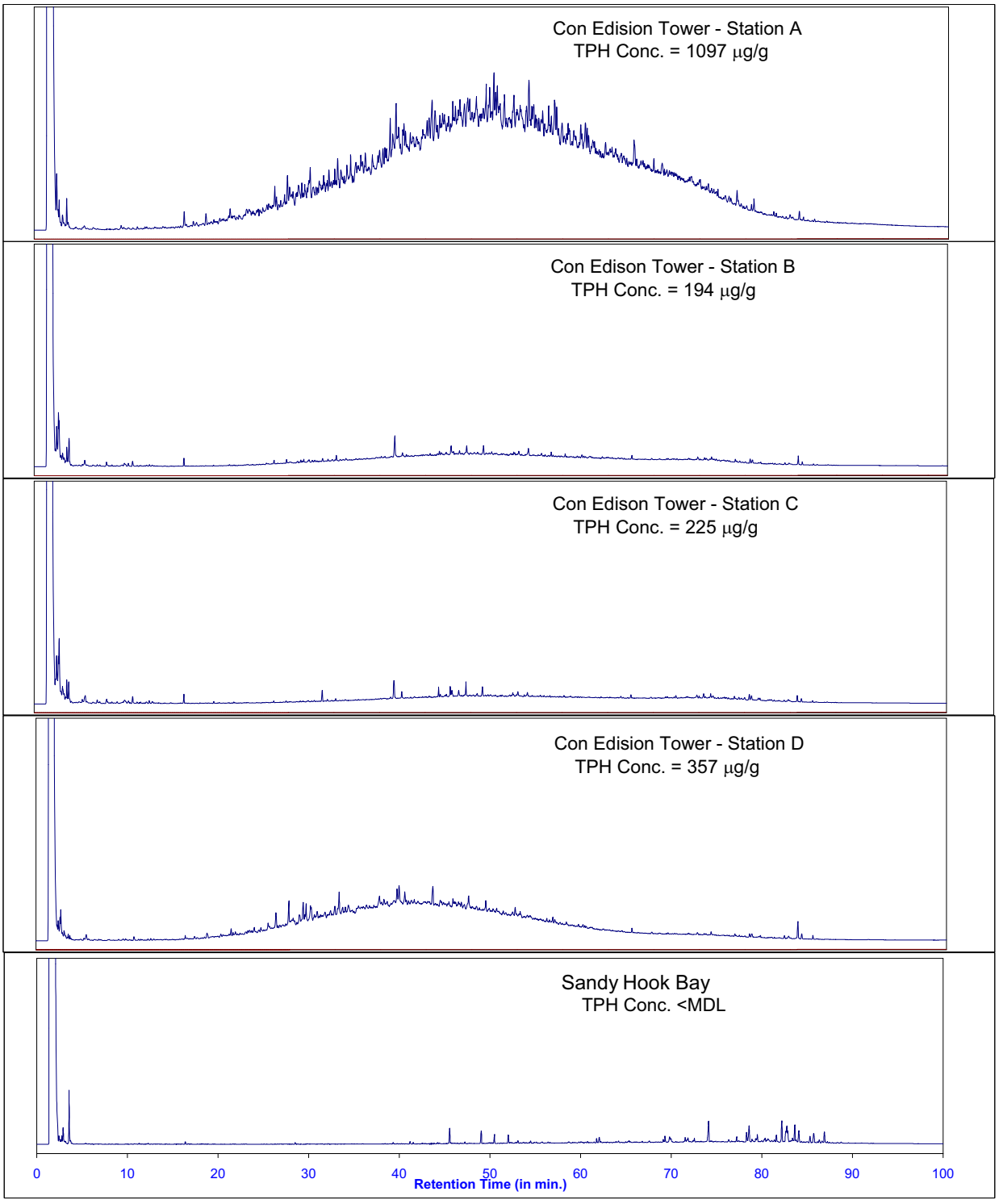


Figure E14. Normalized GC-FID chromatograms for Con Ed Tower marsh and Sandy Hook Bay marsh surface scoop samples

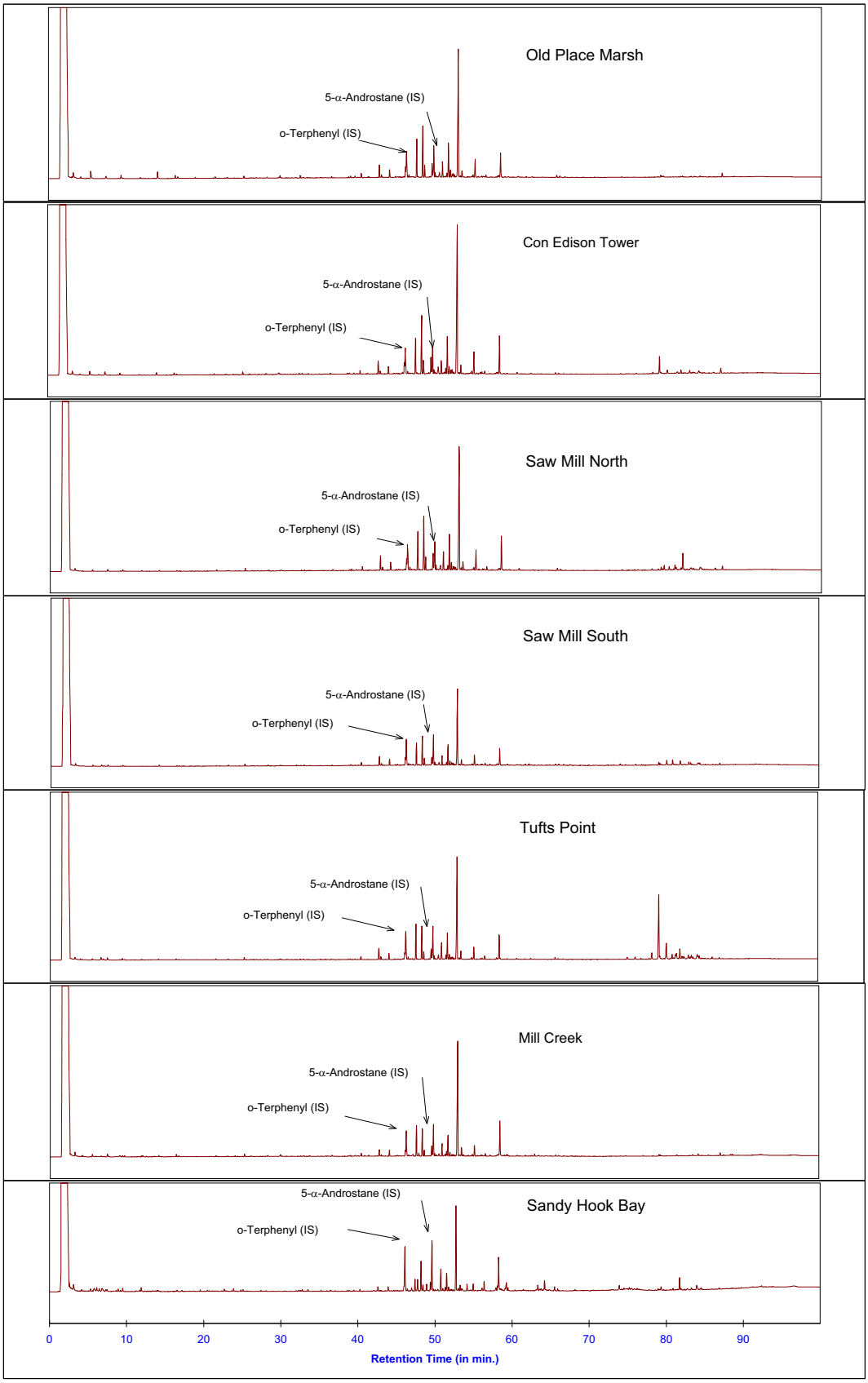


Figure E15. Representative GC-FID chromatograms for Arthur Kill and Sandy Hook Bay ribbed-mussels collected in September 1996

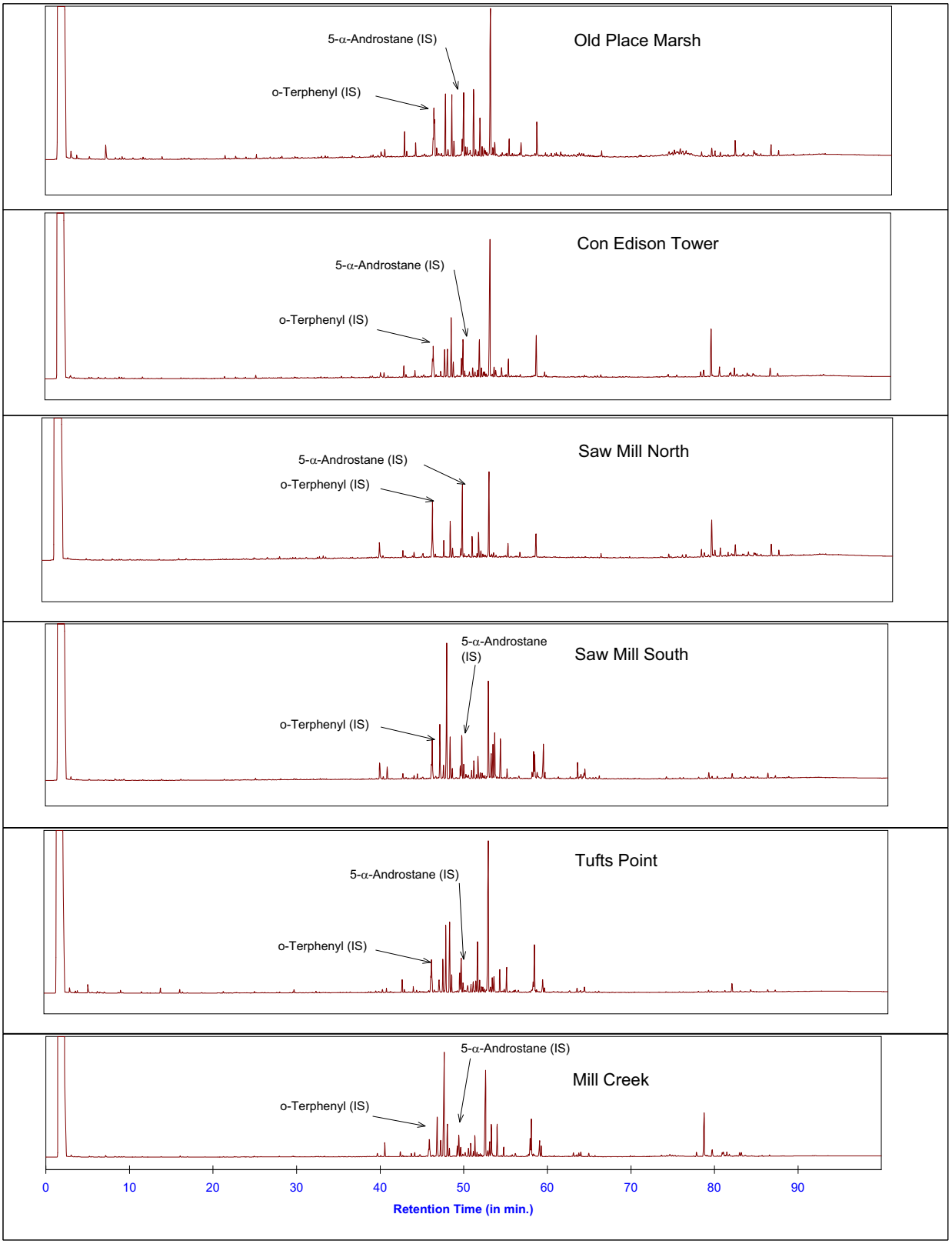


Figure E16. Representative GC-FID chromatograms for Arthur Kill ribbed-mussels collected in May 1997

APPENDIX F

REDOX VALUES

Table F1. Summary of redox data (E_h measured in mV, and listed as mean ± standard deviation) by station, depth range, and season for the replanted marsh sites of Old Place Creek and Saw Mill Creek North. (Most oxic season per station and depth range indicated by underlining. If neither season is underlined, then there was no significant difference between seasons.)

Depth range (cm)	Station A		B		C		D	
	Fall '96	Spring '97	Fall '96	Spring '97	Fall '96	Spring '97	Fall '96	Spring '97
Old Place Creek								
0 to -2	+398 ± 34	+336 ± 46	+105 ± 165	+70 ± 195	+143 ± 181	+157 ± 110	+197 ± 60	+307 ± 39
-3 to -5	+453 ± 19	+414 ± 20	-201 ± 22	-231 ± 21	-262 ± 245	-196 ± 16	-142 ± 39	+268 ± 193
-6 to -10	+421 ± 205	+346 ± 121	-269 ± 6	-267 ± 25	+398 ± 34	-168 ± 42	-270 ± 182	+41 ± 172
Saw Mill Creek North								
0 to -2	+106 ± 80	+187 ± 152	+227 ± 97	+248 ± 74	+170 ± 93	+282 ± 80	+87 ± 247	+148 ± 146
-3 to -5	-35 ± 97	-57 ± 75	+70 ± 245	+405 ± 21	+17 ± 77	+76 ± 188	-204 ± 8	+86 ± 274
-6 to -10	-159 ± 17	-178 ± 13	-168 ± 17	+444 ± 8	-15 ± 61	-68 ± 55	-213 ± 8	-173 ± 4

Table F2. Summary of redox data (E_h measured in mV, and listed as mean ± standard deviation) by station, depth range, and season for the unplanted marsh sites of Con Ed Tower and Saw Mill Creek South. (Most oxic season per station and depth range indicated by underlining. If neither season is underlined, then there was no significant difference between seasons.)

Depth range (cm)	Station A		Station B		Station C		Station D	
	Fall '96	**Spring '97**	**Fall '96**	**Spring '97**	**Fall '96**	**Spring '97**	**Fall '96**	**Spring '97**
				Con Ed Tower				
0 to -2	+59 ± 161	+169 ± 99	+23 ± 123	+167 ± 104	+109 ± 44	+83 ± 113	+8 ± 113	+230 ± 74
-3 to -5	-206 ± 28	+52 ± 238	-184 ± 38	-139 ± 177	+56 ± 115	-118 ± 89	-156 ± 18	+143 ± 280
-6 to -10	-239 ± 10	+223 ± 24	-252 ± 9	-206 ± 32	-134 ± 9	-232 ± 8	-170 ± 21	-97 ± 212
				Saw Mill Creek South				
0 to -2	+113 ± 149	+103 ± 154	+161 ± 136	+133 ± 146	+188 ± 123	+144 ± 110	+109 ± 133	+103 ± 130
-3 to -5	-151 ± 15	-179 ± 18	-129 ± 40	-140 ± 24	-58 ± 65	-18 ± 36	-176 ± 12	+32 ± 148
-6 to -10	-191 ± 18	-184 ± 6	-201 ± 14	-198 ± 33	-6 ± 111	-129 ± 36	-205 ± 8	+61 ± 98

Table F3. Summary of redox data (E_h measured in mV, and listed as mean ± standard deviation) by station, depth range, and season for the reference marsh sites of Tufts Point and Mill Creek. (Most oxic season per station and depth range indicated by underlining. If neither season is underlined, then there was no significant difference between seasons.)

Depth range (cm)	Station A		Station B		Station C		Station D	
	Fall '96	Spring '97	Fall '96	Spring '97	Fall '96	Spring '97	Fall '96	Spring '97
Tufts Point								
0 to -2	+79 ± 182	+171 ± 103	+121 ± 109	+115 ± 95	+201 ± 89	+217 ± 160	+183 ± 123	+175 ± 86
-3 to -5	-165 ± 33	+75 ± 85	-173 ± 24	+153 ± 155	+11 ± 138	+38 ± 129	-98 ± 163	+6 ± 78
-6 to -10	-219 ± 42	No data	-179 ± 22	+36 ± 170	+103 ± 65	+118 ± 107	-253 ± 155	-141 ± 67
Mill Creek								
0 to -2	+173 ± 125	+149 ± 26	+78 ± 139	+188 ± 110	+76 ± 219	+74 ± 141	-130 ± 71	+175 ± 64
-3 to -5	-8 ± 117	+33 ± 75	-132 ± 19	-92 ± 44	-169 ± 11	-132 ± 26	-196 ± 6	-55 ± 64
-6 to -10	-150 ± 23	-137 ± 40	-181 ± 41	-137 ± 20	-197 ± 22	-173 ± 18	-209 ± 6	-191 ± 19

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