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MONITORING OF OLYMPIC NATIONAL PARK BEACHES TO DETERMINE FATE AND EFFECTS OF SPILLED BUNKER C FUEL OIL

Final Report

U.S. Department of the Interior
Minerals Management Service
Alaska OCS Region

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Final Report

Prepared for:

U.S. Department of the Interior
Minerals Management Service
Pacific OCS Region
1340 West Sixth Street
Los Angeles, California 90017

Prepared by:

J. A. Strand
V. I. Cullinan
E. A. Crecelius
T. J. Fortman
R. J. Citterman
M. L. Fleischmann

Battelle/Marine Sciences Laboratory
439 West Sequim Bay Road
Sequim, Washington 98382

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SUMMARY

On December 23, 1988, the barge Nestucca was accidentally struck by its tow, a Souse Brothers Towing Company tug, releasing approximately 230,000 gallons of Bunker C fuel oil and fouling beaches from Grays Harbor north to Vancouver Island. Affected beaches in Washington included a 40-mile-long strip that had been recently added to Olympic National Park. The purpose of the monitoring program documented in this report was to determine the fate of spilled Bunker C fuel oil on selected Washington coastal beaches. We sought to determine 1) how much oil remained in intertidal and shallow subtidal habitats following clean-up and weathering, 2) to what extent intertidal and/or shallow subtidal biotic assemblages have been contaminated, and 3) how rapidly the oil has left the ecosystem.

Beach surveys to determine the distribution and fate of spilled Bunker C fuel oil were scheduled during the lowest tides in July and September 1989 and February 1990. A total of eight study sites was selected from inside Olympic National Park: four from areas of known contamination (Second Beach, Kayostla Beach, and beaches south of Cape Alava [Wedding Rocks] and north of Norwegian Memorial); and four areas of no known contamination (Ruby Beach and beaches south of Hole-in-the-Wall, Cedar Creek, and Norwegian Memorial). Additionally, four study sites of known contamination from outside the Olympic National Park (Sand Island in Grays Harbor, Ocean Shores near the breakwater, and beaches near Whale Creek and Point Grenville on the Quinault Indian Reservation) were selected. Infrared (IR) spectrophotometry of surface (0 to 15 cm) sediments and gas chromatography (GC) of surface (0 to 15 cm) sediments and invertebrate tissues were used to evaluate contamination levels.

Despite relatively high concentrations of oil (6255 and 19,015 μg/g dry weight by IR) found on Sand Island in Grays Harbor during the second survey, the finding of relatively low concentrations of oil (63 to 250 μg/g dry weight by IR), essentially trace amounts, associated with the coastal stations during the third survey suggests that little residual oil remains from the December 1988 Nestucca spill. Attempts to relocate oil on Sand

Island during the third survey were unsuccessful, suggesting that even this relatively high concentration of oil has been weathered and depurated.

The repeated findings of no detectable oil at Ocean Shores (North Jetty), even though this site initially was one of the most heavily oiled, suggests that open, high-energy, and sandy beaches cleanse themselves naturally much faster than do protected rock, cobble, and rubble beaches, such as those encountered at Kayostla Beach, Norwegian Memorial, and Cape Alava (Wedding Rocks). Our findings also suggest that clean-up of oil mats and oil debris following the Nestucca spill served to reduce the level of residual oil contaminating affected beaches.

Chromatograms of oil (both aromatics and saturates) found within Sand Island sediments during the second survey display patterns strikingly similar to those of Bunker C fuel oil collected from the barge Nestucca. The lower carbon preference index (CPI) (odd to even saturates ratio) values (0.92 and 0.94) of the Sand Island sediment samples also are indicative of an anthropogenic source of contamination. The evidence, then, strongly suggests that the oil found on Sand Island came from the barge Nestucca. There is, however, less certainty as to the source of oil found in sediments collected during the third survey at Norwegian Memorial, Kayostla Beach, Wedding Rocks, Second Beach, Ruby Beach, and Hole-in-the-Wall. The Norwegian Memorial, Kayostla Beach, Wedding Rocks, and Second Beach sediments contained some hydrocarbon components which are consistent with weathered Bunker C oil but also contained hydrocarbons that could be associated with other oils including those of biogenic origin. The chromatograms (both aromatics and saturates) for sediment from Ruby Beach and Hole-in-the-Wall were not consistent with comparable chromatograms for the Nestucca oil. This does not eliminate the possibility that oil in these samples represents highly weathered Bunker C, but because the uncertainty associated with determining the source is great, no conclusion can be made.

Concentrations of aromatic hydrocarbons in California mussels, razor clams, and other invertebrates following the Nestucca spill were all $\leq$100 ng/g (dry weight). Most concentrations were $\leq$45 ng/g (dry weight). These levels are significantly (10 to 100 times) lower than those found in

mussels collected in South Puget Sound, a relatively clean urban estuary, and the more polluted areas of Puget Sound (Commencement Bay and Elliott Bay) in recent years as part of the National Status and Trends Program for Marine Environmental Quality. Under the same program, concentrations of aromatic hydrocarbons in mussels found at coastal sites including Cape Flattery, Grays Harbor, and Coos Bay, Oregon ranged from 20 to 141 ng/g (dry weight) from 1986 to 1989. Based on the relatively low concentrations of known carcinogenic aromatic hydrocarbons (4 to 15 ng/g dry weight) contained in the shellfish collected during the present study, the estimated lifetime cancer risk is also low (~5 x 10^{-7}, assuming the consumption of 1.1 g/day).

Because relatively high concentrations of Bunker C oil were found on Sand Island in Grays Harbor, and because some biological tissues collected during the study contained detectable levels of carcinogenic aromatic hydrocarbons, we recommend to continue minimal sampling of sediments from Sand Island and of mussels from selected Olympic National Park beaches (Kayostla Beach, Norwegian Memorial North, Wedding Rocks) annually for the next 3 to 4 years.

ACKNOWLEDGMENTS

This final report summarizes studies conducted between June 15, 1989, and June 22, 1990, by Pacific Northwest Laboratory (PNL)[a] for the U.S. Department of Interior, Minerals Management Service (MMS), Pacific OCS Division, Los Angeles, California, in cooperation with Olympic National Park, Port Angeles, Washington. This project was under the technical direction of Dr. John A. Strand, Battelle/Marine Sciences Laboratory, Sequim, Washington. Dr. Valerie I. Cullinan, also from Battelle/Marine Sciences Laboratory, designed, organized, and conducted the beach surveys of the Washington coast. She was assisted by Ms. Andrea J. Von Tom and Mr. Bruce W. Claiborne, both Northwest College and University Association for Science summer appointees, and Mr. Greg C. Spencer and Mr. Liam D. Antrim, both of Battelle/Marine Sciences Laboratory, and Dr. Strand. Mr. Timothy J. Fortman, Mr. Ronald J. Citterman, Ms. Mary L. Fleischmann, and Dr. Eric A. Crecelius analyzed environmental samples for total oil and grease (using IR) and aromatic and saturate hydrocarbon (using GC/mass selective and flame ionization detectors). Mr. John H. Aho, Mr. John H. Meyer, and Mr. Bruce B. Moorehead of Olympic National Park provided logistic support and accompanied the field team on the second beach survey, and Dr. Ahmad E. Nevissi, University of Washington, Seattle, Washington, acted as technical advisor to the project. Mr. Martin Golden served as the Contracting Officer's Technical Representative for MMS.

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CONTENTS

SUMMARY iii

ACKNOWLEDGEMENTS vii

1.0 INTRODUCTION 1

1.1 BACKGROUND 1

1.2 PURPOSE AND SCOPE 3

2.0 STUDY PLAN AND METHODOLOGY 5

2.1 SELECTION OF STUDY SITES 5

2.2 SELECTION OF SURVEY DATES 5

2.3 SURVEY DESIGN AND COMPOSITING STRATEGY 6

2.4 SEDIMENT SAMPLING 10

2.5 FAUNAL SAMPLING 13

2.6 ANALYTICAL CHEMISTRY 14

3.0 RESULTS AND DISCUSSION 17

3.1 SAMPLE COLLECTIONS AND LOCATIONS 17

3.2 INTERTIDAL AND SHALLOW SUBTIDAL SEDIMENTS 22

3.2.1 Total Oil and Grease 22

3.2.2 Aromatic and Saturate Hydrocarbons 24

3.3 INVERTEBRATE TISSUES 28

3.4 SOURCE IDENTIFICATION 41

3.4.1 Intertidal and Shallow Subtidal Sediments 41

3.4.2 Invertebrate Tissues 44

3.5 QUALITY-ASSURANCE RESULTS FOR CHEMICAL ANALYSES 46

3.5.1 Oil and Grease in Sediments 46

3.5.2 Saturate Hydrocarbon Compounds in Tissues and Sediments 46

3.5.3 Aromatic Hydrocarbon Compounds in Tissues and Sediments 47

3.6 PERSPECTIVE ON LEVELS OF RESIDUAL CONTAMINATION 47

3.7 FACTORS INFLUENCING WEATHERING AND DEPURATION 52

3.7.1 Time of Year 52

3.7.2 Type of Beach 53

3.7.3 Efficacy of Clean-up 53

4.0 CONCLUSIONS AND RECOMMENDATIONS 55

4.1 CONCLUSIONS 55

4.1.1 Contamination of Intertidal and Shallow Subtidal Sediments 55

4.1.2 Source of Oil Found on Washington State Beaches 55

4.1.3 Contamination of Biotic Assemblages 56

4.1.4 Factors Influencing Weathering and Depuration 56

4.2 RECOMMENDATIONS 57

5.0 REFERENCES 59

APPENDIX A1 SAMPLING INFORMATION A1.1

APPENDIX A2 SEDIMENT SAMPLE COMPOSITING A2.1

APPENDIX B INFRARED SPECTROPHOTOMETRIC OIL AND GREASE DETERMINATIONS IN SEDIMENT B.1

APPENDIX C1 GAS CHROMATOGRAPHIC/MS ANALYSES OF TISSUES AND SEDIMENTS . . C1.1

APPENDIX C2 GAS CHROMATOGRAPHIC/FID ANALYSES OF TISSUES AND SEDIMENTS . C2.1

FIGURES

1 Sample Strata within the Intertidal and Upper Subtidal Regions 7

2 Compositing Design 9

3 Faunal and Sediment Sampling Stations 11

4 Relative Locations of Each Study Site and Known Naturally Occurring Oil or Gas Seeps Along the Washington Coast 19

5 Beach Profiles for Oiled and Unoiled Sites Within the Olympic National Park and for Oiled Sites from Other Washington Coast Beaches 21

6 Sediment Concentrations of Total Aromatic Hydrocarbons 25

7 Sediment Concentrations of Total Resolved Saturate Hydrocarbons. 27

8a Tissue Concentrations of Total Aromatic Hydrocarbons From Oiled Beaches Within the Olympic National Park 29

8b Tissue Concentrations of Total Aromatic Hydrocarbons From Unoiled Beaches Within the Olympic National Park 30

8c Tissue Concentrations of Total Aromatic Hydrocarbons From Other Oiled Washington Coast Beaches 31

9a Tissue Concentrations of Resolved Saturate Hydrocarbons From Oiled Beaches Within the Olympic National Park 33

9b Tissue Concentrations of Resolved Saturate Hydrocarbons From Unoiled Beaches Within the Olympic National Park 34

9c Tissue Concentrations of Resolved Saturate Hydrocarbons From Other Oiled Washington Coast Beaches 35

10a Tissue Concentrations of Even Saturate Hydrocarbons From Oiled Beaches Within the Olympic National Park 36

10b Tissue Concentrations of Even Saturate Hydrocarbons From Unoiled Beaches Within the Olympic National Park 37

10c Tissue Concentrations of Even Saturate Hydrocarbons From Other Oiled Washington Coast Beaches 38

11 Total Ion Chromatograms for Surface Sediments Compared with Total Ion Chromatogram for Nestucca Oil 42

12 Total Ion Chromatograms for Surface Sediments 45

TABLES

1 Target Sampling Requirements of Intertidal and Shallow Subtidal Habitats 12

2 Study Sites Selected to Follow the Fate of Bunker C Fuel Oil . . . 18

3 Extra Sediments and Sediment Composites with Above-Detection Limits of Total Oil and Grease 23

4 Sediment and Tissue Composite Samples and Extra Sediment Locations in Which Elevated Hydrocarbon Concentrations Were Found 26

5 Tissue Concentrations of Total Aromatic Hydrocarbons. 32

6 Tissue Concentrations of Total Resolved and Even Saturate Hydrocarbons 39

7 Summary of Saturate Hydrocarbon Ratios and Infrared Spectrophotometric Concentrations of Oil and Grease in Selected Environmental Samples 43

8 Hydrocarbon Concentrations for Uncontaminated Areas as a Function of Time After Oiling 50

1.0 INTRODUCTION

1.1 BACKGROUND

On December 23, 1988, the barge Nestucca was accidentally struck by its tow, a Souse Brothers Towing Company tug, releasing approximately 230,000 gallons of Bunker C fuel oil and fouling beaches from Grays Harbor north to Vancouver Island. Affected beaches in Washington included a 40-mile-long strip that recently had been added to Olympic National Park (ONP). Due to the patchy nature of oil hitting the shoreline, all impacted beaches had areas that were heavily oiled and other areas without any visible contamination. The variation in oiling of the coast line ranged from the heavily oiled southern shores of Sand Island in Gray's Harbor and the rocky beaches of Norwegian Memorial to no apparent oiling of areas just north of Gray's Harbor and areas south of Norwegian Memorial.

Clean-up operations on selected beaches of ONP located significant quantities of weathering oil in intertidal environments. Although intertidal oil concentrations were reduced by the removal of oiled debris, concentrations from a few hundred to several thousand parts per million (ppm) remained intertidally after clean-up operations in some locations. Past experience indicated that buried oil from the spill could remain unweathered for three years or more (Teal et al. 1978; Burns and Teal 1979) and provide a continuing source of toxic exposure.

Literature on the biological impacts of oil spills demonstrates that every oil spill is unique. Different types of oil impact any one habitat type very differently (because such characteristics as toxic fractions, stickiness, and persistence vary greatly), and one type of oil can impact different habitat types differently (reviewed in Dethier 1988; Strickland and Chassan 1989). Thus, predicting the biological impacts of a specific oil spill is almost impossible. It is known, however, that oil can kill both plants and animals (by direct smothering, poisoning by toxic fractions, or narcotization leading to death by predation or from movement into an inappropriate habitat) and that sublethal effects, such as reduced growth rates or reproductive output, are also common. In addition, the presence of

oil in or on the substratum or in the water column can negatively impact organism recruitment to a habitat, slowing the post-spill recovery of the community. The effects actually can vary from virtual destruction of local communities to no detectable change to the local ecosystem.

Recruitment studies (Vanderhorst et al. 1980; 1981) following the experimental exposure of sediments to crude oil at 1000 and 2000 ppm indicate a recovery period of 3 to 5 years in intertidal communities. Similar long-term persistence, effects, and recovery were documented for the 1969 Falmouth, Massachusetts, and 1971 San Francisco Bay oil spills (Sanders et al. 1980 and Chan 1973, 1975, and 1977, respectively). After the latter spill, the 5-year recruitment (1971 to 1976) result showed no indications of lasting detrimental effects of Bunker C fuel oil on affected populations of marine life.

Given the buoyancy (specific gravity = 0.97) of the oil involved in the December 1988 Nestucca spill, there are probably no significant subtidal deposits in water depths greater than 20 m. Oil of this density will only sink when mixed with sediment suspended from the sea floor by wave action. This mechanism could result in the burial of oil masses within sediments and potential subsequent redistribution to adjacent areas (ESL Environmental Sciences Limited, unpublished data). After the spill of Bunker C into Chedabucto Bay, Nova Scotia in 1970, some subtidal sediments were nearly completely covered by oil. Six years later, sediments were found to contain 10 to 25,000 μg/g hydrocarbons (by fluorescence) (Harding and Englar 1989).

In addition to impacting recruitment, the presence of oil on the sea floor could profoundly affect the feeding, reproduction, and survival of many of the species found along the Washington coast. As an example, gray whales, known to be important predators on infauna in the Pacific Northwest (Oliver and Kvitek 1984; Kvitek and Oliver 1986), could be severely affected if their baleen were to become fouled with the tar-like residue of the spilled oil. Other species found along the Washington coast that are of great economic and ecological importance include the Dungeness crab and certain rockfish species. These species rely heavily or exclusively on benthic invertebrate prey and thus could be severely affected in contaminated habitats. The

contamination (tainting) of commercially or recreationally important marine resources is always a concern following an oil spill. More than one million razor clams are harvested from Ocean Shores annually (Ayres, in press), and unknown numbers of California mussels and razor clams are harvested by Native Americans and by visitors to Olympic National Park.

In rocky habitats, subtidal oil tends to collect in cracks and crevices. A 1987 subtidal survey of the Washington outer coast (Kvitek et al. 1988) found the vast majority of large epifauna (crabs, urchins, sea cucumbers) to be confined to these refugia, and these organisms are critical prey species in the diet of the endangered (as listed by the State of Washington) sea otter and other valued species.

Following the spill, the extent of weathering and release of persistent hydrocarbons to the water column from oil buried both intertidally and subtidally along ONP beaches was largely unknown. Seven months after the Arco Anchorage spill, oily sheens emanating from buried oil along the Ediz Hook shoreline were still evident (Word et al. 1987a, b). The potential for long-term effects of the Grays Harbor spill (Souse Brothers Ocean Towing Company) on marine life suggested that a monitoring program should be initiated to assess the fate and effects of unrecovered oil on the ONP beaches.

1.2 PURPOSE AND SCOPE

The U.S. Department of Interior, Minerals Management Service (MMS) provided the U.S. Department of Energy funding for Pacific Northwest Laboratory's Proposal No. 16058 through an Interagency Agreement. The proposal called for studying the fate of spilled Bunker C fuel oil from the Nestucca incident and determining the potential effects of the fuel on Washington coastal beaches. The Olympic National Park was a principal cooperator in the study. This proposal was submitted by Battelle/Marine Sciences Laboratory (MSL) and the University of Washington, who were the prime contractor and subcontractor, respectively, conducting the monitoring. (Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy.)

The key questions addressed by the research team were 1) How much oil remained on Washington coastal beaches following clean-up and weathering? 2) To what extent have intertidal and subtidal biotic assemblages been contaminated and/or affected? 3) How rapidly has oil left the system? and 4) How rapidly have the biotic assemblages recovered?

This report, the first of three, was prepared by MSL. It focuses on the fate of spilled Bunker C fuel oil in intertidal and shallow subtidal sediments. A second report, dealing with the fate of spilled oil in deeper subtidal sediments (0 to 20 m mean lower low water [MLLW]), is being prepared by the University of Washington and will be published later in 1990. The third report, also by the University of Washington and available in early 1991, will treat the potential effects of oiling on intertidal communities.

2.0 STUDY PLAN AND METHODOLOGY

To fulfill the purpose stated in Section 1.2, the following study plan and methodology were implemented.

2.1 SELECTION OF STUDY SITES

Study sites were selected by a consensus of staff from ONP, MMS, and MSL. A total of eight study sites were selected from inside the park; four from areas of known contamination, and four from areas of no known or very light contamination, to serve as reference sites. Additionally, four study sites of known contamination were selected from outside the park. Because of interest in the extent of residual oil, whether or not an area had been cleaned was an important criterion in site selection. Other important site-selection criteria included the presence or absence of valued biological communities, beach substrate type (sand, gravel, cobble), beach slope, and accessibility. It was particularly important to sample cobble beaches, because such substrates do not naturally depurate rapidly and are inherently difficult to clean. Study sites were also selected so as not to interfere with any other planned or ongoing research in the same general area. Study sites were established, as far away as practical, from known or suspected natural oil-seep areas.

2.2 SELECTION OF SURVEY DATES

Beach surveys to determine the distribution and fate of spilled Bunker C fuel oil were scheduled during the lowest tides in July and September 1989 and in February 1990. The July and September surveys occurred during the times when beach accretion was at or near maximum annual height. Any oil remaining on the target beaches at these times could have been buried under a meter or more of sand/sediment and been difficult to detect. The February survey occurred when beach accretion was minimal, i.e., when target beaches were at their lowest height. Any stranded oil remaining on the target beaches was then closer to the surface and potentially easier to detect.

2.3 SURVEY DESIGN AND COMPOSITING STRATEGY

In the very patchy shoreline environment impacted from oil spilled at sea, it is easy to miss the oil altogether when sampling. On the other hand, sampling directly in areas with visible residue, while important for determining a chemical signature of the residual oil, biases any comparisons between beaches. Because one of the objectives of this monitoring plan was to determine the adequacy of the clean-up program, comparisons between oiled and relatively clean beaches were highlighted. Therefore, random sampling was essential.

As is the case for most sampling strategies, random sampling is augmented by some form of structure. The resulting sampling convention is known as stratified random sampling. The terms statum and strata are used here to define sampling subpopulations and should not be confused with geologic strata. Stratification concentrates the sampling effort in those areas with a greater probability of containing oil residue without biasing later comparisons between beaches. Because wave action buries oil into the mixed sand and gravel beaches (Hayes and Gundlach 1979) and because the duration of wave action along the Washington coast is greatest at about the +4-ft elevation contour, the lower- and mid-intertidal zones were expected to contain the greatest amounts of oil residue. Thus, we chose sampling strata parallel to the shoreline and spaced them logarithmically such that sampling was greatest within the mid-and lower-intertidal zone (Figure 1).

The decision of how to sample each stratum is often based on logistical concerns. Sampling could be done randomly within each stratum or, alternatively, along a transect placed perpendicular to the coastline (e.g., beginning at a random position in the upper intertidal stratum and crossing each remaining stratum). Randomly sampling within each stratum would allow a greater area of coverage and, thus, a greater probability of encountering oil residue. However, sampling along a transect is much easier logistically than locating many random sample collection sites within different strata. For making statistical comparisons between beaches, either method is appropriate. In the light of possible rough water conditions, safety, and time, transects starting from a random location within the upper intertidal stratum is

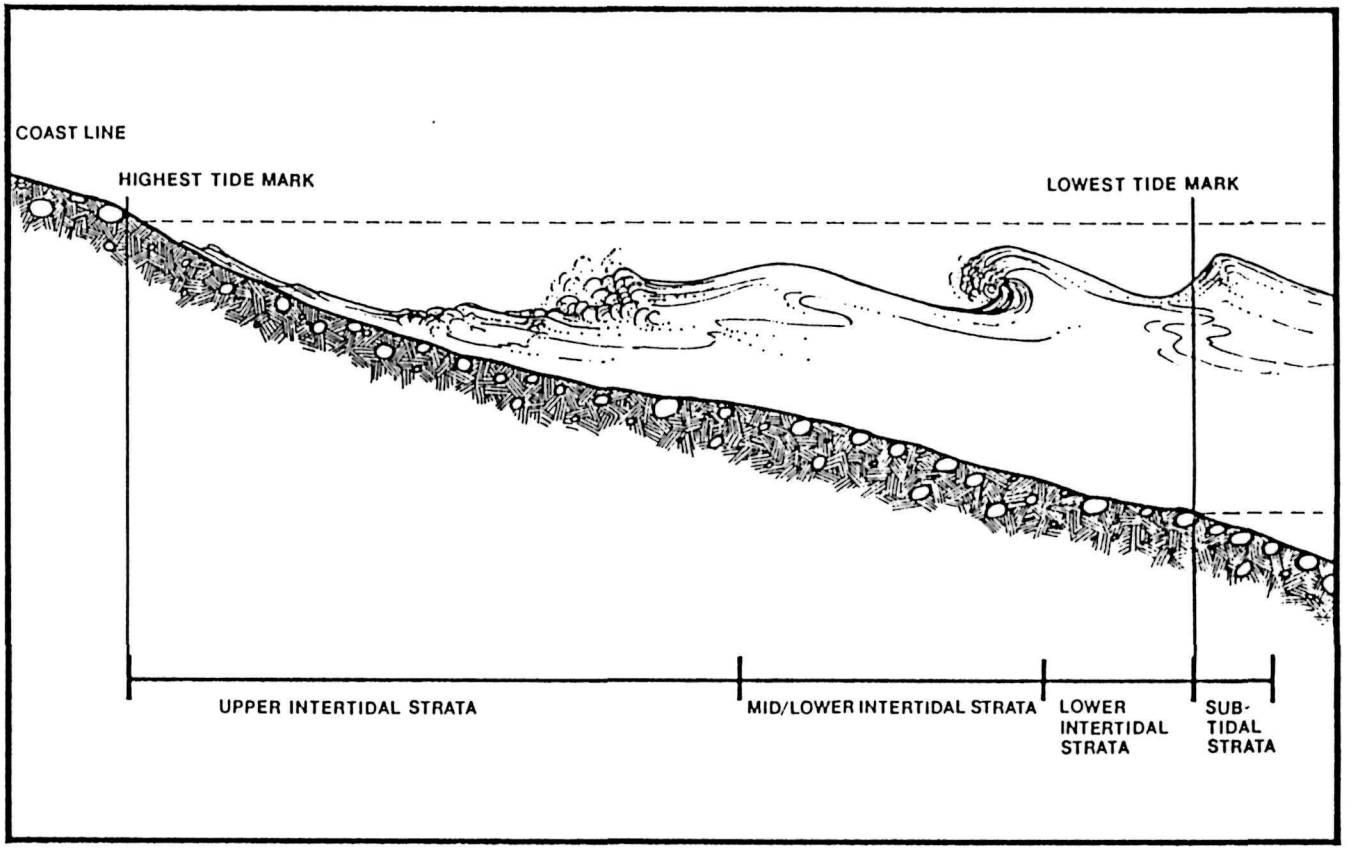


FIGURE 1. Sampling Strata Logarithmically Spaced Within the Intertidal and Upper Subtidal Regions for Monitoring the Fate of Residual Oil on Washington Coast Beaches

preferred. Further, this combination of parallel sampling strata crossed by perpendicular transects forms a grid or lattice design for which sample compositing is easily accommodated.

Sediment and tissue chemical analyses were conducted on composited samples to reduce costs and yet maintain a large spatial coverage. Samples were composited in such a way that samples were not diluted with clean sediments below a chosen level of concern (LC) and so that information on the location of observed oil residue was not lost. Compositing was done with equal quantities of materials from each sampling station included in a composite so that the analytical results represented the mean concentration of the oil residue for the beach location sampled.

To minimize dilution of sediment samples, the number of composited samples (N) was determined by the formula

$$N \leq LC/DL$$

where DL is the analytical detection limit (Skalski and Thomas 1984). Data from Vanderhorst et al. (1980) show that along the Strait of Juan de Fuca, background levels of total hydrocarbon concentrations ranged from 20 to 140 ppm in intertidal sediments. Based on this data, an LC of 100 ppm was selected for the present study. The DL of infrared spectrophotometry (IR) for total hydrocarbon concentration is about 20 ppm; thus, to minimize dilution, no more than five samples were composited. For capillary gas chromatography (GC), the DL for both saturated and polycyclic aromatic hydrocarbons in sediment was about 10 parts per billion (ppb), yielding an N much greater than that for IR.

Compositing samples in similar rows (strata) and columns (transects) of a lattice design, as described above, preserves information on the location of oil residue without requiring an analytical analysis for each sampling station. For example, compositing samples 1) from the same transect and 2) from the same sampling strata but from different beach locations pinpoints the location of high contamination, since both composites (within a transect and within a sampling strata) will have a high concentration of oil if, and only if, any station within those composites has a high concentration of oil (Figure 2).

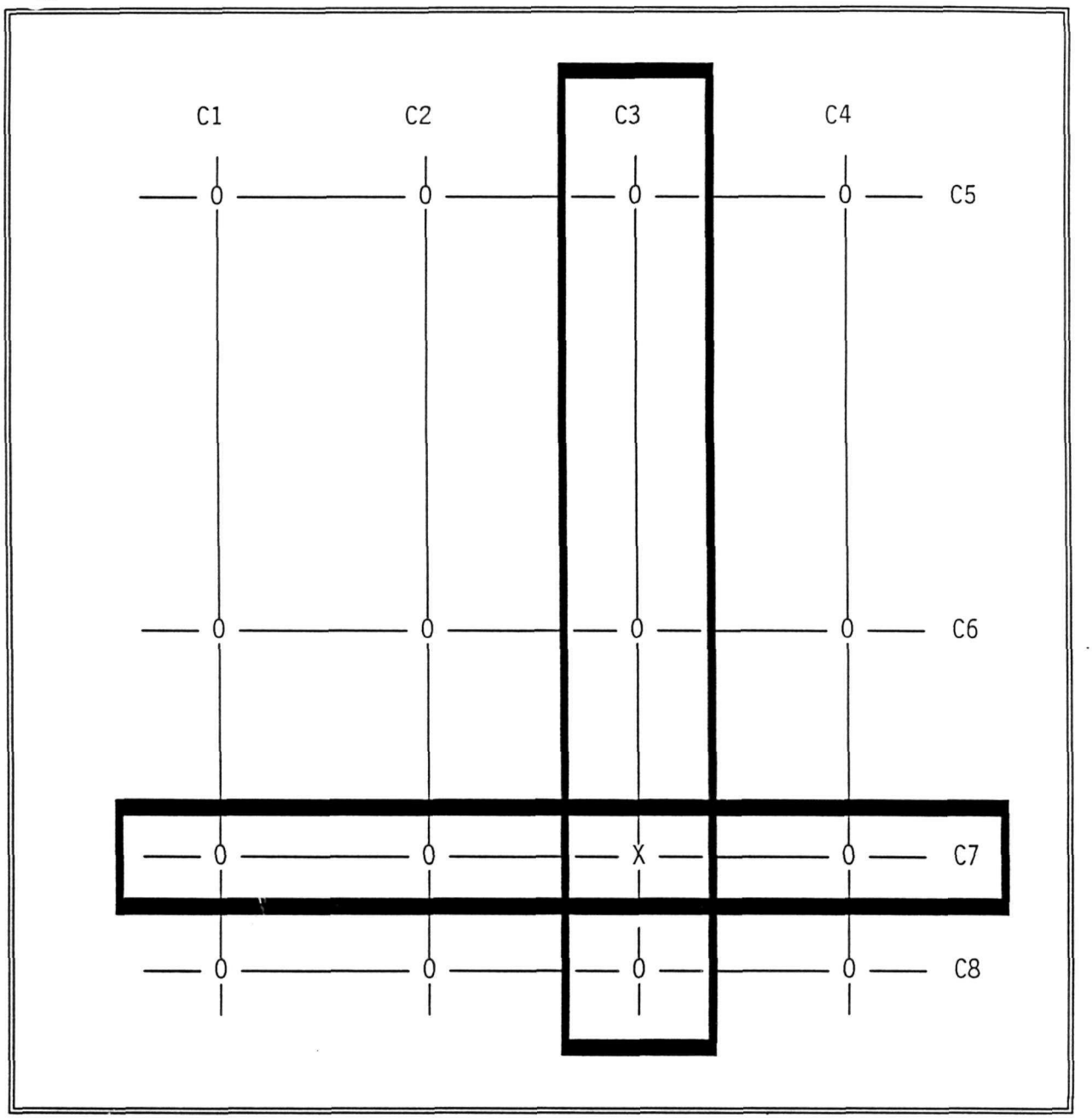


FIGURE 2. Compositing Design for Which Samples Are Composited Across Columns (C1 to C4) and Rows (C5 to C8). This design preserves the location of contamination without requiring chemical analysis at every sampling station (O). In this scenario, high oil residue was detected in composites C3 and C7, indicating contamination at sampling-station X.

2.4 SEDIMENT SAMPLING

Stations (four per transect) were logarithmically spaced so that sampling effort was greater within the lower intertidal zone (Figure 3). Thus, a total of 12 transects with four sampling stations each yielded a target of 48 sampling stations where sediment was to be collected (Table 1).

All four sediment samples from each transect were composited for chemical analysis. Similarly, all four sediment samples from each sampling strata from beaches with the same designation of contamination (high or low exposure to oil and within or outside the park boundaries) were composited for chemical analysis. Thus, from the 48 sampling stations, there were 24 composited sediment samples for chemical analysis (two duplicate analyses bring the total to 26 analyses). Note that the number of composited samples was less than the maximum allowable number of five, and thus samples were not diluted below 100 ppm, the determined level of concern.

The starting locations of transects were determined using a discrete uniform random-number generator with parameters 1 and 100 (the starting and ending values respectively, of the distribution). Each beach was assigned a pair of random numbers for locating the position of the survey transect. The first number determined the relative direction, north or south, of an arbitrary starting point. A value <50 indicated that the transect was north of the arbitrary starting point, a value of ≥50 that the transect was south of the arbitrary starting point. The second number determined the distance in meters from the arbitrary starting point to the location of the transect. The arbitrary starting point was selected without knowledge of either the direction or distance to the transect location.

For the first survey, identifying the location of intertidal and upper subtidal sampling sites required establishing a set of range marks (stakes or monuments) at the upland end of each beach transect and then determining tidal height (elevation) at four locations along the transect from the high-tide line to the upper subtidal zone. Keeping the range marks in line allowed the investigator always to find a location along the azimuth (bearing) line of the transect. Elevations (tidal height) at the four positions

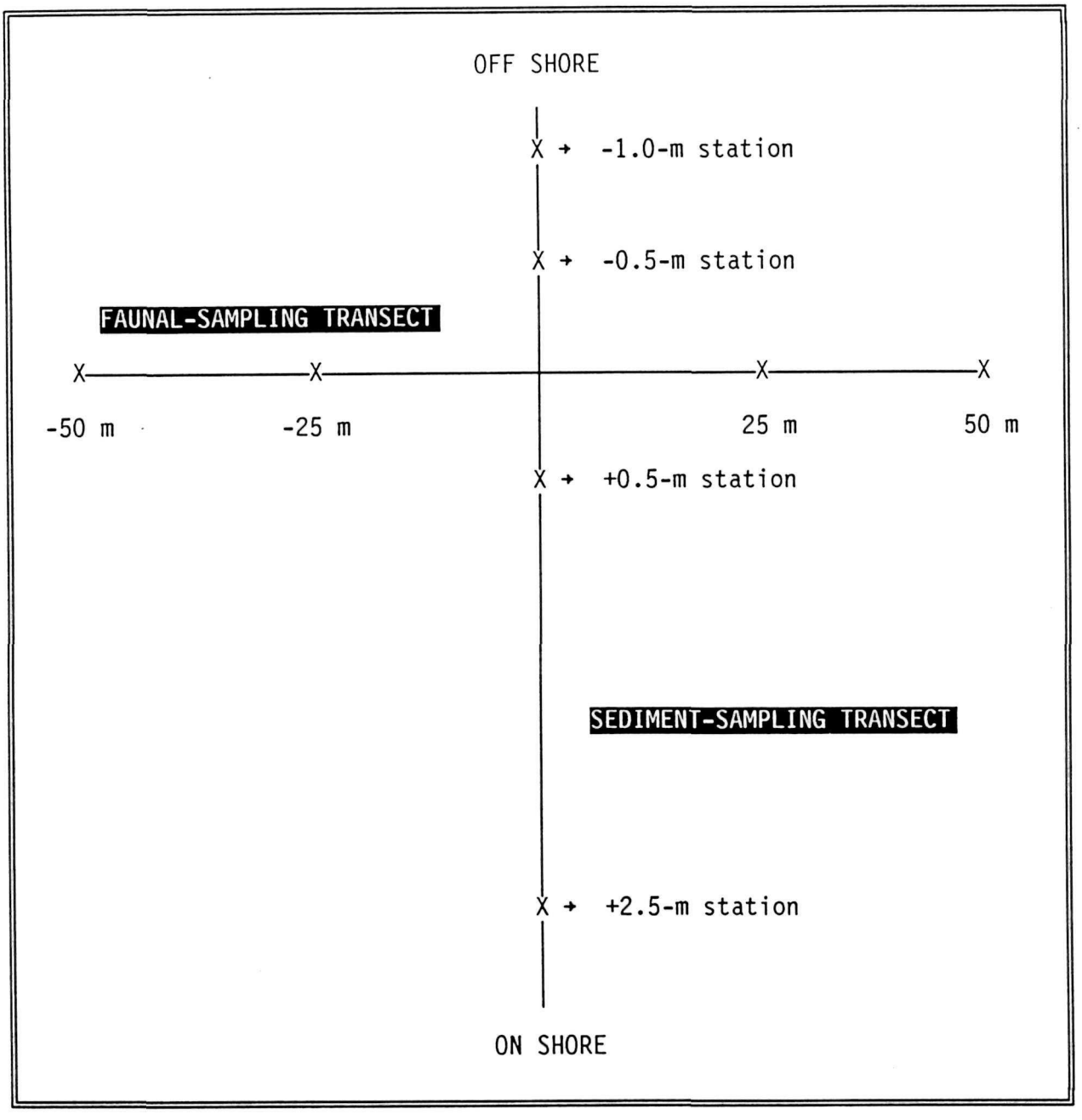


FIGURE 3. Faunal and Sediment Sampling Stations (X). The stations form perpendicular transects such that each sampling station lies within a specific tide-height contour. Sediment sampling stations are spaced logarithmically within intertidal and subtidal sampling zones while the faunal sampling stations are equally spaced away from the sediment sampling transect between the +0.5-m and -1.0-m tide-height contour.

TABLE 1. Target Sampling Requirements of Intertidal and Shallow Subtidal Habitats

Sample Type	No. Samples/ Station	No. Stations/ Transect	No. Transects	Total Samples	Composites Analyzed (a)
Sediment (IR)	1	4	12	48	26
Sediment (GC)	1	4	12	48	16
Tissue (GC)	1	4	12	48	26

(a) Includes duplicates.

along the transect line were determined by level and stadia rod by referencing known tidal heights determined in accordance with the appropriate tide tables (NOAA 1988 and 1989).

Distances to each sampling location on each transect also were recorded. During the second and third surveys, sampling location on each transect was determined solely by distance from the high-tide-line monument. The lowest tides encountered in September 1989 and February 1990 often occurred before sunrise or after sunset, making it difficult to use a level and stadia rod. Also, based on elevation, it is not generally possible to sample the same location twice on any given transect, because of the continuous process of beach accretion or erosion. For example, the 8.2-ft-level sample was often located many meters closer to the high-tide line in winter than in summer.

As shown in Figure 3, sampling of sediment along each transect occurred at the +8.2-ft (+2.5-m), +1.1-ft (+0.5-m), -1.7-ft (-0.5-m), and -3.0-ft (-1.0-m) tidal contours. At the designated sampling locations, a 0.5-L sediment sample was collected from the top 15 cm of the beach surface. At each location, the sediment was collected from a 0.1-m surface area. Sediments from cobble areas necessarily were collected from depths shallower or deeper than 15 cm, depending on the depth of cobble. Samples were taken from the beach using a solvent-rinsed stainless-steel trowel and 5.08-cm-diameter butyrate cores and placed in labeled and dated collection jars, also solvent-rinsed. Sediment composition was recorded. At least once a day, a control (trip) blank was collected by following the same sampling procedure

except that no sediment was placed in the sample jar. Control blanks were analyzed using solvent extractions in the same manner as jars containing sediments. It should be noted, however, that while every attempt was made to sample the -3.0-ft tidal contour, weather conditions that could endanger the investigator attempting the sample sometimes necessitated sampling at a shallower subtidal depth.

2.5 FAUNAL SAMPLING

Faunal samples were collected from four sampling stations along a 100-m transect established parallel to the coastline along a tidal-height contour between the +1.1-ft and -3.0-ft sediment sample stations (Figure 3). Four sampling locations were placed 25 and 50 m from either side of the sediment sampling transect. The flexibility in designating the exact tidal height for this transect increased our ability to locate appropriate organisms for tissue analysis. We intended that the faunal transects for each beach location be located on the same tidal-height contour and substrate, or as close to these as possible. Procedures for locating faunal sampling sites were the same as those described above for locating sediment sampling sites.

A total of 10 organisms were collected at each station to allow for enough tissue for chemical analyses. The species collected depended on the substrate (sand, cobble, rock, etc.) of the beach selected for sampling (see Section 3.1). If a sandy beach was selected, razor clams (Siliqua patula) were collected. From a cobble or rocky beach, we expected to find California mussel (Mytilus californianus) or the sabellid polychaete (Eudistylia vancouveri). If these species were unavailable at selected sites, organisms-of-opportunity were collected. Upon collection, the organisms were transported immediately to the laboratory, where they were frozen at -18°C until dissection. After freezing, samples of tissue were obtained through dissection and packed in wide-mouthed glass jars with Teflon®-lined caps.

® Teflon is a registered trademark of E. I. Dupont de Nemours, Wilmington, Delaware.

Samples were then refrozen and stored at -75°C until use. Sampling locations, dates of sampling, and MSL sampling numbers were recorded and affixed to each sample as it was collected.

Tissue samples from each of the two stations positioned an equal distance from the sediment transect were combined for a composite chemical analysis. A value of N equal to two was less than an allowable number, based on the data from Boehm et al. (1988), which suggested an LC of 0.5 ppm. The detection limit for GC on tissues was at worst 100 ppb, yielding $N \leq 5$. Thus, there were 24 composited tissue samples (2 duplicate chemical analyses brings the total to 26 analyses) (see Table 1). Note that compositing organisms from varying tidal elevations sacrifices any chance of determining the vertical variation in tissue hydrocarbon concentrations.

2.6 ANALYTICAL CHEMISTRY

All analytical and associated quality-assurance and -control procedures (including the use of standard reference materials, chemical spikes, and duplicate analyses) followed Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound (Tetra Tech, Inc. 1986). The analytical procedures for each sample type are outlined below with references to the specific techniques used.

Sediments

Analytical chemistry was conducted in stages, using composite samples to minimize unnecessary analytical costs. Composite sediment samples first were screened for oil residue by analyzing for total oil and grease using IR, a relatively inexpensive method of analysis. Samples were analyzed by a Beckman Acculab™ Model 4 Infrared Spectrophotometer with a spectral range of 4000 to 600 cm^{-1} and a scan time of 2.5 to 27 min. Hydrocarbons were extracted from sediment with freon following the Standard Method 503 (APHA 1985). To distinguish between the target oil and oils of biogenic origin,

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™ Acculab is a trademark of Beckman Instruments, Inc., Fullerton, California.

the extract was mixed with silica gel to remove fatty acids. The extracts were placed into IR cells made of sodium chloride with a path-length of 14 mm, for maximum sensitivity.

Any sediment samples showing a signal above detection were analyzed by GC for a finer characterization of the source of contamination (fingerprinting). Samples were analyzed using a Hewlett Packard (HP) 5890A gas chromatograph equipped with a HP 7673A automatic sampler and a flame ionization detector (FID) or a 5970 mass-selective detector (MS). An HP 5895A gas-chromatographic workstation was used for control of the GC, integration, quantification, and preparation of the chromatograms. Sediment was analyzed using an extraction process developed by NOAA (Krahn et al. 1988). Briefly, methylene chloride was used to extract saturates and aromatics and was followed by alumina gel chromatography to purify the saturate and aromatic hydrocarbons for analysis by GC/FID and GC/MS, respectively.

Tissues

Composite tissue samples were homogenized using a Tekmar Tissumizer•. Five-gram subsamples of wet tissue were digested with 30 mL of 6 M KOH at 35°C for 18 hours, then extracted three times with 30 mL of ethyl ether, followed by U.S. Environmental Protection Agency Method 3611 (USEPA 1986) alumina column cleanup procedure to remove matrix interferences.

For both tissues and sediments, petroleum residues were characterized by relative peak areas for the concentration of individual identified normal branched saturate and polycyclic aromatic hydrocarbons, the ratios of nC_{17}/Pristane and nC_{18}/Phytane, and the carbon preference index (CPI) (odd to even saturates ratio). Changes in one or more of these characteristics provided an estimate of weathering and/or the degree of mixing with other potential sources of hydrocarbons. Chromatograms from all sediment and tissue samples were compared with chromatograms from identical analyses of the spilled oil obtained from the Washington State Department of Ecology.

• Tissumizer is a registered trademark of Tekmar Co., Cincinnati, Ohio.

3.0 RESULTS AND DISCUSSION

3.1 SAMPLE COLLECTIONS AND LOCATIONS

Sediment and faunal samples were collected from four oiled and four reference beaches inside the Olympic National Park and four oiled beaches outside the park (Table 2). The four sites outside the park were chosen from those sites most heavily oiled. Sand Island, an important nesting area for many marine birds, and Ocean Shores were some of the most heavily hit areas. Whale Creek and Point Grenville on the Quinault Indian Reservation, where shellfish make up an important part of the diet, were not as severely oiled. Three of the chosen oiled sites have a rock/cobble substrate, and the remaining five have a sand substrate. Of the four reference sites, two have cobble and two have sand substrates. All oiled beaches in this study were cleaned. At a minimum, cleaning was no more than the removal of oiled logs. Maximum cleaning was the removal of oil mats and the collection of oil with pompoms. Because of the patchy nature of the oiling of the Olympic National Park beaches, the close proximity of oiled and reference beach sites (Norwegian Memorial and Kayostla) was not considered a problem. In fact, all beaches along the Washington coast may have received some oiling, if not from the December 1988 spill, then from indiscriminate bilge pumping in the past.

Figure 4 depicts relative locations of each study site and known natural oil seeps. Although natural seeps occur near the Pysht River, Hoh Head near Ruby Beach, east along the Hoh River (not shown) and near Taholah on the Quinault River, the only *in situ* oil occurs in microseeps in unnamed Middle Eocene melanges exposed at Shi Shi Beach and at Ruby Beach (Snavely and Kvenvolden 1989). The microseep at Ruby Beach may be within 2 km of the Ruby Beach reference site used in this study.

Three beach surveys were conducted at all sampling sites except Sand Island, which had only two surveys, due to poor weather conditions (Appendix A1). Because of severe weather, high wave action, and periodic unavailability of appropriate organisms, the full set of sediment and faunal samples was only achieved at one sampling site: Second Beach. Of the possible 12 sediment samples per sampling site, all sites had a minimum of 8 samples

TABLE 2. Study Sites Selected to Follow the Fate of Bunker C Fuel Oil Spilled on Washington Coastal Beaches in December 1988 (Holcomb 1989)

Beach	Location	Status	Substrate
Wedding Rocks	Olympic National Park	Light Oil	Rock/Cobble
Norwegian Memorial North	Olympic National Park	Heavy Oil	Rock/Cobble
Norwegian Memorial South	Olympic National Park	Reference	Rock/Cobble
Kayostla Beach North	Olympic National Park	Moderate-Heavy Oil	Rock/Cobble
Cedar Creek	Olympic National Park	Reference	Sand/Cobble
Hole-in-the-Wall	Olympic National Park	Reference	Rock/Cobble
Second Beach	Olympic National Park	Moderate-Heavy Oil	Sand
Ruby Beach	Olympic National Park	Reference	Sand
Whale Creek	Quinault Indian Reservation	Moderate Oil	Sand
Point Grenville	Quinault Indian Reservation	Transitory	Sand
Ocean Shores-North Jetty	Grays Harbor	Heavy Oil	Sand
Sand Island	Grays Harbor	Heavy Oil	Sand

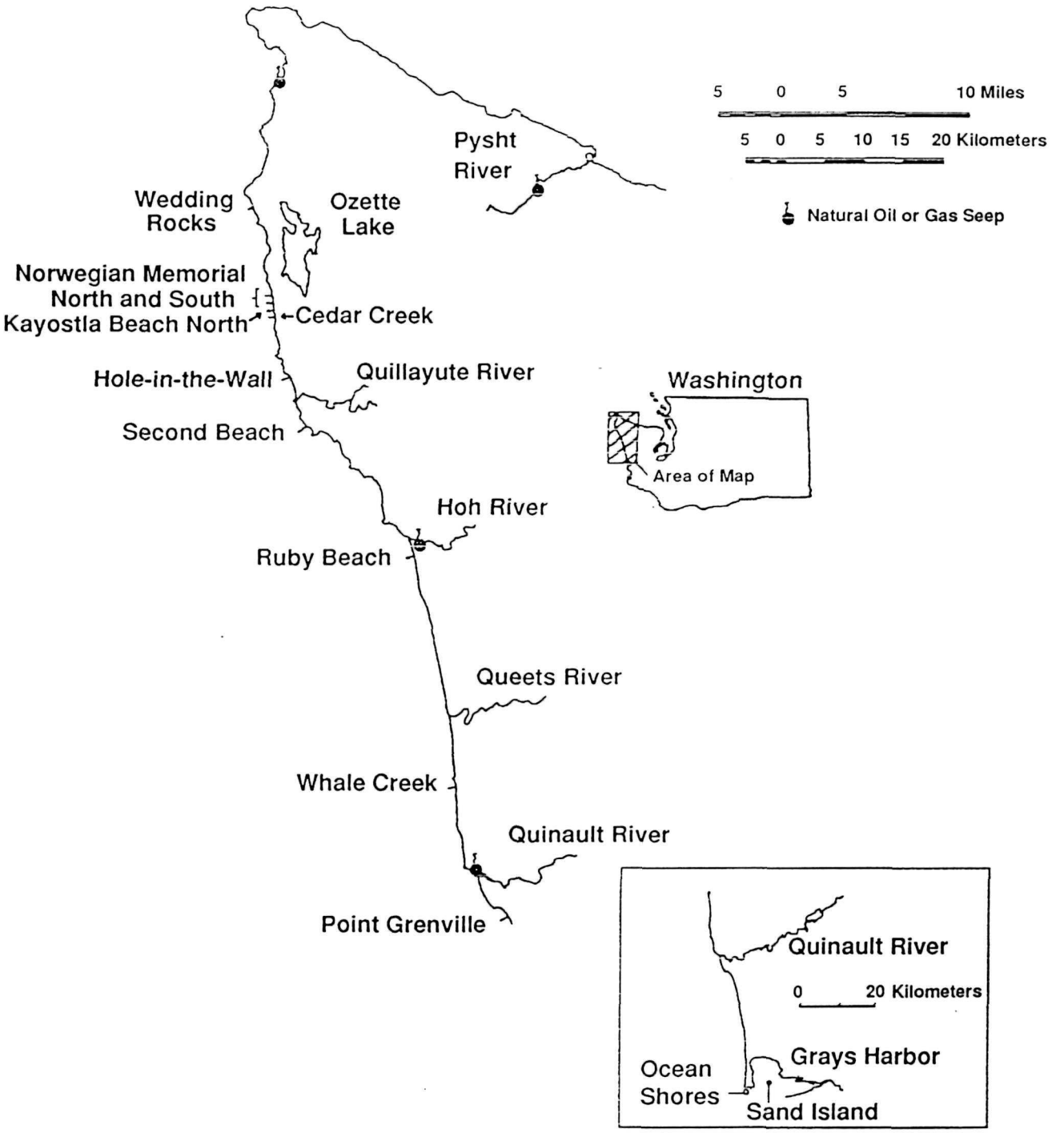


FIGURE 4. Relative Locations of Each Study Site and Known Naturally Occurring Oil or Gas Seeps Along the Washington Coast

collected, except for Sand Island. All planned sediment composite samples were made, with the exception of the Sand Island composite from the first survey (Appendix A2). Of a possible six faunal samples per collection site, six sites had all six samples taken, and the remaining sites resulted in a minimum of three samples taken, again except for Sand Island, where no faunal samples were obtained.

The intertidal fauna at Sand Island appear to be restricted to sparse populations of clams occupying sediments too dense to excavate using a clam gun. Only the sample from Whale Creek (WC2+25) proved to be of insufficient weight for chemical analysis.

When possible, extra sediments, cores, and/or faunal samples were collected at some of the oiled beaches during each of the surveys. Because of suspected contamination from a small yet unconfirmed spill occurring in February 1990, extra samples were also collected from Hole-in-the-Wall and Ruby Beach during the third beach survey. Two sediment samples from a site further north of the Norwegian Memorial North transect (designated as HNMX) and from Goose Island in Grays Harbor also were taken during the third beach survey. The HNMX site is the location of a University of Washington transect. Because of the very gradual beach slope at Sand Island, sediment samples were only taken at +15.2-, +13.3-, +8.2-, and +7.8-ft tidal levels. The sediment sample taken at the +7.8-ft tidal height was 210 m from the +8.2-ft height. This sample was composited as if it were the +1.1-ft sample.

The beach profiles from the July and August 1989 survey at the selected sampling sites fell into four groups (Figure 5). Profiles for the Norwegian Memorial North and South sites and for Wedding Rocks have long gradual sloping beaches of 0.7°. Second Beach, Cedar Creek, Whale Creek, Ocean Shores, and Point Grenville fall into a middle range of moderately sloping beaches of approximately 1.1°. Ruby Beach and Hole-in-the-Wall had the steepest beach slopes, averaging approximately 2.3°. Sand Island had the least slope, 0.03°.

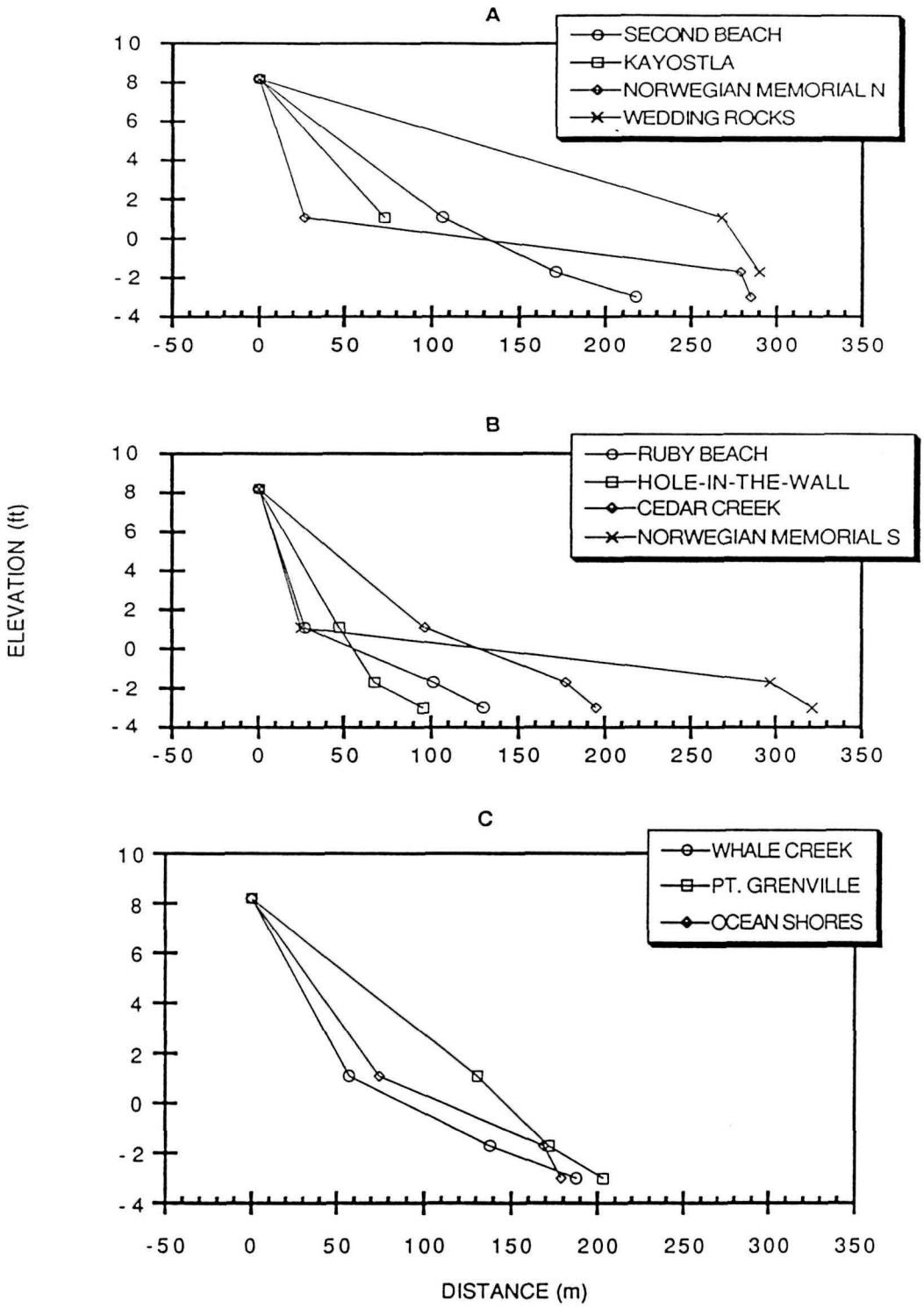


FIGURE 5. Beach Profiles for Oiled (A) and Unoiled (B) Study Sites Within the Olympic National Park and for Oiled Sites from Other Washington Coast Beaches (C) for July and August 1989. The profile for Sand Island is not shown.

3.2 INTERTIDAL AND SHALLOW SUBTIDAL SEDIMENTS

3.2.1 Total Oil and Grease

All sediment composites and some of the extra sediments and cores were analyzed for total oil and grease using IR. Those analytical results showing above detection values are presented in Table 3. Analytical results for each sample are found in Appendix B. Sediments were extracted in two, four, and three batches for Surveys 1, 2, and 3 respectively. For Survey 1, all composite samples were less than the detection limits of 15 and 50.2 μg/g respectively, for the two batches. Percent recoveries of a matrix spike were 91 and 51%. Because the composites contained essentially background levels, no sediment composites from the first survey were analyzed further.

The second survey extractions were conducted in four batches and had detection limits of 12, 30, 25, and 23 μg/g. Percent recoveries of a matrix spike were 97, 60, 55, and 75%, respectively. Only the sediments from Sand Island contained detectable levels of oil and grease, with concentrations of 6,255 and 19,015 μg/g dry weight in sediments from the +15.2- and +13.3-ft tide levels, respectively. Oily residue was clearly visible in each of these samples, and a strong petroleum (Bunker C) odor was evident. These sediments were further analyzed for aromatic and saturate hydrocarbons. Because levels of total oil and grease at Norwegian Memorial, Kayostla Beach, and Whale Creek were below detection, extra cores from these sites were not analyzed.

The third survey extractions were conducted in three batches, but because of variable sample dry weights, a separate detection level was derived for each sample. The percent recoveries associated with these batches were between 95 and 96%. Detectable levels of total oil and grease were found in several sediment composites and extra sediments from the third survey, including samples OP3-3.0, WR3, NMN3, KBN3, HNMX+8.2, HNMX+1.1, RB3+14, and HW3+15. The composite, OP3-3.0--which includes sediments from the -3.0-ft tidal contour at Wedding Rocks (WR), Norwegian Memorial North (NMN), and Kayostla Beach North (KBN)--suggests that this elevation contour is potentially contaminated with oil. These eight composites, along with suspect extra sediments, were further analyzed for aromatic and saturate hydrocarbons.

TABLE 3. Extra Sediments and Sediment Composites from Washington Coast Beaches With Above-Detection Limits of Total Oil and Grease (μg/g dry weight) as Detected by Infrared Spectrophotometry

Location	Station/ Composite	Survey Date	Total Oil and Grease (μg/g)
Wedding Rocks	WR	February/March 1990	63
Norwegian Memorial	NMN	February/March 1990	72
Kayostla Beach	KBN	February/March 1990	154
Oiled Park Beaches	OP-3.0	February/March 1990	251
	Extra Sediment/ Cores	**Survey Date**	**Total Oil and Grease (μg/g)**
Sand Island	SI+13.2	September 1989	19015
Sand Island	SI+15.3	September 1989	6255
North of Norwegian Memorial	HNMX+8.2	February/March 1990	115
North of Norwegian Memorial	HNMX+1.1	February/March 1990	73
Hole-in-the-Wall	HW+15	February/March 1990	170
Ruby Beach	RB+14	February/March 1990	86

Several sediments from surveys 2 and 3 were rerun by IR either because the composite pairs produced conflicting results or because the sediments showing oil above the detection level were from unoiled beaches. Because of the nature of the compositing design, if any individual sample was contaminated with greater than background levels, then two composited samples should also reflect a greater-than-background level of oil and grease. Where sediment composites were rerun, one element of the pair was initially below detection and the second element initially produced concentrations above detection. All rerun sediment composites, however, confirmed a level of contamination below detection; thus, no further analysis was conducted. The two extra sediment samples from Ruby Beach and Hole-in-the-Wall, however, both produced greater-than-detection levels of total oil and grease on the rerun and therefore were analyzed further for aromatic and saturate hydrocarbons.

3.2.2 Aromatic and Saturate Hydrocarbons

Two extra sediments from Wedding Rocks and Ocean Shores (WR2+9.2 and COS2+11) and two sediment composites from Sand Island and Cedar Creek (SI2 and CC3) from the second and third surveys were characterized by GC/MS and GC/FID, despite being below detection by IR upon reanalysis. The Ocean Shores sample and the composite from Sand Island demonstrated less than detectable concentrations of aromatic hydrocarbons (Figure 6 and Appendix C1) and mostly less than detectable concentrations of saturate hydrocarbons (Figure 7), and the Cedar Creek composite sample was used for quality assurance (Appendix C2). The sample from Wedding Rocks produced moderately low concentrations (2,875 and 18,236 ng/g dry weight, respectively) of both aromatic and saturate hydrocarbons. The HNMX sample also contained moderately low levels of both hydrocarbon fractions: 654 ng/g of aromatics and 14,178 ng/g of saturates. Only the extra sediments from Sand Island (SI2+15.2 and SI2+13.3) produced significant amounts of both categories of hydrocarbons. The sum of the aromatic hydrocarbons for these samples were 2227,624 and 83,399 ng/g dry weight, respectively. The sum of the resolved saturate hydrocarbons were 488,977 and 1,570,069 ng/g, respectively. Note that no sediment samples from the July/August survey had greater than detection levels of either aromatic or saturate hydrocarbons.

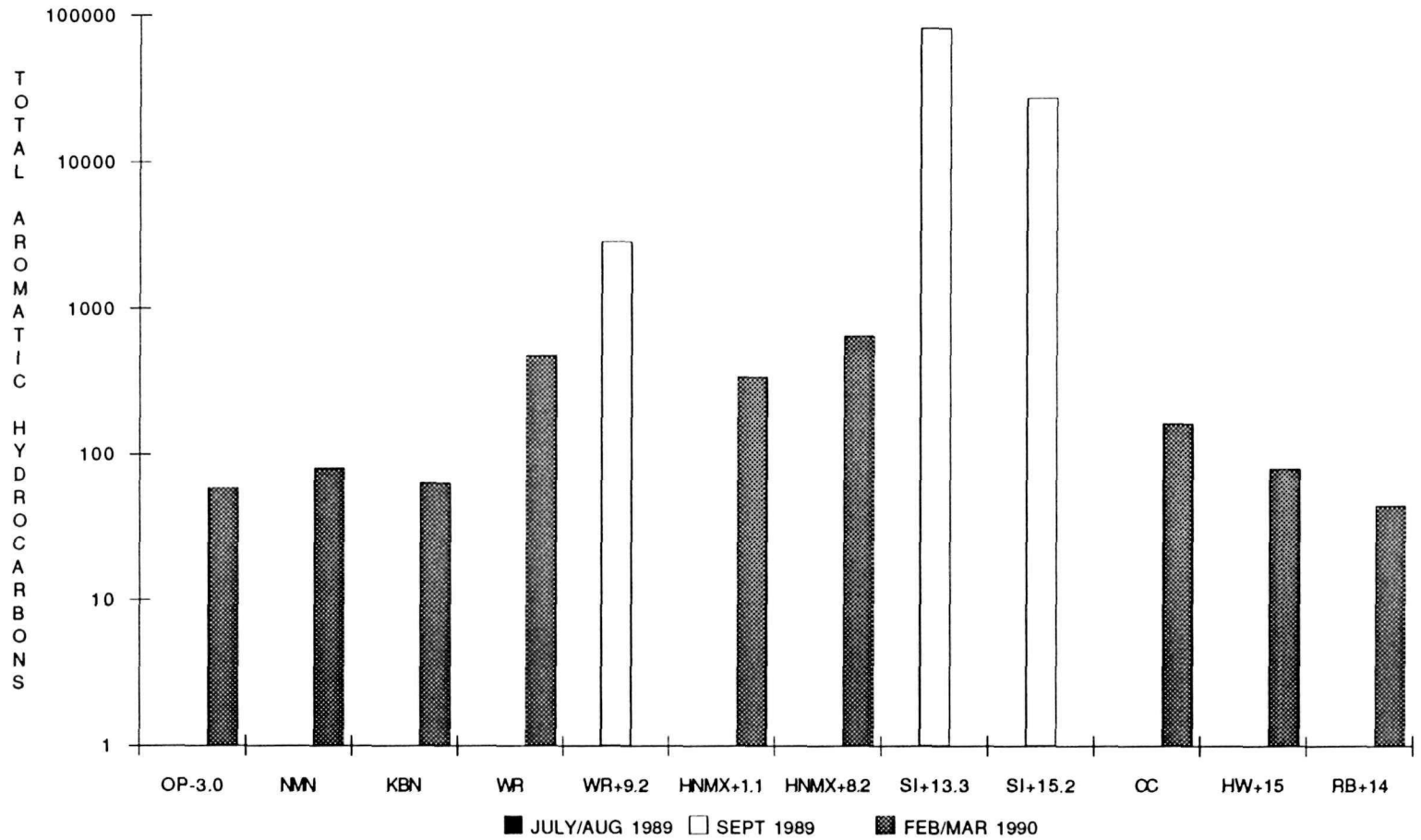


FIGURE 6. Sediment Concentrations of Total Aromatic Hydrocarbons (ng/g dry weight) Collected from Selected Sites Along the Washington Coast. See Table 4 for sample locations.

TABLE 4. Sediment and Tissue Composite Samples and Extra Sediment Locations in Which Elevated Hydrocarbon Concentrations Were Found

Sediment Composites	Location
OP-3.0	-3.0-ft contour from oiled beaches within the Park: Wedding Rocks, Norwegian Memorial North, Kayostla Beach, and Second Beach
NMN	Norwegian Memorial North
KBN	Kayostla Beach
WR	Wedding Rocks
SI	Sand Island
CC	Cedar Creek
Extra Sediments	
WR+9.2	+9.2-ft contour from Wedding Rocks
HNMX+1.1	+1.1-ft contour from an area north of Norwegian Memorial
HNMX+8.2	+8.2-ft contour from an area North of Norwegian Memorial
S1+13.3	+13.3-ft contour from Sand Island
S1+15.2	+15.2-ft contour from Sand Island
OS+11	+11-ft contour from Ocean Shores
HW+15	+15-ft contour from Hole-in-the-Wall
RB+14	+14-ft contour from Ruby Beach
Tissue Composites	
NMN+50, NMN+25	Norwegian Memorial North
KBN+50, KBN+25	Kayostla Beach
2B+50, 2B+25	Second Beach
WR+50, WR+25	Wedding Rocks
HW+50, HW+25	Hole-in-the-Wall
NMS+50, NMS+25	Wedding Rocks
RB+50, RB+25	Ruby Beach
CC+50, CC+25	Cedar Creek
WC+50, WC+25	Whale Creek
PG+50, PG+25	Point Grenville
OS+50, OS+25	Ocean Shores

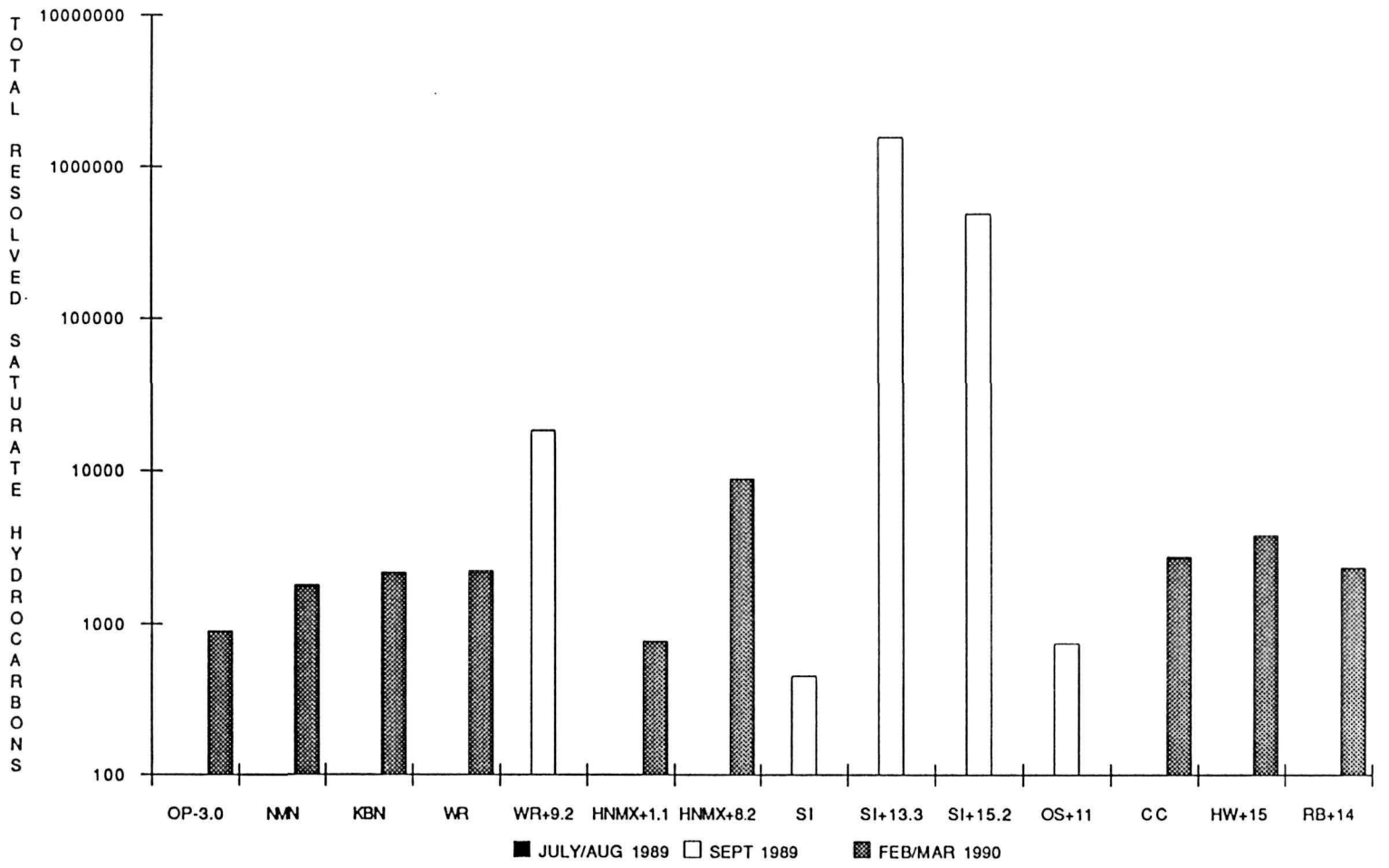


FIGURE 7. Sediment Concentrations of Total Resolved Saturate Hydrocarbons (ng/g dry weight) Collected from Selected Sites Along the Washington Coast. See Table 4 for Sample Locations.

3.3 INVERTEBRATE TISSUES

All tissue composites were analyzed by GC/MS and GC/FID (Appendixes C1 and C2). The tissue samples from oiled beaches within Olympic National Park had greater concentrations of total aromatic hydrocarbons than tissue samples from all other beaches (Figure 8a-c). Tissues from Norwegian Memorial North and Wedding Rocks ranged from 90 to 100 ng/g (dry weight). All other tissue concentrations were below 50 ng/g, and most were less than 20 ng/g. The extra tissue sample collected from a location farther north of the Norwegian Memorial North site (University of Washington transect) had a total aromatic hydrocarbon concentration of 24 ng/g.

Even though all tissues indicated low concentrations of total aromatic hydrocarbons (<100 ppb), analysis of variance of tissues collected from oiled beaches within the Olympic National Park demonstrated significantly greater ($p < 0.001$) concentrations of total aromatic hydrocarbons averaged over all species and surveys. There were no significant differences among the surveys averaged over location and species. However, there was a significant difference among species ($p < 0.05$), with razor clams showing the least contamination averaged over the three surveys (Table 5).

Tissue samples from Whale Creek and Point Grenville had the greatest concentrations of total resolved saturate hydrocarbon concentrations (Figure 9a-c). However, tissue samples from Kayostla Beach North and Hole-in-the-Wall had the greatest concentrations of even saturate hydrocarbons (Figure 10a-c), which do not include those saturates of biogenic origin.

Thirteen tissue samples, five each from the oiled and unoiled (reference) sites within the Olympic National Park and three from sites outside the park, had concentrations of even saturates greater than 3500 ng/g dry weight. As expected, analysis of variance produced no significant differences ($p < 0.05$) among locations for either the total or the sum of the even saturates. Although it is not significant ($p < 0.05$), a trend exists for a reduced concentration of total and even saturates from the third-survey tissue samples averaged over locations and species. There was also not a significant ($p < 0.05$) difference among species averaged over location and surveys for either total or even saturates (Table 6).

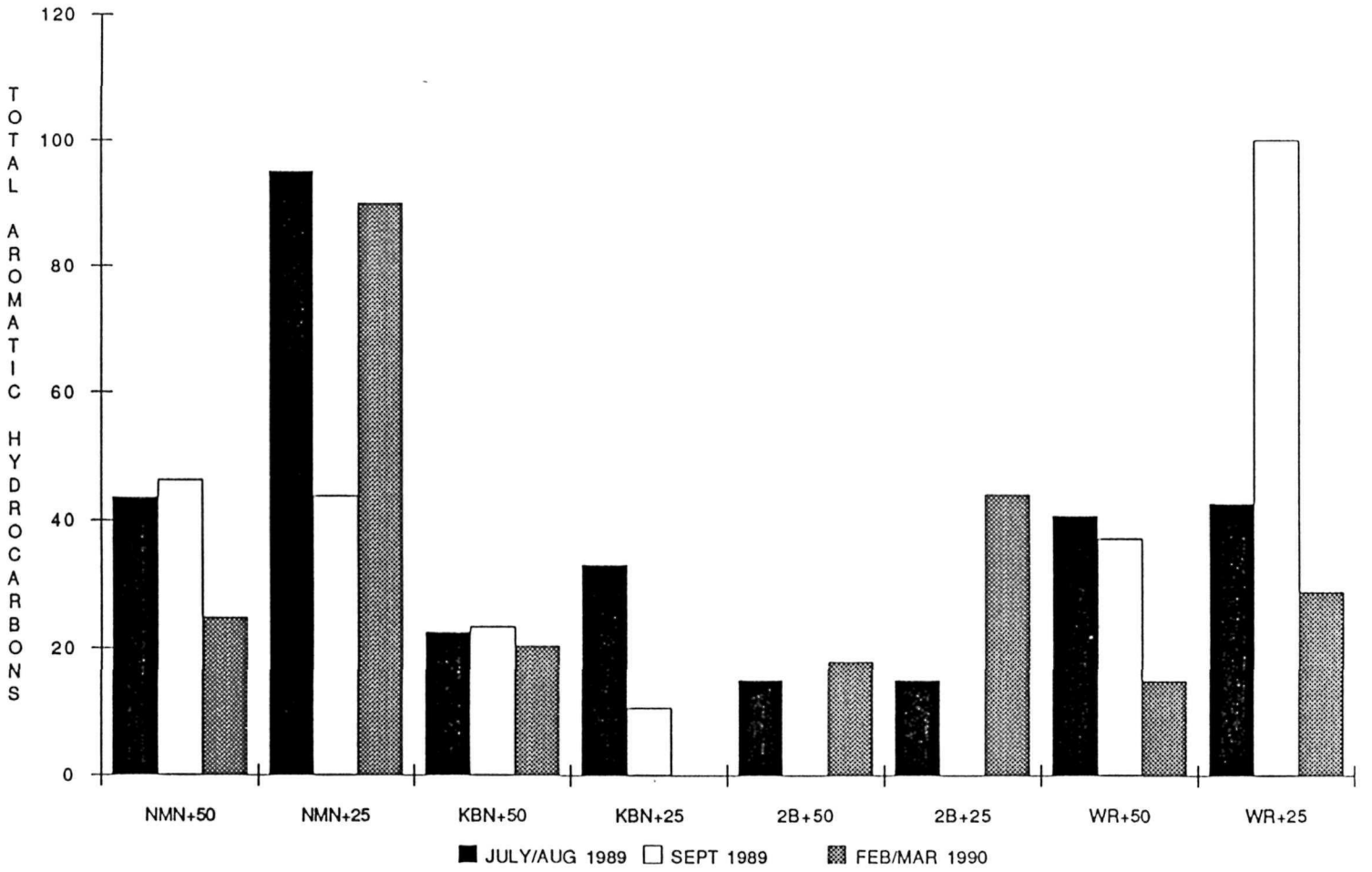


FIGURE 8a. Individual Tissue Concentrations of Total Aromatic Hydrocarbons (ng/g dry weight) from California Mussels, Razor Clams, and Other Invertebrates Collected from Oiled Beaches Within the Olympic National Park. See Table 4 for sample locations.

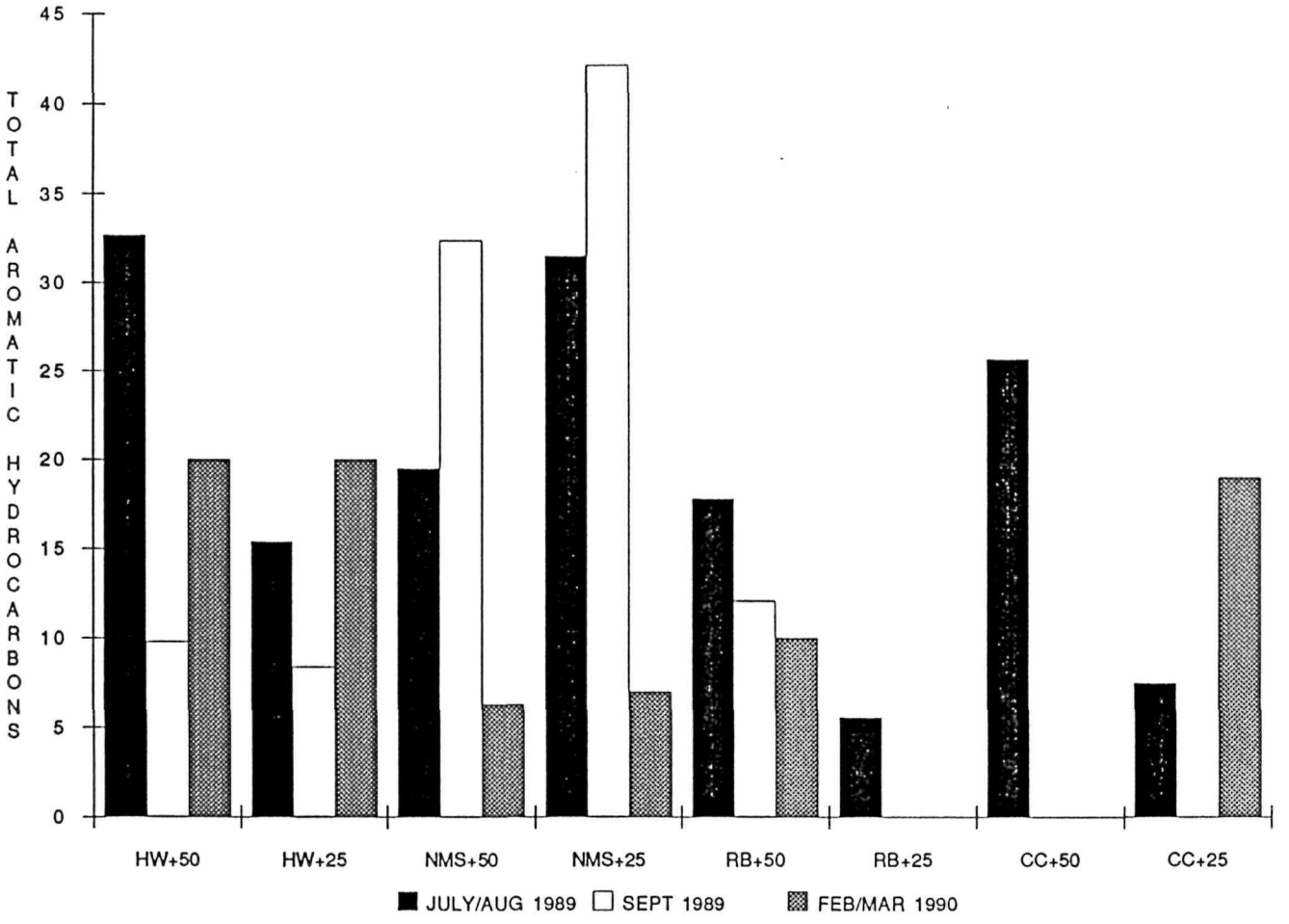


FIGURE 8b. Individual Tissue Concentrations of Total Aromatic Hydrocarbons (ng/g dry weight) from California Mussels, Razor Clams, and Other Invertebrates Collected from Unoiled Beaches Within the Olympic National Park. See Table 4 for sample locations.

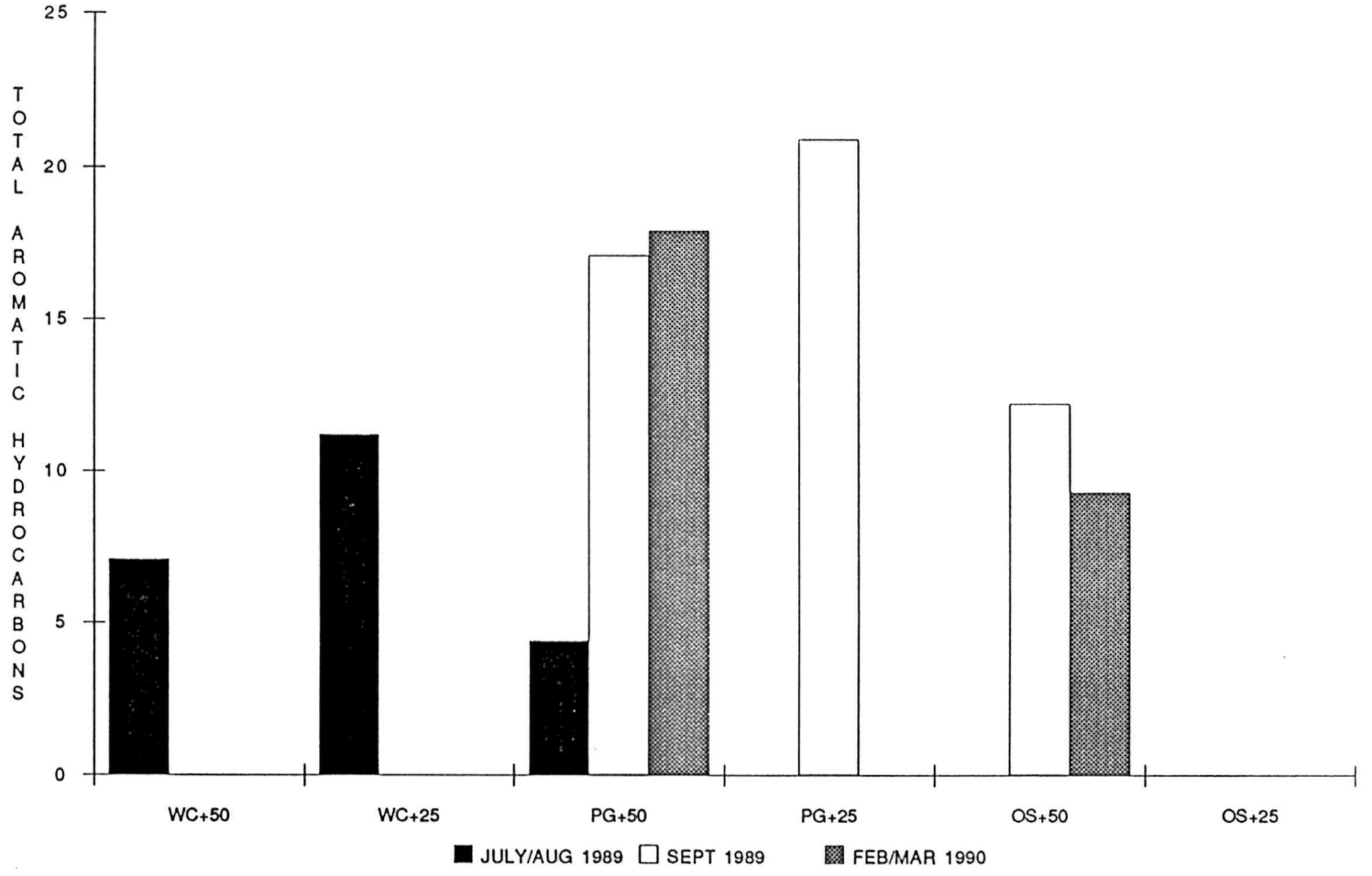


FIGURE 8c. Individual Tissue Concentrations of Total Aromatic Hydrocarbons (ng/g dry weight) from California Mussels, Razor Clams, and Other Invertebrates Collected from Other Oiled Washington Coast Beaches. See Table 4 for sample locations.

TABLE 5. Tissue Concentrations of Total Aromatic Hydrocarbons (ng/g dry weight) Averaged Over Three Beach Surveys Following the December 1988 Oil Spill

Location And Status		Species			
		California Mussels	Razor Clams	Other[a]	All
Olympic National Park Oiled					
	Mean	44	15	27	35
	SD	32	0	17	27
	N	13	2	8	23
Olympic National Park Reference					
	Mean	11	9	22	15
	SD	10	8	13	12
	N	10	4	9	23
Washington Coast Beaches Oiled					
	Mean	13	7	11	9
	SD	4	9	--	8
	N	3	7	1	11
All Beaches					
	Mean	28	9	23	22
	SD	28	8	15	22
	N	26	13	1	57

(a) This category includes limpets, snails, chitons, polycheates, and assorted crustaceans.

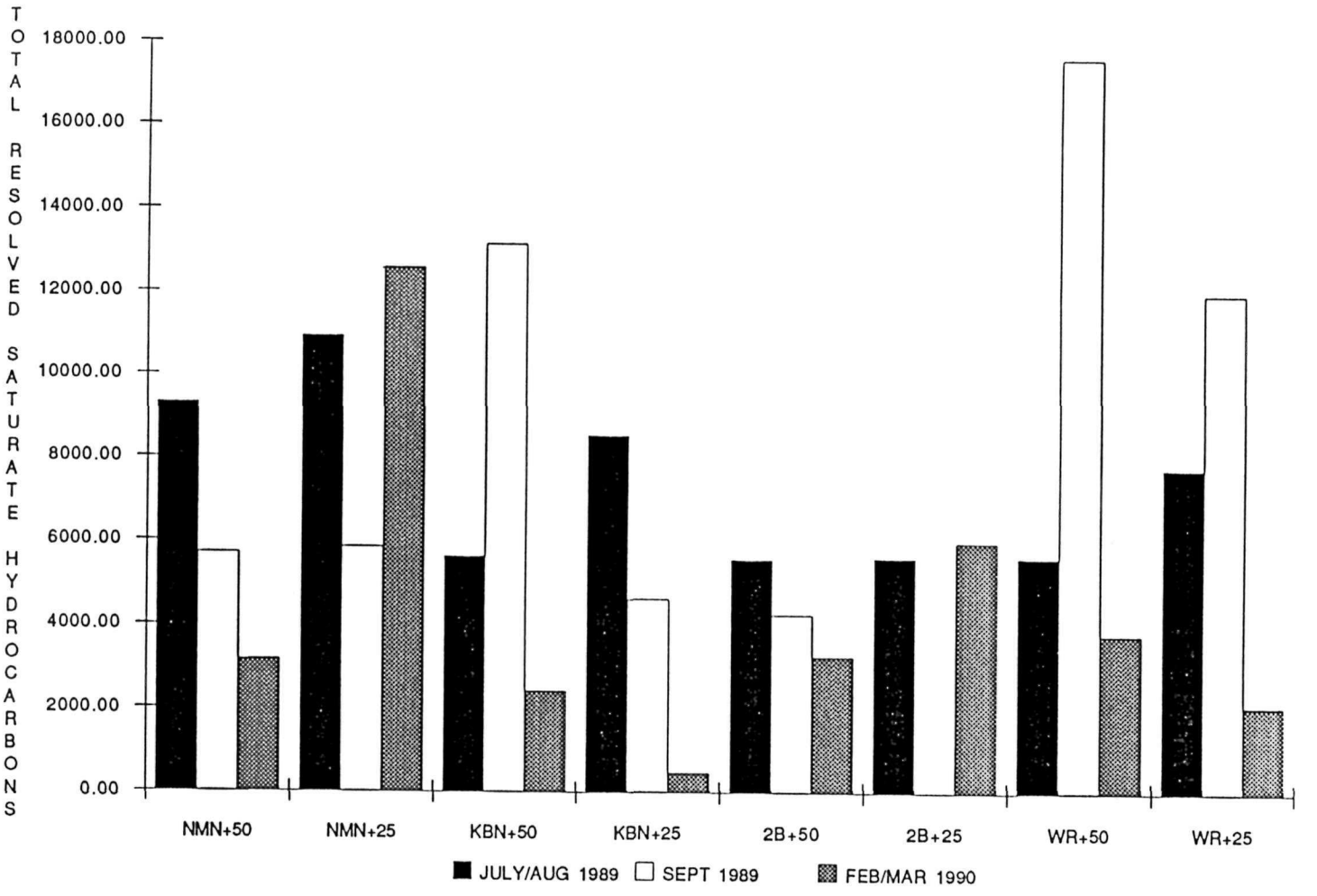


FIGURE 9a. Individual Tissue Concentrations of Total Resolved Saturate Hydrocarbons (ng/g dry weight) from California Mussels, Razor Clams, and other Invertebrates Collected from Oiled Beaches Within the Olympic National Park. See Table 4 for sample locations.

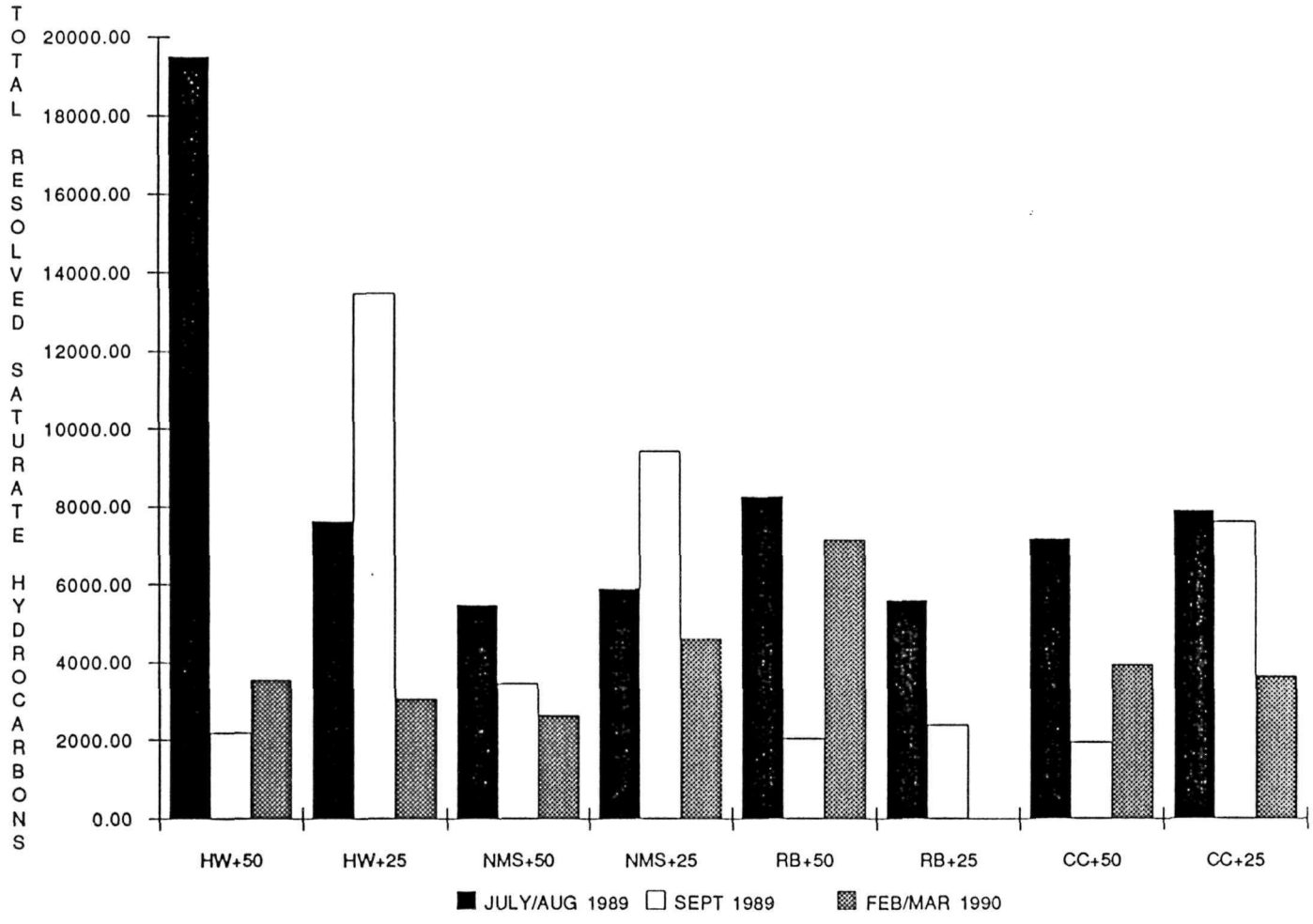


FIGURE 9b. Individual Tissue Concentrations of Total Resolved Saturate Hydrocarbons (ng/g dry weight) from California Mussels, Razor Clams, and Other Invertebrates Collected from Unoiled Beaches Within the Olympic National Park. See Table 4 for sample locations.

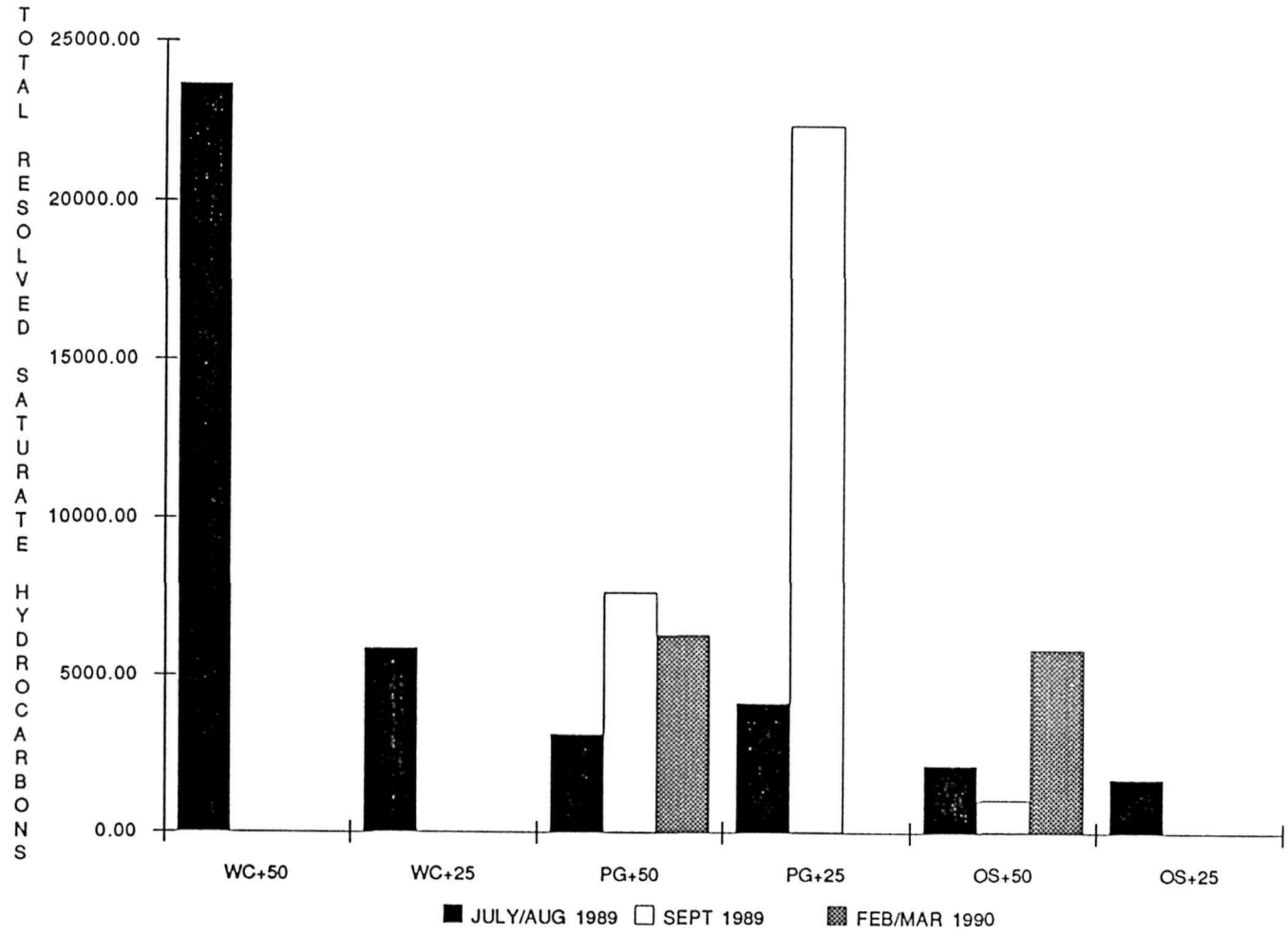


FIGURE 9c. Individual Tissue Concentrations of Total Resolved Saturate Hydrocarbons (ng/g dry weight) from California Mussels, Razor Clams, and Other Invertebrates Collected from Other Oiled Washington Coast Beaches. See Table 4 for sample location.

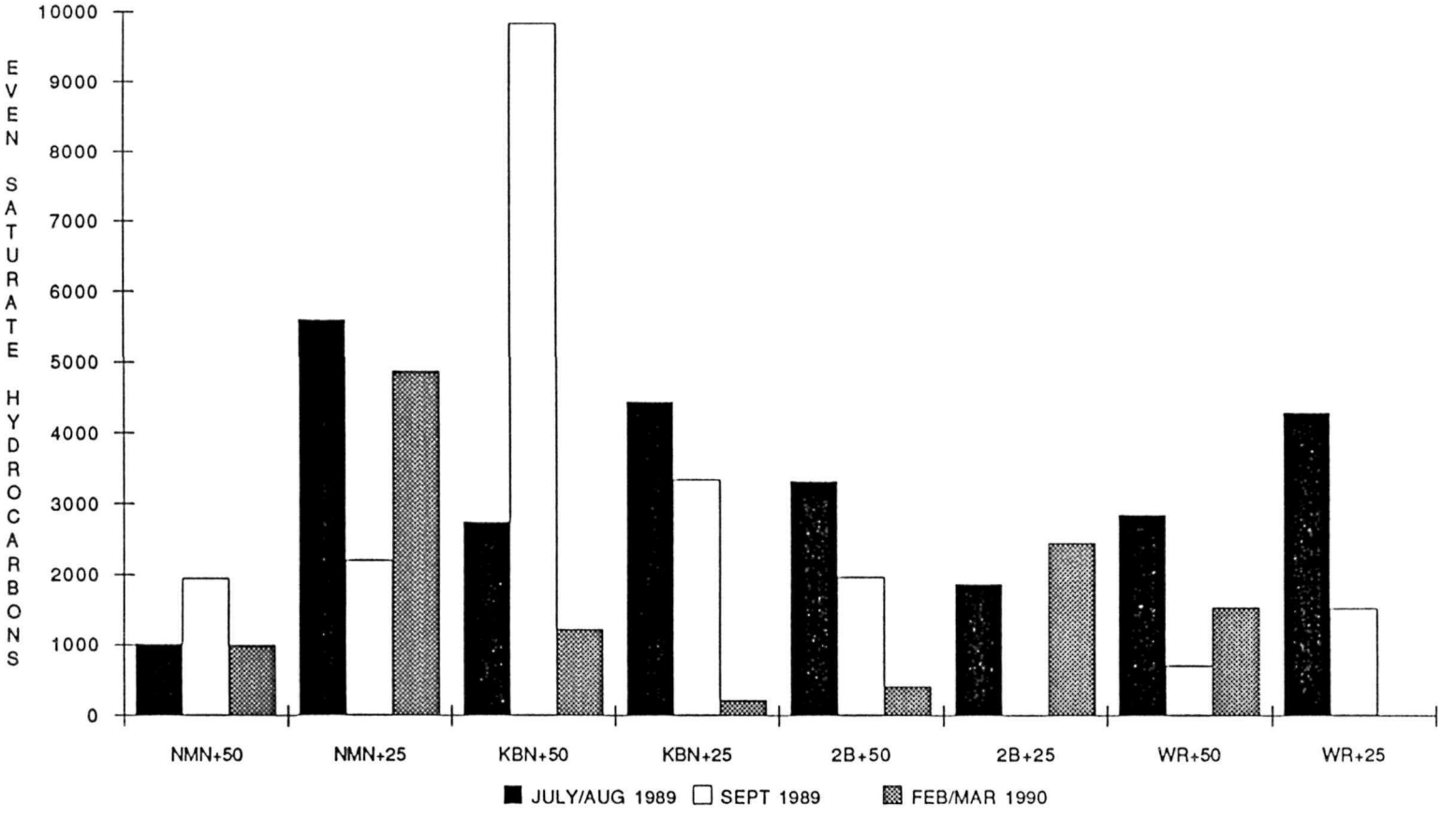


FIGURE 10a. Individual Tissue Concentrations of Even Saturate Hydrocarbons (ng/g dry weight) from California Mussels, Razor Clams, and Other Invertebrates Collected from Oiled Beaches Within the Olympic National Park. See Table 4 for sample locations.

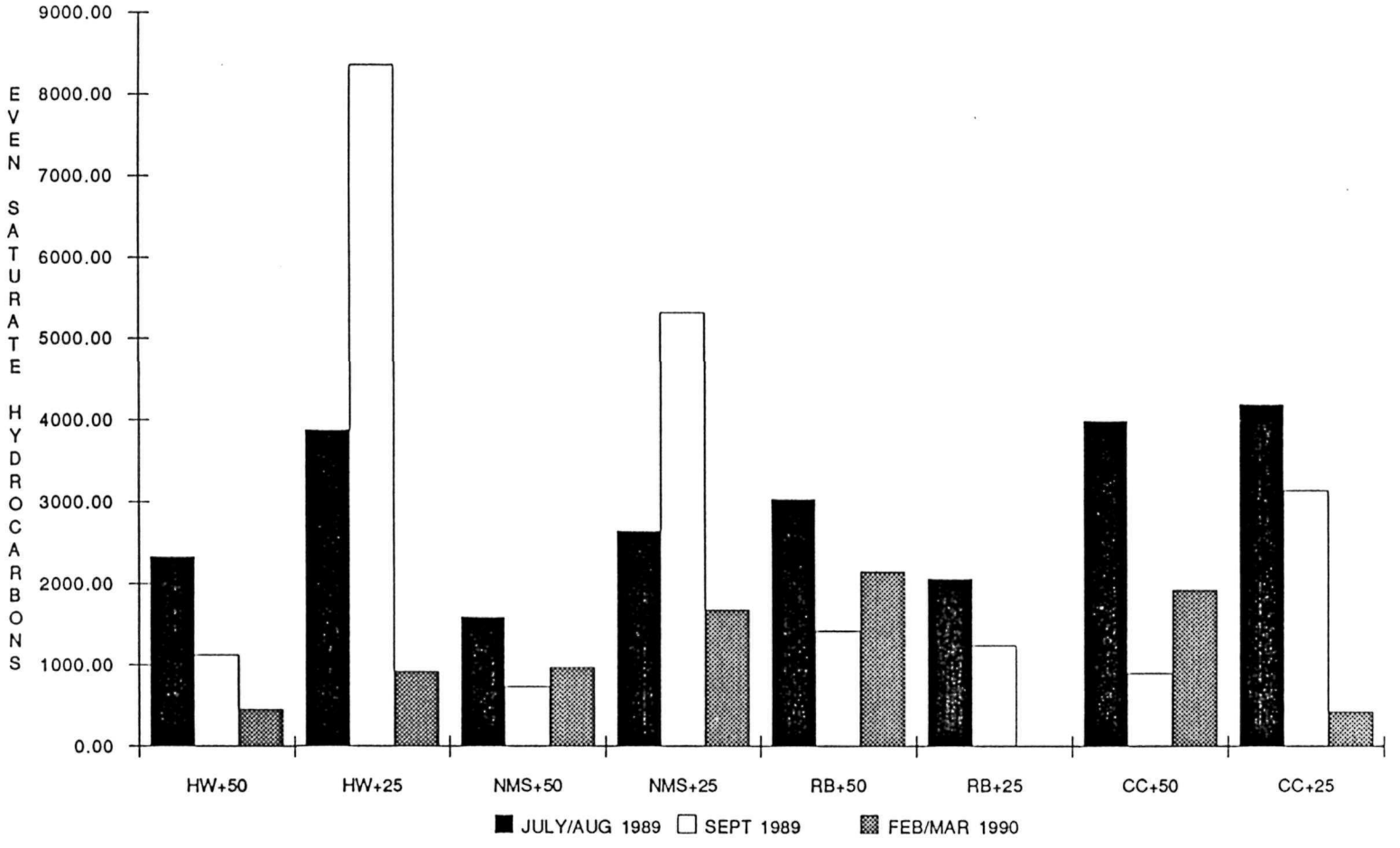


FIGURE 10b. Individual Tissue Concentrations of Even Saturate Hydrocarbons (ng/g dry weight) from California Mussels, Razor Clams, and Other Invertebrates Collected from Unoiled Beaches Within the Olympic National Park. See Table 4 for sample locations.

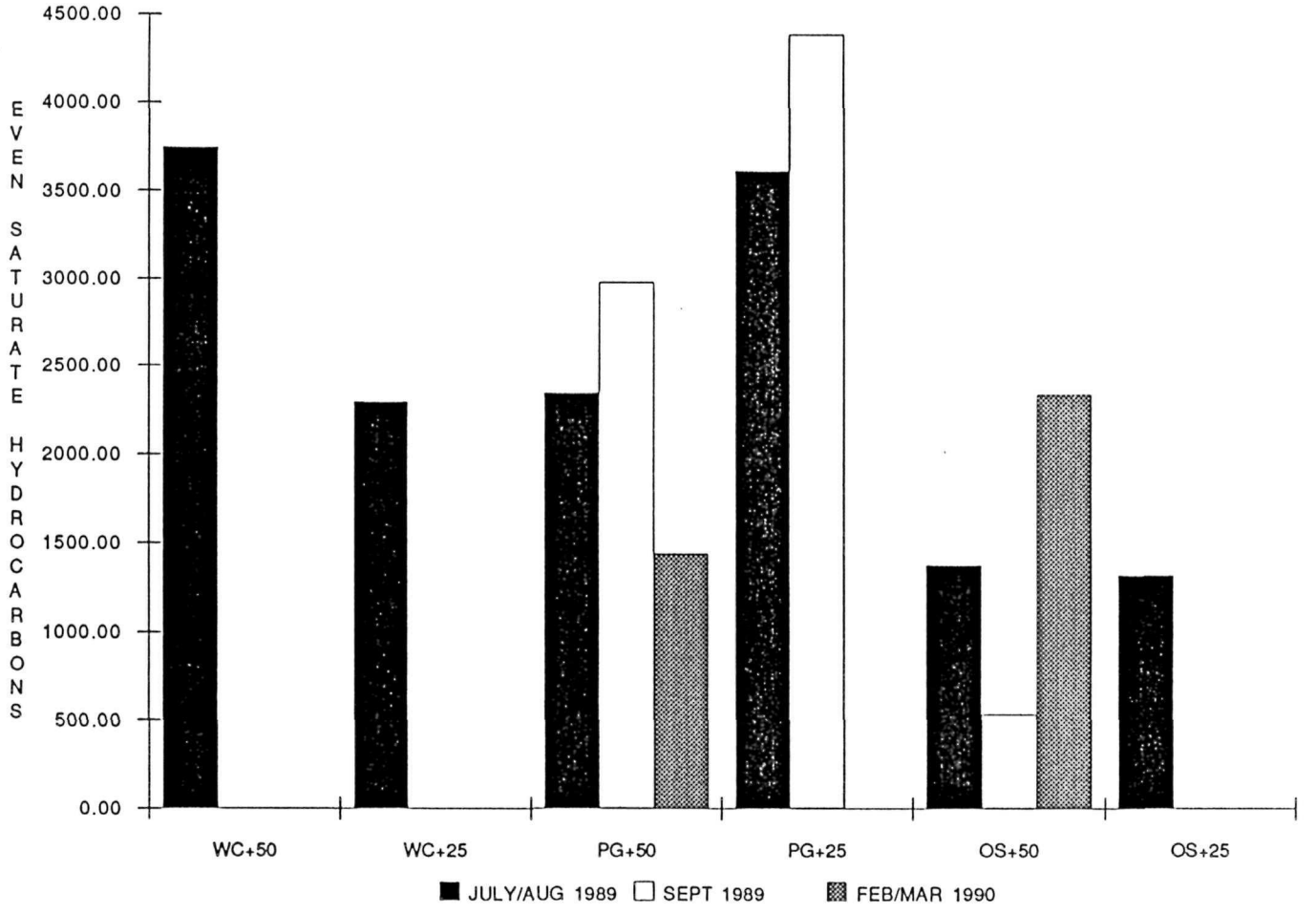


FIGURE 10c. Individual Tissue Concentrations of Even Saturate Hydrocarbons (ng/g dry weight) from California Mussels, Razor Clams, and Other Invertebrates Collected from Other Oiled Washington Coast Beaches. See Table 4 for sample locations.

TABLE 6. Tissue Concentrations of Total Resolved and Even Saturate Hydrocarbons (ng/g dry weight) Averaged over Three Beach Surveys Conducted on the Washington Coast Following the December 1989 Oil Spill

		Species			
		California Mussels		Razor Clams	
Location and Status	Statistic	Total Resolved	Even Saturates	Total Resolved	Even Saturates
Olympic National Park - Oiled	Mean	7939	2456	2597	5167
	SD[a]	4469	1839	29	1023
	N[b]	13	13	2	2
Olympic National Park - Reference	Mean	4818	1921	4571	1939
	SD	2361	1419	2934	813
	N	10	10	4	4
Washington Coast Beaches - Oiled	Mean	4403	1437	9267	2823
	SD	291	901	9588	1191
	N	3	3	7	7
All Beaches	Mean	6331	2133	7254	2516
	SD	3870	1595	7304	1062
	N	26	26	13	13

TABLE 6. (contd)

Location and Status	Statistic	Other[c] Total Resolved	Other[c] Even Saturates	All Total Resolved	All Even Saturates
Olympic National Park - Oiled	Mea	5167	2773	6770	2578
	SD[a]	3759	3009	4155	2190
	N[b]	8	8	23	23
Olympic National Park - Reference	Mean	8015	3055	6026	2368
	SD	5429	2457	4104	1851
	N	9	9	23	23
Washington Coast Beaches - Oiled	Mean	5873	2295	7631	2397
	SD	--	--	7884	1191
	N	1	1	11	11
All Beaches	Mean	6630	2887	6636	2458
	SD	4663	2571	4985	1869
	N	18	18	57	57

(a) SD = standard deviation.
(b) N = the sample size.
(c) This category includes limpets, snails, chitons, polycheates, and assorted crustaceans.

Although the relatively low concentrations of petroleum hydrocarbons found in most molluscan tissues collected on oiled beaches during the third survey could reflect a low but continuous exposure to residual oil found within the sediments on oiled beaches, these low concentrations likely also reflect the relatively slow depurative abilities of molluscs in general. Vandermeulen et al. (1977) determined that clams from chronically oiled beaches transferred to oil-free water gradually lost tissue-bound hydrocarbons rapidly during the first 2 days, but much more slowly thereafter. Even after 92 days, depuration was incomplete with tissues retaining 30% of the initial hydrocarbon burden. Anderson et al. (1974) and Anderson (1975) also presented data indicating that molluscs do not depurate hydrocarbons rapidly.

3.4 SOURCE IDENTIFICATION

3.4.1 Intertidal and Shallow Subtidal Sediments

Chromatograms of oil (aromatics fraction) associated with Sand Island sediments in September 1989 display patterns strikingly similar to those of Bunker C oil collected from the barge Nestucca by the Washington State Department of Ecology in December 1988 (Figure 11). The lower CPI values (<1) associated with the Sand Island sediment samples also are indicative of an anthropogenic source of contamination (Table 7). The CPI values for the Nestucca oil, Alaska North Slope (ANS) crude oil, and Sand Island sediments are all essentially the same (0.90 - 0.94).

Additionally, the ratios of nC_{17}/pristane and nC_{18}/phytane for the Sand Island residues are comparable to those for the Nestucca oil (Table 7). Significant changes have been reported in these ratios after 6 to 9 months of weathering of intertidal sediments amended with ANS crude oil (Anderson et al. 1978), suggesting the presence of hydrocarbon-degrading microorganisms (Blumer and Sass 1972). The finding of little change in these key hydrocarbon ratios indicates that biodegradation played a relatively minor part in the weathering of the Sand Island residues. This is not surprising, since the oil on Sand Island was buried in relatively coarse sediments in the high (+13.3 to +15.2-ft) intertidal zone.

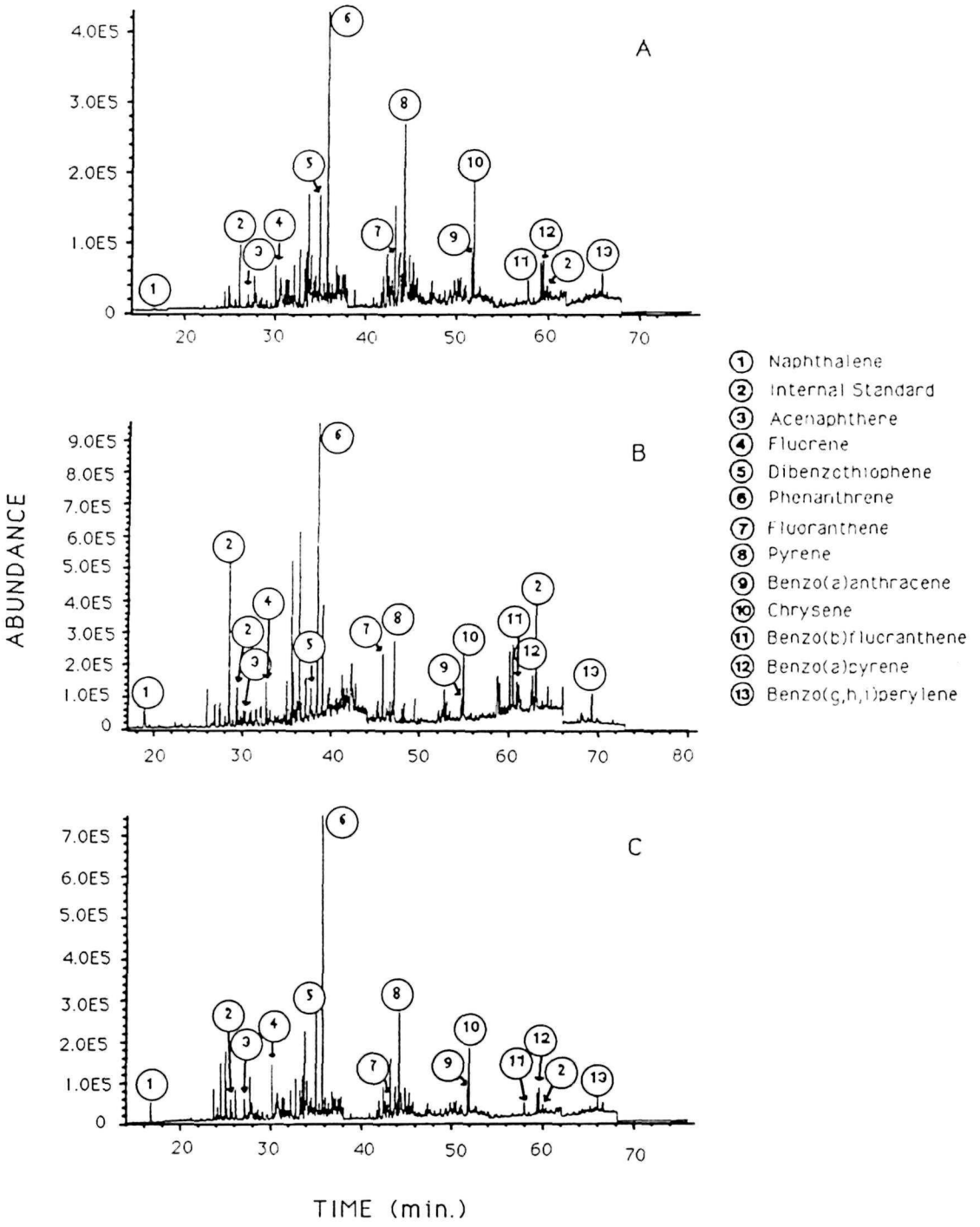


FIGURE 11. Total Ion Chromatograms (Polynuclear Aromatic Hydrocarbons) for Surface Sediments from Sand Island (A) and Norwegian Memorial - UW Transect (B) Compared with the Total Ion Chromatogram for Nestucca Oil (C). (The symbol E5 denotes values times 10^5.)

TABLE 7. Summary of Saturate Hydrocarbon Concentrations, the Ratios of nC_{17}/Pristane and nC_{18}/Phytane, the Carbon Preference Index (CPI), and Infrared Spectrophotometric Concentrations (IR) of Oil and Grease in Selected Environmental Samples. See Table 4 for Sample Locations

Station	Saturate Hydrocarbon Concentration nC17-nC26 (mg/kg)	Saturate Hydrocarbon Ratios nC17/ Pristane	nC18/ Phytane	CPI	IR (µg/g)
Nestucca Oil	(a)	1.83	1.27	0.90	(a)
ANS Crude Oil	(a)	1.54	1.78	0.94	(a)
SI+15.2	339.45	1.33	0.90	0.94	6255
SI+13.3	962.05	1.67	1.16	0.92	19015
OP3-3.0	0.0006	(b)	(b)	0.67	250
HW+15	0.001	(b)	(b)	0.68	170
RB+14	0.001	(b)	2.20	1.02	86
HNMX+8.2	0.007	0.34	1.33	1.11	115
HNMX+1.1	0.0003	0.51	(b)	0.78	73

(a) Not calculated.
(b) Ratio not calculated because target hydrocarbon not detected.

The lack of significant weathering, however, is evident in the chromatographic analyses of both aromatic and saturate hydrocarbons from the Sand Island residues. The only significant changes that occurred are associated with light-ends (the more volatile compounds). While concentrations of the more volatile compounds from the Nestucca oil are relatively low, the notable difference when comparing the aromatic hydrocarbon fractions of each chromatogram is the absence of naphthalene from the Sand Island samples (Figure 11, Appendix C1). There are, however, few other changes. Dibenzothiophene, phenanthrene, pyrene, chrysene, benzo(b)fluoranthene, and benzo(g,h,i)perylene all persist in the Sand Island samples at generally the same relative concentrations as in the Nestucca oil.

Similarly, changes in saturate hydrocarbons are slight (Appendix C2). As anticipated, some of the saturate hydrocarbons (C_9 - C_{13}), although present in the Nestucca oil, are not detectable in either of the Sand Island

samples. However, the remaining saturate hydrocarbons (C_{14} - C_{36}) were detected in the Sand Island samples, generally at the same relative concentrations encountered in the Nestucca oil.

Sediments collected during the third survey from the Norwegian Memorial University of Washington transect (Figure 11) and from the -3.0 ft contour from Wedding Rocks, Norwegian Memorial North, Kayostla Beach North, and Second Beach (Figure 12) may contain remnants of weathered Bunker C oil. The relative concentrations of fluorene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)- fluoranthene, benzo(a)pyrene, and benzo(g,h,i)perylene are comparable to the Nestucca oil. A complication to source identification, however, is that these samples contain other hydrocarbon components which are not consistent with Bunker C oil and may be of a biogenic origin. There is even less certainty as to the origin of oil associated with the samples collected from Ruby Beach and Hole-in-the-Wall. The chromatograms (aromatics fraction) for neither of these samples match the comparable chromatograms for the Nestucca oil (Figures 11 and 12). This does not eliminate the possibility that oil in these samples represents highly weathered Bunker C oil, but due to the uncertainty associated with determining its origin, no conclusion can be made.

3.4.2 Invertebrate Tissues

Likewise, chromatographic analyses of mussels, razor clams, or other invertebrates revealed little information useful in determining the origin of essentially trace quantities of aromatic hydrocarbons contained in some of their tissues. While no napthalenes were found in any of the tissues, phenanthrenes occurred in tissues from seven of the twelve sampled beaches, including Ocean Shores, Point Grenville, Second Beach, Kayostla Beach, Norwegian Memorial North and South (including the transect sampled by the University of Washington), and Wedding Rocks (see Appendix C2). What phenanthrenes were found, however, were generally less than 20 ng/g.

While many of the tissue samples yielded a CPI of less than 1.0, many of these have a low total concentration (<9 μg/g) of normal branched saturate hydrocarbons (Appendix C2). On the other hand, most (8 of 12) of the tissue samples with a total concentration of normal branched saturates of >9 μg/g

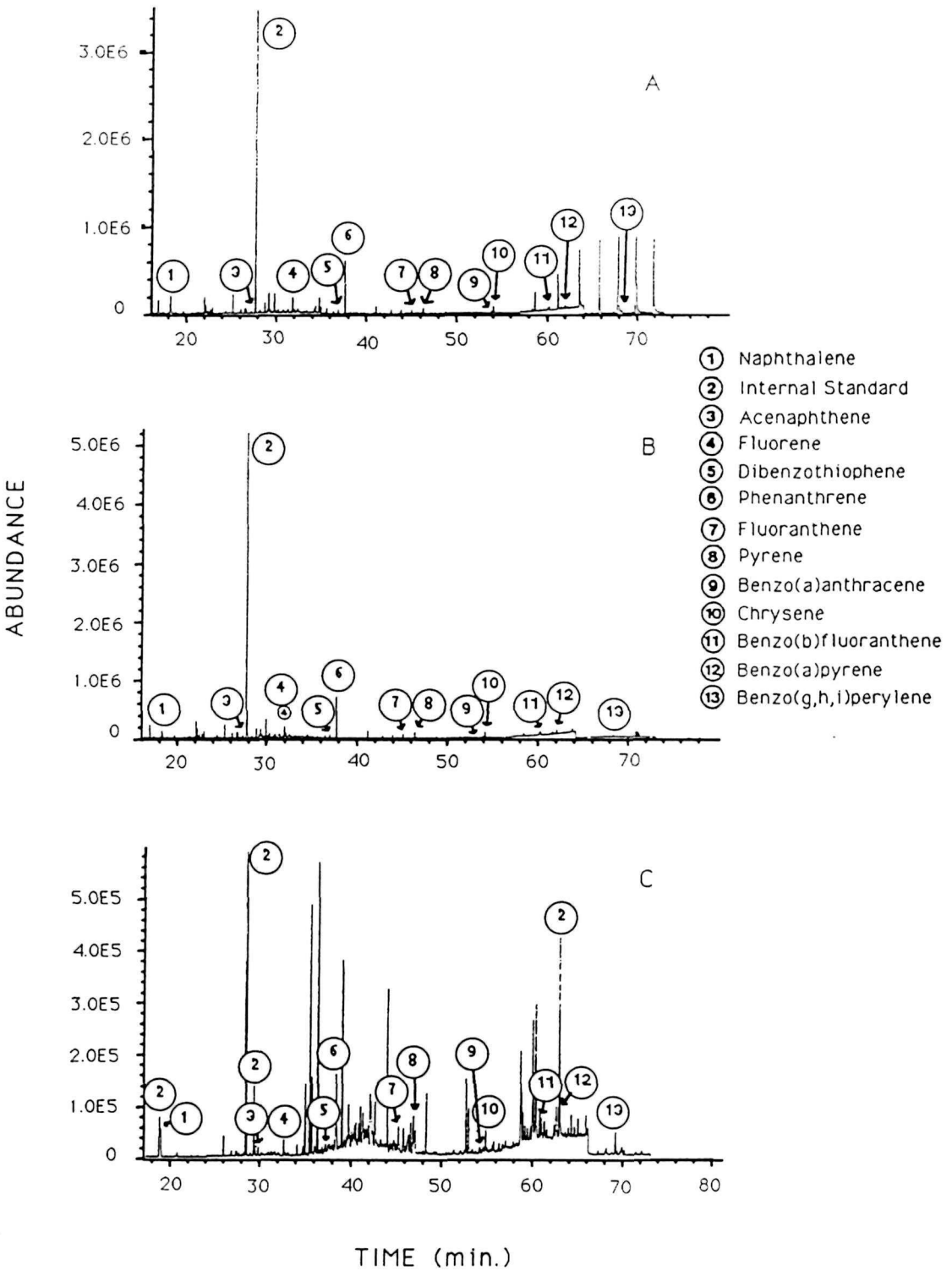


FIGURE 12. Total Ion Chromatograms (Polynuclear Aromatic Hydrocarbons) for Surface Sediments from Hole-in-the-Wall (A), Ruby Beach (B), and from a Composite Containing Surface Sediments from the -3.0-ft Tidal Contour at Kayostla Beach, Norwegian Memorial North, and Wedding Rocks (C) (The symbol E5 denotes values times 10^5)

have a CPI greater than 1. Because extensive weathering should have occurred since the spill, we might have expected a CPI greater than 1 from the loss of petroleum-derived saturate hydrocarbons. The CPIs being greater than 1 indicated that the odd-numbered organics, or biogenic hydrocarbons, were the dominant form of saturate hydrocarbons present.

Also surprising is the finding that most of the nC_{17}/pristane and nC_{18}/phytane ratios equalled or exceeded those calculated for the Nestucca oil and the oil found associated with intertidal sediments at Sand Island. Again, however, the usefulness of these ratios as indicators of biodegradation may be limited at such low hydrocarbon levels. If the target organisms had been contaminated by oil, we would have expected most of the samples to show nC_{17}/pristane and nC_{18}/phytane ratios of less than 1.83 and 1.27, respectively.

3.5 QUALITY-ASSURANCE RESULTS FOR CHEMICAL ANALYSES

3.5.1 Oil and Grease in Sediments

Two parameters (procedural blank and matrix-spike recovery) were used to evaluate the quality of the oil and grease in sediment data. Procedural blanks were usually less than 41 μg/g dry weight, assuming a 10-g sediment sample. The detection limit, calculated as 3 times the standard deviation of the mean for blanks, was in the range of 12 to 50 μg/g. Matrix-spike recoveries ranged from 51 to 97%, but only two were below 60%.

3.5.2 Saturate Hydrocarbon Compounds in Tissues and Sediments

Tissue and sediment samples were spiked with a surrogate compound, o-terphenyl (OTP) before extraction. The percent recovery of OTP (shown in Appendix C2) is an indication of the recoveries of the saturate compounds. The recovery of OTP was usually in the acceptable range of 50 to 100%. Lower recoveries were usually observed for the lower-molecular-weight compounds, which are volatile. Several field samples were spiked with a known amount of eleven saturate compounds and then extracted. The percent recoveries for these matrix spikes usually were in the range of 40 to 140%. Procedural blanks were usually below the detection limit of approximately 100 ng/g for each compound.

3.5.3 Aromatic Hydrocarbon Compounds in Tissues and Sediments

Each tissue or sediment sample analyzed for Polynuclear Aromatic Hydrocarbons (PAH) was spiked with three surrogate compounds (d8-napthalene, d10-acenaphthene, and d12-perylene) at the beginning of the extraction procedure. The percent recoveries of these surrogates indicate the recoveries of similar PAH compounds in the samples. The surrogate-recovery data were not used to correct any of the data. The recovery of d8-naphthalene was usually in the range of 20 to 60%, d10-acenaphthene was 30 to 90%, and d12-perylene was 60 to 120% (Appendix C1). Because d8-napthalene is the most volatile PAH surrogate, this recovery is frequently below 50%. However, the surrogate recoveries are generally in the acceptable range.

Several field samples were spiked with known quantities of PAH compounds and then extracted and quantified to determine the percent recovery of matrix spikes. Matrix spike recoveries (shown in Appendix C1) were usually in the range of 50 to 120%, with the lowest recoveries for the most volatile compounds.

Procedural blanks were usually below the detection limits, which were in the range of 3 to 10 ng/g for individual PAH compounds.

3.6 PERSPECTIVE ON LEVELS OF RESIDUAL CONTAMINATION

For comparing the hydrocarbon levels in the present study with background or historical levels in the study area, only a few studies, unfortunately, are germane (Brown et al. 1979, 1981; Vanderhorst et al. 1980; Strand et al. 1986; Word et al. 1987a, b). While numerous studies on the fate of spilled oil, particularly Bunker C or No. 6 fuel oil, exist (McLeod et al. 1978; Nadeau 1978; Petersen 1978; Ayers 1978; Soule et al. 1978), there is, unfortunately, relatively little specific information as to how long Bunker C fuel persists in the marine environment. Betancourt and McLean (1973), however, found that Bunker C oil spilled from the tanker Arrow in Nova Scotia weathered only 20% after one year in low-energy environments such as on the shoreline above the limit of wave activity. By contrast, they found that high-energy environments weathered and depurated rapidly.

While we found relatively high concentrations of oil (6255 and 19,015 μg/g dry weight) on Sand Island in Grays Harbor during the second survey, we found relatively low concentrations of oil (63 to 250 μg/g), essentially trace amounts, associated with the coastal stations during the third survey, indicating that little residual of the 1988 Nestucca spill remains. These findings suggest that the long-term impacts on intertidal communities should not be as severe as first believed. The lack of any appreciable hydrocarbon signal occurring in biological tissues examined during this study tends to support this suggestion. The relatively high concentrations of oil found on Sand Island were restricted to a narrow band 3 to 4 m wide over a 10- to 13-m stretch of beach on the southwest side of the island. Attempts to relocate this band of oil during the third survey were unsuccessful. Shifts in the configuration of sand dunes mediated by storm events during the winter of 1989/1990 undoubtedly were partially responsible.

Interestingly, oil was not found associated with beaches hypothesized to be oiled (Kayostla, Norwegian Memorial, Wedding Rocks) until the third survey (February/March 1990). Low concentrations of oil were also detected at Ruby Beach and at Hole-in-the-Wall (both hypothesized unoiled beaches), although analyses of all samples collected from both beaches during the first and second surveys (July and September 1989, respectively) failed to detect the contaminant. While it is difficult to eliminate the possibility of altogether missing the oil on our first two visits to the oiled beaches, the more likely reason for this finding is associated with the normal cycle of beach accretion and erosion. Because the spill occurred in December and January, when beaches were fully eroded, it follows that as beaches accreted sediments in summer and autumn months (also at the time of our first and second surveys), oil not removed by the clean-up crews was buried and hence inaccessible to our sampling. On sandy beaches, we generally sampled at a depth of 15 cm, though beach accretion on sandy beaches may total 1 to 2 m. Hence, when the beaches again eroded in the winter of 1990 (at the time of our third survey), the previously buried oil became accessible to our sampling methods.

With the exception of Ruby Beach (a sand beach), all those beaches showing residual oil during the third survey were classified as rock and/or

cobble beaches. Although the heaviest oiling occurred at Ocean Shores, near the North Jetty, none of our surveys detected any oil residual in this location. These results suggest, then, that high-energy (open) sand beaches can cleanse themselves quickly (in a matter of months), while the protected rock, cobble, and rubble beaches, encountered at Kayostla Beach, Norwegian Memorial, and Cape Alava (Wedding Rocks), require a substantially longer period (potentially years) for natural cleansing.

We have found no reports that address hydrocarbon levels in intertidal sediments along the outer Washington coast. However, three studies address hydrocarbon levels in intertidal sediments along the Strait of Juan de Fuca. In the first, Brown et al. (1979, 1981) sampled intertidal sediments at +2.0 ft (+0.6 m) at 10 sites along the Strait of Juan de Fuca to determine background levels of hydrocarbons. Total saturate and total unsaturate hydrocarbons were measured microgravimetrically after silica gel extraction, and selected alkane and aromatic hydrocarbons were determined by glass-capillary gas chromatography. Over three quarterly sampling periods, total saturate hydrocarbons ranged from less than 1 to 19 μg/g dry weight, and total unsaturate hydrocarbons from 1 to more than 3 μg/g. The highest concentrations were at Ediz Hook, whereas the sampling site at the base of Dungeness Spit had among the lowest concentrations. After a spill of diesel fuel in Port Angeles Harbor, total saturate hydrocarbons measured microgravimetrically ranged from 7 μg/g at Peabody Creek to 1500 μg/g at the boat ramp. Any comparison between the microgravimetric results and the IR results presented here should consider that the IR method measures total oil and grease concentration and yields higher values than the microgravimetric method, which measures selected hydrocarbon concentrations of the total oil and grease in the sample.

The second study, which concerned field experiments to determine how intertidal areas recover from oiling, provides measurements of IR values in uncontaminated natural sediments used as controls in field experiments (Vanderhorst et al. 1980). The control sediments were naturally occurring sandy sediments from intertidal habitat at Protection Island and Sequim Bay in the Strait of Juan de Fuca. During the course of the experiments, periodic monitoring showed that the mean IR values (n=3) changed with time as

shown in Table 8. Vanderhorst et al. (1980) attributed the observed increase in IR values with time in the field to increasing organic content of the sandy sediments. These data indicate that background IR levels for sandy beach sediments can be expected to be within a range of 20 to 140 mg/kg dry weight.

The concentrations of oil and grease occurring on Washington coast beaches immediately following the Nestucca spill undoubtedly were many times higher than those measured during our latter surveys. The 6255 to 19,015 μg/g oil and grease found on Sand Island in Grays Harbor during the second survey is a level likely to have occurred on other affected beaches of the Washington coast. The concentrations of total oil and grease in intertidal sediments at Ediz Hook following the December 1985 spill of ANS crude oil from the ARCO Anchorage was approximately 30,000 mg/kg (Word et al. 1987a, b). However, these high concentrations of total oil and grease were significantly reduced through clean-up procedures implemented by ARCO Marine, Inc. Average concentrations of residual oil and grease at the end of clean-up were 450 μg/g. The maximum observed average concentration within treated areas was about 1100 μg/g. Vanderhorst et al. (1980, 1981) showed in field experiments that residual oil concentrations in intertidal sediments decreased from about 2000 μg/g to undetectable levels within 18.5 months. While the type of oil and the sediment characteristics in these studies are different than those analyzed in the present study, it would appear that those areas of the Washington coast oiled by the Nestucca spill are returning to essentially background levels with the same general kinetics. Presumably,

TABLE 8. Hydrocarbon Concentrations (mg/kg dry weight) for Uncontaminated Areas as a Function of Time After Oiling (Vanderhorst et al. 1980)

	Total Hydrocarbon Concentration (mg/kg) by IR, $\bar{x}$ ± S.D.		
	Time in Field		
Areas	0 Months	3 Months	15 Months
Sequim Bay	21 (±8)	32 (±15)	136 (±52)
Protection Island	37 (±10)	24 (±7)	132 (±54)

residual oil on Washington coastal beaches following the Nestucca spill was also significantly reduced by removal of grounded oil mats and/or oiled debris. The finding of significantly decreased nC_{17}/pristane and nC_{18}/phytane ratios associated with sediments collected in the Norwegian Memorial area (samples HNMX+8.2, HNMX+1.1) of Olympic National Park confirm that weathering has occurred very rapidly in selected Washington coastal sediments (Table 7).

Concentrations of aromatic hydrocarbons in California mussels, razor clams, and other invertebrates following the Nestucca spill were all ≤100 ng/g (dry weight). Most concentrations were ≤45 ng/g (dry weight). In comparison, concentrations of aromatic hydrocarbons in mussels collected from polluted areas in Elliott Bay and Commencement Bay in Puget Sound were 23,000 and 2,400 ng/g (dry weight), respectively (NOAA 1987). Of the 100 sites sampled routinely as part of the NOAA Status and Trends program, only 26 sites resulted in aromatic hydrocarbon concentrations of ≤45 ng/g (dry weight) in oyster or mussel tissue (NOAA 1987). Coastal sites at Cape Flattery, Grays Harbor, and Coos Bay, Oregon ranged from 20 to 141 ng/g (dry weight) from 1986 to 1989.

An evaluation of human health risk associated with chemical contamination of Puget Sound fish and shellfish was recently conducted for the Office of Puget Sound, U.S. Environmental Protection Agency (EPA) Region 10 (Tetra Tech 1988). The evaluation included health risks for polynuclear aromatic hydrocarbons in recreationally harvested seafood. Graphs are provided for estimating health risk (lifetime cancer risk from consumption of PAH) for a wide range of exposure conditions. However, in this exercise the estimated risk is associated with four potentially carcinogenic PAHs, including benzo(a)anthracene, benzo(b)fluoranthene, chrysene, and benzo(a)pyrene. The estimated health risk is not based on total PAH or all seventeen PAH quantitated in the present study.

Relating this convention to data derived in the present study, we found that shellfish collected at Norwegian Memorial North and Wedding Rocks contain relatively low concentrations (4 to 15 ng/g dry weight) of at least one of the above compounds (benzo[a]anthracene). The Wedding Rocks sample also

contained a very low concentration of chrysene. These levels, however, if used in the EPA risk analysis (Tetra Tech 1988), would result in an estimated lifetime cancer risk of $\sim 5 \times 10^{-7}$, which is relatively low. This calculation, not shown, was based on an average consumption of shellfish of 1.1 g/day (2.7 servings/year) and corrects for the conversion of dry weight to wet weight. For comparison, the average estimated lifetime cancer risk associated with consumption of shellfish from Puget Sound was 1×10^{-5}, with a minimum of 6×10^{-7} and a maximum of 6×10^{-4} (Tetra Tech 1988). The $\sim 5 \times 10^{-7}$ risk calculated here falls within EPA's regulatory target range of 10^{-7} to 10^{-4} associated with managing risks from PAH. Individual risk levels greater than 10^{-3} are usually subject to regulatory action while those less than 10^{-7} rarely are.

3.7 FACTORS INFLUENCING WEATHERING AND DEPURATION

There are likely several factors that accounted for the relatively rapid depuration of oil following the Nestucca spill, including 1) the time of year in which it occurred, 2) the type of beach or coastline affected, and 3) the timely and efficient clean-up.

3.7.1 Time Of Year

Because the spill occurred in winter, when water and air temperatures were lowest, much of the oil rapidly congealed into "blobs," "patties" and large "mats" before coming ashore. In some cases, the Bunker C oil from the Nestucca was at sea from 1 to 2 weeks before grounding on some of the ONP beaches, and it had weathered significantly during this period. The relatively high sea state at the time of the spill also likely served to enhance weathering; high winds increased evaporation and the resulting high seas increased dissolution and dispersion. This was not the case in every location affected by the spill, however. Shortly after the accident, heavy accumulations of fresh (unweathered) Bunker C came ashore at Ocean Shores and also entered Grays Harbor. Relatively fresh oil also stranded at Whale Creek on the Quinault Indian Reservation and on the more southern beaches of ONP (Second Beach, Kayostla Beach, and Norwegian Memorial). A decision to tow

the disabled barge Nestucca farther seaward until emergency repairs could be affected, however, reduced the likelihood of more fresh oil reaching Washington Coast beaches.

3.7.2 Type of Beach

The area of the Washington coast most affected by the spill is characterized by unprotected, high energy, rocky headlands and sand beaches. Fortunately, this type of shoreline tends to cleanse itself most rapidly (ESL Environmental Sciences Limited, unpublished data). Most Bunker C stranding on the rocky shorelines of the Washington coast (Kayostla Beach, Norwegian Memorial, Wedding Rocks) was removed relatively quickly by wave action and a series of severe winter storms that occurred immediately following the spill. The relatively low concentrations of oil (63 to 250 μg/g by IR), essentially trace amounts, associated with these coastal stations during the third survey confirmed that weathering and depuration proceeded rapidly. What residue remained was restricted to the more protected rock and cobble substrates associated with gently sloping beaches at Kayostla Beach and Norwegian Memorial. The finding of significantly decreased nC_{17}/Pristane and nC_{18}/phytane ratios associated with sediments collected in the Norwegian Memorial area (samples HNMX+1.1) of ONP also confirmed that weathering occurred very rapidly in selected Washington coastal sediments (Table 6). Additionally, even though the sand beaches at Ocean Shores (North Jetty area) were heavily oiled, oil was not detected during any of the three surveys conducted at this location, suggesting more rapid depuration from open sand beaches. Finally, even though very high concentrations of oil (6,255 and 19,015 μg/g dry weight by IR) were found on Sand Island during the second survey, attempts to relocate this oil during the third survey proved unsuccessful, further indicating that weathering and depuration proceeded rapidly. Shifts in the configuration of sand dunes mediated by intense storm events during the winter of 1989-1990 were likely partially responsible.

3.7.3 Efficacy of Clean-up

Finally, clean-up was well organized and immediate. Clean-up crews visited all affected beaches; only one "set-aside" beach was established in

ONP to study potential effects of oiling on intertidal ecology. For the most part, oil in the form of "mats," smaller "patties," and "blobs" was easily picked up or scraped off rocks. Oiled debris consisting of kelp mats, eel grass, driftwood, and other flotsam were also readily removed for ultimate disposal in a certified landfill. Absorbent pads were only used during the first few days of the spill, when the oil was still fresh. Pompoms were installed and used effectively over cobble substrates containing buried oil at Norwegian Memorial. Intense winter storm activity accompanied by extremely high tides at the time of the spill refloated extensive amounts of stranded debris, effectively adding much natural oil-absorbent material to affected waters. Helicopter access to even the most remote beaches on the coast greatly facilitated the clean-up process. Logs too large for removal by truck or helicopter were burned at the site. Approximately 45,000 yd^3 of oiled logs were burned on Washington coastal beaches (including those of ONP) following the spill.(a) Other logs as well as large rocks and boulders were "brush-torched" to remove oil, although this technique enjoyed only limited success. Oil adhering to logs and rocks was heated until formation of an ash, but rocks often exploded during this process, raising concern for operator safety. Propane-fired torches were also used on heavily oiled, cobble beaches of Vancouver Island, but again with little success (Harding and Englar 1989).

Clean-up on Vancouver Island following the Nestucca spill proceeded in much the same way and over essentially the same time frame. Canadian officials (Harding 1990) also indicated that a rapid and thorough clean-up program following grounding of the oil in early January 1989 served to reduce the impacts of the spill. The grounding of oil in locations where natural self-cleaning was at maximum (high wave action) also limited impacts.

(a) Personal communication, Lt. Mike Smith, Marine Safety Office, U. S. Coast Guard, Seattle District.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

4.1.1 Contamination of Intertidal and Shallow Subtidal Sediments

Although relatively high concentrations of oil (6255 and 19,015 μg/g dry weight by IR) were found on Sand Island in Grays Harbor during the second survey, the relatively low concentrations of oil (63 to 250 μg/g by IR), essentially trace amounts, associated with the coastal stations during the third survey indicate that relatively little oil residual remains from the 1988 Nestucca spill. Even the relatively high concentrations of oil found on Sand Island were restricted to a narrow band 3 to 4 m wide over a 10- to 13-m stretch of beach on the southwest side of the island, and attempts to relocate this band of oil during the third survey proved unsuccessful, further indicating that weathering and depuration have proceeded rapidly.

Additionally, even though the Ocean Shores (North Jetty) area was heavily oiled, oil was not detected during any of the three surveys at this location. This suggests that open, high-energy, and sandy beaches cleanse themselves naturally much faster than do rocky and cobble beaches. Our results also suggest that the clean-up of grounded oil mats and oiled debris following the Nestucca spill reduced the level of residual oil contamination on affected beaches.

4.1.2 Source of Oil Found on Washington State Beaches

Chromatograms of oil (aromatics fraction) found associated with Sand Island sediments during the second survey display patterns strikingly similar to those of Bunker C fuel oil collected from the barge Nestucca. The lower carbon preference index values (0.92, 0.94) of the Sand Island sediment samples are also indicative of an anthropogenic source of contamination. The preponderance of evidence, then, strongly suggests that the oil found on Sand Island came from the barge Nestucca.

There is, however, less certainty as to the source of oil found in sediments collected during the third survey at Norwegian Memorial, Kayostla Beach, Wedding Rocks, Ruby Beach, and Hole-in-the-Wall. The Norwegian Memorial, Kayostla Beach, and Wedding Rocks sediments contained some

components that are consistent with weathered Bunker C oil but also contained hydrocarbons that could be associated with other oils including those of biogenic source. The chromatograms (aromatics fraction) for Ruby Beach and Hole-in-the-Wall sediments were not consistent with comparable chromatograms for the Nestucca oil. This does not rule out the possibility that the oil found in these samples represents highly weathered Bunker C, but due to the uncertainty associated with determining the source, no conclusion can be made.

4.1.3 Contamination of Biotic Assemblages

Concentrations of PAH contained in California mussels, razor clams, and other invertebrates following the Nestucca spill were all ≤100 ng/g (dry weight). Most concentrations were ≤45 ng/g (dry weight). These levels are significantly (10 to 100 times) lower than those found in mussels collected in South Puget Sound, a relatively clean urban estuary, and the more polluted areas of Puget Sound (Commencement Bay and Elliott Bay) in recent years by the National Oceanic and Atmospheric Administration (NOAA) as part of the National Status and Trends Program for Marine Environmental Quality. Under the same program, concentrations of aromatic hydrocarbons in mussels found at coastal sites including Cape Flattery, Grays Harbor, and Coos Bay, Oregon ranged from 20 to 141 ng/g (dry weight) from 1986 to 1989. Based on the relatively low concentrations of known carcinogenic PAH (4 to 15 ng/g dry weight) contained in the shellfish collected during the present study, the estimated lifetime cancer risk should also be considered low ($\sim 5 \times 10^{-7}$).

4.1.4 Factors Influencing Weathering and Depuration

Factors likely accounting for the relatively rapid weathering and depuration of oil from the Nestucca spill include 1) the time of year in which the spill occurred, 2) the type of beach or coastline affected, and 3) the timely and efficient clean-up. Because the spill occurred in winter, when air and water temperatures were lowest, most of the Bunker C fuel oil congealed into "blobs," "patties," and "mats." Large amounts of floating debris also tended to catch (adsorb) significant quantities of oil. The area of the Washington coast most affected is characterized by unprotected, high-energy sand beaches and rocky headlands, which tend to rapidly cleanse

themselves. Finally, clean-up was immediate and well organized. The large oil mats were easily picked up, and helicopter access to affected beaches facilitated removal of oiled debris.

4.2 RECOMMENDATIONS

Despite our conclusion that little oil remains from the 1988 Nestucca spill, the potential for buried, virtually unweathered oil resurfacing on Sand Island in Grays Harbor still exists. Sampling on Sand Island and the Washington coast in general was minimal, and our results and conclusions should be observed with that understanding. Because Sand Island is an important nesting ground for marine birds and because relatively high concentrations of Bunker C oil were found during the second survey, we recommend continuing minimal sampling of these sediments for the next 3 to 4 years. Sampling should occur during the lowest tides of February, when beach accretion is at its lowest, thus allowing the greatest potential of detecting resurfaced oil. We also recommend continuing use of a single randomly chosen transect and collecting sediments from the +15-, +13-, and +8-ft elevations annually.

Finally, because the quantities of shellfish harvested for consumption by both Native Americans and visitors to the Washington coast is relatively unknown and because small but detectable levels of carcinogenic aromatic hydrocarbons were found in some biological tissues collected from the Olympic National Park beaches, we recommend continuing minimal sampling of mussel tissues collected annually from the Norwegian Memorial area and Wedding Rocks for the next 3 to 4 years. Since the concentrations of aromatic hydrocarbons from the three surveys did not differ significantly, we cannot recommend any one sampling time over any other.

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APPENDIX A1

SAMPLING INFORMATION

Beach	Date	Sediment Samples Achieved				Faunal Samples Achieved		Organisms Collected	
		+8.2 ft	+1.1 ft	-1.7 ft	-3.0 ft	+/- 50 m	+/- 25 m	+/- 50 m	+/- 25 m
RUBY BEACH	17-Jul-89	RB+8.2	RB+1.1	RB-1.7		RB+50	RB+25	RC	RC
SECOND BEACH	18-Jul-89	2B+8.2	2B+1.1	2B-1.7	2B-3.0	2B+50	2B+25	RC	RC
HOLE-IN-THE-WALL	19-Jul-89	HW+8.2	HW+1.1	HW-1.7	HW-3.0	HW+50	HW+25	L	L
KAYOSTALA BEACH NORTH	20-Jul-89	KBN+8.2	KBN+1.1	KBN-1.7	KBN-3.0	KBN+50	KBN+25	CM,L	CM
CEDAR CREEK	20-Jul-89	CC+8.2	CC+1.1	CC-1.7	CC-3.0	CC+50	CC+25	CM	CM
NORWEGIAN MEMORIAL NORTH	21-Jul-89	NMN+8.2	NMN+1.1	NMN-1.7	NMN-3.0	NMN+50	NMN+25	CM	CM
NORWEGIAN MEMORIAL SOUTH	22-Jul-89	NMS+8.2	NMS+1.1	NMS-1.7	NMS-3.0	NMS+50	NMS+25	L,AC	L,AC,P
WEDDING ROCKS	23-Jul-89	WR+8.2	WR+1.1	WR-1.7		WR+50	WR+25	CM	CM
WHALE CREEK	31-Jul-89	WC+8.2	WC+1.1	WC-1.7	WC-3.0	WC+50	WC+25	RC	DC
POINT GRENVILLE	01-Aug-89	PG+8.2	PG+1.1	PG-1.7	PG-3.0	PG+50	PG+25	RC	RC,CM
OCEAN SHORES	02-Aug-89	OS+8.2	OS+1.1	OS-1.7	OS-3.0	OS+50	OS+25	RC,RM	RC
SAND ISLAND	02-Aug-89								
NORWEGIAN MEMORIAL NORTH	12-Sep-89	NMN2+8.2	NMN2+1.1	NMN2-1.7		NMN2+50	NMN2+25	C,S	C,S
NORWEGIAN MEMORIAL SOUTH	12-Sep-89	NMS2+8.2	NMS2+1.1	NMS2-1.7		NMS2+50	NMS2+25	L,S	L,S
CEDAR CREEK	13-Sep-89	CC2+8.2	CC2+1.1			CC2+50	CC2+25	CM,C,S	CM,C,S
KAYOSTALA BEACH NORTH	13-Sep-89	KBN2+8.2	KBN2+1.1	KBN2-1.7		KBN2+50	KBN2+25	L,S	C,S
HOLE-IN-THE-WALL	14-Sep-89	HW2+8.2	HW2+1.1	HW2-1.7		HW2+50	HW2+25	CM	L,C,S
SECOND BEACH	14-Sep-89	2B2+8.2	2B2+1.1	2B2-1.7	2B2-3.0	2B2+50	2B2+25	CM	P
WHALE CREEK	15-Sep-89	WC2+8.2	WC2+1.1	WC2-1.7	WC2-3.0		WC2+25		MS,H
POINT GRENVILLE	15-Sep-89	PG2+8.2	PG2+1.1	PG2-1.7	PG2-3.0	PG2+50	PG2+25	RC	RC,MS
RUBY BEACH	16-Sep-89	RB2+8.2	RB2+1.1	RB2-1.7	RB2-3.0	RB2+50	RB2+25	RC	RC
WEDDING ROCKS	27-Sep-89	WR2+8.2	WR2+1.1			WR2+50	WR2+25	CM	CM
OCEAN SHORES	28-Sep-89	OS2+8.2	OS2+1.1	OS2-1.7	OS2-3.0	OS2+50	OS2+25	CM	CM
SAND ISLAND	28-Sep-89	SI2+8.2	SI2+7.8						

Beach	Date	Sediment Samples Achieved				Faunal Samples Achieved		Organisms Collected	
		+8.2 ft	+1.1 ft	-1.7 ft	-3.0 ft	+/- 50 m	+/- 25 m	+/- 50 m	+/- 25 m
WEDDING ROCKS	23-Feb-90	WR3+8.2	WR3+1.1	WR3-1.7		WR3+50	WR3+25	CM	CM
HOLE-IN-THE-WALL	27-Feb-90	HW3+8.2	HW3+1.1			HW3+50	HW3+25	CM	CM
NORWEGIAN MEMORIAL NORTH	28-Feb-90	NMN3+8.2	NMN3+1.1	NMN3-1.7	NMN-3.0	NMN3+50	NMN3+25	L,C,S	CM
NORWEGIAN MEMORIAL SOUTH	28-Feb-90	NMS3+8.2	NMS3+1.1			NMS3+50	NMS3+25	L,S	L,S
CEDAR CREEK	01-Mar-90	CC3+8.2	CC3+1.1	CC3-1.7		CC3+50	CC3+25	CM	CM
KAYOSTLA BEACH NORTH	01-Mar-90	KBN3+8.2	KBN3+1.1	KBN3-1.7		KBN+50	KBN+25	L,C,S	S
SECOND BEACH	02-Mar-90	2B3+8.2	2B3+1.1	2B3-1.7	2B3-3.0	2B3+50	2B3+25	CM	P
RUBY BEACH	05-Mar-90	RB3+8.2	RB3+1.1	RB3-1.7	RB3-3.0	RB3+50		CM	
POINT GRENVILLE	06-Mar-90	PG3+8.2	PG3+1.1	PG3-1.7		PG3+50		CM	
WHALE CREEK	07-Mar-90	WC3+8.2	WC3+1.1	WC3-1.7	WC3-3.0				
OCEAN SHORES	15-Mar-90	OS3+8.2	OS3+1.1	OS3-1.7	OS3-3.0	OS3+50		CM	
SAND ISLAND	28-Mar-90	SI3+8.2							

Beach	Date	Extra Sediments and Cores		Extra Faunal Samples		Organisms Collected	
				+/- 50 m	+/- 25 m	+/- 50 m	+/- 25 m
SECOND BEACH	18-Jul-89	C2B-1.7					
KAYOSTLA BEACH NORTH	20-Jul-89	CKBN+4.0	KBN>100				
WHALE CREEK	31-Jul-89	CWC-3.0					
OSEAN SHORES	02-Aug-89	COS+8.2					
NORWEGIAN MEMORIAL NORTH	12-Sep-89	CNMN2+1.1					
KAYOSTALA BEACH NORTH	13-Sep-89	CKBN2-1.7					
WHALE CREEK	15-Sep-89	CWC2-1.7	WC2+9.2				
OCEAN SHORES	28-Sep-89	COS2+11					
SAND ISLAND	28-Sep-89	SI2+15.2	SI2+13.3				
HOLE-IN-THE-WALL	27-Feb-90	HW3+15					
NORWEGIAN MEMORIAL	28-Feb-90	HNMX+8.2	HNMX+1.1		HNMX+25		CM
KAYOSTLA BEACH NORTH	01-Mar-90	KBN3+15					
RUBY BEACH	05-Mar-90	RB3+14		RB3+50-2		CM	
OCEAN SHORES	15-Mar-90			OS3+50-2		CM	
SAND ISLAND	28-Mar-90	SI3+15.2	SI3+13.3				
GOOSE ISLAND	28-Mar-90	GI-1	GI-2				

KEY

RC = RAZOR CLAMS
L = SHIELD LIMPETS
CM = CALIFORNIA MUSSELS
AC = ASSORTED CRUSTACIANS
P = POLYCHEATES
DC = DUNGENESS CRABS
RM = RAY MUSSELS
C = CHITONS
S = SNAILS
MS = MUD SHRIMP
H = HOPPERS

APPENDIX A2

SEDIMENT SAMPLE COMPOSITING

(See Appendix A1 for Sample Locations)

Survey 1

Composite ID	Samples Composited			
NOP+8.2	RB+8.2	HW+8.2	CC+8.2	NMS+8.2
NOP+1.1	RB+1.1	HW+1.1	CC+1.1	NMS+1.1
NOP-1.7	RB-1.7	HW-1.7	CC-1.7	NMS-1.7
NOP-3.0		HW-3.0	CC-3.0	NMS-3.0
RB	RB+8.2	RB+1.1	RB-1.7	
HW	HW+8.2	HW+1.1	HW-1.7	HW-3.0
CC	CC+8.2	CC+1.1	CC-1.7	CC-3.0
NMS	NMS+8.2	NMS+1.1	NMS-1.7	NMS-3.0
OP+8.2	2B+8.2	KBN+8.2	NMN+8.2	WR+8.2
OP+1.1	2B+1.1	KBN+1.1	NMN+1.1	WR+1.1
OP-1.7	2B-1.7	KBN-1.7	NMN-1.7	WR-1.7
OP-3.0	2B-3.0	KBN-3.0	NMN-3.0	
2B	2B+8.2	2B+1.1	2B-1.7	2B-3.0
KBN	KBN+8.2	KBN+1.1	KBN-1.7	KBN-3.0
NMN	NMN+8.2	NMN+1.1	NMN-1.7	NMN-3.0
WR	WR+8.2	WR+1.1	WR-1.7	
ONP+8.2		OS+8.2	PG+8.2	WC+8.2
ONP+1.1		OS+1.1	PG+1.1	WC+1.1
ONP-1.7		OS-1.7	PG-1.7	WC-1.7
ONP-3.0		OS-3.0	PG-3.0	WC-3.0
OS	OS+8.2	OS+1.1	OS-1.7	OS-3.0
PG	PG+8.2	PG+1.1	PG-1.7	PG-3.0
WC	WC+8.2	WC+1.1	WC-1.7	WC-3.0

Survey 2

Composite ID	Samples Composited			
NOP2+8.2	RB2+8.2	HW2+8.2	CC2+8.2	NMS2+8.2
NOP2+1.1	RB2+1.1	HW2+1.1	CC2+1.1	NMS2+1.1
NOP2-1.7	RB2-1.7	HW2-1.7		NMS2-1.7
NOP2-3.0	RB2-3.0			
RB2	RB2+8.2	RB2+1.1	RB2-1.7	RB2-3.0
HW2	HW2+8.2	HW2+1.1	HW2-1.7	
CC2	CC2+8.2	CC2+1.1		
NMS2	NMS2+8.2	NMS2+1.1	NMS2-1.7	
OP2+8.2	2B2+8.2	KBN2+8.2	NMN2+8.2	WR2+8.2
OP2+1.1	2B2+1.1	KBN2+1.1	NMN2+1.1	WR2+1.1
OP2-1.7	2B2-1.7	KBN2-1.7	NMN2-1.7	
OP2-3.0	2B2-3.0			

Composite ID	Samples Composited			
2B2	2B2+8.2	2B2+1.1	2B2-1.7	2B2-3.0
KBN2	KBN2+8.2	KBN2+1.1	KBN2-1.7	
NMN2	NMN2+8.2	NMN2+1.1	NMN2-1.7	
WR2	WR2+8.2	WR2+1.1		
ONP2+8.2	SI2+8.2	OS2+8.2	PG2+8.2	WC2+8.2
ONP2+1.1		OS2+1.1	PG2+1.1	WC2+1.1
ONP2-1.7		OS2-1.7	PG2-1.7	WC2-1.7
ONP2-3.0		OS2-3.0	PG2-3.0	WC2-3.0
SI2	SI2+8.2	SI2+7.8		
OS2	OS2+8.2	OS2+1.1	OS2-1.7	OS2-3.0
PG2	PG2+8.2	PG2+1.1	PG2-1.7	PG2-3.0
WC2	WC2+8.2	WC2+1.1	WC2-1.7	WC2-3.0

Survey 3

Composite ID	Samples Composited			
NOP3+8.2	RB3+8.2	HW3+8.2	CC3+8.2	NMS3+8.2
NOP3+1.1	RB3+1.1	HW3+1.1	CC3+1.1	NMS3+1.1
NOP3-1.7	RB3-1.7		CC3-1.7	
NOP3-3.0	RB3-3.0			
RB3	RB3+8.2	RB3+1.1	RB3-1.7	RB3-3.0
HW3	HW3+8.2	HW3+1.1		
CC3	CC3+8.2	CC3+1.1	CC3-1.7	
NMS3	NMS3+8.2	NMS3+1.1		
OP3+8.2	2B3+8.2	KBN3+8.2	NMN3+8.2	WR3+8.2
OP3+1.1	2B3+1.1	KBN3+1.1	NMN3+1.1	WR3+1.1
OP3-1.7	2B3-1.7	KBN3-1.7	NMN3-1.7	WR3-1.7
OP3-3.0	2B3-3.0		NMN3-3.0	
2B3	2B3+8.2	2B3+1.1	2B3-1.7	2B3-3.0
KBN3	KBN3+8.2	KBN3+1.1	KBN3-1.7	
NMN3	NMN3+8.2	NMN3+1.1	NMN3-1.7	NMN3-3.0
WR3	WR3+8.2	WR3+1.1	WR3-1.7	
ONP3+8.2	SI3+8.2		PG3+8.2	
ONP3+1.1			PG3+1.1	
ONP2-1.7			PG3-1.7	
SI3	SI3+8.2			
PG3	PG3+8.2	PG3+1.1	PG3-1.7	

APPENDIX B

INFRARED SPECTROPHOTOMETRIC OIL AND GREASE DETERMINATIONS IN SEDIMENT

(See Appendix A1 for Sample Locations and A2 for Composite Identification)

Station	Oil & Grease (µg/g Dry Weight) Survey 1	Survey 2	Survey 2 Rerun	Survey 3	Survey 3 Rerun
WR	< 15	< 12		63	
2B	< 15	< 12		< 45	
NMN	< 15	< 12		72	
KBN	< 15	< 12		154	
OP+8.2	< 15	50	< 22	< 43	
OP+1.1	< 15	61	< 22	< 44	
OP-1.7	< 15		< 22	< 41	
OP-3	< 15	80	< 22	251	
HW	< 15	< 12		< 38	
NMS	< 15	< 12		< 40	
CC	< 15	< 12		< 45	
RB	< 15	< 12		< 42	
NOP+8.2	< 15	< 12		< 36	
NOP+1.1	< 15	< 12		< 45	
NOP-1.7	< 15	< 12		557	< 30
NOP-3	< 15	< 12		108	< 30
WC	< 50	121	< 22	< 40	
PG	< 50	92	< 22	< 45	
OS	< 50	97	< 22	< 42	
SI		34	< 22	< 43	
ONP+8.2	< 50	56	< 22	< 39	
ONP+1.1	< 50	< 30		< 43	
ONP-1.7	< 50	< 30		< 45	
ONP-3	< 50	< 30		< 44	
WR-BLK	< 25				
HW-BLK	< 50	< 25			
NMN-BLK	< 50			< 41	
KBN-BLK		< 25			
2B-BLK	< 50			< 41	
NMS-BLK		< 25			
CC-BLK	< 50				
RB-BLK	< 50			< 41	
WC-BLK	< 50	< 25			
PG-BLK	< 50				
OS-BLK	< 50				

Station	Oil & Grease (ug/g Dry Weight) Survey 1	Survey 2	Survey 2 Rerun	Survey 3	Survey 3 Rerun
BLANK 3/28				< 41	
BLANK 4/3				< 41	
COMPOSITE BLANK				< 41	
% RECOVERY	91%	55%		96%	
	51%	60%		95%	
		97%			
		75%			
DET. LIMIT	15	25			
	50	30			
		12			
		22			
Cores/Extra Sediments					
HNMX+8.2				115	
HNMX+1.1				73	
KBN+4.0	< 25				
KBN>100	< 50				
KBN+15				< 41	
WR+9.2		78	< 22		
2B-1.7	< 25				
HW+15				119	170
RB+14				82	86
OS+8.2	< 25				
OS+11		26	< 22		
WC-3.0	< 25				
WC+14				< 41	
SI+15.2		6255		< 38	
SI+13.3		19015		< 36	
GI-1				< 36	
GI-2				< 38	

APPENDIX C1

GAS CHROMATOGRAPHIC/MS ANALYSES OF TISSUES AND SEDIMENTS

(See Appendix A1 for Sample Locations and Appendix A2 for Composite Identification)

GLOSSARY

DATA BASE QUALIFIERS	MEANING
$	Flag used if secondary ion, rather than primary ion, is used for quantitation of an analyte (mass spectrometry methods, only). Qualifies analyte data.
H	Flag used to indicate that surrogate recoveries could not be measured because the sample was diluted for instrumental analysis. Qualifies surrogate data only.
%	Flag used when relative intensities of the primary/confirmation ion vary by greater than ± 20% of these masses in the reference mass spectrum due to interferences to the confirmation ion. Qualifies analyte data.
ND	Not detected. This qualifier will be used when analytes are not detected in samples. The data base will automatically cross-reference the proper method detection limits (MDL) for data base users. Qualifies analyte data.
J	Indicates an estimated value. This flag is used either when estimating a concentration for tentatively identified compounds where a 1:1 response is assumed (i.e., alkylated PAH compounds) or when the data indicate the presence of a compound that meets the identification criteria but the result is less than the method detection limit but greater than zero. Qualifies analyte data.
B	Value reported, but integrity possibly compromised by contamination. This value will be inserted by the lab if unacceptable levels of the target analyte(s) is observed in the quality control samples above the detection limit or for other reasons that the lab justifies and documents. Qualifies analyte data.
G	Value not reported because of matrix interference. This qualifier will be used if a non-analyte interferes with the measurement or identification of a target analyte. Qualifies analyte, surrogate data.

DATA BASE QUALIFIERS	MEANING
NA	Not applicable. This qualifier is used by the laboratory if, for a specific project, selected analytes have not been measured at the direction of the Study Director. General.
&	Surrogate recovery is outside control limits. Qualifies surrogate data.

COMPOUND LIST(a)	MEANING
NAPH	Napthalene
NAPHQ	
ACENAPL	Acenaphthylene
ACENAPLQ	
ACENAPH	Acenaphthene
ACENAPHQ	
FLUOREN	Fluorene
FLUORENQ	
PHENAN	Phenanthrene
PHENANQ	
ANTHRAC	Anthracene
ANTHRACQ	
DIBENZ	Dibenzothiophene
DIBENZQ	
FLUORAN	Fluoranthene
FLUORANQ	
PYRENE	Pyrene
PYRENEQ	
BENaAN	Benzo(a)anthracene
BENaANQ	
CHRYSEN	Chrysene
CHRYSENQ	
BENbFLU	Benzo(b)fluoranthene
BENbFLUQ	
BENkFLU	Benzo(k)fluoranthene
BENkFLUQ	
BENaPYR	Benzo(a)pyrene
BENaPYRQ	
I123cdP	Indeno(1,2,3-c,d)pyrene
I123cdPQ	
DBahANT	Dibenz(a,h)anthracene
DBahANTQ	

(a) Measured in units dry weight.

(contd)

COMPOUND LIST	MEANING
BghiPER	Benzo(g,h,i)perylene
BghiPERQ	
D8NAPH%	d8-Naphthalene (Surrogate recovery rate)
D10ACEN%	d10-Acenaphtene (Surrogate recovery rate)
D12PERL%	d12-Perylene

Tissue Samples

SAMPID	UNIT	NAPH	NAPHQ	ACENAPL	ACENAPLQ	ACENAPH	ACENAPHQ	FLUOREN	FLUORENQ
TNMN+50	ng/g	5.3	%,B		ND		ND		ND
TNMN+25	ng/g	9.0	B		ND		ND		ND
NMN2+50	ng/g	4.5	B		ND		ND	3.5	
NMN2+25	ng/g	6.7	B		ND	2.1		3.3	
NMN3+50	ng/g		ND		ND		ND		ND
NMN3+25	ng/g		ND		ND		ND		ND
NMNH3	ng/g		ND		ND		ND		ND
TKBN+50	ng/g	9.0	%,&,B		ND		ND		ND
TKBN+25	ng/g	12	%,&,B		ND		ND		ND
KBN2+50	ng/g	11	B		ND		ND	1.4	%
KBN2+25	ng/g	3.8	B		ND		ND		ND
KBN3+50	ng/g		ND		ND		ND		ND
KBN3+25	ng/g		ND		ND		ND		ND
T2B+50	ng/g	6.7	%,&,B		ND		ND		ND
T2B+25	ng/g	5.7	%,B		ND		ND		ND
T2B+25 SP	ng/g	211		288		302		346	
RECOVERY (%)		34		48		51		58	
T2B+25D	ng/g		ND		ND		ND		ND
T2B2+50	ng/g		ND		ND		ND		ND
T2B3+50	ng/g		ND		ND		ND		ND
T2B3+25	ng/g		ND		ND		ND		ND
TWR+50	ng/g	6.2	%		ND		ND		ND
TWR+25	ng/g	7.0	%,B		ND		ND		ND
TWR2+50	ng/g	5.0	B		ND		ND		ND
TWR2+25	ng/g	4.7	B		ND		ND	1.5	
TWR3+50	ng/g		ND		ND		ND		ND
TWR3+25	ng/g		ND		ND		ND		ND
THW+50	ng/g	9.3	%,B		ND		ND		ND
THW+25	ng/g	7.3	%,B		ND	2.6	%		ND
THW+25 SP	ng/g	265		316		360		411	
RECOVERY (%)		46		57		64		74	
THW2+50	ng/g	5.9	%,B		ND		ND		ND
THW2+25	ng/g		ND		ND	2.4	&		ND
THW3+50	ng/g		ND		ND		ND		ND
THW3+25	ng/g		ND		ND		ND		ND
TNMS+50	ng/g	5.7	B		ND		ND	2.6	
TNMS+25	ng/g	7.9	B		ND	2.3	%	1.9	
NMS2+50	ng/g		ND		ND	5.8		2.8	
NMS2+25	ng/g		ND		ND	6.3	%	3.5	%
NMS3+50	ng/g		ND		ND		ND		ND
NMS3+25	ng/g		ND		ND		ND		ND

SAMPID	UNIT	PHENAN	PHENANQ	ANTHRAC	ANTHRACQ	DIBENZ	DIBENZQ	FLUORAN	FLUORANQ
TNMN-50	ng/g	13	%		ND		ND		ND
TNMN-25	ng/g	21	%	5.1	%	2.7	%		ND
NMN2-50	ng/g	19			ND	1.3	%	5.3	J
NMN2-25	ng/g	15			ND	1.4	%		ND
NMN3-50	ng/g	21			ND		ND		ND
NMN3-25	ng/g	41	%		ND		ND	11	%
NMNH3	ng/g	15	%		ND		ND		ND
TKBN-50	ng/g		ND		ND		ND		ND
TKBN-25	ng/g	10	%,&		ND		ND		ND
KBN2-50	ng/g	11			ND		ND		ND
KBN2-25	ng/g	6.9	%		ND		ND		ND
KBN3-50	ng/g	13			ND		ND		ND
KBN3-25	ng/g		ND		ND		ND		ND
T2B-50	ng/g		ND		ND		ND		ND
T2B-25	ng/g		ND		ND		ND		ND
T2B-25 SP	ng/g	368		403		5.7	%	471	
RECOVERY (%)		62		68		NOT SPIKED		79	
T2B-25D	ng/g	7.2	&		ND		ND		ND
T2B2-50	ng/g		ND		ND		ND		ND
T2B3-50	ng/g	18			ND		ND		ND
T2B3-25	ng/g	8.3	%		ND		ND	5.8	%
TWR-50	ng/g	13	%		ND		ND		ND
TWR-25	ng/g	13	%		ND		ND		ND
TWR2-50	ng/g		ND		ND		ND		ND
TWR2-25	ng/g	9.7	%		ND		ND		ND
TWR3-50	ng/g	15			ND		ND		ND
TWR3-25	ng/g	29	%		ND		ND		ND
THW-50	ng/g	14	%		ND	1.4	%		ND
THW-25	ng/g	5.5	J		ND		ND		ND
THW-25 SP	ng/g	460		487		9.1		588	
RECOVERY (%)		82		88		NOT SPIKED		106	
THW2-50	ng/g		ND		ND		ND		ND
THW2-25	ng/g	6.0	J,&		ND		ND		ND
THW3-50	ng/g	20	%		ND		ND		ND
THW3-25	ng/g	20	%		ND		ND		ND
TNMS-50	ng/g	8.1	J		ND	1.4	%		ND
TNMS-25	ng/g	8.5	J		ND		ND		ND
NMS2-50	ng/g	13		2.9	%	1.3	%		ND
NMS2-25	ng/g	15		2.8	%	1.3	%		ND
NMS3-50	ng/g	6.3	%		ND		ND		ND
NMS3-25	ng/g	7.0	%		ND		ND		ND

SAMPID	UNIT	PYRENE	PYRENEQ	BENaAN	BENaANQ	CHRYSEN	CHRYSENQ	BENbFLU	BENbFLUQ
TNMN-50	ng/g		ND	11		6.3	%		ND
TNMN-25	ng/g	3.5	%	15		8.4	%	5.8	%
NMN2-50	ng/g	3.6		3.7	%	5.4	%		ND
NMN2-25	ng/g	3.0	%	3.0	%	5.4	%		ND
NMN3-50	ng/g	3.8	%		ND		ND		ND
NMN3-25	ng/g		ND	23		15	%		ND
NMNH3	ng/g		ND	9.3	%		ND		ND
TKBN-50	ng/g		ND	4.7	%,&		ND		ND
TKBN-25	ng/g		ND	5.6	%,&		ND		ND
KBN2-50	ng/g		ND		ND		ND		ND
KBN2-25	ng/g		ND		ND		ND		ND
KBN3-50	ng/g		ND		ND		ND		ND
KBN3-25	ng/g		ND		ND		ND		ND
T2B-50	ng/g		ND		ND	4.7	&		ND
T2B-25	ng/g	3.0	%		ND		ND		ND
T2B-25 SP	ng/g	458		523		485		491	
RECOVERY (%)		76		88		82		83	
T2B-25D	ng/g	3.8	%,&		ND	3.8	&	3.7	%,&
T2B2-50	ng/g		ND		ND		ND		ND
T2B3-50	ng/g		ND		ND		ND		ND
T2B3-25	ng/g	5.2	%	6.6	%	11	%	4.0	%
TWR-50	ng/g		ND	6.5		4.2	%		ND
TWR-25	ng/g		ND	7.5		4.3			ND
TWR2-50	ng/g	1.9	J	3.7			ND	5.1	%
TWR2-25	ng/g		ND	6.1			ND	5.6	%
TWR3-50	ng/g		ND		ND		ND		ND
TWR3-25	ng/g		ND		ND		ND		ND
THW-50	ng/g		ND	5.0	%	3.0	J		ND
THW-25	ng/g		ND		ND		ND		ND
THW-25 SP	ng/g	573		657		614		676	
RECOVERY (%)		103		118		110		122	
THW2-50	ng/g		ND		ND	3.9	%		ND
THW2-25	ng/g		ND		ND		ND		ND
THW3-50	ng/g		ND		ND		ND		ND
THW3-25	ng/g		ND		ND		ND		ND
TNMS-50	ng/g	1.7	J		ND		ND		ND
TNMS-25	ng/g		ND		ND	2.7	J		ND
NMS2-50	ng/g		ND		ND		ND		ND
NMS2-25	ng/g	2.9	%	2.9	%	4.0	%		ND
NMS3-50	ng/g		ND		ND		ND		ND
NMS3-25	ng/g		ND		ND		ND		ND

SAMPID	UNIT	BENkFLU	BENkFLUQ	BENaPYR	BENaPYRQ	I123cdP	I123cdPQ	DBahANT	DBahANTQ
TNWN+50	ng/g		ND		ND		ND		ND
TNWN+25	ng/g		ND	5.6	%		ND		ND
NWN2+50	ng/g		ND		ND		ND		ND
NWN2+25	ng/g		ND	3.9	%		ND		ND
NWN3+50	ng/g		ND		ND		ND		ND
NWN3+25	ng/g		ND		ND		ND		ND
NWNH3	ng/g		ND		ND		ND		ND
TKBN+50	ng/g		ND		ND		ND		ND
TKBN+25	ng/g		ND		ND		ND		ND
KBN2+50	ng/g		ND		ND		ND		ND
KBN2+25	ng/g		ND		ND		ND		ND
KBN3+50	ng/g		ND		ND		ND		ND
KBN3+25	ng/g		ND		ND		ND		ND
T2B+50	ng/g		ND		ND		ND		ND
T2B+25	ng/g		ND	6.4	%		ND		ND
T2B+25 SP	ng/g	452		462		387		384	
RECOVERY (%)		76		77		65		65	
T2B+25D	ng/g		ND	4.5	%,&	17	%,&		ND
T2B2+50	ng/g		ND		ND		ND		ND
T2B3+50	ng/g		ND		ND		ND		ND
T2B3+25	ng/g	3.3	%		ND		ND		ND
TWR+50	ng/g		ND		ND	3.3	J		ND
TWR+25	ng/g		ND		ND		ND		ND
TWR2+50	ng/g		ND	8.6	%		ND		ND
TWR2+25	ng/g		ND	8.5	%	30	%	5.1	%
TWR3+50	ng/g		ND		ND		ND		ND
TWR3+25	ng/g		ND		ND		ND		ND
THW+50	ng/g		ND		ND		ND		ND
THW+25	ng/g		ND		ND		ND		ND
THW+25 SP	ng/g	643		646		635		661	
RECOVERY (%)		116		116		114		119	
THW2+50	ng/g		ND		ND		ND		ND
THW2+25	ng/g		ND		ND		ND		ND
THW3+50	ng/g		ND		ND		ND		ND
THW3+25	ng/g		ND		ND		ND		ND
TNWS+50	ng/g		ND		ND		ND		ND
TNWS+25	ng/g		ND		ND		ND		ND
NWS2+50	ng/g		ND	3.5	%		ND		ND
NWS2+25	ng/g		ND		ND		ND		ND
NWS3+50	ng/g		ND		ND		ND		ND
NWS3+25	ng/g		ND		ND		ND		ND

SAMPID	UNIT	BghiPER	BghiPERQ	D8NAPH%	D10ACEN%	D12PERL%	TOTAL PAHs
TNMN-50	ng/g	8	%	29	43	126	44
TNMN-25	ng/g	19	%	34	49	114	95
NMN2-50	ng/g		ND	30	56	89	46
NMN2-25	ng/g		ND	33	62	108	44
NMN3-50	ng/g		ND	13	40	61	25
NMN3-25	ng/g		ND	26	43	62	90
NMNH3	ng/g		ND	8	35	98	24
TKBN-50	ng/g	8.8	%,&	40	54	164	22
TKBN-25	ng/g	5.5	%,&	44	57	162	33
KBN2-50	ng/g		ND	43	75	130	23
KBN2-25	ng/g		ND	30	50	85	11
KBN3-50	ng/g	7.4	%	18	44	86	20
KBN3-25	ng/g		ND	0	13	91	0
T2B-50	ng/g	3.7	%,&	28	43	148	15
T2B-25	ng/g		ND	21	35	136	15
T2B-25 SP	ng/g	341		47	70	97	6378
RECOVERY (%)		57		AMOUNT SPIKED 595 ng/g			
T2B-25D	ng/g	43	&	18	51	156	83
T2B2-50	ng/g		ND	20	49	140	0
T2B3-50	ng/g		ND	25	43	81	18
T2B3-25	ng/g		ND	17	39	52	44
TWR-50	ng/g	7.7	%	24	36	75	41
TWR-25	ng/g	11	%	32	49	111	43
TWR2-50	ng/g	13	%	36	60	111	37
TWR2-25	ng/g	29	%	20	41	106	100
TWR3-50	ng/g		ND	15	32	82	15
TWR3-25	ng/g		ND	6	37	74	29
THW-50	ng/g		ND	32	68	97	33
THW-25	ng/g		ND	21	59	74	15
THW-25 SP	ng/g	579		42	63	105	8580
RECOVERY (%)		104		AMOUNT SPIKED 556 ng/g			
THW2-50	ng/g		ND	20	53	109	10
THW2-25	ng/g		ND	9	31	104	8
THW3-50	ng/g		ND	24	40	75	20
THW3-25	ng/g		ND	23	41	65	20
TNMS-50	ng/g		ND	36	71	94	20
TNMS-25	ng/g	8.2	%	52	73	105	32
NMS2-50	ng/g	3.1	%	20	67	105	32
NMS2-25	ng/g	3.5	%	19	66	109	42
NMS3-50	ng/g		ND	18	41	48	6
NMS3-25	ng/g		ND	16	45	64	7

SAMPID	UNIT	NAPH	NAPHQ	ACENAPL	ACENAPLQ	ACENAPH	ACENAPHQ	FLUOREN	FLUORENQ
TRB+50	ng/g	5.8	%,B		ND		ND		ND
TRB+25	ng/g		ND		ND		ND		ND
TRB2+50	ng/g		ND,&		ND,&		ND,&		ND,&
TRB2+25	ng/g		ND		ND		ND		ND
TRB3+50-1	ng/g		ND		ND		ND		ND
TRB3+50-2	ng/g		ND		ND		ND		ND
TCC+50	ng/g	10	%,B		ND		ND		ND
TCC+25R	ng/g		ND,&		ND,&		ND,&		ND,&
TCC2+50	ng/g		ND,&		ND,&		ND,&		ND,&
TCC2+25	ng/g		ND,&		ND,&		ND,&		ND,&
TCC3+50	ng/g		ND		ND		ND		ND
TCC3+25	ng/g		ND		ND		ND		ND
TWC+50	ng/g	7.1	B		ND		ND		ND
TWC+25	ng/g	8.6	B		ND		ND		ND
TPG+50	ng/g	4.4	%,B		ND		ND		ND
TPG+25	ng/g		ND		ND		ND		ND
TPG2+50	ng/g	4.7	%,B		ND		ND	1.3	
TPG2+25	ng/g	5.6	B		ND		ND		ND
TPG3+50	ng/g		ND		ND		ND		ND
TOS+50	ng/g		ND		ND		ND		ND
TOS+25	ng/g		ND		ND		ND		ND
TOS+25D	ng/g		ND		ND		ND		ND
TOS2+501	ng/g	5.6	B		ND		ND		ND
TOS2+502	ng/g		ND		ND		ND		ND
TOS3+50	ng/g		ND		ND		ND		ND
BLANK R5	ng/g	11	%,&		ND		ND		ND
BLANK 1	ng/g		ND		ND		ND		ND
BLANK 2	ng/g		ND		ND		ND		ND
BLANK 5	ng/g	11	%		ND		ND		ND
BARGE OIL	ug/g	172		< 26		107		250	

SAMPID	UNIT	PHENAN	PHENANQ	ANTHRAC	ANTHRACQ	DIBENZ	DIBENZQ	FLUORAN	FLUORANQ
TRB-50	ng/g		ND		ND		ND		ND
TRB-25	ng/g		ND		ND		ND		ND
TRB2-50	ng/g	4.5	J,&		ND,&		ND,&		ND,&
TRB2-25	ng/g		ND		ND		ND		ND
TRB3-50-1	ng/g	10	%		ND		ND		ND
TRB3-50-2	ng/g		ND		ND		ND		ND
TCC-50	ng/g	11	%		ND		ND		ND
TCC-25R	ng/g		ND,&		ND,&		ND,&		ND,&
TCC2-50	ng/g		ND,&		ND,&		ND,&		ND,&
TCC2-25	ng/g		ND,&		ND,&		ND,&		ND,&
TCC3-50	ng/g		ND		ND		ND		ND
TCC3-25	ng/g	19	%		ND		ND		ND
TWC-50	ng/g		ND		ND		ND		ND
TWC-25	ng/g		ND		ND		ND		ND
TPG-50	ng/g		ND		ND		ND		ND
TPG-25	ng/g		ND		ND		ND		ND
TPG2-50	ng/g	4	J		ND		ND		ND
TPG2-25	ng/g	5.7	J		ND		ND		ND
TPG3-50	ng/g	11			ND		ND	4.1	%
TOS-50	ng/g		ND		ND		ND		ND
TOS-25	ng/g		ND		ND		ND		ND
TOS-25D	ng/g		ND		ND		ND		ND
TOS2-501	ng/g		ND	2.5	%		ND		ND
TOS2-502	ng/g		ND		ND		ND		ND
TOS3-50	ng/g	9.3			ND		ND		ND
BLANK R5	ng/g		ND		ND		ND		ND
BLANK 1	ng/g		ND		ND		ND		ND
BLANK 2	ng/g		ND		ND		ND		ND
BLANK 5	ng/g		ND		ND		ND		ND
BARGE OIL	ug/g	1247		98		462		57	

SAMPID	UNIT	PYRENE	PYRENEQ	BENaAN	BENaANQ	CHRYSEN	CHRYSENQ	BENbFLU	BENbFLUQ
TRB+50	ng/g		ND		ND		ND		ND
TRB+25	ng/g		ND		ND		ND		ND
TRB2+50	ng/g	2.9	&	1.7	J,&	3.0	&		ND,&
TRB2+25	ng/g		ND		ND		ND		ND
TRB3+50-1	ng/g		ND		ND		ND		ND
TRB3+50-2	ng/g		ND		ND		ND		ND
TCC+50	ng/g		ND	2.6	%	2.1	J		ND
TCC+25R	ng/g		ND,&		ND,&		ND,&		ND,&
TCC2+50	ng/g		ND,&		ND,&		ND,&		ND,&
TCC2+25	ng/g		ND,&		ND,&		ND,&		ND,&
TCC3+50	ng/g		ND		ND		ND		ND
TCC3+25	ng/g		ND		ND		ND		ND
TWC+50	ng/g		ND		ND		ND		ND
TWC+25	ng/g		ND		ND		ND		ND
TPG+50	ng/g		ND		ND		ND		ND
TPG+25	ng/g		ND		ND		ND		ND
TPG2+50	ng/g		ND		ND	2.6	J	4.5	%
TPG2+25	ng/g	3.0			ND		ND	4.0	%
TPG3+50	ng/g	2.8	%		ND		ND		ND
TOS+50	ng/g		ND		ND		ND		ND
TOS+25	ng/g		ND		ND		ND		ND
TOS+25D	ng/g		ND		ND		ND		ND
TOS2+501	ng/g		ND		ND	1.7	J		ND
TOS2+502	ng/g		ND		ND		ND		ND
TOS3+50	ng/g		ND		ND		ND		ND
BLANK R5	ng/g		ND		ND		ND		ND
BLANK 1	ng/g		ND		ND		ND		ND
BLANK 2	ng/g		ND		ND		ND		ND
BLANK 5	ng/g		ND		ND		ND		ND
BARGE OIL	ug/g	322		77		193		31	

SAMPID	UNIT	BENkFLU	BENkFLUQ	BENaPYR	BENaPYRQ	I123cdP	I123cdPQ	DBahANT	DBahANTQ
TRB+50	ng/g		ND		ND	12			ND
TRB+25	ng/g		ND		ND	5.6			ND
TRB2+50	ng/g		ND,&		ND,&		ND,&		ND,&
TRB2+25	ng/g		ND		ND		ND		ND
TRB3+50-1	ng/g		ND		ND		ND		ND
TRB3+50-2	ng/g		ND		ND		ND		ND
TCC+50	ng/g		ND		ND		ND		ND
TCC+25R	ng/g		ND,&		ND,&		ND,&		ND,&
TCC2+50	ng/g		ND,&		ND,&		ND,&		ND,&
TCC2+25	ng/g		ND,&		ND,&		ND,&		ND,&
TCC3+50	ng/g		ND		ND		ND		ND
TCC3+25	ng/g		ND		ND		ND		ND
TWC+50	ng/g		ND		ND		ND		ND
TWC+25	ng/g		ND		ND		ND		ND
TPG+50	ng/g		ND		ND		ND		ND
TPG+25	ng/g		ND		ND		ND		ND
TPG2+50	ng/g		ND		ND		ND		ND
TPG2+25	ng/g		ND		ND		ND		ND
TPG3+50	ng/g		ND		ND		ND		ND
TOS+50	ng/g		ND		ND		ND		ND
TOS+25	ng/g		ND		ND		ND		ND
TOS+25D	ng/g		ND		ND		ND		ND
TOS2+501	ng/g		ND		ND	2.4	J		ND
TOS2+502	ng/g		ND		ND		ND		ND
TOS3+50	ng/g		ND		ND		ND		ND
BLANK R5	ng/g		ND		ND		ND		ND
BLANK 1	ng/g		ND		ND		ND		ND
BLANK 2	ng/g		ND		ND		ND		ND
BLANK 5	ng/g		ND		ND		ND		ND
BARGE OIL	ug/g	< 7		77		< 7.4		10	

SAMPID	UNIT	BghiPER	BghiPERQ	D8NAPH%	D10ACEN%	D12PERL%	TOTAL PAHs
TRB-50	ng/g		ND	25	41	95	18
TRB-25	ng/g		ND	23	38	65	5.6
TRB2-50	ng/g		ND,&	11	40	40	12
TRB2-25	ng/g		ND	16	44	130	0.0
TRB3-50-1	ng/g		ND	23	43	83	10
TRB3-50-2	ng/g		ND	23	36	61	0.0
TCC-50	ng/g		ND	34	47	107	26
TCC-25R	ng/g	7.5	&	10	26	78	7.5
TCC2-50	ng/g		ND,&	10	37	64	0.0
TCC2-25	ng/g		ND,&	7	27	43	0.0
TCC3-50	ng/g		ND	5	41	118	0.0
TCC3-25	ng/g		ND	26	43	81	19
TWC-50	ng/g		ND	55	78	97	7.1
TWC-25	ng/g	2.6	J	38	85	118	11
TPG-50	ng/g		ND	28	52	131	4.4
TPG-25	ng/g		ND	34	65	67	0.0
TPG2-50	ng/g		ND	28	45	88	17
TPG2-25	ng/g	2.6	J	54	67	122	21
TPG3-50	ng/g		ND	6	20	52	18
TOS-50	ng/g		ND	34	81	100	0.0
TOS-25	ng/g		ND	28	55	122	0.0
TOS-25D	ng/g		ND	28	66	147	0.0
TOS2-501	ng/g		ND	34	60	93	12
TOS2-502	ng/g		ND	11	33	58	0.0
TOS3-50	ng/g		ND	13	29	71	9.3
BLANK R5	ng/g		ND	11	17	95	11
BLANK 1	ng/g		ND	24	38	101	0.0
BLANK 2	ng/g		ND	20	36	98	0.0
BLANK 5	ng/g		ND	11	17	95	11
BARGE OIL	ug/g	29		H	H	102	3132

Sediment Samples

SAMPID	UNIT	NAPH	NAPHQ	ACENAPL	ACENAPLQ	ACENAPH	ACENAPHQ	FLUOREN	FLUORENQ
OP3+3.0	ng/g	7.3			ND		ND	4.5	
NMN3	ng/g	3.0			ND		ND	7.5	
3HNMX+1.1	ng/g	9.7		1.1	%	4.3		19	
3HNMX+8.2	ng/g	1.5	%		ND	4.0		24	
3HMNX+8.2 REP1	ng/g	100			ND	13	%	65	
3HMNX+8.2 REP2	ng/g	110			ND	24		85	
KBN3	ng/g	2.4			ND		ND	7.3	
WR2+9.2	ng/g	320			ND		ND	683	
WR3	ng/g	40			ND	2.4		49	
CC3	ng/g	7.6			ND		ND	15	
CC3 SP	ng/g	41		49		48		68	
RECOVERY %		28		41		40		45	
HW3+15	ng/g	2.2	%		ND		ND		ND
RB3+14	ng/g	5.4			ND		ND	5.1	
SI2	ng/g		ND		ND		ND		ND
SI2+15.2	ng/g	< 573		< 584		< 900		3808	
SI2+13.3	ng/g	< 357		< 365		477	J	1517	%
COS2+11	ng/g		ND		ND		ND		ND
COS2+11 SP	ng/g	163		166		167		165	
RECOVERY (%)		96		98		99		98	
SED. BLANK	ng/g		ND		ND		ND		ND
SED. BLANK 2	ng/g	2.8	%		ND		ND		ND
SEDIMENT DET LIMIT		< 9.0		9.1		14		11	

SAMPID	UNIT	PHENAN	PHENANQ	ANTHRAC	ANTHRACQ	DIBENZ	DIBENZQ	FLUORAN	FLUORANQ
OP3+3.0	ng/g	23			ND	1.6	%	3.2	
NWN3	ng/g	29		1.2	%	1.8		5.9	
3HNWX+1.1	ng/g	150		3.0	%	17		32	
3HNWX+8.2	ng/g	340		5.0	%	45		52	
3HWNX+8.2 REP1	ng/g	650		6.6		81		73	
3HWNX+8.2 REP2	ng/g	740		9.2		95		89	
KBN3	ng/g	24			ND	2		4.7	
WR2+9.2	ng/g	1364			ND	67		27	
WR3	ng/g	240		1.4	%	7.6		12	
CC3	ng/g	78			ND			ND	
CC3 SP	ng/g	152		77		5.8		115	
RECOVERY %		64		65		NOT SPIKED		97	
HW3+15	ng/g	18			ND		ND		ND
RB3+14	ng/g		ND		ND		ND	4.9	
SI2	ng/g		ND		ND		ND		ND
SI2+7.35	ng/g	36747		2369		12988		2822	
SI2+5.5	ng/g	10102		781		3818		772	%
COS2+11	ng/g		ND		ND		ND		ND
COS2+11 SP	ng/g	164		168		NOT SPIKED		174	
RECOVERY (%)		97		99		0		103	
SED. BLANK	ng/g		ND		ND		ND		ND
SED. BLANK 2	ng/g	5.6			ND		ND		ND
SEDIMENT									
DET LIMIT		5.9		6.4		6.0		3.6	

SAMPID	UNIT	PYRENE	PYRENEQ	BENaAN	BENaANQ	CHRYSEN	CHRYSENQ	BENbFLU	BENbFLUQ
OP3+3.0	ng/g	5.9		1.0	%	5.0		2.5	%
NWN3	ng/g	7.8		2.7	%	9.9		4.7	
3HNWX+1.1	ng/g	43		13	%	3.0		17	%
3HNWX+8.2	ng/g	48		27		52		25	%
3HNWX+8.2 REP1	ng/g	80		32		73		21	%
3HWNX+8.2 REP2	ng/g	96		43		93		30	%
KBN3	ng/g	7.6		1.7		7.4		3.3	
WR2+9.2	ng/g	58		10		230		76	
WR3	ng/g	24		6.9	%	62		17	%
CC3	ng/g	16			ND	20		6.4	
CC3 SP	ng/g	126		122		132		128	
RECOVERY %		92		103		94		102	
HW3+15	ng/g	18			ND	3.5		1.6	%
RB3+14	ng/g	13			ND	2.8	%		ND
SI2	ng/g		ND		ND		ND		ND
SI2+7.35	ng/g	1624		3880		10787	%	1672	
SI2+5.5	ng/g	4473		1027		2709		455	
COS2+11	ng/g		ND		ND		ND		ND
COS2+11 SP	ng/g	168		202		193		213	
RECOVERY (%)		99		120		114		126	
SED. BLANK	ng/g		ND		ND		ND		ND
SED. BLANK 2	ng/g	4.5	%		ND		ND		ND
SEDIMENT									
DET LIMIT		3.6		3.3		3.3		2.5	

SAMPID	UNIT	BENkFLU	BENkFLUQ	BENaPYR	BENaPYRQ	I123cdP	I123cdPQ	DBahANT	DBahANTQ
OP3+3.0	ng/g		ND	1.0	%	0.8			ND
NWN3	ng/g		ND	2.1	%	1.1		0.7	%
3HNMX+1.1	ng/g		ND	11		5.1		2.8	%
3HNMX+8.2	ng/g		ND	14		3.8		4.3	
3HMNX+8.2 REP1	ng/g	17	%	25		6.6			ND
3HMNX+8.2 REP2	ng/g	21	%	32		23		24	%
KBN3	ng/g		ND	1.0	%	0.5	%	0.5	%
WR2+9.2	ng/g		ND	11		4.9		12	
WR3	ng/g		ND	4.1		1.9		3.3	%
CC3	ng/g	2.6	%	3.3	%		ND		ND
CC3 SP	ng/g	120		128		134		132	
RECOVERY (%)		99		105		113		111	
HW3+15	ng/g	2.0	%	4.9	%	5.0			ND
RB3+14	ng/g	1.7	%	2.7	%		ND		ND
SI2	ng/g		ND		ND		ND		ND
SI2+7.35	ng/g	328	%	3895	%	438		556	%
SI2+5.5	ng/g	< 97		957	%	< 104		139	%
COS2+11	ng/g		ND		ND		ND		ND
COS2+11 SP	ng/g	208		214		223		245	
RECOVERY (%)		123		127		132		145	
SED. BLANK	ng/g		ND		ND		ND		ND
SED. BLANK 2	ng/g		ND		ND		ND		ND
SEDIMENT									
DET LIMIT		2.4		2.9		2.6		3.1	

SAMPID	UNIT	BghiPER	BghiPERQ	D8NAPH%	D10ACEN%	D12PERL%	TOTAL PAHs
OP3+3.0	ng/g	3.3		21	30	77	59
NWN3	ng/g	2.7		20	27	103	80
3HNMX+1.1	ng/g	11		16	29	113	342
3HNMX+8.2	ng/g	9		0	10	91	655
3HMNX+8.2 REP1	ng/g	25		27	53*	98*	1268
3HMNX+8.2 REP2	ng/g	39		32	67*	97*	1553
KBN3	ng/g	1.6		20	26	82	64
WR2+9.2	ng/g	13		84	92	87	2876
WR3	ng/g	6.9		13	21	99	478
CC3	ng/g	9.3		37	51*	98*	164
CC3 SP	ng/g	140		31	46*	92*	1718
RECOVERY (%)		110					
HW3+15	ng/g	25		19	42*	87*	80
RB3+14	ng/g	9.2		18	29*	50*	45
SI2	ng/g		ND	78	84	96	0
SI2+7.35	ng/g	1485		H	98	130	83399
SI2+5.5	ng/g	397		55	89	99	27624
COS2+11	ng/g		ND	86	94	90	0
COS2+11 SP	ng/g	206		88	95	109	3039
RECOVERY (%)		122		AMOUNT SPIKED 169 ng/g			
SED. BLANK	ng/g		ND	91	95	51	0
SED. BLANK 2	ng/g	4.6		36	50*	101*	17
SEDIMENT DET LIMIT		2.3					

* d10Acenapthalene was replaced with d10Fluorene and d12Perylene was replaced with d12Crysene

APPENDIX C2

GAS CHROMATOGRAPHIC/FID ANALYSES OF TISSUES AND SEDIMENTS

(See Appendix A1 for Sample Locations and Appendix A2 for Composite Identification)

COMPOUND LIST(a)	MEANING
n-C9	Value of analyte concentration or spike recovery
n-C9	Qualifier codes, e.g., ND (see glossary for C1)
n-C10	
n-C10Q	
n-C11	
n-C11Q	
n-C12	
n-C12Q	
n-C13	
n-C13Q	
n-C14	
n-C14Q	
n-C15	
n-C15Q	
n-C16	
n-C16Q	
n-C17	
n-C17Q	
PRISTAN	
PRISTANQ	
n-C18	
n-C18Q	
PHYTANE	
PHYTANEQ	
n-C19	
n-C19Q	
n-C20	
n-C20Q	
n-C21	
n-C21Q	
n-C22	
n-C22Q	
n-C23	
n-C23Q	
n-C24	
n-C24Q	
n-C25	
n-C25Q	
n-C26	
n-C26Q	
n-C27	
n-C27Q	
n-C28	
n-C28Q	
n-C29	

(a) Measured in units by dry weight.

(contd)

COMPOUND LIST	MEANING
n-C30	
n-C30Q	
n-C32	
n-C32Q	
n-C34	
n-C34Q	
n-C36	
n-C36Q	
OTP%	Surrogate recovery rate value

Tissue Samples

SAMPID	UNIT	C9	C9Q	C10	C10Q	C11	C11Q	C12	C12Q	C13	C13Q	C14	C14Q
TNMN+50	ng/g	17	J	125		24	J	25	J	6375		28	J
TNMN+25	ng/g		ND		ND		ND		ND		ND		ND
TNMN2+50	ng/g		ND		ND		ND		ND	76			ND
TNMN2+25	ng/g		ND	32	J		ND		ND	34	J	26	J
TNMN3+25	ng/g		ND		ND		ND		ND		ND		ND
TNMN3+50	ng/g		ND		ND		ND		ND		ND		ND
TKBN+50	ng/g		ND		ND		ND		ND		ND		ND
TKBN+25	ng/g		ND		ND		ND		ND		ND		ND
TKBN2+50	ng/g		ND	88			ND		ND		ND		ND
TKBN2+25	ng/g		ND	58	J		ND		ND		ND		ND
TKB3+25	ng/g		ND		ND		ND		ND		ND		ND
TKB3+50	ng/g		ND		ND		ND		ND		ND	81	
T2B+50	ng/g		ND		ND		ND	89			ND		ND
T2B+25	ng/g		ND		ND		ND		ND		ND		ND
T2B+25 SP	ng/g		ND	101	J		ND	127	J		ND	181	J
RECOVERY (%)				17				21				30	
T2B2+50	ng/g		ND		ND		ND		ND		ND		ND
T2B2+50	ng/g		ND		ND		ND		ND		ND		ND
T2B3+25	ng/g		ND	334			ND		ND		ND		ND
T2B3+50	ng/g		ND		ND		ND		ND		ND		ND
TWR+50	ng/g		ND	129			ND		ND		ND		ND
TWR+25	ng/g		ND		ND		ND		ND		ND		ND
TWR2+50	ng/g		ND		ND		ND		ND		ND		ND
TWR2+25	ng/g		ND	38	J		ND		ND		ND		ND
TWR3+25	ng/g		ND		ND		ND		ND		ND		ND
TWR3+25 SP	ng/g		ND	268			ND	152		159		494	
RECOVERY (%)				41				23				75	

SAMPID	UNIT	C15	C15Q	C16	C16Q	C17	C17Q	PRISTAN	PRISTANQ	C18	C18Q	PHYTANE	PHYTANEQ
TNWN+50	ng/g	143		129		508		72		119		32	
TNWN+25	ng/g	315		136		512		106		245			ND
TNWN2+50	ng/g	183		75		599			ND	114			ND
TNWN2+25	ng/g	165		65		696			ND	80		49	
TNWN3+25	ng/g		ND		ND	264			ND		ND		ND
TNWN3+50	ng/g	68	J		ND	608			ND		ND		ND
TKBN+50	ng/g	342		95		319		75		138			ND
TKBN+25	ng/g	934		183		766			ND	206			ND
TKBN2+50	ng/g	550		123		310		80		171			ND
TKBN2+25	ng/g	67		48	J	104			ND	41			ND
TKB3+25	ng/g		ND		ND		ND		ND		ND		ND
TKB3+50	ng/g	140			ND	745		53			ND		ND
T2B+50	ng/g		ND		ND		ND		ND	175			ND
T2B+25	ng/g		ND		ND		ND		ND		ND		ND
T2B+25 SP	ng/g	191	J	262	J		ND		ND	225			ND
RECOVERY (%)				44						38			
T2B2+50	ng/g	212		26	J	276		157		146		42	
T2B2+50	ng/g		ND		ND		ND		ND	63			ND
T2B3+25	ng/g	65	J	170		382		327		88			ND
T2B3+50	ng/g	76	J		ND	131		114	J		ND		ND
TWR+50	ng/g	299		112		280			ND		ND		ND
TWR+25	ng/g	198		117		352			ND		ND		ND
TWR2+50	ng/g		ND		ND	216		47	J	134			ND
TWR2+25	ng/g	32	J		ND	145			ND	111			ND
TWR3+25	ng/g		ND		ND		ND		ND		ND		ND
TWR3+25 SP	ng/g	954		691		461			ND	478			ND
RECOVERY (%)		145		105						73			

SAMPID	UNIT	C19	C19Q	C20	C20Q	C21	C21Q	C22	C22Q	C23	C23Q	C24	C24Q
TNMN+50	ng/g	214			ND	165		77			ND		ND
TNMN+25	ng/g	310		243		352		2076		406		407	
TNMN2+50	ng/g	136		145		238		1332		85		55	
TNMN2+25	ng/g		ND		ND	1274		1678		277		30	J
TNMN3+25	ng/g		ND	200		466		532		805		1060	
TNMN3+50	ng/g	60		160		317		119		190		192	
TKBN+50	ng/g	224		380		277		1467		133		132	
TKBN+25	ng/g	290		292		256		1522		219		208	
TKBN2+50	ng/g	339		390		854		8197		309			ND
TKBN2+25	ng/g	98		177		286		2488		176		39	J
TKB3+25	ng/g	47		88			ND		ND		ND	85	
TKB3+50	ng/g	61		575			ND	230		131		168	
T2B+50	ng/g	223			ND	1330		2691			ND		ND
T2B+25	ng/g		ND		ND	311			ND	704		843	
T2B+25 SP	ng/g		ND	253	J		ND	382	J	108	J	1110	
RECOVERY (%)				42				64				22	
T2B2+50	ng/g	104		101		85		926		103		97	
T2B2+50	ng/g	64		32	J	74	J	1653		409		532	
T2B3+25	ng/g		ND	469		1493		260		431		673	
T2B3+50	ng/g	103		303		361			ND		ND	105	
TWR+50	ng/g	266		157		233		1325		130		118	
TWR+25	ng/g	262		173		253		1568		298		336	
TWR2+50	ng/g	111		145		14292			ND	108		62	
TWR2+25	ng/g	77		97		9466		1063		125		64	
TWR3+25	ng/g		ND		ND		ND		ND		ND		ND
TWR3+25 SP	ng/g	206		914		480		736		330		1810	
RECOVERY (%)				139				112				138	

SAMPID	UNIT	C25	C25Q	C26	C26Q	C27	C27Q	C28	C28Q	C29	C29Q	C30	C30Q
TNMN+50	ng/g	276		82	J	8		226		198		207	
TNMN+25	ng/g	1131		533		748		1430		835		523	
TNMN2+50	ng/g	1496		133		433			ND	311		90	J
TNMN2+25	ng/g		ND	125		244			ND		ND	162	
TNMN3+25	ng/g	1145		1256		1235		1117		1606		706	
TNMN3+50	ng/g	184		185		185		200	J	411	J	133	J
TKBN+50	ng/g	208		146		224		152		427		229	
TKBN+25	ng/g	348		313		271		1404		552		318	
TKBN2+50	ng/g	64		70	J		ND	658		304		135	
TKBN2+25	ng/g	64		49	J		ND	346		161		90	J
TKB3+25	ng/g	64			ND		ND	44	J	135	J		ND
TKB3+50	ng/g		ND	49		67		77			ND	44	
T2B+50	ng/g	107		132		137			ND	341		233	
T2B+25	ng/g	892		1030		1180			ND		ND		ND
T2B+25 SP	ng/g	132	J	154	J		ND	1066		151	J	450	J
RECOVERY (%)								179					
T2B2+50	ng/g	120			ND	176		407			ND	258	
T2B2+50	ng/g	572		547		40	J	92	J	3261		139	
T2B3+25	ng/g		ND	186			ND	263	J		ND		ND
T2B3+50	ng/g	125			ND		ND		ND		ND		ND
TWR+50	ng/g	242		127		273		875		333			ND
TWR+25	ng/g	505		433		520		1214		597		453	
TWR2+50	ng/g	293			ND	274			ND	231		359	
TWR2+25	ng/g	345			ND	155			ND		ND	149	
TWR3+25	ng/g		ND		ND		ND		ND	2085			ND
TWR3+25 SP	ng/g	301		263			ND	621			ND	446	
RECOVERY (%)								94					

SAMPID	UNIT	C32	C32Q	C34	C34Q	C36	C36Q	RECOVERY OTP (%)	SUM C9 - C36	C10 - C30 SUM EVEN	C9 - C29 SUM ODD
TNMN+50	ng/g	160		76	J	17	J	51	9302	1017	7927
TNMN+25	ng/g	616			ND		ND	57	10923	5592	4609
TNMN2+50	ng/g	160		48	J		ND	79	5710	1944	3558
TNMN2+25	ng/g	841		48	J	23	J	74	5850	2198	2690
TNMN3+25	ng/g	1659		521			ND	56	12571	4870	5520
TNMN3+50	ng/g	94	J	59	J		ND	65	3166	990	2023
TKBN+50	ng/g	320		232		98		59	5619	2739	2155
TKBN+25	ng/g		ND	448			ND	62	8530	4446	3636
TKBN2+50	ng/g	496			ND		ND	115	13137	9831	2731
TKBN2+25	ng/g	322			ND		ND	76	4614	3336	956
TKB3+25	ng/g		ND		ND		ND	38	463	217	247
TKB3+50	ng/g		ND		ND		ND	76	2421	1225	1143
T2B+50	ng/g		ND	101	J		ND	64	5559	3320	2138
T2B+25	ng/g		ND	638			ND	54	5599	1873	3087
T2B+25 SP	ng/g	483	J	142	J	371	J		5888	4310	582
RECOVERY (%)		81				62					
T2B2+50	ng/g	950		72	J		ND	63	4256	1959	1075
T2B2+50	ng/g		ND	131			ND	85	7610	3059	4421
T2B3+25	ng/g	834			ND		ND	71	5976	2443	2371
T2B3+50	ng/g	1935			ND		ND	69	3254	408	797
TWR+50	ng/g	317		241		158		45	5613	2843	2055
TWR+25	ng/g		ND	265		201		48	7745	4293	2985
TWR2+50	ng/g	963		197		155		154	17589	700	15527
TWR2+25	ng/g		ND	76	J		ND	123	11945	1523	10345
TWR3+25	ng/g		ND		ND		ND	70	2085	0	2085
TWR3+25 SP	ng/g	682			ND	1111			11556	6872	2891
RECOVERY (%)		104				169					

SAMPID	UNIT	ODD/EVEN	C17/ PRISTANE	C18/ PHYTANE
TNWN+50	ng/g	7.8	7.0	3.7
TNWN+25	ng/g	0.8	4.9	
TNWN2+50	ng/g	1.8		
TNWN2+25	ng/g	1.2		1.6
TNWN3+25	ng/g	1.1		
TNWN3+50	ng/g	2.0		
TKBN+50	ng/g	0.8	4.2	
TKBN+25	ng/g	0.8		
TKBN2+50	ng/g	0.3	3.9	
TKBN2+25	ng/g	0.3		
TKB3+25	ng/g	1.1		
TKB3+50	ng/g	0.9	14.0	
T2B+50	ng/g	0.6		
T2B+25	ng/g	1.6		
T2B+25 SP RECOVERY (%)	ng/g	0.1		
T2B2+50	ng/g	0.5	1.8	3.5
T2B2+50	ng/g	1.4		
T2B3+25	ng/g	1.0	1.2	
T2B3+50	ng/g	2.0	1.2	
TWR+50	ng/g	0.7		
TWR+25	ng/g	0.7		
TWR2+50	ng/g	22.2	4.6	
TWR2+25	ng/g	6.8		
TWR3+25	ng/g			
TWR3+25 SP RECOVERY (%)	ng/g	0.4		

SAMPID	UNIT	C9	C9Q	C10	C10Q	C11	C11Q	C12	C12Q	C13	C13Q	C14	C14Q
TWR3+50	ng/g		ND		ND		ND		ND		ND		ND
THW+50	ng/g		ND	101		35	J		ND		ND		ND
THW+25	ng/g		ND	77	J	63	J		ND		ND		ND
THW+25 SP	ng/g		ND	201		248		179		75		290	
RECOVERY (%)				22				32				52	
THW2+50	ng/g		ND		ND		ND		ND		ND		ND
THW2+25	ng/g		ND		ND	99	J		ND		ND		ND
THW3+25	ng/g		ND		ND		ND		ND		ND		ND
THW3+50	ng/g		ND		ND		ND		ND		ND		ND
TNMS+50	ng/g		ND	118		111	J		ND		ND		ND
TNMS+25	ng/g		ND	68	J	41	J		ND		ND		ND
TNMS2+50	ng/g		ND		ND		ND		ND		ND		ND
TNMS2+25	ng/g		ND		ND		ND		ND		ND		ND
TNMS3+25	ng/g		ND		ND		ND		ND		ND		ND
TNMS3+50	ng/g		ND		ND		ND		ND		ND	78	
TRB+50	ng/g		ND	112		78	J		ND		ND		ND
TRB+25	ng/g		ND		ND		ND		ND		ND		ND
TRB2+50	ng/g		ND		ND		ND		ND		ND		ND
TRB2+25	ng/g		ND		ND	8	J		ND		ND	6	J
TRB3+50-1	ng/g		ND		ND		ND		ND		ND		ND
TRB3+50-2	ng/g		ND		ND		ND		ND		ND		ND
TCC+50	ng/g		ND	112			ND		ND		ND		ND
TCC+25	ng/g		ND		ND		ND		ND		ND		ND
TCC2+50	ng/g		ND		ND		ND		ND		ND		ND
TCC2+25	ng/g		ND		ND		ND		ND		ND		ND
TCC3+25	ng/g		ND		ND		ND		ND		ND		ND
TCC3+50	ng/g		ND		ND		ND		ND		ND		ND

SAMPID	UNIT	C15	C15Q	C16	C16Q	C17	C17Q	PRISTAN	PRISTANQ	C18	C18Q	PHYTANE	PHYTANEQ
TWR3+50	ng/g		ND	113		106			ND		ND		ND
THW+50	ng/g	126		100		439		74		219		45	
THW+25	ng/g	215			ND	834			ND		ND		ND
THW+25 SP	ng/g	351		502		164		135		574			ND
RECOVERY (%)				90						103			
THW2+50	ng/g	35	J		ND	182		33	J	111			ND
THW2+25	ng/g	235		65		759			ND	111			ND
THW3+25	ng/g		ND		ND	107			ND		ND		ND
THW3+50	ng/g		ND		ND	108			ND		ND		ND
TNWS+50	ng/g	78			ND	193		28	J	68		70	
TNWS+25	ng/g	104			ND	378			ND	61			ND
TNWS2+50	ng/g	163		57		936			ND	52			ND
TNWS2+25	ng/g	295		94		936			ND	74			ND
TNWS3+25	ng/g	123	J		ND	770			ND		ND		ND
TNWS3+50	ng/g	79	J		ND	543			ND		ND		ND
TRB+50	ng/g		ND		ND		ND		ND	95			ND
TRB+25	ng/g		ND		ND		ND		ND	63			ND
TRB2+50	ng/g	68			ND	46	J	31	J	37			ND
TRB2+25	ng/g	59	J	11	J	61	J	22	J	33		183	
TRB3+50-1	ng/g	71	J	76		229		126	J	54			ND
TRB3+50-2	ng/g		ND		ND	169		111	J		ND		ND
TCC+50	ng/g	152		92		286			ND	120			ND
TCC+25	ng/g	290			ND	243			ND	78			ND
TCC2+50	ng/g	23	J	16	J	143		26	J	34		13	J
TCC2+25	ng/g	113		77		510		42	J	184		37	
TCC3+25	ng/g		ND		ND	149		81			ND		ND
TCC3+50	ng/g		ND		ND	84	J		ND		ND		ND

SAMPID	UNIT	C19	C19Q	C20	C20Q	C21	C21Q	C22	C22Q	C23	C23Q	C24	C24Q
TWR3+50	ng/g	126		119		250		163		341		421	
THW+50	ng/g	238		170		290		1563		166		41	J
THW+25	ng/g	71		140		1208		2646		106		57	
THW+25 SP	ng/g	88		415		102		538		126		1557	
RECOVERY (%)				49				-380				135	
THW2+50	ng/g	35	J		ND	62	J	757		79		32	J
THW2+25	ng/g	197			ND		ND	5378		907		173	
THW3+25	ng/g		ND	171		174			ND	122		227	
THW3+50	ng/g	97		151		193			ND	120		161	
TNWS+50	ng/g	76		79		75		351		201		225	
TNWS+25	ng/g	65		81		402		1057		248		194	
TNWS2+50	ng/g	148		78			ND		ND	222		40	J
TNWS2+25	ng/g	177		104			ND	4750		218		59	
TNWS3+25	ng/g	92		208			ND	208		409		402	
TNWS3+50	ng/g	53		177			ND	111		194		148	
TRB+50	ng/g	101		98		751		1304			ND		ND
TRB+25	ng/g	88		96		1056		954		65	J	64	
TRB2+50	ng/g	30	J	20	J	33	J	655		41	J	31	J
TRB2+25	ng/g	109		27	J	82		804		77		37	J
TRB3+50-1	ng/g	134		317		435		266		544		425	
TRB3+50-2	ng/g	134		234		371		559		831		1015	
TCC+50	ng/g	311			ND	356		1855		182		203	
TCC+25	ng/g	225		102		259		2449		112		106	
TCC2+50	ng/g	150		37	J	49	J	398		50	J	31	J
TCC2+25	ng/g	144		75		118		1195		213		95	
TCC3+25	ng/g	130		185		493			ND		ND	142	
TCC3+50	ng/g	122		150		250		624		157		233	

SAMPID	UNIT	C25	C25Q	C26	C26Q	C27	C27Q	C28	C28Q	C29	C29Q	C30	C30Q
TWR3+50	ng/g	375		413		364		305	J		ND		ND
THW+50	ng/g	172		71	J	142			ND	1755		70	J
THW+25	ng/g	205		126		128		662		534		169	
THW+25 SP	ng/g	158		148		716		1414		307		605	
RECOVERY (%)								135					
THW2+50	ng/g	123		136		125			ND	216		84	J
THW2+25	ng/g	560		413		827		1885		485		327	
THW3+25	ng/g	148		181		159		177	J		ND	160	J
THW3+50	ng/g	119		139		107			ND		ND		ND
TNWS+50	ng/g	754		290			ND	153		2093		309	
TNWS+25	ng/g	313		288		400		895		513			ND
TNWS2+50	ng/g	560		125		467		330		237		46	J
TNWS2+25	ng/g	1714		164		453			ND	312		69	J
TNWS3+25	ng/g	335		384		350		302	J	501		179	J
TNWS3+50	ng/g	174		220		169		145	J	356	J	90	J
TRB+50	ng/g	73		93	J	139		1043		530		290	
TRB+25	ng/g	72		81	J	107		637		291		171	
TRB2+50	ng/g	51	J	59	J	70		550		86	J	62	J
TRB2+25	ng/g	29	J	59	J	72		222		94	J	40	J
TRB3+50-1	ng/g	454		459		444		351		362		201	J
TRB3+50-2	ng/g	1173		1235		1190		1041		1305		586	
TCC+50	ng/g	296		289		266		1076		474		249	
TCC+25	ng/g	209		111		244		1097		416		253	
TCC2+50	ng/g		ND	20	J	72		307		205		55	J
TCC2+25	ng/g	617		297		252		1058		341		165	
TCC3+25	ng/g	109		95	J		ND		ND		ND		ND
TCC3+50	ng/g	199		253		272		317		367	J	347	J

SAMPID	UNIT	C32	C32Q	C34	C34Q	C36	C36Q	RECOVERY OTP (%)	SUM C9 - C36	C10 - C30 SUM EVEN	C9 - C29 SUM ODD
TWR3+50	ng/g	414		124	J	145		63	3779	1534	1561
THW+50	ng/g	13436		209		35	J	85	19497	2335	3363
THW+25	ng/g	54	J	77	J	265		54	7637	3879	3362
THW+25 SP	ng/g	578		88	J	741		75	10301	6423	2335
RECOVERY (%)		94				86					
THW2+50	ng/g	135		47	J		ND	29	2192	1120	857
THW2+25	ng/g	794		93	J	172		82	13478	8351	4069
THW3+25	ng/g	968		479	J		ND	53	3075	917	711
THW3+50	ng/g	950		450	J	958		54	3553	451	744
TNMS+50	ng/g	74	J	89	J	52	J	98	5487	1594	3580
TNMS+25	ng/g	422		254		113		70	5897	2643	2464
TNMS2+50	ng/g		ND		ND		ND	61	3461	729	2732
TNMS2+25	ng/g		ND		ND		ND	91	9419	5314	4105
TNMS3+25	ng/g	123	J		ND	233	J	68	4616	1680	2581
TNMS3+50	ng/g	106	J		ND		ND	65	2643	970	1568
TRB+50	ng/g	2673		773		108		49	8260	3035	1671
TRB+25	ng/g	1433		417			ND	42	5595	2067	1678
TRB2+50	ng/g		ND	169			ND	43	2041	1414	426
TRB2+25	ng/g	313		43	J		ND	31	2389	1239	590
TRB3+50-1	ng/g	1647		415	J	132	J	69	7142	2148	2674
TRB3+50-2	ng/g	1899		431	J		ND	45	12282	4670	5171
TCC+50	ng/g	490		290		77		59	7177	3995	2324
TCC+25	ng/g	1110		516		77		53	7896	4195	1998
TCC2+50	ng/g	253		50	J	18	J	27	1950	899	692
TCC2+25	ng/g	1875		164		42	J	58	7611	3145	2307
TCC3+25	ng/g	2257			ND		ND	56	3640	421	881
TCC3+50	ng/g	379		192	J		ND	60	3945	1923	1451

SAMPID	UNIT	ODD/EVEN	C17/ PRISTANE	C18/ PHYTANE
TWR3+50	ng/g	1.0		
THW+50	ng/g	1.4	6.0	4.9
THW+25	ng/g	0.9		
THW+25 SP RECOVERY (%)	ng/g	0.4	1.2	
THW2+50	ng/g	0.8	5.5	
THW2+25	ng/g	0.5		
THW3+25	ng/g	0.8		
THW3+50	ng/g	1.6		
TNWS+50	ng/g	2.2	6.8	1.0
TNWS+25	ng/g	0.9		
TNWS2+50	ng/g	3.7		
TNWS2+25	ng/g	0.8		
TNWS3+25	ng/g	1.5		
TNWS3+50	ng/g	1.6		
TRB+50	ng/g	0.6		
TRB+25	ng/g	0.8		
TRB2+50	ng/g	0.3	1.5	
TRB2+25	ng/g	0.5	2.8	0.2
TRB3+50-1	ng/g	1.2	1.8	
TRB3+50-2	ng/g	1.1	1.5	
TCC+50	ng/g	0.6		
TCC+25	ng/g	0.5		
TCC2+50	ng/g	0.8	5.6	2.7
TCC2+25	ng/g	0.7	12.0	4.9
TCC3+25	ng/g	2.1	1.8	
TCC3+50	ng/g	0.8		

SAMPID	UNIT	C9	C9Q	C10	C10Q	C11	C11Q	C12	C12Q	C13	C13Q	C14	C14Q
TWC+50	ng/g		ND	88	J		ND		ND		ND		ND
TWC+25	ng/g		ND	197		708			ND	112			ND
TPG+50	ng/g		ND		ND		ND		ND		ND		ND
TPG+25	ng/g		ND		ND		ND		ND		ND		ND
TPG2+50	ng/g		ND		ND	52	J		ND		ND		ND
TPG2+25	ng/g		ND	53	J		ND		ND		ND		ND
TPG3+50	ng/g		ND		ND		ND		ND		ND	83	
TOS+50	ng/g		ND		ND	43	J		ND		ND		ND
TOS+50 SP	ng/g		ND	42	J	49	J	43	J		ND	77	J
RECOVERY (%)				11				11				20	
TOS+25	ng/g		ND		ND		ND		ND		ND		ND
TOS+25D	ng/g		ND		ND		ND		ND		ND		ND
TOS2+50-1	ng/g		ND		ND		ND		ND		ND		ND
TOS2+50-2	ng/g	62			ND		ND		ND		ND		ND
TOS3+50	ng/g		ND	145			ND		ND		ND	143	
BLANK 1	ng/g		ND		ND		ND		ND		ND		ND
BLANK 2	ng/g		ND		ND		ND		ND		ND		ND
BLANK 5	ng/g		ND		ND		ND		ND		ND		ND
BARGE OIL	ng/g		ND		ND	227009		635575		1439084		3913328	

SAMPID	UNIT	C15	C15Q	C16	C16Q	C17	C17Q	PRISTAN	PRISTANQ	C18	C18Q	PHYTANE	PHYTANEQ
TWC+50	ng/g		ND		ND	97		88		137			ND
TWC+25	ng/g		ND		ND	48	J	160		60			ND
TPG+50	ng/g		ND		ND		ND		ND	104			ND
TPG+25	ng/g		ND		ND		ND		ND		ND		ND
TPG2+50	ng/g		ND		ND		ND		ND	170			ND
TPG2+25	ng/g		ND		ND		ND	109		163			ND
TPG3+50	ng/g	108	J	95		400		384		98			ND
TOS+50	ng/g	24	J		ND	46	J	76		32			ND
TOS+50 SP	ng/g	86	J	121	J	26	J	37	J	97	J		ND
RECOVERY (%)				31						17			
TOS+25	ng/g		ND		ND		ND		ND		ND		ND
TOS+25D	ng/g		ND		ND		ND	79			ND		ND
TOS2+50-1	ng/g	18	J	12	J	64	J	25	J	11	J		ND
TOS2+50-2	ng/g	77			ND	129		122		60			ND
TOS3+50	ng/g	171	J	209		486		322			ND		ND
BLANK 1	ng/g		ND		ND		ND		ND		ND		ND
BLANK 2	ng/g		ND		ND		ND		ND		ND		ND
BLANK 5	ng/g		ND		ND		ND		ND		ND		ND
BARGE OIL	ng/g	3687672		3699562		3958975		2165041		3192770		2521705	

SAMPID	UNIT	C19	C19Q	C20	C20Q	C21	C21Q	C22	C22Q	C23	C23Q	C24	C24Q
TWC+50	ng/g	141		178		1026		1686		273		235	
TWC+25	ng/g	48		122		78		877		146		96	
TPG+50	ng/g	50		51		362		1021		119		76	
TPG+25	ng/g		ND		ND		ND	686			ND		ND
TPG2+50	ng/g	52		67		218		2469		89		61	
TPG2+25	ng/g	58		92		251		2358		95		69	
TPG3+50	ng/g	215		478		678		176			ND	207	
TOS+50	ng/g	54		32	J	56	J	716		153		204	
TOS+50 SP	ng/g	21	J	157	J	34	J	595		93	J	472	
RECOVERY (%)				32				-31				34	
TOS+25	ng/g		ND		ND		ND	738		105		147	
TOS+25D	ng/g		ND	64		122		1375		115		133	
TOS2+50-1	ng/g	16	J	16	J	106		297	ND		J	41	J
TOS2+50-2	ng/g	116		143		113		1180		257		200	
TOS3+50	ng/g	172		406		471		239		510		373	
BLANK 1	ng/g		ND		ND	41	J	79		119		135	
BLANK 2	ng/g		ND		ND		ND	57	J	85		113	
BLANK 5	ng/g		ND		ND		ND		ND		ND		ND
BARGE OIL	ng/g	3215828		3263812		2072925		1936588		1587042		1513855	

SAMPID	UNIT	C25	C25Q	C26	C26Q	C27	C27Q	C28	C28Q	C29	C29Q	C30	C30Q
TWC+50	ng/g	286		379		82		601		3308		444	
TWC+25	ng/g	201		182		153		686		1631		76	J
TPG+50	ng/g	95		113		106		555			ND	424	
TPG+25	ng/g		ND		ND	329		1790			ND	1135	
TPG2+50	ng/g	139		70	J	144			ND	1182		139	
TPG2+25	ng/g	166		97	J	197		1461		3101		89	J
TPG3+50	ng/g	197		145		106		158	J		ND		ND
TOS+50	ng/g	278		309			ND	30	J		ND	53	J
TOS+50 SP	ng/g	54	J	72	J	150	J	424	J	183	J	170	J
RECOVERY (%)								101					
TOS+25	ng/g	200		244			ND		ND		ND	192	
TOS+25D	ng/g	151		160		93		65	J	166		166	
TOS2+50-1	ng/g	51		119	J	58	ND		J	138	J	40	ND
TOS2+50-2	ng/g	271		287		322		1559		406		265	
TOS3+50	ng/g	499		369		332		290	J		ND	164	J
BLANK 1	ng/g	141		138		142		545		191		149	
BLANK 2	ng/g		ND	152			ND		ND		ND		ND
BLANK 5	ng/g		ND	76	J	87		704			ND		ND
BARGE OIL	ng/g	1285798		1118334		1190391		1113888		973545		1396514	

SAMPID	UNIT	C32	C32Q	C34	C34Q	C36	C36Q	RECOVERY OTP (%)	SUM C9 - C36	C10 - C30 SUM EVEN	C9 - C29 SUM ODD
TWC+50	ng/g	14450		153			ND	110	23650	3748	5212
TWC+25	ng/g	210		84	J		ND	116	5873	2295	3125
TPG+50	ng/g		ND	73	J		ND	68	3149	2345	732
TPG+25	ng/g		ND	211			ND	53	4151	3611	329
TPG2+50	ng/g	2385		436			ND	167	7671	2976	1874
TPG2+25	ng/g	13768		219			ND	98	22349	4384	3869
TPG3+50	ng/g	2312		470	J		ND	76	6308	1439	1703
TOS+50	ng/g		ND	59	J		ND	92	2166	1377	654
TOS+50 SP	ng/g	260	J	27	J	51	J	46	3340	2270	695
RECOVERY (%)		67				13					
TOS+25	ng/g		ND	93	J		ND	61	1719	1322	305
TOS+25D	ng/g		ND	76	J		ND	77	2767	1964	648
TOS2+50-1	ng/g		J	35	ND		J	37	1046	536	452
TOS2+50-2	ng/g	817		152		45	J	79	6583	3694	1753
TOS3+50	ng/g	554			ND		ND	70	5854	2337	2641
BLANK 1	ng/g	123	J	69	J		ND	77	1872	1047	634
BLANK 2	ng/g		ND	76	J		ND	64	483	323	85
BLANK 5	ng/g	112	J		ND		ND	51	6832	779	87
BARGE OIL	ng/g	2374570		1344424		1144816		57	50973051	21784226	19638269

SAMPID	UNIT	ODD/EVEN	C17/ PRISTANE	C18/ PHYTANE
TWC+50	ng/g	1.4	1.1	
TWC+25	ng/g	1.4	0.3	
TPG+50	ng/g	0.3		
TPG+25	ng/g	0.1		
TPG2+50	ng/g	0.6		
TPG2+25	ng/g	0.9	0.0	
TPG3+50	ng/g	1.2	1.0	
TOS+50	ng/g	0.5	0.6	
TOS+50 SP RECOVERY (%)	ng/g	0.3	0.7	
TOS+25	ng/g	0.2		
TOS+25D	ng/g	0.3	0.0	
TOS2+50-1	ng/g	0.8	2.6	
TOS2+50-2	ng/g	0.5	1.1	
TOS3+50	ng/g	1.1	1.5	
BLANK 1	ng/g	0.6		
BLANK 2	ng/g	0.3		
BLANK 5	ng/g	0.1		
BARGE OIL	ng/g	0.9	1.8	1.3

Sediment Samples

SAMPID	UNIT	C9	C9Q	C10	C10Q	C11	C11Q	C12	C12Q	C13	C13Q	C14	C14Q
WR2+9.2	ng/g	123		352		455		573		664		869	
WR3 SED	ng/g	3	J	11	J	6	J	8	J	12	J	29	J
KB3 SED	ng/g	6	J	13	J	13	J	14	J	18	J	34	J
NMN3 SED	ng/g	4	J	6	J	8	J	7	J	11	J	21	J
NMNH3	ng/g		ND		ND		ND		ND		ND		ND
OP3-3.0 SED	ng/g	8	J		ND		ND	7	J	10	J	16	J
3HNMX+8.2	ng/g	17	J		ND	55	J	64	J	98		162	
3HNMX+8.2 REP	ng/g	48			ND	163		178		259		371	
3HNMX+1.1	ng/g	8	J	20	J	22	J	23	J	32	J	54	J
CC3 SED	ng/g	26	J	32	J	55	J	41	J	45	J	75	
CC3 SPIKE II	ng/g	25	J	69	J	52	J	89		50	J	148	
3HW+15	ng/g		ND	12	J		ND		ND	6	J	10	J
3RB+14	ng/g		ND		ND		ND		ND		ND		ND
COS2+11	ng/g	74		22	J	14	J	14	J	11	J		ND
COS2+11 SP	ng/g	34	J	87	J		ND	107			ND	131	
RECOVERY (%)				38				55				78	
SI2	ng/g	28	J		ND		ND		ND		ND		ND
SI+15.2	ng/g		ND		ND		ND		ND		ND	12713	
SI+13.3	ng/g		ND		ND		ND		ND		ND	15421	
SED. BLANK S2	ng/g	63	J		ND	15	J		ND		ND		ND
BLK SED S3	ng/g		ND		ND		ND		ND		ND		ND

SAMPID	UNIT	C15	C15Q	C16	C16Q	C17	C17Q	PRISTAN	PRISTANQ	C18	C18Q	PHYTANE	PHYTANEQ
WR2+9.2	ng/g	771		786		893		530		785		179	
WR3 SED	ng/g	20	J	28	J	85			ND	25	J		ND
KB3 SED	ng/g	24	J	23	J	44	J	33	J	43		16	J
NWN3 SED	ng/g	13	J	14	J	33	J		ND		ND		ND
NWNH3	ng/g	49	J	57	J	229			ND	72			ND
OP3-3.0 SED	ng/g	13	J	17	J	47	J		ND		ND		ND
3HNMX+8.2	ng/g	160	J	166		289		1177		867			ND
3HNMX+8.2 REP	ng/g	301		280		387		1148		383		288	
3HNMX+1.1	ng/g	47	J	47	J	92		182	J		ND		ND
CC3 SED	ng/g	59	J	48	J	86		104	J	228		124	
CC3 SPIKE II	ng/g	123	J	140		88		87	J	260		97	
3HW+15	ng/g	8	J	14	J	84			ND	602			ND
3RB+14	ng/g		ND		ND	37	J		ND	155		71	
COS2+11	ng/g		ND	12	J	24	J		ND	21	J		ND
COS2+11 SP	ng/g	128		189			ND		ND	127			ND
RECOVERY (%)				105						63			
SI2	ng/g		ND		ND		ND		ND		ND		ND
SI+15.2	ng/g	20926		31487		43779		32940		36861		40994	
SI+13.3	ng/g	37639		65616		97345		58161		92509		79705	
SED. BLANK S2	ng/g		ND		ND		ND		ND		ND		ND
BLK SED S3	ng/g		ND		ND		ND		ND		ND		ND

SAMPID	UNIT	C19	C19Q	C20	C20Q	C21	C21Q	C22	C22Q	C23	C23Q	C24	C24Q
WR2+9.2	ng/g	845		911		870		1038		1207		1225	
WR3 SED	ng/g	449		142		162		168		171		198	
KB3 SED	ng/g	59		57		76		90		103		271	
NWN3 SED	ng/g	55		49		60		59	J	69	J	218	
NWNH3	ng/g	127		223		386		364		477		613	
OP3-3.0 SED	ng/g		ND	86		93		85		105		200	
3HNWX+8.2	ng/g		ND	506		499		484		537		593	
3HNWX+8.2 REP	ng/g	537		482		609		659		771		788	
3HNWX+1.1	ng/g		ND		ND		ND		ND		ND		ND
CC3 SED	ng/g	286		102		111		107		113		105	
CC3 SPIKE II	ng/g	239		203		110		216		112		330	
3HW+15	ng/g		ND	93		86		72	J	90		165	
3RB+14	ng/g	163		40	J	49	J	49	J	63	J	114	
COS2+11	ng/g	23	J	18	J	25	J	34	J	36	J	27	J
COS2+11 SP	ng/g		ND	156			ND	183		13	J	504	
RECOVERY (%)				82				89				141	
SI2	ng/g		ND	11	J	13	J		ND	56	J	48	
SI+15.2	ng/g	39179		43262		21727		20913		17441		18061	
SI+13.3	ng/g	106106		115533		78843		77466		66377		66177	
SED. BLANK S2	ng/g		ND		ND		ND		ND		ND		ND
BLK SED S3	ng/g		ND		ND		ND		ND		ND		ND

SAMPID	UNIT	C25	C25Q	C26	C26Q	C27	C27Q	C28	C28Q	C29	C29Q	C30	C30Q
WR2+9.2	ng/g	1010		942		880		730		704		501	
WR3 SED	ng/g		ND		ND		ND		ND	300	J	216	J
KB3 SED	ng/g	170			ND	321		302	J	237	J		ND
NWN3 SED	ng/g	123			ND	286		256	J	229	J	160	J
NWNH3	ng/g	687		767		732		658		1266		426	
OP3-3.0 SED	ng/g		ND		ND		ND		ND		ND		ND
3HNMX+8.2	ng/g	697			ND		ND	899		876		430	
3HNMX+8.2 REP	ng/g	808		813		1199		1067		1229		640	
3HNMX+1.1	ng/g	35	J		ND		ND	159	J		ND		ND
CC3 SED	ng/g	116		127		258		206	J	213	J	63	J
CC3 SPIKE II	ng/g	132		138		221		306	J	208	J	170	J
3HW+15	ng/g	266		266		420		592		483		293	J
3RB+14	ng/g	163		149		208		299	J	333	J	186	J
COS2+11	ng/g	32	J	44	J	47	J		ND	61	J	52	J
COS2+11 SP	ng/g		ND	16	J		ND	201			ND	204	
RECOVERY (%)								119					
SI2	ng/g		ND	57	J	63	J	72	J	62	J	46	J
SI+15.2	ng/g	15168		9132		12096		10139		13007		11644	
SI+13.3	ng/g	70673		56156		59665		53375		45688		67679	
SED. BLANK S2	ng/g		ND	16	J		ND	28	J		ND		ND
BLK SED S3	ng/g	64			ND		ND		ND	252	J		ND

SAMPID	UNIT	C32	C32Q	C34	C34Q	C36	C36Q	RECOVERY OTP (%)	SUM C9 - C36	C10 - C30 SUM EVEN	C9 - C29 SUM ODD
WR2+9.2	ng/g	230		165			ND	21	18236	8709	8423
WR3 SED	ng/g	82	J	82	J	39	J	77	2236	824	1208
KB3 SED	ng/g	104	J	67	J	21	J	67	2158	847	1070
NMN3 SED	ng/g	47	J	32	J	31	J	97	1792	791	892
NMNH3	ng/g	2455			ND	175		63	9761	3179	3952
OP3-3.0 SED	ng/g	75	J	61	J	78	J	131	901	411	277
3HNMX+8.2	ng/g	178	J	69	J	71	J	68	8893	4170	3228
3HNMX+8.2 REP	ng/g	447		271	J	52	J	85	14178	5661	6311
3HNMX+1.1	ng/g		ND	54	J		ND	54	775	304	236
CC3 SED	ng/g	27	J		ND		ND	33	2756	1135	1367
CC3 SPIKE II	ng/g	128	J	25	J	68	J	29	3833	2070	1359
3HW+15	ng/g	153	J	75	J	36	J	146	3829	2119	1444
3RB+14	ng/g	138	J	89	J	48	J	83	2354	993	1015
COS2+11	ng/g	84	J	49	J	25	J	98	748	242	348
COS2+11 SP	ng/g	197			ND	197		97	2473	1906	174
RECOVERY (%)		67				102					
SI2	ng/g		ND		ND		ND	86	455	234	221
SI+15.2	ng/g	17433		10203		9872		42	488977	194212	183323
SI+13.3	ng/g	112455		58620		88860		52	1570069	609932	562336
SED. BLANK S2	ng/g		ND		ND		ND	99	123	44	79
BLK SED S3	ng/g		ND		ND		ND	57	316	0	316

SAMPID	UNIT	ODD/EVEN	C17/ PRISTANE	C18/ PHYTANE
WR2+9.2	ng/g	1.0	1.7	4.4
WR3 SED	ng/g	1.5		
KB3 SED	ng/g	1.3	1.3	2.6
NWN3 SED	ng/g	1.1		
NWNH3	ng/g	1.2		
OP3-3.0 SED	ng/g	0.7		
3HNMX+8.2	ng/g	0.8	0.2	
3HNMX+8.2 REP	ng/g	1.1	0.3	1.3
3HNMX+1.1	ng/g	0.8	0.5	
CC3 SED	ng/g	1.2	0.8	1.8
CC3 SPIKE II	ng/g	0.7	1.0	2.7
3HW+15	ng/g	0.7		
3RB+14	ng/g	1.0		2.2
COS2+11	ng/g	1.4		
COS2+11 SP RECOVERY (%)	ng/g	0.1		
SI2	ng/g	0.9		
SI+15.2	ng/g	0.9	1.3	0.9
SI+13.3	ng/g	0.9	1.7	1.2
SED. BLANK S2	ng/g	1.8		
BLK SED S3	ng/g			

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